OFFICE OF STRUCTURES
MANUAL ON HYDROLOGIC AND HYDRAULIC DESIGN

CHAPTER 11
EVALUATING SCOUR AT BRIDGES

OFFICE OF
STRUCTURES

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Preface

ABSCOUR 10 is the current version of the scour evaluation program used by the Office of Structures, and all previous versions should be discarded. The user is advised to check the web site below for any revisions to the program:

www.gishydro.eng.umd.edu

The material presented in Chapter 11 and the ABSCOUR User's 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 ABSCOUR 10 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.

Questions regarding the use of the ABSCOUR Program or the interpretation of any of the policies, guidance or methodologies contained in Chapter 11 or its Appendices should be directed to the Office of Structures, Structures Hydrology and Hydraulics Division.

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APPENDICES

11.1 Introduction

11.1.1 General

<u>Overview</u>

The guidance in Chapter 11 recognizes and stresses that the primary responsibility of the Engineer is to provide for the safety of the public.

Chapter 11 provides policies, guidelines and methodologies for the evaluation of scour at bridges and bottomless arch culverts. This information is based on and incorporates the experience of the Office of Structures (OOS) as well as recommendations and policy guidance of various FHWA, AASHTO and ASCE manuals and guidelines. In particular, the guidance presented in FHWA Manual HEC-18, "Evaluating Scour at Bridges" Fifth Edition dated April 2012 is discussed and utilized as appropriate. For most design situations, we have found that the policies and procedures used by this office provide more reasonable estimates of scour for Maryland bridges than some of the guidance in HEC-18. ABSCOUR 10 is the computer program developed by the Office of Structures for evaluating scour, and it incorporates a number of the scour evaluating methods in HEC-18 as described below.

The Office of Structures has approved the following policies and procedures for the evaluation of scour at bridge structures.

- General HEC-18 method for evaluating scour at piers; This HEC-18 method is incorporated in the ABSCOUR 10 Pier Module. The method does not take into account the composition of the bed load material
- HEC-18 method for evaluating scour at piers in coarse bed) materials (D50>20 mm) : This method is incorporated in the ABSCOUR 10 Utilities Module. The method is recommended as a check on the General HEC-18 pier scour method for piers in coarse bed materials. It can evaluate scour at pier stems but not at pile caps or spread footings.
- HEC -18 method for Pier Scour with Debris: This method is incorporated in the ABSCOUR 10 Utilities Module
- HEC-18 Pressure Scour method: This method is incorporated in the ABSCOUR 10 Abutment Module
- MDSHA method for Evaluating contraction and Abutment scour: This method is incorporated in the ABSCOUR 10 Abutment Module
- MDSHA method for Evaluating scour in Bottomless Culverts: This method is incorporated in the ABSCOUR 10 Culvert Module
- HEC-18 method for Evaluating Pier Scour in Erodible Rock: This method is incorporated in the Erodibility Index Worksheet located with the Office of Structures software programs.
- Selection of the design flood for scour and the check flood for scour: See Section 11.4.4.
- Criteria for the design of bridge foundations for scour: See Section 11.4.5.

ABSCOUR 10 has the capability of inputting and solving other scour evaluating methodologies in HEC-18. In fact, every example problem of the scour equations in HEC-18 is listed and solved in ABSCOUR 10. While these other methods are available for use within the ABSCOUR 10 Program, the Office of Structures recommends that they be considered for conducting sensitivity analyses and for comparisons with the approved procedures listed above rather than for the design of Maryland bridges. These other HEC-18 methods for evaluating scour are listed below:

- NCHRP 24-20 Method for evaluating abutment scour
- Modified Laursen's method for evaluating contraction scour
- FHWA Method for evaluating clear water scour in bottomless culverts
- Florida method for evaluating scour at piers.

HEC-18 contains a wealth of information regarding the background and development of methodologies for evaluating scour at bridges, and should be considered as a companion manual to the Office of Structures H&H Manual.

Qualifications of Personnel

Personnel involved in the evaluation of scour at bridges need to possess the technical qualifications, including practical experience, education, and professional judgment, to perform the individual technical tasks assigned. Interpretation of results and conclusions of scour analyses shall be accomplished by registered engineers qualified in the appropriate disciplines. Because of the complexity of bridge scour, it is recommended that evaluations be performed by an interdisciplinary team of engineers with the requisite knowledge in structural, hydraulic, river mechanics and geotechnical engineering.

11.1.2 Definitions

The following definitions are provided to assure uniform understanding of some selected terms as they are used in this chapter:

100-Year Flood - The flood due to storm, tide or mixed population flood event having a one-percent chance of occurring in any one year. It serves for assessing flood hazards and meeting flood plain management requirements. This will also be the design flood for bridge scour unless the incipient overtopping flood is of a lesser flow magnitude.

500-Year Flood - The flood due to storm, tide or mixed population flood event having a 0.2 percent chance of occurring in any one year. This flood may also be selected for the check flood for scour unless the incipient overtopping flood is smaller. Typically, it is based on conditions of ultimate development in the watershed.

Aggradation - A long term general and progressive build-up or raising of the longitudinal profile of the channel bed due to sediment deposition.

Bankfull Flow - a discharge used to classify and evaluate stream channel morphology and stability. The bankfull flow normally occurs in natural, stable channels for a recurrence interval in the range of the 1.5-year flood. This recurrence interval can be considerably lower for unstable channels. The magnitude of the bankfull flow is usually obtained from field measurements.

Bendway Scour - Scour which occurs on the river bed near the outside of the bend due to the variable velocity distribution and the resulting secondary currents which develop across the bendway cross-section.

Check Flood for Bridge Scour - This flood serves for investigating the adequacy of the bridge to remain stable and not fail during a catastrophic flood event. This flood event represents the *ultimate loading condition*, since a bridge failure may occur for flood flows of a greater magnitude:

- If the incipient overtopping flood is less than the 500-year flood, the overtopping flood may represent the worst case condition and serve as the check flood for scour,
- If the incipient overtopping flood is greater than the 500-year flood, the 500-year flood will normally serve as the check flood for scour,
- If the site conditions are such that a more severe flood event is considered to be warranted, the Engineer may use such a flood event for the check flood for scour. This may be the case for a crossing site where the overtopping flood has a low recurrence interval and creates less of a hazard than is caused by floods with higher recurrence intervals. The Engineer may also wish to investigate special conditions caused by ice or debris dams, flows on controlled waterways, or locations near confluences involving varying tail waters.

Contraction Scour - Scour in a channel or on a flood plain that is caused by a constriction or contraction of the flow due to a naturally occurring confinement of the river or the construction of a bridge or other feature in the channel or flood plain. To satisfy the law of continuity of flow, velocities in the contracted section are higher than in the normal section; consequently, the channel bottom is subject to higher shear stress forces and tends to scour out. In a channel, contraction scour usually affects all or most of the channel width.

Degradation - A general and progressive lowering of the longitudinal profile of the channel bed due to long-term scour and erosion.

Design Flood - A flood of a specified recurrence interval used for sizing the waterway opening for the various functional classes of highways to satisfy the design policies and criteria of the SHA (See Chapter 10).

Design Flood for Bridge Scour – This event serves for estimating the total scour at the bridge and the design of the bridge foundations to resist damage from the scour. Generally, the magnitude of the design flood for bridge scour is the lesser of the 100-year flood or the overtopping flood. If the site conditions are such that a more severe flood event is considered to be warranted, the Engineer may use such a flood event for the design flood for bridge scour. This may be the case for a crossing site where the overtopping flood has a low recurrence interval and creates less of a hazard than the 100-year flood. The Engineer may also wish to investigate special conditions caused by ice or debris dams, flows on controlled waterways, or locations near confluences involving varying tail waters.

Estuary - A tidal reach at the mouth of a stream.

Flood Plain - nearly flat, alluvial lowland bordering a stream that is subject to inundation by floods.

Historic flood - A recorded past flood event that is useful for calibrating water surface profiles and evaluating the performance of existing structures.

Channel Lateral Movement Zone - The area on the floodplain that the stream channel may reasonably occupy at some future time during the service life of the crossing structure is referred to herein as the *channel lateral movement zone* (CLMZ). The boundaries of the CLMZ should envelop the extent of likely channel migration and pathways for channel avulsion.

Limit State - A condition in which the forces stabilizing a structure are equally balanced by the forces tending to destabilize the structure. This represents the ultimate loading condition for the structure, since any increase in the destabilizing forces will cause the structure to fail (no reserve capacity).

Local Scour - Scour in a channel or on a flood plain that is caused by an obstruction to the flow such as a pier or abutment, and is therefore localized in the immediate vicinity of the obstruction.

Mixed Population Flood Event - A flood event which involves the mixing of two types of flows such as tidal flow and riverine flow, or snow melt and rainfall runoff.

Overtopping Flood (Incipient overtopping flood). This flood is determined by finding the maximum flow that will be accommodated by the bridge without overtopping of the bridge, its approach roads or other drainage divide. It serves for assessing risks to highway users and damage to the bridge and its roadway approaches. The magnitude and frequency of the overtopping flood is a function of the highway/bridge design and must be determined from hydraulic analysis. The incipient overtopping flood may be designated as both the design flood for bridge scour and the check flood for bridge scour if overtopping occurs for a flood with a recurrence interval less than the 100-year event.

Preliminary Bridge Plans - For the purpose of this guide, preliminary plans are developed to the extent of depicting the type, size and location (TS&L) of a proposed structure.

Scour - Erosion due to flowing water, usually considered as being localized as opposed to general bed degradation,

Scour Prism (total scour line) - A 3-dimensional shape or solid comprised of the scourable material located above the elevation of the total scour line.

Super flood - A term used to denote a flood with a recurrence interval greater than a 100-year flood that is commonly used as the check flood for scour.

Thalweg - The line or thread extending down a channel that follows the lowest elevation of the bed.

11.2 Overview of Scour Concepts and Process

Scour is the result of the erosive action of flowing water, excavating and carrying away material from bed and banks of streams and other waterways. Different materials scour at different rates. Loose granular soils are rapidly eroded by flowing water, while cohesive or cemented soils are more scour resistant. However, ultimate scour in cohesive or cemented soils can be as deep as scour in sand bed streams. Scour will reach its maximum depth in sand and gravel bed materials in hours; cohesive bed materials in days; glacial tills, sandstones and shales in months, limestone in years and dense granites in centuries. Total scour at a highway crossing is comprised of three elements (Reference 1):

1. Aggradation and degradation. These are long term stream bed elevation changes due to natural causes or to development of the river, its flood plain or watershed. Aggradation involves the deposition of material eroded from other sections of a stream reach, whereas degradation involves the scouring or lowering of the stream bed.
2. Contraction Scour: Contraction scour in a natural channel involves the removal of material from the bed and banks across all or most of the channel width. This component of scour results from a contraction of the flow resulting from a natural constriction or a constriction caused by the bridge and its roadway approaches. Contraction scour is caused by increased velocities and the resulting increased shear stresses on the bed and banks.

3. Local scour: Local scour involves removal of material from around piers, abutments, spurs and embankments. It is caused by an acceleration of flow and resulting vortices induced by the flow obstructions.

In addition to the types of scour mentioned above, naturally occurring lateral movement of a stream may erode the approach roadway or change the total scour by changing the flow angle of attack. Factors that affect lateral movement also affect the stability of a bridge. These factors include the geomorphology of a stream, location of the crossing with respect to the stream plan form, flood characteristics, characteristics of the bed and bank materials and land use in the watershed basin (See Chapter 9).

Case studies of various bridges in the United States which have collapsed as a result of scour graphically illustrate how one or more of the elements of scour discussed above contributed to the bridge failure. For example, the collapse of the New York State Thruway Bridge over Schoharie Creek on April 5, 1987 has been attributed directly to local scour at the bridge piers. The failure of the U. S. Highway 51 Hatchie River Bridge on April 1, 1989, has been attributed to a combination of (a) lateral shifting of the stream channel induced by contraction scour and (b) local scour of bridge piers that had originally been built on the flood plain but which became river piers due to the shift in the stream channel.

Long term stream bed elevation changes may be the natural trend of the stream or may be the result of some modification to the stream or its watershed. The problem for the engineer is to estimate the long term bed elevation changes that will occur over the life of the structure. This involves assessing the present state of the stream and its watershed, and then evaluating the probable effect of anticipated future changes in the river system (See Chapter 14).

Contraction scour occurs when the shear stress created by flowing water acting on the bed and bank material exceeds the ability of the material to resist this force; consequently, the material moves downstream. There are two types of contraction scour to be considered. Live bed scour occurs when there is stream bed sediment being transported into the contracted section from upstream. Most streams and rivers carry a sediment load during floods, and bridges spanning such streams are likely to be subject to live bed scour. Clear water scour occurs when there is an insignificant amount of stream bed sediment being transported into the contracted section. Clear water scour might be expected to occur at relief bridges on flood plains or at constrictions in some tidal waterways. In Maryland, clear water scour may predominate in some watersheds where these is not enough sediment supply to maintain live bed scour conditions during floods.

Bendway scour occurs primarily on the outside of bends due to the formation of secondary currents created by the bend. For bridges located on bends subject to contraction scour, the engineer will need to use judgment in the distribution of contraction scour at the bridge section to be consistent with the anticipated bendway scour (Reference 18).

Pressure flow occurs when the water surface elevation of the upstream face of the bridge is higher than the low chord of the bridge superstructure. This condition results in a vertical contraction of the flow, causing the flow velocity to increase and to enter the bridge at a downward angle to the horizontal. Both of these factors contribute to an increase in the depth of contraction scour under the bridge.

The basic mechanism causing local scour at a pier is the formation of vortices at their base. The formation of these vortices results from the pileup of water on the upstream surface and subsequent acceleration of the flow around the nose of the pier. The action of the vortex removes bed material from around the base of the pier. When the transport rate of the sediment away from the pier caused by the vortex is greater than the transport rate of sediment into the region around the pier, a scour hole develops. As the depth of the scour hole increases and widens, the strength of the vortices is reduced, thereby reducing the transport rate of sediment out of the scour hole. At the same time, the widened scour hole is able to capture a greater amount of the bed load moving past the pier. Eventually, an equilibrium condition is established and scouring ceases.

Abutment scour is perhaps the most complex and difficult aspect of scour at a bridge to predict. The OOS methodology for computing abutment scour considers it to be a combination of contraction scour and local scour as explained in Appendix A.

The configuration of a scour hole at a bridge or abutment can be expected to change with time. The scour hole initially forms and increases in size and depth as flood flow increases at the bridge. The scour hole generally reaches its maximum depth near the peak of the flood hydrograph, and then partially refills during the recession of flow from the peak. For this reason, post flood measurements of the bed surface of the scour hole may neither reveal the maximum depth of scour experienced at the bridge nor be indicative of the maximum threat to the stability of the bridge. Maximum scour depths during floods are best obtained by on-site personnel making continuous measurements or by the installation of scour monitoring equipment that are programmed to make continuous readings during floods.

11.3 Design Philosophy

There are a number of considerations involved in the design of a bridge waterway and its roadway approaches. Each highway agency has developed its own standards and criteria for sizing of the waterway opening and for determining an acceptable recurrence interval of the overtopping flood. Higher standards are set for major interstate highways and expressways while lower standards are usually set for minor local roads with low traffic counts. Various other factors may be considered in the selection of the design flood for the bridge waterway area such as the uses of the road (school bus route and access for fire and emergency vehicles), the character and size of the river, the proximity of other river crossings and the detour routes that will be available for use in the event that the roadway and bridge are inundated and closed to traffic. Bridge owners often use some type of a formal or informal risk assessment to organize and document the decision-making process for selection of the design flood and overtopping flood. The OOS criteria is set forth in Chapter 10 Bridges

A different approach is used in the design of the bridge substructure to resist scour. All bridges should be designed to remain stable for the worst case scour condition which can reasonably be expected to occur at the crossing. The added cost of making a bridge less vulnerable to scour damage is usually small in comparison to the total costs of a bridge failure including:

- The personal costs of the injuries or deaths caused by a bridge collapse,
- Reconstruction of the bridge,
- Added time and travel costs incurred by road users on detour routes while the bridge is being repaired or reconstructed, and
- Indirect economic losses to a local community or an entire region due to lost business opportunities.

There are many sources of uncertainty in predicting the worst case scour condition and the depth of the resulting scour. These include model, parameter, hydrologic and hydraulic uncertainties.

The extent of these uncertainties can vary significantly from bridge to bridge depending upon the site conditions and the difficulties in estimating the parameters used in the scour estimate.

Model uncertainty results from using a model or equation form that may not be representative of the physical processes which occur in the river. In the case of bridge scour, most of the current models have been developed from small scale laboratory experiments which are then extrapolated to the prototype scale. Complexities in the field cannot be modeled entirely in the laboratory and the degree of accuracy of the model in predicting phenomena at prototype structures is often unknown.

If the field conditions differ significantly from the laboratory conditions used to calibrate and develop the scour estimating equations or procedures, the model uncertainty is increased to the extent that it may overshadow all other types of uncertainty.

When using scour equations developed from laboratory studies, the engineer should consider the following questions:

- What are the laboratory conditions used to develop the equations?
- Can the field conditions be represented in a way that is compatible with the laboratory conditions?

If the answer to the second question is no, then additional study and evaluation of the problem is most likely warranted.

Parameter uncertainty results from an inability to accurately assess parameters and model coefficients required in the model. For example, for many bridges, the pier width is not a simple measurement but rather an estimation of the size of the obstruction that the piles and pile caps or footings create in the flow field.

Hydrologic uncertainty results from the difficulty in accurately estimating the 100-year and 500-year flood peaks due to relatively short gaging station records or to a lack of runoff data for the watershed.

Hydraulic uncertainty is the result of attempting to estimate the flow depth and velocity for a specific discharge at a specific site. This uncertainty increases when there are limited data available for use in calibrating flood stage with discharge.

Economic uncertainty results from the large number of alternative choices and decisions involved in the location and design of a bridge and its roadway approaches. The Engineer is expected to achieve a design that is safe, compatible with the river environment and cost-effective.

It is the responsibility of the engineer to use judgment in the development and evaluation of scour estimates. This judgment should extend to the evaluation of the interactions of the uncertainties discussed above, along with the sensitivity of the scour estimate to changes in these uncertainties. The basis for decisions and assumptions relating to the predicted scour depths and the resulting foundation design should be clearly documented in the project records.

11.4 Policy

11.4.1 General Policies

The following policies apply to the preparation of scour evaluation reports and to the design of bridge foundations to resist damage from scour. Please contact the Office of Structures if you have questions regarding the interpretation or application of any of the policies presented below. Such early coordination will serve to minimize problems and delays in the preparation of project studies and plans.

1. The primary responsibility of the Engineer is to provide for the safety of the public (Section 11.1).
2. Locate and design structures, to the extent practicable, to minimize obstructions to flood flows and thereby minimize the scour potential (Section 11.6).
3. Prepare a scour evaluation report or a scour assessment report for each project involving a structure crossing of a stream. The report shall address the considerations set forth in Sections 11.6 or 11.7.
4. Prepare scour evaluations and assessments using an interdisciplinary team of engineers and specialists with the requisite knowledge in structures, hydraulics, river mechanics, geotechnical engineering and geomorphology (Section 11.1.2).
5. Conduct a stream morphology study as per the guidance in Chapter 14 and use the results in the scour evaluation study. Key information includes an evaluation of the stability of the channel, the extent of estimated degradation or aggradation; the width of the channel lateral movement zone; information on the location and properties of soil and rock at the bridge; whether the type of scour to be expected at the bridge is live-bed or clear water scour; and the classification and evaluation of debris carried by the stream.
6. Coordinate the structural, hydraulic, geotechnical and geomorphic aspects of foundation design and resolve any differences at an early date following the approval of the TS&L (Section 11.6.9).
7. The FHWA Manuals (References 1, 2, 7 and 15) serve as basic guidelines for evaluation of stream stability and scour, except for the specific policies and procedures of the SHA set forth in this chapter and its appendices, primarily with regard to scour evaluations of abutments, piers and geomorphic studies. It is the responsibility of the Engineer to assure that the hydraulic, stream stability, scour evaluation and geomorphic procedures utilize current knowledge and technology consistent with the state of practice of hydraulic engineering, are appropriate for the site conditions under consideration (Sections 11.1, 11.2 and 11.3), and are consistent with the polices set forth in this OOS manual. Design structures to be stable for worst-case conditions for the design flood for scour and verify that they remain stable for conditions of the check flood for scour (Section 11.6 and 11.8).

11.4.2 Typical Scour Evaluation

The scope of a typical scour evaluation consists of analyzing the following aspects of scour and channel morphology which may have an effect the design of the bridge foundations:

1. Estimated channel degradation;
2. Estimated contraction, abutment and pier scour elevations, taking into account the potential for future channel movement at the bridge; and
3. Measured elevations of competent bedrock.

11.4.3 Recommended Scour Evaluation Process

The Office of Structures recommends that the scour evaluation process consist of the following steps:

1. Review the Stream Morphology Report for the bridge (Reference 4). Obtain the elevation of the degraded stream bed at the bridge and the limit of potential channel movement which may affect the design of the foundation elements. This zone of potential channel movement is defined as the "lateral channel movement zone" or LCMZ.
2. Use the HEC-RAS and ABSCOUR Models to compute contraction scour for proposed conditions.
3. Use ABSCOUR and/or math computations to compute the effect of the potential lateral movement of the stream on the depth of contraction scour at the foundation elements. Compute local abutment and pier scour using this information.
4. Review the Project Boring Logs to determine the elevation of competent (scour-resistant) rock at each foundation unit. Obtain the concurrence of the interdisciplinary team regarding the quality of the rock.
5. Summarize the elevations determined from the above studies. Make a judgment as to the appropriate elevation to use in the design of each foundation element considering 1) rock elevations; 2) contraction scour, 3) local pier and abutment scour elevations, taking into account channel movement, 4) degradation and 5) a combination of the above factors. For example, in some cases it may be appropriate to consider contraction scour, channel movement and local scour along with degradation when establishing the worst case elevation for a foundation on scourable material.

11.4.4 Selecting the Design and Check Floods for Scour

The Summary Tables below provides an overview of the Office of Structures guidelines for designing bridge foundations for scour. Use Table 11.1 as a guide in selecting the design and check floods for scour. Use Section 11.4.2 as a guide in selecting the appropriate scour conditions to use in evaluating the stability of bridge foundations. Additional design criteria and guidance are provided in the comments following the Summary Tables. All foundations designs are subject to the approval of the Director, Office of Structures.

Table 11.1 Criteria for Selecting the Design and Check Floods for Scour

Magnitude of the incipient overtopping flood (Q_{ot})	Design flood for scour*	Check flood for scour*
$Q_{ot} < Q_{100} < Q_{500}$	Q_{ot} , Q_{100}	Q_{100}, Q_{500}
$Q_{100} < Q_{ot} < Q_{500}$	Q_{100}	Q_{ot} ,Q_{500}
$Q_{100} < Q_{500} < Q_{ot}$	Q_{100}	Q_{500}

*If the Engineer selects a different flood for the design flood for scour or the check flood for scour, it must be approved by the Office of Structures.

Caution should be exercised when selecting the incipient overtopping flood as the design flood for scour or the check flood for scour. It is recommended that the Engineer evaluate the incipient overtopping flood, the 100-year flood and the 500-year flood in the process of determining the worst case condition. It is recognized that available technology has not developed sufficiently to provide fully reliable scour estimates for every site condition. Engineering judgment is needed to assure that scour estimates are reasonable.

11.4.5 Designing Foundations for Scour

Design for the design flood for scour; taking into account the normal geotechnical safety factors used in design: Ensure the foundation remains stable for the specified scour condition for the check flood for scour. This flood serves for investigating the adequacy of the bridge to remain stable and not fail (structural safety factor of at least 1) during a catastrophic flood event. This flood event represents the ultimate loading condition, since a bridge failure may occur for flood flows of a greater magnitude.

Evaluate abutment, pier and contraction scour using the ABSCOUR Program. Obtain estimates of long-term bed degradation and channel lateral movement from stream morphology reports. It is likely that long-term bed degradation will not occur on the flood plain beyond the limits of the channel lateral movement zone, but this assumption should be verified during the design of the structure.

Abutments: Provide scour countermeasures whenever practicable to protect the abutment approach fill and backfill from damage for conditions created by the design flood for scour. If scour countermeasures are not provided at abutments, ensure that the abutment approach fill and backfill are not vulnerable to damage for conditions created by the design flood for scour.

Piers: Normally, the worst-case hydraulic condition (highest channel velocity) for evaluating scour will occur at or near the channel thalweg. Use the worst-case condition to evaluate scour at all piers located within the lateral channel movement zone. Design piers to be structurally stable without reliance on scour countermeasures.

Scour countermeasures: In Maryland, scour countermeasures normally consist of riprap or sheet piling. These measures need to be specifically planned to fit the conditions of the structure under design. Detailed typical examples of riprap installations are set forth in Appendix 11D.

11.4.5.1 Spread Footings within the Channel Lateral Movement Zone

Analyze scour at spread footing foundations for both the design flood for scour and the check flood for scour for the specified design conditions listed below.

Piers and abutments without scour countermeasures: Place the bottom of the spread footing at one foot below the total scour elevation computed by subtracting local scour, contraction scour, and long-term bed degradation from the existing channel elevation.

Abutments with scour countermeasures: Place the top of the spread footing at one foot below the scour elevation computed by subtracting contraction scour and long-term bed degradation from the existing channel elevation. Provide a minimum embedment of the bottom of the spread footing of six feet below the channel thalweg.

11.4.5.2 Spread Footings outside of the Channel Lateral Movement Zone

Analyze scour at spread footing foundations for both the design flood for scour and the check flood for scour for the specified design conditions listed below.

Piers, and abutments without scour countermeasures: Place the bottom of the spread footing at one foot below the total scour elevation computed by subtracting local scour, and contraction scour, from the existing overbank area elevation.

Abutments with scour countermeasures: Place the top of the spread footing one-foot below the elevation of the contraction scour. Provide a minimum embedment of the bottom of the spread footing of six feet below the elevation of the flood plain.

11.4.5.3 Spread Footings on Rock

Design and construct spread footings keyed one-foot minimum into scour resistant rock using construction practices that minimize fracturing and damage to the supporting rock. Evaluate spread footing designs on weathered or other potentially erodible rock formations using the interdisciplinary team and an experienced engineering geologist familiar with the area geology. Estimate the potential scour depth in the rock and place the footing depth below this depth. The footing should be poured in contact with the sides of the excavation for the full designed footing thickness to minimize water intrusion below footing level. Factors to consider include rock cores and analyses, local geology, rock strata, hydraulic data, structure design life and risk to the public.

Use the Erodibility Index Method (Ref. 1) as a guide in the assessment of the quality of the rock. The worksheet developed by the SHA is based on the Erodibility Index Method developed by Dr. George Annandale. See FHWA Manual HEC-18 (Ref. 1), page 7.43 for up-dated guidance on use of the method. This spreadsheet is available at the WEB site listed in the Preface to this Chapter. A geologist or other specialist familiar with rock mechanics needs to be a part of the interdisciplinary team involved in determining the Erodibility Index of the rock and in designing foundations on rock.

11.4.5.4 Deep Foundations within the Channel Lateral Movement Zone

Evaluate deep foundations (Foundations on Piles) for both the design flood for scour and the check flood for scour. Design for the design flood for scour; taking into account the normal geotechnical safety factors used in design: Ensure that the foundation remains stable for the specified scour condition for the check flood for scour.

Design abutments and piers for total scour by subtracting local scour, contraction scour, and long-term bed degradation from the channel elevation. When designing for channel movement, compute the elevation of total scour using the sketch in Figure 11.1. Design pile caps to minimize exposure of piles using the following recommendations:

Piers, and abutments without scour countermeasures: Set top of pile cap at the scour depth elevation for the design flood for scour computed by subtracting contraction scour and long-term bed degradation (as referenced to the channel thalweg) from the elevation of the existing channel bed. When designing for channel movement, compute the elevation of the pile cap using the guidance in the sketch below (Fig. 11.1). For abutments, protect the abutment backfill from damage from being undermined by scour.

Abutments with scour countermeasures: Set bottom of pile cap at the scour depth elevation for the design flood for scour computed by subtracting contraction scour and long-term bed degradation (as referenced to the channel thalweg) from the elevation of the existing channel bed. When designing for channel movement, compute the elevation of the pile cap using the guidance in the sketch below.

For all foundations, determine if exposure of piles is acceptable. A deeper embedment of the pile cap may be warranted where piles could be damaged by erosion or corrosion.

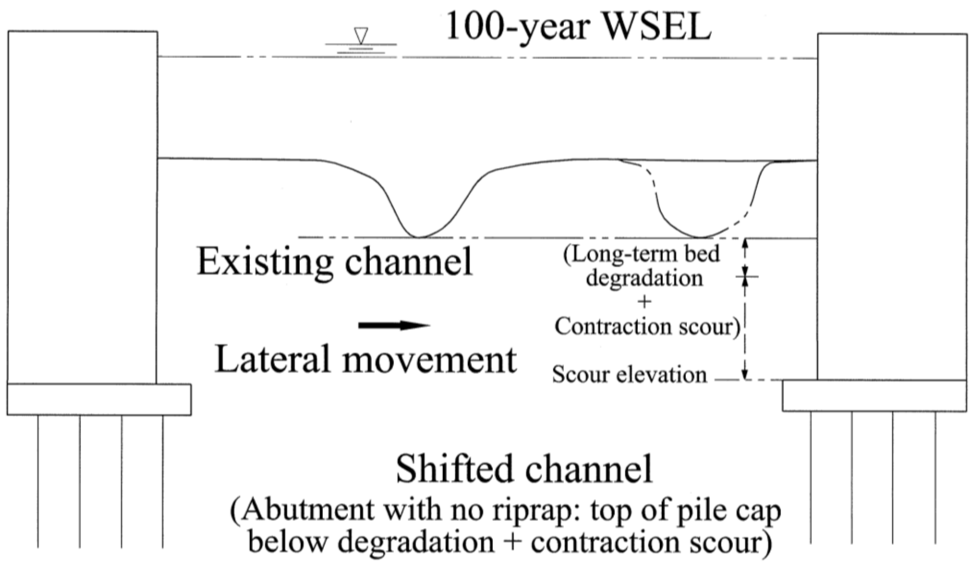


Figure 11.1. Design of Pile Cap for Deep Foundations within the Channel Lateral Movement Zone

11.4.5.5 Deep Foundations Outside of the Channel Lateral Movement Zone

Evaluate deep foundations (Foundations on Piles) for both the design flood for scour and the check flood for scour. Design for the design flood for scour, taking into account the normal geotechnical safety factors used in design. Ensure that the foundation remains stable for the specified scour condition for the check flood for scour. Design abutments and piers for total scour by subtracting local scour and contraction scour from the overbank elevation. Design pile caps to minimize exposure of piles using the following recommendations:

Piers, and abutments without scour countermeasures: Set top of pile cap at the scour depth elevation for the design flood for scour computed by subtracting contraction scour from the elevation of the existing overbank area. For abutments, protect the abutment backfill from damage from being undermined by scour.

Abutments with scour countermeasures: Set bottom of pile cap at the scour depth elevation for the design flood for scour computed by subtracting contraction scour from the elevation of the existing overbank area.

For all foundations, provide a minimum embedment of the bottom of the pile cap of six feet below the flood plain elevation. Determine if exposure of piles is acceptable. Even deeper embedment of the pile cap may be warranted where piles could be damaged by erosion or corrosion.

11.4.5.6 Deep Foundations: Stub Abutments on Spill-Through Slopes

Design stub abutments on spill-through slopes to remain stable in the event that the riprap protection is destroyed, the spill-through slope is eroded, and the piles are exposed. Two methods of analysis are recommended for consideration for this condition (see Figures 11.2a and 11.2b below). Design for the design flood for scour; taking into account the normal geotechnical safety factors used in design. Ensure that the foundation remains stable for the check flood for scour.

The angle of repose of the soil contained in the spill-through slope is an important factor in the stability analysis. Typical ranges of the angle of repose are depicted below:

Table 11.2 Typical values of the angle of repose for selected soils

Material	Typical Angle of Repose (Degrees)
Sand	30
Gravel	31-37
Cobbles	37-39
Clay	56-63

The Soils Lab should be involved in evaluating the angle of repose, since it can vary depending on such factors as density, surface area, and coefficient of friction.

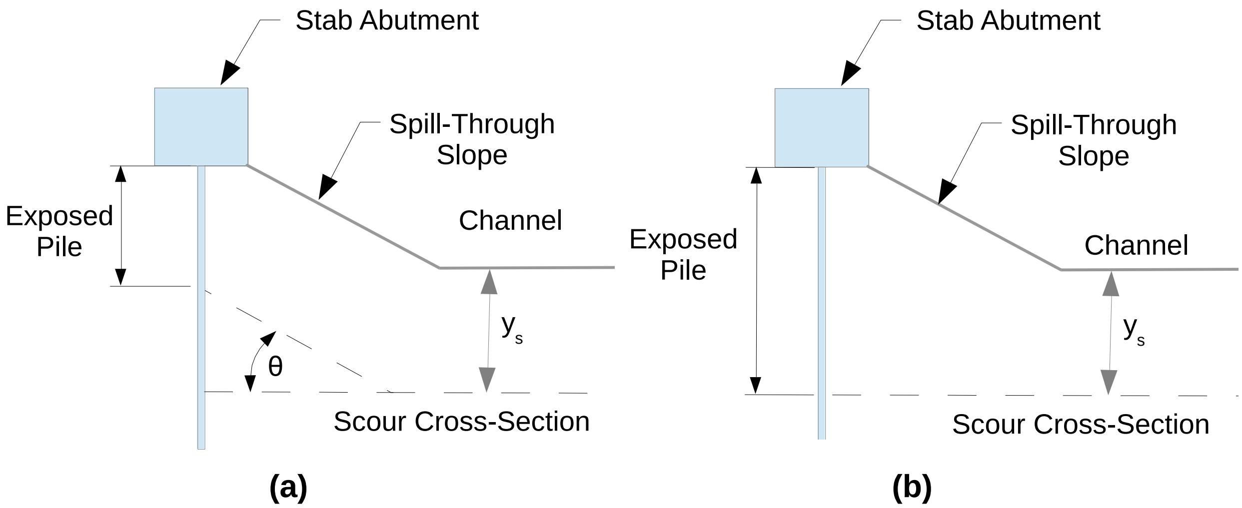
Case 1 and Case 2 described below serve to define an upper and lower limit for scour evaluation. The engineer will need to decide which case is most appropriate for the site being evaluated.

Case 1 is typical of a small stream crossing where the stream has a limited ability to erode the abutment slope.

- Compute the combined effect of contraction scour, channel movement and long-term bed degradation and plot the elevation of this scour depth at the toe of the spill-through slope.
- From this point, assume that the spill-through slope erodes at the angle of repose of the soil (typically 30 degrees for sand) and determine the elevation at which this line for the angle of repose intersects the piles.
- Evaluate the stability of the piles for this condition assuming all soil above the angle of repose has been scoured out. (See Figure 11.2a below).

Case 2 is possible for a larger stream or river with the stream power to completely erode the spill-through slope. This approach may be particularly appropriate for an abutment near the channel bank on the outside of a bend or for a location where it is reasonable to assume that the river will move into the abutment.

- Compute the combined effect of contraction scour, channel movement, and long-term degradation, and plot this total scour depth at the toe of the spill-through slope.
- From this point, draw a horizontal line to the location of the piles.
- Evaluate the stability of the piles for this condition assuming all soil above the zero angle of repose has been scoured out.(See Figure 11.2b below)



y_s = sum of contraction scour, degradation and effect of lateral channel movement. Scour cross-section elevation is used to determine the length of exposed piles for worst-case scour.

θ = angle of repose of backfill material, usually 30 degrees for sand

Figure 11.2. Stub Abutments on Spill-through Slopes

(a) Case 1: A Small Stream With A Limited Capacity To Scour The Spill-Through Slope
(b) Case 2: A Large River Where The River Moves Into The Abutment.

11.4.5.7 Abutments Utilizing Mechanically Stabilized Earth (MSE)

Under some site conditions, abutments constructed with MSE walls have been considered to be cost-effective alternatives to standard abutment designs. However, the MSE walls may be vulnerable to scour, and may need to be protected with a scour wall designed for worst case conditions of scour as described earlier in this chapter.

11.5 General Location and Design Features

11.5.1 Location Considerations

Rivers are dynamic, continually changing their dimensions, patterns and profile in response to changes in the discharge and sediment load carried by their channels. Bridges are static and remain in a fixed location. The task of the interdisciplinary team is to locate and size the structure to remain stable throughout its design service life, and to accommodate the anticipated flood discharges, sediment loads and accompanying changes in the river that will occur during this time.

It is generally safer and more cost effective to avoid hydraulic problems through the selection of favorable crossing locations than to attempt to minimize the problems at a later time in the project development process through design measures.

To the extent practicable, bridges over waterways and their approach roadways on flood plains shall be located to provide for the desired level of traffic service and safety and to:

- be consistent with flood plain management objectives and strategies, discouraging uneconomic, hazardous or incompatible use and development of flood plains,
- avoid changes to the bankfull flow conditions,
- minimize changes to existing flood flow distribution and elevations in the channel and on the flood plain, upstream, through and downstream of the bridge, particularly where such changes may adversely affect improved properties in the flood plain,
- minimize adverse changes to wetlands and other sensitive environmental features within the river's flood plain,
- select favorable crossing sites where the hydraulic flow conditions and resulting scour can be analyzed and accounted for within a reasonable degree of confidence,
- avoid locations of complex or hazardous hydraulic flow conditions (stream confluences, alluvial fans, sharp bend sections, alignments with high skew angles, sections with special problems with ice build-up or debris accumulation, etc.) conducive to the development of hazardous scouring at bridge abutments and piers.
- achieve the above objectives in a cost-effective manner, giving appropriate attention to their importance as well as the costs of construction, operation, maintenance and inspection associated with the structure.

11.5.2 Evaluation of Alternative Location Sites

The choice of location of bridges shall be supported by analyses of alternatives. The scope of such studies should be commensurate with the risks involved. Studies of alternative crossing locations should include assessments of:

- the hydrologic, hydraulic and morphological characteristics of the waterway and its flood plain, including channel stability, flood history and in estuarine crossings, tidal ranges and cycles,
- the effect of the proposed bridge on flood flow patterns and the resulting scour potential at bridge foundations,
- the potential for creating new or augmenting existing flood hazards,
- environmental impacts on the waterway and its flood plain, and
- life cycle costs of each alternative.

Experience at existing bridges in the vicinity of the project should be used to evaluate the reasonableness of all computations and conclusions regarding the proposed structure and can be helpful in selecting the type, size and location of the structure.

Further guidance on procedures for evaluating the location of bridges and their approaches on flood plains is contained in Chapter 9, Channels, and Chapter 10, Hydraulic Design of Bridges. Other references include those of the Federal Highway Administration and the American Association of State Highway and Transportation Officials (AASHTO). See References 1, 2, 3, 4, 14 and 15.

11.6 Bridge Scour Evaluation Studies and Reports

11.6.1 General

Submit Scour Evaluation Reports to the OOS for review and approval. Submit the final report both as a hard copy report and on a computer disk. In addition, fill out and date the Hydraulics and Hydrology (H&H) sheet and summary report presented in Chapter 4, and include it as a part of the final submission. The scour report and scour cross-section developed using the ABSCOUR program is also an integral part of every scour evaluation report.

Each bridge scour evaluation report should be developed to address the stability of the structure for the perceived worst case scour conditions at the site, the resulting effect on the safety of the traveling public and the measures to be taken to assure the appropriate degree of inspection and maintenance of the structure. The studies and information that should be addressed in scour reports are listed below:

- Introduction and background
- Scope of study
- Summary and Recommendations
- Hydrology study,
- Site investigation,
- Stream classification, geomorphology, and stability study. (The scope of such studies are defined by the level of detail required and may range from simple field classifications and evaluations (Level 1 analyses) to detailed stream sedimentation studies (Level 3 analyses),
- Subsurface investigation of underlying soils and rock, based on borings,
- Type, size and location of the bridge, including the geometry and dimensions of the superstructure and substructure elements and any proposed scour countermeasures,
- Line, grade and typical sections of the approach roadways,
- Hydraulic study, including evaluation of the consistency of the proposed design with the objectives of State and Federal policies and criteria regarding flood plain management,
- Scour evaluation and development of the scour cross-section under the bridge,
- Significance of scour evaluation,
- Structural and geotechnical design considerations,
- Scour countermeasures,
- Appendices, and
- Documentation

Each of these studies or report items, along with references of manuals and guidelines which provide further direction and guidance, is addressed in the following sections.

11.6.2 Introduction and Background

This section of the report should provide information on the highway section under design, the traffic it carries and other information regarding the need for the bridge project.

11.6.3 Scope of Study

The accuracy of the scour evaluation for a proposed bridge site is highly dependent upon the accuracy of the hydrologic and hydraulic data used in the equations for estimating the scour depths.

The scope of the bridge scour studies will depend upon the degree of accuracy to be achieved in the analysis. It is expected that water surface profiles will be developed for the reach of the river under study. One-dimensional hydraulic models such as the Corps of Engineers HEC-RAS model is commonly used for this purpose (See References 10 and 12). However, sites with complex flood flow patterns may warrant the use of a two dimensional model, such as the FESWMS model, to establish the hydraulic flow conditions (Reference 11). For tidal flows, different methodologies involving one and two-dimensional models are needed to define the hydraulic flow conditions. See Chapter 10 and References 11 and 13. Where conditions warrant, such as a major structure with complex hydraulic flow conditions, physical models can be used to more accurately evaluate the flow and resulting scour in the bridge opening. The selection of the study scope and the methodologies to be used in the analysis are among the most important decisions to be made in the preparation of a scour evaluation report.

One-dimensional models are based on the assumption that the slope of the energy line of the flood flow at any cross-section is the same across the entire cross-section. For many streams and rivers, this assumption provides for a reasonable approximation of the relationship between the flow in the river and the flow on the flood plain. Various techniques are built into the models to account for the more complex flow patterns which occur just upstream of a bridge crossing. One-dimensional models serve best for streams with relatively narrow flood plains where most of the flood flow is carried by the main channel.

Two-dimensional models are developed to account for changes in the energy slope longitudinally along the river and laterally between the channel and the flood plain. A two-dimensional network of triangles or quadrilaterals is established and the flow is calculated into and out of each of the network elements. The output is a plan view of the river and flood plain with vectors depicting the direction and velocity of the flow at each of the network elements. The water surface elevation and the magnitude of the flow are also provided at each network element.

While the two-dimensional model provides more information for use in a scour analysis, the cost and the time required for its application is greater. The engineer must decide which type of model is most appropriate for use based on traffic service and safety considerations, the extent of the flooding hazard and the particular site conditions at the proposed river crossing.

11.6.4 Summary and Recommendations

It is helpful to readers of the report to place the summary and recommendation section near the beginning of the report to provide an overview of the results of the scour evaluation. It should include a drawing of the scour cross-section which depicts the horizontal and vertical locations of the various foundation elements in relation to the estimated scour. Proposed scour countermeasures should also be included.

11.6.5 Hydrology Study

Appendix A presents a convenient method of summarizing hydrologic, hydraulic and bridge scour data that is currently being used by a state highway agency. SHA policies and procedures regarding Hydrology Studies are addressed in detail in Chapter 3, Policy, Chapter 8, Hydrology and in Chapter 10, Hydraulic Design of Bridges. The following discussion provides an overview of hydrologic considerations for bridge scour and stream stability study reports.

The assessment of hydrologic site conditions necessarily involves many assumptions. Key among these assumptions involves the prediction of flow magnitudes for floods with high recurrence intervals, e.g., the 500-year flood. The runoff from a given storm can be expected to change with the seasons, immediate past weather conditions and long-term natural changes or development of the watershed.

The ability to statistically predict such rare flood events is a function of the adequacy of the data base of past floods, and such predictions often change as a result of the addition of new data. The above factors make the check flood investigation of scour an important, but highly variable, safety criterion.

The assumptions used by the engineer to predict the magnitude and frequency of flood peaks used for the design and check floods for scour must be reasonable with respect to the data, conditions and projections available at the time of the bridge design. These assumptions need to be identified and documented in the hydrology study and report.

In general, use ultimate development land use, or if a TR-20 model is not available, use the upper limit of the 67% confidence interval from the Tasker Analysis.

The general trend is that the magnitude of scour increases with the magnitude of the river discharge, but this may not always be true. It is possible that the worst-case scour condition may occur for a discharge other than the design flood for scour or the check flood for scour. Such conditions may be most likely to occur at confluences or in controlled rivers with highly variable tail water. It is the responsibility of the Engineer to verify that the flows selected for analysis represent worst-case conditions for scour.

The recurrence intervals, periods and elevations of storm tides used to predict tidal scour should be correlated with the hurricane or storm tide elevations as reported in studies by the Federal Emergency Management Agency (FEMA), the Corps of Engineers (COE), the National Oceanic and Atmospheric Administration (NOAA) or other agencies.

The SHA and the Maryland Department of the Environment have jointly developed procedures for estimating peak flood flows in Maryland using the Maryland GIS Hydro 2000 Program. Detailed guidance on the methodology to be used in estimating flood peaks is presented in the publication "Application of Hydraulic Methods in Maryland dated February 1, 2001. Bankfull stages and discharges are normally obtained from field surveys as discussed in Chapter 9, Channels.

The scope of the hydrology study should be determined on the basis of the functional highway classification, the applicable federal and state requirements, and the flood hazards at the site. A range of flood flows should be determined to evaluate (1) the hydraulic adequacy of the proposed waterway opening of the bridge, (2) the effect of the bridge on the river, (3) the effect of the river on the bridge, and (4) the worst case conditions for designing the bridge foundations to resist scour. The development of a flood frequency plot is recommended to depict the magnitude of flood flows for recurrence intervals from the 1.5-year flood (typically bankfull stage for natural rivers) to the 500-year flood.

The riverine flood flows, storm tides or mixed population events listed in Section 11.1.3, Definitions, should be considered for use for the evaluation of stream stability and the design of the bridge waterway and foundations (See Reference 4). *Particular attention should be given to selecting design and check flood discharges for mixed population flood events.* For example, flow in an estuary may consist of both tidal flow and runoff from the upland watershed. If the mixed population flows are both dependent on the occurrence of a major meteorological event, such as a hurricane, the relative timing of the individual peak flow events needs to be evaluated and considered in selecting the design discharge. This is likely to be the case for flows in an estuary. If the events tend to be independent, as might be the case for floods in a mountainous region caused by rainfall runoff or snow melt, the Engineer should evaluate both events independently and then consider the probability of their occurring at the same time.

11.6.6 Site Investigation

A site-specific data collection plan should be developed for the proposed bridge crossing. Development of this plan is discussed in detail in Chapter 6, Data Collection. The following information should be considered in the preparation of the bridge scour report:

- collection of aerial and/or ground survey data for appropriate distances upstream and downstream from the bridge for the main stream channel and its flood plain,
- estimation of roughness elements for the stream and the flood plain within the reach of the stream under study,
- subsurface information including borings, soil and/or rock samples, and soil and/or rock testing,
- factors affecting water stages, including high water from streams, reservoirs, detention basins, tides and flood control structures and operating procedures,
- stream confluences,
- existing studies and reports including those conducted in accordance with the provisions of the National Flood Insurance Program or other flood control programs,
- improved properties on the flood plain,
- available historical information on the behavior of the stream and the performance of existing structures during past floods, including observed scour, bank erosion and structural damage due to scour, debris or ice,
- information on the stream channel including the bankfull cross-section, slope, plan form and materials in the stream bed and banks,
- Special studies may be warranted in some cases to collect detailed information regard the potential effect of ice, debris or bed forms to affect stream stability and the extent of scour at the bridge.
- Information obtained from field inspections and office reviews needs to be carefully identified and documented so that the source data used in the bridge scour evaluation can be identified and located at a later date.

11.6.7 Stream Classification, Morphology and Stability Study

A study is needed to evaluate the stability of the waterway and to assess the effect of the proposed highway/bridge construction on the waterway. The results of this study should include an assessment of the magnitude of the long term aggradation or degradation of the stream bed at the bridge site. It should also include an assessment and projection of the long term tendency of the stream to move laterally as a result of meander patterns, potential cutoffs of goose neck bends, etc. (See Chapter 14). This information may be of prime importance in the location and sizing of the bridge. In some instances, it may indicate that a crossing should not be attempted for the reach of the stream under study.

A stable stream can be defined as one with the ability, over time, to carry discharges and sediment loads in a manner that maintains its dimension (cross-section), pattern (plan form) and profile (slope) so that the channel neither aggrades nor degrades. If the stream to be crossed is stable, appropriate design measures need to be taken to assure that the highway/bridge construction maintains the existing flow conditions. Since minor changes in any of the above factors may cause a stream to meander and change the lateral location of its bed and banks, the likely future lateral movement of the stream needs to be considered in the bridge location and design.

If the stream is unstable, appropriate measures need to be taken to protect the structure from anticipated aggradation or degradation of the channel bed, or from lateral movement and sloughing of its banks as a result of the stream instability. The Office of Structures has developed detailed procedures for the evaluation of stream stability, as set forth in Chapter 14

11.6.8 Subsurface Study of Underlying Soil and Rock

Exploration of underlying soil and rock is essential for the geotechnical design of the bridge foundations, and subsurface exploration studies are normally planned and carried out by the geotechnical and bridge foundation engineers (See Reference 20). This information is also important in predicting the extent of scour which will occur in the channel and at the various piers and abutments. The question of the timing of the soil exploration needs to be considered early in the project development process, since the use of this information for the hydraulic and scour studies is often required at an earlier date than for the foundation design. In some cases, it may be necessary to obtain preliminary information for the scour analysis, followed up at a later date by final borings for the individual foundation elements. This type of approach requires coordination with the geotechnical engineers.

It is helpful to prepare subsurface profiles of the various soil layers and the location of the rock for purposes of evaluating the effect of the soils and rock on the total scour to be expected at the bridge crossing.

11.6.9 Type Size and Location of the Bridge (TS&L)

It is necessary to have information about the bridge dimensions and geometry for purposes of estimating contraction scour and local scour at piers and abutments. It is desirable to conduct the scour evaluation at an early stage in project development so that any needed changes to the bridge design can be more easily made to avoid serious potential scour problems. The TS&L stage of the project development process is a desirable stage for the consideration of the significance of scour. When complete information on the factors affecting scour is not available, it may be appropriate to make preliminary scour studies for purposes of establishing the significance of the scour problem. The estimates of scour can then be refined at a later date when more information becomes available.

The structural, hydraulic, and geotechnical aspects of foundation design need to be coordinated and differences resolved at the time of the foundation review.

In developing the bridge TS&L, consideration should be given to the following general design concepts to reduce the vulnerability of the bridge to scour damage:

- set deck elevations as high as practical for the given site conditions to minimize overtopping by floods, and to provide for freeboard for passage of ice and debris,
- utilize relief bridges, guide banks, dikes and other river training devices as appropriate to reduce the turbulence and hydraulic forces acting at the bridge foundations,
- utilize continuous span designs, anchor superstructures to their substructures where subject to the effects of hydraulic loads, buoyancy, ice or debris impacts or accumulations, and provide for venting and draining the superstructure,
- locate abutments back from the channel banks to minimize problems with ice/debris build up, scour or channel stability, or where special environmental or regulatory needs must be met, e.g., spanning wetlands, and
- where practical, limit the number of piers in the channel; use cylindrical piers to minimize the effect of the angle of attack; where cylindrical are not feasible, streamline pier shapes and align piers with the direction of flood flows; avoid pier types that collect ice and debris; locate piers beyond the immediate vicinity of stream banks,
- design piers on flood plains as river piers and locate their foundations at the same depth as the river piers if it is likely that the stream channel will shift during the life of the structure or that channel cutoffs are likely to occur,
- where ice or debris build-up is likely to occur, their effects should be minimized by providing for freeboard and streamlining bridge elements. Furthermore, anticipated ice and debris build-up needs to be accounted for in determining scour depths and hydraulic loads.

The stream hydrology, hydraulics and geomorphology need to be considered in the selection of a structure location, size and type that is compatible with the existing stream conditions. This includes consideration of the items listed below:

- whether the stream reach is degrading, aggrading or in equilibrium,
- for stream crossing near confluences, the effect of the main stream and the tributary on the flood stages, velocities, flow distribution, vertical and lateral movements of the stream, and the effect of the foregoing conditions on the hydraulic design of the bridge, location of a favorable stream crossing site, taking into account whether the stream is straight, meandering, braided or transitional; use of control devices to protect the bridge from existing or anticipated future adverse stream conditions,
- the effect of any proposed channel changes,
- the effect of dredging, aggregate mining or other operations in the channel,
- potential changes in the rates or volumes of runoff due to land use changes,
- the anticipated effect of the structure on the existing stream plan form, profile and cross-section and anticipated changes to the structure due to future changes in the stream geomorphology.

11.6.10 Approach Roadways

It is necessary to have information about the line, grade and typical section of the approach roads to the bridge for the entire flood plain in order to evaluate the effect of the proposed construction on flood plain flows. Highway embankments on flood plains serve to redirect overbank flow, cause it to flow generally parallel to the embankment and return to the main channel at the bridge. For such cases, the highway designs should include countermeasures where necessary to limit damage to highway fills and bridge abutments. Such countermeasures may include:

- relief bridges,
- slope protection of riprap or other types of countermeasures

Where bridges are subject to overtopping, develop the roadway/bridge profile so that one or both roadway approaches are at a lower elevation than the bridge. This provides for overtopping of the roadway approach section(s) before overtopping of the bridge, thus providing relief from the hydraulic forces acting on the bridge. This is particularly important for streams carrying a heavy ice or debris load which may clog its waterway opening.

Special hydraulic design problems may need to be dealt with on wide flood plains including the need for relief structures and the possible pocketing of flood plain waters at skewed crossings.

11.6.11 Hydraulics Study

Agreement should be reached at an early stage of project development regarding the analytical models and techniques to be used and whether they are consistent with the required level of accuracy. Where appropriate, consideration should be given to the use of laboratory studies to determine information that cannot be obtained from analytical models. The hydraulic study needs to be performed to a sufficient degree of accuracy so as to (1) size the waterway opening and (2) evaluate scour at the bridge. These two aspects of the bridge design are interdependent and should not be considered as separate, independent studies. Where use is made of existing flood studies, their accuracy should be evaluated at an early stage in the design process so that any necessary additional studies can be carried out in a timely manner.

Specific guidance and policies for the conduct of hydraulic studies are set forth in Chapter 3, Policy, Chapter 9, Channels, and Chapter 10, Hydraulic Design of Bridges.

Special procedures are set forth in Chapter 10 to define worst case scour conditions for tidal waterways. Once the worst case flow conditions are established, the scour evaluation will normally follow the same procedure used for riverine channels.

11.6.11.1 Hydraulics Considerations for Sizing the Bridge Waterway

The design process for sizing the bridge waterway should include:

- the evaluation of flood flow patterns in the main channel and flood plain for existing conditions, and
- the evaluation of trial combinations of highway profiles, alignments and bridge lengths for consistency with the design objectives.

