

Drainage	<i>Chapter</i> Bridges
	<i>Subject</i> General

DR 801-1 DEFINITION

Bridges are used to transport traffic over waterways or other obstructions. Hydraulically bridges are different than culverts because they generally use portions of natural or constructed channels to provide conveyance for water. As far as hydraulics is concerned, the bridge also includes approach roadway over the floodplain, relief openings and the bridge structure itself. This is necessary because of the importance of these items on the total hydraulic performance of the crossing.

Bridges are defined as a structure having an opening equal to or more than 20 ft as measured from inside face to inside face, along the center of the roadway.

DR 801-2 DESIGN CONSIDERATIONS

The following considerations are applicable to bridge design:

- The bridge design should provide a level of traffic service compatible with that commonly expected for the class of highway and compatible with projected traffic volumes. This is accomplished by sizing the structure such that the water surface elevations caused by the design storm do not inundate the roadway.
- Increases to water surface elevations should not cause damage to surrounding property. NFIP requirements are an important part of this consideration.
- When roadway inundation is determined to be acceptable, the crest vertical curve should be considered the preferred alternate for the crossing. This allows the approaches to provide conveyance for the flowing water, and keeps the bridge at a higher elevation, thus reducing the risk of a washout. If a crest vertical curve is not appropriate, the bridge designer should be made aware of the overtopping potential.
- The final design should not significantly alter the flow distribution in the stream or floodplain. Pier spacing and orientation as well as abutment alignment and shape should be designed to minimize flow disruption and potential scour.

-
- The structure should be designed with adequate clearance over the resulting water surface elevations for passage of ice and/or debris. For navigable waterways clearance must also be provided for navigational clearances. Coordinate this with the Division of Structural Design.
 - Degradation or aggradation of the stream and contraction and local scour should be estimated. Appropriate positioning of the foundation, below the total scour depth if practicable, should be included as part of the final design.
 - The bridge design should minimize disruption of ecosystems and values unique to the floodplain and stream.
 - Unstable stream reaches, such as braided streams and/or alluvial fans should be avoided for stream crossing sites if possible.
 - Certain projects may require relaxing some of the drainage criteria for economic reasons. This includes but is not limited to bridge replacement projects. Bridge replacements are often scoped to require little approach work. Also many existing bridges will have substantial amounts of overtopping flow. Designing these structures to eliminate overtopping flow may require significantly larger structures, and considerable approach work; which may exceed the scope of the project.
 - When overtopping flow is expected, the Division of Structural Design should be notified so that buoyancy forces can be accounted for in the design.

DR 801-3 SURVEYING

Hydraulic structures have unique requirements for collection of survey data. Bridges and other large drainage structures require the collection of more extensive data when compared to smaller pipes. See DR 1104 for more information.

DR 801-4 HYDRAULIC STRUCTURE TYPES

The hydraulic structures type used at a particular location is dependent on several factors. Often times this decision is between a culvert and a bridge. Generally speaking:

Culverts are used:

- where bridges are not hydraulically required,
- where debris and ice are tolerable, and
- where more economical than a bridge.

Bridges are used:

- where culverts cannot be used,

-
- where more economical than a culvert,
 - to satisfy land-use requirements,
 - to mitigate environmental harm caused by a culvert,
 - to avoid floodway encroachments, and
 - to accommodate ice and large debris.



<i>D</i>rainage	<i>Chapter</i> Bridges
	<i>Subject</i> Environmental and Permitting

DR 802-1 INTRODUCTION

The primary environmental impacts caused by bridges are a result of their intrusion into a stream channel. DR 506 discusses impacts to stream channels and how to quantify them.

As discussed in DR 801, there are several factors that go into the selection of a hydraulic structure type for a particular location. However, bridges generally cause a much smaller intrusion into a stream than culverts do. For this reason they usually cause smaller environmental impacts than culverts. As such, bridges may be used as an alternative to culverts to minimize the environmental impacts to a stream.

DR 802-2 PERMITTING CONSIDERATIONS

Bridges and culverts that impact streams require different types of permits. The Division of Environmental Analysis obtains and manages these permits (except for US Coast Guard Permits). However, the drainage engineer should have an understanding of them so the design of these projects can minimize the permitting and environmental issues.

Nearly all bridge and culvert projects that involve streams require permits from the United States Army Corps of Engineers and the Division of Water. Bridges over larger navigable streams also require a permit from the US Coast Guard. These permits are briefly discussed below. For more detailed information see HD 500 of the Highway Design Manual.

ARMY CORP OF ENGINEERS PERMITS

The United States Army Corps of Engineers (USACE) authorizes permits in accordance with Section 10 of the Rivers and Harbors Act of 1899 (33 USC 403) and Section 404 of the Clean Water Act (33 USC 1344). These permits are also referred to as 404 Permits.

Nationwide Permits are issued for specific activities that fall below certain thresholds. Instead of covering activities on a project by project basis, these permits cover specific activities. If the project impacts meet certain criteria, permit coverage is provided under these Nationwide Permits. The primary

Nationwide Permit pertaining to bridges and culverts is Nationwide Permit No. 14, "Linear Transportation Crossings." Bridges that cause less than 0.5 acre loss of waters or impact less than 500 linear feet of stream are automatically covered under this permit. Once these thresholds are exceeded, an Individual Permit is required. It should be noted that these impact thresholds are specific to USACE permits and are different than those discussed in DR 506. The quantification of stream impacts is discussed in DR 506.

Although "Linear Transportation Crossing" permits are the most common type for KYTC projects, there are other Nationwide Permits that cover some of the activities involved in a highway project. For more information on Nationwide and Individual Permits, refer to HD 504 of the Highway Design Manual.

DIVISION OF WATER - STATE WATER QUALITY CERTIFICATIONS

The Kentucky Natural Resources and Environmental Protection Cabinet, through the Division of Water, authorizes and issues these certifications in accordance with Section 401 of the Clean Water Act (33 USC 1341). These certifications are to be obtained before conducting any activity that discharges a pollutant into waters of the United States. For more information refer to HD 504 of the Highway Design Manual.

U. S. COAST GUARD PERMITS

The US Coast Guard has regulatory authority under Section 9 of the Rivers and Harbors Act of 1899, 33 USC 401 (delegated through the Secretary of Transportation in accordance with 49 USC 1655 (g)) to approve plans and issue permits for bridges and causeways across navigable rivers.

See SD 204 of the Structural Design Manual for more information on US Coast Guard Permits. Unlike the aforementioned permits, the Division of Structural Design coordinates and applies for these permits. Obtaining these permits could add more time to the design process.

DR 802-3 PROJECT DESIGN FOR MINIMIZATION

The drainage, bridge and roadway designer should be aware of the requirements for the various permits necessary for KYTC projects. Minimizing impacts during the design phase is both good for the environment, and can save money and time in the project design phase by:

- Keeping impacts to a level that is covered under a Nationwide Permit
- Avoiding mitigation fees
- Minimizing mitigation fees

See DR 500 for information on quantifying impacts to stream channels.



