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Hydraulic Considerations for Shallow Abutment Foundations

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ABSTRACT

The Federal Highway Administration published a Technical Brief that provides programmatic and technical considerations for evaluating and mitigating abutment scour at bridges with shallow foundations. The Technical Brief describes how scour may impact shallow abutment foundations at bridged waterways and provides design recommendations to protect at-risk shallow abutment foundations from scour (scour countermeasures) and identifies the major hydraulic components that, when properly considered, will provide greater assurance that the shallow abutment foundation will perform as intended. The Technical Brief illustrates the recommended bridge hydraulic and scour design process applicable to shallow abutment foundations and reflects the necessary multi-disciplinary approach. The document provides explanations on the scour related components, evaluations, and analyses associated with the new approaches and improvements.

INTRODUCTION

The Federal Highway Administration (FHWA) has oversight for over 616,000 publicly owned bridges, of which about 461,000 span waterways. Oversight responsibilities include administrating FHWA's Scour Program, in part, through the National Bridge Inspection Program.

Scour is defined as 'Erosion of streambed or bank material due to flowing water; often considered as being localized around piers and abutments of bridges.' (23 CFR 650.305) Bridges with foundation elements that are or have the potential to be unstable for the observed or evaluated scour condition are label as 'scour critical'. These bridges' criticality is mitigated through the development and implementation of Plans of Action (POAs).

Additionally, FHWA's Scour Program includes research initiatives that are, in part, aimed at the protection of at-risk shallow abutment foundations from scour. The 'Hydraulic Considerations for Shallow Abutment Foundations' TechBrief (1) represents over 4 years of comprehensive research by FHWA and others on abutment scour and the performance of various abutment scour countermeasure designs. The research insights and outcomes apply to both new and existing bridges.

Specifically, for shallow foundations, the TechBrief provides information of hydraulic considerations and processes; scour components, evaluations, and analyses; and scour countermeasure design and details that dramatically affect the existing design procedures in FHWA Hydraulic Engineering Circular No. 18, "Evaluating Scour at Bridges", 5th edition (HEC-18) and No. 23 "Bridge Scour and Stream Instability Countermeasures", 3rd edition (HEC-23). The TechBrief provides images intended to help convey important aspects of such information.

BACKGROUND

Creating a National Bridge Inspection Program. As a result of the collapse of the Silver Bridge over the Ohio River at Point Pleasant, West Virginia, Congress passed legislation requiring FHWA to create a National Bridge Inspection Program (NBIP) and implement, oversee, and maintain the National Bridge Inspection Standards (NBIS) (2).

To comply, FHWA wrote NBIS regulations to ensure the safety of U.S. in-service highway bridges (2). The NBIS achieves this through comprehensive standards for State inspection programs. FHWA is responsible for leading the inspection program, primarily through maintaining effective inspection standards and verifying State compliance with the NBIS.

FHWA's Scour Program. The scour induced collapse of New York's I-90 Schoharie Creek Bridge and the lateral scour migration that led to the collapse of Tennessee's Hatchie River Bridge, gave impetus for FHWA to address the threat of scour-related failure of bridge foundations. Clearly, FHWA and transportation community recognized a need for scour research. The September 16, 1988 publication of TA 5140.20 *"Scour at Bridges"*(3) established a national scour evaluation program as an integral part of NBIS (3). Additionally, a November 18, 1988 FHWA policy memorandum (4) introduced a new regulatory NBI data collection item "113" named "Scour Critical Bridges".

This regulatory addition, combined with TA 5140.20 resulted in the first, formal FHWA Scour Program. The program included conducting scour evaluations, addressing scour critical bridges, identifying bridges with unknown foundations, developing POAs for scour critical and unknown foundation bridges, as well as selecting reasonable and appropriate countermeasures for bridges determined to be scour critical or having unknown foundations.

A New Approach. In 2012, FHWA instituted new design approaches as well as a NBIP oversight approach, applying risk/data to develop strategies, including a "new" Scour Program. Bridge owners compare bridge importance and likelihood or consequence of failure (risk component) against a suite of facility specific operational characteristics (data component). Engagement of the new design approaches as well as the NBIP allow FHWA to leverage resources needed to refine, implement, and oversee efforts to assure structural integrity and public safety of the nation's bridges. FHWA strives to enhance both safety and effective use of resources. The new Scour Program builds on this strategy, so that bridge owners can place greatest level of effort on areas with the most important needs.

Every Day Counts Initiative. The Every Day Counts (EDC) program is an initiative conceived by the Federal Highway Administration (FHWA) designed to identify and deploy the latest technologic innovation aimed at shortening project delivery, enhancing the safety of our roadways, and protecting the environment.