Trial combinations should take the following into account:

- increases in flood water surface elevations caused by the bridge,

- changes in flood flow patterns and velocities in the channel and on the flood plain,
- location of hydraulic controls affecting flow through the structure or long-term stream stability,
- clearances between the flood water elevations and low sections of the superstructure (free board) to allow passage of ice and debris,
- need for relief structures on the flood plain,
- need for protection of bridge foundations and stream channel bed and banks, and
- Evaluation of capital costs and flood hazards associated with the candidate bridge alternatives through risk assessment or risk analysis procedures.

11.6.11.2 Hydraulics Considerations for Conducting Bridge Scour Evaluations

Once a preliminary bridge alternative and waterway opening has been selected, it should be evaluated for its adequacy to resist scour. In this evaluation, particular attention needs to be given to developing accurate estimates of the following hydraulic parameters at (1) the upstream approach section, (2) the bridge crossing and (3) the downstream full valley section for bridge scour studies. Estimated scour depths will be quite sensitive to these values:

- Unit flow discharges (discharge per foot) on the left overbank, right overbank and main channel,
- Flow depths and velocities for the unit flow discharges noted above,
- Vegetation, its critical shear strength and roughness for overbank areas,
- Evaluation of stream morphology and it's effect on the proposed bridge design,
- Particle size distribution and shear strength of soils in the channel bed and banks and in the overbank areas,
- Flow distribution and velocity distribution in the section immediately upstream of the bridge and in the bridge cross-section,
- Placement of foundations to minimize obstructions to the flow (spanning of channels where feasible, locating piers away from the channel thalweg, etc.)
- Tail water elevations in the downstream section,
- Superstructure geometry and its effect in the initiation of pressure scour.

Trial combinations should take the following into account:

- increases in flood water surface elevations caused by the bridge,
- changes in flood flow patterns and velocities in the channel and on the flood plain,
- location of hydraulic controls affecting flow through the structure or long-term stream stability,
- clearances between the flood water elevations and low sections of the superstructure (free board) to allow passage of ice and debris,
- need for relief structures on the flood plain,
- need for protection of bridge foundations and stream channel bed and banks, and

- evaluation of capital costs and flood hazards associated with the candidate bridge alternatives through risk assessment or risk analysis procedures.

Once a preliminary bridge alternative and waterway opening has been selected, it should be evaluated for its adequacy to resist scour. In this evaluation, particular attention needs to be given to developing accurate estimates of the following hydraulic parameters at (1) the upstream approach section, (2) the bridge crossing and (3) the downstream full valley section for bridge scour studies.

Every effort should be made to minimize changes to existing flood flow patterns and elevations in the channel and on the flood plain, upstream, through and downstream of the bridge, particularly where such changes will adversely affect improved properties in the flood plain.

11.6.12 Scour Evaluation; Development of the Bridge Scour Cross-Section

Scour at bridge foundations is to be investigated for the two conditions presented below (See Reference 4). Section 11.6.5 establishes the hydrologic definitions of these flood flows.

11.6.12.1 The Design Flood for Scour

The stream bed material in the scour prism above the total scour line shall be assumed to have been removed for design conditions. For piles and other types of deep foundations, the normal foundation design procedures and criteria are to be followed, except that no soil support is to be considered for soils in the scour prism above the total scour line.

11.6.12.2 The Check Flood for Scour

The stream bed material in the scour prism above the total scour line shall be assumed to have been removed for this condition. For piles and other types of deep foundations the normal foundation design procedures and criteria are to be followed, except that:

- no soil support is to be considered for soils in the scour prism above the total scour line. Deep foundations, such as piles, shall be designed using normal foundation design procedures, but with no soil support available above the total scour line.
- excess reserve beyond that required for stability under this condition is not necessary.

11.6.12.3 Scour Estimates

The ABSCOUR 10 Program is to be used to estimate scour at bridges and bottomless arch culverts. Detailed information on this program is contained in the program help files and in Appendix A of this chapter.

11.6.12.4 Other Considerations

When fenders or other pier protection systems are used, their effect on pier scour and collection of debris shall be taken into consideration in the design.

11.6.12.5 Scour Evaluation Procedure

The design flood for scour shall be determined on the basis of the Engineer's judgment of the hydrologic and hydraulic flow conditions at the site. The recommended procedure is to evaluate scour due to the specified flood flows and to design the foundation for the event expected to cause the deepest total scour. The recommended procedure for determining the total scour depth at bridge foundations is as follows:

- evaluate the long-term channel profile aggradation or degradation over the service life of the bridge as per Chapter 14.
- evaluate the long-term channel plan form changes over the service life of the bridge, and evaluated the extent of the Channel Lateral Movement Zone (CLMZ) as explained in Chapter 14.
- consult with the SHA on the findings of the above evaluations; determine jointly the need for any revised cross-sections to reflect anticipated long term changes,
- determine the combination of existing or likely future conditions and flood events that might be expected to result in the deepest scour for design conditions,
- determine water surface profiles for a stream reach that extends both upstream and downstream of the bridge site for the various combinations of conditions and events under consideration, and select the worst case condition for scour. Where the worst case condition is not obvious, select several cases for detailed study,
- determine the magnitude of total scour at piers and abutments,
- determine the total scour which will occur at the bridge and plot the total scour line for both the design flood for scour and the check flood for scour.

11.6.12.6 Scour Evaluation Review

The Engineer needs to decide the most appropriate method for combining the various scour elements. In most cases, a reasonable approach will be to add the long term degradation to the scour estimates obtained from ABSCOUR. If degradation values are large, additional evaluation of this simplified procedure may be necessary.

Foundation designs should be based on the total scour depths estimated by the above procedure, taking into account appropriate geotechnical safety factors. Where necessary, to minimize or avoid a hazard resulting from scour, bridge modifications may include:

- relocation of the crossing to avoid an undesirable location.
- relocation or redesign of piers or abutments to avoid areas of deep scour or overlapping scour holes from adjacent foundation elements,
- enlargement of the bridge waterway area or addition of guide banks, dikes or other river training works to provide for smoother flow transitions or to control lateral movement of the channel, or
- installation of scour countermeasures.

Foundations shall be designed to withstand the conditions of scour for the design flood and the check flood. In general, this will result in deep foundations. The design of the foundations of existing bridges that are being rehabilitated should consider underpinning or supplemental bents if the scour evaluation indicates the need. Riprap and other scour countermeasures in combination with monitoring may be appropriate if underpinning is not cost effective.

11.6.13 Significance of the Scour Evaluation

- Evaluate the results of the scour analysis, taking into account the probable accuracy of the variables in the methods used, whether or not the scour prediction equations are appropriate for the given site conditions, the available information on the behavior of the watercourse, and the performance of existing structures during past floods. Also, consider present and anticipated future flow patterns in the channel and its flood plain,
- Develop a mental picture of the existing flow patterns, how they will be affected by the bridge and how these changed conditions will affect the stability of the bridge,
- Modify the scour evaluation as necessary to assure that the evaluation is consistent and reasonable.
- Modify the bridge design or location as necessary to satisfy concerns raised by the stream stability scour analyses.

Structural and Geotechnical Design Considerations

Since the results of the scour evaluation will have an effect on the foundation design of the structure, it is important that persons conducting the hydraulics, structures and geotechnical studies work together in the conduct of their respective studies. As noted earlier in this guide, the structural, hydraulic and geotechnical aspects of foundation design need to be coordinated and differences resolved prior to the approval of the TS&L.

11.6.14 Scour Countermeasures

Scour countermeasures are features incorporated into the design of a bridge for purposes of preventing, delaying or reducing the severity of hydraulic problems and resulting scour. Specific guidance, policy and design procedures for scour countermeasures are included in Chapter 11, Appendix D and Reference 7

The recommended solutions for minimizing scour damage at new bridges include:

- Locating the bridge to avoid adverse flood flow patterns,
- Streamlining bridge elements, using features such as round piers, to minimize obstructions to the flow,
- Designing pier foundations to be stable for the worst case scour condition so that
- reliance on riprap or other similar types of scour countermeasures is not necessary (Section 5.12.3), and
- Designing abutment foundations in accordance with Section 11.6.12.4, using stone riprap, or other types of materials to protect the highway embankment and
- channel banks adjacent to the abutment.

For existing bridges, the alternatives available for protecting the bridge from scour are listed below in a rough order of cost:

- Monitoring scour depths and closing bridge if excessive,
- Providing riprap or other types of scour countermeasures at piers and abutments, when combined with monitoring,
- Constructing guide banks (spur dikes) to streamline the flow and reduce scour at the abutments,
- Constructing channel improvements,
- Strengthening the bridge foundations,
- Constructing sill or drop structures to control degradation and scour, and
- Constructing relief bridges or lengthening existing bridges

A number of considerations may affect the selection of an appropriate scour countermeasure including:

- The type of scour problem to be addressed, and the assessment of the risk involved,
- The experience in the area or region with the success or failure of various types of scour countermeasures,
- The design criteria and specifications of the bridge owner and the ability of the contractor to construct with available materials the installation envisioned by the designer, and
- The availability and cost of alternative scour countermeasures.

These factors warrant careful consideration by the engineer during the design and installation of the countermeasure. Periodic inspection and evaluation of such countermeasures are necessary to assure that the installation is intact and is able to perform its function of scour protection.

There are currently a considerable number of types of scour protection that can be used in place of riprap including sheet piling, grout bags, gabions, articulated revetment units, concrete linings, and various other types of commercially made materials. Guidance on the selection, design and installation of various types of scour countermeasures and filter materials is included in the Federal Highway Administration Publications (See References 7).

Where available, stone riprap is generally preferred as a scour countermeasure at bridges. The equations in Reference 1 are recommended for the selection of an appropriate riprap size for protecting bridge piers and abutments, since they are based on the Ishbash criteria for incipient motion of particles. The Corps of Engineers method is recommended for design of bank protection.

A recurring question with regard to the use of sheet piling is whether it should be pulled or cut off below ground elevation and left in place. This decision requires the exercise of engineering judgment with regard to the particular site conditions and the following considerations:

- pulling the sheet piling may permit the contractor to get salvage value or possible reuse at another site; however, the process of pulling the sheet piling tends to disturb the ground around the bridge foundation element and could accelerate local scour.
- Sheet piling left in place could be exposed by contraction scour and general degradation, thereby effectively increasing the width of the foundation element. This condition may cause additional local scour.
- Sheet piling left in place and backfilled and protected with an erosion resistant material may serve as an effective countermeasure, particularly if it is not exposed much above the stream bed.

There are available a number of types of natural or bio-engineering materials which, if properly designed and installed, can serve effectively as bank protection materials. These include such features as willow planting, root wads and other vegetative type treatments. Installation of natural materials requires special experience and training, and it may be prudent to use a design-build type of contract for these materials.

These natural or environmental treatments are not recommended for use at locations involving the integrity of the highway/ bridge or the safety of the persons using the highway. However, they can serve effectively in other less critical locations where a failure will not endanger lives or damage developed properties.

11.6.15 Appendices to the Scour Report

Appendices should include input to and output from computer models, plots of the location of subsurface borings along with the results of tests and measurements made of the soil and rock, scour computations, etc.

11.6.16 Documentation

Project documentation involves a system for keeping track of all significant field data, assumptions, the computer models used, input to and output from the computer models and other information on which the scour estimates are based. It is desirable to keep this information on file as hard copy as well as on computer storage disks.

The Office of Structures has developed a Hydraulics and Hydrology (H&H) Sheet and Report which is to be completed as a part of the hydrology, hydraulic and scour evaluation for bridge structures. The report is presented in Chapter 4, Documentation. The H&H Sheet is to be included as a part of the permanent bridge plans for each bridge design.

11.7 Scour Assessment Studies

In some instances, the interdisciplinary scour team may determine that a full scour evaluation report is not needed to assure that a structure can be designed and constructed in a manner that meets the intent of this guideline. An example of this type of situation might include replacement of a superstructure on an existing foundation over a stable stream when the existing piers and abutments are founded on erosion resistant rock and the footings are located below the channel thalweg. For such situations, a scour assessment report may be prepared which generally addresses the topics listed in Section 11.6 and provides the judgmental factors which serve to support the adequacy of the proposed design. If the scour assessment report cannot provide a reasonable basis on which to support the proposed design, then a more detailed scour evaluation report should be undertaken. Scour evaluations and assessments for county projects are discussed in Appendix 11F.

11.8 Changes in Foundation Conditions Due to Scour

Scour is not a force effect, but by changing the conditions of the substructure it may have a significant effect in altering the force effects acting on structures. The AASHTO Standard Specifications set forth detailed requirements for applying loads and load factors to bridge foundations (Reference 4). The consequences of changes in foundation conditions resulting from the design flood for scour shall be considered. Structures will be designed under this provision using normal design considerations and factors of safety selected by the foundation engineer. The assumption is made that all material in the scour prism has been removed and is unavailable for foundation support. The effect of the check flood for scour is to be considered with respect to the stability of structures over water. In the evaluation of this condition, the assumption is made that all material in the scour prism has been removed and is unavailable for foundation support. The structure is to remain stable for this condition, but is not required to have any reserve capacity to resist loads.

11.9 Scour in Bottomless Arch Culverts

Refer to Appendix 11C for policy and guidance on the design of culverts on footings.

11.10 Temporary Structures

Temporary structures for the Contractor's use or for accommodating traffic during construction shall be designed with regard to the safety of the traveling public and adjacent property owners as well as minimization of impacts to the stream channel and its flood plain (See References 4 and 20). The SHA may permit revised design requirements consistent with the intended service period for flood hazard posed by the temporary structure. Contract documents for the temporary structure shall delineate the respective responsibilities and risks to be assumed by the SHA and the contractor (See Chapter 19, Section 5, Temporary Structures and Flow Diversions)

References

1) Federal Highway Administration, Hydraulic Engineering Circular Number 18, *Evaluating Scour at Bridges*, Fifth Edition, April 2012.
2) Federal Highway Administration, Hydraulic Engineering Circular Number 20, *Stream Stability at Highway Structures*, Fourth Edition, 2012.
3) Federal Highway Administration, Hydraulic Engineering Circular Number 23, *Bridge Scour and Stream Instability Countermeasures*, Volumes 1 and 2, 2009
4) AASHTO LRFD Bridge Design Specifications, 2010
5) AASHTO Drainage Guidelines, Fourth Edition, 2007
6) Bridge Pressure Flow Scour for Clear Water Conditions, (See FHWA HEC-18)
7) SHA, Highway Drainage Manual and Supplements, thereto, 1981
8) Federal Highway Administration Memorandum from Chief, Bridge Division, to Regional Federal Highway Administrators dated July 19, 1991 on the subject of Scourability of Rock Formations.
9) Federal Highway Administration Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges, 2003.
10) U.S. Code of Federal Regulations, 23 CFR 650, Subpart A.
11) Corps of Engineers HEC-RAS (River Analysis System) User's Manual, Version 4.1 January 2010
12) Froehlich, D. C., Finite Element Surface-Water Modeling System, FESWMS-2DH, Version 2 User's Manual, FHWA Research Report, 1996.

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14) Corps of Engineers Hydraulic Engineering Center, UNET-- One Dimensional Unsteady Flow Through a Full Network of Open Channels, User's Manual,

15) HEC, "UNET – One-Dimensional Unsteady Flow Through a Full Network of Open Channels", User's Manual, CPD-66 Version 3.2, US Army Corps of Engineers, Hydrologic Engineering Center, Davis, CA, 1997.

16) Federal Highway Administration, HDS-6, *Highways in the River Environment*. December 2001.

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18) Maynord, Steven T., Toe Scour Estimation in Stabilized Bendways, Technical Note, Journal of Hydraulic Engineering, August 1996.

19) Applied River Morphology, David Rosgen, Wildland Hydrology, Pagosa Springs, Colorado, 1996.

20) Stream Channel Reference Sites, An Illustrated Guide to Field Techniques, United States Department of Agriculture, Forest Service, General Technical Report RM-245, April, 1994.

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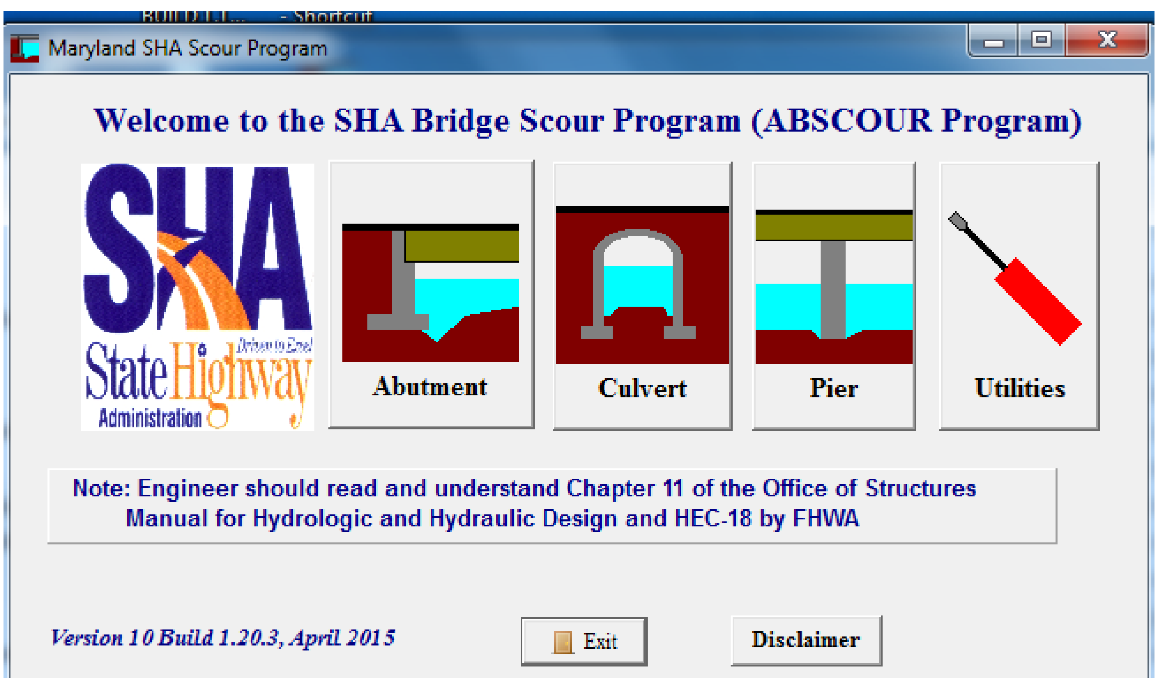
OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

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, 5th 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 5th 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. <u>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.</u>
3 Calibration studies have been conducted, in cooperation with the US Geological Survey, for estimating <u>clear water scour</u> 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.

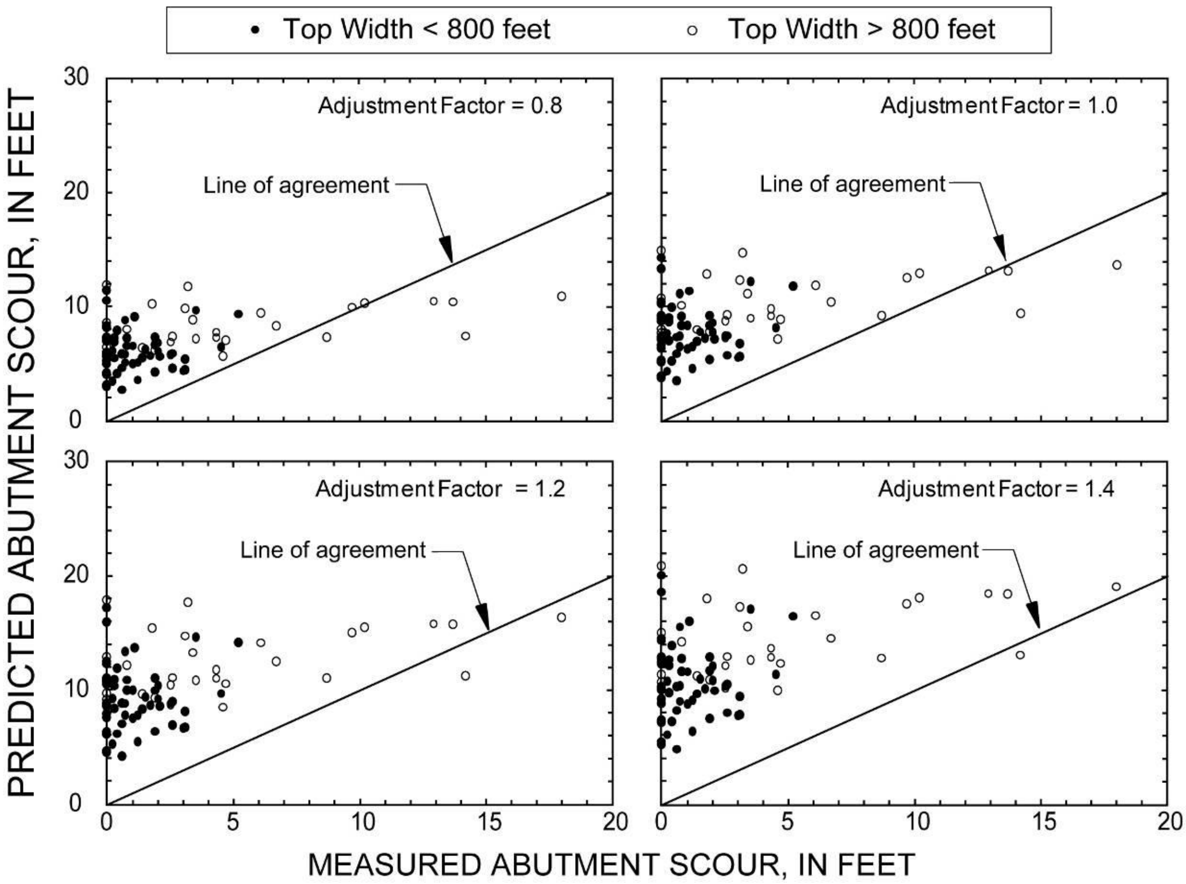
We have had the opportunity to apply ABSCOUR to many of the larger river crossing in Maryland with reasonable success. The scour evaluation equations for pier scour and contraction scour are essentially the same as those used in HEC-18. The concept of combining abutment scour and contraction scour as 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)

TABLE OF CONTENTS

PART 2: GUIDELINES FOR APPLYING THE ABSCOUR PROGRAM

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 θ by Laursen).

These dimensions are illustrated in Figure 1-1

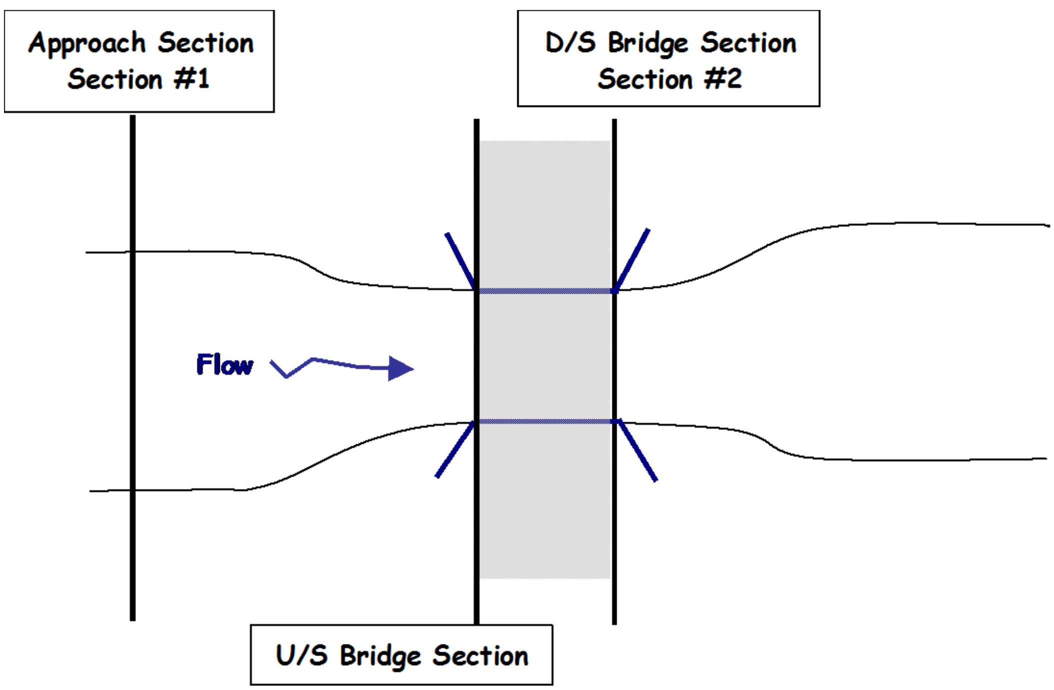


Figure 1-1
Plan View of Approach and Bridge Sections

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.

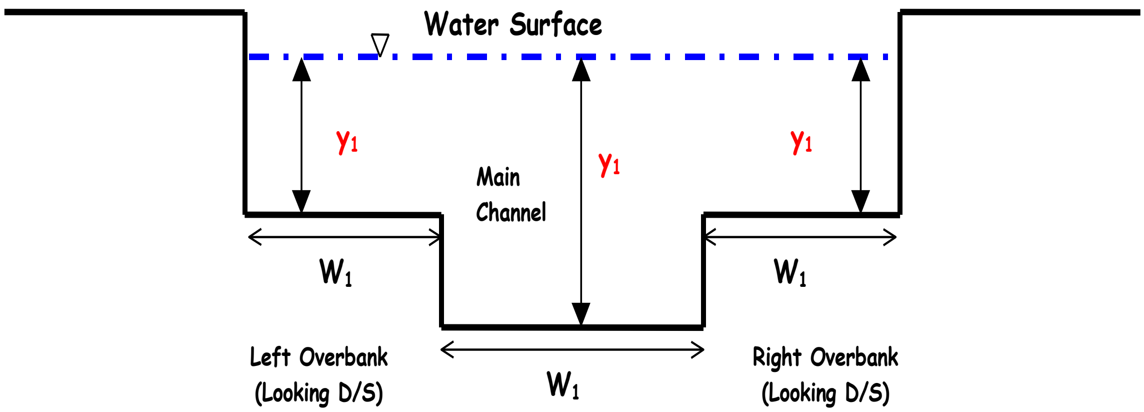


Figure 1-2: Definition sketch for the Approach Section (Looking Downstream)

(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.

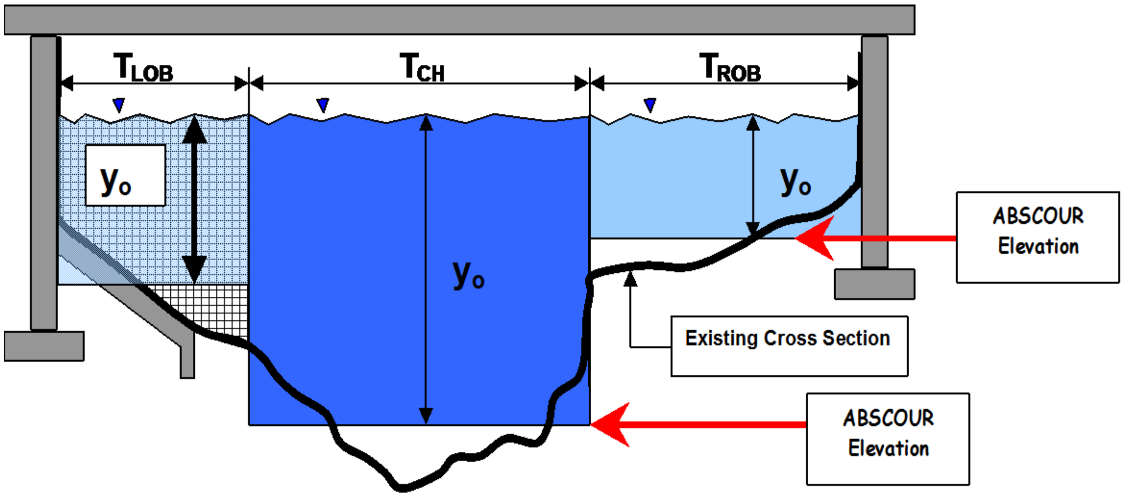


Figure 1-3

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.

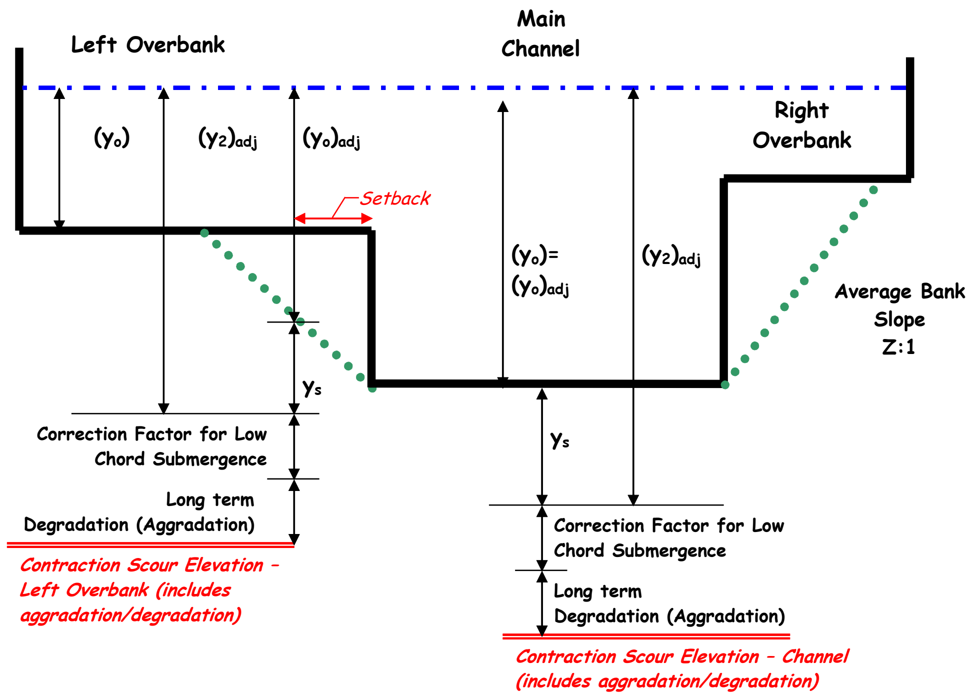


Figure 1-4

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

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

The final contraction scour depth is computed as:

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

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:

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

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

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

  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):

  $$\mathbf{Q_1 = Q_2}$$
  $$\mathbf{q_1 W_1 = q_2 W_2}$$
  $$\mathbf{q_2 = q_1 * W_1 / W_2} \qquad \textbf{(1-7)}$$

  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:

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

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

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

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

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 θ:

The value of k_2 (θ) 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 θ-value as a function of τ_c/τ_1 as shown in Figure 2.24 in ASCE Manual on Sedimentation (2). This curve may be approximated by the following equation:

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

Where τ_c is the critical shear stress and τ_1 is the boundary shear stress in the upstream or normal channel section. If τ_c is equal to or greater than τ_1, then clear water scour can be expected to take place at the bridge, and the value of k_2 (θ) 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, τ_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:

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

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, τ_1, in the approach channel or overbank subarea may be calculated as:

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

where:

γ = 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.

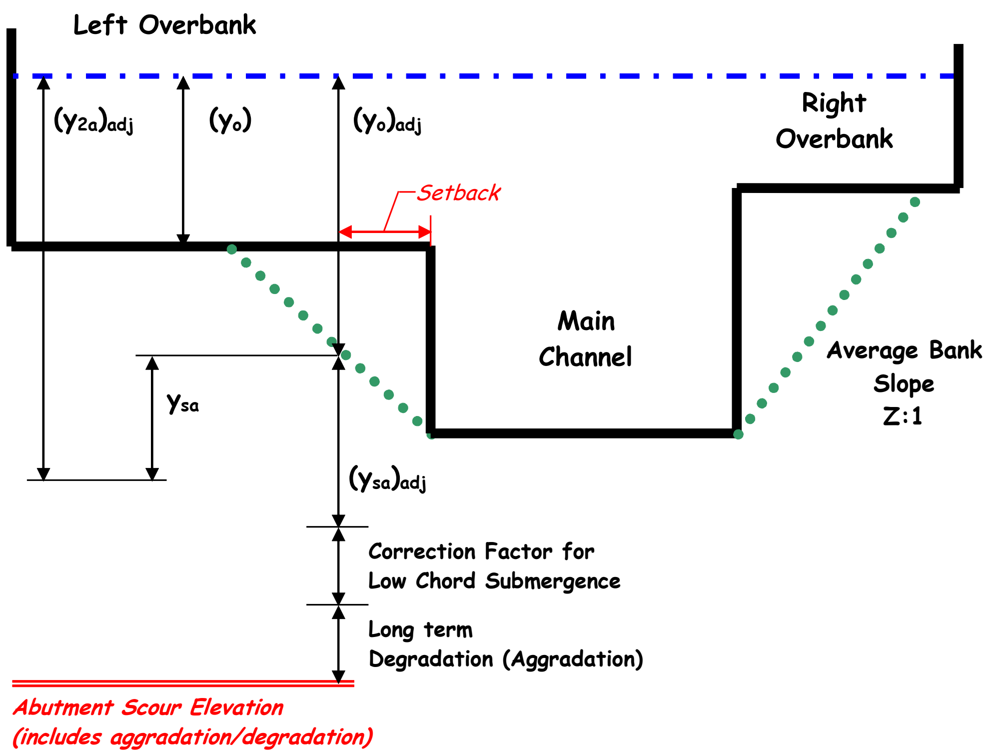


Figure 1-5: Definition Sketch for Abutment Scour Computations at Section 2, Bridge Section (Looking Downstream)

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:

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

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:

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

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.

$$\mathbf{F = V_1 / (g y_1)^{0.5}} \qquad \textbf{(1-22)}$$

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 θ 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.

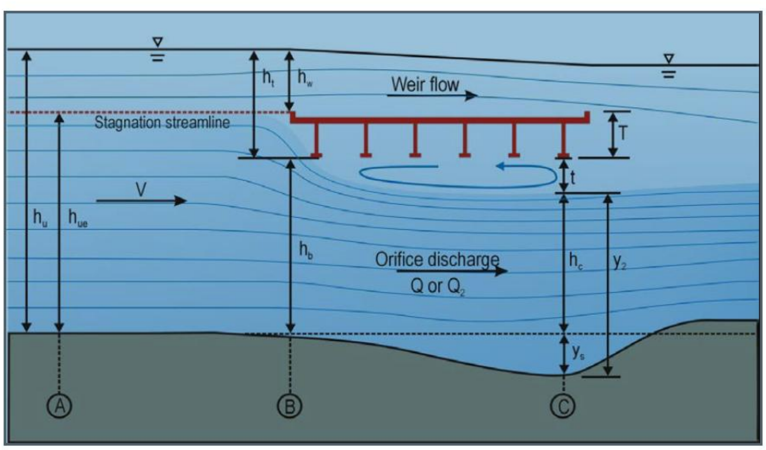


Figure 6.18. Vertical contraction and definition for geometric parameters.

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, α , is the angle between the direction of flow and the centerline of the roadway (bridge) at the left or right abutment:

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

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

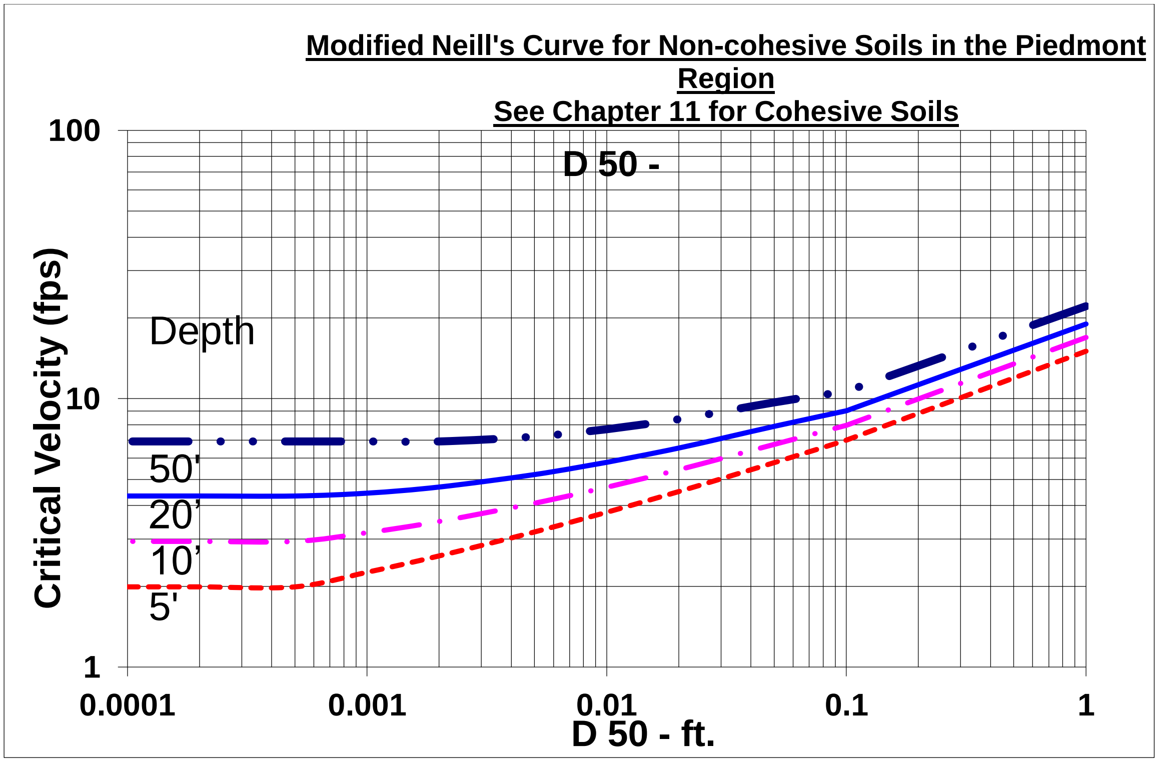
For conditions of clear-water scour, the following equations are used in the ABSCOUR program to solve for y_2. These equations were originally developed from Neill's competent velocity curves, Reference 11, and modified as a result of the findings of the USGS studies of abutment scour in South Carolina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

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

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:

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

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 ($y_{sa} = y_{2a} - (y_o)_{adj}$)

<u>Consolidated Clear-water Abutment Scour Equation</u>

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*

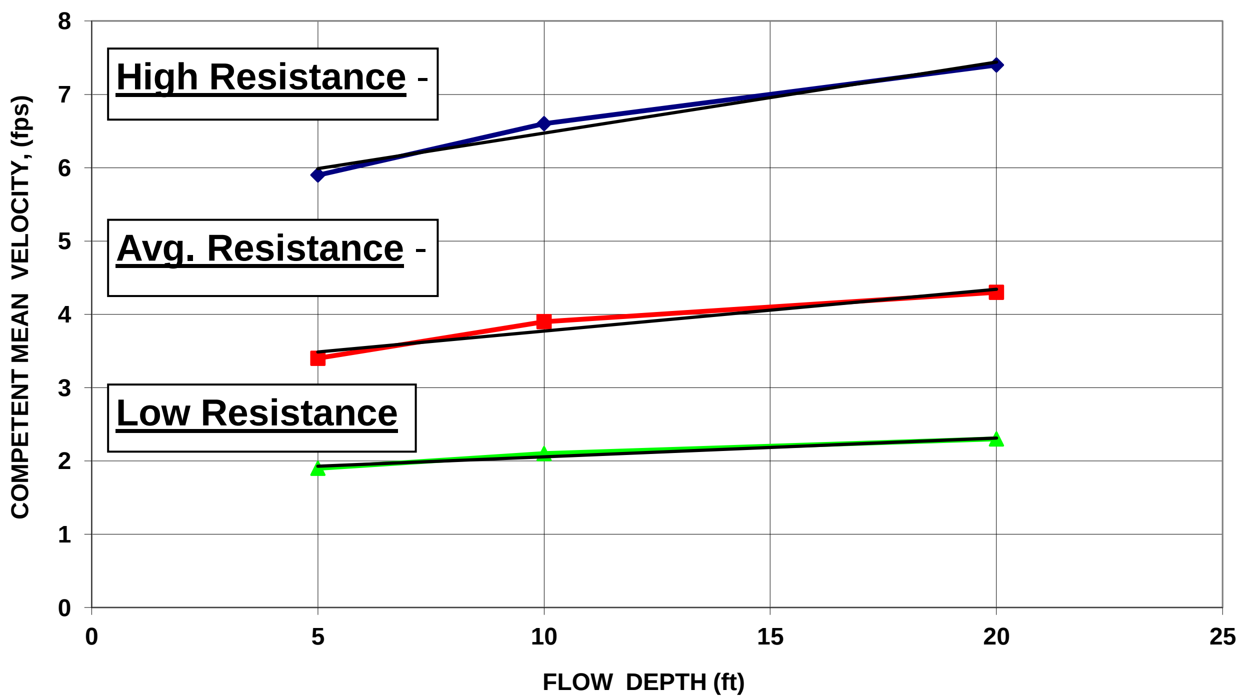
FS is a calibration/safety factor

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

1. FHWA, “Evaluating Scour at Bridges,” HEC No. 18, Fifth Edition, April 2012

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4. Milne-Thomson, L. M., Theoretical Aerodynamics, Fourth Edition, Macmillan, London, 1968.

5. Palaviccini, M., “Scour Predictor Model at Bridge Abutments,” Doctor of Engineering Dissertation, The Catholic University of America, Washington, D.C., 1993.

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8. Maryland State Highway Administration, Office of Structures, Manual for Hydrologic and Hydraulic Design, May 2015

9. Peggy A. Johnson, Pier Scour at Wide Piers, ASCE North American Water and Environment Congress, June 1996.

10. FHWA, “Bridge Scour and Stream Instability Countermeasures,” HEC No. 23,
11. “Guide to Bridge Hydraulics”, Second Edition, Transportation Association of Canada, 2001.

12. Evaluation of the Maryland Abutment-Scour Equation using Selected Threshold-Velocity Methods. November, 2008 Stephen T. Benedict, US Geological Survey

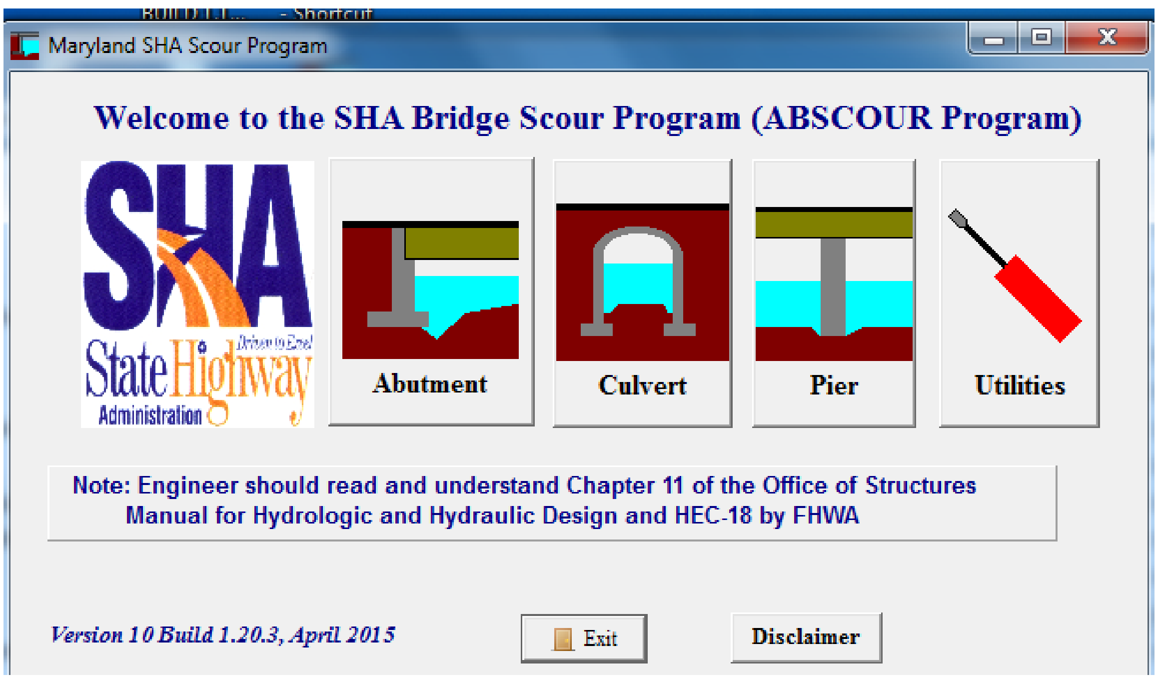
13. USGS, Clear-Water Abutment and Contraction Scour in the Coastal Plain and Piedmont Provinces of South Carolina, 1996 to 1999, Water Resources Report 03-4064

OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX A

ABSCOUR 10
USERS MANUAL

PART 2
GUIDELINES FOR APPLYING THE ABSCOUR PROGRAM



MAY 2015

PART 2: GUIDELINES FOR APPLYING THE ABSCOUR PROGRAM
(See Part 1 for a Table of Contents)

I. INTRODUCTION

Available technology has not developed sufficiently to provide reliable scour estimates at abutments for all possible site conditions. The policies and guidance in the abutment scour program ABSCOUR and in Chapter 11 of the SHA Manual of Hydraulic and Hydrologic Design have been developed with this consideration in mind.

The ABSCOUR program provides for considerable flexibility in the input format and the computations to permit the user to model field conditions. However, the user should make a critical review of all scour computations, using ABSCOUR for sensitivity analyses of input factors, to evaluate whether the answers obtained are reasonable. Part 2 guide has been written to assist the user in this evaluation.

> **The user assumes all responsibility for any decisions or actions taken as a result of the use of this program.**

Please note that definitions used and references cited refer back to the text in Part 1.

The discussion on abutment scour in the FHWA HEC-18 Manual (Reference 1) explains why the early abutment scour equations developed from laboratory flume studies are generally not reliable for predicting scour at abutments. The essence of this discussion is that a rectangular flume with a constant depth and velocity of flow across the width of the flume does not accurately model the field conditions of a channel and its flood plain; consequently, the equations developed from these lab studies generally predict conservative estimates of scour.

In the last several years, various researchers have begun to model "compound channels" to reproduce more accurately the field conditions of a channel and its flood plain. Information from these studies has been used to develop the ABSCOUR software program. The background on the development of the logic and the equations used in the ABSCOUR analysis is presented in Part 1 of this Appendix. The Engineer is encouraged to read and understand this information as well as the information in Part 2, Users Guide, before using the ABSCOUR computer program.

In addition to calibrating the ABSCOUR methodology with information obtained from flume studies conducted by the FHWA, ABSCOUR was calibrated using information from the USGS database of abutment scour measurements of bridges in South Carolina (See the discussion in Part 1 of this Appendix)

The ABSCOUR program is an expanded application of Dr. Emmett Laursen's live bed contraction scour equation as presented in the FHWA HEC-18 Manual, with certain modifications developed to account for the distribution of flow under the bridge, the bridge geometry and the computation of velocity at the bridge abutments. The ABSCOUR program computes both clear water and live bed scour and selects the appropriate scour type based on the input information. Careful application of the ABSCOUR Program will provide the user with insight into the factors affecting contraction and abutment scour at the bridge site under evaluation. Judgment is needed to modify input information and the ABSCOUR cross-sections so as to best represent actual site conditions during a flood event. *Computed scour depths provided by the ABSCOUR Program require evaluation to determine if the results are reasonable.*

Abutment scour can be viewed as a combination of contraction scour and local scour. The ABSCOUR Program computes the *total* *scour at the abutment; therefore, the user should not add contraction scour to this value.*
procedure.

The following information is needed to provide the input information for the ABSCOUR program:

1. Hydrologic estimates of Q_{100}, Q_{500}, $Q_{overtopping}$ and Q_{design}
2. topographic map of the stream and its flood plain, the location of the bridge crossing and stream channel cross-sections,
3. information from the geomorphology report regarding estimated channel degradation, the channel lateral movement zone, D50 soil particle sizes in the channel/flood plain and whether the type of scour to be expected is clear-water or live-bed.
4. Surface and subsurface information on channel bed load, flood plain soils, borings, etc.
5. geometric information about the bridge and approach roads
6. HEC-RAS runs for the given hydraulic conditions including:
7. stream channel cross-sections,
8. hydraulic data tables,
9. reliable bridge tailwater elevations,
10. selection of appropriate approach section and flow distribution, and
11. appropriate flow distribution at bridge with regard to channel, flood plain and overtopping flows.

II. DEVELOPMENT OF THE INPUT DATA FOR THE ABSCOUR (ABUTMENT SCOUR) MODEL

SHA has been conducting and reviewing ABSCOUR analyses for a number of years. It is our experience that one of the biggest sources of error in scour computations is an incorrect hydraulic model. It is not an easy task to model a 3-D flow pattern with a 1-D model such as HEC-RAS. In particular, special care needs to be given to the following three primary sources of error in developing the input data:

- Water surface elevation under bridge. The hydraulic model should include a sufficient reach downstream of the bridge to establish a reliable tailwater elevation at the downstream side of the bridge. Guidance on the required length of the downstream reach is provided in Chapter 4 of the H&H Manual.

- Flow distribution for overtopping flow. The Engineer needs to develop a rational flow distribution to account for the flow through the bridge and the flow over the bridge and approach roads. A trial and error approach to the HEC-RAS runs is often used to obtain a balanced flow condition.
- Approach section. Selection of a cross-section and of hydraulic flow parameters that are representative of the flow distribution in the approach section is essential to the scour evaluation. (See Step 3 below).

The guidance below, provided in a step-by-step format, is offered to assist the user in applying the ABSCOUR Program to a specific bridge site. The user is referred to Part 1 for a discussion of definitions and the derivation of equations used for scour calculations.

Help Options

There are two sources of help. Short help is available for most input cells by placing the cursor on the cell and pressing the F-1 key. More detailed help is available from the HELP tab on the Menu Bar at the top of the ABSCOUR screen. It is a good idea to use the short help (F-1 key) to check the text and sketches for clarification of the information to be provided in the cell.

The following guidance provides for a step-by-step explanation of how to input information into the ABSCOUR model. An actual scour evaluation (MD 313 over Marshy Hope Creek) has been used to illustrate the process and to comment on the parameters selected.

A. STEP ONE - HYDRAULIC MODEL

Prior to entering data for the ABSCOUR Model, the user will need to obtain hydraulic data as discussed below:

A.1 Water Surface Profile

Prepare a water surface profile using HEC-RAS or other program to model flow conditions upstream of, through and downstream of the bridge. Discharges selected for evaluation of scour should include the overtopping flow, Q_{100} , Q_{design} *and* Q_{500} *in order to develop the anticipated worst case scour conditions at the bridge.*

Field check Manning's "n" values to obtain the proper flow distribution between the channel and flood plains. Use sufficient downstream cross-sections to establish reliable bridge tailwater elevations.

A.2 Development of ABSCOUR Model Cross-sections

Two cross-sections are required to run the ABSCOUR program:

- **Section 1: Upstream approach section**. This section should be upstream of the area of influence of the bridge contraction and should be representative of the approach flow conditions. In some cases, the user may need to modify the actual approach section so that it is representative of actual approach flow conditions. (See Step 3).

- **Section 2: Downstream Bridge Section.** This section is located under the bridge *at the downstream end*.

<u>B. STEP TWO INPUTTING INFORMATION INTO THE ABSCOUR PROGRAM.</u>

<u>PROJECT INFORMATION MENU</u>

Figure 2-1 shows the ABSCOUR Project Information Menu screen. The following section explains each of the input parameters.

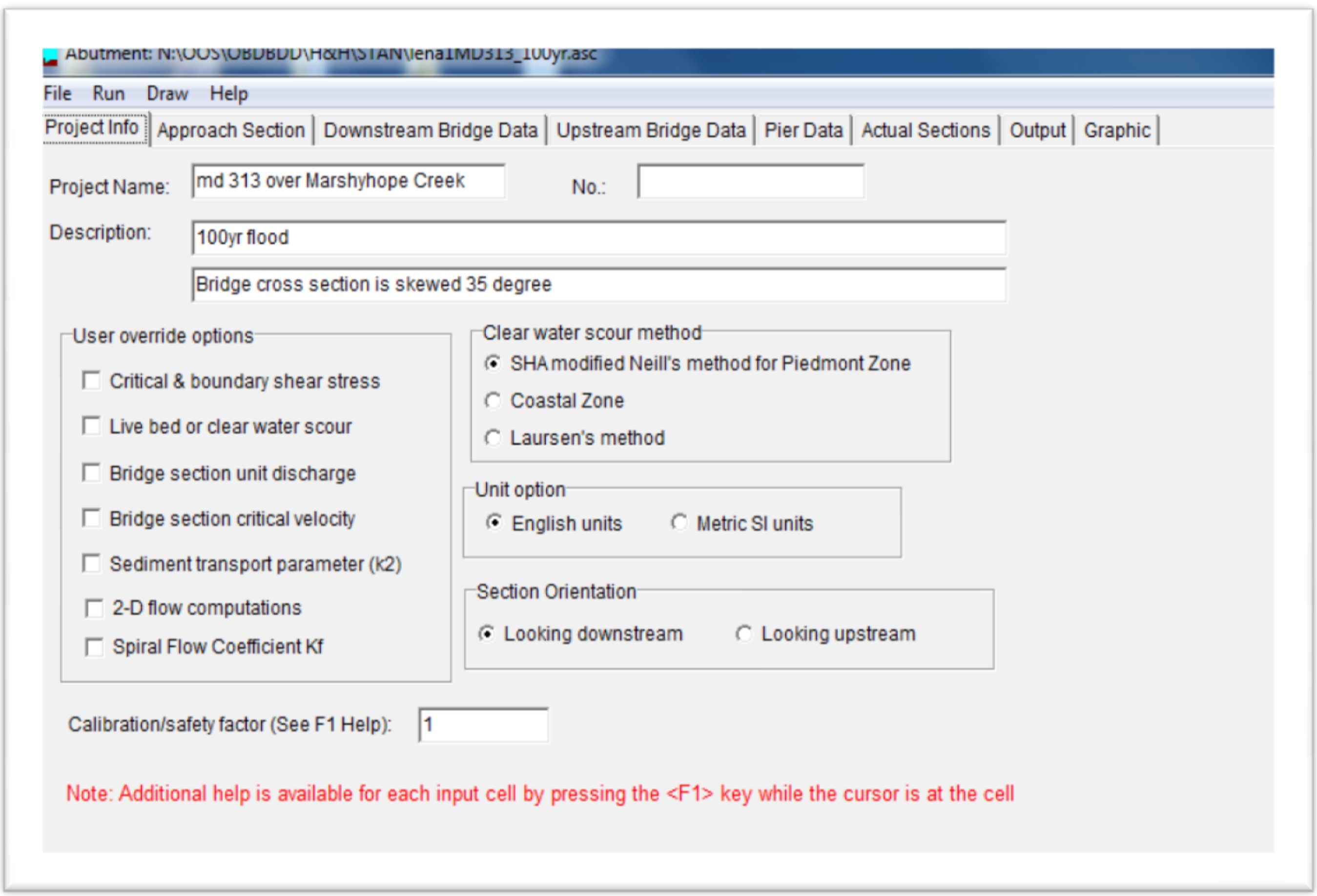


Figure 2-1: ABSCOUR Project Information Screen

Project Name and Description

Use this input to provide information on the project, bridge number, magnitude and frequency of the flood being evaluated, special conditions used in the analysis, etc. Since the user may make several ABSCOUR runs, this section can be used to detail the flood-frequency and magnitude, and any special conditions or modifications used in the analysis. This approach will help to clearly delineate and identify each run.