Drainage	<i>Chapter</i> Bridges
	<i>Subject</i> Bridge Hydraulics

DR 803-1 FLOW CLASSIFICATION

The open channel flow concepts discussed in DR 503 also apply to the hydraulic analysis of bridges. When analyzing bridge structures, open channel calculations are used to determine the hydraulics of the stream segments upstream and downstream of bridges.

Flow through a bridge structure is analyzed with open channel flow concepts when the water surface elevations are below the low chord. The low chord is the lowest portion of the superstructure (bottom of the lowest beam or girder, see DR 805-5). When the water surface elevations reach the low chord, pressure and weir flow concepts apply.

Flow through bridges is generally assumed to be steady gradually varying flow, or steady rapidly varying flow.

DR 803-2 HYDRAULIC MODELING (WATER SURFACE PROFILE MODELING)

It is impracticable to perform the hydraulic analysis for a bridge by manual calculations due to the flow complexities being simulated and the interactive, complex nature of the calculations involved. These analyses should be compiled using an appropriate computer program such as HEC-RAS. See DR 1102 for a more complete discussion on computer programs used for bridge analysis.

Flow through bridges may be computed using a one-dimensional or a two-dimensional model. A one-dimensional approach determines the flow rate through the bridge on the basis of the water surface elevations at the upstream and downstream sides of the structure assuming steady, gradually varied flow conditions. These models rely on the step-backwater analysis procedures described in DR 503-11 to calculate water surface profiles along the stream. One-dimensional models recognize flow only in the upstream-downstream direction: vertical and transverse velocity vector components are ignored.

When gradually varied assumptions are not valid, the methods are modified to account for the rapidly varying situations. This is commonly the case with flow through a bridge structure. Other methods may be used to calculate the hydraulics through the structures when gradually varied conditions do not apply. These other methods include: momentum theory, weir and orifice flow theory, and other empirical relationships.

Where conditions at the site depart significantly from the one-dimensional assumptions, a two-dimensional model may be considered. These conditions may include streams with broad floodplains where storage and acceleration effects could be substantial or where pressure flow in possible combination with overtopping flow may be present. The concepts involved in two-dimensional models are not discussed in this manual.

Although the most often used programs provide a one-dimensional solution, it is increasingly more practicable to use two-dimensional models such as FESWMS to analyze unsteady, rapidly varying flow conditions at hydraulic structures.

Detailed discussions on the methods used in the various hydraulic modeling software is reserved for the documentation provided with the individual software applications.

DR 803-3 FLOW TYPES

There are three types of open channel flow which may be encountered in bridge waterway design when the structure is not subject to pressure flow. Pressure flow occurs when the water surface elevation at the upstream face of the bridge is greater than or equal to the low chord of the bridge superstructure (See DR 805-5).

These open channel flow types are labeled Types I through III on Figure 803-1. The long dash lines shown on each profile represent normal water surface, or the stage the design flow would assume prior to placing a constriction in the channel. The solid lines represent the configuration of the water surface after the bridge is in place. The short dash lines represent critical depth, or critical stage in the main channel (Y_{1C} and Y_{4C}) and critical depth within the constriction, Y_{2C} , for the design discharge in each case. Since normal depth is shown essentially the same in the four profiles, the discharge, boundary roughness, and slope of channel must all increase in passing from type I to type IIA, to type IIB, to type III flow.

The basic hydraulic variables and flow types shown in Figure 803-1 are discussed below:

- Backwater (h_1) is measured relative to the normal water surface elevation without the effect of the bridge at the approach cross section (Section 1). It is the result of contraction and reexpansion head losses and head losses due to bridge piers. Backwater can also be the result of a “choking condition,” in which critical depth is forced to occur in the contracted opening with a resultant increase in depth and specific energy upstream of the contraction. This is illustrated in Figure 803-1.
- Type I flow consists of subcritical flow throughout the approach, bridge and exit cross sections and is the most common condition encountered in practice.

- Types IIA and IIB flows both represent subcritical approach flows that have been choked by the contraction resulting in the occurrence of critical depth in the bridge opening. In Type IIA, the critical water

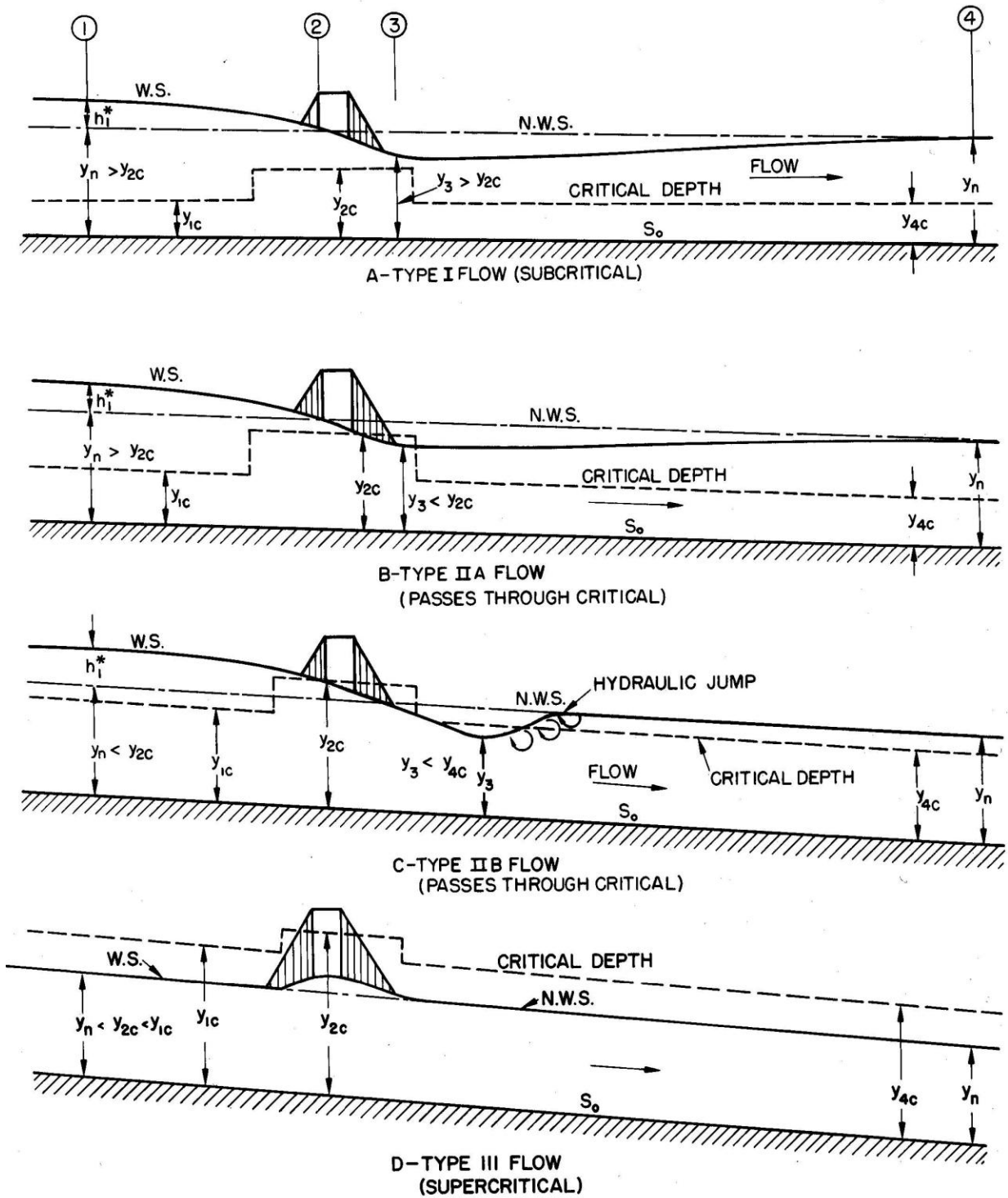


Figure 803-1
Bridge Flow Types

surface elevation in the bridge opening is lower than the undisturbed normal water surface elevation. In Type IIB, it is higher than the normal water surface elevation, and a weak hydraulic jump immediately downstream of the bridge contraction is possible.