Geosynthetic reinforced soil-integrated bridge system (GRS-IBS) technology was introduced in EDC 1 in 2011 and continued in EDC 2. GRS-IBS was a proven system that can help meet the country's demand for small, single-span bridges by delivering low-cost, durable structures that can be built with readily available equipment and materials. A GRS-IBS project can be built in weeks instead of months, saving time and cutting work zone congestion. While this application is attractive to many owners since they can be constructed with the owners' own staff, addressing potential scour was not consistently considered by all owners. This may also be a concern for other types of bridges whose abutments are founded on shallow abutment foundations.

Because of this risk, comprehensive research by FHWA and others was conducted on abutment scour and the performance of various abutment scour countermeasure designs. The research insights and outcomes apply to both new and existing bridges.

FHWA 'HYDRAULIC CONSIDERATIONS FOR SHALLOW ABUTMENT FOUNDATIONS' TECHNICAL BRIEF

Historically, FHWA has provided updates to our hydraulics-related guidance documents (EX. HEC-18 and HEC-23) to incorporate the results of successful research findings and other best practices for use by designers, however this process often takes 2-3 years for final publication of the updates. FHWA recently began using Technical Briefs as a means to provide programmatic and technical considerations and processes for the users to consider in their designs, without the encumbrances of the revision process. Information included in these TechBriefs will ultimately be included in future updates to FHWA's guidance documents.

A shallow foundation is a type of structure foundation that transfers structure loads to the earth very near the surface, rather than to a subsurface layer or to a range of depths as does a deep foundation.

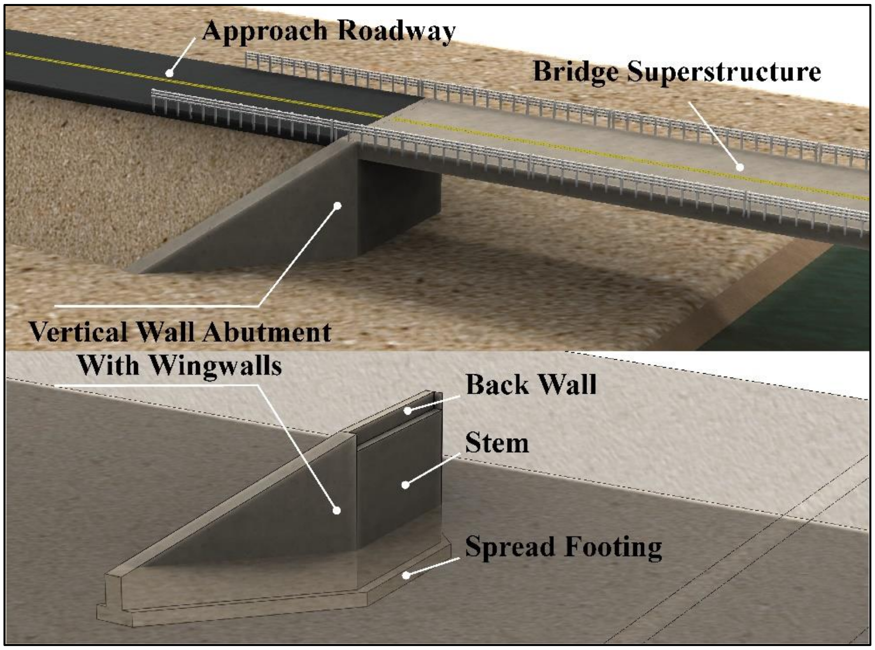

Figure 1: Typical Shallow Foundation Abutment.

FHWA recognized that scour was not consistently being considered for bridges with shallow abutment foundations and our guidance documents lacked updated direction for designers of shallow abutment foundations. This TechBrief represents over 4 years of comprehensive research by FHWA and others on abutment scour and the performance of various abutment scour countermeasure designs. The research insights and outcomes apply to both new and existing bridges. The following research projects are the basis of this TechBrief:

- FHWA-HRT-17-013, "Shallow Foundations for the Support of Vertical-Wall Bridge Abutments: Interaction between Riprap and Contraction Scour" (FHWA, 2017a). (5)
- NCHRP 24-20, Draft Final Report, "Estimation of Scour Depth at Bridge Abutments" (NCRHP, 2010). (6)

Superseded and Updated Materials. The TechBrief information related to shallow abutment foundations supersedes related information in:

- Hydraulic Engineering Circular (HEC) No. 18, "Evaluating Scour at Bridges," 5th edition, (HEC-18) (FHWA, 2012a). Specifically:
  - o TechBrief section 3.1 "Scour Analyses" replaces HEC-18, Chapter 2, Section 2.2, Page 2.5, Step 7, #2 "Spread Footing on Soil – Abutment."
- HEC No. 23 "Bridge Scour and Stream Instability Countermeasures," 3rd edition, (HEC-23) (FHWA, 2009). Specifically, for HEC-23, Volume 2, page DG 14.8, Step 4a:
  - o TechBrief Figures 6 through 10 replace HEC-23 Figure 14.7 (page DG 14.11).
  - o TechBrief eliminates the "25 foot" criteria because of the relationship of the applicable scour depth and the countermeasure fill slope.
  - o TechBrief allows the apron extension to be greater than 25 feet.

  - TechBrief recommends that the upstream and downstream embankment coverage should extend a maximum of either $2(y_0)$ or 25 feet.

This TechBrief provides updated and improved information for:

- FHWA "Design and Construction Guideline for Geosynthetic Reinforced Soil Abutment and Integrated Bridge Systems" (FHWA, 2017b) (7). Specifically,
  - TechBrief pressure scour approaches may replace pressure scour approaches in Appendix "D" (i.e., pages 190 to 191).

General Hydraulic Design Selection considerations. This TechBrief provides a discussion on complicating factors that affect the performance of a bridge in a riverine or coastal environment. Because of this, FHWA recommends the inclusion of a multidisciplinary team of structural, geotechnical and hydraulic engineers. In order to fully understand the hydraulic requirements surrounding shallow abutment foundations, FHWA identifies several major hydraulic components that better ensure successful performance of shallow foundations.

Specific Hydraulic Design Selection considerations. When deciding whether a shallow or deep abutment foundation is appropriate for a waterway bridge, the bridge owner should evaluate the following specific hydraulic considerations:

- Site Selection: Stream stability is discussed in the TechBrief, related to locating shallow abutment foundations.
- Abutment Location: FHWA discusses its recommendation for setting the abutment back from the channel bank some minimum distance. If an abutment cannot be set back from the channel stream bank, the owner should consider using a deep foundation.
- Complex Flow Conditions: This TechBrief discusses "complex flow" conditions and how they may affect the suitability of a bridge site for shallow abutment foundations. FHWA recommends evaluating crossings with one or more of these adverse conditions with two-dimensional modeling to identify flow depths and velocities at the necessary locations.
- Risk-Based Design Approaches: In accordance with statutory provisions of the 2012 "Moving Ahead for Progress in the 21st Century" Act (MAP-21), FHWA adopted risk-based design approaches so bridge owners can better balance the flood frequency they use for bridge design with the risks associated with the crossing (e.g. cost of the bridge, importance of bridge, and traffic characteristics). Risk-based approaches are included in these considerations.
- Local Drainage: To a lesser degree, local drainage may have an impact on foundation selection. FHWA offers some considerations in regard to local drainage.

These design considerations are consistent with 23 CFR 650 subpart A, which requires analyses of design alternatives with *"... consideration given to capital costs and risks; economic, engineer, social and environmental concerns; and including risk assessments or risk analyses."* [23 CFR 650.115(a)] and the recommended design process is discussed in more detail in the 'Recommended Process'.

Recommended Process.

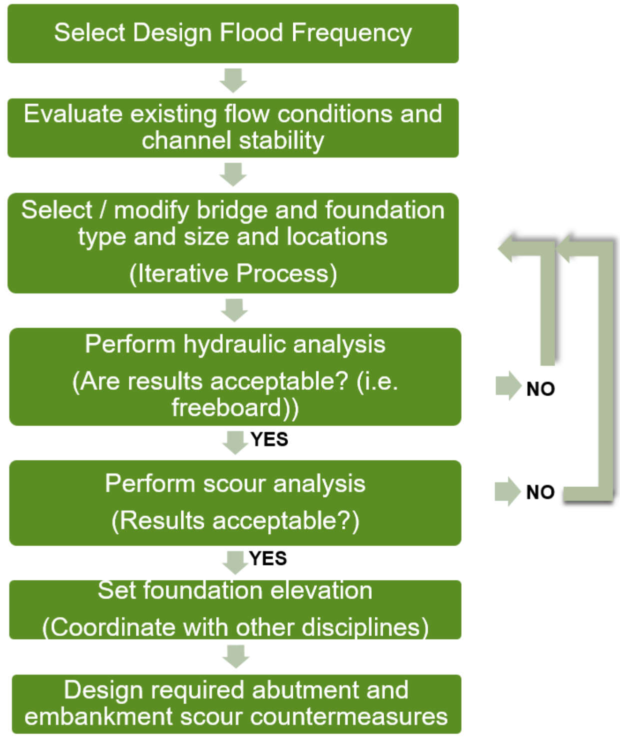

Figure 2. Steps for Bridge Hydraulic and Scour Design Process

Figure 2 illustrates the recommended bridge hydraulic and scour design process applicable to shallow abutment foundations and reflects the necessary multi-disciplinary approach. The TechBrief describes in more detail the required steps and considerations in this process. One significant point is FHWA's recommendation to adopt the NCHRP 24-20 approach to computing abutment scour (NCHRP, 2010) (6).