User Over-Ride Options

The ABSCOUR Program contains various over-ride features to allow the user flexibility in making the scour evaluation. The user is cautioned to use the over-ride features only after giving full consideration to the consequences of this approach. *Problems with the program output or with unrealistic scour estimates can often be traced to improper use of the over-ride functions*. We recommend that none of these features be used on the initial run. They are provided primarily to assist in the evaluation of a bridge with special problems or flow conditions. We suggest that users contact the Office of Structures for guidance on using the over-ride functions. The common overrides include:

- **Critical and Boundary Shear Stress:** For use where these values have been measured and determined to be reasonable.
- **Live Bed/Clear Water:** Use to change the determination made by ABSCOUR regarding the scour condition - live bed scour or clear water scour. A common use for the override is made for the condition on flood plains where there are low flow velocities and depths coupled with heavy vegetative cover, and a clear water scour condition is considered reasonable. Note that the stream morphology report is typically the best source of information regarding the type of scour to be expected.
- **Bridge Section Unit Flow Values:** This over-ride can be useful in conducting sensitivity analyses of complex flow patterns. For example, consideration of higher unit flow values on the outside of a bend.
- **Bridge Section Critical Velocity:** This over-ride should be helpful in evaluating the characteristics of the critical velocity for cohesive soils.
- **Sediment transport parameter:** Not recommended for use unless the engineer has specialized knowledge of the sediment transport characteristics of the stream.
- **Two-Dimensional Flow**: For studies utilizing 2-D flow models, the user can input directly, the velocity of flow measured at the abutment face.
- **Spiral Flow Coefficient k_f:** ABSCOUR 9 has been calibrated using the k_f values computed by the program. A higher kf value override may be justified in certain cases such as an abutment located in a wide wetland where flood plain velocities are low.

Clear water scour method: The SHA has experienced reasonable results in the use of the modified Neill's equation for evaluating clear water scour. In general, Laursen's equations result in much deeper scour estimates for very fine grained, non-cohesive bed material in channels. The user may wish to compare both methods. A (non-tidal) Coastal Zone method is included because of a number of bridges located in the wide wetlands of

South Carolina that were a part of the U.S.G. S calibration study. This method is not recommended at this time.

Unit Option: The user can choose between Metric and English units.

Calibration/Safety Factor: Information from the USGS study of scour at South Carolina bridges was used to modify the recommended calibration factors in earlier versions of ABSCOUR. In general, lower factors are now recommended. Please note that the current scour evaluation process described in Chapter 11 of the Manual recommends the calculation of the potential effect of channel movement and degradation. This calculation serves to decrease the need for reliance on a safety factor to account for lateral channel movement and degradation.

Factors higher than the recommended values should be considered for complex flow conditions.

C. STEP THREE - APPROACH SECTION

Figure 2-2 shows the input screen for the Approach Section. In order to enter the data for this sheet, the actual cross-section must be converted to the ABSCOUR model cross-section for the sub-areas of the left overbank, main channel and right overbank. Refer to Figure 2-3 for a definition sketch of the conversion from the actual cross section to the ABSCOUR cross section. The User has the option of superimposing the actual cross-section on the ABSCOUR cross-section for comparison purposes by using the importing function of ABSCOUR. Represent each sub-area as a rectangle having a width and average depth. Obtain the top width (T) and flow area (A) of each sub area from the HEC-RAS Program. Be careful not to include ineffective flow areas. Compute the average depth of flow or hydraulic depth for each sub-area as $y_{ave} = A/T$.

The model assumes an ideal one-dimensional flow pattern with a straight channel. The occurrence of a bend would affect the flow distribution in the reach of the stream under study. Refer to the discussion included under Upstream Bridge Data for ideas on how to modify flow distributions to account for 2-D flow patterns in the reach of the stream upstream of the bridge.

The ABSCOUR program uses Laursen's live bed contraction scour equation to determine scour. This equation serves to compare the unit discharges and scour in the approach section and in the contracted (bridge) section, assuming similar bed materials and hydraulic conditions. The best results will be obtained by selecting an approach section where the flow patterns and bed conditions in the channel are similar to the bridge section, keeping the following considerations in mind:

1. The approach section should be in a relatively straight reach and be representative of the upstream channel and flood plain. (If the bridge is in a bend, the approach section may be selected in an upstream bend with a similar configuration).
2. The cross-section should be perpendicular to the stream tube lines.
3. The approach section should be near the bridge, but far enough upstream (when

practicable) to be out of the influence of the bridge contraction.

4. If upstream conditions are complex, select the approach section one bridge length upstream and reevaluate the ineffective flow areas in the analysis. Refer also to the discussion under Upstream Bridge Data for ideas on complex flow patterns.
5. In many cases, there is no “ideal” approach section. For a complex flow pattern, it may be of help to evaluate scour by comparing the results obtained from two alternative approach sections.

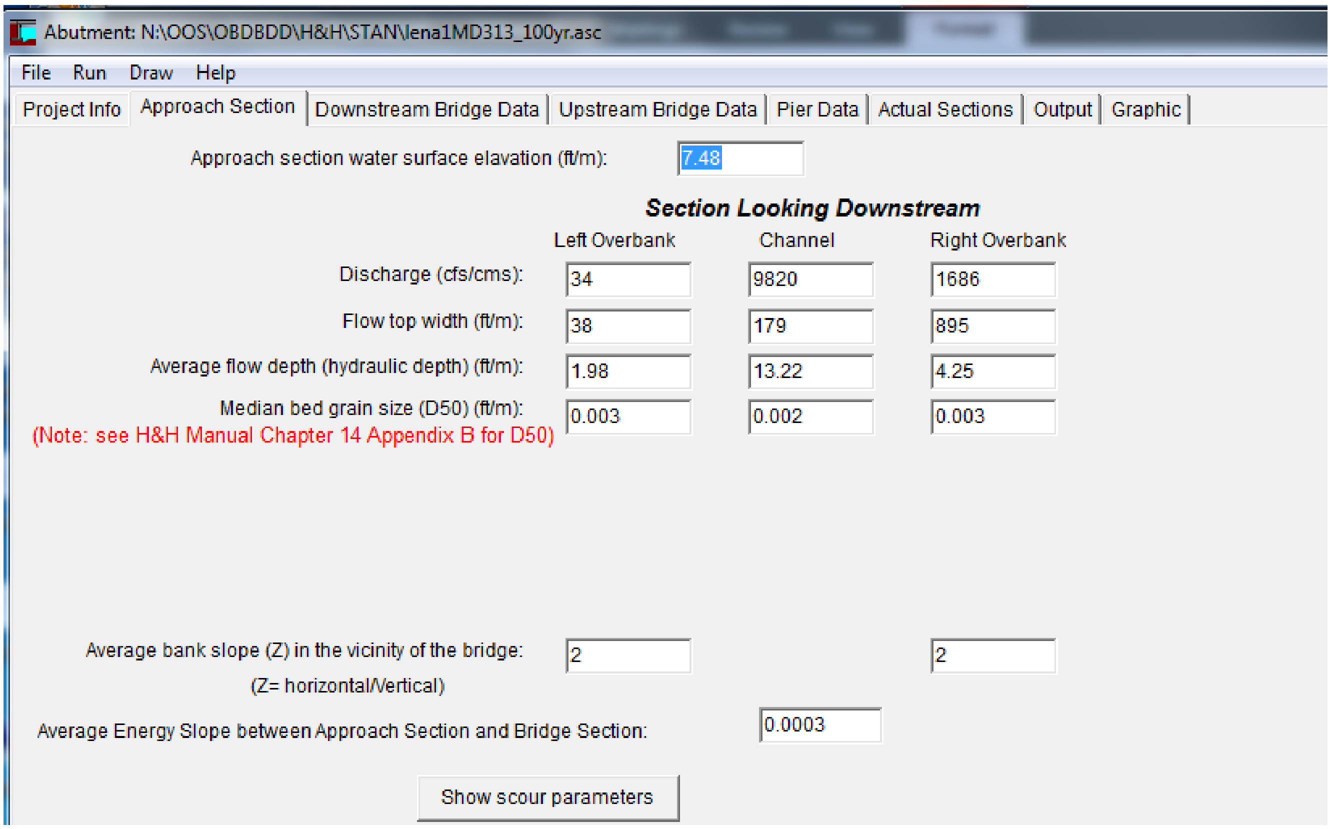


Figure 2-2: ABSCOUR Approach Section input sheet

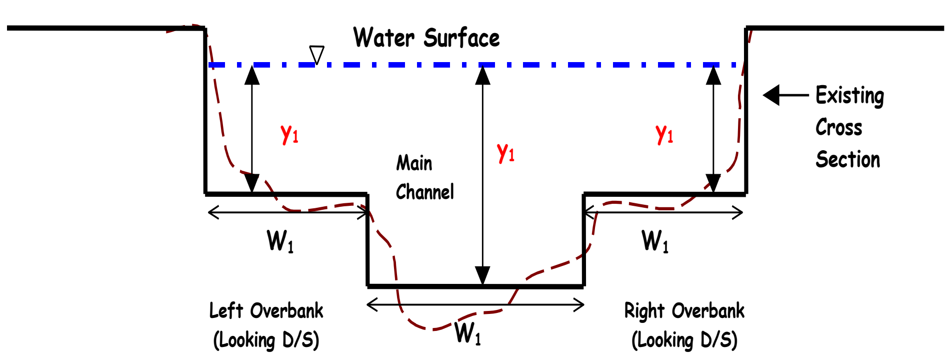


Figure 2-3: Definition Sketch for ABSCOUR Approach Section (Looking Downstream)

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

C.1 Enter Approach Section Data

The water surface profile models compute flow velocities, depths and discharges for the approach section on the basis of conveyance calculations. Modify these values as necessary to fit the ABSCOUR cross-sections as discussed above.

Verify that values used for y (depth), V (velocity), T (top width), q (discharge per foot of width) and Q (discharge) are consistent (q = V*y; Q= q*T).

As a general rule, information on each channel and overbank subsection is readily available from the output tables of the water surface profile model. For example, HEC-RAS computes the area of each subsection as the top width times the hydraulic depth. With a known area, hydraulic depth, and discharge provided for each subsection of the approach cross-section, the user can readily obtain the velocity and unit discharge values needed for the program.

3 **Approach Section Water Surface Elevation:** This elevation is used as a datum for importing the HEC-RAS cross-section for the approach section. It is a good idea to compare the ABSCOUR and HEC-RAS cross-sections.

- **Discharge, Q:** Enter the approach section discharge for the left overbank, channel and right overbank in cfs or cms.
- **Flow Top Width, W:** From HEC-RAS, obtain the flow top width for the left overbank, channel and right overbank. Be careful not to include ineffective areas in the top width computations.
- **Average Flow Depth (Hydraulic Depth):** From HEC-RAS, obtain the hydraulic depth for the left overbank, channel and right overbank. Be careful to adjust the hydraulic depth to account for any ineffective flow areas.
- **Median Bed Grain Size, D50:** Determine the D50 median grain size for material on the overbank areas and in the channel from field samples taken at the approach section. (Guidance on collecting samples and measuring D50 is provided in Appendix E of Chapter 11).

Average Bank Slope, Z: Enter the average bank slope of the stream in the vicinity of the bridge. . The program uses this information in evaluating scour when the abutment is close to the channel bank. The average bank slope (Z) of the left side of the channel is the horizontal projection of the slope when vertical is 1. The slope is used to adjust the ground line between the channel and the flood plain. The adjustment modifies the idealized ABSCOUR rectangular sections in order to model a more reasonable geometry for the bank condition. This adjustment provides for a better prediction of the abutment scour depth for abutments with short setbacks. as explained in Attachment 1

The bank slope also determines the relative effect of the channel scour on scour at the abutment for abutments with short setbacks. Steeper slopes such as 1:1 will reduce the effect of channel scour whereas flatter slopes such as 4:1 will increase the effect of channel scour. The bank slope can be used as a variable in sensitivity analyses of factors affecting abutment scour. See Contraction Scour, Adjustment for Short Setback Abutment (Case A).

- **Average Energy Slope:** This value is used in computing the boundary shear stress. Enter the average energy slope of the flow in the stream reach between the approach section (1) and the downstream bridge section (2). Refer to Figure 2-4 for details. The average energy slope is computed as:

  S_{ave} = (Energy Line Elevation Section 1 - Energy Line Elevation Section 2)/ L
  where L = distance between Sections 1 and 2.

  Please note that alternative methods may be more appropriate for some flow conditions, especially for backwater conditions. The computed value should be compared with information obtained from the HEC-RAS runs.

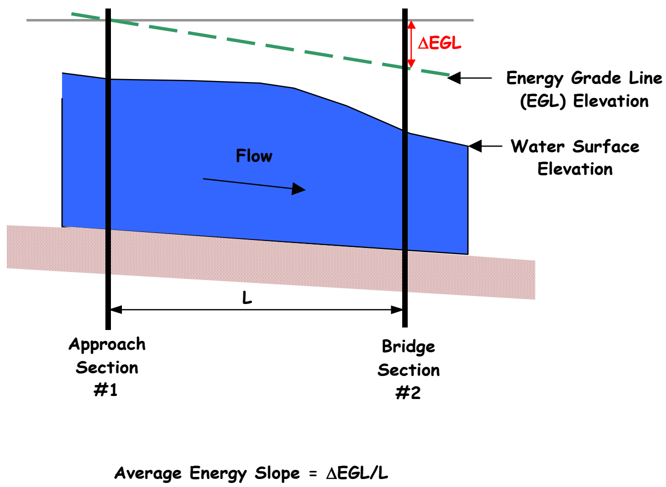


Figure 2-4: Average Energy Slope

- **Scour Parameter Button:** Click on the scour parameter button to view ABSCOUR scour parameters computed from the approach flow conditions. Refer to Figure 2-5. As noted earlier, over-riding any of these values should be undertaken with caution and an understanding of the flow and sediment transport conditions. For example, if the computations indicate live bed scour on the flood plain and the flood plain is covered with heavy vegetation with attendant low velocities, it is likely that clear water scour will actually occur on the flood plain. The scour parameter can be over-ridden to indicate clear water scour for the flood plain approach flow.

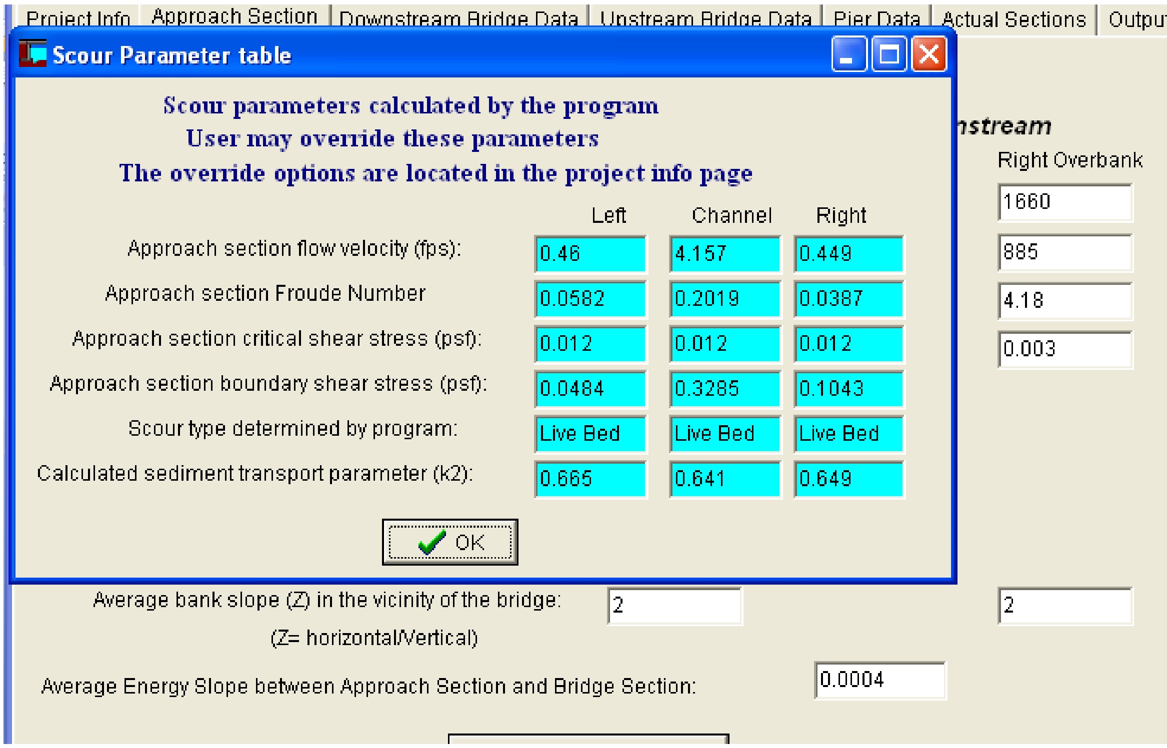


Figure 2-5: Scour Parameter Table

Please be aware that the sediment transport parameter, k_2, represents a complex function. The Level 2 analyses provided by HEC-RAS and ABSCOUR offer a reasonable approach for estimating this function. However, the water surface profile and hydraulic variables are assumed to be fixed for the HEC-RAS/ABSCOUR analysis, remaining constant for changes in the particle size of the bed load. This limitation can be minimized by making small changes to the HEC-RAS runs to account for varying 'n' values, but such refinement is normally unnecessary. However, we have observed an unusual and special condition for live bed scour while running sensitivity checks. For certain combinations of hydraulic flow conditions, a slight increase in the D50 particle size will result in an <u>increase</u> in the scour depth. This result, of course is the opposite of what we would expect. The anomaly is typically small and can be modified by the user to obtain a reasonable answer. The user has the option of overriding the calculated values and substituting other values for the critical shear stress and boundary shear stress. A first step in the evaluation of these parameters would be to refine the boundary shear stress as calculated by ABSCOUR ($\tau_1 = \gamma\ RS_{ave}$) at the approach section by obtaining more detailed information about the flow in the channel reach between Section 1 and Section 2.

D. STEP FOUR - DOWNSTREAM BRIDGE DATA

D.1 Enter the Downstream Bridge Data

Figure 2-6 shows the ABSCOUR input screen for the downstream bridge data. Figure 2-

7 shows the definition sketch for the downstream bridge data. Please note that the program is set up to input the flow estimates under the bridge as computed by the HEC-RAS model. However, the user has the option of using the over-ride cells to select a different flow distribution where there is a question regarding the HEC-RAS distribution which is based on conveyance calculations. Examples include a bridge on a bend where the user may expect a larger portion of the flow to move to the outside of the bend, a complex overtopping situation or an upstream confluence. See also the discussion on balancing the flows regarding the Upstream Bridge Data Card.

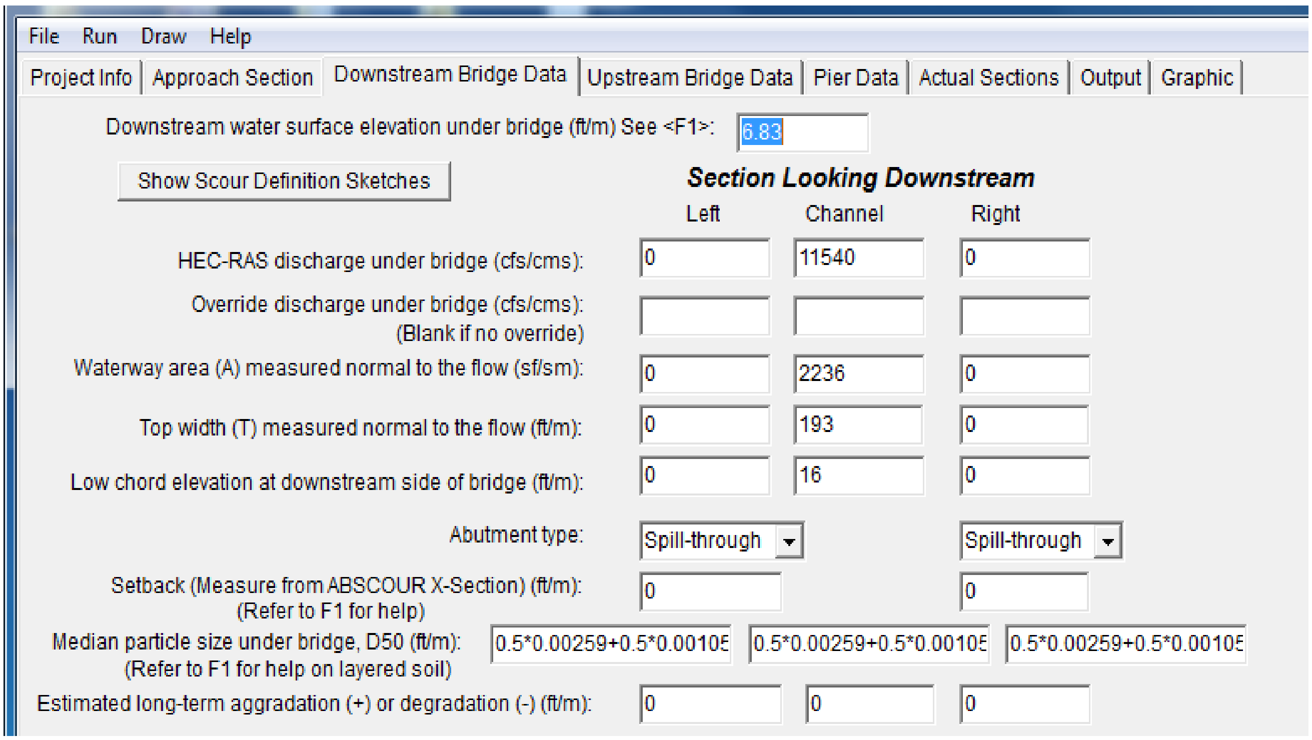


Figure 2-6: Downstream Bridge Input Screen.

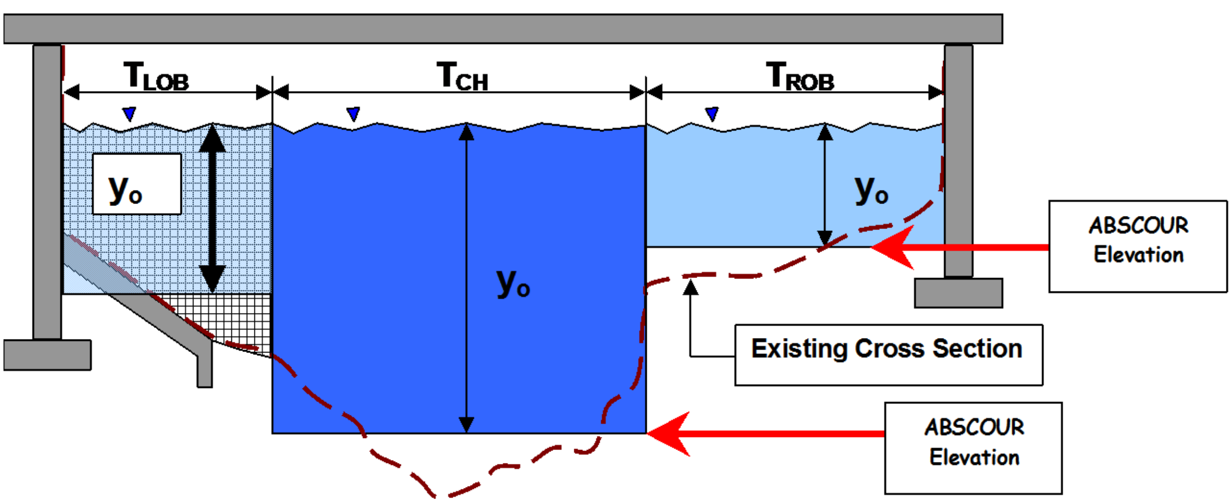


Figure 2-7: Definition sketch for Bridge Section

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

- **Downstream water surface elevation under bridge:** Enter the information from the hydraulic model. Check that there are enough downstream cross-sections to provide for a reliable estimate of the tailwater elevation. Please note that the measurement is to be made at the downstream side of the bridge and on the inside of the bridge. For pressure flow conditions, enter the water surface elevation immediately downstream from the bridge.
  The downstream water surface elevation serves as the datum for all ABSCOUR computations.
- **Show Scour Parameters Button:** This button provides a quick reference to scour terms when that are used in the program.
- **Waterway Area *(Measured normal to the flow):*** Measure the waterway area bounded by the water surface elevation and the channel cross-section for the right overbank section, channel section and left overbank section. (Typically, this information cannot be directly obtained from the HEC-RAS Tables. The bridge plans or the HEC-RAS cross-sections provide good information for use in measuring the waterway area). Please note that for pressure flow conditions where the water elevation is above the low chord, the top of the waterway area will be defined by the low chord.
- **Top Width, W or T, *(Measured normal to the flow):*** Measure the top width for the channel and the right and left overbank areas under the bridge. Judgment needs to be applied in obtaining this information. In some cases, the left and right overbank top widths may be very small, and it may be more reasonable to model the channel so as to incorporate these small overbank areas as a part of the main channel. If there is a pier within the limits of the ABSCOUR cross-section, the top width and flow area should be adjusted to subtract the pier width/ pier area.

  The program will compute the hydraulic depth for each downstream sub-area (left overbank, channel and right overbank) as $y = A/T$.

- **Low Chord Elevation:** Enter the average low chord (lowest superstructure element) elevation at the downstream side of the bridge for the left overbank section, right overbank section and channel section. Refer to Figure 2-8.

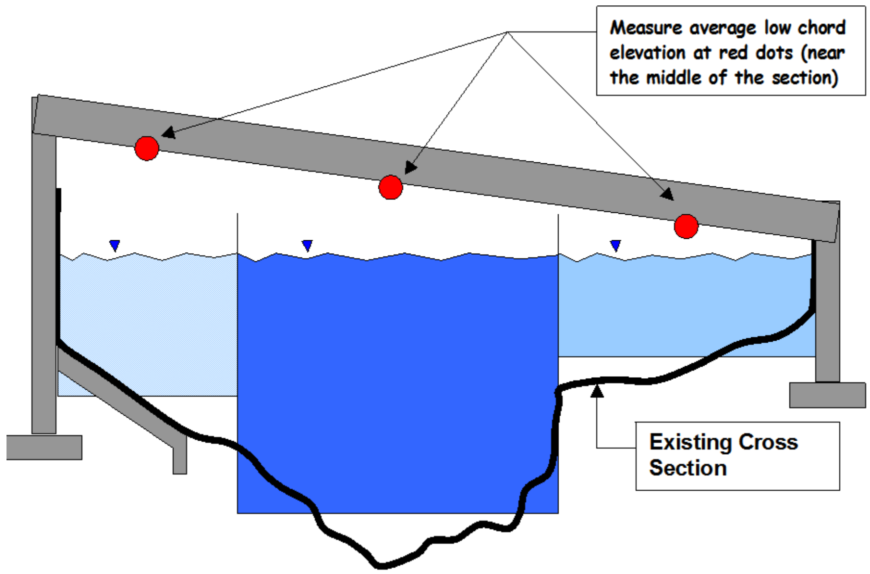


Figure 2-8: Average Low Chord Elevation

- **Abutment Type:** Select the abutment type (Vertical Wall, Wing-wall or Spill-through Slope)
- **Setback:** Setback is the horizontal distance measured from the channel bank or edge of channel to the abutment:
  - For a vertical wall or a wing wall abutment, measure the setback from the channel bank to the face of the abutment.
  - For a bottomless arch culvert, measure the setback from the channel bank to the culvert wall
  - For an abutment on a spill through slope, measure the setback from the channel bank to the point where the ground line intersects the spill-through slope. If the ABSCOUR cross-section is above the existing ground, use the ABSCOUR cross-section to define the ground line. If the ABSCOUR cross-section is below the existing ground, use the existing ground to define the ground line.
  - If there is a pier on the over-bank section, the pier width should not be included in the top width value T. This may result in a condition that the top width as measured from the channel edge will not extend to the abutment, and abutment scour will be computed as zero. For this case, the setback distance needs to be adjusted to equal the top width, T.
  - If the abutment projects into the channel beyond the channel bank, enter the setback as a negative number.

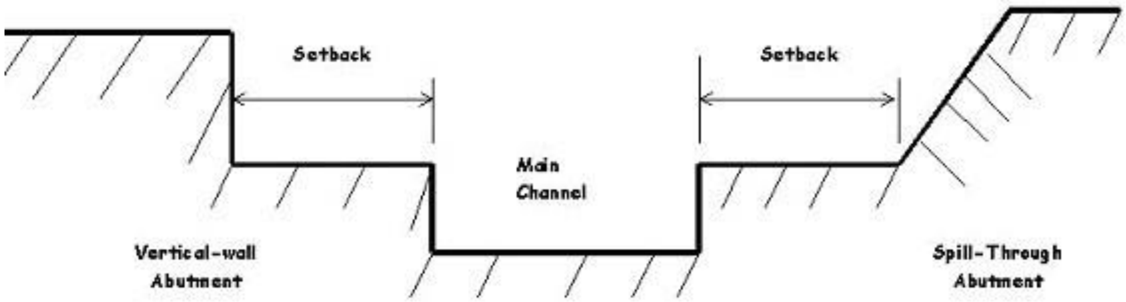


Figure 2-9: Illustration of Setback

- **Median particle size:** This value is important for clear water scour and should represent the particle size at the bottom of the scour hole. The D50 particle size can be entered for up to three soil layers and the program will compute the extent of the scour into each layer (See the F-1 help card)
- **Input the median (D50) particle size in feet (meters) for the material under the bridge/culvert using following format.**
- **For single soil layer, input the D50 in feet/meter.**
- **For two soil layers, input: (top layer thick)*(top layer D50)+(bottom layer D50). For example: 2.5*0.05+0.25**
- **For three soil layers, input: (top layer thick)*(top layer D50)+(2nd layer thick)*(2nd layer D50)+(3rd layer D50). For example: 2.5*0.05+5*0.25+2.5**

- The first layer should be the stream channel in which D50 is obtained by sampling (fine-grained) or by pebble count (coarse grained materials). Subsurface estimates for the D-50 are often available from borings or possibly the stream morphology report. This selection of particle size is often a judgment call due to the lack of good soils data at a distance of 5, 10 or 15 feet below the channel bed. A conservative approach is recommended where there is limited data for selecting a particle size.

- **Cohesive Soils:** A D50 particle size should not be selected for cohesive soils. If the soils are clearly cohesive, the clear water scour condition should be evaluated by using an over-ride feature and estimating the critical velocity of the soil. For particle sizes of about 0.1 mm or less, soils may behave more like a cohesive material and the assumption of a cohesionless bed material used in the ABSCOUR computations becomes less valid. For silt and clay soils, the User is referred to the discussion in Attachment 4. When a critical velocity of such soils can be estimated, select the Bridge Section Critical Velocity override function on the Project Information Screen. This will activate additional cells on the Downstream Bridge Data Screen so that the appropriate critical velocity values can be entered.

- **Armoring:** A complicating factor in selecting a representative particle size for clear water scour is the potential for armoring of the channel bed. A discussion of this consideration is presented in Part 1 of Appendix A; however, a comprehensive treatment of the armoring of channel beds is beyond the scope of this guide, and the user is referenced to the FHWA publication HDS 6, River Engineering for Highway Encroachments or similar texts on river mechanics to evaluate this condition. *In general, great reliance should not be placed on the expectation that armoring of the bed will limit the extent of contraction scour.*

- **Estimated long term bed degradation/aggradation:** The stream morphology report typically addresses the potential for long-term changes in bed elevation at the bridge. If it does not, the Engineer will need to make an evaluation of the stream morphology and utilize available information to determine a best estimate of future conditions. When a value is provided in the input cell, ABSCOUR will include this value in the elevation of the bottom of the scour hole.
- **Safety Factor:** Please refer to the table in Attachment 3 and the accompanying examples for guidance in selecting a safety factor for the abutment scour estimations
- **Over-rides:** Please note that one of the over-ride options on the Project Information Card permits the user to select a unit discharge under the bridge that is different from that computed by the program. An example of the use of this option would be a bridge crossing located in a bend with higher unit discharges on the outside of the bend. If the override is selected, then the input cells are displayed on the Downstream Bridge Data Card. Typically, such over-ride uses might be considered as a part of the sensitivity analyses of the scour evaluation*(Use all over-ride features with caution).*

E. STEP FIVE - UPSTREAM BRIDGE DATA

E.1 Enter the Upstream Bridge Data – See definition sketch Figure 1-6 below

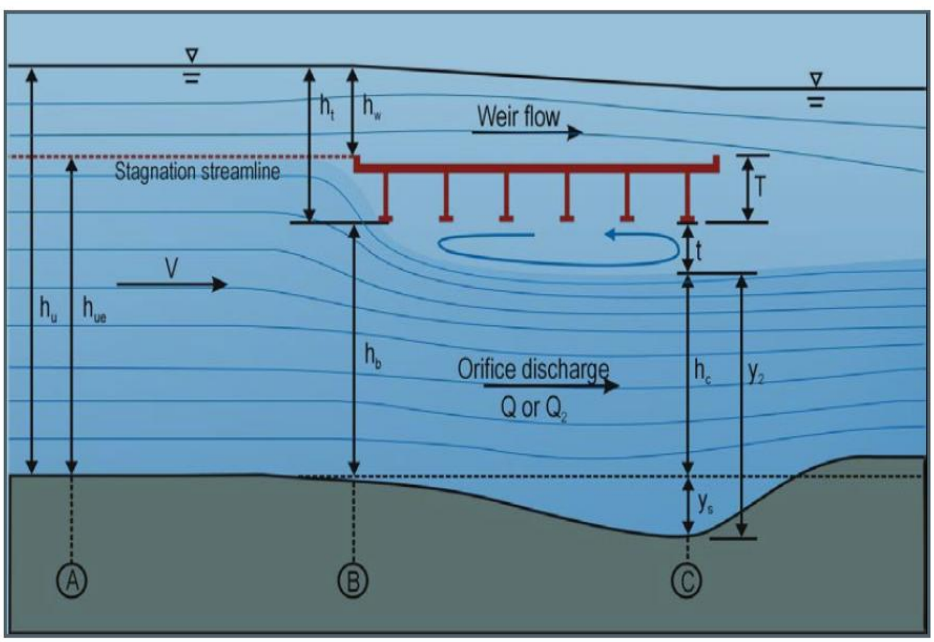


Figure 1-6 Definition Sketch for Upstream Bridge Data
(See Figure 2-10 for the input screen for the upstream bridge data.)

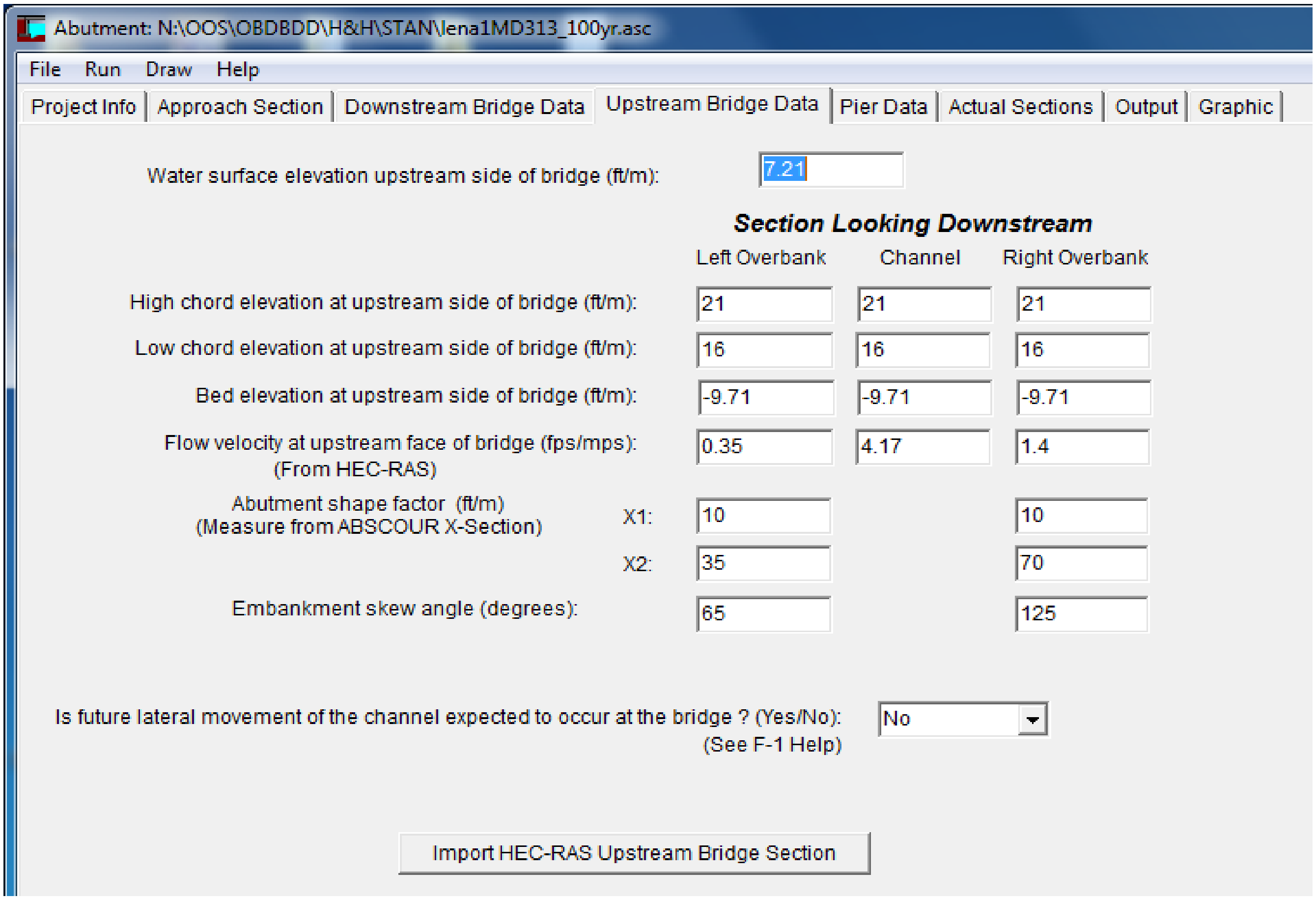


Figure 2-10: Upstream Bridge Data Input Screen

- **Water surface elevation upstream of the structure:** The water surface elevation just upstream of the structure is determined from the water surface profile (HEC-RAS) model. The ABSCOUR program compares this elevation with the upstream bridge low chord or culvert crown elevations to determine whether pressure flow occurs. If so, a pressure scour factor (t) is computed. (See Figure 1-6)

- **High chord elevation at upstream side of bridge:** The average elevation of the high chord (or highest part of the superstructure) on the upstream side of the bridge over the channel and left and right overbank sections. The elevation of the high chord is used by the program to determine whether the bridge will be subject to pressure flow. If pressure flow exists, the program adjusts the predicted scour value to account for pressure flow. (See Figure 1-6).

- **Low chord elevation at upstream side of bridge:** The average elevation of the low chord (or lowest part of the superstructure) on the upstream side of the bridge over the channel and left and right overbank sections. The elevation of the low chord is used by the program to determine whether the bridge will be subject to pressure flow. If pressure flow exists, the program adjusts the predicted scour value to account for pressure flow. (See Figure 1-6).

- **Bed elevation at upstream side of bridge:** This value can be obtained from HEC-RAS. It is also used in the pressure flow computations. (See Figure 1-6).

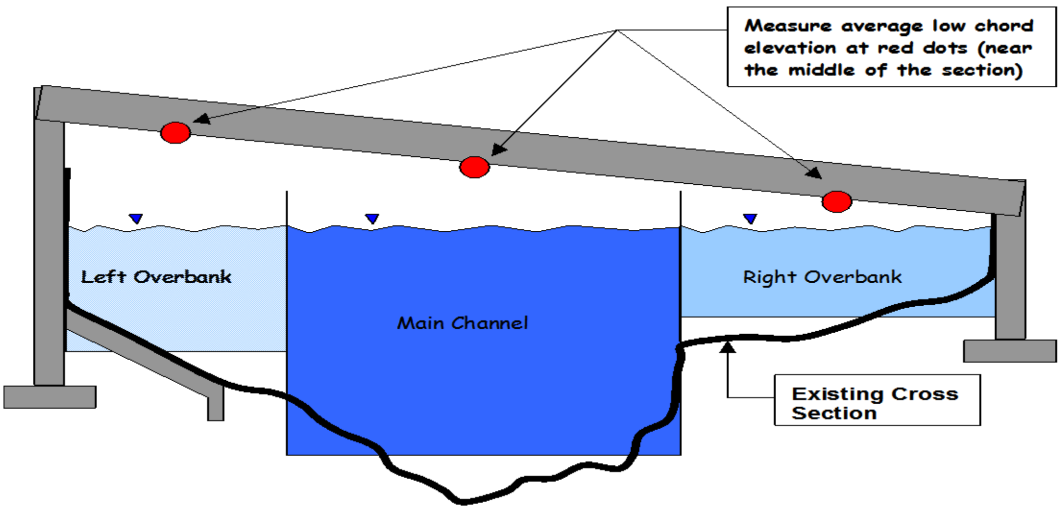


Figure 2-11: Input Values for Low Chord Elevations

- **Flow Velocity at Upstream Side of Bridge Face.** This value can be obtained from HEC-RAS. It is also used in the pressure flow computations. (See Figure 1-6).

Abutment shape factor Left and Right Overbanks: Abutment scour is reduced by a streamlined shape that facilitates a smooth transition of the flow and a corresponding reduction in turbulence. Two common examples of streamlined abutment shapes are vertical wall abutments with flared wing walls and abutments placed on spillthrough slopes. The effectiveness of the abutment shape in reducing scour depends on two factors: (1) the horizontal length, X1, of the streamlined portion of the abutment or spillthrough slope and (2) the total horizontal abutment and approach road length, X2, that is within the effective flow width of the approach flow. Please refer to Figure 2-12 for an illustration of the X1 and X2 values. As indicated in the Figure, measure X1 and X2 on the ABSCOUR cross-section; not on the actual cross-section:

1 The X1 value for a flared wing wall is the horizontal distance perpendicular to the flow from the abutment face to the end of the wing wall
2 The X1 value for a spillthrough slope is the horizontal distance perpendicular to the flow between the abutment toe (on the ABSCOUR cross-section) and the location of the water surface line on the spillthrough slope. (In some cases, the water surface may extend back to the abutment.)
3 A vertical wall abutment without wing walls or with a 90 degree wing wall is not a streamlined shape and has an X1 value of zero.

The shape factor, Kt, is defined as the ratio of X1/X2. Equations 1-29 and 1-30 compute the value of Kt. Kt is used in Equation 1-28 to compute the reduction in scour due to any streamlining of the abutment shape.

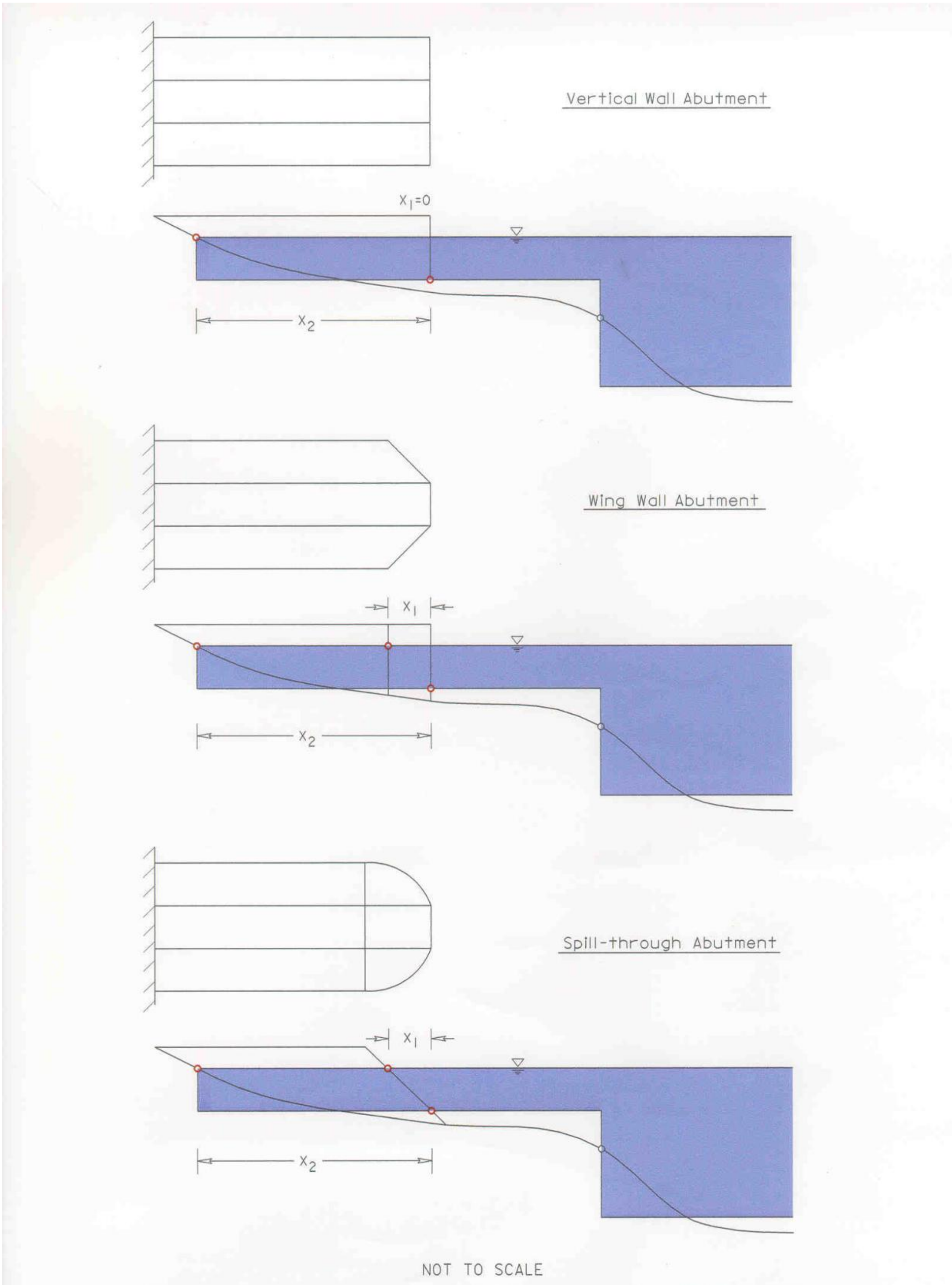


Figure 2-12 Abutment Shape Factor
Selection of X_1 and X_2 Measurements

- **Embankment skew angle:** The angle measured from the flow direction to the centerline of the left or right approach roadway embankment, in degrees. Refer to sketch Figure 2-13. The embankment angle is used to account for the effect of the orientation of the embankment on the contracting approach flow. For an embankment angled downstream, the scour depth is decreased; for an embankment angled upstream, the scour depth is increased. Please note that the embankment skew angle may be different from the abutment skew angle.

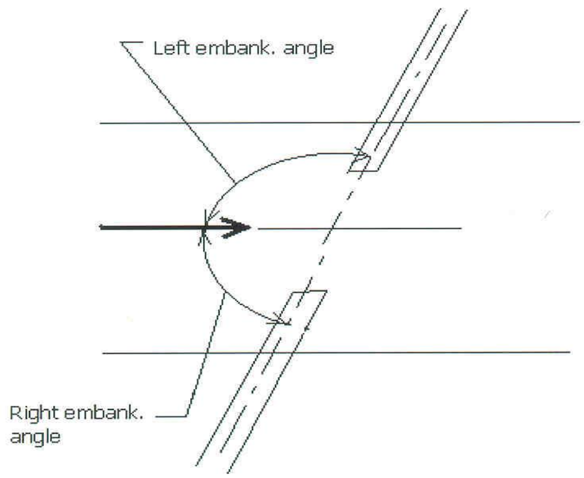


Figure 2-13: Embankment Skew Angle

- **Future lateral movement of the channel:** This input is a yes or no answer. It serves as a reminder to take lateral movement into account. Lateral movement needs to be considered for both bridges and culverts. The structure is fixed, but the channel is free to modify its bed and banks over time. Design considerations for piers and abutments relative to channel movement are presented in the SHA Chapter 11 Scour Manual and in the FHWA publications HEC-18 and HEC-20. The stream morphology study, including the evaluation of the stream location over time, typically provides insight as to future trends of the stream channel and guidance on providing for an adequate abutment setback and scour protection. Please note that the design approach should be made for every bridge foundation element within the channel lateral movement zone to use the thalweg velocity and depth to compute the scour at the bridge foundation element. The Utility Module in ABSCOUR 9 provides a convenient method for computing the effect of channel movement on abutment scour.

F. STEP SIX - PIER DATA

Figure 2-14 depicts the Pier Data Card. It is used to input information on the bridge piers into the ABSCOUR Program so that a complete scour cross-section under the bridge can be generated for the scour report. The User needs to calculate the elevation of total pier scour (contraction scour elevation - local pier scour) before entering information on the Pier Data Card. Use the Pier Local Scour module, Option 4, to calculate total pier scour.

Obtain the contraction scour at the pier from the ABSCOUR output. Once this is done, the following information needs to be supplied on the Pier Data Screen.:

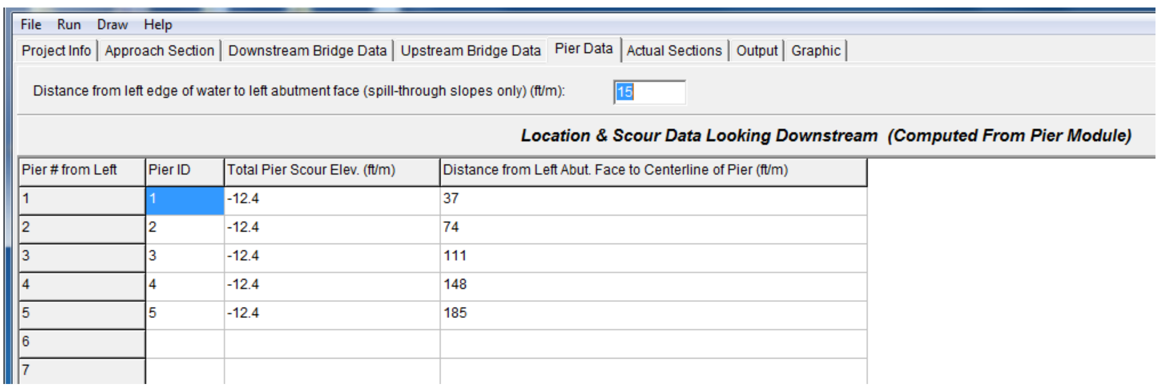
Column 1 - A listing of pier numbers beginning with the pier closest to the left abutment looking downstream (already listed).

Column 2 - The Pier ID number depicted on the plans

Column 3 - The elevation of the bottom of the scour hole at the pier. This needs to be the elevation of the total scour depth - the sum of local scour plus contraction scour + degradation.

Column 4- Distance from the left abutment face to the centerline of the pier.

For the special case of a spill-through slope at which the water edge is at the spill-through slope instead of the abutment face, one more piece of information needs to be input into the cell at the top of the card: Distance from the water's edge to the left abutment face. This step locates the left abutment with regard to the edge of water. All measurements are made from the left abutment face.

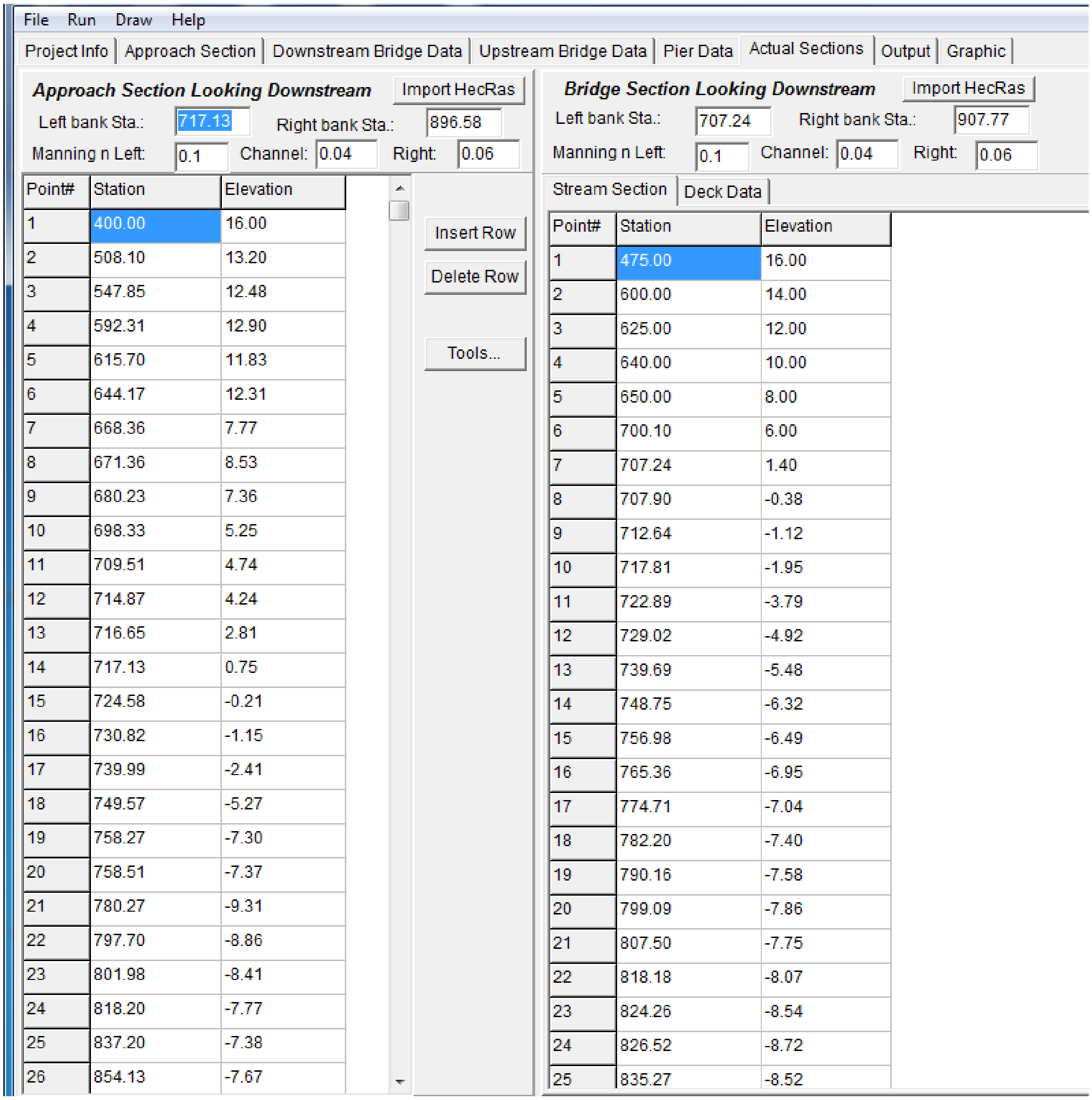


Pier # from Left	Pier ID	Total Pier Scour Elev. (ft/m)	Distance from Left Abut. Face to Centerline of Pier (ft/m)
1	1	-12.4	37
2	2	-12.4	74
3	3	-12.4	111
4	4	-12.4	148
5	5	-12.4	185
6			
7			

Figure 2-14 Pier Data Card

G. STEP 7 ACTUAL SECTIONS

The Actual Sections menu allows the user to import HEC-RAS cross-sections into the ABSCOUR program and to superimpose the HEC-RAS (Actual) Sections on the ABSCOUR (Computed) Sections. This option can be exercised for both the APPROACH SECTION 1 and the BRIDGE SECTION 2. The user can view and compare the fit between the Actual and ABSCOUR sections by accessing the DRAW option on the top MENU bar for the Approach Section, Bridge Section and Scour Section.