- Type III flow is supercritical approach flow and remains supercritical through the bridge contraction. Such a flow condition is not subject to backwater, unless it chokes and forces the occurrence of a hydraulic jump upstream of the contraction.

DR 803-4 OVERTOPPING FLOW

As discussed in DR 605-4, roadway overtopping can provide a significant amount of flow conveyance through a hydraulic crossing. When overtopping flow is blocked by high approach grades, it forces all the flow through the bridge opening, causing the need for the structure opening to become larger. For low volume routes it may be more economical to keep the approach roadway at a low grade to allow for overtopping flow.

When overtopping flow is a part of the design of the crossing, the designer should consider perching the bridge above the approaches by keeping the approach roadway at lower elevation than that of the bridge structure. This allows for overtopping flow without submergence of the bridge, thus reducing the chances of damage to the bridge structure caused by hydraulic forces and/or drift.

DR 803-5 FLOW DISTRIBUTION & AUXILIARY OPENINGS

Existing flow distribution patterns should be maintained to the extent practical. To maintain flow distribution patterns, auxiliary waterway openings, or relief openings as they are commonly termed, may be needed for streams with wide floodplains. These openings will pass a portion of the flood flow in the floodplain when the stream reaches a certain stage. It does not provide relief for the principal waterway opening in the sense that an emergency spillway at a dam does, but it has predictable capacity during flood events. However, the hydraulics engineer should be aware that the presence of overtopping or relief openings may not result in a significant reduction in flow through the bridge opening.

Basic objectives in choosing the location of auxiliary openings include:

- maintenance of flow distribution and flow patterns,
- accommodation of relatively large flow concentrations on the floodplain,
- avoidance of floodplain flow along the roadway embankment for long distances,
- crossing of significant tributary channels, and
- accommodation of eccentric stream crossings.

A technological weakness in modeling auxiliary openings is in the use of one-dimensional models to analyze two-dimensional flow that results when using auxiliary openings. Although one-dimensional modeling will provide the desired accuracy for most bridge modeling analyses, two-dimensional models (e.g., FESWMS) may be used to provide a more adequate analysis of complex stream-crossing systems.

The most complex factor in designing auxiliary openings is determining the division of flow between two or more structures. If incorrectly proportioned, one or more of the structures may be overtaxed during a flood event. The design of auxiliary openings should usually be generous to guard against that possibility.

DR 803-6 PERFORMANCE CURVES

As discussed in DR 605, performance curves are representations of flow rate versus headwater elevations for a hydraulic structure. Performance curves can be used to help the designer understand the hydraulics for a full range of flows. This becomes especially important when examining the hydraulics involving overtopping flow and auxiliary openings.

DR 803-7 BRIDGE DECK DRAINAGE

The hydraulics of bridge deck drainage is the same as that of pavement inlet drainage. Bridge deck inlets are either through barrier (or curb) or through deck drains. Through barrier drains are analyzed as curb inlet openings and through deck drains are analyzed as grated inlets. Bridge deck drains should be located in a manner that limits the spread of water as discussed in DR 707. Generally speaking, deck drains are unnecessary for bridges with less than 2000 square feet of deck area. See DR 702-7 "Bridge Deck Inlets" for more information.

DR 803-8 BRIDGE END DRAINAGE

Drainage structures should be provided at bridge ends to collect water at the ends of the bridge structure. Water flowing from a bridge deck can be damaging to the adjacent slopes supporting the bridge end if it is simply released to flow down the slopes; for this reason is often necessary to collect the water on the downstream end of a bridge in controlled manner to avoid damage to the adjacent slopes on the end of the bridge. On the upstream end of a bridge, it is good practice to collect roadway drainage before it reaches the bridge end, to minimize the amount of water entering joints on the end of the bridge. Standard Drawings RBB 001 and 002 show standard bridge end drainage installations used on KYTC bridge projects.



Drainage	<i>Chapter</i> Bridges
	<i>Subject</i> Scour

DR 804-1 INTRODUCTION

Reasonable and prudent hydraulic analysis of a bridge design requires that an assessment be made of the proposed bridge's vulnerability to undermining due to potential scour. Because of the extreme hazard and economic hardships posed by a rapid bridge collapse, special considerations must be given to selecting appropriate flood magnitudes for use in the analysis. The hydraulics engineer must always be aware of and use the most current scour forecasting technology.

Scour prediction techniques used by KYTC are described in the FHWA publication HEC-18 "Evaluating Scour at Bridges." For further details on this topic, consult HEC 18.

DR 804-2 SCOUR TYPES

Present technology dictates that bridge scour be evaluated as interrelated components:

- plan-form change (lateral channel movement),
- long-term profile changes (aggradation/degradation),
- contraction scour/deposition, and
- local scour (abutment and pier scour).

DR 804-3 PLAN-FORM CHANGES

Plan-form changes are morphological changes resulting from stream stability issues (e.g., meander migration, bank widening). The lateral movement of meanders can threaten bridge approaches and increase scour by changing flow patterns approaching a bridge opening. Bank widening can cause significant changes in the flow distribution and thus the bridge's flow contraction ratio. Plan-form changes are discussed more thoroughly in DR 507.

DR 804-4 LONG TERM PROFILE CHANGES

Long-term profile changes can result from stream bed profile changes that occur from aggradation and/or degradation:

- Aggradation is the deposition of bedload due to a decrease in stream sediment transport capacity that results from a reduction in the energy gradient.
- Degradation is the scouring of bed material due to increased stream sediment transport capacity that results from an increase in the energy gradient.

Forms of degradation and aggradation may be considered as imposing a permanent future change for the stream bed elevation at a bridge site where they can be identified. Aggradation and degradation are also discussed in DR 507.

DR 804-5 CLEAR WATER AND LIVE BED SCOUR

There are two scour conditions: clear-water and live-bed scour. Clear-water scour occurs when there is no movement of the bed material in the flow upstream of the crossing. Live-bed scour occurs when there is transport of bed material from the upstream reach into the crossing. Live-bed local scour is cyclic in nature; that is, the scour hole that develops during the rising stage of a flood refills during the falling stage.