Scour Components, Evaluations and Analysis. This TechBrief section provides explanations on the scour related components, evaluations, and analyses associated with the new approaches and improvements. The following is a summary of topics discussed:

- Total Scour Components are discussed. This includes the upstream sediment transport regime and whether the scour floods are under Free-Surface or Pressure Flow conditions. In addition, the abutment scour component is sensitive to the location of the abutment, relative to the main channel. The following individual scour components are discussed:
  - Under Free-Surface Flow
    - Long-Term Degradation
    - Contraction Scour
    - Abutment Scour
  - Under Pressure Flow
    - Long-Term Degradation plus Contraction Scour

  - Vertical Contraction Scour
- Considerations for final determination of total scour depth are discussed

Considerations for Scour Analysis. Laboratory studies of both "wide-opening" and "narrow-opening" bridge simulations have shown that for various flow conditions, when placed below the appropriate scour depths, several schemes of countermeasures can be effective in protecting shallow abutment foundations (FHWA, 2017a) (5). They include:

- No scour countermeasure required
- Countermeasures for wide bridge openings –Three figures depict the use of aprons when the length of the bridge meets the "wide-opening"
- Countermeasures for narrow bridge openings – There is a figure that depicts the use of a rip-rap countermeasure for a "narrow-opening"
- Countermeasures for pressure flow – There is a figure that depicts the use of full-width rip-rap countermeasures for locations with Pressure Flow.

There is a summary and Figures that describe (for each flow condition and scour countermeasure application) the manner in which to combine the individual scour components. See Figure 3 below as an example. It is important for the interdisciplinary team to tie scour depths to an appropriate reference elevation. For abutments located near the main channel, the interdisciplinary team should use the channel thalweg elevation as the reference elevation. For abutments set back from the main channel with no potential for lateral channel migration, the interdisciplinary team should use the overbank elevation as the reference elevation.