Point#	Station	Elevation
1	400.00	16.00
2	508.10	13.20
3	547.85	12.48
4	592.31	12.90
5	615.70	11.83
6	644.17	12.31
7	668.36	7.77
8	671.36	8.53
9	680.23	7.36
10	698.33	5.25
11	709.51	4.74
12	714.87	4.24
13	716.65	2.81
14	717.13	0.75
15	724.58	-0.21
16	730.82	-1.15
17	739.99	-2.41
18	749.57	-5.27
19	758.27	-7.30
20	758.51	-7.37
21	780.27	-9.31
22	797.70	-8.86
23	801.98	-8.41
24	818.20	-7.77
25	837.20	-7.38
26	854.13	-7.67

Point#	Station	Elevation
1	475.00	16.00
2	600.00	14.00
3	625.00	12.00
4	640.00	10.00
5	650.00	8.00
6	700.10	6.00
7	707.24	1.40
8	707.90	-0.38
9	712.64	-1.12
10	717.81	-1.95
11	722.89	-3.79
12	729.02	-4.92
13	739.69	-5.48
14	748.75	-6.32
15	756.98	-6.49
16	765.36	-6.95
17	774.71	-7.04
18	782.20	-7.40
19	790.16	-7.58
20	799.09	-7.86
21	807.50	-7.75
22	818.18	-8.07
23	824.26	-8.54
24	826.52	-8.72
25	835.27	-8.52

Figure 2-15 Actual Sections

The user can use this information to advantage in making an evaluation of the ABSCOUR scour computations:

1. Identify errors in the input data for the ABSCOUR cross-sections
2. Compare how well the ABSCOUR Section fits the Actual Section.
3. Determine if "fine tuning" adjustments in scour elevations should be made in order to match the actual cross-section more closely.

Application

Clicking on the Actual Sections Menu brings up two tables: the “Approach Section Looking Downstream” and the “Bridge Section Looking Downstream.” The top of each table provides cells to input the beginning cross-section station (Left Bank Station) and the ending cross-section station (Right Bank Station). Additional cells are provided to input Manning “n” values for the channel and left and right flood plains.

The body of each table consists of 3 columns: the designated point number, its station and elevation. The information in this table can be filled in manually or imported directly from the appropriate HEC-RAS model. It is useful to run the example problem included with the ABSCOUR program to view the format for the data in a typical table.

Manual Input: Input the data in the same manner as is depicted by the table for the example problem:
Import Cross-section Data Use of the import function is recommended, since it is much easier to do. This function imports the actual cross section of the stream at the approach and at the bridge. At the bridge, the program will also import the bridge deck data from HECRAS. Note, only the geometry file of the last selected plan in HECRAS project will be used.

To import the approach section, select the HECRAS project file in the open file dialog. The program will read the current active plan of HECRAS project and generate a list of available cross sections. The User can then choose the cross section of the desired approach section on the list. The imported data includes the station and elevation of the ground point in the cross section and the left bank and right bank point station.

For the bridge section, the program will search through the geometry file of the current active plan of HECRAS project and find the available bridges. If more than one bridge exists, a list of bridges will be generated and the user can select the appropriate bridge. If there is only one bridge, the program will import the bridge data without asking. The bridge data includes the downstream section (or upstream section for the upstream tool) and the bridge deck high chord and low chord elevations. The left bank and right bank point stations are also obtained. If the left bank and right bank stations do not match the ABSCOUR stations used in the scour analysis, the user can make the following adjustment: Change the HEC-RAS stations to match the ABSCOUR section.

III. COMPUTATIONS AND PROGRAM OUTPUT INFORMATION

Please note that the ABSCOUR program presents computations with up to three decimal points. However, final scour values used for design should be rounded off to the nearest foot, since the assumption of accuracy of scour estimates to a tenth of a foot is not valid. After entering the data on the input menus as described in Steps 1 through 5, click on the RUN button to compute the scour. If the program inputs are correctly entered, the output file appears. If there are any of the input items are not filled in, an error message will appear prompting the user to correct the input files. All input data and output computations are summarized in the output report.

Figure 2-16 shows the screen that appears after running the ABSCOUR program. The user can scroll down through the output to look at input data, output data and program notes. The output can be sent directly to a printer or it can be saved as a text file so that it can be inserted into an electronic report.

Figure 2-16 ABSCOUR Output Report, MD 313 over Marshy Hope Creek

File Run Draw Help

Project Info | Approach Section | Downstream Bridge Data | Upstream Bridge Data | Pier Data | Actual Sections | Output | Graphic

```
************************************************************
*          Maryland State Highway Administration           *
*                  Office of Structures                    *
*         Maryland Scour Program - Abutment Scour          *
*                MDSHA ABSCOUR 10 Method                   *
*            Version 10 Build 1.18, June 2014              *
************************************************************
Time stamp: 07/31/2014 10:17:37 AM

Input Data:

Project information:
--------------------------------------------------------------------------------------------------------
Project name: md 313 over Marshyhope Creek
Project number:
Description: 100yr flood
             Bridge cross section is skewed 35 degree
Project options:
  Program calculates critical and boundary shear stresses at approach section
  Program decides the scour type as either live bed or clear water scour
  Program calculates the unit width discharge at the bridge section
  Program calculates critical velocity at bridge section
  Program calculates sediment transport parameter k2
  Program calculate the flow velocity at abutment face
  Program calculates spiral flow coefficient Kf
  Clear-water scour uses a modified Neill's method for Piedmont Zone
  English Units
  Section orientation is looking downstream

Approach Section Data:
--------------------------------------------------------------------------------------------------------
                                                                    Left        Channel          Right
                                                                    ----------------------------------
Approach section discharge (cfs):                                     34           9820           1686
Approach section top width (ft):                                      38            179            895
Approach flow depth (hydraulic depth) (y1) (ft):                    1.98          13.22           4.25
Approach median particle size, D50(ft):                            0.003          0.002          0.003
Bank slope (Z) in the vicinity of the bridge (Z=H/V):                  2                             2
Energy slope (S) at approach section: 0.0003

ABSCOUR Overrides

Reserved for override approach critical shear stress
Reserved for override approach boundary shear stress
Reserved for override scour type
Reserved for override sediment transport parameter
Reserved for override location header
Reserved for override unit width discharge
Reserved for override critical velocity
Reserved for override 2-D velocity at abutment
Reserved for override average velocity in portion of bridge
Reserved for override spiral flow coefficient

```

```
54:  Downstream Bridge Data:
55:  ------------------------------------------------------------------------------------------
56:  Downstream water surface elevation under bridge: 6.83 ft
57:                                                             Left        Channel          Right
58:                                                             ----------------------------------
59:  HEC-RAS discharge under Bridge (cfs):                         0          11540              0
60:  Waterway area (A) measured normal to flow (sf):               0           2236              0
61:  Top width (T) measured normal to flow (ft):                   0            193              0
62:  Hydraulic depth (A/T) (ft):                               11.59          11.59          11.59
63:  ABSCOUR X-Section elevation (#56-#62) (ft):               -4.76          -4.76          -4.76
64:  Abutment type:                                    Spill-through                 Spill-through
65:  Setback (- for an abutment in channel) (ft):                  0                             0
66:  Low chord elevation downstream side of bridge (ft):           0             16              0
67:  Correction factor for low chord submergence (#56-#66>0)(ft):  6.83       0.00           6.83
68:  Median particle size under bridge, D50(ft): Layer 1  0.5*0.0025   0.5*0.00259   0.5*0.00259
69:  Median particle size under bridge, D50(ft): Layer 2  0.5*0.0010   0.5*0.00105   0.5*0.00105
70:  Median particle size under bridge, D50(ft): Layer 3   4*0.00089     4*0.00089     4*0.00089
71:  Estimated long-term aggradation(+) or degradation(-) (ft):     0              0              0
72:  Calibration/safety factor (See F-1): 1
73:
```

```
74:  Upstream Bridge Data
75:  ------------------------------------------------------------------------------------------
76:  Water surface elevation upstream side of bridge: 7.21 ft
77:                                                             Left        Channel          Right
78:                                                             ----------------------------------
79:  High chord elevation upstream side of bridge (ft):           21             21             21
80:  Low chord elevation upstream side of bridge (ft):            16             16             16
81:  Bed elevation at upstream side of bridge (ft):            -9.71          -9.71          -9.71
82:  Water depth at upstream side of bridge (#76-#81) (ft):    16.92          16.92          16.92
83:  Flow velocity at upstream face of bridge (fps):            0.35           4.17            1.4
84:  Low chord height (#80-#81) (ft):                          25.71          25.71          25.71
85:  Vertical blockage of flow by superstructure (ft):          0.00           0.00           0.00
86:  Pressure flow, Yes or NO: (Yes if #82>#84)                   No             No             No
87:  X1: (ft):                                                    10                            10
```

```
88:  X2: (ft):                                                    35                            70
89:  Ratio (X1/X2):                                             0.29                          0.14
90:  Embankment skew angle (degrees):                             65                           125
91:  Is future lateral migration of channel likely to occur?: No
92:  Output Computation And Results
93:
94:  Approach Section:
95:
96:  Total approach discharge (cfs): 11540
97:                                                             Left        Channel          Right
98:                                                             ----------------------------------
99:  Approach average flow velocity (fps):                     0.452           4.15          0.443
100: Approach unit width discharge (cfs/ft):                   0.895          54.86          1.884
101: Approach section depth (ft):                               1.98          13.22           4.25
102: Approach section Froude Number:                          0.0566         0.2011         0.0379
103: Approach section critical shear stress(psf):              0.012          0.008          0.012
104: Approach boundary shear stress(psf):                     0.0371         0.2475         0.0796
105: Approach sediment transport parameter (k2):               0.677           0.64          0.653
106: Scour type:                                            Live Bed       Live Bed       Live Bed
107:
```

Figure 2-16 ABSCOUR Output Report, MD 313 over Marshy Hope Creek

Continued

```
108: Downstream Bridge Computations:
109:
110: Total discharge under Bridge (cfs): 11540
111:                                                                  Left        Channel          Right
112:                                                                  ---------------------------------
113: Method of computing flow velocity adjustment:              Short Setback               Short Setback
114: Flow velocity (fps):                                           5.161          5.161          5.161
115: Adjustment to hydraulic depth (y0)adj (ft):                   11.585         11.585         11.585
116: Unit width discharge (#115*#114)(cfs/ft):                     59.793         59.793         59.793
117:
118: Downstream Contraction Scour Computations:
119:
120:                                                                  Left        Channel          Right
121:                                                                  ---------------------------------
122: Control soil layer No.:                                            3              3              3
123: Critical velocity (fps):                                       3.877          3.877          3.877
124: Clear water scour flow depth (y2)(ft):                        15.422         15.422         15.422
125: Live bed scour flow depth (y2)(ft):                           34.055         13.969         40.586
126: Interpolated scour flow depth (y2)(ft):                       13.969         13.969         13.969
127: Pressure flow separation zone thick (t)(ft):                       0              0              0
128: Adjusted scour flow depth (y2)adj (#127+#126>(y0)adj)(ft):    13.969         13.969         13.969
129: Contraction scour depth (ys) (#128-#115>Top soil depth)(ft):   2.384          2.384          2.384
130: Final contraction scour depth (ys)f (#129*#72)(ft):            2.384          2.384          2.384
131: Aggr/Degr + Contraction scour EL.(#56-#115-#130-#67+#71)(ft): -13.969         -7.139        -13.969
132:
133: Total Bridge Scour At Abutment:
134:
135:                                                                  Left        Channel          Right
136:                                                                  ---------------------------------
137: Control soil layer No.:                                            3                             3
138: Interpolated contraction scour flow depth (y2)ft:             13.969                        13.969
139: Abutment unit discharge ratio (q2/q1):                          1.09                          1.09
140: Abutment local velocity factor (Kv):                           1.001                         1.004
141: Abutment spiral flow factor (Kf):                                1.4                           1.4
142: Abut. scour flow depth (y2a)adj(#138*#141*#140^#105+#127)(ft): 19.576                      19.614
143: Initial abutment scour depth (ysa)(#142-#115>0)(ft):           7.991                         8.029
144: Coefficient for abutment shape factor (Kt):                    0.675                          0.85
145: Coefficient for embankment angle (Ke):                         0.959                         1.044
146:
147: Final abutment scour depth (ysa)adj(#143*#144*#145*#72)(ft):    5.17                         7.122
148: Recommended minimum abutment scour depth (ft):                     6                             6
149: Control abutment scour depth (ft):                                 6                         7.122
150: Aggr/Degr + Abutment scour EL.(#56-#115-#149-#67+#71)(ft):    -17.585                       -18.708
```

Figure 2-16 ABSCOUR Output Report, MD 313 over Marshy Hope Creek

Continued

The ABSCOUR output file contains the scour calculations necessary for inclusion in the scour report. Each line of the output file has an accompanying line number for easy identification. Many of the formulas and the adjustment parameters are shown in the output file reference. The output sheets are labeled in the same manner as the input menu cards. The following is a summary of the sample output sheets included below. Please note that the line numbers and descriptions may vary slightly from run to run, depending on the input data.

INPUT DATA

1. Project information - Lines 1-29
2. Approach Section Data - Lines 30 - 40
3. ABSCOUR Over-rides Lines 41-52
4. Downstream Bridge Data Lines 54- 73
5. Upstream Bridge Data Lines 74 - 93

OUTPUT COMPUTATIONS AND RESULTS

1. Approach Section Lines 94 - 107
2. Downstream Bridge Computations, Lines 107- 117
3. Downstream Contraction Scour Computations, Lines 118 - 132
4. Total Bridge Scour at Abutments, Lines 133 - 150.

ABSCOUR can also generate plots of the approach section, bridge section and the bridge scour cross-section. Figures 2-15, 2-16, and 2-17 show the plots created for the approach section, bridge section and bridge scour section respectively. The plots may be printed directly from the program to a specified scale or the user may export *.dxf files for inclusion in AutoCAD or Microstation. The cursor can be used to determine various elevations and distances depicted on the plots.

If the HEC-RAS Approach Section and Bridge Section have been imported into ABSCOUR, they will be included in the above noted Figures. Comparison of these cross-sections will be helpful in evaluating the answers obtained from the program.

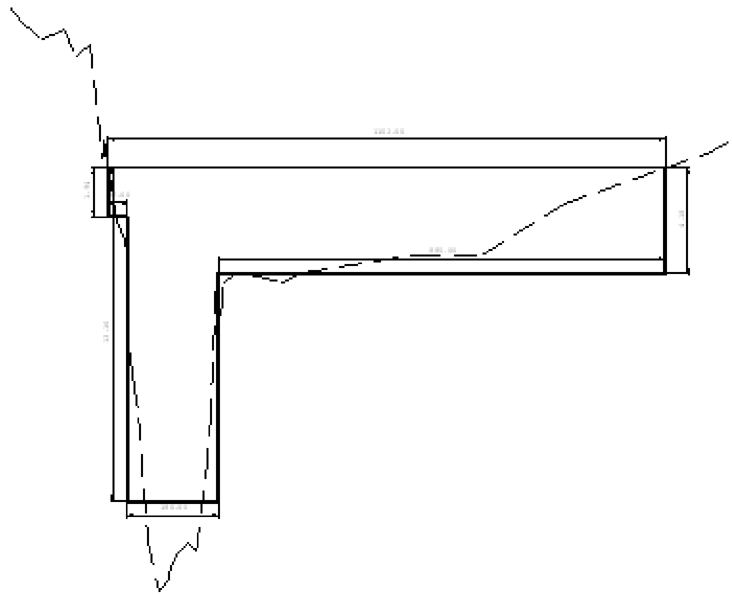


Figure 2-17: Approach Section Plot: MD 313 over Marshy Hope Creek

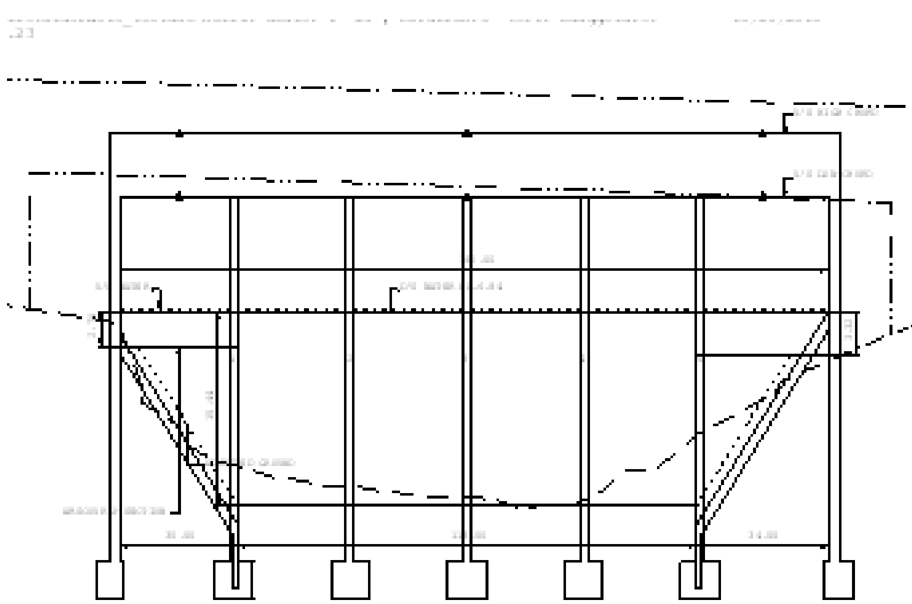


Figure 2-16: Bridge Section Plot: MD 313 over Marshy Hope Creek

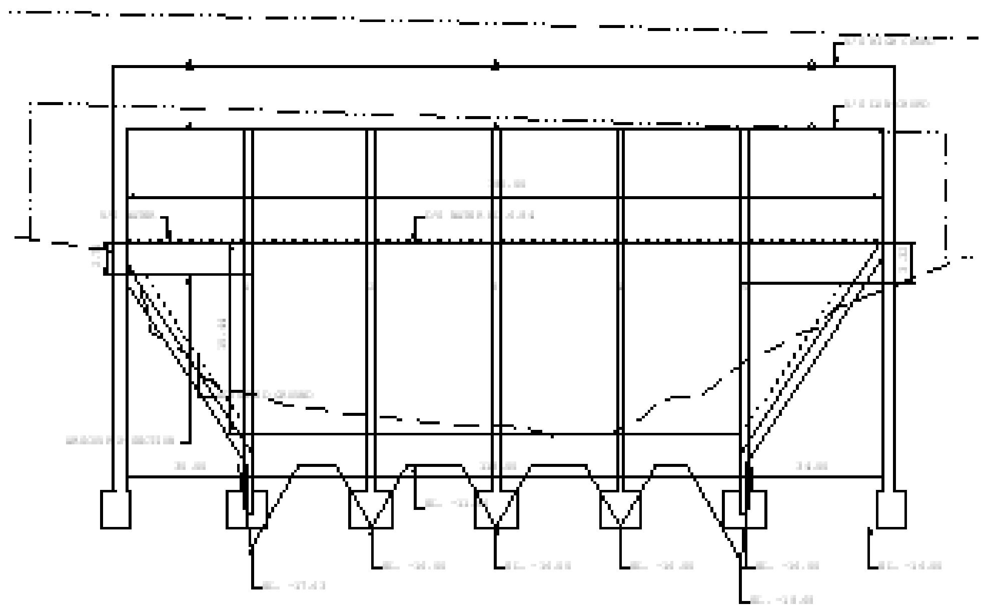


Figure 2-18: Sample Scour Cross-Section Under Bridge

ABUTMENTS SET BACK FROM THE EDGE OF THE CHANNEL

Excerpts from the Office of Structures scour report for the MD Route 313 bridge crossing over Marshy Hope have been presented above. MD 313 a six span steel structure with abutments on spill-through slopes. All foundation elements are on piles. The ABSCOUR abutment module computes the scour cross-section at the bridge across the channel up to the toe of the spill-through slope which, in this case, happens to be a bulkhead. The Pier Scour Module computes the total pier scour, taking into account the effect of contraction scour.

The ABSCOUR program prints out the scour cross-section for the bridge. The procedure for evaluating “worst-case” scour at the abutment piles, set back from the channel, is illustrated below in the sketch of the elevation view of the bridge. The contraction scour elevation is plotted at the toe of the spill-through slope; then the scour profile is continued up the spill-through slope along the estimated angle of repose of the abutment material as illustrated in the blow-up for the bridge sketch for the left abutment. The intersection of the scour line with the piles can be used to evaluate the potential loss of support and the resulting stability of the piles.

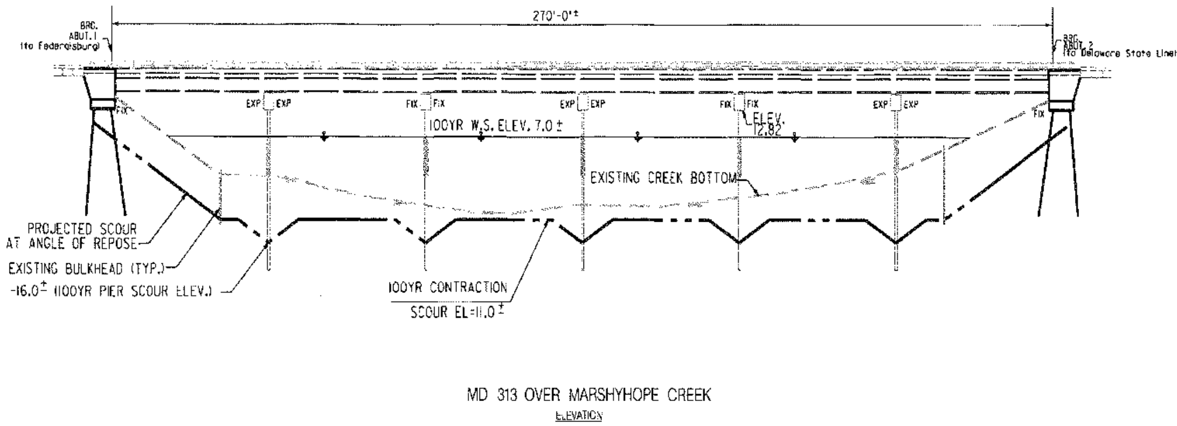


Figure 2-19
CADD Plot of Scour Cross-Section for Marshy Creek Bridge.

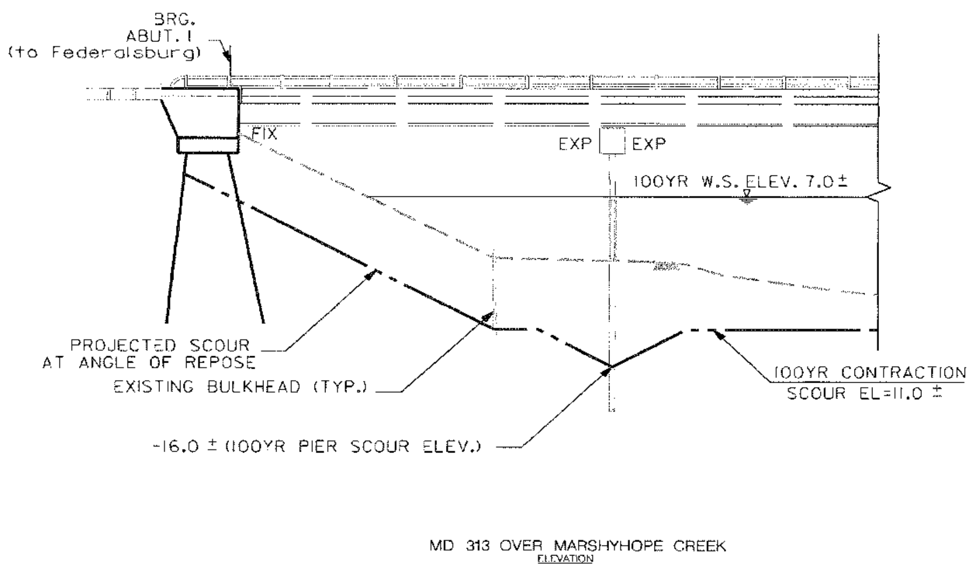


Figure 2-20
Blow-up of the CADD Plot for the Scour Cross-Section for the Marshy Hope Bridge.

The existing bulkhead is at the toe of the spill-through slope. The elevation of the contraction scour is computed at this point. Then the scour cross-section is continued at the angle of repose of the spill-through-slope material back to the abutment piles. The length of the exposed piles are determined to provide a basis for evaluating the stability of the abutment.

DISCUSSION OF THE ABSCOUR REPORT

A. ABSCOUR PROJECT INFORMATION:

- **Project Information:** Use this section to outline the primary factors of interest in the scour evaluation: flood flow, project description and any special conditions to be evaluated (discharge, trial selections for soils, types of scour).
- **Project Options:** This section prints the options used by the program.

B. INPUT DATA:

- **Approach Section Data:** These numbers reflect the information provided by the User for the Approach Section. An important item to check here (Line 101) is whether the flow is live bed or clear water.
- **ABSCOUR Overrides:** This summary should always be reviewed to make sure that the User is aware of any overrides input into the program.
- **Downstream Bridge Data:** This summarizes the information used to construct the ABSCOUR cross-section under the bridge. It computes a correction factor for the case where the downstream water surface is higher than the elevation of the low bridge chord.
- **Upstream Bridge Data:** This is a summary of the information needed to compute the shape factor for the bridge and to determine if pressure flow will occur.

OUTPUT COMPUTATIONS AND RESULTS

- **Approach Section:** This is a summary of the data used to compute the unit discharges at Section 1 and to develop the computations to determine if the flow condition is for live bed or clear water scour.
- **Downstream Bridge Computations:** Based on the abutment setback and channel flow depth, the program computes the flow distribution and velocities as described in Part 1 for short setback, intermediate setback or long setback. There are 16 possible combinations of flood plain geometry and abutment setback distances that are utilized in the ABSCOUR Program to compute the appropriate velocity used in the scour equations. These combinations are presented in Attachment 1.

  For clear water scour, the user has the option to compute the critical velocity from Laursen's equations or the SHA modification of Neill's curves. The ABSCOUR program computes contraction scour depth by setting the average flow velocity equal to the critical velocity (Neill's competent velocity) of the D50 stone size.

  An adjustment is made for the hydraulic depth at the abutment if the abutment is within the limits of the bank slopes line 110.

- **Downstream Contraction Scour Equations:** Line 118 and 119 reflect computed contraction scour for clear water and live bed, respectively, and Line 120 provides for an interpolated scour depth depending on the scour conditions. In the Case C example presented above, there is live bed scour on the overbank and in the channel.

The live bed scour flow depth in the channel (line 119) is 12.4 feet; and on the left overbank at a distance of 5yo (34 feet) it is 5.9 ft. The abutment setback for the left overbank is 169 feet. The program makes a parabolic interpolates between the two scour values to compute the contraction scour flow depth in the left overbank as 12.0 ft. In some cases, the flow width under the bridge for one or more abutments may be less than the abutment setback.   When this occurs, the program assumes that there is no water behind the abutment and the abutment scour is calculated as zero. Consequently, the extent of scour at the abutment is limited to the value of the contraction scour. *In general, this case is more likely to be based on user error than on an actual field condition.*

- **Total Bridge Scour at Abutment:** The abutment scour flow depth (y2a) at the abutment (line 134) is computed by multiplying the adjusted contraction scour flow depth determined in line 122 by the kv and kf factors using the procedure explained in line 134 (see also Equation 1-23 or 1-24).

  The computations for final abutment scour depth (Line 139) is explained in Equation 1-28 and also by the accompanying notes on Line 139. Please note that SHA uses a minimum (default) abutment scour depth of 5 feet

COMMENTS ON THE ABSCOUR PROGRAM SCOUR CROSS-SECTION

- **Program Sketches:** After running the program, the user can click on the “DRAW” button on the “Menu Bar at the top of the screen. Three options are presented: Approach Section, Bridge Section and Scour Results. We recommend careful inspection of each of these sketches to check for a reasonable representation of the actual HEC-RAS sections and to view a depiction of the scour cross-section. This exercise is well worthwhile to assure that there are no obvious errors in the input data.

  Please note that the user can input the results of the pier scour modules into the ABSCOUR bridge cross-section (Scour Results) to prepare a complete scour cross-section at the bridge. However, the pier scour elevations apply to the upstream side of the bridge whereas the abutment scour elevations are computed at the downstream side of the bridge. Combining these results provides a simplified and conservative means of evaluating the scour. The user is encouraged to redraw the scour cross-section on the bridge plans to develop a more readable sketch and to account for the issues discussed below.

  1. Perhaps the most common problem encountered with the ABSCOUR bridge section with the irregular HEC-RAS section. In most cases the two sections should be reasonably congruent. However, there are situations where adjustments are needed to refine the scour cross-section:
     - PROBLEM: The area of bridge piers is subtracted from the ABSCOUR waterway area under the bridge; consequently, in some cases the ABSCOUR 9 cross-section area may be smaller than the HEC-RAS section. Consequently the ABSCOUR channel bottom may plot above the HEC-RAS channel bottom.

EXAMPLE SOLUTION: Compute the ABSCOUR contraction scour area and distribute it along the length of the HEC-RAS channel at the elevation of the HEC-RAS channel.

- PROBLEM: For small one-span bridges crossing V-shaped channels, the ABSCOUR contraction scour elevation may plot above the channel thalweg.

  EXAMPLE SOLUTION: It is likely that the channel thalweg may move within the limits of the abutments over the life of the bridge. Subtract the contraction scour depth from the thalweg elevation to compute the elevation of contraction scour for the scour cross-section.

- PROBLEM: A narrow flood plain under bridge; ABSCOUR cross-section divided between the channel and the flood plain does not fit well with the HEC-RAS cross-section. As a basis for comparison, this section will be referred to as Model A

  EXAMPLE SOLUTION: Assume area under bridge is all channel and compute the scour cross-section on this basis. This section will be referred to as Model B; compare the scour cross-sections for Model A and Model B; select the most reasonable answer

- PROBLEM: For a bridge location on a sharp bend, contraction/bend scour may be unequally distributed with most of the scour occurring on the outside of the bend.

  EXAMPLE SOLUTION: (1) use the ABSCOUR program to compute the area of contraction scour. (2) pro-rate more of the scour on the outside of the bend, keeping the scour area constant. .

Other guidance on plotting the scour cross-section on the bridge plans

1. For vertical wall abutments, plot values of y2 and y2a under the bridge, measuring down from the water surface at the downstream side of the bridge.

1 Where the abutment scour is deeper than the channel scour, use an angle of 30 degrees to define the sides of the scour hole. Use a nominal value of 5 feet to determine the width of the bottom of scour hole.

3 Where the abutment scour depths are at a higher elevation than the channel contraction scour, use a smooth curve to define the transition area.

4 The user will need to determine the total scour at each foundation element, taking into account the following factors:

   - Contraction scour

- Abutment scour
- Local pier scour
- Lateral channel movement
- Degradation

The current policy of the Office of Structures is to make a judgment on how to best consider the total effect of these different aspects of scour on a case by case basis as discussed in Chapter 11.

B. ABSCOUR PROGRAM LOGIC

The following discussion is provided for insight into the logic used by the program in computing flow distribution and velocity distribution at the bridge.

A current limitation of the HEC-RAS program used to model flow through a bridge is that it provides for the distribution of flow under the bridge based on conveyance calculations. This approach does not reflect the three dimensional flow patterns actually observed in the field at bridge contractions. To obtain reasonable estimates of scour depth, it is necessary 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 laboratory studies of compound channels indicate that the velocity of flow under a bridge tends to be highest at the abutments (due to rapid acceleration and turbulence of the overbank flow entering the bridge contraction) and in the thalweg section of the channel. This phenomenon has been observed in field surveys conducted by the U. S. Geological Survey and is consistent with the theory of potential flow at a contraction. The procedure used by the ABSCOUR Program to determine the flow distribution under the bridge is explained in Part 1 of this guideline.

C. EVALUATION OF THE PROGRAM OUTPUT

C.1 Overrides

A special message indicating that “OVERRIDE IS ACTIVE” is printed when the user over-rides the computer values. *Any over-ride function should be used with caution, and the logic of the over-ride carefully checked in this evaluation phase.* Please be aware that the sediment transport functions and the hydraulic flow conditions must be compatible. If the user imposes unrealistic conditions on the program, the resulting scour estimates will be in error.

C.2 Bridge Section Data

Based on the user’s input data, the program determines the discharge, unit discharge and velocity of flow for each cross-section sub-element under the bridge. As noted earlier, the widths input by the user and the abutment setbacks should be measured normal to the direction of the approach flow.

The method of analysis (Method A, Short Setback, B Long Setback, or Method C, Intermediate or Transition Setback) is determined on the basis of a comparison of the abutment setback with the depth of flow in the main channel at the bridge (Section 2) as previously described. The unit discharges, q, and velocity, V_2 are computed from the equations set forth in Part 1. Attachment 1 provides detailed examples of how the computations are made for various combinations of channel and overbank geometry, and abutment setback.

The critical velocity required for the incipient motion of the D_{50} particle size for flow under the bridge for clear water scour is computed from the particle size of the channel bed or flood plain material and the flow depth using Neill's competent velocity curves, as modified by the Office of Structures. An over-ride table is provided to allow the user to change this value to account for cohesive soils or other factors. This over-ride process is the same as that for the scour parameter table. The user is also given the option of using Laursen's relationship for clear water scour.

C.3 Contraction Scour Table

The value of y_2 in this table is the vertical distance between the water surface and the stream bed after contraction scour has occurred. The program calculates this value using the Equations in Appendix A. The scour depth y_s is the depth of contraction scour:

$$\mathbf{y_s = y_2 - y_o}$$

Where:

y_s = depth of contraction scour
y_2 = vertical distance from the water surface to the stream bed after contraction scour has occurred, and
y_o = depth of flow under bridge before scour occurs (Bridge Section Data)

Please note that the output table will indicate whether or not pressure scour is computed in accordance with the procedure in Part 1.

C.4 Abutment Scour Table

The abutment scour depth, $(ysa)_{adj}$ represents the total scour, including contraction scour and local scour which is predicted to occur at the abutment. It does not include long term degradation, which the user must account for in the final scour evaluation. The scour depth elevation is the elevation the Engineer should use to evaluate scour. It reflects all of the adjustments made by the program to account for the various factors affecting abutment scour. These adjustments include the following:

- For a skewed embankment crossing, the ABSCOUR program will adjust the computed scour by a skew coefficient in accordance with the procedure set forth in

FHWA Hydraulic Engineering Circular 18, 2001 Edition. The user must enter the theta angle of the orientation of roadway with respect to the direction of the flow.

- The program increases scour depths where necessary to account for the effects of pressure flow,
- An abutment shape factor is used to evaluate the effect of the abutment shape on the predicted scour.
- A safety factor, input by the user, is applied to increase the calculated scour depth. This safety factor permits the user to apply judgment to the design considerations based on the site conditions, reliability of available data and the risks to the bridge, the transportation system and the traveling public.

C.5 Scour Depth Elevation

The scour depth elevation is used for plotting the scour cross-section and for evaluating the scour.

C.6 Occurrence of Rock

Where rock of varying elevations and resistance to scour is encountered, the user needs to take this into account in the scour cross-section.

C.7 Evaluation of the Computed Scour Values

Use the computed values of scour from the ABSCOUR program *as a guide* in the design of the bridge abutment, keeping the following considerations in mind:

- the SHA policies and procedures set forth in Chapter 11, Bridge Scour,

- the guidance in the FHWA HEC-18 Manual regarding abutment scour (Reference 1).

- the need to provide some form of scour countermeasure to protect the bridge abutment and inhibit the formation of a scour hole. Base the design of the riprap on the anticipated contraction scour depths near the abutment. Use the utility section of the program to compute the minimum D50 size of the riprap for each abutment. These calculations are based on the procedures set forth in the 2001 edition of HEC-23. Use this information to select the appropriate riprap size, typically Class 2 or 3.

There are factors which can affect the extent of contraction scour and abutment scour at a bridge that are not directly computed by the ABSCOUR model. However, various procedures have been suggested in this manual to permit the user to take some of the factors into consideration in the scour evaluation:

- the possible effect of nearby adjacent piers in modifying flow patterns and resultant abutment scour (engineering judgment; model studies)

- effect of bends and upstream tributaries in the distribution of contraction scour (bendway scour) and the effect of a severe angle of attack causing flow to impinge directly on the abutment. These conditions may increase scour at abutments located on the outside of bends. (See Attachment 2 and Reference Numbers 1, 2, and 8).

- effect of ice or debris in clogging a waterway opening, deflecting channel currents and increasing flow velocities and resulting scour (See HEC-18).

- effect of two dimensional flow patterns, especially for wide flood plains, in modifying the flow conditions at a bridge (See Attachment 2; use a 2-D model).

- effect of confluences or other geomorphological features affecting the lateral migration of stream channels (See Attachment 2).

- the method does not directly address critical shear stress or critical velocity for cohesive soils or rock. The user is provided a means of partial evaluation of this condition by use of the over-ride functions.

The engineer also needs to keep in mind the limitations of the ABSCOUR model used to estimate the depth of clear water scour. The concept is that the area under the bridge will scour and thereby increase the flow area while decreasing the flow velocity. This process will continue until the flow velocity is below the critical velocity needed to move the selected D50 particle size under the bridge. The model application is likely to result in high clear water scour depths for high flow velocities in fine-grained non-cohesive soils. The following factors need to be evaluated in this regard:

- Please note that the user can now input the thickness and D50 value of up to three layers of bed material under the bridge on the downstream bridge data card.

- The particle size should be representative of the soil at the elevation of <u>the bottom of the scour hole</u>. Armoring of the stream bed may inhibit the depth of the scour.

- SHA’s experience on Maryland streams is that critical velocities for fine particle sizes are best modeled by the Office of Structures modification to Neill’s curves as discussed in the calibration of ABSCOUR. The user has the option of using Laursen’s method for clear water scour.

- The hydrograph for the worst case scour conditions should be considered. For flashy streams on small watersheds, the time period during which scouring velocities actually occur may be relatively short, especially for overbank areas.

- The conditions for clear water or live bed scour are not always clear cut, and it is possible that both types of scour may occur during different stages of a flood hydrograph. The user is encouraged to evaluate both cases.

As indicated above, a limited flexibility has been built into the ABSCOUR program to allow the engineer to account for some of the above factors. The engineer is encouraged to consider all information obtained from field and office studies, the limitations of the scour model, and to apply judgment in the selection of the appropriate foundation elements. *The user should consider the need for a calibration (safety) factor on the Bridge Data card(consistent with the guidance in Attachment 3 of this Appendix) which reflects the uncertainties of the scour parameters at the site and the importance of the bridge under design.*

The ABSCOUR program requires accurate hydrologic, hydraulic and soils data in order to compute accurate contraction and abutment scour depths. The extent to which the Engineer can obtain accurate data will vary from site to site. In some cases, for example subsurface soils data, it may not be practical to obtain a complete and accurate description of all the input parameters. However, the use of incomplete or inaccurate input data may significantly affect the accuracy of the ABSCOUR output results of predicted scour depths. The Engineer needs to exercise judgment to arrive at a practical solution to this problem.

A big advantage of the ABSCOUR program is the ease of checking the sensitivity of the scour estimate to the different input parameters. Where there is a question about the value of the input parameter, the recommended procedure is to input the best estimate of the value and then check the sensitivity of the scour depths for reasonable maximum and minimum values of the parameter

IV QUESTIONS TO ASK AND FACTORS TO CONSIDER IN REVIEWING THE ABSCOUR OUTPUT

1. Is the ABSCOUR model being used the most up-to-date version? (ABSCOUR 9-BUILD 2.1)

   Check for updates on the web at ***www.gishydro.eng.umd.edu***

2. Are the contraction scour and abutment scour values reasonable? If not, what are the likely sources of error in the input data that are creating what appears to be high or low scour values?
3. Have you checked the performance history of the original structure being replaced or of other nearby bridges? What historical information is available on scour or on bridge failures during previous floods?
4. Does the hydrology study provide for reasonable estimates of flood magnitudes? Follow the latest Maryland Hydrology Panel Recommendations. (Use of TR-20 by itself may overestimate the magnitude of flood discharges and corresponding scour depths).
5. Does the HEC-RAS analysis provide reasonable values for flow distribution

and energy slopes? Are the approach section and bridge section reasonable representations of actual effective flow conditions during a major flood? Do you need to modify the Approach Section or select a different section? How reliable is your estimate of the tailwater elevation at the bridge? Do you have a reasonable flow distribution model for overtopping flow at the bridge?

6. How accurate and complete are the soils data? This is particularly important for clear water scour conditions. Was the appropriate information obtained from the geomorphology report? Do borings and subsurface investigations indicate the presence of rock? Have you consulted a geologist if RQD values are less than 75%? Is the rock erodible or scour resistant? How does the rock affect the scour cross-section under the bridge? If the rock is erodible, have you used Annandale's Erodibility index method or other methods to assess the extent to which it will scour? If the bed conditions indicate cohesive soils, have you selected a critical velocity for cohesive soils to compute clear-water scour?
7. Have you made sensitivity analyses to evaluate the field conditions you are modeling? For example, (a) live bed vs. clear water scour; (b) Maryland SHA modifications to Neill's curves vs. Laursen's curves for clear water scour, etc.

V. COMPUTATION OF PIER SCOUR

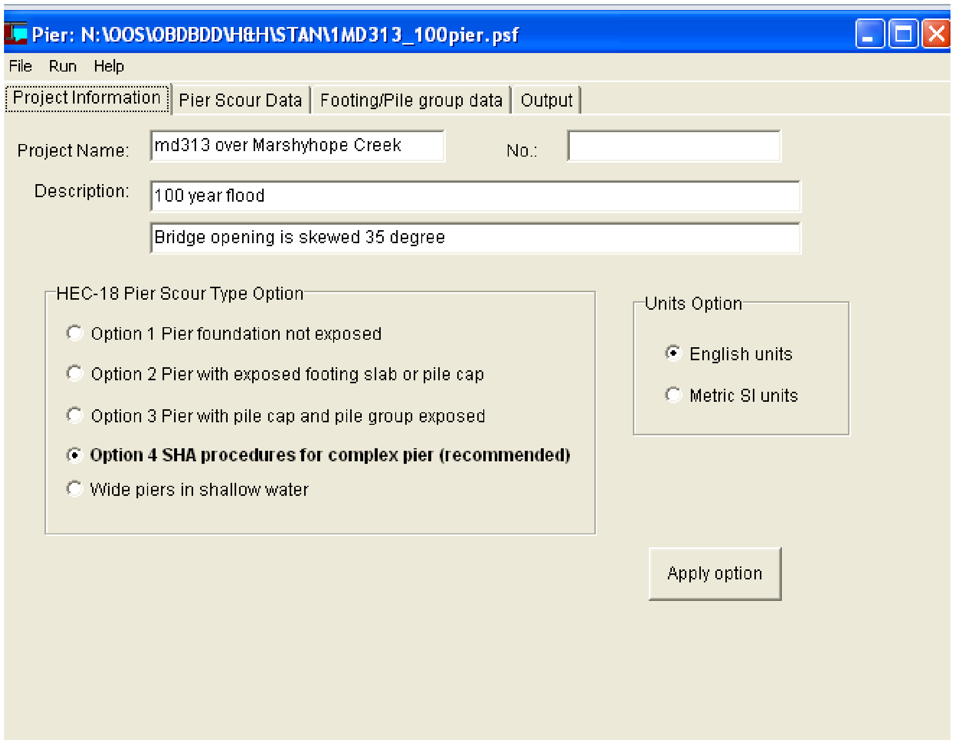
A. Pier Scour Introduction

The computational method in the Pier Local Scour Module of ABSCOUR 9 is based on the research reported by the FHWA in HEC-18, Evaluating Scour at Bridges, May 2001 Edition. The FHWA method and scour equations account for complex pier geometry as well as bed load conditions. The User is encouraged to review HEC-18 for a discussion on the research used to develop the pier scour equations and the implementation method developed for computing pier scour. The Maryland program facilitates the computations required to obtain pier scour depths. To simplify the computations for Pier Scour included in previous ABSCOUR versions, ABSCOUR 9 incorporates Option 4 which automatically makes the pier scour computations and provides a complete output file for the pier.

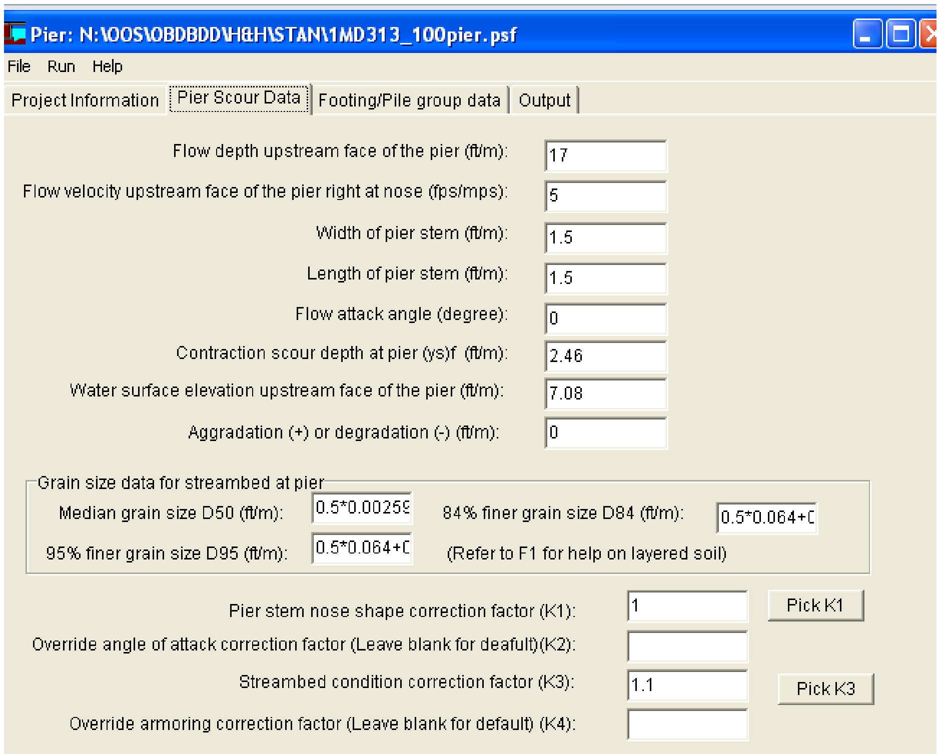
USING OPTION 4 TO COMPUTE PIER SCOUR

The following example is taken from the MD 313 bridge over Marshy Hope Creek. Since all piers are in the channel, the conditions of highest velocity and deepest depth were used to design all of the piers.

Open the pier scour module and select OPTION 4 on the Project information Menu. Click on the "Apply Option" button. Then click on the Pier Scour Data Tab.



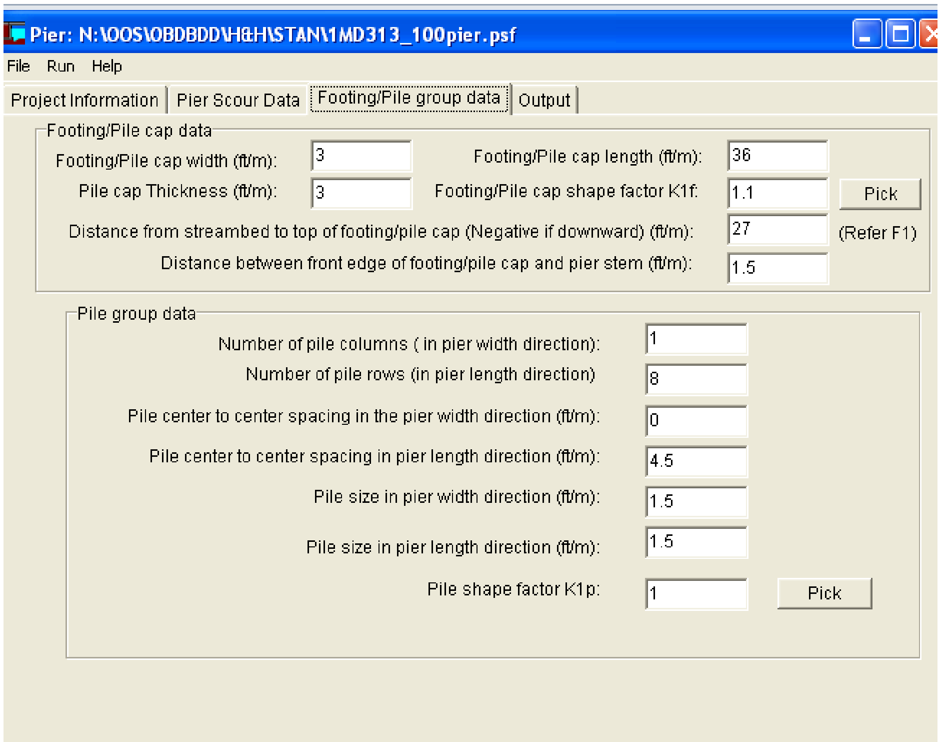
Project Information Data



Pier Scour Data

The information for the Pier Scour Data Menu can be obtained from the HEC-RAS run the stream morphology report and the bridge plans.

- Use the initial flow velocity immediately upstream of the bridge as determined from HEC-RAS. For small channels compute the velocity as $V_1=q/y_1$ where q is the unit flow in the channel. For larger channels, use the velocity distribution (flow tube) option in HEC-RAS to select the highest velocity in the channel.
- Soils information can be obtained from the Stream Geomorphology Report and borings taken at the pier. Degradation and Contraction Scour values should be consistent with the input used in the ABSCOUR Program. When the input data for this card is complete, click on the Footing/Pile group data tab.



Footing/Pile Group Data Menu.

The information for the Footing/Pile Group Data should be available from the bridge plans. When this information is completed, click on “Run” to obtain the program scour calculations. The output results for scour at the MD 313 bridge are presented below:

```
**********************************************************
*          Maryland State Hightway Administration          *
*                 Office of Structures                     *
*           Maryland Scour Program - Pier Scour            *
*             Version 9 Build 2, December 2009             *
**********************************************************

Time stamp: 10/15/2010 1:02:17 PM

Input data:

Project information:
---------------------------------------------
Project name: md313 over Marshyhope Creek
Project number:
Description: 100 year flood
             Bridge opening is skewed 35 degree

Pier scour condition: Option 4 Pier with pile group auto solve options 1 thru 3 and contraction conditions
Units used: English Units
Flow depth upstream face of the pier (ft/m): 17 ft
Flow velocity upstream face of the pier right at nose (fps/mps): 5 fps
Width of pier stem (ft/m): 1.5 ft
Length of pier stem (ft/m): 1.5 ft
Flow attack angle (degree): 0 degree
Contraction scour depth at pier (ys)f  (ft/m): 2.46 ft
Water surface elevation upstream face of the pier (ft/m):  7.08 ft
Aggradation (+) or degradation (-) (ft/m):  0 ft
Median grain size D50 (ft/m):  0.5*0.00259+0.5*0.00105+4*0.000089 ft
84% finer grain size D84 (ft/m): 0.5*0.064+0.5*0.0059+4*0.0038 ft
95% finer grain size D95 (ft/m): 0.5*0.064+0.5*0.0059+4*0.0038 ft
Pier stem nose shape correction factor (K1): 1
K2 calculated by the program
Streambed condition correction factor (K3): 1.1
K4 calculated by the program
Footing/Pile cap width (ft/m): 3 ft
Footing/Pile cap length (ft/m): 36 ft
Pile cap Thickness (ft/m): 3 ft
Footing/Pile cap shape factor K1f:  1.1
Distance from streambed to top of footing/pile cap (Negative if downward) (ft/m): 27 ft
Distance between front edge of footing/pile cap and pier stem (ft/m): 1.5 ft
Number of pile columns ( in pier width direction): 1
Number of pile rows (in pier length direction) 8
Pile center to center spacing in the pier width direction (ft/m): 0 ft
Pile center to center spacing in pier length direction (ft/m): 4.5 ft
Pile size in pier width direction (ft/m): 1.5 ft
Pile size in pier length direction (ft/m): 1.5 ft
Pile shape factor K1p: 1

Output Results:


***** Method 1 Option 3 *****

Revised flow depth: 17 ft
Revised flow velocity: 5 fps
Revised distance from streambed to top of footing/pile cap: 27 ft
Revised soil layer 1 thick: 0.5 ft
Revised soil layer 2 thick: 0.5 ft

Control soil is layer no. 3 with D50=0.000089 ft   D95=0.0038 ft

Scour component for the pier stem in the flow:

Pier stem is not in the water, no contribution to the scour component

Scour component for the exposed footing/pile cap:

Pile cap is not in the water, no contribution to the scour component

Scour component for the exposed pile group:

Only one pile column, the pile spacing in width direction is set to 7 times pile size
Adjusted depth of flow upstream of pier y3: 17 ft
Adjusted velocity for the flow approaching the pier v3: 5 fps
Sum of overlapping projected width of piles: 1.5 ft
Coefficient of pile spacing Ksp: 1
Coefficient of number of aligned pile rows Km: 1
Effective width of the pile group: 1.5 ft
Correction factor for armoring K4 for pile group: 1
Height of pile group aboved lowered stream bed h3: 24 ft
Pile group height factor Kh(pg): 1
Froude Number Fr3 for pile group: 0.2137
Scour component for the exposed pile group: 3.975 ft
Total pier scour depth with respect to revised flow depth: 3.975 ft
Total pier scour depth with respect to initial flow depth: 3.975 ft

***** Method 2 Option 3 *****

Revised flow depth: 19.46 ft
Revised flow velocity: 4.3679 fps
```

```
File:C:\scour\1MD313_100pier.psf  Date:10/15/2010                                        Page:2

Revised distance from streambed to top of footing/pile cap: 27 ft
Revised soil layer 1 thick: 0 ft
Revised soil layer 2 thick: 0 ft

Control soil is layer no. 3 with D50=0.000089 ft   D95=0.0038 ft

Scour component for the pier stem in the flow:

Pier stem is not in the water, no contribution to the scour component

Scour component for the exposed footing/pile cap:

Pile cap is not in the water, no contribution to the scour component

Scour component for the exposed pile group:

Only one pile column, the pile spacing in width direction is set to 7 times pile size
Adjusted depth of flow upstream of pier y3: 19.46 ft
Adjusted velocity for the flow approaching the pier v3: 4.368 fps
Sum of overlapping projected width of piles: 1.5 ft
Coefficient of pile spacing Ksp: 1
Coefficient of number of aligned pile rows Km: 1
Effective width of the pile group: 1.5 ft
Correction factor for armoring K4 for pile group: 1
Height of pile group aboved lowered stream bed h3: 24 ft
Pile group height factor Kh(pg): 1
Froude Number Fr3 for pile group: 0.1745
Scour component for the exposed pile group: 3.82 ft
Total pier scour depth with respect to revised flow depth: 3.82 ft
Total pier scour depth with respect to initial flow depth: 6.28 ft

Summary of results:

Control Method: Assume contraction scour does occur
Control option: Option 3 Pier with pile cap and pile group exposed
Contraction scour depth at pier: 2.46 ft
Local scour depth at pier: 3.82 ft
Total scour depth at pier: 6.28 ft
Total pier scour elevation: -16.2 ft
Aggr/Degr + total Pier Scour Elevation: -16.2 ft
```

BACKGROUND ON THE MARYLAND SHA (HEC-18) PIER SCOUR COMPUTATIONS

The following information is offered only to provide insight into the approach used in ABSCOUR to compute pier scour. **As noted earlier, Option 4 automatically solves the pier scour equations for all the cases discussed below. This is the recommended option to use.**

1. Two alternative methods for evaluating pier scour are described below. The recommended procedure is to compare the scour computed from both Method 1 and Method 2; Select the method which results in the deepest scour elevation. Use this value as the total pier scour value.