Some scour prediction methods differentiate between clear water and live bed scour, when determining local and contraction scour. However, the techniques described in HEC 18 only account for the difference between clear water and live bed when determining contraction scour. Pier and abutment scour equations are the same for both live bed and clear water scour.

DR 804-6 CONTRACTION SCOUR

Contraction scour results from a constriction of the channel. Typically, contraction scour occurs where a bridge opening is smaller than the flow area of the upstream channel and/or floodplain. Deposition can result from an expansion of the channel or the bridge site being positioned immediately downstream of a steeper reach of stream. Highways, bridges and natural channel contractions are the most commonly encountered cause of contraction scour.

Contraction scour is dependent on the flow rate, velocity, depth of flow and bed material size in the stream. Live bed and clear water contraction scour equations are given as equations 5.2 and 5.4 respectively in HEC 18.

DR 804-7 LOCAL SCOUR

Exacerbating the potential scour hazard at a bridge site are any abutments or piers located within the flood-flow prism. The amount of potential scour caused by these features is termed local scour. Local scour is a function of the geometry of these features as they relate to the flow geometry. However, the importance of these geometric variables will vary. As an example, increasing the pier or cofferdam width either through design or debris accumulation will increase the amount of local scour, but only up to a point in subcritical flow streams. After reaching this point, pier scour should not be expected to measurably increase with increased stream velocity or depth. This threshold has not been defined in the rarer, supercritical flowing streams.

PIER SCOUR

Pier scour is discussed in chapter 6 of HEC 18. The Colorado State Pier Scour Equation is recommended for computation of pier scour. This equation is presented as equation 6.1 in HEC 18. As can be seen from inspection of this equation, pier scour is dependant on flow geometry, pier shape, pier orientation, depth of flow, velocity, bed condition and bed material size.

ABUTMENT SCOUR

Abutment scour is discussed in chapter 7 of HEC 18. Two equations are given: Froehlich's Live Bed Abutment Scour Equation and HIRE Live Bed Abutment Equation. Although these two equations were developed based on live bed scour conditions, it is determined that they should also be used for clear water scour. Abutment scour as calculated by these equations is dependant on flow geometry, abutment shape, length of obstruction, depth of flow and velocity.

DR 804-8 TOTAL SCOUR ANALYSIS METHODS

Before the various scour forecasting methods for contraction and local scour can be applied, it is first necessary to:

1. Obtain the fixed-bed channel hydraulics,
2. If necessary, estimate the profile and plan-form scour or aggradation.
3. Adjust the fixed-bed hydraulics to reflect any changes determined in step 2.
4. Compute the bridge hydraulics.

Two methods are provided in this manual for combining the contraction and local scour components to obtain total scour. Method One should have application where more precise scour estimates are not deemed necessary. Method Two should be used when more precise scour estimates are deemed necessary.

METHOD ONE

This method is considered a conservative practice, because it assumes that the scour components develop independently. The potential local scour to be calculated using this method would be added to the contraction scour without considering the effects of contraction scour on the channel and bridge hydraulics. The general approach with this method is as follows:

- Estimate the natural channel's hydraulics for a fixed-bed condition based on existing conditions.
- Assess the expected profile and plan-form changes.
- Adjust the fixed-bed hydraulics to reflect any expected profile or plan-form changes.

-
- Select a trial bridge opening and compute the bridge hydraulics.
 - Estimate contraction scour using the empirical contraction formula and the adjusted fixed bed hydraulics. If the reach is expanding, estimate the deposition by “reversing” the empirical equation application and considering deposition as “negative” scour.
 - Estimate local scour using the adjusted, fixed-bed channel and bridge hydraulics.
 - Add the local scour to the contraction scour or aggradation (“negative” scour) to obtain the total scour.

METHOD TWO

This analysis method is based on the premise that the contraction and local scour components do not develop independently. As such, the local scour estimated with this method is determined based on the expected changes in the hydraulic variables and parameters due to contraction scour or deposition; i.e., through what may prove to be an iterative process, the contraction scour and channel hydraulics are brought into balance before these hydraulics are used to compute local scour. Additionally, with this method, the effects of any armoring may also be considered. The general approach for this method is as follows:

- Estimate the natural channel’s hydraulics for a fixed-bed condition based on existing site conditions.
- Assess any expected profile and plan-form changes.
- Adjust the natural channel’s hydraulics based on the expected profile and plan-form changes.
- Select a trial bridge opening and compute the bridge hydraulics.
- Estimate contraction scour or deposition.
- Once again, revise the natural channel’s geometry to reflect these contraction scour or deposition changes, and then again revise the channel’s hydraulics (repeat this iteration until there is no significant change in either the revised channel hydraulics or bed elevation changes—a significant change would be a ((five percent)) or greater variation in velocity, flow depth or bed elevation).
- Using the foregoing revised bridge and channel hydraulic variables and parameters obtained considering the contraction scour or deposition, calculate the local scour.
- Extend the local scour assessment below the predicted contraction scour depths to obtain the total scour.

DR 804-9 RETURN INTERVALS

The extreme hazard posed by bridges subject to bridge scour failures dictates a different philosophy in selecting suitable return intervals to use in the scour analysis.

With bridge flood hazards other than scour (e.g., those caused by roadway overtopping, property damage from inundation), a prudent and reasonable practice is to first select a design flood to determine a trial bridge opening geometry and check the design using a 100 year return interval.

With bridge scour, it is required to consider bridge scour from much larger return intervals. Experience has shown that when the overtopping flood return interval is less than a 100 year return interval, the overtopping flood will produce the most severe scour conditions. Therefore the bridge scour design is based on the 100 year flood when the overtopping flood is larger than the 100 year flood and it is based on the overtopping flood, when the overtopping flood is less than the 100 year flood. Bridge scour calculations are checked for the 500 year return interval.

DR 804-10 GEOTECHNICAL CONSIDERATIONS

In addition to the hydraulic information obtained through water surface profile modeling (See DR 803-2), scour calculations require information on the gradation of the bed material in the stream. This usually consists of the D_{50} and D_{95} values for the bed material. Requests for this information should be made through the Geotechnical Branch, Division of Structural Design.

Scour calculations made by the hydraulic engineer will be used by the geotechnical and bridge designers to design the foundation for the bridge structure. The scour calculations will be required on all wet crossings unless the Geotechnical Branch waives this requirement.

DR 804-11 COUNTERMEASURES

A countermeasure is defined as a measure incorporated into a highway-stream crossing system to monitor, control, inhibit, change, delay, or minimize stream and bridge stability problems.

Countermeasures for highway crossings are discussed in the FHWA publication HEC-23 "Bridge Scour and Stream Instability Countermeasures" (2009). Table 2.1, gives a listing of the various scour countermeasures that have been used for stream crossings.