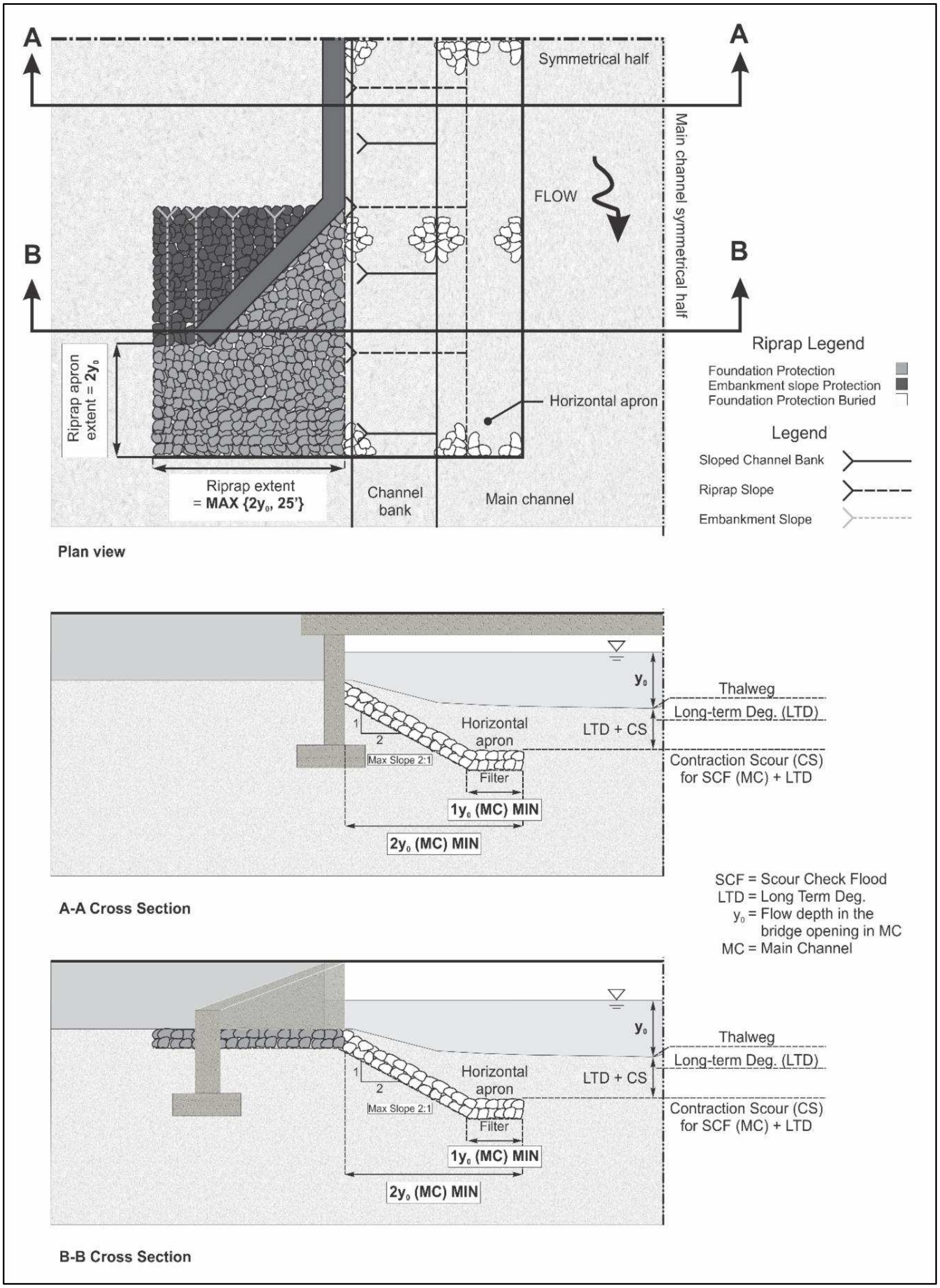

Figure 3. Free-Surface Flow, Wide-Opening Scour Countermeasure, Abutment near Channel Bank – Scour Condition (A) and sloping riprap extends into main channel (Option 2a).

Scour Countermeasures. FHWA considers a shallow foundation abutment to be scour critical when it has been determined to be unstable for the observed or evaluated scour condition (23 CFR 650.305). To comply with regulation, addressing such situations necessitates including scour countermeasures into the design (new bridges) or developing a plan of action (for existing bridges) that involves scour countermeasures (23 CFR 650.313(e)(3)).

This TechBrief focuses on such physical countermeasures and includes detailed discussions related to:

- Environmental and resource agency considerations.
- Designing the foundation apron elevations for riprap. This protects the abutment face and avoids local abutment failure.
- Countermeasure design considerations. Planform limits of the countermeasure are discussed, not only for the abutment but the embankment limits as well. Figures are provided to illustrate the appropriate design and countermeasure configurations for various flow conditions and applications. It is noted that HEC-18 provides some risk-based considerations for countermeasures.
- Specifications for riprap scour countermeasure design is discussed in this document. Causes for premature failure are discussed as well as recommendations for provisions that should be considered in bridge-related contracts; an example from FHWA's Office of Federal Lands Highway is provided.

Unless specifically cited with a regulation, these represent technical recommendations and not regulatory requirements.

CONCLUSIONS

Over three decades, FHWA's Scour Program has evolved from a reaction to catastrophic bridge failures into risk/data approaches that seeks proactive solutions and will reach a stable and steady state program. Success required understanding how the program evolved, and looking for means to provide actionable and consistent policy and guidance.

While challenges remain, FHWA and bridge owners have already seen progress in making the nation's bridges safer from potential scour failure.

REFERENCES

(1) FHWA-HIF-19-007. December 21, 2018. Tech Brief: *Hydraulic Considerations for Shallow Abutment Foundations.*

(2) Public Law 90-495. August 23, 1968. *Federal-Aid Highway Act of 1968*. Section 26, "Bridge Inspections."

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(4) FHWA. November 18, 1988. *Compliance with the National Bridge Inspection Standards – Underwater Inspection and Bridge Scour.* Office of Engineering, internal FHWA memorandum to Regional Administrators.

(5) FHWA-HRT-17-013. 2017. "Shallow Foundations for the Support of Vertical-Wall Bridge Abutments: Interaction between Riprap and Contraction Scour".

(6) NCHRP 24-20. 2010. Draft Final Report, "Estimation of Scour Depth at Bridge Abutments".

(7) FHWA-HRT-17-080. June 2018. "Design and Construction Guideline for Geosynthetic Reinforced Soil Abutment and Integrated Bridge Systems".