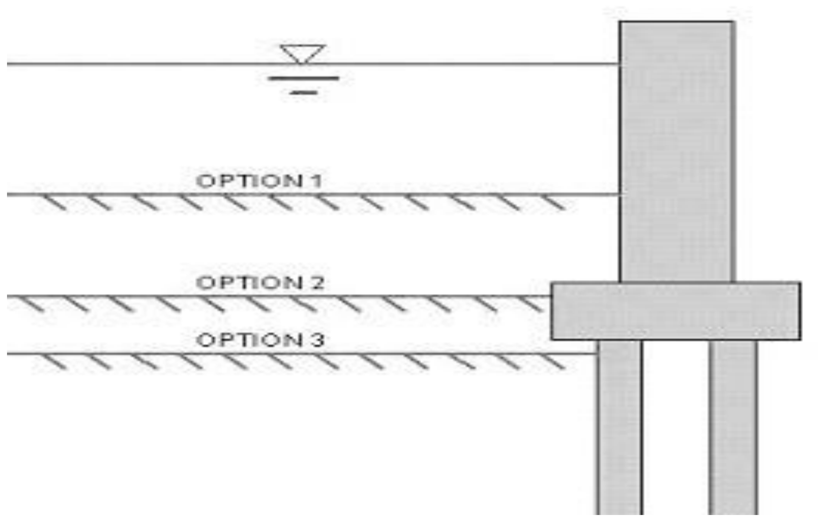
2. **Method 1** Assume contraction scour does not occur. Compute pier scour following the procedure outlined below, using the flow depths and velocities obtained from the water surface model (typically HEC-RAS) and the existing channel bed elevation

3. **Method 2** Assume contraction scour does occur. Compute pier scour following the procedure outlined below using the revised elevation of the channel to account for contraction scour. Also, modify the flow depth and velocity to account for the effect of the contraction scour:

Computing Pier Scour using the ABSCOUR Pier Scour Module.

For both Methods 1 and 2, three options are evaluated (See sketch below):

- Option 1 only the pier stem is contributing to scour
- Option 2 – the pier stem and pile cap/footing is contributing to the scour
- Option 3 – the pier stem, pile cap and piles contribute to the scour



Computing Pier Scour Using Method 1.

Assume contraction scour does not occur. Compute pier scour following the procedure outlined below, using the flow depths and velocities obtained from the water surface model (typically HEC-RAS) and the existing channel bed elevation

- Set the initial channel bed elevation equal to the existing channel bed elevation.
- Set the initial flow depth, y_1, equal to the distance between the water surface and the existing bed elevation.
- Select the initial flow velocity immediately upstream of the bridge as determined from HEC-RAS. For small channels compute the velocity as $V_1=q/y_1$ where q is the unit flow in the channel. For larger channels, use the velocity distribution (flow tube) option in HEC-RAS to select the highest velocity in the channel.
- Proceed to Option 1

Option 1

Option 1 computes local scour for the pier stem only. Fill in the required information, including the initial flow depth, y_1 and the flow velocity V_1 as discussed above. Click the run button.

- If the scour computed by Option 1 is less than the elevation of the top of the footing/pile cap, use this value for the pier scour depth. Then, $y_2 = y_1 + y_s$
- If the scour computed by Option 1 is deeper than the top of the footing/pile cap, continue on to Option 2 below. Note that $ys_{pier} = y_2 - y_1$.

Option 2

1. Fill in the information for the footing/pile cap; use the following revised input values for flow depth and velocity.

2. Set a revised flow depth at an elevation of 1 foot below the top of the footing/pier cap. The total flow depth to this point $= y_2 = y_1 + (ys)$ where ys is the pier scour depth between the channel bottom and the selected elevation one foot below the elevation of the top of the footing/pier cap.

3. Compute a new approach flow velocity as $V_2 = V_1 * y_1 / (y_1 + ys / 2)$

4. Run the program, and note the computed scour depth

   Subtract this computed scour depth from the revised flow depth set in Step 2 above. This determines the scour elevation for Option 2.

5. If the scour elevation from Step 4 is within the limits of the footing/pile cap use this value for the pier scour. If the scour elevation from Step 4 is below the bottom of the footing/pile cap, go to Option 3.

Option 3

Fill in the information regarding the pile group. Use revised input values for flow depth and velocity as described below.

1 Set a revised flow depth y3 at an elevation of one foot below the bottom of the footing: $y3 = y_1 + (ys)$ where ys is the scour depth measured from the existing channel bottom to the point one foot below the bottom of the footing.

2. Compute a new approach flow velocity as $V_3 = V_1 * (y_1) / (y_1 + ys/2)$

3. Run the program for Option 3 and obtain the scour depth

5. Compute the scour elevation as the elevation of the selected point one foot below the bottom of the footing/pile cap (step 1 above) – scour depth (Step 3)
6. Compare this scour elevation with the scour elevation determined from Method 2. Use the lower scour elevation as the total pier scour elevation.

Computing Pier Scour Using Method 2.

Assume contraction scour does occur. Compute pier scour following the procedure outlined below.

- Set the initial bed elevation equal to the contracted channel bed elevation.
- Set the initial flow depth, y_1, equal to the distance between the water surface and the contracted channel bed elevation.
- Select the initial flow velocity V_1 for Method 2 taking into account the effect of the contracted scour.

V1(method 2) = V1 (method 1) * (y1) / (y1+ ys)

where ys = contracted scour depth.

- Proceed to Option 1

Option 1 for Method 2

-

Option 1 computes local scour for the pier stem only. Fill in the required information, including the initial flow depth, y_1 and the flow velocity V_1 as discussed above. Use the contracted scour bed elevation as the initial bed elevation.

Click the run button and note the scour depth computed by Option 1. Subtract this depth from the initial contraction scour bed elevation to obtain the pier scour elevation.

- If the pier scour elevation is less than the elevation of the top of the footing/pile cap, use this value for the pier scour .
- If the scour computed by Option 1 is deeper than the top of the footing/pile cap, continue on to Option 2 below. Note that $ys_{pier} = y_2 - y_1$.

Option 2 for Method 2

1. Fill in the information for the footing/pile cap; use the following revised input values for flow depth and velocity.

2 Set a revised flow depth at an elevation of 1 foot below the top of the footing/pier cap. The total flow depth to this point = $y_2 = y_1 + (ys)$ where y1 is the depth of the contracted scour bed and ys is the pier scour depth between the contracted channel bottom and the selected elevation one foot below the elevation of the top of the footing/pier cap. (Note: If the contracted channel elevation is already below the bottom of the footing/pile cap, proceed to Option 3)

3. Compute a new approach flow velocity as $V_2 = V_1 * (y_1) / (y_1 + ys / 2)$

4. Run the program, and note the computed scour depth

Subtract this computed scour depth from the revised flow depth set in Step 2 above. This determines the scour elevation for Option 2.

5. If the scour elevation from Step 4 is within the limits of the footing/pile cap use this value for the pier scour. If the scour elevation from Step 4 is below the limits of the footing/pile cap, go to Option 3 for Method 2

Option 3 for Method 2

Fill in the information regarding the pile group. Use revised input values for flow depth and velocity as described below.

1 Set a revised flow depth y3 at an elevation of one foot below the bottom of the footing: $y3 = y_1 + (ys)$ where ys is the scour depth measured from the channel bottom to the point one foot below the bottom of the footing.

2. Compute a new approach flow velocity as $V_3 = V_1 * (y_1) / (y_1 + ys/2)$

3. Run the program for Option 3 and obtain the scour depth

4. Compute the scour elevation as the elevation of the selected point one foot below the bottom of the footing/pile cap (step 1 above) – scour depth (Step 3)

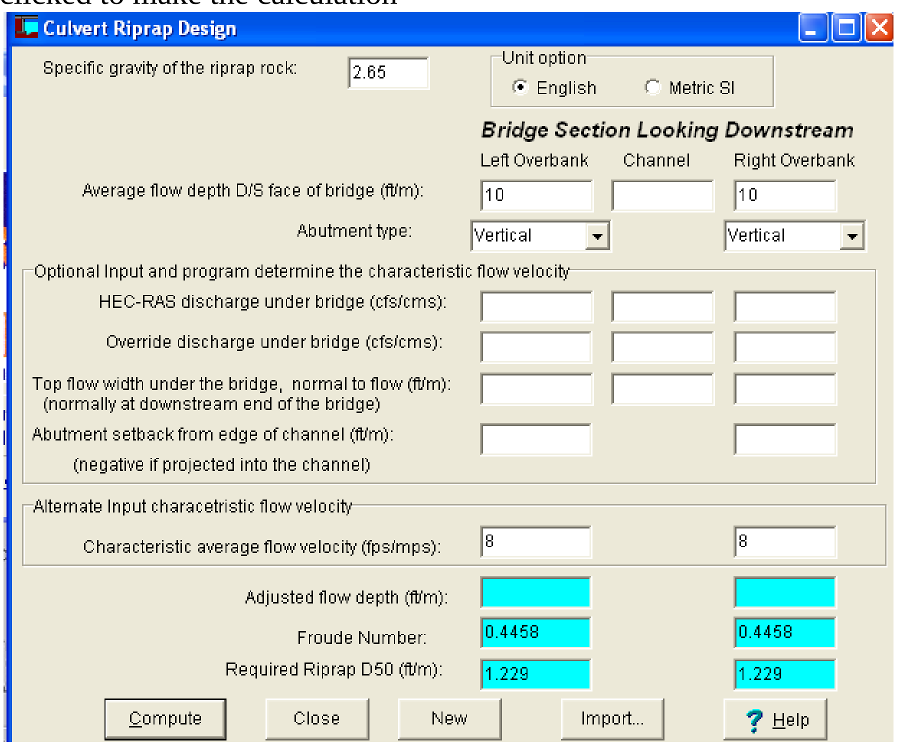
5. Compare this scour elevation with the scour elevation determined from Method 1. Use the lower scour elevation as the total pier scour elevation.

VI. UTILITY MODULE

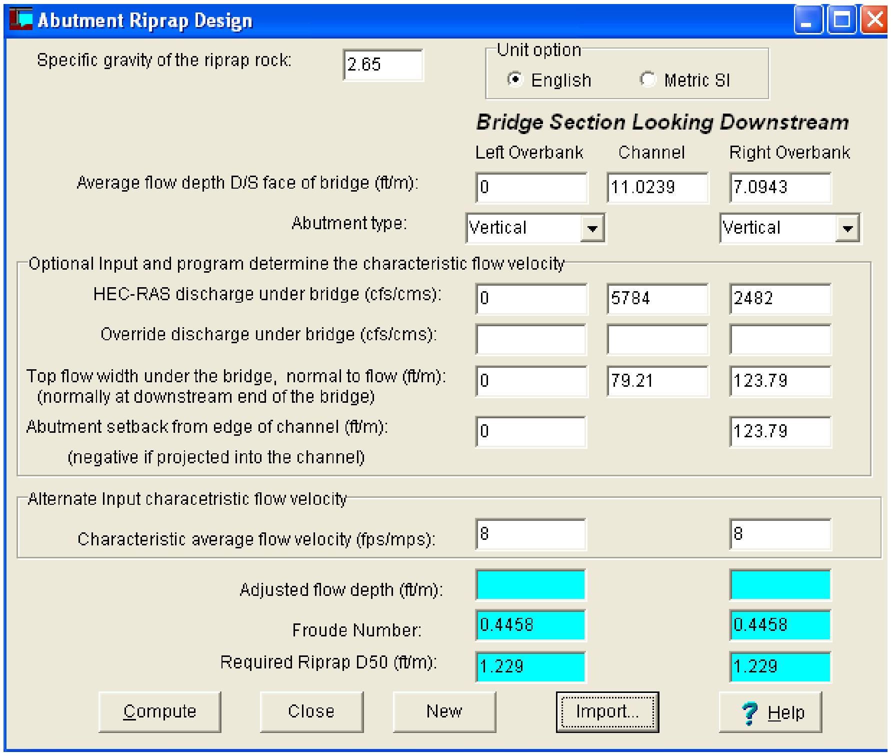
A. RIPRAP

The Utility module provides a means of selecting the D50 size of riprap for abutments culverts and piers. The computations for the riprap D50 size for piers and abutments use the procedures set forth in the 2001 edition of HEC-23. Use this information to select the appropriate riprap size, typically Class 2 or 3. The computations for the D50 size for bottomless culverts are based on a cooperative FHWA-Maryland SHA research study conducted in the FHWA Hydraulic Laboratory.

The process for using this module is the same as for the other modules previously discussed. The various input cells are to be filled in; then the "COMPUTE" button is clicked to make the calculation

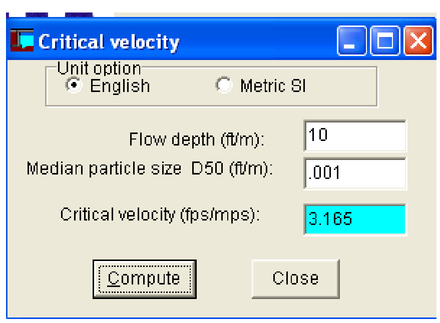


After running the ABSCOUR Program, The utility program can be used in to import the output data from the ABSCOUR run to compute the riprap size required for an abutment or pier. This option is illustrated below



B. CRITICAL VELOCITY

This is a handy tool for approximating the critical velocity of the soils in a channel bed, given the D50 particle size and the flow depth. Calculations are based on Neill's competent velocity curves (Reference 11). Short Help (F-1 key) and Regular Help are available for this module. A more accurate estimate can be made by using the modified Neill's curves presented later in this appendix



C. SCOUR IN ROCK

The Utility Module provides a methodology for the computation of scour in rock entitled ROCK SCOUR. **However, we currently recommend the use of the SHA Spread sheet in the Software Package of this manual for making the erodibility index computations.** The evaluation of the resistance of rock to scour requires the services of an engineer or geologist who has the specialized training to make such judgments. The Rock Scour Module and the Erodibility Index Spreadsheet are based on the Erodibility

Index Method. The Erodibility Index Method was developed by Dr. George Annandale, currently the President of Engineering and Hydrosystems, Inc. of Littleton Colorado. The Office of Structures recommends that the Erodibility Index Method be used as an additional resource by specialists who have the knowledge to apply the method. **Currently the Rock Scour Module in ABSCOUR 10 is not recommended for use.** The following overview provides background information on the Erodibility Index Method.

C.1 Application of the Erodibility Index Method

The Erodibility Index Method involves the following steps:

1. Calculation of the Erodibility Index of the rock, based on its physical characteristics and orientation with respect to the flow direction of the water.
2. Calculation of the stream power of the flow in the stream or river for the hydraulic conditions under investigation.
3. Calculation of the modified stream power at a pier or abutment due to the effect of the obstruction on the flow. These modified values are calculated by a series of equations developed in the FHWA Hydraulic Laboratory for different types of piers under different flow conditions.

   The piers scour equations are recommended for design when used with caution and the application of engineering judgment.

   <u>The abutment scour equations should not be used for design</u>. The SHA has derived the abutment scour equations from the rectangular pier equations developed by the FHWA lab studies, and there are no data at this time to assure that this approach is valid. However, these equations can be useful of in comparing the estimated scour in rock with the equivalent scour in sand. This information can serve as one factor in making an engineering judgment regarding scour at abutments founded in rock.

Using the empirical relationships presented in the Erodibility Index Method described above, a comparison can be made between stream power and the ability of the rock to resist the hydraulic forces. If the rock at the surface of the stream cannot withstand the hydraulic forces of the water, it will scour and a scour hole will form at the base of the pier or abutment. As the scour hole deepens, the stream power at the bottom of the scour hole diminishes in accordance with the relationships determined by the FHWA studies. At some point, the hydraulic power of the water and the resistance of the rock will achieve a balance, and the scour will end.

A safety factor should be applied to the above scour evaluation, to take into account the limited understanding of and experience with evaluating the resistance of rock to scour. This safety factor should be determined on a case by case basis; however, the current SHA thinking is to use a safety factor in the range of 2 to 5, with a range of 2 to 3 being used for most bridges.

C-2. STREAM POWER CALCULATIONS

The hydraulic calculations are relatively straight-forward and consist of the following:

1. Inputting the velocity, hydraulic radius and energy slope of the flow so that the program can calculate the stream power (Pa): Pa = γVRS.

- For piers, select a section just upstream of the bridge to compute the stream power.
- For abutments, select the downstream section under the bridge (Section 2 as defined in the ABSCOUR Program) to compute the stream power.

2. Selecting the pier type along with the angle of attack of the flow.
3. Calculating the maximum scour in sand for the selected foundation geometry and flow conditions.
    - For piers, select a section just upstream of the bridge to obtain the hydraulic values in the pier scour equation. Use the Pier Scour Module in the ABSCOUR Program to calculate the scour depth in sand.
    - For abutments, select the downstream section under the bridge (Section 2 as defined in the ABSCOUR Program) to compute the maximum scour in sand. Use the ABSCOUR Program to make this computation.

C-3 ERODIBILITY INDEX CALCULATIONS

The recommended approach for computing the Erodibility Index is to use the Spread Sheet developed by the SHA. (See SHA Software Module in the Manual)

Computations of the Erodibility Index of the rock should be made only by engineers or geologists with knowledge and experience in evaluating the properties of rock. It is the practice of the Office of Structures to meet with the SHA geologists for the purpose of:

1. inspection of the rock cores, and
2. selection of appropriate rock characteristics for purposes of computing the erodibility index of the rock.

The steps for computing the Erodibility index are outlined below:

C-4 COMPUTING THE ERODIBILITY INDEX FOR ROCK

Please note that the erodibility index can be expected to vary with the depth of the rock below the channel. Typically it will increase, but this is not necessarily true in all cases.

In conducting studies of scour in rock, it is necessary to compute the erodibility index for the same elevation at which the rock scour will occur. Normally this will involve a trial and error approach using the computer program.

The references below pertain to appropriate tables and pages in Dr. Annandale's manual "Calculation of Pier Scour Using the Erodibility Index Method" The Erodibility Index is computed from the following equation:

K = Ms Kb Kd Js **(2-2)**

where:

K = erodibility index
Ms = mass strength number
Kb = block size factor
Kd = inter-particle bond shear strength number
Js = relative ground structure number

C-5 DESIGN PROCEDURE

STEP 1 DETERMINE (Ms) THE MASS STRENGTH NUMBER

This value is selected from Table 5, Intact Material Strength Number Ms for Rock, Page 18.

STEP 2 COMPUTE Kb, THE BLOCK SIZE FACTOR:. Kb = RQD/Jn

- RQD = Rock quality designation where RQD > 5. This is obtained by qualified engineers and geologists through an inspection of rock cores taken at the bridge site
- Obtain Jn , the joint set number, from Table 7, page 21

STEP 3 COMPUTE KD, THE INTER-PARTICLE BOND SHEAR STRENGTH NUMBER, Kd = Jr/Ja

- Obtain the joint roughness number, Jr, from Table 8, page 26
- Obtain the joint alteration number, Ja, from Table 9, page 27

STEP 4 COMPUTE Js, THE RELATIVE GROUND STRUCTURE NUMBER,

The information required to obtain Js is obtained from Table 10, the Relative Ground Structure Number Table, page 29.

The value of Js depends upon the appropriate selection of the following rock properties:

- Dip direction in direction of stream flow or dip direction against direction of stream flow (degrees)
- Dip angle of closer spaced joint set (degrees)
- Ratio of joint spacing , r

The SHA spread sheet provides the user with a convenient method to compute and compare the erodibility index and the stream power, and to determine the extent to which the rock will scour for the given conditions. The method allows the user to select an appropriate safety factor to be considered in applying the results of the evaluation.

The following guidance is provided for use in applying the computational method included in the Utility Module. Use the following input menu cards:

PROJECT DATA CARD

1. Project description
2. Pier or Abutment Data

HYDRAULIC DATA

1. Input the data described above in Stream Power Calculations
2. Input the desired safety factor

ROCK DATA

1. Input the data as described in the above section on computing the erodibility index for rock.

After inputting the above noted data, click the run tab, and then the output tab to obtain the scour report. The program will compute the depth of scour in rock along with the computed safety factor.

D. BRIDGE UPSTREAM SECTION.

This Utility can be used to import the cross-section of the upstream face of the bridge from HEC-RAS in order to provide a check on the values that are used to estimate the ground elevation, high chord elevation and low chord elevation.

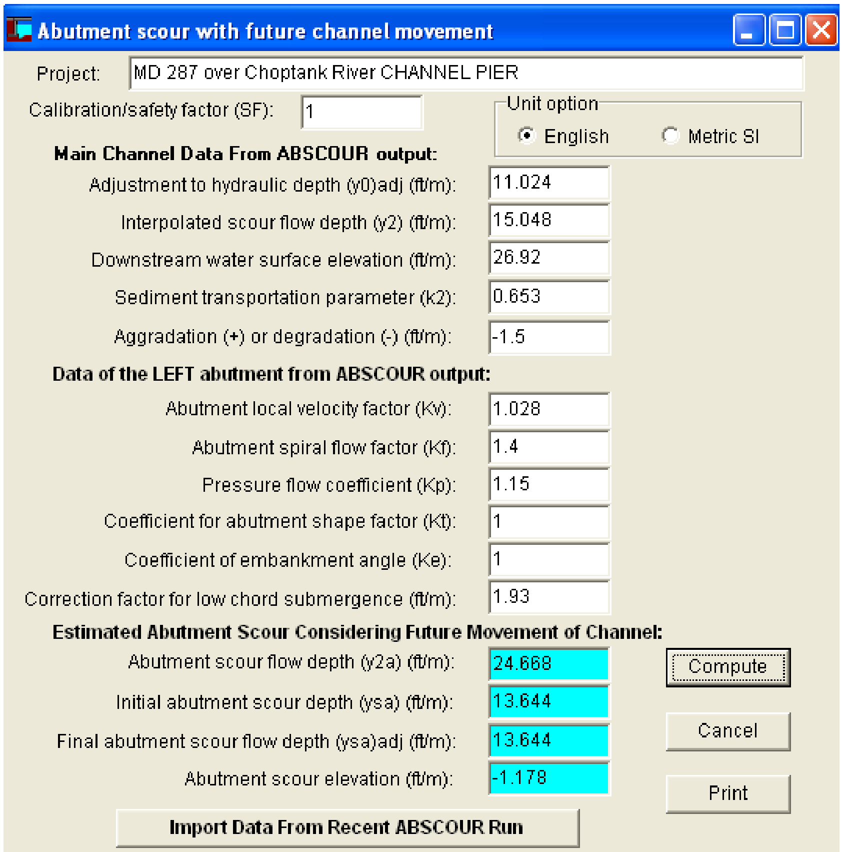
E. ABUTMENT SCOUR CONSIDERING THE FUTURE MOVEMENT OF THE STREAM CHANNEL INTO THE ABUTMENT.

This Utility is a valuable addition to ABSCOUR 9. It is common to find a conclusion in the Stream Morphology Report that one or more of the abutments of a bridge are within the Lateral Channel Movement Zone of the stream being crossed. For this case it is necessary to estimate the scour at the abutment in the event that the channel does move into the abutment. Up to now, such computations have been required to be done manually.

This Utility is used in the following manner:

- Run the ABSCOUR program for the existing conditions
- Open the utility and click on Import Data from Recent ABSCOUR run. In the window which opens up indicate which abutment (left or right) that you wish to evaluate, and then click OK
- The program computes the scour which is expected to occur for main channel flow next to the abutment.

The MD 313 Bridge over Marshy Hope Creek could not be used as an example for this condition, since both abutments are in the channel. Instead, an example was taken from the MD 287 bridge over the Choptank River since the abutment for this bridge is set back a distance from the edge of the channel. The program takes the input information for the main channel flow and the abutment characteristics and the “moves” the main channel to the abutment to compute the abutment scour for this condition.


Abutment scour with future channel movement
Project: MD 287 over Choptank River CHANNEL PIER
Calibration/safety factor (SF): 1
Unit option
English
Metric SI
Main Channel Data From ABSCOUR output:
Adjustment to hydraulic depth (y0)adj (ft/m): 11.024
Interpolated scour flow depth (y2) (ft/m): 15.048
Downstream water surface elevation (ft/m): 26.92
Sediment transportation parameter (k2): 0.653
Aggradation (+) or degradation (-) (ft/m): -1.5
Data of the LEFT abutment from ABSCOUR output:
Abutment local velocity factor (Kv): 1.028
Abutment spiral flow factor (Kf): 1.4
Pressure flow coefficient (Kp): 1.15
Coefficient for abutment shape factor (Kt): 1
Coefficient of embankment angle (Ke): 1
Correction factor for low chord submergence (ft/m): 1.93
Estimated Abutment Scour Considering Future Movement of Channel:
Abutment scour flow depth (y2a) (ft/m): 24.668
Initial abutment scour depth (ysa) (ft/m): 13.644
Final abutment scour flow depth (ysa)adj (ft/m): 13.644
Abutment scour elevation (ft/m): -1.178
Compute
Cancel
Print
Import Data From Recent ABSCOUR Run

ATTACHMENT 1: COMPUTATION OF THE VELOCITY OF FLOW USED IN THE ABUTMENT SCOUR COMPUTATIONS.

I. COMPUTATION OF VELOCITY AND SCOUR

Field observations of flows at bridge crossings in wide streams revealed that the flow in the overbank sections is contracted by the abutment and moves toward the main channel where it mixes with the main channel flow. When the abutment setback from the main channel was less than five times the flow depth in the channel, the flows were well mixed and the flow velocity in the channel and overbank became uniform. If the abutment setback was large, being located near the edge of the flood plain, the flows in the main channel and in the overbank section remained separated as they passed under the bridge. These findings are utilized in computing flow velocity in ABSCOUR program.

Abutment setbacks are classified into three categories: short, intermediate, and long setbacks. The term short setback is used to define the condition where the setback is equal to or less than five times the channel flow depth ($5y_0$). The term long setback is used to define the condition where the setback being is equal or greater than 75% of the overbank width (0.75W). A setback between these two limits is defined as an intermediate setback.

For short setbacks, the velocity (V) is computed as a uniform velocity (V=Q/A) in the waterway area under the bridge(A) where Q is the discharge through the bridge.

For long setbacks, the velocity in the overbank is computed independently from the channel flow. It is based only on the discharge and flow area of the overbank section.

For intermediate setbacks, the velocity is computed by interpolating the velocity of the mixed flow (at a setback distance of $5y_o$ from the channel bank) with the velocity of separate flow (at a setback distance of 0.75W).

In each case above, the unit flow discharge under the bridge is computed by multiplying the velocity and flow depth (q = V* yo). For short setbacks very close to the channel banks and within the limits of the bank slope, the flow depth is adjusted to reflect the actual location within the bank area. Finally, the scoured flow depth, y_2, used to define contraction scour is computed by using the appropriate scour equation:

- Laursen's equations for live-bed contraction scour, or
- The user's choice of Laursen's equation or Neill's competent velocity equation to compute clear-water contraction scour.

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) whereas it may be subject to live bed scour from the main channel. Some transition is needed 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 (y2) 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 no interpolation is required. When the setback is within this transition zone of from zero to 5yo, the following scheme is used to compute contraction scour:

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

The channel contraction scour flow depth (y2) is the scour when the setback is equal to or less than zero - that is no setback case.

The overbank contraction scour flow depth (y2) 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 = 5yo)

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

1 clear water scour with no setback
2. clear water scour with setback = 5yo
3. live bed scour with no setback
4. live bed scour with setback = 5yo

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 = 5yo).

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 (y2) since this method provides for a smooth transition that approximates the scour depths computed through the application of Laursen's contraction scour equations. The following parabolic equation is used for interpolation.

y2=(y2)bank + ((y2)channel - (y2)bank)*(1-(setback)/(5*yo))^p

Where: p=4.5-Z and p is limited to the values of 1<=p<=4
Z is the approach section bank slope H/V
(y2)bank is the scour flow depth at setback=5y0
(y2)channel is the scour flow depth with no setback

Please note that the bank slope determines the shape of the parabola and therefore the relative effect of the channel scour on scour at the abutment. Steeper bank slopes such as 1:1 will reduce the effect of channel scour whereas flatter slopes such as 4:1 will increase the effect of channel scour. The bank slope can be used as a variable in sensitivity analyses of factors affecting abutment scour.

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.

Next, the abutment scour flow depth (y2a) is computed directly from the interpolated contraction scour value:

y2a =(kf * (kv)^k2) * (contraction scour)

Abutment scour (ysa) = y2a - (yo)adj , where (yo)adj = flow depth before scour occurs.

The final or adjusted abutment scour value (ysa)adj is determined as

(ysa)adj = Kt * Ke *FS * ysa

Where

Kt = modification for abutment shape

Ke = modification for embankment skew

FS = factor of safety.

ysa = initial abutment scour estimate noted above (ysa = y2 - (yo) adj)

The logic presented above is based on the assumption that the overbank area is wide and that 0.75W > $5y_0$. A special case may exist for a narrow flood plain where 0.75W < $5y_0$. In this instance, no intermediate zone exists and the interpolation scheme for the intermediate setback cannot be applied. If the setback is equal or larger than $5y_0$, the velocity and resulting contraction scour depth is computed assuming that the setback is equal to $5y_0$. If the setback is smaller than $5y_0$, the velocity and scour depth are computed the same as it would be for the short setback case.

Here are some example problems to illustrate the computation of flow velocity and contraction scour for various setback distances from the channel bank.

II. EXAMPLE PROBLEM 1

GIVEN:

	LEFT OVERBANK	CHANNEL	RIGHT OVERBANK
APPROACH SECTION			
- DISCHARGE cfs	600	1600	1200
- TOP FLOW WIDTH ft	80	20	100
- HYDRAULIC DEPTH ft	4.8	9.8	3.8
UNIT DISCHARGE (q1) cfs/ft	7.5	80	12
BRIDGE SECTION			
- DISCHARGE cfs	600	1600	1200
- TOP FLOW WIDTH ft	80	20	100
- HYDRAULIC DEPTH ft	5	10	4

III. COMPUTATION OF CONTRACTION SCOUR:

Computations for the contraction scour flow depths, y_2, for the right overbank section are presented for different abutment setbacks. The left abutment is kept at a fixed location with its setback at a distance of 20 ft from the channel edge. The methods of computation are demonstrated only for the right overbank. Contraction scour of the left overbank for different setbacks can be computed in the same way by keeping the right abutment at the actual fixed location.

A. Short Setback - CASE A in Figure A1-1

Since the channel depth is 10 feet, any setback less than (5 X 10 = 50) feet is a short setback.

Let the setback of the right abutment be 30 ft. Since the left abutment setback is also short, being 20 feet, the velocity is computed as if all flows are mixed. The contraction scour depth then shall be computed by interpolating the contraction scours at the setbacks set at the channel edge and at five times the channel flow depth, $5y_{0.}$

Step 1. Compute flow velocity.

As the setback of the left abutment is short as well as the right abutment, total flow will be mixed.

For right setback of 30 ft:
V2= Q/A = (3400)/(20*5+20*10+30*4)=8.1 ft/s

Step 2. Compute Unit discharges, q2 = V*yo

For setback of 0 ft:
q2=8.1*10=81 cfs/ft

For setback of 50 ft:
q2=8.1*4=32.4 cfs/ft

Step 3. Compute contraction scour depth

The ABSCOUR program will compute two scour depths for each setback for two sediment transport modes (live-bed and clear-water). All together four values will be included on the output sheet. For this example, only the live-bed contraction scour computations for the two setbacks will be presented. The sediment transport coefficient, k2, is computed as 0.638.

For setback 0 ft:
Approach section y1=9.8 ft; q1=1600/20=80 cfs/ft

Bridge section y2 =(to be computed) ; q2=8.1*10=81 cfs/ft

Computation by Lausen's Equation, for a setback equal to zero (at the channel bank):
y2/y1=(81/80)^0.638=1.01
y2=1.01*9.8=9.89 ft

For setback 50 ft:
Approach section: y1=3.8 ft ; q1=12 cfs/ft
Bridge section: y2= value to be computed; q2= 8.1*4=32.4 cfs/ft

y2/y1=(32.4/12)^0.638=1.88
y2=1.88*3.8=7.14 ft

Step 4. The contraction scour for the setback of 30 ft requires interpolation. ABSCOUR will use two appropriate values based on the modes of sediment transport in the channel and the overbank, one at 0 ft setback and another at 50 ft setback. In this example, only the live bed condition is used. The contraction scour for a setback at 30 ft is calculated as:

y2=7.14+(9.89-7.14)*((50-30)/(50-0))^2.5=7.14+0.278=7.42 ft

B. Intermediate Setback of 70 Feet -Wide Overbank Section - CASE B in Figure A1-1

The Intermediate Setback zone exist only for an overbank wider than 6.67 y_0. For this example the channel flow depth is 10 ft and the right overbank at bridge is 100 ft. The intermediate zone exists. The computation of contraction scour depth for the right setback of 70 ft is as follows:

Step 1. Compute flow velocity

For an intermediate setback, the flow is neither mixed nor separate. It will gradually change from mixed flow to separate flow. ABSCOUR first computes the mixed flow velocities at $5y_0$=50 ft setback and separate flow velocity at 0.75W=75 ft setback. Then, the velocity at 70 ft setback will be computed by linear interpolation.

For 50 ft setback:
V2= Q/A = (600+1600+1200)/(20*5+20*10+50*4)=6.8 ft/s

For 75 ft setback:
V2=Q/A = 1200/(75*4)=4 ft/s

For 70 ft setback:
by linear interpolation

V2=4+(6.8-4)*(75-70)/(75-50)=4.56 ft/s

Step 2. Compute unit discharge
q2= V*y0 = 4.56*4=18.27 cfs/ft

Step 3. Compute contraction scour depth

y2/y1=(18.27/12)^0.638=1.31
y2=1.31*3.8=4.98 ft

C. Long Setback CASE C in Figure A1-1

For a long setback, the flow in the overbank is considered independent and not affected by the channel flow. For the setback of 80 ft, the contraction scour will be

Step 1. Compute unit discharge
q2=1200/80=15 cfs/ft

Step 2. Compute contraction scour
y2/y1=((15/12)^0.638=1.15
y2=1.15*3.8=4.37 ft

D. Special Case Intermediate Setback-Narrower Overbank - CASE D in Figure A1-1

When the setback > $5y_0$ in a narrow overbank section (width < $6.67y_{0)}$, there is no intermediate flow; consequently, the normal interpolation does not apply. For this case (Figure 1c), ABSCOUR will compute contraction scour assuming that the setback is equal to $5y_0$ for a conservative approximation. For example, the contraction scour for a setback of 60 ft in a 65ft-wide overbank in Figure 1c will be computed the same as that for a setback of 50 ft.

Step 1. Compute flow velocity assuming the setback is at 5y0=50ft
V2=(600+1600+1200)/(20*5+20*10+50*4)=6.8 ft/s

Step 2. Compute unit discharge
q1=1200/65=18.46 cfs/ft
q2=6.8*4=27.2 cfs/ft

Step 3. Compute scour depth
y2/3.8=(27.2/18.46)^0.638=1.28
y2=1.28*3.8=4.87 ft

Figure A1-1 illustrates the four contraction scour examples presented above for varying setback distances. Figure A1-2 illustrates the resulting contraction scour for these cases, although the details of the abutment scour calculations are not presented.

The general procedure to compute the abutment scour flow depth is:

y_{2a} = kf *(k_v)^{k2} *(contraction scour)

The final abutment scour depth is computed using the equations presented in Part 1.

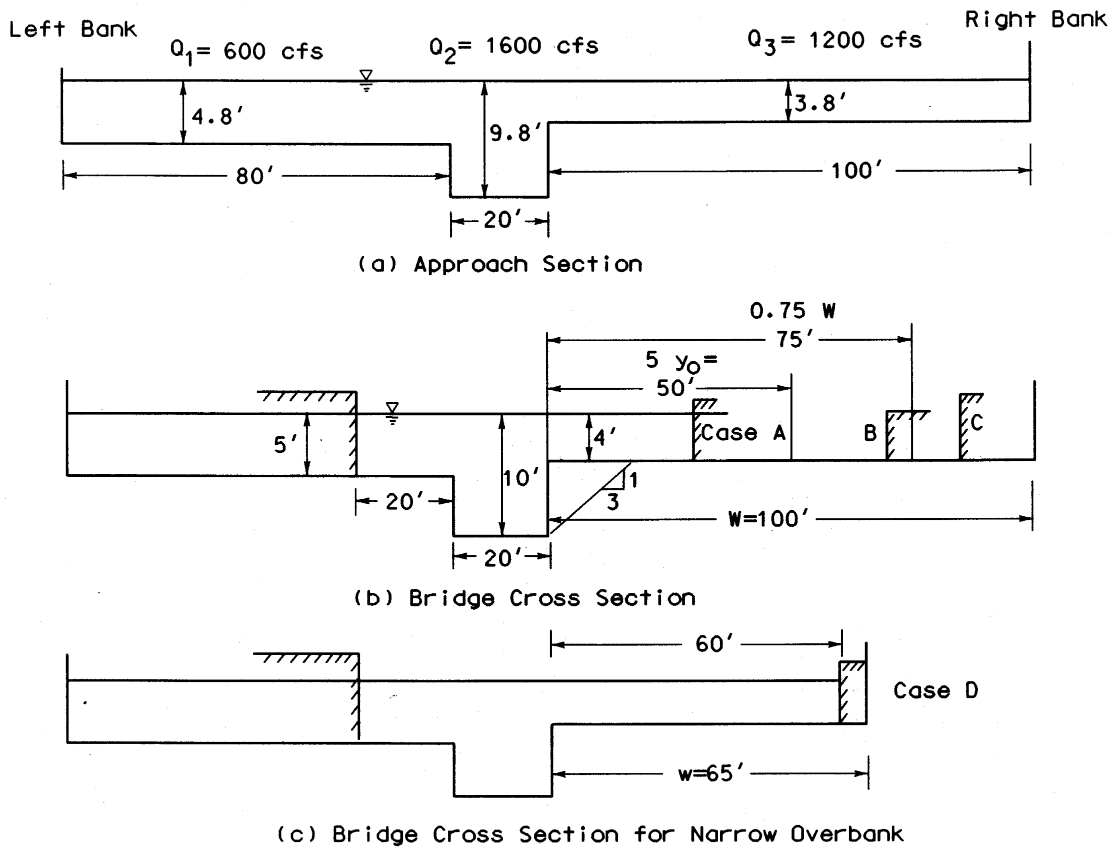


Figure A1-1: Cross Sections of Approach Flow and Under Bridge

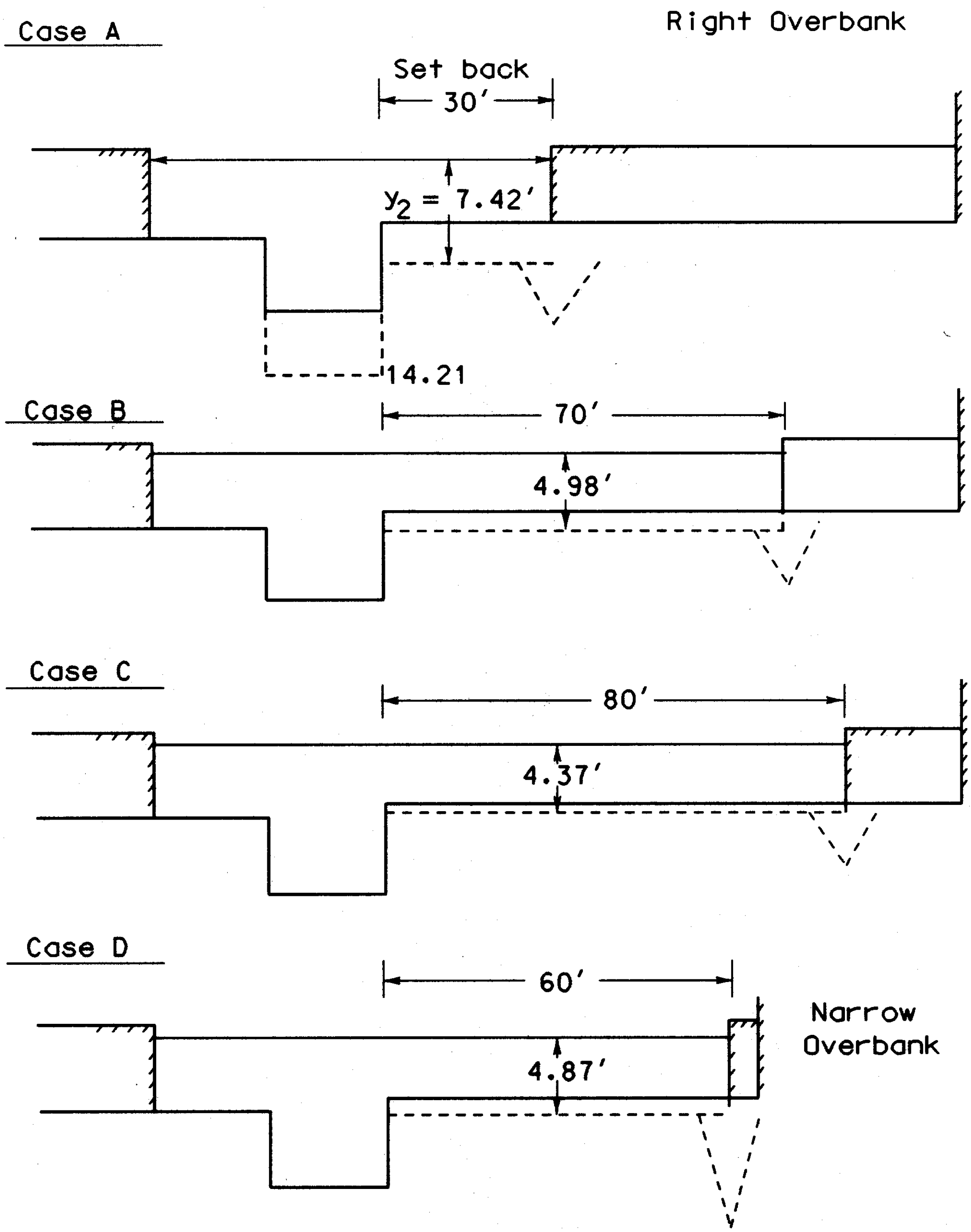


Figure A1-2: Scour Profile of Right Overbank for Different Abutment Setbacks

ATTACHMENT 2: COMPLEX APPROACH FLOW CONDITIONS

The ABSCOUR Program computations are based on rectangular sections for the channel and overbank areas in the approach section and the bridge section with a straight channel reach between the sections. However, the user has considerable flexibility in assigning input values on the ABSCOUR menu cards so that the program can be used to model much more complex flow patterns. Examples of these flow patterns might include:

1 a bridge on a bend in the channel,
2 large overtopping flows on one or both approach roads,
3 the confluence of a tributary stream just upstream of the bridge, and
4 combinations of the above conditions.
5

Please note that any changes to a HEC-RAS model should be made solely for the purpose of sensitivity analysis in assessing scour. A deeper scour elevation may be approved based on the sensitivity analysis, where justified.

In the above noted cases, it is likely that the distribution of flow determined by HEC-RAS (using a 1-D approach based on flow conveyance) may not be truly representative of the actual site conditions. The ABSCOUR program provides for input boxes for both the HEC-RAS analysis and a special analysis provided by the user to explore a worst-case type of condition

The use of flow distributions other than that provided by HEC-RAS is recommended for use only by modelers who have a thorough understanding of the HEC-RAS program. Further, the HEC-RAS distribution should always be tested first in the ABSCOUR program so that there is a basis for comparison for the flow distribution selected by the user. The accuracy of the modeling for such cases will depend on the skill and experience of the user in evaluating flood flows. It requires the user to be able to visualize the flow condition so as to select a reasonable flow distribution at the bridge. In some cases, the momentum equation or other computational methods can be employed to assist with this visualization.

The ABSCOUR computations are illustrated in the table below, with all numbers representing flood flows in cfs:

	LEFT OVERBANK	CHANNEL	RIGHT OVERBANK
APPROACH SECTION	500	2000	250
OVERTOPPING	300	0	0
BRIDGE SECTION	500 - 300 = 200	2000- 0 = 2000	250 - 0 = 250

The user inputs the discharges for the approach section flows and the bridge flows, based on the results obtained from the HEC-RAS runs. As discussed earlier, the HEC-RAS program computes flow on the basis of conveyance. For complex, rapidly changing conditions upstream of the bridge, conveyance calculations may not represent the worst-case scour conditions.

Four examples are presented below to discuss the evaluation of the HEC-RAS flow distribution and to suggest approaches to use in arriving at the worst-case scour condition as a part of the sensitivity assessment of the scour calculations.

I. Example 1: Typical Flow Distribution

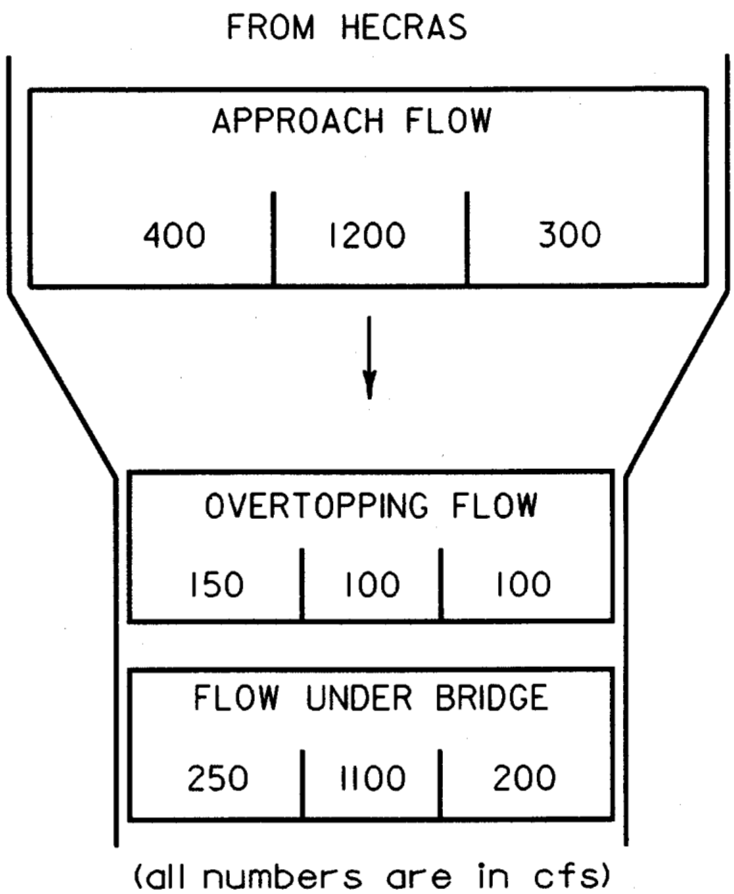


Figure A2-1: Flow re-distribution example

Example 1 presents information obtained from HEC-RAS for a straight reach, depicting the flow distribution at the approach and bridge sections. In the HEC-RAS model, overtopping flow is subtracted from the approach flow to compute the flow through the bridge. This appears to be a reasonable flow distribution at the bridge to use in the ABSCOUR computations

II. Example 2: Unbalanced Flow Condition

The sketch on the left depicts discharge values obtained from HEC-RAS for the approach and bridge sections. Note that there is 300 cfs at the approach on the left overbank section (looking downstream) and 400 cfs of overtopping flow at the left bridge section. HEC-RAS distributes the flow under the bridge according to conveyance, and may underestimate the flow at the right abutment.

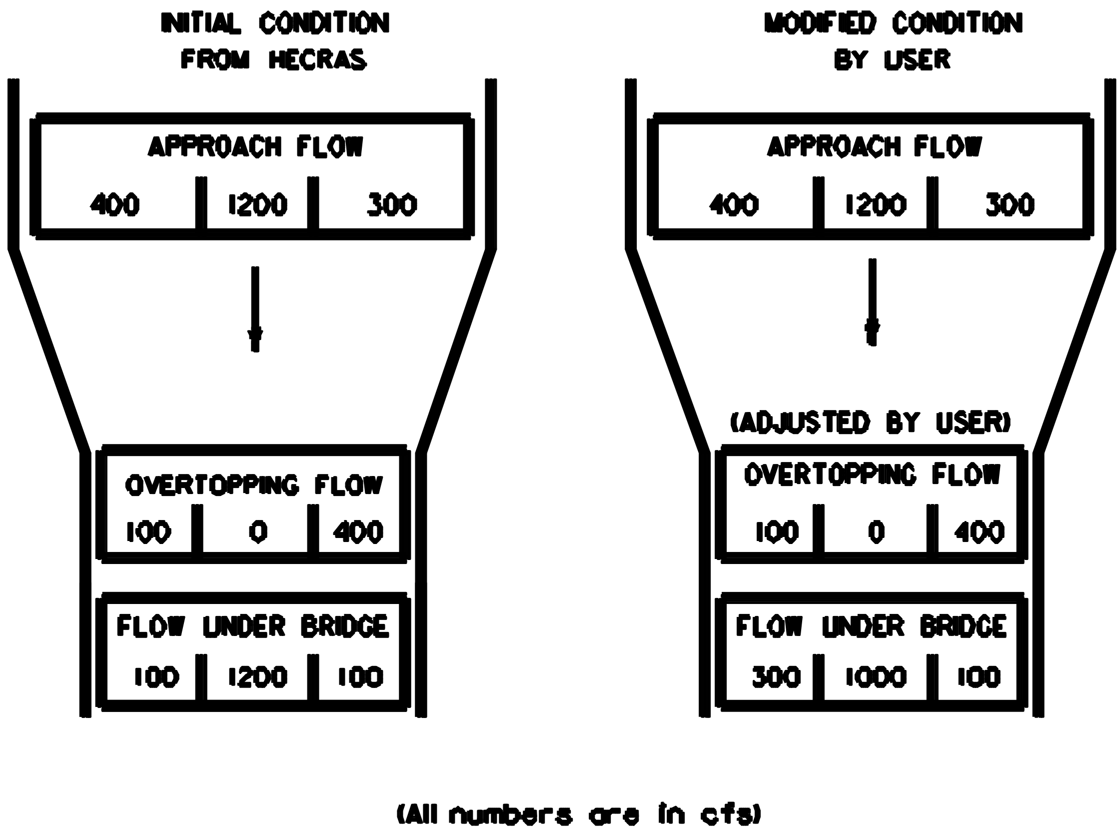


Figure A2-2: Flow re-distribution examples

By inspection, some of the overtopping flow on the left is coming from the main channel and the right overbank section. A rapid shift of the flow from left to right occurs in order to meet the HEC-RAS distribution based on conveyance. This redistribution of flow may not actually occur. Accordingly, the user may wish to consider the consequences of a greater flow on the right overbank section. A trial flow distribution, as depicted on the right sketch, can be selected for a worst case type of analysis. These values may be input instead of the HEC-RAS values to assess worst case scour at the right abutment. The total flow through the bridge remains the same in both cases, as does the total overtopping flow. The difference is that the user can modify the program to provide a different flow distribution under the bridge.

III Example 3: Bend in the River

For a bridge located on a bend in the river, particularly a sharp bend, momentum forces may affect the flow distribution under the bridge. More flow may move to the outside of the bend than is indicated by the HEC-RAS conveyance calculations. This condition can be investigated in the ABSCOUR model by changing the HEC-RAS flow distribution.

IV Example 4 Confluence Upstream of the Bridge

There can be a great deal of uncertainty about the flow distribution at a bridge located just below the confluence of two streams. The location of the confluence is likely to shift over time. Further, the time of concentration of the two streams is likely to vary, affecting the quantity and distribution of flood flows. A worst-case type of scour analysis is recommended for this type of situation. Consider using two or more flow distributions, assuming (1) a worst case condition for the left abutment and then (2) a worst case condition for the right abutment.

ATTACHMENT 3
SAFETY/CALIBRATION FACTORS

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 evaluating 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 value of the coefficient for the spiral flow adjustment factor, k_f . These initial studies were augmented by a second set of flume studies conducted by the FHWA in 2004.
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 suggested to take into account the effect of complex flow patterns which can be expected to occur at bridges abutments. However, the ABSCOUR calibration/safety factors have been reassessed on the basis of the USGS comparison study of ABSCOUR computed scour values vs. measured abutment scour at South Carolina Streams. The current recommended factors, based on both the flume and field studies, are presented below.