There is distinction between new and existing structures as it pertains to the use of countermeasures. Countermeasures for new structures focus on design elements. Existing structures do not provide the opportunity to control the design elements, and therefore lend themselves to retrofitting techniques. There are several countermeasures listed in HEC 23, however countermeasures for new structures should be limited to the ones listed below:

- Foundation design (pier and abutment scour)
 - Founding shallow footings for hydraulic structures on solid non-erodible rock
 - Providing deep foundations that account for loss of scoured material for instances where piling or drill drilled shafts are used.
- Rip rap protection for spill through abutment slopes (abutment scour)
- Design Alternatives (pier, abutment and contraction scour)
 - Longer bridges
 - Relief bridges
 - Superstructures elevated above flood stages
 - Crest vertical curves, with overtopping approaches
 - Improved flow orientation at bridge (90 degrees)
 - Favorable pier shape and orientation

The countermeasures listed above are primarily intended to address scour as opposed to stream stability problems such as plan form changes. However, rip rap and foundation design can be used to mitigate stream stability problems as well. DR 507 has some further discussion on countermeasures for stream stability problems. The most effective countermeasure against stream stability issues is locating hydraulic structures in stable stream reaches.

PIERS

Due to their proximity to the main channel flow, countermeasures for new piers on KYTC projects are limited to foundation design and design alternatives as listed above. Experience has shown that armoring around these structures is not cost effective or reliable.

ABUTMENTS

Abutment scour problems can best be avoided by locating them outside of the main channel banks. When it is not practical to locate abutments out of the main channel, foundation design countermeasures are the most reliable solution.

All spill-through abutments involving wet crossings on KYTC projects shall have Cyclopean Stone Riprap Slope Protection or Class IV Channel Lining on the sloped surface inside the bridge. See Section 703 of the Standard Specifications, Section DR 805-3 of the Drainage Manual, Section SD 306 of the Structural Design Manual, and Standard Drawings RGX-100 and RGX105 for more information.

Design Guideline 14 in HEC-23 gives guidance on sizing rip rap at abutments. The equations in this design guideline are used to calculate the D_{50} required for the rip rap material to stay in place. The D_{50} value for Cyclopean Stone Riprap Protection as specified in the Standard Specifications for Road and Bridge Construction is 1.0'.

Inspection of equations 14.1 and 14.2 in Design Guide 14 reveal that at characteristic average velocities above 7 ft/s in combination with flow depths at the abutment above 2' can be problematic to rip rap protection with a D_{50} of 1.0'. When the characteristic average velocity and depth combination exceed these

thresholds, check to ensure that the required rip rap size does not exceed a D_{50} of 1'. If the required D_{50} is larger than 1' consider one (or a combination) of the following:

- Modify the bridge design to make the opening larger
- Pull the abutments back away from the channel
- Include special notes to include the use of larger rip rap protection. Use Design Guide 14 in HEC 23 to size the rip rap in this case.

The characteristic average velocity is dependant on how far back the abutments are set from the main channel. For a precise definition see Design Guide 14 in HEC 23.



Drainage	<i>Chapter</i> Bridges
	<i>Subject</i> Layout Considerations

DR 805-1 GENERAL

For wet crossings, the primary consideration when laying out a bridge is providing the proper hydraulic opening. In light of this, the drainage engineer is often the person developing the layout for the proposed bridge when there is a wet crossing involved. It is beneficial for the drainage engineer to have a general understanding of bridge components and layout considerations.

Generally bridge structures consist of a foundation, substructure and superstructure. The foundation is provided by bearing directly on solid surfaces such as rock, or by vertically driving pile or drilling shafts into the soil. The substructure includes the appurtenances above the foundation and below the beams or girders. Piers and abutments are typical substructure components. Finally the superstructure includes those items above the substructure. Beams, girders, diaphragms and the deck are common superstructure items.

The material in this section is intended to present basic information to aid the designer in laying out bridge structure and is not intended to replace the communication between the drainage engineer and the structural engineer. It is imperative that the drainage and structural engineer communicate throughout the bridge layout process. For detailed information on the various bridge components refer to the Structural Design manual.

DR 805-2 BRIDGE FOUNDATIONS

The type of foundation used for the various substructure components to bear on is dependant on the depth to available suitable rock strata. Generally this depth is measured by the vertical difference between the top of the suitable rock strata surface and the bridge seat (elevation where beams rest on the substructures). The Geotechnical Branch provides a report on all bridge structures. This report is a key component of the foundation design as it determines the depth and quality of available rock. Depending on where suitable rock is located, KYTC generally uses three foundation types:

- Spread footings on rock
- Piles or drilled shaft bearing on rock
- Piles or drill shafts supported by skin friction between the pile/shaft and the surrounding soil.

DR 805-3 BRIDGE SUBSTRUCTURE TYPES

The substructure bears on one of the foundation types described above and provides support to the superstructure components. Substructure components include piers and abutments. The various substructure types are discussed below.

WALL ABUTMENTS

Wall type abutments are continuous vertical walls that are constructed of reinforced concrete. These walls support the approach fill and provide a seat for the beams or girders.

Wall type abutments have foundations that bear on rock. Wall type abutments are generally not economical when the vertical distance from the foundation rock to the bridge seat exceeds 20'.

SPILL THROUGH ABUTMENTS

Spill through abutments consist of large concrete supports sitting on top of columns or piles. Since the columns or piles make an open structure for the concrete support, the earth material can "spill through" these piles or columns. These are the preferred abutment type for most bridges.

Most often, spill through abutments utilize piling for their foundations. This type of abutment is referred to as a Pile Bent Abutment or End bent. Furthermore, the concrete support is often poured around the beams to make the beam end and abutment integral. This is often called an Integral Pile Bent Abutment. This is the preferred spill through abutment type used by the Division of Structural Design, but needs to have a minimum vertical distance of 15' from the foundation rock to the bridge seat to provide lateral support for the piling.

PIERS

As far as the drainage engineer is concerned, the main component of a pier design is its width perpendicular to the flow and the shape of the nose of the pier. There is some limited guidance on pier width in the Structural Design Manual (See Exhibits SD 604 through SD 611), more detailed estimates can be determined by contacting the Division of Structural Design.

DR 805-4 BRIDGE SUPERSTRUCTURE TYPES

The location and spacing of substructure components is limited by the type of superstructure selected. The location of the substructure components and the total depth of the superstructure significantly impact the amount of hydraulic opening provided by a bridge.

Most KYTC superstructures are composite. This means that the deck and the beams or girders are tied together and act as one unit. The most common KYTC superstructure types are discussed individually below.

SIDE BY SIDE BOX BEAMS

This structure is constructed by placing box beams directly adjacent to one another. Usually a composite deck is poured on the tops of the beams for the final riding surface. However, the Division of Structural Design will entertain the use of these structures without a deck. This should only be considered for low volume roads with no anticipated truck traffic.

Standard KYTC box beams and their dimensions are shown in Standard Drawings BDP-007 through BDP-012. Available span lengths for these structures are shown on these drawings.

SPREAD BOX BEAMS

Spread box beam superstructures consist of a composite deck on top of precast prestressed concrete box beams that are separated by a fixed distance. Generally the deck is a little thicker than that of the side by side box beam superstructure, but it contains fewer beams. This serves to make them cheaper than the side by side box beam superstructures. This superstructure is very common and provides a good combination of small superstructure depth and good riding surface.

The beam length shown for the “CB” series beams in Standard Drawings BDP-007 through BDP-012 provide of a good approximation possible span lengths for these structures.

SPREAD CONCRETE “I” BEAMS

Spread concrete “I” beam superstructures consist of a composite deck on top of precast prestressed “I” beams that are separated by a constant distance. These are the most economical structure used by KYTC. However, because the beams are tall, the superstructures are generally deep. Details for standard KYTC “I” beams are available from the division of structural design. The table below shows the common “I” beams used by KYTC, as well as their depth and approximate span lengths.

KYTC Precast Prestressed Concrete “I” Beams		
Type	Depth (Inches)	Span (Feet)
2	36	60
3	45	80
4	54	100
5	60	120
6	66	130
7	72	140
8	78	150

SPREAD STEEL “I” BEAMS

Spread steel “I” beam superstructures consist of a composite deck on top of steel “I” beams that are separated by a constant distance. These superstructures are more costly than spread concrete “I” beams, but do offer longer span lengths. Span lengths for these superstructures range from 150’ to 550’.

Use the following table to approximate the beam depth for steel “I” beams:

Steel “I” Beam Depth	
Application	Depth (Feet)
Simple Span	1/25 x span length
Tail Span of a Multi-Span Bridge	1/25 x span length x 0.8
Interior Span of a Multi Span Bridge	1/25 x span length x 0.7

SLAB BRIDGES

Slab bridges consist of a single slab spanning between the substructure components. Since these structures do not have supporting beams, they do have limitations on span lengths. However they do compete well with 12” – 17” box beam bridges.

OTHER SUPERSTRUCTURE TYPES

The most common superstructure types used on KYTC projects were listed above. Other types include:

- Trusses
- Cable Stayed
- Box Girders
- Through Girders
- Post Tensioned Concrete Girders

These are generally used for large structures. For layout considerations involving these structures contact the Division of Structural Design.

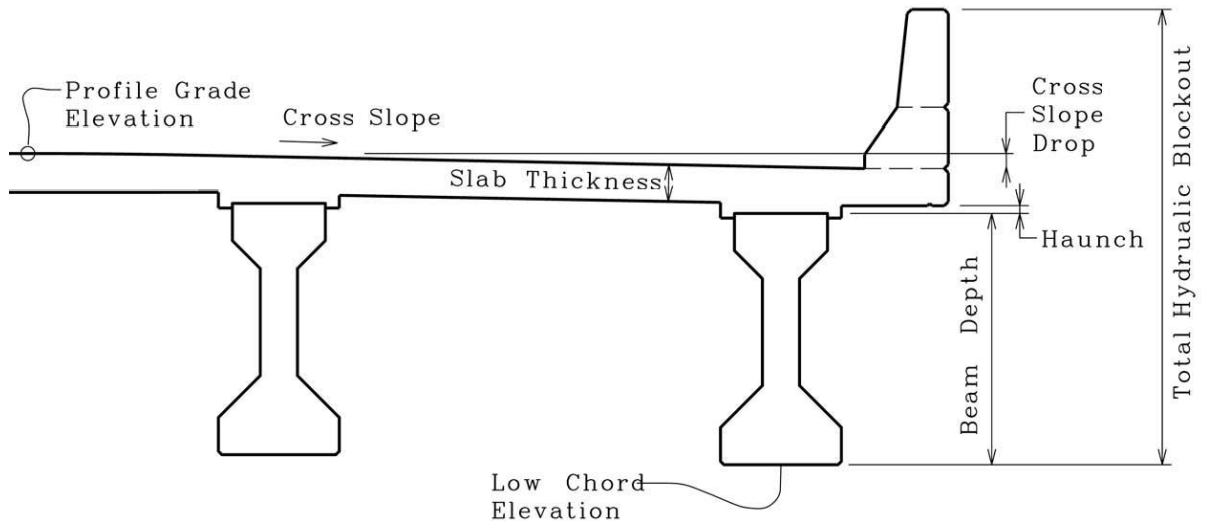
DR 805-5 STRUCTURE DEPTH CALCULATIONS

When determining the flow area and the resulting conveyance available at a bridge crossing, the total depth of the structure and the location of the low chord are extremely important. The low chord is the lowest portion of the superstructure (bottom of the lowest beam or girder). This low chord elevation is extremely important for determining the amount of flow area under a bridge and the available freeboard for passing debris.

Calculation of the low chord elevation begins at the profile grade line and proceeds to the lowest beam (See Figure 805-1). It takes into account the cross slope, slab thickness, haunch and beam depth. The basic equation is:

Low Chord Elevation = Profile Grade Elevation – Cross Slope Fall – Slab Thickness – Haunch (Usually 2") – Beam or Girder Depth

When a bridge is designed to overtop, the total profile thickness of the bridge that blocks conveyance is needed. This is shown in Figure 805-1 as the total hydraulic blackout.



**FIGURE 805-1
BRIDGE SECTION**

DR 805-6 BRIDGE AND SPAN LENGTHS

Use the following guidance when laying out and communicating the span arrangements to the Division of Structural Design:

- Show clear distances between the faces of abutments. The Division of Structural Design determines the official stationing of the abutments based on skew, beam type, expansion joint requirements and other considerations.
- Locate piers out of the main channel where possible. This may not be possible on large river crossings. The primary structural limitation to location of piers is due to the type of superstructure used. Coordinate this layout with the Division of Structural Design.
- When using spill-through abutments assume a 1' berm for dry structures and a 3' berm for wet structures. The berm for a bridge is the constructed portion of level surface on the inside of an abutment.

DR 805-7 OTHER BRIDGE LAYOUT CONSIDERATIONS

The following considerations should be applied if possible when developing bridge layouts:

- Due to costs and construction issues, curved bridges should be avoided if possible.
- Avoid superelevation transitions on bridges.
- Avoid superelevation rates greater than 6%.
- Avoid skews that are greater than 40 degrees.
- Sump drainage inlets should be avoided on bridge decks.
- Avoid longitudinal grades less than 0.5%.
- Provide maximum grades in accordance with the Highway Design Manual.



<i>D</i>rainage	<i>Chapter</i> Bridges
	<i>Subject</i> Design Procedures

DR 806-1 BRIDGE DESIGN PROCEDURE

I. Data Collection

A. Survey

- Topography
- Geology
- High-water marks
- History of debris accumulation, ice and scour
- Review of hydraulic performance of existing structures
- Maps and aerial photographs
- Rainfall and stream gage records
- Field reconnaissance
- Bridge maintenance files

B. Studies by other agencies

- Federal Flood Insurance Studies (FEMA)
- Federal Floodplain Studies by USACE, USGS and NRCS.
- State and Local Floodplain Studies
- Hydraulic performance of existing bridges
- USGS

C. Influences on hydraulic performance of site

- Other streams, reservoirs and water intakes
- Structures upstream or downstream
- Natural features of stream and floodplain
- Channel modifications upstream or downstream
- Floodplain encroachments
- Sediment types and bed forms
- Existing or proposed developments in the watershed
- Stream Stability issues

D. Environmental impact

- Floodplain land use and flow distribution
- Environmentally sensitive areas (fisheries and wetlands)