SELECTION OF BASE CALIBRATION/SAFETY FACTORS

100-YEAR FLOOD PLAIN WIDTH	CHANNELS AND FLOOD PLAINS WITH FINER BEDLOADS	CHANNELS AND FLOOD PLAINS WITH COARSER BEDLOADS
	D50 < 2 MM	D50>2MM
LESS THAN 800 FEET	0.8	1.0
GREATER THAN 800 FEET	1.1	1.0

SELECTION OF INCREMENTAL CALIBRATION/SAFETY FACTORS
BASED ON SITE CONDITONS

Channel Description at Bridge Site	Incremental Safety Factor
Straight channel with uniform flow.	Add 0.0
Moderately meandering upstream channel	Add 0.0
Severely meandering upstream channel	Add 0.1
Channel with complex approach flow conditions (Sharp upstream bend in channel, confluence, unstable reach, lateral migration, etc.)	Add 0.2
Non-tidal river with wide flood plains and complex two dimensional river and flood plain flow patterns that may change with river stage where a 2-D analysis is appropriate but not available	Add 0.1
Tidal river with wide tidal flats or wetlands and complex two dimensional river and flood plain flow patterns that may change with river stage where a 2-D analysis is appropriate but not available	Add 0.1

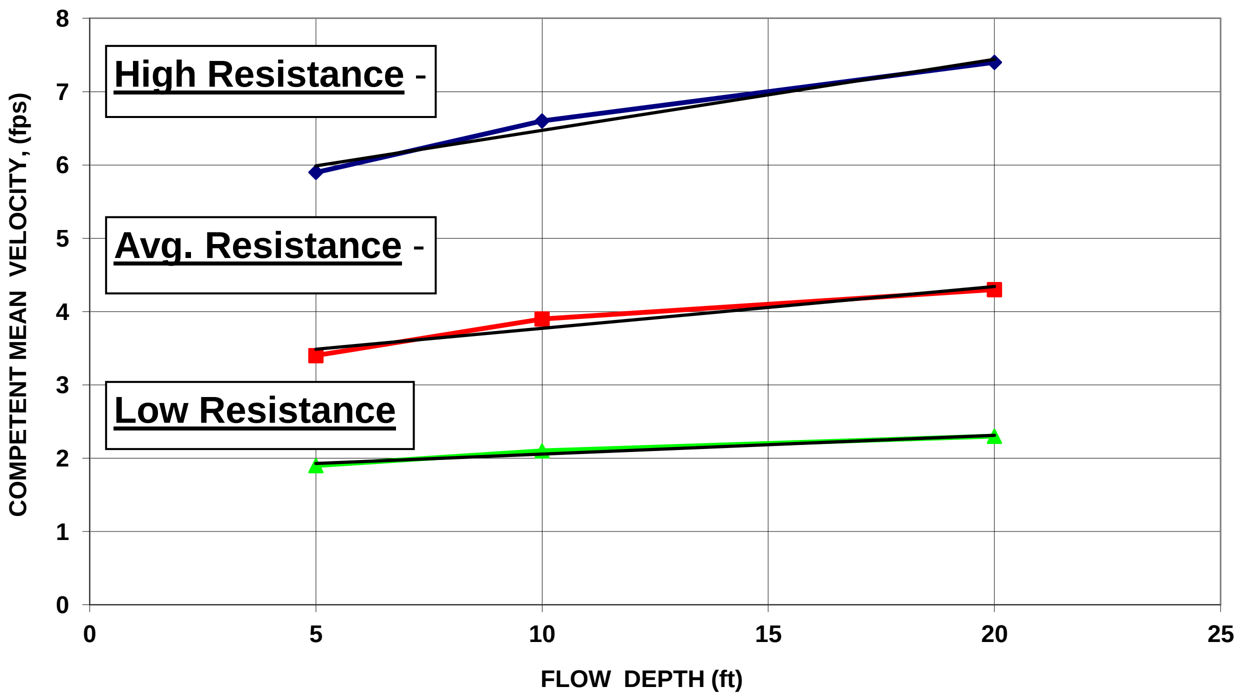
This table is used in the following manner. The user reviews the site conditions or descriptors which are present at the bridge site under consideration, and selects the factor in the table that best describes the crossing site under consideration. The engineer may select a higher safety factor if it is considered necessary to reflect a high risk crossing site.

Please note that the current scour evaluation procedure described in Chapter 11 of the Manual directly calculates the potential effects of both channel migration and degradation. This calculation serves to decrease the need for reliance on a safety factor to account for lateral channel movement and degradation.

ATTACHMENT 4
CRITICAL VELOCITIES IN COHESIVE SOILS

There are 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, OBD 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 there are two lines drawn close together for the top two curves representing two different soil types. The top line is comprised of straight lines drawn through the data points in Neill's table. The lower line is a curve mathematically fitted to the data points.
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 the EFA Apparatus in the SHA Soils Lab.



ATTACHMENT 5
ESTIMATING CONTRACTION AND ABUTMENT SCOUR AT BRIDGES CROSSING LARGE SWAMPS AND WETLANDS. (NON-TIDAL COASTAL PLAIN OF SOUTH CAROLINA)

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 plain in South Carolina. Accordingly, an alternative approach to estimating scour for such sites, based on the U.S Geological Survey's studies (Reference 13), is proposed below. We anticipate that such crossing sites will not be common in Maryland. The characteristics of the South Carolina Streams, excerpted from the USGS Report, are depicted below:

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.

The significant factor in this table for the Coastal Plain is that, for the most part contraction and abutment scour at bridges crossing these wetlands and swamps is small, with some notable exceptions.

Procedures for Estimating Contraction and Abutment Scour in swamp-wetland areas with characteristic similar to that of the (non-tidal) Coastal Plain of South Carolina (T1)

Design Procedure No. 1: USGS Envelope Curve

Applicability

This procedure is recommended only for bridges crossing wetlands and swamps with characteristics similar to those presented in Table 1 for a (non-tidal) Coastal Plain

The USGS envelope curve depicted above is an empirical method which reports the results of their field investigation of the wetland areas in the South Carolina (Non-tidal) Coastal Zone. The method should be viewed as a tool to assist the engineer in applying engineering judgment.

There is a prescribed method for applying the clear-water abutment-scour envelope curves (See the report section, "Guidance for assessing abutment-scour depth using the envelop curves" on page 91 of Benedict, 2003). In order to properly apply the curves it is important that the engineer develop some understanding of the data and its limitations. To do this, the engineer should become familiar with the content of the USGS reports For the application of clear-water abutment-scour envelope curves the engineer should refer to Benedict (2003) and for the clear-water contraction-scour envelope curves he should refer both Benedict (2003) and Benedict and Caldwell (2006). Both are available on line at the links below:

Benedict, S.T., 2003, Clear-water abutment and contraction scour in the Coastal Plain and Piedmont Provinces of South Carolina, 1996-99: U.S. Geological Survey Water Resources Investigation Report 03-4064, 137p.
http://pubs.usgs.gov/wri/wri034064/

Benedict, S.T. and Caldwell, A.W., 2006, Development and Evaluation of Clear-Water Pier and Contraction Scour Envelope Curves in the Coastal Plain and Piedmont Provinces of South Carolina: U.S. Geological Survey SIR 2005-5289, 112 p.
http://pubs.usgs.gov/sir/2005/5289/

Selection of Scour Parameters

The USGS study will be used to identify those sites where measurements of abutment scour values were high. They key factors in identifying locations with potentially large abutment scour depths are discussed below:

1. Geometric-Contraction Ratio (m), is defined as:

$m = 1 - b/B$

Where b = bridge opening width, and B = approach flow width.

As an example, if a bridge opening (b) is 150 feet and the approach flow width is 1500 feet, m = 1- 150/1500 = 0.9; Conversely, if the bridge opening is 1200 feet and the approach flow width is 1500 feet, m = 1-1200/1500 = 0.2. Therefore, if the value of m is large, this is an indication of contracted flow with resulting high velocities and scour. If the value of m is small, this is an indication of little change to velocities at the bridge and resulting low values of scour.

<u>2. Contraction Scour</u>
The maximum contraction scour observed at the 42 measured sites was 3.9 feet. For design purposes, a contraction scour value of 5 feet will be used in this assessment process.

<u>3. ABSCOUR Abutment scour</u>
For streams with low approach velocities, as occurs in wetlands, the ABSCOUR amplification factor is typically 1.4. (The amplification factor is multiplied by the contraction scour to obtain the abutment scour.) For a contraction scour value of 5 feet, the corresponding abutment scour value is: 5ft. x 1.4 = 7 feet. This value will serve as the minimum abutment scour value

<u>4. USGS Envelope Curve of All Abutment Scour Measurements in the Coastal Plain.</u>

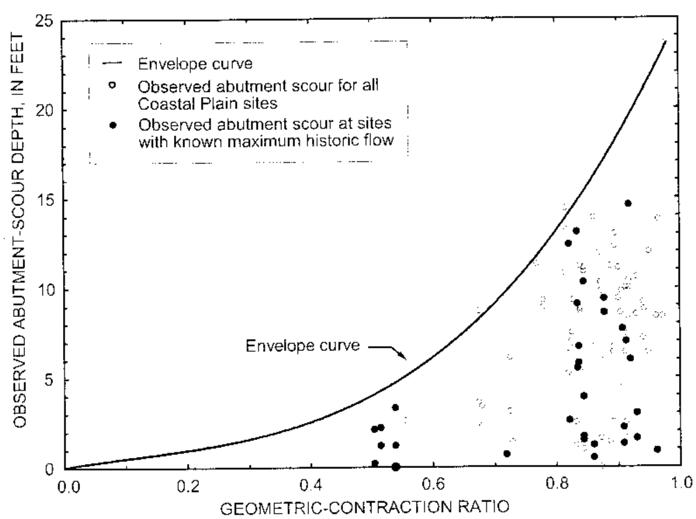


Figure 76. Relation of observed clear-water abutment-scour depth and the 100-year-flow geometric-contraction ratio identifying sites with known maximum historic flows in the Coastal Plain of South Carolina.

The USGS Envelope Curve (Figure 76) plots all of the measured abutment scour depths in the Coastal Plain Vs the geometric-contraction ratio associated with the bridge site where the measurements were taken.

CONTRACTION SCOUR: Use a value of 5 feet

ABUTMENT SCOUR:
1. Measure the geometric- contraction ratio (m) for the bridge site:

$m = 1 - b/B$

Where b = bridge opening width, and B = approach flow width.
Note: for overtopping flows, use only that portion of the approach flow width that actually goes through the bridge.

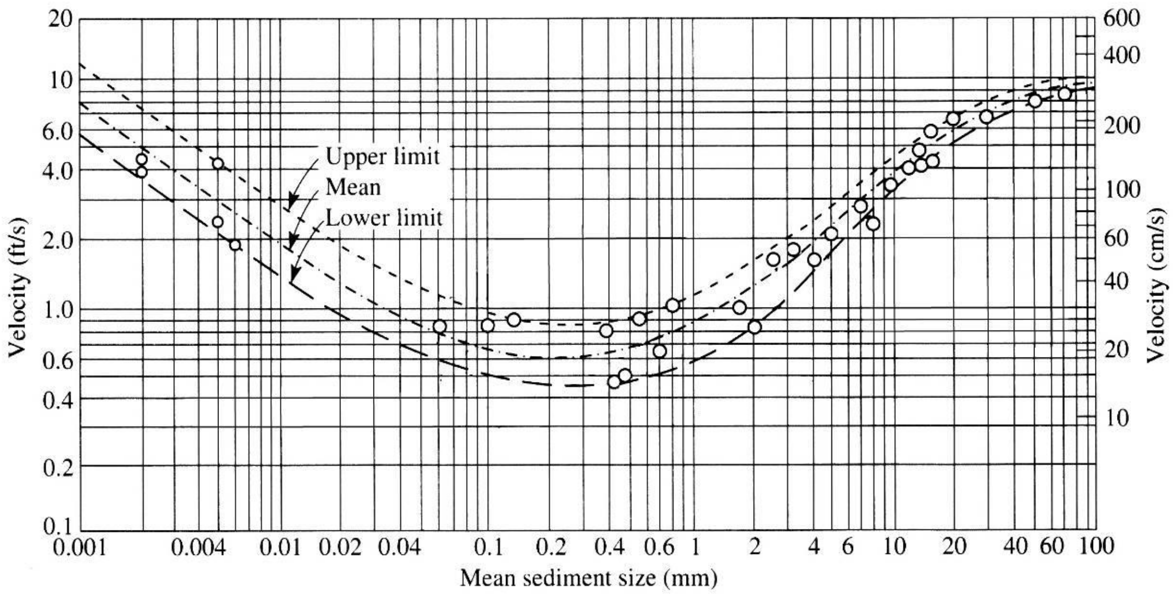
2. Read the Observed Abutment Scour Depth from the Envelope Curve in Figure 76
   - Use a minimum abutment scour depth of 7 feet
   - Use a maximum abutment scour depth of 15 feet

Design Procedure No. 2 – Using the Vanoni Upper Limit Curve for Estimating Threshold (Critical) Velocities for Clear-Water Abutment Scour

The following guidance is excerpted from the studies by Stephen Benedict of clear-water abutment scour at bridges in the (non-tidal) Coastal Plain of South Carolina (Ref. 12):
"*For the low gradient streams and sandy soils of the Coastal Plain, the Fortier and Scobey (8), Laursen (9), and Neill (10) methods have a significant number of under predictions particularly with respect to abutment scour. This trend is undesirable for design and assessment purposes, making them a poor method for application at such streams. In contrast, the Vanoni (7) upper limit curve has a significantly lower number of under predictions but with over predictions that are at times excessive. None of these methods perform in an ideal way for the lower gradient streams and sandy soils of the Coastal Plain, but the Vanoni (7) upper curve performs the best with regard to limiting significant under prediction.*"

<u>Application:</u>
1. This procedure is recommended only for bridges crossing wetlands and swamps with characteristics similar to those presented in Table 1 for a (non-tidal) Coastal Plain
2. For the abutment under consideration, estimate the D50 particle size of the soil at the expected depth of scour. (This may involve several attempts to correlate the scour depth with the appropriate layer of soil)
3. Select the corresponding value of the critical velocity from the Vanoni <u>upper limit curve</u> in the plot below.
4. Use the over-ride feature in ABSCOUR 9 to enter the critical velocity of the soil at the abutment, and compute the abutment scour for the selected condition.

Discussion: There may be a significant difference between the abutment scour estimates determined from Design Procedures 1 and 2. Use engineering judgment to select the most appropriate scour depth for the given conditions.



Design Procedure No. 2 – Using the Vanoni Upper Limit Curve for Estimating Threshold (Critical) Velocities for Clear-Water Abutment Scour

OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX B

TIDEROUT2

USERS MANUAL

MAY 2015

TABLE OF CONTENTS

Preface

TIDEROUT 2, Build 1.22.4 dated April 2015 is the current version of this program and all previous versions should be discarded. 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 TIDEROUT 2 Users Manual has been carefully researched and evaluated. It is periodically 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.

TIDEROUT 2 is a flood routing program. Its primary purpose is to serve to estimate scour at bridges in tidal waterways. It can be used to route riverine flows from an upland watershed down to the tidal basin and then route the combined riverine/tidal flow through the bridge (and perhaps over the road) down to the sea:

- Basic equation: Inflow – Outflow = Storage
- Bridge flow+roadway overtopping flow = tidal flow + riverine flow

Many newly designed tidal bridges span wetlands and do not constrict tidal flow so as to cause significant contraction scour. Contraction scour may be more of a problem with older structures that do constrict the waterway area.

Please refer to the Introduction to this Appendix for a discussion of the advantages of using both the Tiderout 2 and the HEC-RAS program for determining the worst-case conditions for scour

The advantages of the TIDEROUT program include:

1. Takes into account conditions of unsteady tidal flow
2. Evaluates potential benefits of storage in the tidal basin upstream of structure
3. Provides a means of combining riverine and tidal flow hydrographs to estimate the worst case scour condition
4. The user can very quickly change input parameters to do sensitivity testing of reasonable combinations of storm tides, riverine flow, wind conditions, etc. to find the worst case scour.

The limitations of the TIDEROUT 2 program include:

1. Method does not address other aspects of tidal flow such as littoral drift or movement of sediment through the tidal basin.
2. Method cannot be used for complex tidal currents resulting from flows between islands where wind forces predominate
3. User needs to separately compute contraction and local abutment scour
4. User needs to import TIDEROUT2 output into ABSCOUR to compute pier scour.

Introduction

Chapter 10, Appendix A, Hydraulics of Tidal Bridges, provides a comprehensive discussion of various aspects of the hydraulic design of tidal bridges. The user of the TIDEROUT 2 program is encouraged to become familiar with the guidance in Chapter 10, Appendix A before conducting a tidal analysis at a bridge. The user needs to recognize that unsteady tidal flow is complex, and that TIDEROUT 2 provides for simple hydraulic and scour models to evaluate it. Nevertheless the program can be used effectively in the design of structure foundations to evaluate and determine worst-case scour conditions.

Tide Models

The Office of Structures currently uses TIDEROUT 2 and HEC-RAS to analyze tidal flow at a bridge. Two dimensional flow models are useful for evaluating flow in large estuaries, but are not considered necessary for the typical SHA tidal crossing. The SHA guidance is geared towards tidal areas tributary to the Chesapeake Bay. Special studies may be necessary for estuaries discharging directly to the ocean. The following guidance is provided with regard to selection of a tidal model for Chesapeake Bay estuaries. Most likely, a typical bridge site will not exhibit the clear-cut categories listed below and judgment will be needed to select the most appropriate model. It may be helpful to use both models, compare the results and then select the most appropriate results.

	TIDEROUT 2	HEC-RAS
Tidal crossing in close proximity to the bay (Tide elevations control downstream tailwater elevations)	X	
Tidal crossing at a considerable distance from the outlet to the bay. (Downstream tailwater controlled by normal depth (Manning) considerations		X
Small riverine discharge; tidal flow predominates	X	
Large upland drainage basin, riverine discharge predominates		X

Boundary Conditions for TIDEROUT 2

During a major storm such as a hurricane, there are two different events that need to be considered in evaluating flow through a tidal bridge and the resulting scour at the foundations. One event is the discharge through the bridge caused by the storm tide, and the other related event is the riverine discharge through the bridge caused by the heavy rains on the upland drainage basin. The peak discharges from these two events may or may not occur at the same time .There is no standard or “correct” way of evaluating these flows, since each tidal bridge will present a different set of conditions to consider. However, the Office of Structures recommends that the following procedure be followed as a guide in deciding how to combine the upland riverine flow with the storm tide flow. A preliminary meeting with the Office of Structures is recommended to discuss the tidal conditions. The results of this approach also need to be discussed with the Office of Structures to determine whether the computed discharges are reasonable. If an alternative scenario is determined to offer a better approach, the alternative method should be discussed with the Office of Structures prior to the commencement of the tidal study.

Combining Riverine And Storm Tide Discharges

100 -Year Combined Riverine And Storm Tide Discharges

It has been the experience of the Office of Structures that determining the relative timing of the occurrence of the peak riverine flow with the timing of the peak tidal surge is not subject to a rigorous analysis. Many factors can influence the way in which these two peak flows will develop to form the peak flow conditions at the bridge.. The following guidance is based on previous studies conducted by the office of Structures. However, it may not be appropriate for all tidal crossings..

Estimate the 10-year and 100-year riverine hydrographs from the upland drainage basin. Use the TR-20 dimensionless hydrograph in TIDEROUT 2 for drainage areas under 25 square miles. If the drainage area is over 25 square miles, follow the guidance in Chapter 8 for computing the TR-20 hydrograph. For drainage areas greater than 300 square miles, use the U.S. Geological Survey (USGS) dimensionless hydrograph described in USGS Water-Resources Investigations Report 97-4279. The use of this approach should be discussed with the Office of Structures prior to the commencement of the tidal study.

1. If the drainage area for the 100-year riverine hydrograph is less than 25 square miles, assume that the peak riverine discharge and the peak storm surge elevation occur at the same time (match the peaks of the hydrographs).

2. If the time of concentration of the 100-year riverine hydrograph is more than 24 hours, treat the storm tide and riverine flood as independent events. To evaluate the effects of the 100-year riverine hydrograph separately, use a tidal hydrograph with a tidal period of 24 hours and an average tidal condition having a range between mean lower low water and mean higher high water. (This essentially provides a low tailwater condition for evaluating scour at the bridge.)

3. If (1) the drainage area is over 25 square miles, and (2) the time of concentration of the riverine hydrograph is less than 24 hours, then compute the riverine discharge as a constant discharge. The recommended approach for the TIDEROUT 2 analysis is to start the routing procedure for the combined riverine and tidal flows assuming the tidal basin

is full. For this condition, use a constant riverine discharge equal to the 10-year peak discharge (cfs)

<u>500-Year Combined Riverine And Storm Tide Discharges</u>

Estimate the 2-year and 500-year riverine hydrographs from the upland drainage basin. (Also estimate the 10-year hydrograph if not already computed for the 100-year combined riverine and storm tide discharge). Use the SCS dimensionless hydrograph in TIDEROUT 2 for drainage areas under 25 square miles. If the drainage area is over 25 square miles, follow the guidance in Chapter 8 for computing the TR-20 hydrograph. For drainage areas greater than 300 square miles, use the U.S. Geological Survey (USGS) dimensionless hydrograph described in USGS Water-Resources Investigations Report 97-4279. The use of this approach should be discussed with the Office of Structures prior to the commencement of the tidal study.

1. If the drainage area for the 500-year riverine hydrograph is less than 25 square miles, use TIDEROUT 2 to compute the flow of the 500-year tidal storm surge through the bridge. Use a constant discharge value for the riverine flow equal to the 10-year peak discharge.

4. If the time of concentration of the 500-year riverine hydrograph is more than 24 hours treat the storm tide and riverine flood as independent events. To evaluate the 500-year riverine hydrograph separately, use a tidal hydrograph with a tidal period of 24 hours and an average tidal condition having a range between mean lower low water and mean higher high water. This essentially provides a low tailwater condition for evaluating scour at the bridge.)

2. If (1) the drainage area is over 25 square miles, and (2) the time of concentration of the riverine hydrograph is less than 24 hours, then evaluate the 500-year tidal storm surge and compute the riverine discharge as a constant discharge equal in value to the 2-year peak discharge.

Other Considerations

Tidal flow is complex, especially if a combination of riverine and tidal discharges is to be used in the analysis:

- In low-lying tidal basins (particularly on the Eastern shore) the tidal basin boundary elevations may be at four feet or less while the storm tide elevations may be at six feet or more. Careful analysis is needed to decide the proportion of the flows going through the bridge, over the road, and across the drainage divide to other watersheds.

- FEMA maps which are commonly used to define peak storm tide elevations are based on the NGVD datum of 1929 while SHA current project mapping is based on NAVD datum of 1988. The user will need to convert tidal data from the NGVD datum to NAVD datum when using the program (See Chapter 10, Appendix A)

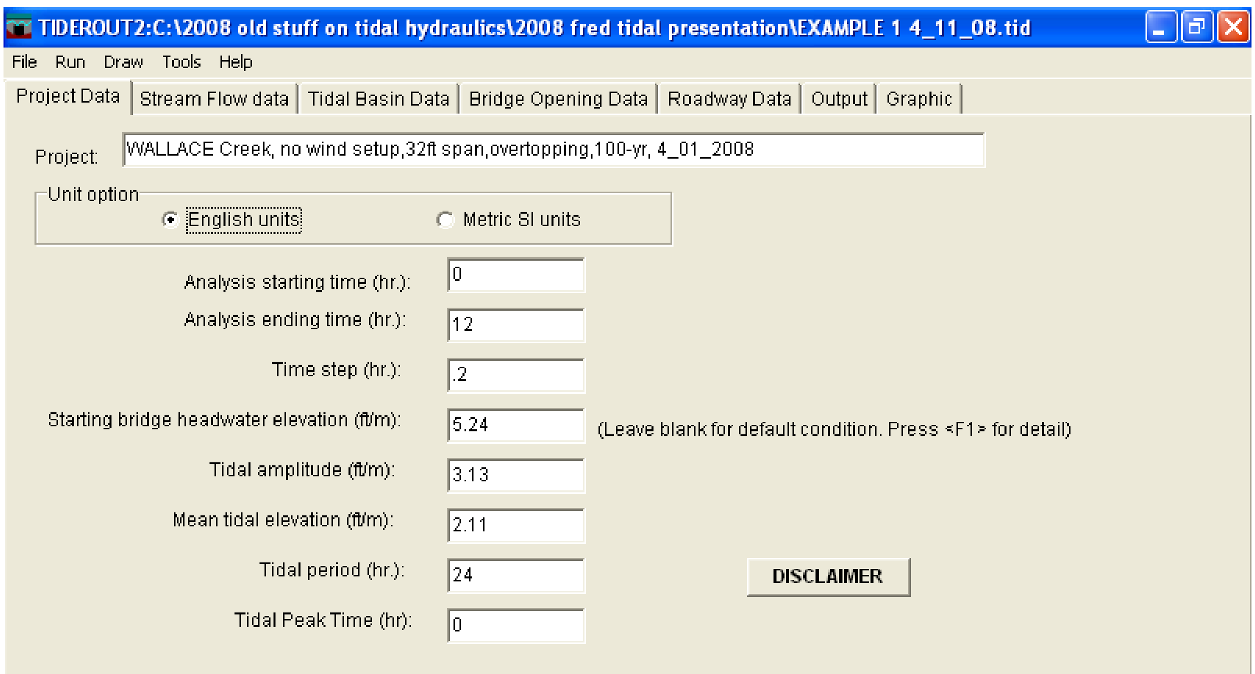
- Various other factors, such as the wind, may influence the flow through the bridge. Please refer to Chapter 10, Appendix A for a discussion of these factors.

- The Office of Structures in currently evaluating the feasibility of constructing a scour module for TIDEROUT 2 that would compute contraction scour on a step by step basis. This approach should add to the accuracy of the estimated scour computed for tidal bridges.

<u>Input Data for TIDEROUT 2</u>

Typical input values are described below. (Tidal elevations for use in the analysis will depend on the location of the structure and other factors.) The user may wish to select other values depending on the issues to be addressed.

PROJECT DATA



TIDEROUT 2 opens to the Project Data Card. This card has the following characteristics:

1. TOOL BAR

- File – File management including accessing and saving TIDEROUT 2 files.
- Run – Run the program
- Draw- Draws a schematic of the output results

- Tools – Utility tools for quick calculations
- Help – Help menus to answer questions about the program
- F-1 (Short Help) – Help for any input window can be obtained by placing the cursor in the input field (window) and clicking on the F1 Key

2. TAB BARS

A. PROJECT DATA

- Project: Describe the highway and the estuary being crossed; include information on particular aspects of the study i.e. flood discharges, referenced tidal station, etc.

- Unit option: SHA prefers English units

- Analysis starting time: For the Chesapeake Bay the storm tide period is assumed to be 24 hours. Typically, the worst case scour is expected to occur during the 12 hour ebb tide period starting when the tidal basin is full (high tide) and at the elevation of the design storm tide (time 0 hours) and ending when the basin has emptied (time 12 hours)

- Analysis ending time 12 at low tide

- Time step – See F1

- Starting bridge headwater elevation – High tide elevation of the design storm tide or See F1 guidance

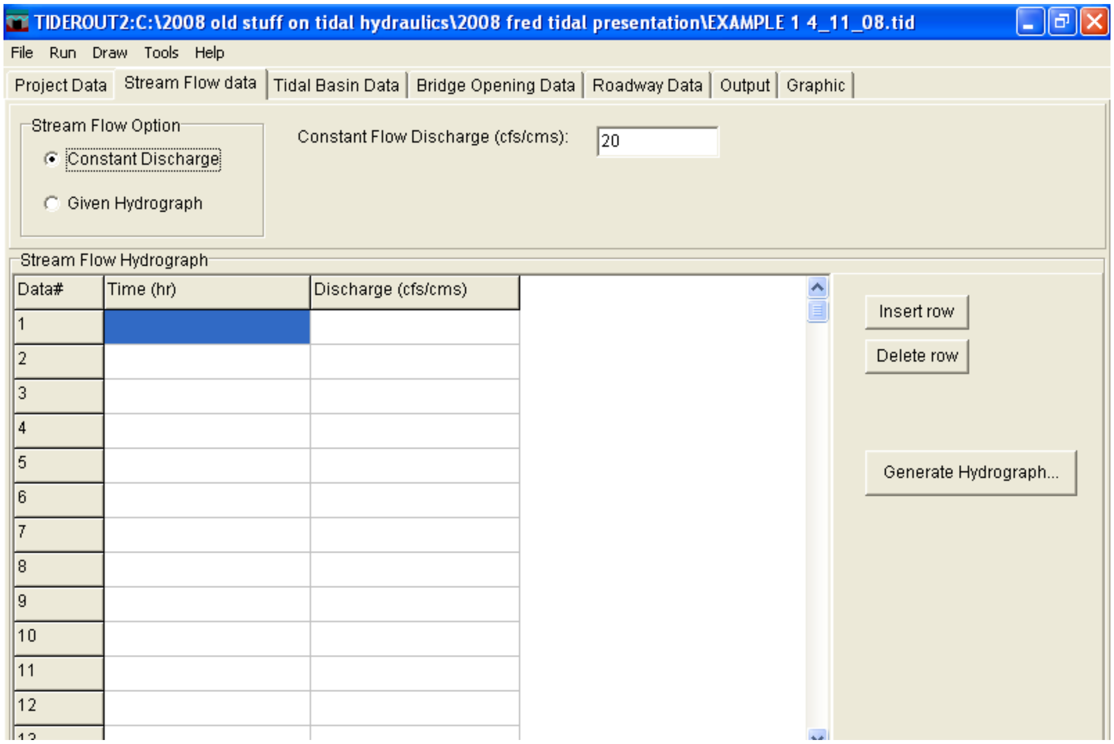
- Tide amplitude – See F1

- Tidal period – Default value is 24 hours

- Tidal peak time (hrs) is Zero

Please click on and read the Disclaimer button

STREAM FLOW DATA



STREAM FLOW OPTION: The User has two options with regard to stream flow data. The objective is to get a conservative, yet reasonable, model combining tidal flow and riverine (stream) flow that includes the peak tidal flow and the peak riverine flow.

- Given Hydrograph: A conservative approach would be to arrange the time of a riverine hydrograph to peak at the same time as the tidal hydrograph peaks (usually time zero). Judgment is needed to decide whether it is reasonable to assume that the time of concentration of the riverine hydrograph will coincide with the peak tidal hydrograph.

- Constant Discharge: A second option is to convert the riverine hydrograph to a hydrograph with a constant discharge. The height (discharge) of this rectangular hydrograph is determined by dividing the total area (runoff volume) under the hydrograph by the length of the hydrograph base. This approach has the advantage of combining tidal and riverine flows when the relative timing of peak flows is problematical.

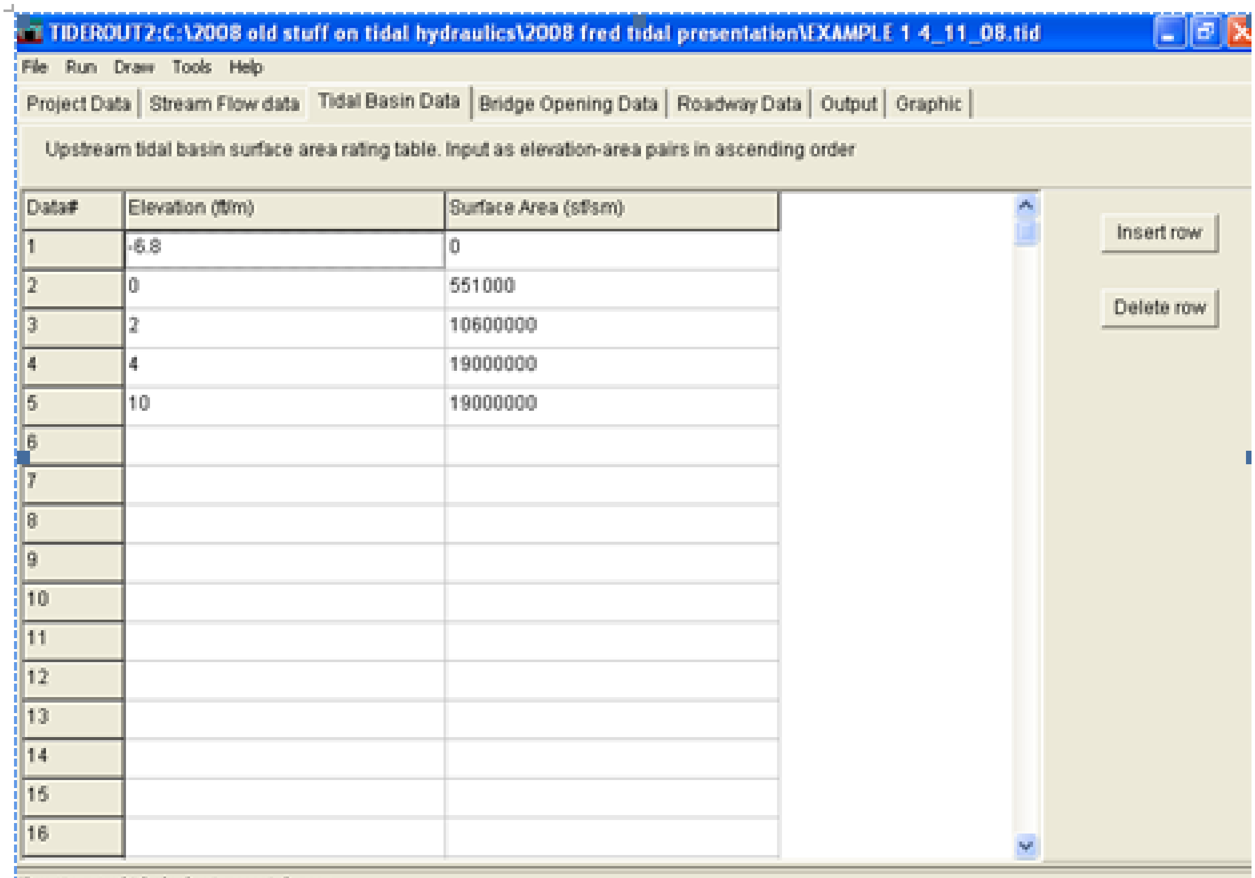
CONSTANT FLOW DISCHARGE: If the constant discharge option is selected, input the value of the computed constant flow discharge; otherwise leave this field blank.
STREAM FLOW HYDROGRAPH:

If the stream flow hydrograph option is selected, there are two ways of inputting the data:

- If a hydrograph has already been developed as a part of a project study, it can be manually input here

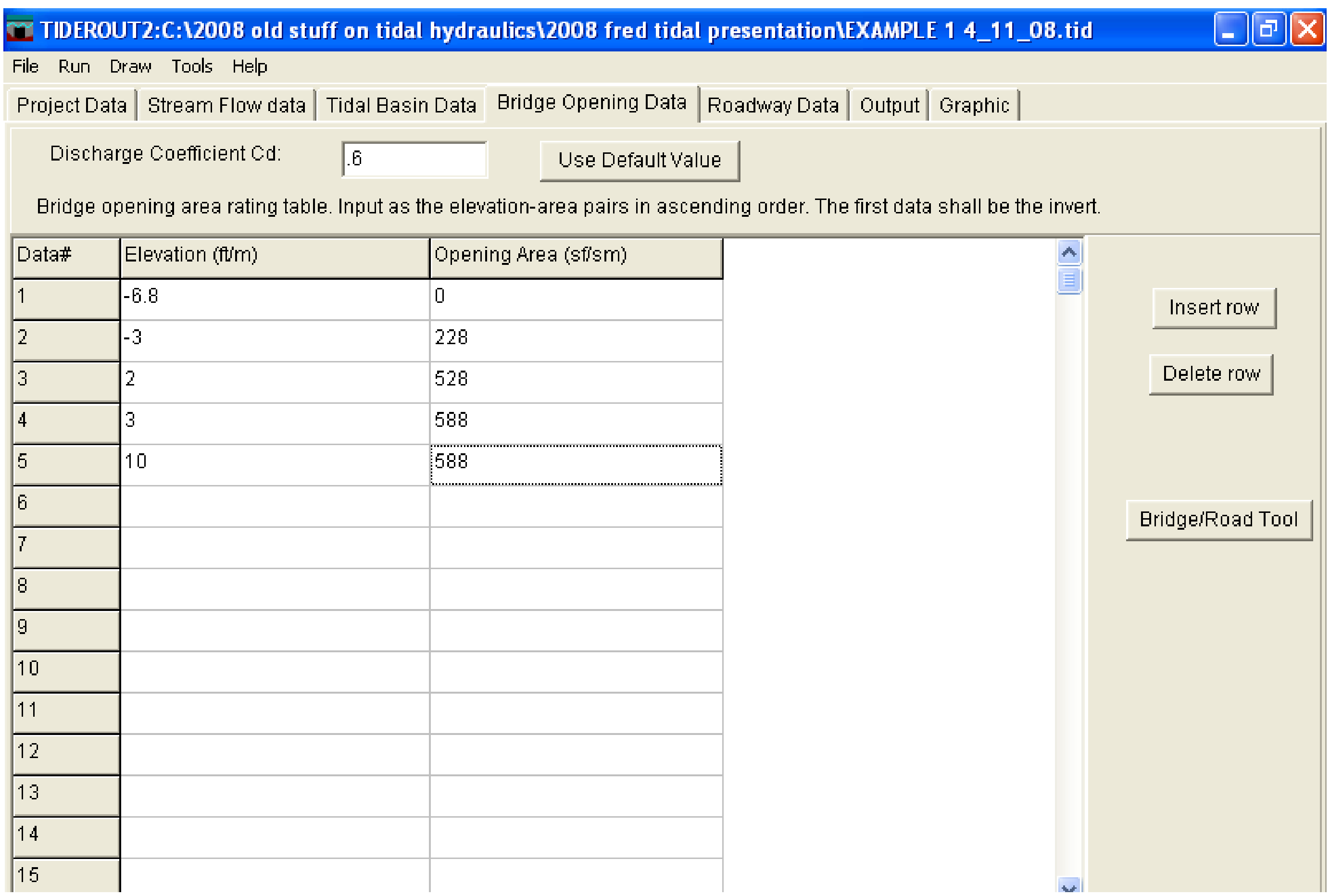
- The user can also click on the generate hydrograph button to obtain a TR-20 single area model. A window is presented to input the hydrograph characteristics. We note that the TR-20 peak factor constant is 484 for all of the physiographic regions in Maryland except for the Eastern Shore which is 284. The time step selected in normally 0.1 to 0.2 hours to be consistent with the tidal hydrograph.
- The user can “shift” the stream inflow hydrograph so that the peak riverine discharge coincides with the peak tidal flow elevation at time zero, or with any other tidal flow elevation or discharge. For example, assume that the time of concentration of the riverine hydrograph peak occurs at time 19 hours and the user desires to shift the hydrograph so that this peak occurs at time zero for the tidal hydrograph. This is accomplished in the following manner: (1) compute the hydrograph and then (2) adjust the hydrograph time/discharge pairs for each time unit to shift the hydrograph peak to the desired time. In the example presented above, the hydrograph would need to start at time -19 hours so that the peak flow would occur at time zero.

TIDE BASIN DATA



The user creates a storage area rating table for the tidal basin upstream of the bridge using the Tidal Basin card. Beginning with the elevation of the channel bottom at the bridge (usually a negative value below zero), the information is provided as a set of elevation-area pairs. The areas corresponding to the elevations can be obtained by measuring the areas between successive contour lines (See F-1 help). The upper limit of the rating table should be selected as an elevation above the design storm tide elevation. The area contained within a given contour line can be measured with a planimeter or can be computed using appropriate software (i.e. GIS Systems, CADD Programs, topographic digital elevation models, etc.)

BRIDGE WATERWAY OPENING DATA


TIDEROUT2:C:\2008 old stuff on tidal hydraulics\2008 fred tidal presentation\EXAMPLE 1 4_11_08.tid

File Run Draw Tools Help

Project Data | Stream Flow data | Tidal Basin Data | Bridge Opening Data | Roadway Data | Output | Graphic

Discharge Coefficient Cd: .6 [Use Default Value]

Bridge opening area rating table. Input as the elevation-area pairs in ascending order. The first data shall be the invert.

Data#	Elevation (ft/m)	Opening Area (sf/sm)
1	-6.8	0
2	-3	228
3	2	528
4	3	588
5	10	588
6		
7		
8		
9		
10		
11		
12		
13		
14		
15		

Insert row

Delete row

Bridge/Road Tool

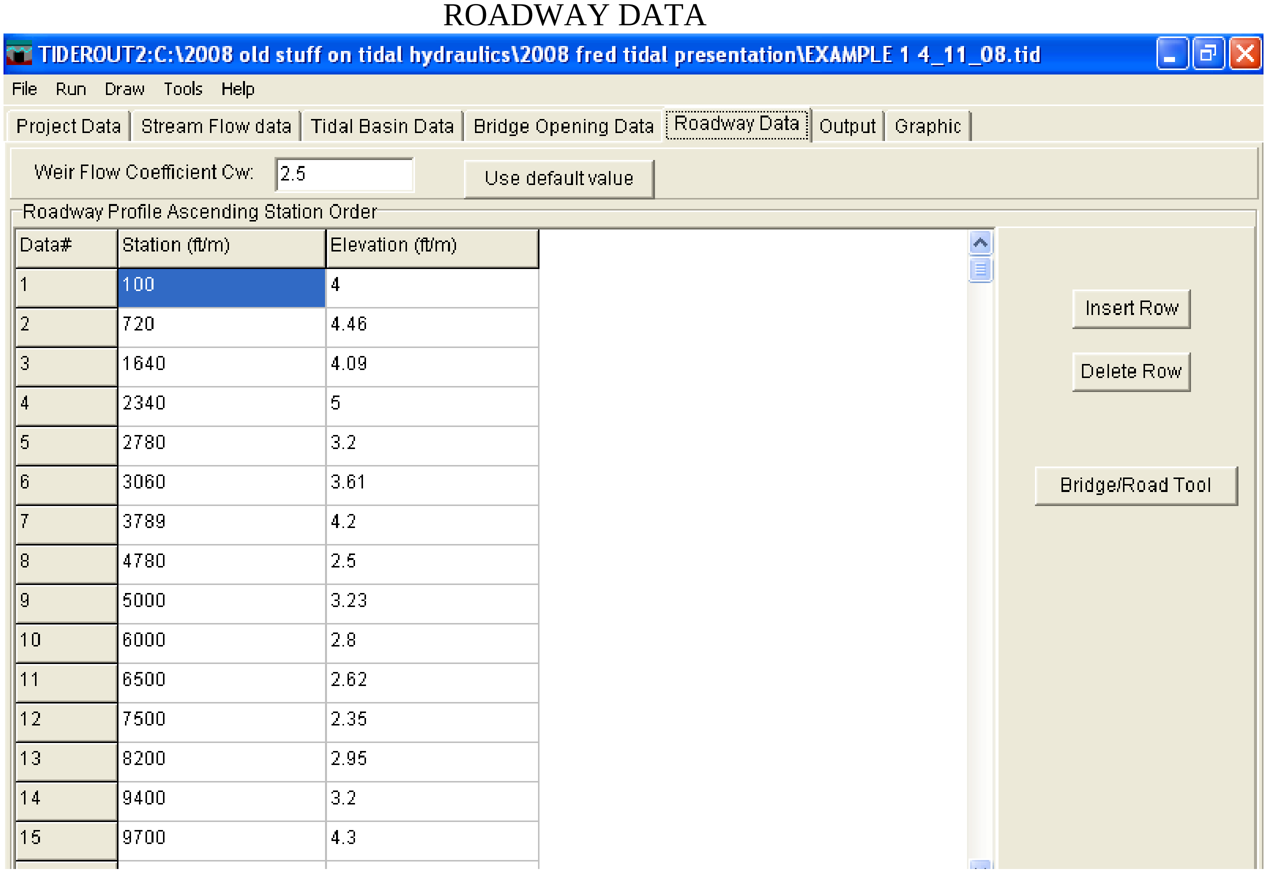
Discharge Coefficient:

Refer to F-1 Help. For l bridges, the default value has been selected as 0.80. For larger bridges, particularly those with streamlined abutments, a higher value may be appropriate.

Bridge Waterway Area Opening Rating Table.

The waterway area rating table is provided by the user as a set of elevation vs. waterway area pairs. See F-1 Help. The waterway area for various water surface elevations can be measured from the bridge plans.

ROADWAY DATA



Weir Flow Coefficient: See F-1 Help

Roadway Profile Ascending Station Order: See F-1 Help.

Boundary Conditions: This roadway data card represents a very important boundary condition for evaluating tidal flow through the bridge. For many Eastern Shore bridges, roadway elevations will be below storm tide elevations, and a large quantity of the tidal prism will flow over the road instead of through the bridge. Similarly, if the watershed boundaries for the tidal basin are lower than the peak storm tide elevations, it may not be possible to estimate the peak tidal flows through the bridge. For this condition the recommended approach is to input an extended roadway length at the watershed overtopping elevation. This will serve to define the flows through the bridge as those flows below the elevation of the watershed divide.

Program Output

The output consists of two parts: (1) a summary of the information input to the program by the user and (2) a time sequence of the changing hydraulic characteristic of the flow during passage of the selected tide and riverine hydrographs.

OUTPUT PRINTOUT
PART 1 – SUMMARY OF USER INPUT

Bridge Opening Data:
Discharge Coefficient: .6
Bridge Opening Area rating Table:

Data#	Elevation (ft)	Area (sf)
1	-6.8	0
2	-3	228
3	2	528
4	3	588
5	10	588

Roadway Data:
Weir Flow Coefficient For Overtopping Flow: 2.5
Roadway Profile:

Data#	Station (ft)	Elevation (ft)
1	100	4
2	720	4.46
3	1640	4.09
4	2340	5
5	2780	3.2
6	3060	3.61
7	3789	4.2
8	4780	2.5
9	5000	3.23
10	6000	2.8
11	6500	2.62
12	7500	2.35
13	8200	2.95
14	9400	3.2
15	9700	4.3

OUTPUT PRINTOUT
PART 2 – TIDEROUT COMPUTATIONS

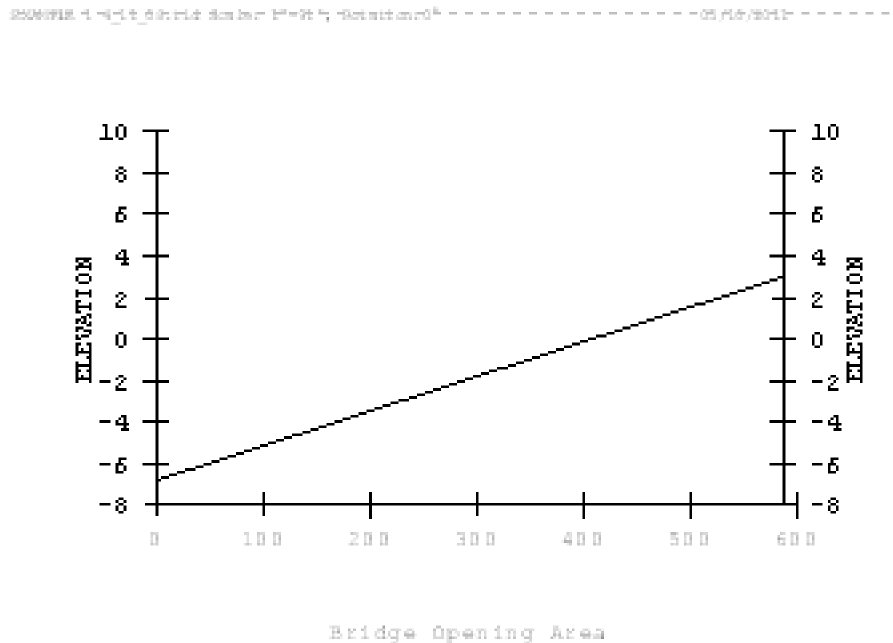
Note: Remark show critical depth for critical flow, with # indicates fail to converge after 100 cycles

Time (hrs)	Tide EL. (ft)	Basin EL. (ft)	Bridge Q av.(cfs)	Weir Q av.(cfs)	Bridge V (ft/s)	Basin Area (sf)	Flow Area av.(sf)	Remark/ dcr(ft)
0.00	5.240	5.240	0.00	0.00	0.000	19000000.0	588.00	
0.20	5.236	5.238	84.99	0.65	0.241	19000000.0	588.00	
0.40	5.223	5.231	195.32	7.88	0.554	19000000.0	588.00	
0.60	5.201	5.218	313.22	32.50	0.888	19000000.0	588.00	
0.80	5.172	5.200	424.62	80.96	1.204	19000000.0	588.00	
1.00	5.133	5.175	527.98	155.65	1.497	19000000.0	588.00	
1.20	5.087	5.142	622.54	255.15	1.765	19000000.0	588.00	
1.40	5.032	5.102	708.16	375.58	2.007	19000000.0	588.00	
1.60	4.969	5.053	785.19	511.95	2.226	19000000.0	588.00	
1.80	4.899	4.997	854.45	657.22	2.422	19000000.0	588.00	
2.00	4.821	4.932	916.93	807.70	2.599	19000000.0	588.00	
2.20	4.735	4.860	973.70	957.74	2.760	19000000.0	588.00	
2.40	4.642	4.780	1025.54	1109.41	2.907	19000000.0	588.00	
2.60	4.542	4.692	1073.00	1257.98	3.041	19000000.0	588.00	
2.80	4.436	4.597	1116.71	1403.00	3.165	19000000.0	588.00	
3.00	4.323	4.496	1158.01	1528.75	3.282	19000000.0	588.00	
3.20	4.204	4.391	1200.28	1609.98	3.402	19000000.0	588.00	
3.40	4.080	4.281	1246.07	1671.13	3.532	19000000.0	588.00	
3.60	3.950	4.168	1296.09	1708.24	3.674	19000000.0	588.00	
3.80	3.815	4.050	1347.54	1787.06	3.820	19000000.0	588.00	

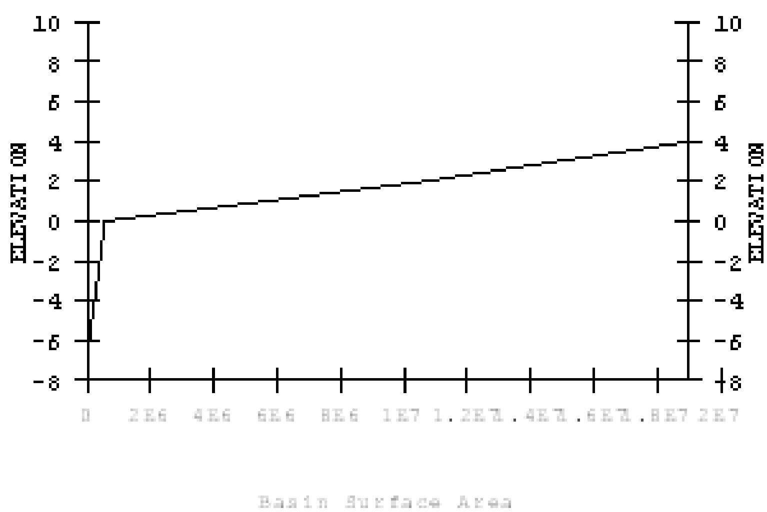
----------------------------------Page Break--

Time (hrs)	Tide EL. (ft)	Basin EL. (ft)	Bridge Q av.(cfs)	Weir Q av.(cfs)	Bridge V (ft/s)	Basin Area (sf)	Flow Area av.(sf)	Remark/ dcr(ft)
4.00	3.675	3.925	1394.72	1882.52	3.953	18686296.2	588.00	
4.20	3.531	3.794	1434.33	1943.29	4.066	18134795.2	588.00	
4.40	3.383	3.656	1465.68	1972.69	4.154	17555526.3	588.00	
4.60	3.232	3.512	1489.67	1973.55	4.222	16952047.7	588.00	
4.80	3.077	3.365	1508.84	1928.10	4.277	16331143.4	588.00	
5.00	2.920	3.221	1528.80	1693.63	4.351	15726982.5	585.60	
5.20	2.761	3.085	1556.27	1381.97	4.484	15155474.9	578.43	
5.40	2.600	2.952	1593.09	1158.37	4.668	14600292.9	568.81	
5.60	2.437	2.825	1638.35	916.68	4.884	14065443.3	559.10	
5.80	2.274	2.708	1695.81	572.10	5.145	13573553.9	549.33	
6.00	2.110	2.600	1765.81	257.25	5.455	13119712.2	539.51	
6.20	1.946	2.494	1836.93	84.84	5.780	12673790.4	529.69	
6.40	1.783	2.384	1897.47	11.47	6.083	12214771.7	519.87	
6.60	1.620	2.269	1941.85	0.00	6.345	11729334.9	510.10	
6.80	1.459	2.147	1969.09	0.00	6.559	11215577.7	500.39	
7.00	1.300	2.018	1980.62	0.00	6.726	10673862.0	490.77	
7.20	1.143	1.881	1977.36	0.00	6.848	10003454.7	481.28	
7.40	0.988	1.736	1959.11	0.00	6.919	9275724.7	471.93	
7.60	0.837	1.582	1925.33	0.00	6.934	8500203.5	462.76	
7.80	0.689	1.417	1875.13	0.00	6.887	7670142.0	453.78	
8.00	0.545	1.239	1806.58	0.00	6.766	6775297.2	445.02	
8.20	0.405	1.045	1715.94	0.00	6.552	5799489.0	436.51	
8.40	0.270	0.829	1595.84	0.00	6.210	4715126.3	428.27	
8.60	0.140	0.581	1430.26	0.00	5.671	3468251.1	420.31	
8.80	0.016	0.272	1173.16	0.00	4.738	1919726.7	412.68	
9.00	-0.103	-0.115	682.75	0.00	2.807	541655.6	405.37	
9.20	-0.216	-0.200	83.44	0.00	0.349	534779.3	398.42	
9.40	-0.322	-0.331	116.03	0.00	0.494	524198.4	391.84	

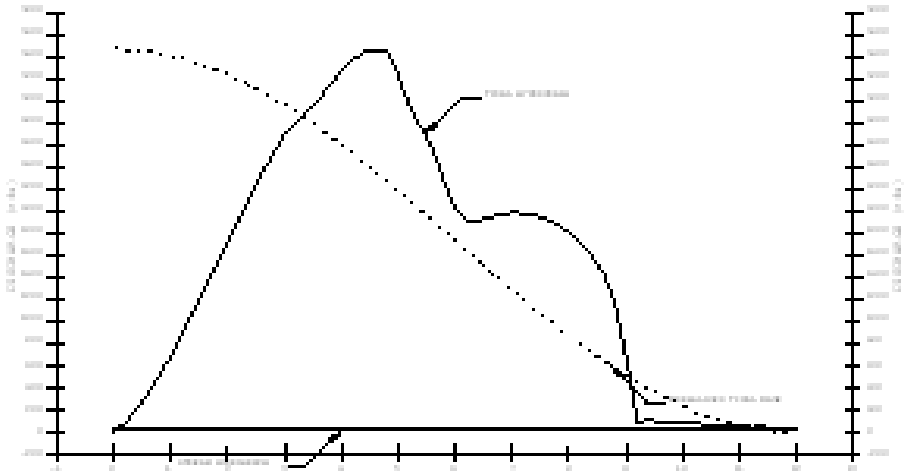
OUTPUT RESULTS – SKETCHES



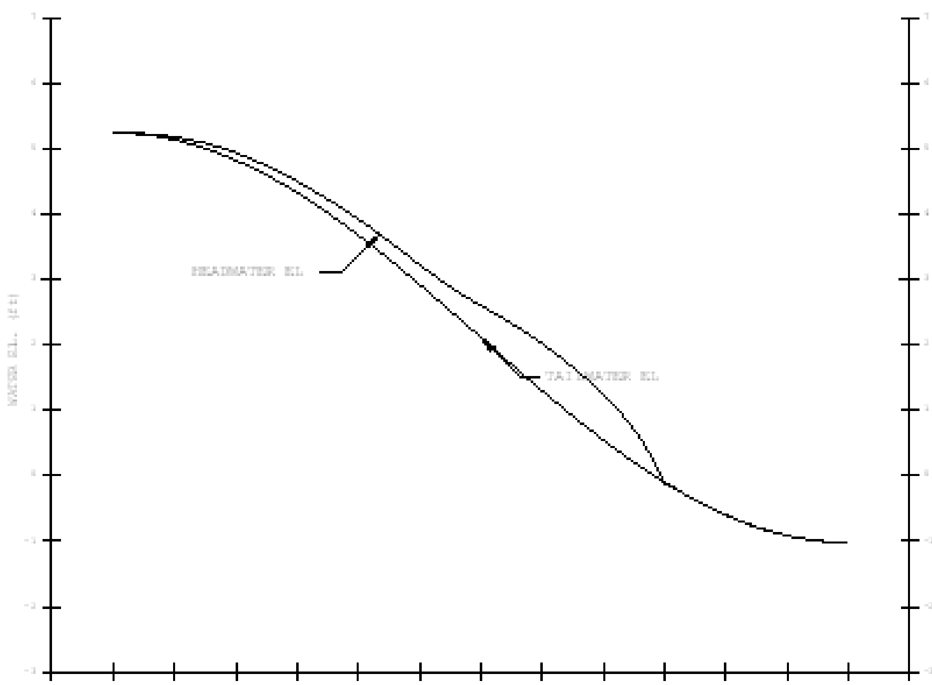
Elevation vs. Bridge Opening Area.