- E. Site-Specific Design Criteria
 - Preliminary risk assessment
 - Application of agency criteria
- II. Perform Risk Assessment and Determine Level of Analysis (See DR 807)
- III. Hydrologic Analysis
 - A. Watershed morphology
 - Drainage area (to be shown on map in Drainage Folder)
 - Watershed and stream slope
 - Channel geometry
 - B. Hydrologic computations
 - Discharge and frequency for historical flood that complements the high-water marks used for calibration
 - Discharges for specified frequencies
- IV. Hydraulic Analysis
 - A. Computer model calibration and verification
 - B. Hydraulic performance for existing conditions
 - C. Hydraulic performance of proposed designs
 - D. Scour computations
- V. Selection of Final Design
 - A. Measure of compliance with established hydraulic criteria
 - B. Consideration of environmental and social criteria
 - C. Design details (e.g., riprap, scour abatement, river training)
- VI. Documentation
 - A. Complete project records including form TC 61-100
 - B. Complete permit applications
 - C. Complete correspondence and reports

DR 806-2 SCOUR ASSESSMENT PROCEDURE

- Step 1 Decide which analysis method is applicable (Method 1 or Method 2). See DR 804-8.
- Step 2 Determine the magnitude of the 100 year flood and the overtopping flood. Accomplish Steps 3 through 12 using the:
 - 100 year flood if - overtopping flood > 100 year flood
 - Overtopping flood if – overtopping flood < 100 year flood

-
- Step 3 Determine the bed material size that will resist movement and cause armoring to occur.
- Step 4 Develop a water surface profile through the site's reach for fixed-bed conditions. It should now be possible to establish a water surface profile and perform subsequent bed-form change and/or bridge scour calculations with a single tool. The USACE "HEC-RAS" software package is intended for just such an application. It includes quasi two-dimensional flow, sediment transport and scour analysis capabilities while also establishing a water surface profile.
- Step 5 Assess the bridge crossing reach of the stream for profile bed scour changes to be expected from degradation or aggradation. Again, consider past, present and future conditions of the stream and watershed to forecast what the elevation of the bed might be in the future. Certain plan-form changes (e.g., migrating meanders causing channel cutoffs) would be important in assessing future streambed profile elevations.
- Assess the possibility of downstream mining operations inducing "headcuts". The quickest way to assess streambed elevation changes due to "headcuts" (degradation) is by obtaining a vertical measurement of the downstream "headcut(s)" and projecting that measurement(s) to the bridge site using the existing stream profile.
- A more time-consuming way to assess elevation changes would be to use some form of sediment routing practice in conjunction with a synthetic flood history.
- Step 6 Assess the bridge crossing reach of the stream for stream stability changes as discussed in DR 507. Attempt to forecast whether an encroaching meander will cause future problems within the expected service life of the road or bridge. Consider past, present and expected future conditions of the stream and watershed to forecast how such meanders might influence the approach flow direction in the future. The sediment routing practice for computing channel contraction scour or aggradation may prove useful in making such assessments—particularly if coupled to a synthetic flood history. This forensic analysis on a site's past geomorphological history to forecast the future may prove useful. Otherwise, this assessment has to be largely subjective in nature.
- Step 7 Based on the expected profile and plan-form scour changes, adjust the fixed-bed hydraulic variables and parameters.
- Step 8 Obtain D_{50} and D_{95} values for the bed material from the Geotechnical Branch

-
- Step 9 Assess the magnitude of channel or bridge contraction scour using Method One or Method Two based on the fixed-bed hydraulics of Step 7.
 - Step 10 Assess the magnitude of local scour at abutments and piers using Method One or Method Two.
 - Step 11 Plot the scour and aggradation depths from foregoing steps on a cross section of the stream channel and floodplain at the bridge site. Using judgment, enlarge any overlapping scour holes. Treat any aggradation as a negative scour.
 - Step 12 Evaluate the findings of Step 11. If the scour is unacceptable, consider the use of scour countermeasures as discussed in DR 804-10, or revise the trial bridge opening and repeat the foregoing steps.
 - Step 13 Once an acceptable scour threshold is determined, the geotechnical engineer can make a preliminary foundation design for the bridge based on the scour information obtained from the foregoing procedure. The structural engineer should evaluate the lateral stability of the bridge based on the foregoing scour.
 - Step 14 Repeat the foregoing assessment procedures 500 year flood discharge. These findings are again for the geotechnical engineer to use in evaluating the foundation design obtained in Step 13.



Drainage	<i>Chapter</i> Bridges
	<i>Subject</i> Design Criteria

DR 807-1 RISK ASSESSMENT

A risk assessment shall be required for all crossings classified as bridges as defined in DR 801. A risk assessment will determine the risks and required level of hydraulic analysis necessary for a highway bridge project. The risk assessment form is shown in Exhibit 800-1. This form is required for all bridge projects, and should be included in the Drainage Folders.

The primary goal of a Level 1 analysis is to determine if a bridge project will have any significant hydraulic impacts to a stream without performing a detailed analysis. A Level 1 analysis will only be adequate for bridge replacement projects. If all of the answers to the questions in the Level 1 block of the form are no, then a Level 1 analysis is adequate and the structure is replaced with an equivalent structure. If the answer to any of the questions in the Level 1 block is yes, a Level 2 analysis will be required.

Equivalent structure means same hydraulic opening without a significant increase in the grade of the roadway above the structure. This increase is limited to the allowable increase as described in DR 204.

Replacing the structure with an equivalent structure ensures that the new bridge will convey the same amount of water (both through the bridge and overtopping the road) that the existing bridge does without impacting water surface elevations.

Other factors related to FEMA requirements can necessitate a Level 2 analysis. Also, a scour analysis may also be necessary for geotechnical foundation design (contact the Geotechnical Branch), or to satisfy National Bridge Inspection Standards (contact the Division of Maintenance). If a scour analysis is needed it will necessitate a Level 2 analysis.

As noted above, a Level 2 analysis is required when the answer to any of the questions in the Level 1 block are Yes. A Level 2 analysis requires the use of water surface profiles (See DR 803) and scour analyses (See DR 804). A determination of the need for a stream stability analysis is also needed for a Level 2 analysis (See DR 507). The level of analysis concept is also used in evaluating stream stability; however there are no formal procedures to determine the level of stream stability analysis required.

A Level 3 analysis is used in unusually complicated projects. A level 3 analysis may be required in complex crossings where two-dimensional modeling is warranted or when modifications to and existing floodway are being considered.

DR 807-2 DESIGN STORM ALLOWABLE HEADWATER

Headwater elevations calculated for the design storm should maintain 2' of freeboard below the low chord (See DR 805-5) of the bridge structure and should not inundate the road. Return intervals used for the design storm are discussed in DR 401 "Return Intervals". Larger storms are used for the design storm for roads with higher ADT's.

For low volume routes, the design team can allow the 2' freeboard and road inundation criteria to be disregarded and allow the design storm to overtop the road as discussed in DR 803-4. This decision must be documented in the project's Drainage Folders.

When replacing an existing bridge with a new bridge, it is good practice to keep the design storm headwater elevation for the proposed bridge at a level that is equal to or less than the design storm headwater elevation for the existing bridge.

DR 807-3 CHECK STORM ALLOWABLE HEADWATER ELEVATION

Evaluation of the check storm headwater elevation is required primarily to assess the impacts to surrounding property. Potential damage to adjacent property or inconvenience to owners should be of primary concern when establishing allowable headwater elevations for the check storm. In urban areas, the potential for damage to adjacent property is greater because of the number and value of properties that can be affected.

The allowable headwater elevations for the check storm are based on acceptable increases in the elevation of the water surface. These allowable increases apply to every point on the water surface profile calculation for the project. When reporting these increases in the drainage folders, record the largest increase in the entire water surface profile resulting from the structure. This will usually be just upstream of the structure. The check storm evaluation is based on a 100 year return interval, which is referred to as the Base Flood in FEMA studies.

BRIDGES SUBJECT TO NFIP REQUIREMENTS

Projects that encroach on FEMA mapped floodplains are subject to National Flood Insurance Program Requirements (NFIP). KYTC Floodplain Management Criteria as discussed in DR 204 are designed to ensure that KYTC projects follow NFIP criteria. KYTC Floodplain Management Criteria apply to crossings that:

- Have a drainage area larger than one square mile or,
- Encroach onto floodplains that are shown on an NFIP map.

Because of the hydraulic size of bridges, nearly all bridge projects will be subject to KYTC Floodplain Management Criteria. When projects are subject to KYTC Floodplain Management Criteria, ensure that the impacts to water surface elevations are within the allowable increase limits described in DR 204. See DR 204-8 for a discussion on determining the amount of allowable increase. The allowable increase is dependent on several items. Below is a summary of the allowable increases for projects as discussed in DR 204:

- For projects that encroach onto to FEMA mapped floodways the allowable increase is Zero (0).
- For projects that encroach onto a FEMA mapped floodplain, but do not encroach on a floodway as shown on the FEMA map; the allowable rise criteria is satisfied without further analysis.
- For project that encroach onto FEMA mapped floodplains, with no floodway shown on the map, the allowable increase will be one of the following:
 - Defined by local ordinance
 - One (1) foot for projects not subject to a local ordinance
- For projects that encroach on unidentified floodplains the allowable increase will be one (1) foot, notwithstanding the exception noted in DR 204-9.

BRIDGES NOT SUBJECT TO NFIP REQUIREMENTS

There are no specific allowable increases to the 100 year headwater elevations for bridges not subject to NFIP requirements. However, the designer should be aware of the affects of any increases in these elevations over the existing conditions. Significant increases that could damage surrounding property shall be avoided. Minor increases that could inconvenience surrounding property owners may require the purchasing of drainage easements or right way.

BRIDGE REPLACEMENTS

When replacing an existing bridge with a new bridge, it is good practice to keep the check storm headwater elevation for the proposed bridge at a level that is equal to or less than the check storm headwater elevation for the existing bridge.

DR 807-4 SITE SPECIFIC ALLOWABLE HEADWATER ELEVATIONS

Other special consideration may be used on a case by case basis to determine additional limits for allowable headwater. These considerations are primarily based on limiting damage to adjacent property. It is not required to develop these site specific criteria, but they may have applications on certain projects.

As an example, a cultivated field may be situated just above the calculated 10 year storm in the existing conditions. The project team can elect to limit the 10 year storm headwater elevations for the proposed conditions to an elevation that is below the field.

These special considerations should be documented in the Drainage Folders and project meeting minutes.

DR 807-5 FLOW DISTRIBUTION

The conveyance of the proposed stream-crossing location shall be calculated to determine the flow distribution and to establish the location of the bridge opening(s). At a minimum, the flow distribution should be divided into the left overbank, main channel and right overbank. The proposed facility shall not cause any significant change in the existing flow distribution. Relief openings in the approach roadway embankment or other appropriate measures should be investigated, if there is more than a 15 percent redistribution of flow.

DR 807-6 SCOUR

Bridge foundations shall be designed considering scour from the 100 year storm (if the 100 year storm is less than the overtopping storm) or the overtopping storm (if the overtopping storm is less than the 100 year storm). Bridge foundations designs shall be checked for scour using the 500 year storm. Once the designer performs these scour calculations the results shall be provided to the structural and geotechnical engineers.



County:	Route:	Station:
UPN:	FPN:	Item No:

LEVEL 1 - Qualitative assessment involving the application of hydrologic, hydraulic, and geomorphic factors to identify potential problems and alternative solutions for bridges. Perform hydrologic analysis and field survey (i.e. bridge opening, roadway profile, stream profile, hydraulic sections, etc).

Review (check) available documentation:

<input type="checkbox"/> County Soils Study	<input type="checkbox"/> Bridge Maintenance File	<input type="checkbox"/> Bridge Plans
<input type="checkbox"/> Flood Insurance Study	<input type="checkbox"/> Old Drainage Folder	<input type="checkbox"/> Flood Insurance Maps
<input type="checkbox"/> USACE Study	<input type="checkbox"/> Geologic Maps	<input type="checkbox"/> Roadway Plans
	<input type="checkbox"/> USGS Study	Other: _____

- Is the proposed structure a new crossing? Yes No
- Is the proposed bridge > 2 bridge widths up or downstream of the existing bridge, > 50 feet long (total bridge length) multispan, > 100 feet long (single span)? Yes No
- Does the proposed bridge have a grade increase that is larger than the allowable increase? Yes No
- Is the proposed bridge in a FEMA Detailed Study Area? Yes No
- Is the proposed bridge in a mapped Floodplain where the community is requesting the development of BFE's? Yes No?
- Is a scour analysis needed Yes No?

Replace with hydrologically, hydraulically, and geomorphically equivalent structure. If all issues are addressed with the equivalent structure document design. If there are outstanding issues that cannot be resolved with a Level 1 analysis, go to Level 2.

LEVEL 2 -Quantitative analysis combined with a more detailed qualitative assessment of the hydrologic, hydraulic, and geomorphic factors of the stream. Generally includes water surface profile and scour calculations.

List Design Controls (i.e. hydraulic, roadway, structure, surrounding property, etc.):

Perform hydraulic analysis and scour analysis. Evaluate stream stability.

If the answer to either of the following 2 questions is Yes, go to LEVEL 3.

Is the deck area >120,000 ft²? Yes No

Is the existing or proposed structure a unique bridge, foundation, etc.? Yes No

Design structure to meet the design controls. If design controls are met, document design. If there are outstanding issues that cannot be resolved with a Level 2 analysis, go to Level 3.

LEVEL 3 -Complex quantitative analysis based on detailed mathematical modeling and possibly physical hydraulic modeling. This analysis is necessary only for high risk locations, extraordinarily complex problems, and after the fact analyses where losses and liability costs are high.

Check if used: FESWMS Analysis Floodway Modification* Overflow structure(s)
 Risk Analysis Other: _____

Document Design.

*IF Existing Floodway Width < Proposed, Purchase Floodway Increase. If Existing Floodway Elevation < Proposed, Purchase Floodplain Increase.