Elevation vs. Basin Surface Area



Tidal and Riverine Hydrographs
(For this case the user selected a riverine hydrograph
with a constant discharge)



Headwater-Tailwater Relationships at Bridge
(Note that the velocity of flow thorough the bridge is highest
When the head differential across the bridge is greatest)

<u>Evaluating Scour Computations At Tidal Bridges</u>

HEC-RAS TIDAL COMPUTATIONS.

Two flow conditions should be checked for each combination of riverine and storm tide discharges to be evaluated:

1. The riverine discharge with low tide elevation.

2. The combination of riverine and maximum storm tide discharges at mid-tide elevation.(Note that the maximum storm tide discharge can be estimated as:

$$Q_{max} = 3.14 \frac{VOL}{T}$$

   Where VOL = volume of water in the tidal prism between high and low tides,
   and T = tidal period (selected as 24 hours for the Chesapeake Bay)

3. The HEC-RAS results can be used as input to ABSCOUR 9 to develop an evaluation of scour at the bridge.

TIDEROUT SCOUR COMPUTATIONS

The clear water scour equation (Refer to the ABSCOUR 9 Users Manual in Chapter 11) is used to estimate scour from the TIDEROUT 2 output tables: A portion of the table depicting flow through the bridge vs. time is excerpted below:

Time (hrs)	Tide EL. (ft)	Basin EL. (ft)	Bridge Q av.(cfs)	Weir Q av.(cfs)	Bridge V (ft/s)	Basin Area (sf)	Flow Area av.(sf)	Remark/ dcr(ft)
4.00	3.675	3.925	1394.72	1882.52	3.953	18686296.2	588.00	
4.20	3.531	3.794	1434.33	1943.29	4.066	18134795.2	588.00	
4.40	3.383	3.656	1465.68	1972.69	4.154	17555526.3	588.00	
4.60	3.232	3.512	1489.67	1973.55	4.222	16952047.7	588.00	
4.80	3.077	3.365	1508.84	1928.10	4.277	16331143.4	588.00	
5.00	2.920	3.221	1528.80	1693.63	4.351	15726982.5	585.60	
5.20	2.761	3.085	1556.27	1381.97	4.484	15155474.9	578.43	
5.40	2.600	2.952	1593.09	1158.37	4.668	14600292.9	568.81	
5.60	2.437	2.825	1638.35	916.68	4.884	14065443.3	559.10	
5.80	2.274	2.708	1695.81	572.10	5.145	13573553.9	549.33	
6.00	2.110	2.600	1765.81	257.25	5.455	13119712.2	539.51	
6.20	1.946	2.494	1836.93	84.84	5.780	12673790.4	529.69	
6.40	1.783	2.384	1897.47	11.47	6.083	12214771.7	519.87	
6.60	1.620	2.269	1941.85	0.00	6.345	11729334.9	510.10	
6.80	1.459	2.147	1969.09	0.00	6.559	11215577.7	500.39	
7.00	1.300	2.018	1980.62	0.00	6.726	10673862.0	490.77	
7.20	1.143	1.881	1977.36	0.00	6.848	10003454.7	481.28	
7.40	0.988	1.736	1959.11	0.00	6.919	9275724.7	471.93	
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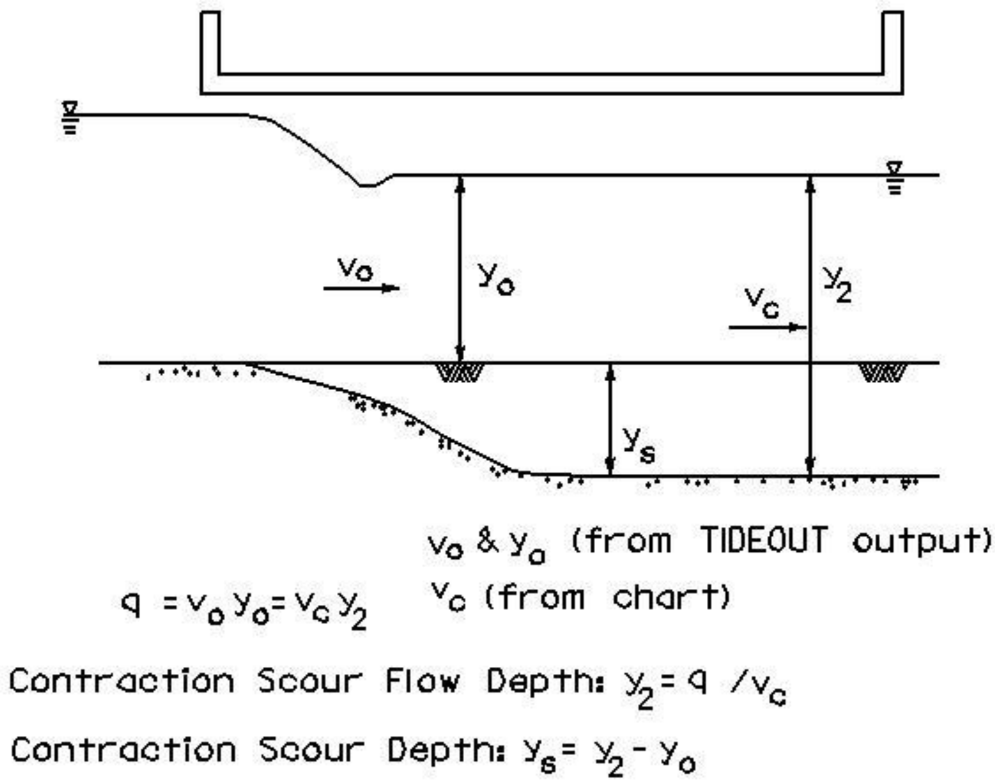
9.00	-0.103	-0.115	682.75	0.00	2.807	541655.6	405.37	
9.20	-0.216	-0.200	83.44	0.00	0.349	534779.3	398.42	
9.40	-0.322	-0.331	116.03	0.00	0.494	524198.4	391.84	

Please note that the highest flow velocity of 6.9 fps occurs at time 7.6 hours (underlined row above) when the downstream tide elevation is at an elevation of 0.84 feet. The channel bed elevation is at -6.8 feet, so the downstream flow depth is computed as 7.6 feet. Surface and subsurface (boring) samples indicate that the channel bed is comprised of a medium sand with a D50 of 0.0016 feet.

Clear Water Scour Equation



The values of vo (6.9 fps) and yo (7.6 feet) are known values obtained from the TIDEROUT output tables and the value of y_2 is the total scour depth we wish to calculate. This missing variable is Vc, the critical velocity of the sand which can be obtained from the chart below excerpted from the ABSCOUR 9 Users Manual

For a flow depth of 7.6 feet and a particle size of 0.0016, the critical velocity of the sand is estimated as 3.6 fps.

Solve the equation for y2 (total contraction flow depth including flow depth)

- **q = Vo*yo = Vc*y2; then**
- **y2 = q/Vc = (Vo/Vc) *yo = (6.9/ 3.7) * 7.6 = 14.2 ft**

Contraction scour depth ys = y2 – yo= 14.2 – 7.6 = 6.6 (say 7) feet

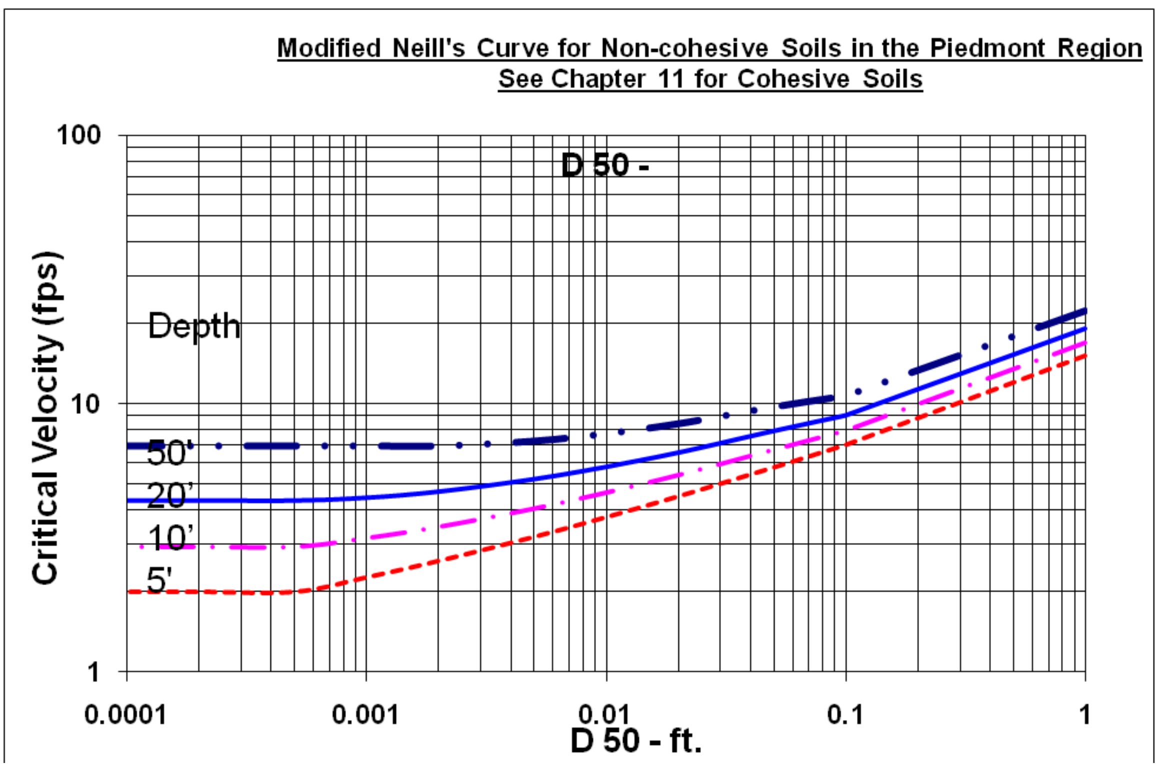
Total Abutment Scour Depth (y2a)

- **y2a ~ 1.4 * y2 = 1.4 * 14.2 = 19.9 ft**

6 Abutment scour (ysa)
ysa = y2a – yo = 19.9 -7.6 = 12 feet.

The estimates of 7 feet of contraction scour and 12 feet of abutment scour should be evaluated in the context of the Office of Structures policies in Chapter 11 to determine the appropriate design for the bridge abutments.

If the bridge foundations include a pier in the waterway, the above information can be input in the pier module in ABSCOUR 10 to compute the pier scour.



OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX C

ESTIMATING SCOUR IN BOTTOMLESS ARCH CULVERTS

MAY 2015

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CHAPTER 11 – EVALUATING SCOUR AT BRIDGES
APPENDIX C
ESTIMATING SCOUR IN BOTTOMLESS CULVERTS

1. INTRODUCTION

Bottomless arch culverts are considered one of many structural options available to a designer when developing solutions to a stream crossing of a highway. As with any option, there are a number of technical and practical factors which must be considered when implementing a structure design. Among these are geotechnical and foundation conditions, hydraulic and scour considerations, stream geomorphology, geometric and structural features, constructability, cost, etc. All of these factors are investigated in determining the most appropriate structure. There are times when a bottomless arch culvert may be feasible, but another structure type is selected for other overriding reasons. OOS does not predetermine the use of any specific type of structure, but determines the most appropriate structure type on a case-by-case basis. County and local bridge owners are encouraged to perform the same type of investigation for their structure projects, including consideration of bottomless arch culverts, if deemed appropriate and if the structures satisfactorily meet all needs of the particular project. Guidance regarding hydrologic, hydraulic, geomorphic and scour considerations are presented in various chapters of the Office of Structures Manual for Hydrologic and Hydraulic Design (8). Structural, geotechnical and other considerations are presented in various other directives of the SHA.

Safety to the traveling public is the primary concern in the selection of a structure. When Federal or State funds are used in the construction of bottomless culverts, the SHA requires that a scour report be prepared to demonstrate that the structure is stable for worst-case scour (8).

The purpose of this Appendix C of Chapter 11 is to present SHA policy regarding the objective of the scour evaluation (a stable structure for worst-case scour conditions) and to provide guidance on the considerations to be evaluated in reaching the design objective.

SHA policy and guidance regarding the scour evaluation of bottomless culverts is presented below. The ABSCOUR Program is the method selected by the SHA Office of Structures for evaluating scour in bottomless culverts (12). Further discussion of the procedures used in developing the design equations for the ABSCOUR Program is contained in Appendix A of Chapter 11 of the H&H Manual (8). Results from recent cooperative studies by the FHWA (Federal Highway Administration), Maryland SHA, Contech and Conspan (9) are used in the development of the design approach presented below.

2. POLICY

A. GENERAL

- Analyze bottomless arch culverts supported on footings for worst case scour conditions in accordance with SHA policy for bridges (Chapter 11, Policy Section). The scour report and other appropriate design studies need to document that the structure is stable for worst-case scour conditions, and needs to be submitted to the Office of Structures for approval.

- Evaluate the 100-year, 500-year and overtopping floods to determine the worst-case scour conditions.

- Prepare scour evaluations and reports in accordance with the provisions of Chapter 11 of the SHA Manual and the Bottomless Culvert module in the Maryland SHA Bridge Scour (ABSCOUR) Computer Program (12).

- Unstable channel conditions below the crossing site, such as headcutting, degradation, and channel migration, if not addressed at the design stage, are likely to have a future adverse effect on the stability of the structure. Do not apply the design procedure presented in this guideline to crossing locations experiencing downstream headcutting and degradation unless other measures to control the channel instability are provided.

B. FOOTINGS ON ROCK OR PILES

- Wherever practicable, place footings on scour resistant rock or on piles.
- Standard SHA geotechnical procedures are to be followed for taking and analyzing rock cores, and for designing foundations on rock or on piles.
- It is standard practice to consult with representatives of the SHA Office of Materials and Technology when evaluating the erodibility of rock.
- Please refer to the Policy Section in Chapter 11for guidance on foundation design.

C. FOOTINGS ON ERODIBLE SOIL

- See Section C-6, Design the Culvert Footing
- Please also refer to Chapter 11, Section 11.4 Policy, for additional guidance on foundation design.
- Riprap installations are to conform to the minimum D50 sizes and blanket thicknesses presented in Chapter 11, Appendix D of the Manual and in the ABSCOUR Program.

Site conditions can be expected to vary widely in Maryland, and there may be locations where judgment is needed in the interpretation and application of the above policy. Questions concerning the interpretation and application of SHA policy and guidance should be directed to Messrs Andrzej Kosicki (410 545-8340), or Lena Berenson (410 545-8354) of the Office of Structures.

3. DESIGN GUIDELINES

A. INTRODUCTION

The design guidance in this section applies to typical stream crossings with low to moderate flow velocities in the culvert. Additional design features and analyses may be warranted to assure the stability of a culvert founded in erodible soil when one or more of the following conditions are present:

- High velocity flow
- Unstable channel conditions

These additional design considerations may include one or more of the following features:

- Redesign of the culvert to increase the waterway area and reduce the velocity of flow in the culvert,
- Use of Class 3 riprap instead of Class 2 riprap for the riprap protection
- Use of a lining such as riprap, concrete, etc. to protect the entire channel bottom within the culvert,
- Placement of the culvert on piles,
- Channel stabilization features upstream and/or downstream of the culvert, or
- Evaluation of alternative designs.

In some cases, bottomless culverts are used at sites where there is little flow and low velocities; consequently scour depths may be insignificant. Foundation elevations and the need for scour protection should be based on the particular site conditions for such culverts.

B. DESIGN CONCEPT

Computing scour in a bottomless culvert is similar to computing scour at a bridge abutment. The flow distribution in the channel and on the flood plain approaching the inlet of a bottomless box culvert is similar to that in a channel contracted by vertical-wall abutments at a bridge. The upstream cross-section of the channel and flood plain is generally wider than the culvert width and the flow velocity is lower than the velocity in the culvert. Discussion of the scour computation procedure is explained in Attachment 3 of this Appendix and also in the ABSCOUR User's Manual, Chapter 11, Appendix A (8). . Please note also the comments in Section C, Design Procedure.

The deepest scour typically occurs at the culvert entrance in the area of the contracting flow; and at the exit in the area of expanding flow (See Figure 2). In the culvert barrel, the flow lines are generally parallel to the culvert walls and the deepest scour, contraction scour, will often occur at the thalweg near the center of the channel. However, it is not unusual for the thalweg to meander over time between the culvert walls.

Figure 2 represents the actual scour measurements taken of a model of a bottomless culvert in the FHWA Hydraulic Laboratory at the Turner Fairbanks Highway Research Center (9). The scour pattern here is very clear with the darkest areas representing the deepest scour at the culvert entrance and exit. The contraction scour within the culvert barrel is not as deep, occurring near the center of the channel. In view of this scour pattern, the typical pattern for placement of the riprap is depicted in Figure 3.

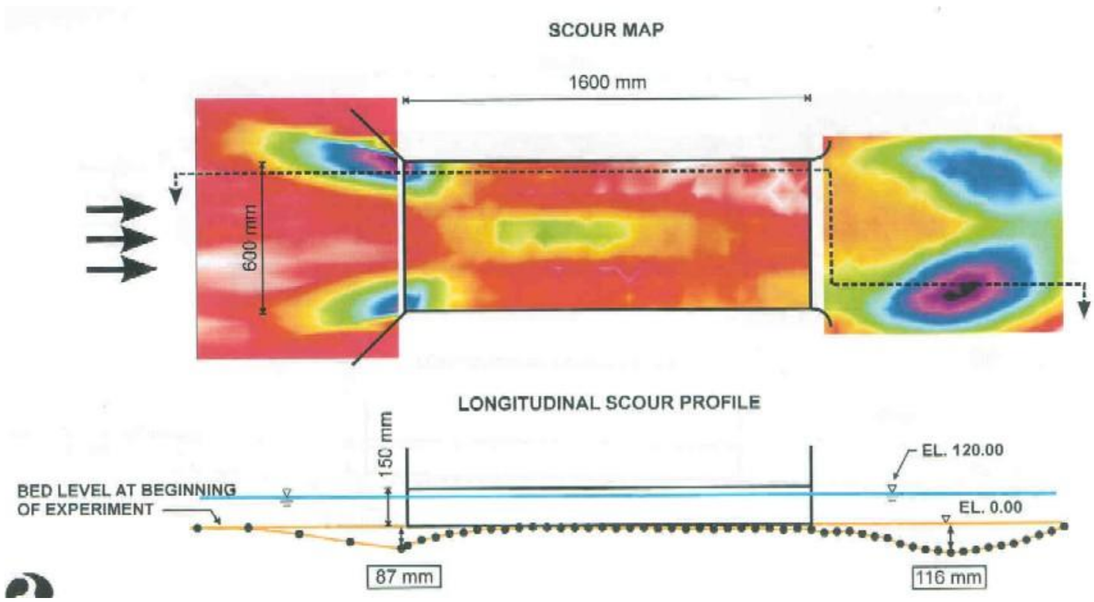

Figure 1
Scour Pattern at a Bottomless Culvert

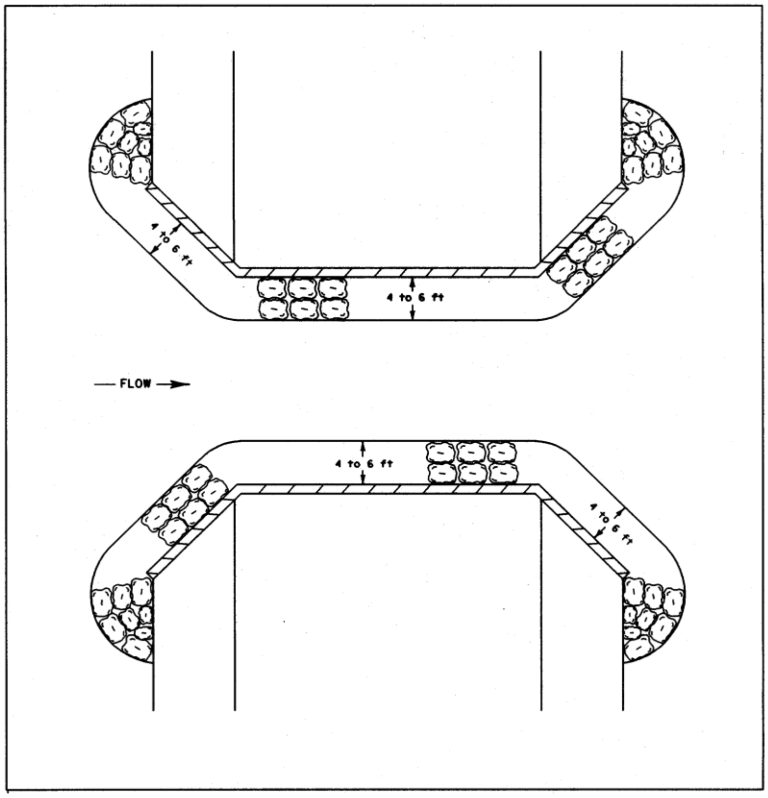

Figure 2
Plan View of Riprap Scour Protection for a Bottomless Culvert

Small streams in Maryland generally have well vegetated overbank areas. For worst case scour conditions, a significant portion of the flood flow conveyed to the culvert may come from these overbank areas. Because of the vegetative cover and the low velocities in the upstream reach, the bed load delivered to the culvert from overbank flow may be small. For such cases, it may be reasonable to assume a clear-water scour condition for the analysis. For clear water scour, the bed material in the bottomless culvert will be scoured by the higher flow velocity. As the scour progresses, the cross sectional area of the flow increases and the flow velocity correspondingly decreases. This process continues until the flow velocity is reduced to the critical (or competent) velocity where the particles on the bed cease to move.

The Bottomless Culvert Module in ABSCOUR (12) can be used to evaluate either clear water or live bed scour. The user is encouraged to consider both conditions and then decide which type of scour is most appropriate for a given site condition.

There are three important considerations for the user to keep in mind when using the clear water scour equations in the ABSCOUR program:

- *It is important that the user select the particle size that will be typical of the material in the* <u>*bottom*</u> *of the scour hole.*
- *There is very little information available regarding the critical velocity of*

- *particles with a D50 size smaller than 0.001 ft. or 0.3 mm. Use of the clear water equations for this material must be tempered with the user's judgment.*
- *Special studies and engineering judgment will be needed to determine the critical shear stress and/or critical velocity of cohesive soils.*

When rock is present, an evaluation needs to be made as to whether it is erodible or scour resistant. For this reason, it is standard practice to consult with representatives of the SHA Office of Materials and Technology when evaluating the erodibility of rock. SHA uses the Erodibility Index Method (See the Erodibility Index Spread Sheet in the H&H Manual, Chapter 13 Software Programs) as a guide in evaluating scour in erodible rock. The need for a full scour evaluation for footings on rock will be determined on a case by case basis.

Conditions at the culvert outlet and downstream channel should be assessed. If the downstream channel is unstable and degrading, or if a head cut is migrating upstream towards the culvert, the foundations may be vulnerable to undermining. The ABSCOUR analysis is not appropriate for this condition.

Placement of stream bed controls (cross vanes, etc,) or other means of channel stabilization may serve to mitigate potential problems with scour and degradation (11).

C. DESIGN PROCEDURE

C.1 Select the typical channel cross-section at the culvert location.
Select a representative cross-section of the channel and overbank area within the limits of the proposed culvert. For preliminary design of shallow channels, select an average elevation as representative of the channel and overbank sections

C.2 Select a Preliminary Culvert Size
Figure 4 presents a nomograph which can be used as a preliminary design aid in selecting a size of culvert that will limit the contraction scour to tolerable depths. (See Example problem on page 9). A trial and error approach is suggested in arriving at a preliminary culvert size. Once a reasonable culvert size is determined, the design computations can be made as outlined below:

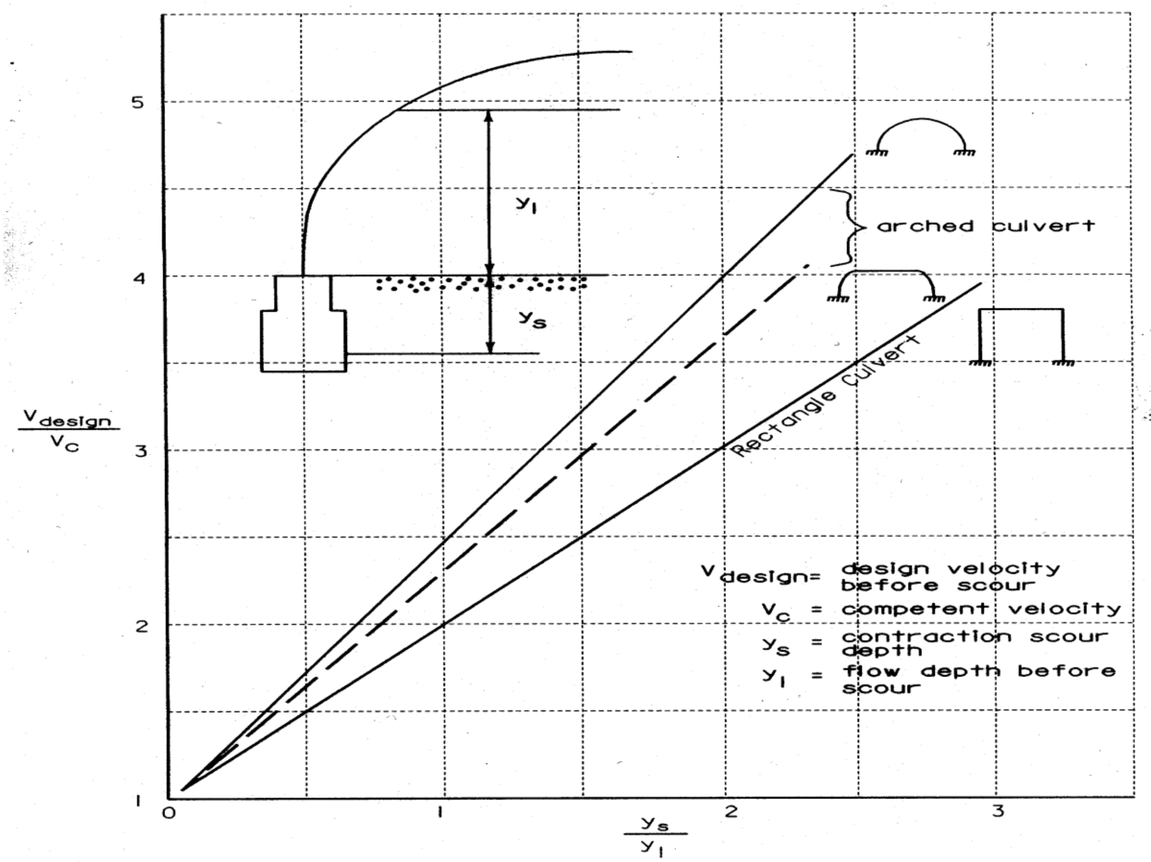

Figure 3

Plot for Preliminary Selection of Culvert Type and Size

An illustrative example of the use of Figure 4 is presented in Attachment 1.

C.3 Use the HEC-RAS Program (13) to compute water surface profiles.

Evaluate the 100-year, 500-year and Overtopping floods as appropriate.

C.4 Compute Contraction Scour and Culvert Wall (Abutment) Scour using the Bottomless Culvert Module in the ABSCOUR Program.

Detailed guidance on the use of the ABSCOUR Program is contained in the Users Manual (Appendix A, Parts 1 and 2 of Chapter 11) as well as in the Help Screens in the ABSCOUR Program.

C.5 Evaluate the potential for long term degradation, headcutting and channel migration

Refer to the procedures in the OBD Manual of Hydrologic and Hydraulic Design, including Chapter 14, Stream Morphology, for assessing concerns with channel instability.

C.6 Design the Culvert Spread Footing

C6.1 – With Scour Countermeasures

Place the top of the footing below the combined depth of channel contraction scour and any estimated long term degradation and consideration of channel movement. As a minimum, the footings on the upstream headwall and downstream endwall should be designed to the same elevation as the culvert footings and protected in a similar manner with riprap. As depicted in Figure 2, the deepest scour can be expected near the culvert headwall. In some cases where the abutment scour is severe, it may be prudent to increase the depth of the footings for the headwall equal to the total scour.

C6.2 – *Without Scour Countermeasures*

Place the bottom of the footing at the elevation of total scour considering local scour, contraction scour, degradation and consideration of channel movement. In some cases, particularly for long culverts, it may not be necessary to include local scour in evaluating scour within the culvert barrel beyond the entrance and exit sections.

Please note that for some installations, it may be cost effective to place the structural footing on a non-erodible base that extends to a depth of one-foot below channel contraction scour plus long term degradation. This type of design should be approved by the structural engineer.

C.7 Select the Scour Countermeasure.

Procedures for selecting the appropriate size of riprap are contained in the Utility Module of the ABSCOUR Program. They are also described in Chapter 11, Appendix D, Scour Countermeasures for Piers and Abutments. These procedures are based on the guidance contained in the FHWA HEC-23, Bridge Scour and Stream Instability Countermeasures. (14) Design the width and thickness of the riprap wall protection to keep the contraction scour away from the wall footings, keeping in mind the minimum blanket dimensions described in the above noted references. Deeper and wider riprap blankets should be considered where the contraction scour exceeds the normal depth of the riprap installation. Obtain prior approval from the SHA before using scour countermeasures other than riprap.

C.8 Evaluate the Trial Design

The objective here is to select the appropriate combination of (1) the culvert cross-sectional area and (2) the footing design so as to achieve a cost effective structure that is compatible with the stream morphology. Where moderate flow velocities are present, achieving a cost-effective design should not be a problem. As culvert velocities increase, however, scour can be expected to increase. Culvert foundation costs will also increase to accommodate the need for deeper footing depths, increased excavation quantities, more extensive riprap installations and more complex stream diversion measures. These factors may also create more disturbances to the stream during and after construction. For very long culverts, the wall or abutment scour component decreases and the risk of undermining the wall also decreases. For these long culverts, it may be reasonable to reduce the size of the riprap blanket at a point well beyond the culvert entrance.

However, such design modifications should be made on a case by case basis, subject to SHA approval.

If the selected culvert size results in deep scour depths, the engineer should consider increasing the culvert size to reduce culvert velocities and scour. If increasing the culvert size is not feasible, there are various countermeasures that can be used to protect the culvert from scour:

- Use of a larger D50 riprap size and a wider, deeper riprap installation,
- Lining the entire channel bottom with riprap, concrete, etc. or
- Placement of the culvert foundation on piles. (Please refer to Chapter 11, Section 11.4 Policy, for guidance on the design of deep foundations).

In some cases where scour is severe, consideration should also be given to use of an alternative design.

<u>D. SPECIAL DESIGN CONSIDERATIONS.</u>

D.1 Pier Scour

It is advantageous to use a single cell bottomless arch culvert, whenever practical, to span the stream. This approach can often serve to minimize obstructions to bankfull flow, thereby minimizing changes to sediment transport and stream morphology. In the event that a multiple cell structure is to be designed, the following guidance is offered with respect to computing scour for the embankment section located between adjacent culvert cells. This guidance applies when the spacing between the adjacent culvert walls is small, being on the order of the dimensions of a pier.

- Treat the area between adjacent culvert walls as a pier
- Calculate local pier scour using the Pier Scour Module in the ABSCOUR Program. Use the depth of flow, y2 (the total flow depth after contraction scour has taken place). Determine the corresponding values for the velocity of flow and the Froude Number at the entrance to the culvert. Measure the local pier scour from the contracted scour depth as determined by the value of y2.

This approach is reasonable for designs where the culvert cell walls of adjacent culverts are close together. It becomes less valid as the intervening space between the culvert cells increases. Judgment is needed in applying this concept to a particular site installation.

D.2 Unstable Channels

For unstable streams, the engineer is encouraged to consider the use of cross-vanes or other stream controls to establish a stable stream channel in the reach of the highway crossing. Reference is made to Chapter 14, Stream Morphology, for a discussion on conducting stream stability studies.

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ATTACHMENT 1
EXAMPLE PROBLEM TO ILLUSTRATE USE OF THE NOMOGRAPH FOR PRELIMINARY CULVERT SELECTION

Given: A 24 foot wide arch culvert with a shape similar to the middle or dotted line in the nomograph in Figure 2. From a preliminary hydraulic analysis, the average flow depth is 8 feet and the average flow velocity is 5 feet per second. The channel bed is composed of gravel with a D50 of 0.055 ft.

TRIAL RUN:

For a flow depth of 8 feet and a D50 gravel size of .055 ft, the competent or critical velocity (determined from Neill's competent velocity curves (15)) is about 4.5 ft/sec. (Please note that critical velocity using Neill's method can be computed by using the procedure in the Utility Module of ABSCOUR)

Vdesign/Vc = 5/4.5 = 1.1
From the Figure 4 nomograph for Vdesign/Vc = 1.1, the corresponding value of ys/y1 is approximately 0.2

The contraction scour depth is 0.2 times the flow depth of 8 feet or 1.6 feet. This rough estimate of contraction scour is considered to be in the right ballpark; use ABSCOUR 9, Bottomless Culvert Module, for a more accurate contraction scour estimate. The input and output information for the ABSCOUR evaluation is presented in Attachment 2 on pages 14- 16 below.

DISCUSSION OF THE ABSCOUR OUTPUT CALCULATIONS

1. Detailed guidance on the analytical procedures used to estimate scour is set forth in the ABSCOUR Users Manual, Appendix A of Chapter 11. Appendix A also provides help in regard to inputting information and interpreting the output results.
2. **For purposes of this example, consideration of degradation is not included. However, degradation is a vital consideration in the design of bottomless culvert installations. If significant degradation is anticipated, the ABSCOUR 9 methodology is not appropriate and should not be used. Additional study is recommended, including consideration of downstream controls to minimize degradation or selection of an alternative design.**
3. The contraction scour depth in the channel is only .04 feet which is essentially zero, the same elevation as the channel bed. The contraction scour elevation is 92.0
4. The wall scour occurs to a depth is 6.6 feet or to Elevation 89.
5. The recommended design procedure is to set the bottom of the wall footing at elevation 91 - one foot below the channel contraction scour elevation of 92
6. A Class 2 riprap installation about 4 feet wide (See Figure 1) should be installed on each side of the channel between the channel bank and the culvert footing.

The recommended depth of the riprap is 3 feet to extend to the contraction scour elevation.

7. . Please note that most of the wall scour is expected to occur in the vicinity of the culvert inlet and culvert outlet.

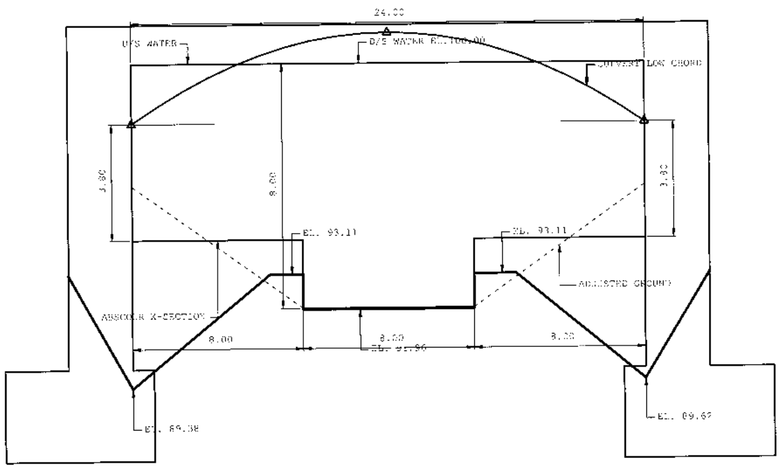
The example discussed above represents a conservative approach to the design of a bottomless arch culvert. A smaller culvert might be considered for this location if increased contraction scour in the channel bottom is acceptable.

ATTACHMENT 2
EXAMPLE PROBLEM OUTPUT REPORT

```
File:N:\OOS\OBDBDD\H&H\H&H MANUAL APRIL 2011\H&H MANUAL APRIL 2011\H&H SO                Page:1

1:   **********************************************************
2:   *          Maryland State Highway Administration          *
3:   *                   Office of Structures                  *
4:   *    Maryland Scour Program - Bottomless Culvert Scour    *
5:   *            Version 9 Build 2.1, January 2010            *
6:   **********************************************************
7:   Time stamp: 04/18/2011 3:18:47 PM
8:
9:   Input Data:
10:
11:  Project information:
12:  ----------------------------------------------------------------------------------------------
13:  Project name: example problem
14:  Project number: Alternative 1
15:  Description: Arch Culvert Alternative
16:
17:  Project options:
18:    Program calculates critical and boundary shear stresses at approach section
19:    Program decides the scour type as either live bed or clear water scour
20:    Program calculates the unit width discharge at the bridge section
21:    Program calculates critical velocity at bridge section
22:    Program calculates sediment transport parameter k2
23:    Program calculate the flow velocity at abutment face
24:    Program calculates spiral flow coefficient Kf
25:    Clear-water scour uses a modified Neill's method for Piedmont Zone
26:    English Units
27:    Section orientation is looking downstream
28:
29:  Approach Section Data:
30:  ----------------------------------------------------------------------------------------------
31:                                                                  Left        Channel        Right
32:                                                                  ---------------------------------
33:  Approach section discharge (cfs):                                130            300          160
34:  Approach section top width (ft):                                  20              8           30
35:  Approach flow depth (hydraulic depth) (y1) (ft):                   6              8            6
36:  Approach median particle size, D50(ft):                         .007           .007         .007
37:  Bank slope (Z) in the vicinity of the bridge (Z=H/V):              2                           2
38:  Energy slope (S) at approach section: .002
39:
40:  ABSCOUR Overrides
41:
42:  Reserved for override approach critical shear stress
43:  Reserved for override approach boundary shear stress
44:  Reserved for override scour type
45:  Reserved for override sediment transport parameter
46:  Reserved for override location header
47:  Reserved for override unit width discharge
48:  Reserved for override critical velocity
49:  Reserved for override 2-D velocity at side wall
50:  Reserved for override average velocity in portion of culvert
51:  Reserved for override spiral flow coefficient
52:
53:  Downstream Culvert Data:
54:  ----------------------------------------------------------------------------------------------
55:  Downstream water surface elevation under culvert: 100 ft
56:                                                                  Left        Channel        Right
57:                                                                  ---------------------------------
58:  HEC-RAS discharge under Culvert (cfs):                           155            280          155
59:  Waterway area (A) measured normal to flow (sf):                 30.4             64         30.4
60:  Culvert flow width (W) measured normal to flow (ft):               8              8            8
61:  Hydraulic depth (A/W) (ft):                                     3.80           8.00         3.80
62:  ABSCOUR X-Section elevation (#55-#61) (ft):                    96.20          92.00        96.20
63:  Culvert type:                                                                Arched
64:  Setback (- for an abutment in channel) (ft):                       8                           8
65:  Low chord elevation downstream side of culvert (ft):           98.04            100        98.04
66:  Correction factor for low chord submergence (#55-#65>0)(ft):    0.00           0.00         0.00
67:  Median particle size under culvert, D50(ft):                    .007           .007         .007
68:  Estimated long-term aggradation(+) or degradation(-) (ft):         0              0            0
69:  Calibration/safety factor (See F-1): 1
70:
71:  Upstream Culvert Data
72:  ----------------------------------------------------------------------------------------------
73:  Water surface elevation upstream side of culvert: 100 ft
74:                                                                  Left        Channel        Right
75:                                                                  ---------------------------------
76:  High chord elevation upstream side of culvert (ft):              105            105          105
77:  Low chord elevation upstream side of culvert (ft):             98.04            101        98.04
78:  Bed elevation at upstream side of culvert (ft):                 94.5             93         94.5
79:  Water depth at upstream side of culvert (#73-#78) (ft):         5.50           7.00         5.50
80:  Flow velocity at upstream face of culvert (fps):                   4              4            4
81:  Low chord height (#77-#78) (ft):                                3.54           8.00         3.54
82:  Vertical blockage of flow by superstructure (ft):               0.00           0.00         0.00
83:  Pressure flow, Yes or NO: (Yes if #79>#81 at channel)             No             No           No
84:  Embankment skew angle (degrees):                                 090                          90
85:  Is future lateral migration of channel likely to occur?: No
```

```
86:  Output Computation And Results
87:
88:  Approach Section:
89:
90:  Total approach discharge (cfs): 590
91:                                                              Left        Channel         Right
92:                                                          ------------------------------------
93:  Approach average flow velocity (fps):                      1.083         4.688         0.889
94:  Approach unit width discharge (cfs/ft):                      6.5          37.5         5.333
95:  Approach section depth (ft):                                   6             8             6
96:  Approach section Froude Number:                           0.0779        0.2921         0.064
97:  Approach section critical shear stress(psf):               0.028         0.028         0.028
98:  Approach boundary shear stress(psf):                      0.7488        0.9984        0.7488
99:  Approach sediment transport parameter (k2):                0.641          0.64         0.641
100: Scour type:                                             Live Bed      Live Bed      Live Bed
101:
102: Downstream Culvert Computations:
103:
104: Total discharge under Culvert (cfs): 590
105:                                                             Left        Channel         Right
106:                                                          ------------------------------------
107: Method of computing flow velocity adjustment:        Short Setback              Short Setback
108: Flow velocity (fps):                                       4.728         4.728         4.728
109: Adjustment to hydraulic depth (y0)adj (ft):                    4             8             4
110: Unit width discharge (#109*#108)(cfs/ft):                  18.91        37.821         18.91
111: Control soil layer No.:                                        1             1             1
112: Critical velocity (fps):                                   3.534         4.201         3.534
113:
114: Downstream Contraction Scour Computations:
115:
116:                                                             Left        Channel         Right
117:                                                          ------------------------------------
118: Clear water scour flow depth (y2)(ft):                     5.353         9.018         5.353
119: Live bed scour flow depth (y2)(ft):                       11.895         8.044        13.503
120: Interpolated scour flow depth (y2)(ft):                    6.893         8.044         6.893
121: Pressure flow coefficient (Kp):                                1             1             1
122: Adjusted scour flow depth (y2)adj (#121*#120>(y0)adj)(ft): 6.893         8.044         6.893
123: Contraction scour depth (ys) (#122-#109>T/SF)(ft):         2.893         0.044         2.893
124: Final contraction scour depth (ys)f (#123*#69)(ft):        2.893         0.044         2.893
125: Aggr/Degr + Contraction scour EL.(#55-#109-#124-#66+#68)(ft): 93.107   91.956        93.107
126:
127: Total Culvert Scour At Side wall:
128:
129:                                                             Left        Channel         Right
130:                                                          ------------------------------------
131: Side wall local velocity factor (Kv):                      1.161                        1.12
132: Side wall spiral flow factor (Kf):                           1.4                         1.4
133: Pressure flow coefficient (Kp):                                1                           1
134: Wall scour flow depth (y2a)adj(#120*#132*#131^#99*#133)(ft): 10.621                   10.377
135: Initial side wall scour depth (ysa)(#134-#109>0)(ft):       6.621                       6.377
136: Coefficient for side wall shape factor (Kt):                   1                           1
137: Coefficient for embankment angle (Ke):                          1                           1
138:
139: Final side wall scour depth (ysa)adj(#135*#136*#137*#69)(ft): 6.621                     6.377
140: Aggr/Degr + Side wall scour EL.(#55-#109-#139-#66+#68)(ft): 89.379                     89.623
```



Computer Sketch of Contraction and Wall Scour
For the Example Culvert.

ATTACHMENT 3 – CLEAR WATER SCOUR EQUATIONS

The ABSCOUR Program computes contraction and abutment scour as described in the Users Manual (Appendix A) of Chapter 11. This procedure is modified slightly for culverts to account for the difference in the shapes between bridges and culverts. The logic of the ABSCOUR program is outlined below.

Obtain the following information for the culvert (See Figure 1):

Q = discharge per culvert barrel, cfs
W = nominal width of culvert (at the spring line), ft
q = discharge per unit width = Q/W, ft2/s
y1 = average depth of flow inside the culvert (not at the culvert inlet or outlet) ft.
V = average flow velocity inside the culvert (not at the culvert inlet or outlet) ft/sec.
D50 = average soil particle sizes for the channel and overbank areas inside the culvert. For live bed scour, the D50 size can be obtained from pebble counts or other sampling techniques. For clear water scour, the D50 particle size should be representative of the soils <u>at the estimated depth of contraction scour, ft</u>.
H = rise of the arch from the stream bed to the crown of the arch (ft.). For pressure flow conditions, assume that the flow depth y1 is equal to H, the crown of the culvert

CLEAR WATER CONTRACTION SCOUR IN RECTANGULAR CULVERTS

The equations below are based on the competent velocity curves contained in Neill's Guide to Bridge Hydraulics, Reference 7:

y2 = y1 + ys **(1)**

Where

y2 = average depth of flow inside the culvert after scour has taken place.

y1 = average depth of flow inside the culvert before scour has taken place.

ys = depth of scour

The following equations are used to solve for y2.

<u>For $D_{50} \leq 0.001$ ft.</u>

$$y_2 = (q / (2.84\,(D_{50})^{0.15}))^{0.67} \quad \textbf{(2)}$$

For 0.1> D_{50}> 0.001 ft.

$$y_2=[q/(11.5D_{50}^{.35})]^x \quad \textbf{(3)}$$

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

For $D_{50} \geq 0.1$ ft.

$$y_2 = [q/(11.5D_{50}^{0.33})]^{0.86} \quad \textbf{(4)}$$

CLEAR WATER CONTRACTION SCOUR IN SIMPLE ARCHED CULVERTS

Most bottomless culverts have the shape of an arch and therefore have less capacity than a structure with vertical walls for the same height and width. The following equations apply for computing contraction scour in arched culverts. Solution of the equations requires either a trial and error approach or plotting of the q Vs y2 relationship. A trial and error approach is used for the ABSCOUR program.

For $D_{50} \leq 0.001$ ft.

$$q = 2.84\, y_2^{0.5}\, D_{50}^{.0.15}\, (y_2 - 1/3\, (y_1/H)^2\, y_1\,). \quad \textbf{(5)}$$

For 0.1> D_{50}> 0.001 ft.

$$q = 11.5\, y_2^x\, D_{50}^{0.35}\, (y_2 - 1/3\, (y_1/H)^2\, y_1\,) \quad \textbf{(6)}$$

Where $x = 0.123/ D_{50}^{0.2}$

For $D_{50} \geq 0.1$ ft.

$$q = 11.5\, y_2^{0.167}\, D_{50}^{0.333}\, (y_2 - 1/3\, (y_1/H)^2\, y_1) \quad \textbf{(7)}$$

COMPUTATION OF WALL OR ABUTMENT SCOUR AT THE CULVERT ENTRANCE

The ABSCOUR Program computes abutment or wall scour in the manner presented below.

The scour depth y2 in equations 1-4 above is defined as the uniform contraction scour depth across the width of the channel inside the culvert. It is measured from the water surface to the channel bottom, taking into account that contraction scour has taken place.

At the entrance to the culvert, however, there will be additional turbulence and resulting scour at the culvert footings as the flow transitions from the flood plain into the culvert.

For a single barrel bottomless culvert, the footings should be treated in the same manner as bridge abutments for purposes of estimating scour. The wall area at the culvert inlet is a region of higher velocity flow due to the rapidly contracting flow and the resulting vortex action. This is similar to the flow at a vertical wall abutment, resulting in localized scour that is deeper than the contraction scour in the channel. The SHA abutment scour equations can be used to estimate the scour depth at the culvert wall near the culvert entrance. This is accomplished as follows: the contraction scour depth y2 computed above is multiplied by the correction factors, Kv and Kf to account for higher velocity and vortex flow, respectively, near the culvert wall. These correction factors are computed by Equations 8 and 9 (See also the Users Manual, App. A of Chapter 11):

$$K_v = 0.8(q_{1'\,ave}/q_{2'\,ave})^{1.5} + 1 \qquad \textbf{(8)}$$

$$K_f = 0.1 + 4.5F \text{ for clear water scour} \qquad \textbf{(9)}$$

Where

$q_{1'\,ave}$ = average unit flow in the approach channel, ft
$q_{2'\,ave}$ = average unit flow in the culvert ft
F = Froude Number of approach flow: $F= V/ (gy)^{0.5}$
V = Velocity of Flow, ft/s
y = flow depth, ft
g = 32.2 ft/sec^2

The term Kv is related to the effect of the higher flow velocity which occurs near the culvert wall.

The term Kf is related to the effect of vortex flow on scour at the corner of the culvert. The limits of the Kf value range from 1.0 to 3.2. If the value computed by Equation 9 is less than 1.0, use a value of 1.0. If the value computed by Equation 9 is greater than 3.2, use a value of 3.2.

The scour depth at the culvert walls, y_w can be written as:

$$\text{Scour depth, } y_w = K_f * (K_v^{0.857}) * y_2 \qquad \textbf{(10)}$$

Where
y_w = total water depth at the culvert wall measured from water surface to the channel bed after scour has taken place.
y_2 = total water depth at the center of the culvert measured from water surface to the channel bed after scour has taken place. If the culvert is operating under pressure flow conditions, the program will compute a pressure scour coefficient, k_p, to apply to the contraction scour as explained in the Users Manual, Appendix A.

For multiple barrel culverts, typically two cell culverts, the center footings should be treated as a pier for purposes of estimating local pier scour. The local pier scour should be added to the contraction scour to obtain the total scour for the middle footing.

OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX D

SCOUR COUNTERMEASURES
FOR
PIERS AND ABUTMENTS

OFFICE OF STRUCTURES

MAY 2015

CHAPTER 11 APPENDIX D
SCOUR COUNTERMEASURES AT PIERS AND ABUTMENTS

TABLE OF CONTENTS

CHAPTER 11 APPENDIX D
SCOUR COUNTERMEASURES AT PIERS AND ABUTMENTS

11D-1.0 INTRODUCTION

The FHWA Hydraulic Engineering Circulars (See References) serve as the primary technical references for the information in this Appendix. In particular, Hydraulic Engineering Circular 23, “Bridge Scour and Stream Instability Countermeasures” consists of an entire manual devoted to scour countermeasures. Engineers are encouraged to use these FHWA Manuals to gain insight into the factors to be considered in the design of scour countermeasures.

Appendix D sets forth the policies and practices of the Office of Structures regarding scour protection at new bridges. For most locations, this scour protection will consist of Class 2 or Class 3 riprap. If the Engineer believes that some other type of scour countermeasure is more appropriate for a given location, he or she should discuss such ideas with the Structures Hydrology and Hydraulics Division (H&H) prior to commencing design on the scour countermeasure.

The Structures Inspection and Remedial Engineering Division (S.I.R.E.) has the primary responsibility for installing scour countermeasures at existing bridges. Designing countermeasures for existing bridges, as compared with new bridges, often involves a different set of conditions and solutions. Therefore, such countermeasures are not considered in this Appendix. The Structure Hydrology and Hydraulics Division often works with S.I.R.E. through the Interdisciplinary Scour Team to evaluate scour countermeasures at existing bridges on a case by case basis.

11D.2 POLICY

The primary objective of the SHA is to provide for the safety of the traveling public. Scour countermeasures serve as an important design features to assure the stability of a bridge to resist damage from scour. The bridge, taking into consideration the protection afforded by scour countermeasures, should be designed to withstand worst-case scour conditions. Early coordination is necessary with environmental and regulatory review agencies to make them aware of proposed scour countermeasures. Designs for scour countermeasures should be included in submittals for necessary permits.

11D.2.1 ABUTMENTS

- Design abutment foundations in accordance with the provisions of Chapter 11, Policy)
- Consider a riprap or other scour countermeasure at every abutment. If there are field conditions which render the scour countermeasure unnecessary, this condition should be explained in the scour report.

- Use Class 2 or larger riprap; place riprap to a minimum depth of 6 feet in the toe section on the flood plain or channel. Section 11D.3 permits an exception to this policy for certain field conditions.
- Abutment protection for existing bridges should be designed in accordance with design criteria used by the Structures Inspection and Remedial Engineering Division.

11D.2.2 PIERS

- Piers for new bridges are to be designed to be stable for anticipated worst-case conditions of scour without reliance on scour countermeasures.
- In the event that a riprap installation is determined to be necessary for a new bridge, the installation should be designed in accordance with the details presented in Section 11D.3.
- Pier protection for existing bridges should be designed in accordance with design criteria used by Structures Inspection and Remedial Engineering.

11D.3.0 DESIGN OF RIPRAP INSTALLATIONS

11D.3.1 GENERAL

It is the general experience of SHA engineers that Class 2 riprap (D50 = 16 inches) serves satisfactorily as scour protection for most non-tidal bridge sites. Class 3 riprap (D50 = 23 inches) requires a thicker blanket and is usually more costly than Class 2 riprap. However, use of Class 3 riprap is necessary in some cases to withstand high velocity flows. Typically, riprap for tidal waterways is designed using the Corps of Engineers criteria to account for the effect of waves on the stability of the scour countermeasure.

Class 1 riprap is not generally recommended for use for scour protection for bridges. There are certain conditions where Class 1 riprap may be considered for bridges on flood plains where flow depths and velocities are low for worst-case scour conditions. These conditions are described in Figure 4.

Special design procedures are required for the analysis of riprap installations to resist wave action. These procedures are discussed in Section 11D.3.5 below.

11D.3.2. SELECTION OF THE RIPRAP D50 SIZE AND BLANKET THICKNESS

The FHWA equations from HEC-23, Bridge Scour and Stream Instability Countermeasures (Design Guideline 8, Rock Riprap at Abutments and Piers) should be used to compute the minimum required D50 size of riprap (Attachment 2). This value is to be compared with the D50 size of riprap in Table 1 below to select the appropriate riprap Class and blanket thickness. As noted previously, use of Class 1 riprap is not recommended except for certain conditions as set forth in Figure _4.

TABLE 1
SELECTION OF THE RIPRAP D50 SIZE AND BLANKET THICKNESS

RIPRAP CLASS	D50 MINIMUM SIZE (INCHES)	APPROXIMATE D50 WEIGHT (POUNDS)	MINIMUM BLANKET THICKNESS (INCHES)*
I	9.5	40	19
II	16	200	32
III	23	600	46

* These dimensions apply to the upper blanket section only, not the toe section

11D.3.3. DESIGN OF THE TOE SECTION

A stable riprap toe is the most important feature in the design of riprap abutment protection installations. Guidance on the design of the toe section is provided in Figure 1. The following criteria serve to establish the design for the riprap toe:

1. Design the riprap toe to extend below the depth of contraction scour in the scour cross-section (See Figure 1).

2. The riprap toe should be at least 6 feet thick. (A lesser toe thickness may be appropriate under certain field conditions as depicted by Figure 4.)

3. The top width of the riprap toe is typically 12 feet or more in order to fit the riprap geometry to the ground conditions. A lesser width may be appropriate for small bridges.

4. An aggregate or geotextile filter cloth is normally used with the riprap installation.

5. It is not always feasible to use the SHA riprap standard for very short bridges, and some modifications may need to be made to fit the site conditions.

11D.3.4 RIPRAP SPECIFICATIONS

The following riprap specifications are set forth in the January 2001 Edition of the SHA Standard Specifications for Construction and Materials:

Construction: Section 312, Riprap Slope and Channel Protection

Materials: Section 901.01, Aggregate Filter Blanket; 901.02 Stone for Riprap; 921.09 Geotextile.

11D.3.5. RIPRAP INSTALLATIONS SUBJECT TO WAVE ACTION

Riprap installations subject to wave action, typically for tidal bridges, should be designed using the guidelines of the Corps of Engineers as set forth in Reference 12.

11D.4 REFERENCES

1. NTSB, 1988, "Collapse of the New York Thruway (I-90) Bridge over the Schoharie, Creek, Near Amsterdam, New York, April 5, 1987," NTSB/HAR-88/02, NTSB, Washington, D.C.

2. RCI (Ayres Associates) and Colorado State University, 1987, "Hydraulic, Erosion, and Channel Stability Analysis of the Schoharie Creek Bridge Failure, New York," for NTSB and NY Thruway Authority, Fort Collins, CO.

3. Hydraulic Engineering Circular 18, Fifth Edition, April.

4. Richardson, E.V., D.B. Simons, and P.F. Lagasse, 2001, "River Engineering for Highway Encroachments - Highways in the River Environment," Report FHWA NHI 01-004, Federal Highway Administration, Hydraulic Design Series NO. 6, Washington, D.C.

5. Parola, A.C., Jr., 1991, "The Stability of Riprap Used to Protect Bridge Piers," FHWA-RD-91-063, U.S. Department of Transportation, Washington, D.C., July.

6. Parker, G., C. Toro-Escobar, and R.L. Voight, Jr., 1998, "Countermeasures to Protect Bridge Piers From Scour," User's Guide, Vol. 1, prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council, NCHRP Project 24-7, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN (revised 7/1/99).

7. Parker, G., C. Toro-Escobar, and R.L. Voight, Jr., 1998, "Countermeasures to Protect Bridge Piers from Scour," Final Report, Vol. 2, prepared for National Cooperative Highway Research Program, Transportation Research Board, National Research Council, NCHRP Project 24-7, St. Anthony Falls Laboratory, University of Minnesota, Minneapolis, MN.

8. Pagán-Ortiz, Jorge E., 1991, "Stability of Rock Riprap for Protection at the Toe of Abutments Located at the Floodplain," FHWA Research Report No. FHWA-RD-91-057, U.S. Department of Transportation, Washington, D.C.

9. Atayee, A. Tamin, 1993, "Study of Riprap as Scour Protection for Spill-through Abutment," presented at the 72nd Annual TRB meeting in Washington, D.C., January.

10. Kilgore, Roger T., 1993, "HEC-18 Guidance for Abutment Riprap Design," unpublished internal correspondence to FHWA, January.

11. Atayee, A. Tamin, Jorge E. Pagán-Ortiz, J.S. Jones, and R.T. Kilgore, 1993, "A Study of Riprap as a Scour Protection for Spill-through Abutments," ASCE Hydraulic Conference, San Francisco, CA.

12. Design of Coastal Revetments, Seawalls and Bulkheads, US Army Corps of Engineers, EM1110-2-1614, 30 June, 1995.

13. NCHRP Report 568, Riprap Design Criteria, Recommended Specifications and Quality Control, Transportation Research Board, 2006

ATTACHMENT 1

DETAILS OF TYPICAL RIPRAP INSTALLATIONS AT PIERS AND ABUTMENTS

Please Note that the conceptual sketches presented below depict design details that may require modification for the particular site conditions at a bridge. This may be especially true for bridges over small channels when there is limited space to install the riprap. The key elements of the riprap design include (1) the thickness (t) of the riprap, based on the riprap class and (2) the depth of the riprap toe which should be equal or greater than 6 feet or the depth of the contraction scour.

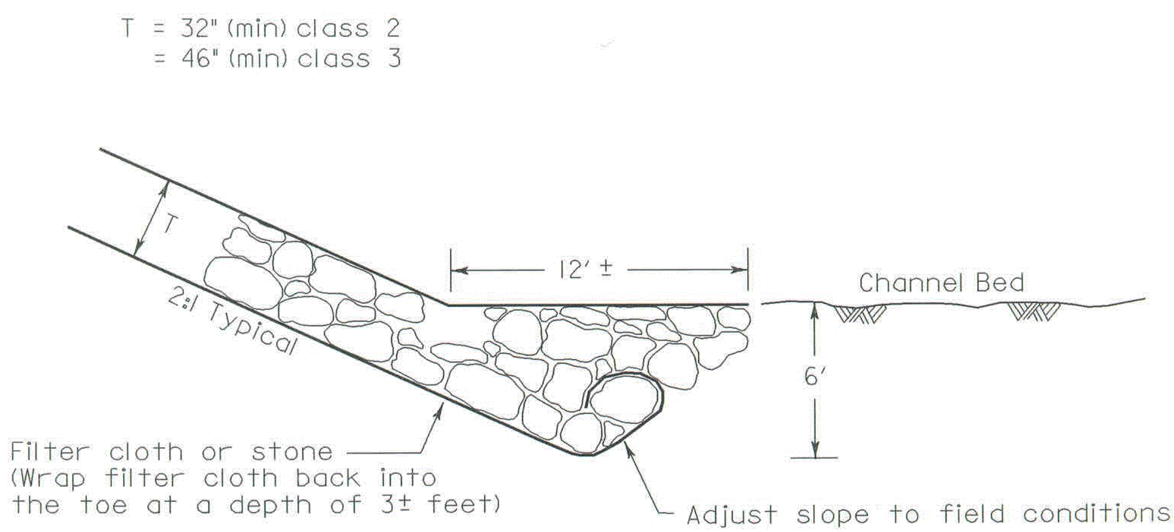


Figure 1
Typical Riprap Blanket and Toe Detail
(Not to Scale)

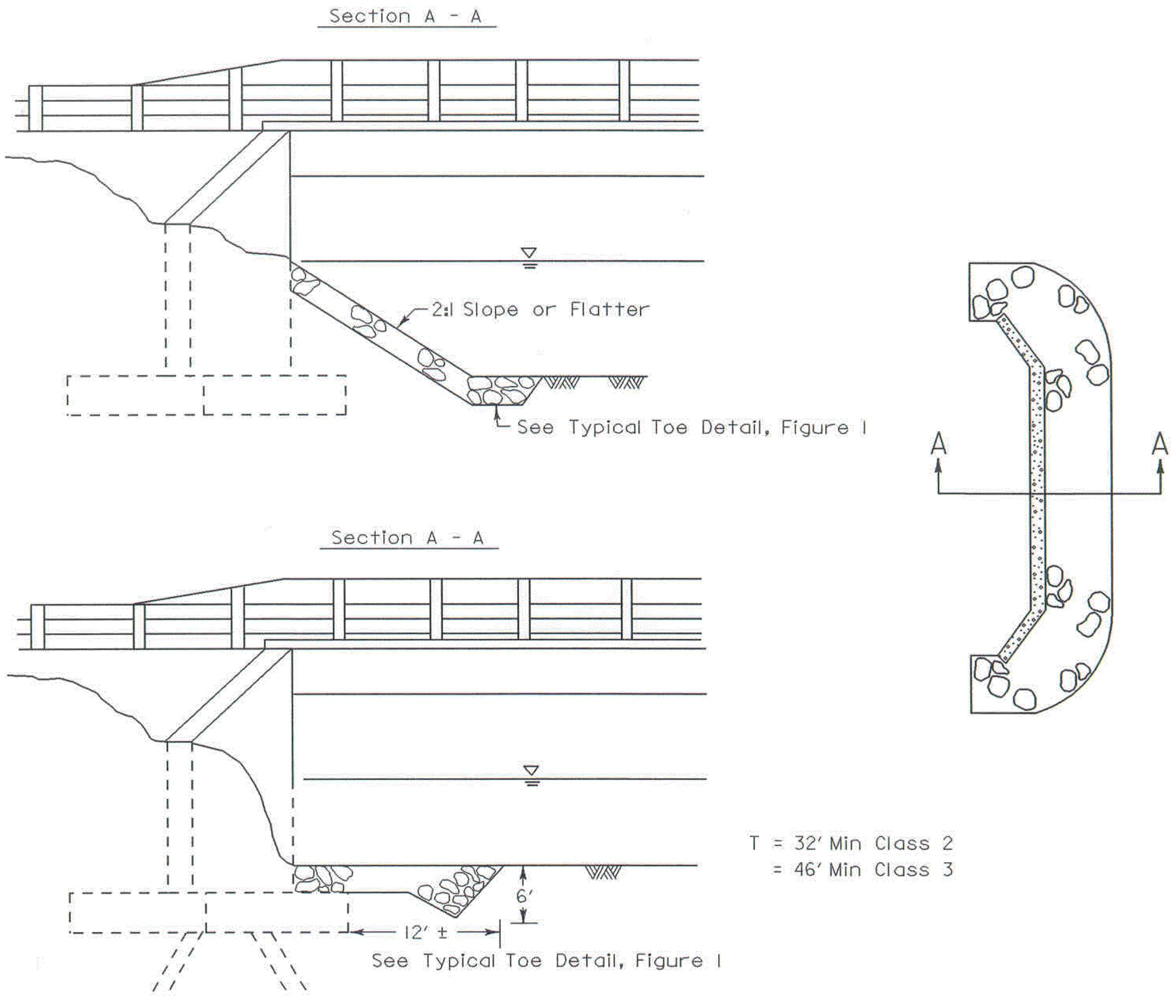


Figure 2
Abutment Near Channel Bank
(Not to Scale)

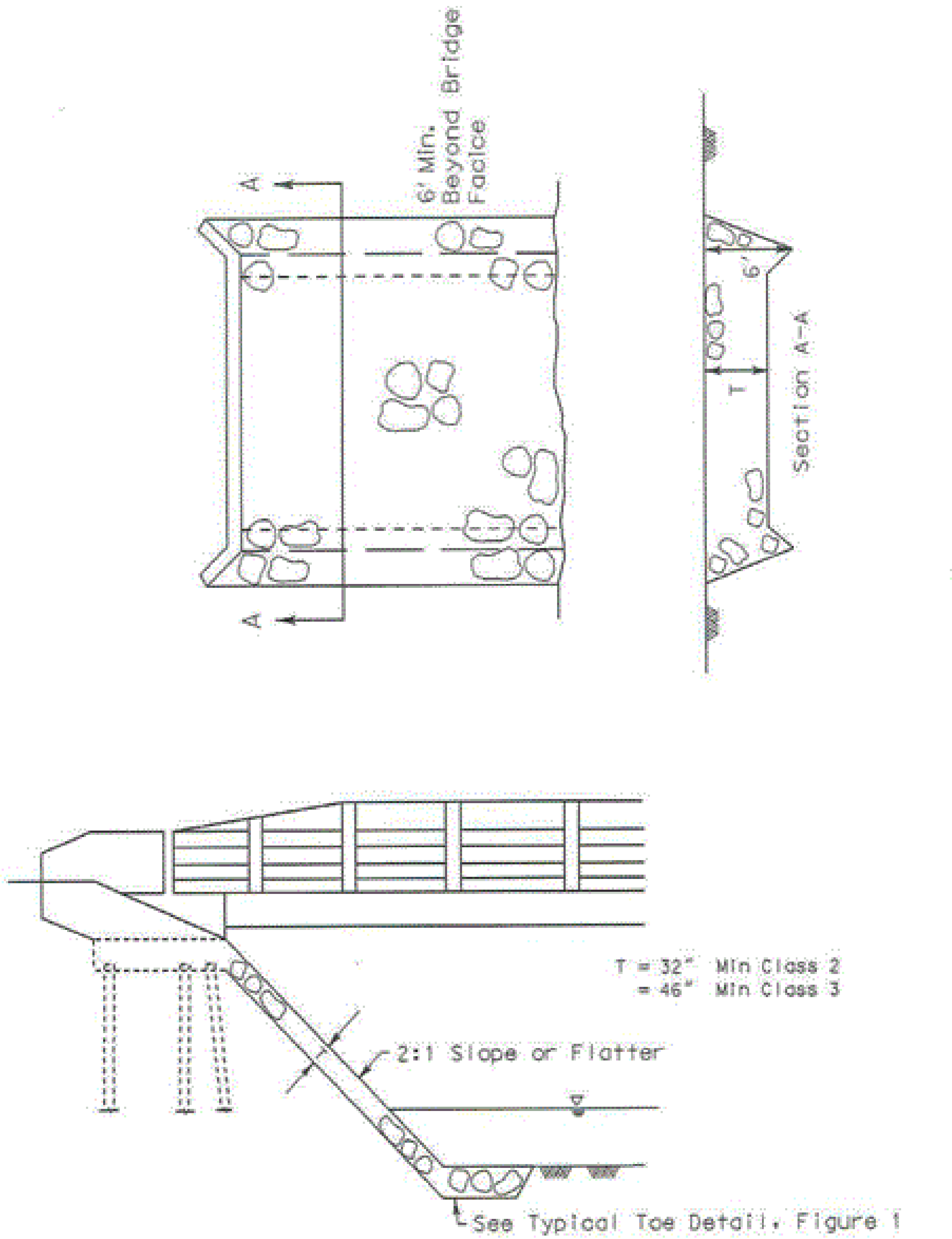
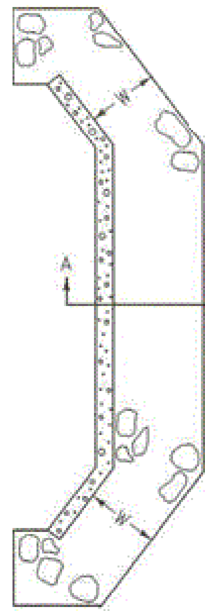
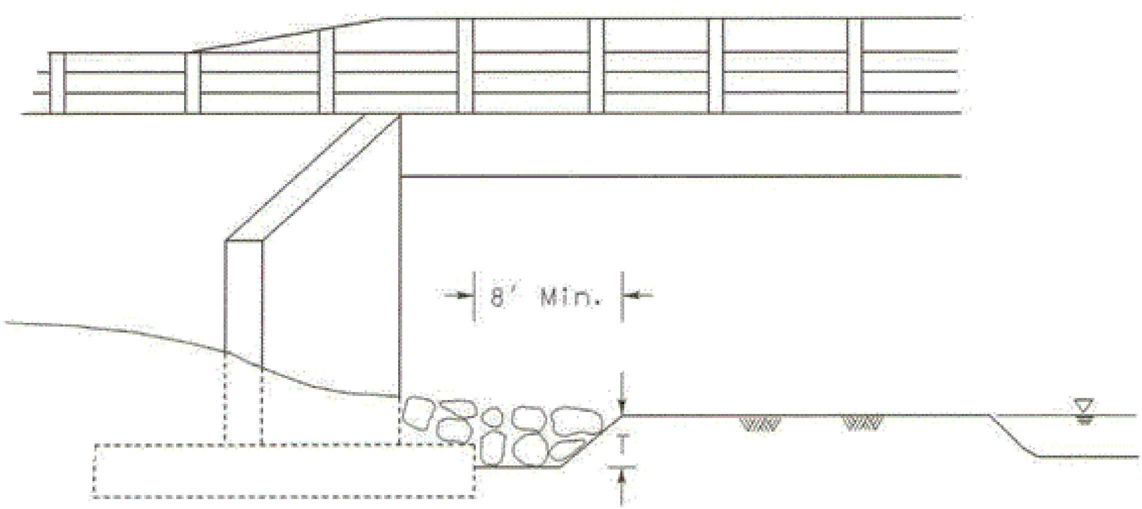


Figure 3
Abutment Near Top of High Channel Bank
(Not to Scale)





Section A-A

Figure 4
Abutment on Flood Plain Set Well Back from Channel Bank with Low Flow Depths and Velocities for Worst Case Scour Conditions
(May consider use of Class 1 riprap for this condition)
(Not to Scale)

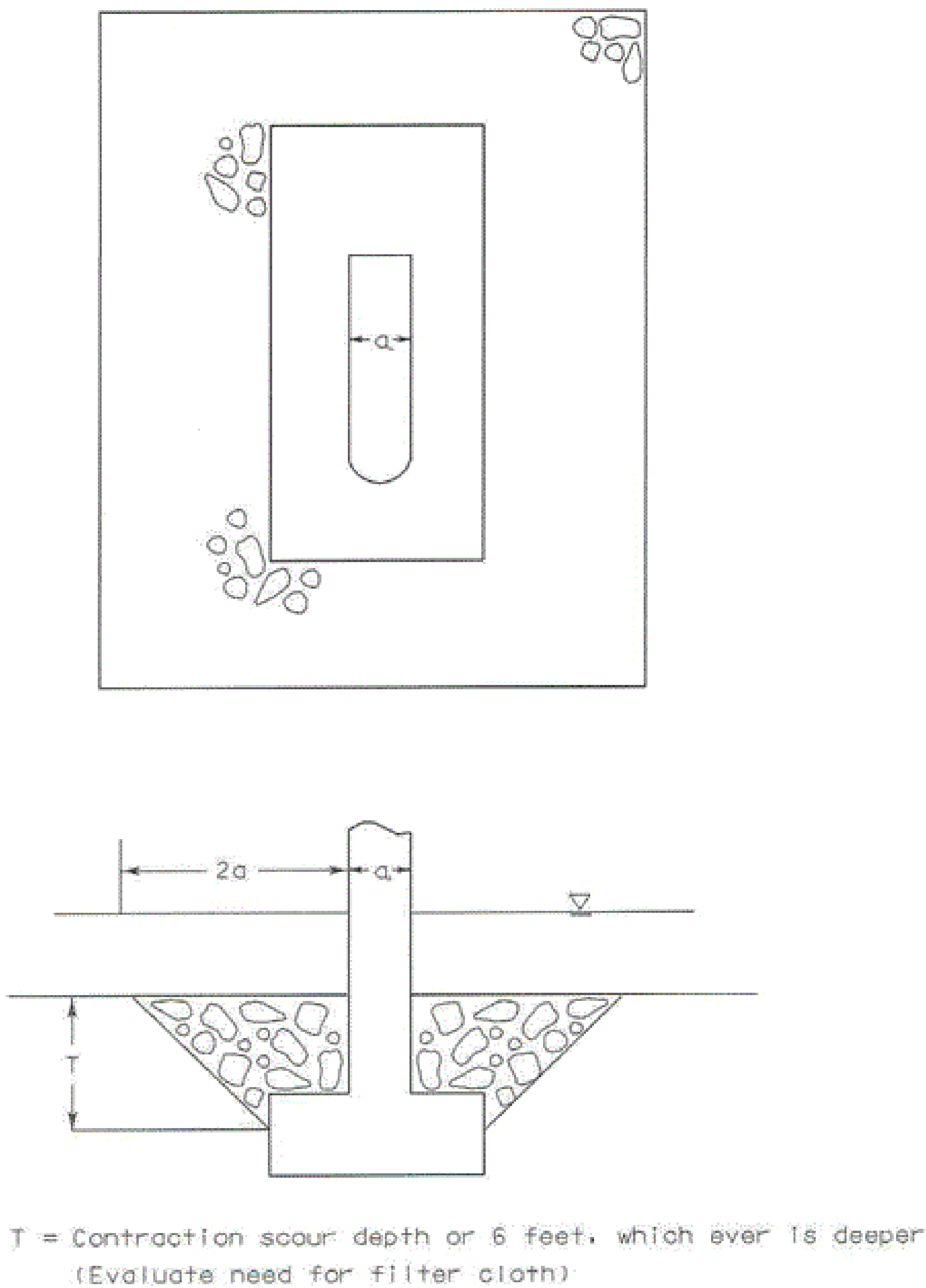


Figure 5
Scour Countermeasure at Pier
(Not to Scale)

(Piers should be designed to be stable for expected worst-case scour conditions without reliance on scour countermeasures. Where additional scour protection is desired, such protection should be related to the site conditions, but would normally be expected to fall within the limits depicted in Figure 5.)

ATTACHMENT 2

EXCERPTS FROM FHWA HEC-23 DESIGN GUIDELINE 8 ROCK RIPRAP AT PIERS AND ABUTMENTS

8.1 INTRODUCTION

The Engineer is encouraged to obtain HEC-23 and read Design Guideline 8 in its entirety. The FHWA continues to evaluate how best to design rock riprap at bridge piers and abutments. Present knowledge is based on research conducted under laboratory conditions with little field verification, particularly for piers. Flow turbulence and velocities around a pier are of sufficient magnitude that large rocks move over time. Bridges have been lost (Schoharie Creek bridge) due to the removal of riprap at piers resulting from turbulence and high velocity flow. Usually this does not happen during one storm, but is the result of the cumulative effect of a sequence of high flows. **Therefore, if rock riprap is placed as scour protection around a pier, the bridge should be monitored and inspected during and after each high flow event to insure that the riprap is stable**.

8.3 SIZING ROCK RIPRAP AT PIERS

As a countermeasure for scour at piers for existing bridges, riprap can reduce the risk of failure and in some cases could make a bridge safe from scour (see HEC-18, Appendix J for additional guidance. **[3]** **Riprap is not recommended as a pier scour countermeasure for new bridges**. Determine the D_{50} size of the riprap using the rearranged Isbash equation [4, 5] to solve for stone diameter (in meters (ft), for fresh water):

$$D_{50} = \frac{0.692\,(KV)^2}{(S_s - 1)\,2g}$$

(8.1)

where:

D_{50}	=	median stone diameter, m (ft)
K	=	coefficient for pier shape
V	=	velocity on pier, m/s (ft/s)
S_s	=	specific gravity of riprap (normally 2.65)
G	=	9.81 m/s^2 (32.2 ft/s^2)
K	=	1.5 for round-nose pier
K	=	1.7 for rectangular pier

To determine V multiply the average channel velocity (Q/A) by a coefficient that ranges from 0.9 for a pier near the bank in a straight uniform reach of the stream to 1.7 for a pier in the main current of flow around a sharp bend.

1. Provide a riprap mat width which extends horizontally at least two times the pier width, measured from the pier face.

2. Place the top of a riprap mat at the same elevation as the streambed. Placing the bottom of a riprap mat on top of the streambed is discouraged. In all cases where riprap is used for scour control, the bridge must be monitored during and inspected after high flows.

   It is important to note that it is a disadvantage to bury riprap so that the top of the mat is below the streambed because inspectors have difficulty determining if some or all of the riprap has been removed. Therefore, it is recommended to place the top of a riprap mat at the same elevation as the streambed.

   a. The thickness of the riprap mat should be three stone diameters (D_{50}) or more. In general, the bottom of the riprap blanket should be placed at or below the computed contraction scour depth.

   b. In some conditions, place the riprap on a geotextile or a gravel filter. However, if a well-graded riprap is used, a filter may not be needed. In some flow conditions it may not be possible to place a filter or if the riprap is buried in the bed a filter may not be needed.

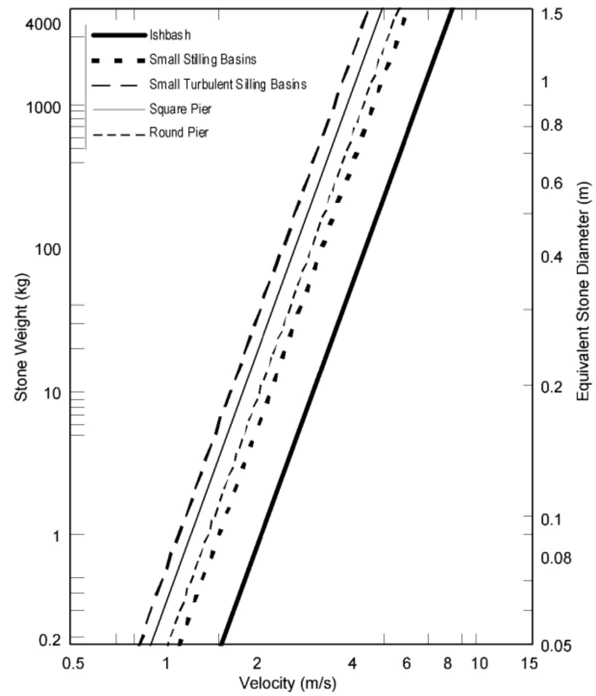
   c. The maximum size rock should be no greater than twice the D_{50} size.

8.4 LABORATORY TESTING OF PIER RIPRAP

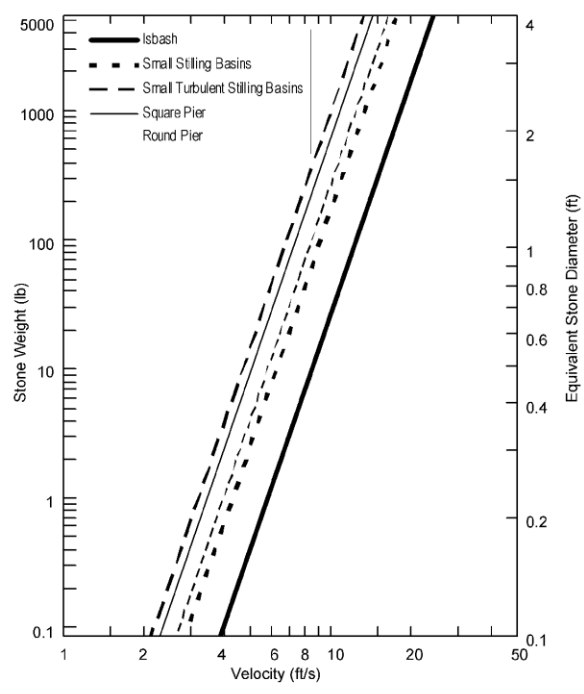
National Cooperative Highway Research Program (NCHRP) Project 24-7, "Countermeasures to Protect Bridge Piers from Scour," was completed in December 1998.[6,7] This project evaluated alternatives to standard riprap installations as pier scour countermeasures, as well as various riprap configurations, including:

- Riprap with prior excavation and with geotextile or granular filter
- Riprap without prior excavation but with geotextile or granular filter
- Riprap without prior excavation, without geotextile or granular filter

Based on laboratory testing, this study concluded that under flood conditions in sand bed streams, riprap placed in the absence of a geotextile or granular filter layer would gradually settle and lose effectiveness over time, even under conditions for which the riprap is never directly mobilized by the flow. This settling is due to deformation and leaching of sand associated with the passage of bed forms. Riprap performance can be considerably improved with the use of a geotextile, especially if the geotextile is sealed to the pier.[7] Design suggestions are provided in a User's Guide for various riprap configurations.[6]



(SI Units)



(English Units)

Figure 8.3. Effect of turbulence intensity on rock size using the Isbash approach.

8.7 SIZING ROCK RIPRAP AT ABUTMENTS

The FHWA conducted two research studies in a hydraulic flume to determine equations for sizing rock riprap for protecting abutments from scour.(8,9) The first study investigated vertical wall and spill-through abutments which encroached 28 and 56 percent on the floodplain, respectively. The second study investigated spill-through abutments which encroached on a floodplain with an adjacent main channel (Figure 8.6). Encroachment varied from the largest encroachment used in the first study to a full encroachment to the edge of main channel bank. For spill-through abutments in both studies, the rock riprap consistently failed at the toe downstream of the abutment centerline (Figure 8.7). For vertical wall abutments, the first study consistently indicated failure of the rock riprap at the toe upstream of the centerline of the abutment.

Field observations and laboratory studies reported in HDS 6(4) indicate that with large overbank flow or large drawdown through a bridge opening that scour holes develop on the side slopes of spill-through abutments and the scour can be at the upstream corner of the abutment. In addition, flow separation can occur at the downstream side of a bridge (either with vertical wall or spill-through abutments). This flow separation causes vertical vortices which erode the approach embankment and the downstream corner of the abutment.

For Froude Numbers $(V/(gy)^{1/2})$ < 0.80, the recommended design equation for sizing rock riprap for spill-through and vertical wall abutments is in the form of the Isbash relationship:

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)} \left[\frac{V^2}{gy} \right] \quad (8.2)$$

where:

D_{50} = median stone diameter, m (ft)
V = Characteristic average velocity in the contracted section (explained below), m/s (ft/s)
S_s = specific gravity of rock riprap
G = gravitational acceleration, 9.81 m/s^2 (32.2 ft/s^2)
Y = depth of flow in the contracted bridge opening, m (ft)
K = 0.89 for a spill-through abutment
1.02 for a vertical wall abutment

For Froude Numbers >0.80, Equation 8.3 is recommended:(10)

$$\frac{D_{50}}{y} = \frac{K}{(S_s - 1)} \left[\frac{V^2}{gy} \right]^{0.14}$$

(8.3)

where:

K = 0.61 for spill-through abutments
= 0.69 for vertical wall abutments

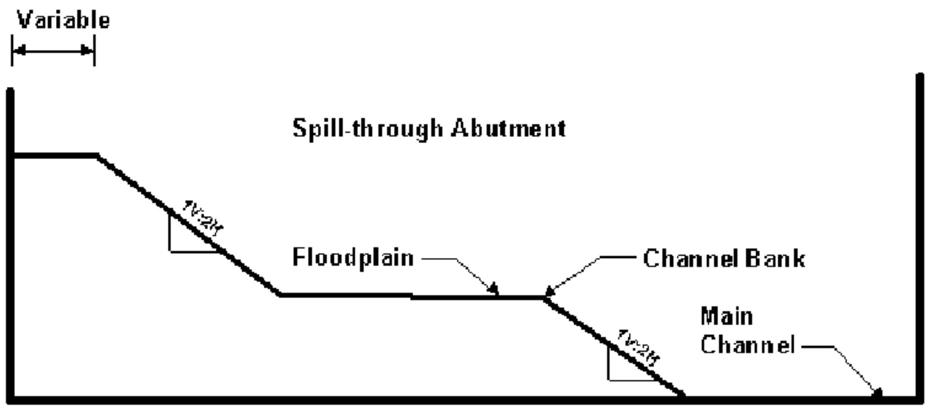


Figure 8.6. Section view of a typical setup of spill-through abutment on a floodplain with adjacent main channel.

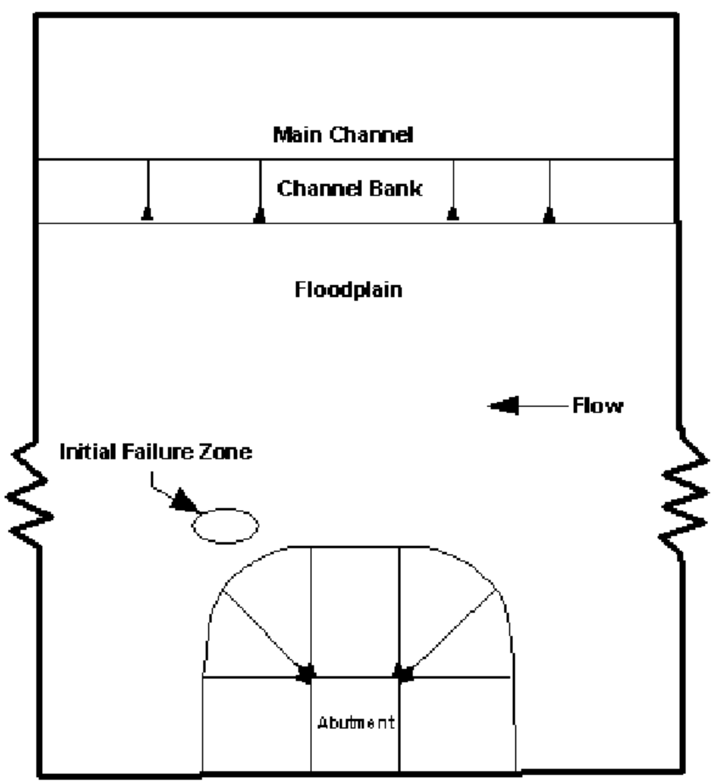


Figure 8.7. Plan view of the location of initial failure zone of rock riprap for spill-through abutment.

In both equations, the coefficient K, is a velocity multiplier to account for the apparent local acceleration of flow at the point of rock riprap failure. Both of these equations are envelope relationships that were forced to over predict 90 percent of the laboratory data.

A recommended procedure for selecting the characteristic average velocity is as follows:

1. Determine the set-back ratio (SBR) of each abutment. SBR is the ratio of the set-back length to channel flow depth. The set-back length is the distance from the near edge of the main channel to the toe of abutment.

   SBR = Set-back length/average channel flow depth

   a. If SBR is less than 5 for both abutments (Figure 8.8), compute a characteristic average velocity, Q/A, based on the entire contracted area through the bridge opening. This includes the total upstream flow, exclusive of that which overtops the roadway. The WSPRO average velocity through the bridge opening is also appropriate for this step.

   b. If SBR is greater than 5 for an abutment (Figure 8.9), compute a characteristic average velocity, Q/A, for the respective overbank flow only. Assume that the entire respective overbank flow stays in the overbank section through the bridge opening. This velocity can be approximated by a hand calculation using the cumulative flow areas in the overbank section from WSPRO, or from a special WSPRO run using an imaginary wall along the bank line.

   c. If SBR for an abutment is less than 5 and SBR for the other abutment at the same site is more than 5 (Figure 8.10), a characteristic average velocity determined from Step 1a for the abutment with SBR less than 5 may be unrealistically low. This would, of course, depend upon the opposite overbank discharge as well as how far the other abutment is set back. For this case, the characteristic average velocity for the abutment with SBR less than 5 should be based on the flow area limited by the boundary of that abutment and an imaginary wall located on the opposite channel bank. The appropriate discharge is bounded by this imaginary wall and the outer edge of the floodplain associated with that abutment.

2. Compute rock riprap size from Equations 8.2 or 8.3, based on the Froude Number limitation for these equations.

3. Determine extent of rock riprap.

   a. The apron at the toe of the abutment should extend along the entire length of the abutment toe, around the curved portions of the abutment to the point of tangency with the plane of the embankment slopes.

   b. *The apron should extend from the toe of the abutment into the bridge waterway a distance equal to twice the flow depth* ***** *in the overbank area near the embankment, but need not exceed 7.5 m (25 ft) (Figure 8.11).*(11)
   *** Please note that SHA uses different criteria to determine the extent of the riprap blanket. See Attachment 1**

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STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX E

GUIDELINE FOR OBTAINING SOIL SAMPLES IN STREAMS AND ON FLOOD PLAINS

THIS APPENDIX HAS BEEN SUPERCEDED BY APPENDIX B OF CHAPTER 14

May 2015

OFFICE OF STRUCTURES
STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX F

SCOUR EVALUATIONS AND ASSESSMENTS
FOR STATE AND COUNTY PROJECTS

May 2015

CHAPTER 11 APPENDIX F
SCOUR EVALUATIONS AND ASSESSMENTS FOR STATE AND COUNTY PROJECTS

SHA policy requires that a scour evaluation or assessment be performed and approved for any bridge or bottomless culvert over a waterway that is to be rehabilitated or replaced with Federal or State funds. Structures with paved bottoms (pipes, pipe arches, box culverts, etc,) do not require a scour evaluation. A scour evaluation is a detailed scour study to estimate scour depths at substructure foundations, and a scour assessment consists of a field and office review of plans and records to determine the degree of risk of scour damage. If the risk of scour damage is low, no further study is needed whereas if the risk is high, detailed scour evaluations or additional studies are needed. Action is needed to address and minimize the potential for scour damage and resulting risk to the public.

EVALUATING RISK

The evaluation of risk is an on-going process that is required for all bridges in Maryland (See the FHWA Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges; and the Office of Structures Guide for Completing Structure Inventory and Appraisal Input Forms – July 2003/currently under revision). Under the coding guide, structures currently coded as a 3 or lower for Item 113-Scour Critical Bridges would be considered as high risk, scour critical structures. Structures currently rated as a 5, 7 or 8 under Item 113-Scour Critical Bridges, may qualify as low risk structures, providing that the assessment process described on the following pages verifies that this rating is still valid and appropriate. In some cases, the installation of scour countermeasures, such as abutment riprap protection, may serve to permit a change in the classification of a structure to low risk. A summary of the item 113 codes is provided below:

Structures with the following code designations for Item 113 are not eligible for processing with a scour assessment:

- Scour critical bridges, Codes 0 – 3
- Temporary/ obsolete Code (T) – bridge over tidal waters
- Temporary/ obsolete Code (U) – non-Interstate bridge with unknown foundation conditions
- Temporary/obsolete Code 6 – Interstate Bridge with unknown foundation conditions.

Structures with the following code designations will not normally require a scour study:

- Code N –bridge not over waterway
- Code 9 – bridge foundations, including piles, on dry land well above flood waters.
- Code 8P – Bridge is a culvert-type structure with a paved bottom.

Structures with the following codes are determined to be stable and may be eligible for processing with a scour assessment:

- Code 4 (rare) – Structure determined to be stable but action is needed to protect exposed foundations. Scour assessment needs to address proposed measures to protect the exposed foundations.
- Codes 5A, 5B, 5C, and 8 – Structure determined to be stable due to a scour assessment or evaluation.
- Code 7 – Countermeasures have been installed to mitigate a previously existing problem with scour. Plan of Action has been implemented to reduce the risk to bridge users.

SCOUR EVALUATIONS

Chapter 11 of the OOS Manual of Hydrologic and Hydraulic Design provides detailed policies and procedures regarding the scour evaluation process and the design of scour countermeasures. The Manual is available on line at www.gishydro.eng.umd.edu. The latest version of the Manual and of associated computer programs is to be used in the conduct of the scour evaluation. Studies in support of the scour evaluation include:

- Hydrology Report
- Geomorphology Study
- Hydraulics (HEC-RAS) Study

The scope and content of these studies as well as the scour evaluation study itself should be comparable to the studies prepared by the OOS.

SCOUR ASSESSMENTS

For certain types of work such as deck replacements or minor superstructure rehabilitation projects which do not affect the foundations, a scour assessment, as compared to a scour evaluation, may be appropriate. This Appendix addresses scour assessments.

1. Purpose of the Scour Assessment: to obtain approval for use of Federal or State funds for certain types of work, such as a deck replacement or minor rehabilitation project, without having to conduct a full scour evaluation as set forth in Chapter 11 of the OOS Manual for Hydrologic and Hydraulic Design. The scour assessment serves to document and support a decision that the risk to the public of a structure failure due to scour is low.

2. Conduct of the Scour Assessment: The Office of Structures has developed Attachment 1 entitled "Scour Assessment Worksheet". It is applicable only to low risk projects where no previous detailed scour study has been made and where a full scour evaluation study is considered to be unnecessary by the bridge owner. It will need to be completed and submitted to the Office of Structures (along with appropriate supporting information) by the bridge owner with a determination that the risk of scour damage and resulting risk to the public is low. Concurrence by the Office of Structures is necessary prior to the start of any work on the project. The Office of Structures will normally arrange for a meeting with the representative of the bridge owner to review the scour assessment and the appropriate back-up information. Agreement should be reached as to the extent of back-

up information required prior to the meeting. In some cases, a meeting may not be necessary if the scour assessment clearly documents and verifies that there is no significant risk of scour damage associated with the structure.

The scour assessment worksheet serves to identify potential areas of concern common to most structures. For any particular structure, some of the items may not apply; conversely, there may be other items not listed that require assessment. The worksheet should be considered as addressing a minimum analysis for evaluating the risk of scour damage or failure of a bridge. For this reason, the worksheet lists items that **need to be addressed** in making a judgment about the stability and safety of a specific structure under review. Of particular interest are as-built plans and field inspections describing the foundation elements and the characteristics of the soil or rock supporting the foundations.

A scour assessment may be submitted only for structures currently rated as 4, 5, 7 or 8 under Item 113-Scour Critical Bridges, of the National Bridge Inventory. A review of office records, followed by a field visit is to be conducted to verify that conditions have not changed and that a structure rating of 5, 7 or 8 is still appropriate. Use the Word.doc file on the attached CD to facilitate the responses to the worksheet items (See Attachment 1).

3. If the scour assessment indicates that there is a significant risk of scour damage, a detailed scour evaluation, as discussed above, will need to be completed and approved prior to the start of any work on the project. If installation of scour countermeasures serves to minimize the potential for scour damage, this option may be considered in lieu of a scour evaluation.

ATTACHMENTS:

1. ATTACHMENT 1: Scour Assessment Worksheet
2. ATTACHMENT 2: Suggested Transmittal Letter for Submitting a Scour Assessment.

ATTACHMENT1
SCOUR ASSESSMENT WORKSHEET

DATE: _______

Please direct any questions you may have about the development and use of this worksheet to the Division Chief, Structure Hydrology and Hydraulics, telephone number 410-545- 8340

(Check and comment on each of the "boxes"; Use the Word.doc file on the attached CD to facilitate the responses to the worksheet items.)

1. **Detailed Description of Structure** (bridge, bottomless arch culvert, etc; Bridge Number; Highway route number, street name or other identifying nomenclature; Stream being crossed; Federal/State project number and location (county or city); Attach small scale location map.

2. Records Reviewed (check and comment on each item)

- ☐ Reviewers (See Item 11)
- ☐ Date(s) of Review
- ☐ Current and previous Inspection reports, including underwater inspections
- ☐ History of previous flood events, including the performance of the structure during these events (scour, overtopping, structural damage, etc.)
- ☐ Bridge plans and reports, including age of structure, information on type of foundations, elevations of spread footings, pile tip elevations, etc.
- ☐ Records of maintenance and repair work on foundations completed in the past
- ☐ Available soils borings, soil and rock classifications, thicknesses, etc.
- ☐ Description/photos of installed scour protection at piers and abutments
- ☐ Recent field Inspections of the structure and the stream being crossed.
- ☐ Other____

3. Field Inspection

- ☐ Field Inspectors – See Item 11
- ☐ Date(s) of Field Visits
- ☐ Photographs – include date taken; structure number and location photographed (i.e. downstream headwall)
- ☐ Summary of findings and observations (include field inspection report)

4. Highway classification and current ADT

5. Performance History of Structure (check and comment on each item)

- ☐ Date built
- ☐ No record of the occurrence of or damage due to scour
- ☐ History of performance during previous flood events (overtopping, incidence of scour and scour damage to structure)
- ☐ Scour issues noted on current bridge inspection and underwater inspection reports

6. National Bridge Inventory Rating Codes

- ☐ Item 60 Substructure ______________________
- ☐ Item 61 Channel and Channel Protection_______
- ☐ Item 71 Waterway Adequacy _______________
- ☐ Item 113 Scour Critical Bridges ______________

7. Foundation Plans Available (check and comment on each item)

- ☐ Abutment and Pier details
- ☐ Pile type; pile tip elevations if available. (Indicate details for each substructure element if pile type varies)
- ☐ Soil and rock classifications and borings
- ☐ Unknown foundations, if applicable

8. Substructure Elements – Abutment Foundations (list each abutment separately; check and comment on each item)

- ☐ Scour-resistant rock
- ☐ Piles driven to rock
- ☐ Deep piles
- ☐ Presently protected with scour countermeasure (describe condition)
- ☐ Unknown foundations, if applicable
- ☐ Other ____

9. Substructure Elements – Pier Foundations (list each pier separately; check and comment on each item)

- ☐ Scour-resistant rock
- ☐ Piles driven to rock
- ☐ Deep piles
- ☐ Presently protected with scour countermeasure (describe condition)
- ☐ Unknown foundations
- ☐ Other ____

10. Channel conditions (check and comment on all that apply)

- ☐ Channel is stable
- ☐ Complex channel conditions including high velocity flow, angle of attack on substructure elements, confluences, etc.
- ☐ Channel instabilities. (Discuss: scour/erosion of riprap; lateral movement of channel; headcutting and long- term degradation of channel bed under or near the structure, etc.)

11. Summary Comments in support of a finding of a low risk scour condition.

Summary of Findings:

Previous NBI Rating Code for Item 113, Scour Critical Bridges________

Revised NBI Rating Code for Item 113, Scour Critical Bridges________
(If changed during the scour assessment process)

Person (Name and Title) who determined that the structure is low risk:

Names and credentials of all reviewers (P.E.; Experienced Hydraulic Engineer, etc)

Date	Office Review (Name and credentials)	Field Review (Name and credentials)

12. Attachments

- ☐ Field Inspection Reports, including findings of inspectors
- ☐ Photographs
- ☐ Office Review Report, including plans and office records in support of the findings included in Items 4 through 10 above.

ATTACHMENT 2

Suggested Transmittal Letter for Scour Assessment

FROM: (Bridge Owner)

TO: (Office of Structures)

DATE:

SUBJECT**:** Scour Assessment Submission (Include highway route, bridge number street name or other identifying nomenclature and stream being crossed; Federal or State project number and location (county or city) for which funds are being requested)

My agency has conducted a scour assessment of the subject bridge in accordance with the procedures specified by the SHA Office of Structures. The Item 113 (Scour Critical Bridges) rating is ___. This corresponds to a low risk of scour damage and resulting safety hazard to the public. I request the concurrence of the Office of Structures in this determination. The Assessment Worksheet is attached, along with appropriate back-up information and details to support the conclusions presented in the scour assessment report.

____
Name and title

OFFICE OF STRUCTURES

STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX G

STREAM MORPHOLOGY STUDIES FOR STRUCTURE CROSSINGS ON SECONDARY (STATE/COUNTY) HIGHWAY SYSTEMS

OFFICE OF STRUCTURES

MAY 2015

CHAPTER 11 APPENDIX G
STREAM MORPHOLOGY STUDIES
FOR STRUCTURE CROSSINGS ON SECONDARY (STATE/COUNTY) HIGHWAY SYSTEMS

The Office of Structures continues to refine the project development process to assure that all significant aspects of hydrologic and hydraulic design are addressed. The reader is referred to the discussion in Chapters 3 and its Appendix (Policy) and Chapter 5 (Project Development) for an overview of the details involved in accomplishing these work tasks. The task of interest here concerns stream morphology.

In the conduct of a stream morphology assessment/study for a proposed bridge project, an understanding of the behavior and characteristics of the stream being crossed is needed in order to answer the following questions:

1. Will the proposed structure have an adverse impact on the morphology of the stream
2. Will the live bed or the clear-water scour mode occur at the structure for design conditions?
3. What is the potential for and anticipated depth of long-term channel degradation?
4. What is the potential for and extent of channel movement at the structure under consideration?

For proposed structures on secondary road systems, especially replacement or reconstruction projects on approximately the same alignment, consideration of stream morphology may not always be a significant issue. The Office of Structures suggests the following two alternative approaches for addressing questions about (1) the effect of the structure on the stream and its flood plain and (2) potential long-term changes to a stream on the stability of the structure:

A. <u>IN-HOUSE STUDIES</u>

A bridge owner may wish to evaluate these stream morphology questions using the in-house technical staff, particularly if they have had some training and experience in evaluating the behavior and characteristics of streams. We offer the following considerations for the conduct of such studies:

1. Will the proposed structure have an adverse impact on the morphology of the stream?

Guidance on answering this question is included in Chapter 14 – See rapid visual assessment.

Staff personnel may be able to conduct a preliminary study of a crossing site (described as a rapid visual assessment) in a one-day field trip. This study can serve the bridge owner in making a decision about the significance of stream morphology concerns in regard to the stability of the structure being evaluated and the potential impacts to the stream.

2. Will the live bed or the clear-water scour mode occur at the structure for design conditions? *Using the ABSCOUR program, evaluate scour for both live bed and clear water conditions, and select the more conservative values*

3. What is the potential for and anticipated depth of long-term channel degradation? *Use the guidance in the References listed below, particularly References A and B, to estimate long-term bed degradation at the structure. References A and B report on field studies conducted in the Blue Ridge and Western Piedmont Provinces to measure long term degradation. Reference B also provides a method that can be used to estimate long-term bed degradation at a structure. Additional guidance on long-term channel degradation will be available in the near future. In Phase 3, the Office of Structures has extended the sampling into urban regions (including impervious ground cover greater than 10%) of the Upland Section of the Piedmont Plateau Province in the following counties: Montgomery, Prince Georges, Baltimore, and Howard Counties. This study should be available by the end of FY 2015. In Phase 4, the long-term degradation study will be continued in Maryland streams in the Western Shore Coastal Plain in both urban and rural watersheds. In this project phase, we propose to extend the sampling into the Western Coastal Plain Province in the following counties: Prince Georges, Anne Arundel, Baltimore, Calvert, St. Mary's and Baltimore City.*

4. What is the potential for and extent of channel movement at the structure under con*sideration?*

- *For all channel and flood plain piers that could reasonably be affected by channel movement, estimate local pier scour for the worst case conditions, typically the conditions that exist in the thalweg of the channel; then compute total scour as per the ABSCOUR procedures.*
- *For abutments, use the procedure in ABSCOUR to evaluate scour for the condition where the channel moves into the abutment*

The bridge owner needs to exercise judgment in the application and review of any such studies to evaluate the approach used, the answers obtained, and to make sure that the results are reasonable for the given site conditions. The approaches discussed above may provide conservative answers.

CONSULTANT STUDIES

It may be helpful to obtain the recommendations of a specialist who has knowledge and experience in evaluating the aspects of stream behavior discussed above and their contributions to scour at the structure. Bridge owners may prefer to obtain the services of a qualified consultant to make these assessments.

Upon request during the project development process, the Office of Structures will be pleased to provide the following assistance to bridge owners who wish to obtain help with the conduct of stream morphology studies for State or Federal-aid highway/structure projects:

- Provide a list of stream morphologists/water resources engineers who have conducted acceptable studies for the SHA in the past,
- Provide assistance in handling the details involved with the preparation and financing of any contracts needed to approve the conduct of the stream morphology studies,
- Provide assistance in the review of the results of the stream morphology studies as they pertain to the evaluation of scour at the structure.

A stream morphologist may be able to conduct a preliminary study of a crossing site (described as a rapid visual assessment) in a one-day field trip at a nominal cost. This study can serve the bridge owner in making a decision about the significance of stream morphology concerns in regard to the stability of the structure being evaluated.

1. REFERENCES:

A. SHA Technical Report MD 11- SP909B4G, Long-Term Bed Degradation in Western Maryland Streams, March 2011, Arthur C. Parola Jr., Ward L. Oberholtzer, and David Black. See Chapter 14 of the H&H Manual, Appendix E

B. Long-Term Bed Degradation in Maryland Streams (Phase 2): Blue Ridge and Western Piedmont Provinces; Arthur C. Parola, Jr., Ward L. Oberholtzer, and David W. Black, March, 2012. . See Chapter 14 of the H&H Manual, Appendix E

C. Office of Structures Manual for Hydrologic and Hydraulic Design, Chapter 14 Stream Morphology, 2014 Update.

OFFICE OF STRUCTURES

STRUCTURE HYDROLOGY AND HYDRAULICS DIVISION

CHAPTER 11 APPENDIX H

Check List for Conducting Scour Evaluations and Scour Assessments for County Bridge and Bottomless Arch Culvert Projects

May 2015

Chapter 11 Appendix H
Check List for Conducting Scour Evaluations and Scour Assessments for County Bridge and Bottomless Arch Culvert Projects

The Office of Structures Manual for Hydrologic and Hydraulic Design contains detailed instructions and guidance for the conduct of scour evaluations and scour assessments. The scour evaluation requires a comprehensive report including hydrologic, stream morphology, hydraulic and bridge scour studies. The scour assessment study, on the other hand, is a simplified method for use on structures where there is a low risk of damage from scour. Its purpose is to demonstrate that the structure can be classified as a low risk structure.

There is a considerable amount of information set forth in the manual that needs to be obtained and applied in conducting scour evaluations and scour assessments. This check list has been developed for county engineers and their consultants for the purpose of presenting the scour evaluation process as a step by step procedure.

Please note that project development study results may not always be available in the order listed below.

Step 1- Preliminary Actions

a. Organize an interdisciplinary scour team
b. Determine the appropriate method for conduct of the scour study:
    - Scour assessment study – See H&H Manual, Chapter 11, Appendix F. If this method is appropriate, follow the guidance in Appendix F
    - Do not continue with this checklist.
    - Scour evaluation study: If a scour assessment study is not appropriate, continue with the scour evaluation study by going to step 2 below

Step 2 – Hydrology Study
Obtain information on the design flood for scour and the check flood for scour
References: Chapter 11 and Chapter 8

Step 3 – Highway Project Studies
Determine the design details regarding the following:

- Bridge foundation and superstructure geometry
- Types of foundation – spread footing, pile cap, etc,
- Borings and subsurface investigations regarding the characteristics of the stream channel and flood plain
- Approach road geometry and profile

Step 4 – Hydraulics Study
Use HEC-RAS to compute the water surface profile upstream of, through and downstream of the bridge for the design flood for scour and the check flood for scour. Important aspects of this study include:

- Downstream initial water surface elevations
- Accurate cross-sections and "n" values for the channel and flood plain
- Flow distribution between channel and flood plain, and between overtopping flows and bridge flows when appropriate.
- Flow velocities and depths at the approach section and at the bridge section.

Step 5 – Stream Morphology Study
There are three major items that need to be addressed with regard to the stream morphology study (See Chapter 11, Appendix G):

- Type of scour – live bed or clear water – if this cannot be determined, use ABSCOUR 10 to check for both conditions and use the one with the deepest scour
- Degradation – use the SHA research studies to estimate the degradation at the location of the bridge (See Chapter 11, Appendix G. and Chapter 14, Stream morphology Studies)

- Channel movement – If there is a potential for movement of the channel:
  - Analyze the pier for scour as if the pier were located at the channel thalweg.
  - Use the special procedure in ABSCOUR 10 to analyze the abutment for the condition that the stream thalweg moves into the abutment.
  - See Chapter 11 Appendix G

Step 6 – Scour Evaluation Study (ABSCOUR 10)

Use the information obtained in Steps 2 through 5 to fill out the data cards listed in the ABSCOUR 10 program. Consider the following guidance

- Import the HEC-RAS cross-sections to verify the accuracy of the selected ABSCOUR sections. Adjust ABSCOUR cross-sections to best fit the HEC-RAS sections at the approach section and the bridge.
- Verify that the hydraulic characteristic of the ABSCOUR sections are reasonable as compared with the HEC-RAS sections.
- Do not use override functions in the project information card for initial scour computations. These functions are available if evaluation of the scour computation results indicates the need for adjustment of the ABSCOUR computations.
- Print out the ABSCOUR 10 reports and note scour depths for abutments and piers. Include long-term degradation as appropriate. Print out the scour cross-section at the bridge.

Step 7 – Review

Review the scour computations and determine if they are reasonable. Use sensitivity analysis to check the relative importance of various factors affecting the degree of scour. This step will be important if certain information, such as soils data, may not be precise.