TechBrief

The Scour Program is an integrated national effort to address or mitigate erosion of streambed or bank material due to flowing water; including erosion localized around bridge abutments and piers.

The Scour Program also addresses bridges with foundation elements that are or have the potential to be unstable for the observed or evaluated scour condition.

The Federal Highway Administration manages the Program through partnerships with state highway agencies, industry and academia.

The Program's primary goals are to improve safety and resilience of the nation's bridges.

Office of Bridges & Structures

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Federal Highway Administration

Scour Considerations within AASHTO LRFD Design Specifications

This Technical Brief (TechBrief) provides programmatic and technical considerations for understanding the interaction of limit states and scour depths in foundation design related to provisions of the American Association of State Highway and Transportation Officials (AASHTO) Load and Resistance Factor Design (LRFD) Bridge Design Specifications.

1 INTRODUCTION

The American Association of State Highway and Transportation Officials (AASHTO) "Load and Resistance Factor Design Bridge Design Specifications" (LRFD) (AASHTO, 2017) is the standard for highway bridge and structure design, evaluation, and rehabilitation practice. The standard is incorporated by reference into Federal Highway Administration (FHWA) regulations in the Code of Federal Regulations (CFR), Title 23, Highways (23 CFR 625.4(d)(1)(v)). The AASHTO LRFD specifications contain chapters, articles and commentary governing the engineering design of structural (e.g., bridge superstructures, decks, etc.), geotechnical (e.g., foundations, piers, abutments, retaining walls, etc.), hydraulic (e.g., hydrology, hydraulics, and *scour*), and other elements for these types of highway infrastructure.

The first portion of the TechBrief will describe common terminology related to LRFD and *scour* and the general application of the AASHTO LRFD specifications to *scour* design. The TechBrief later provides scenarios to illustrate various design flow conditions and how to apply AASHTO LRFD and *scour* for each scenario.

This TechBrief describes how bridge owners and designers can consider *scour*-related provisions in AASHTO LRFD when designing foundations while aligning with compliance requirements of FHWA's Design Standards (23 CFR part 625) and National Bridge Inspection Standards (23 CFR part 650, subpart C). This document does not constitute a standard, specification, or regulation.

The AASHTO describes LRFD as taking the "variability in the behavior of structural elements into account in an explicit manner. LRFD relies on extensive use of statistical methods, but sets forth the results in a manner readily usable by bridge designers and analysts." (AASHTO, 2017). Additionally, AASHTO defines the term "*Load and*

Resistance Factor Design" as "A reliability-based design methodology in which force effects caused by factored loads are not permitted to exceed the factored resistance of the components."

As the term "LRFD" denotes, quantification and probabilistic considerations related to forces (i.e., loads) and capabilities to withstand those forces (i.e., resistance) inform the application of the design specifications.

This is accomplished through consideration of *limit states* or, as defined by AASHTO LRFD, a "condition beyond which the bridge or component ceases to satisfy the provisions for which it was designed." In practice, bridge engineers would factor the capacity and demand upon bridge superstructures, substructure and foundation elements for evaluation at all applicable *limit states*.

This is not the case for *scour* design. The FHWA regulations in 23 CFR § 650.305 define *scour* as "erosion of streambed material due to flowing water; often considered as being localized around piers and abutments of bridges." "Erosion" is the operative word in FHWA's definition.

Similarly, AASHTO LRFD considers *scour* not as a force, but a change in foundation conditions (i.e., loss of bed material above the scour line). In other words, *scour depth* is a condition that has resulted from erosive forces and AASHTO LRFD considers this condition for applicable *limit states*. There are currently no statistically-based factors applied to *scour depth* or its effect to a foundation.

This becomes more problematic as the design of bridge foundations to accommodate *scour* involves close coordination and collaboration of the hydraulics, geotechnical, and structural engineering disciplines. While each of these disciplines have specifications, guidance, and terminology specific to the topic, these are not necessarily well understood by members of the other two disciplines.

Therefore, one of the goals of this TechBrief is to provide some clarification of *scour* and *scour depths* for these various disciplines. The TechBrief describes various AASHTO LRFD and FHWA terms and scenarios to illustrate the various conditions, including *limit states*. Finally, this document provides clarification on FHWA approaches and recommendations.

1.1 A NOTE ON NOMENCLATURE

As an overview of s*cour* and relevant provisions in AASHTO LRFD, this TechBrief uses and applies terms, concepts, and nomenclature not typically used in some areas of the transportation community.

To assist the audience, this TechBrief signifies terms defined by FHWA or AASHTO by combining *italics* and font color. Examples include *limit state* or *scour* or *design flood for waterway opening*.

Providing these indicators to distinguish the origins of the terms is important to allow the audience to properly recognize and understand context.

This usage includes instances when the term or nomenclature requires a plural (e.g., *limit state* into *limit states*), or denotes an action or change in tense (e.g., *scour* into *scoured*), or other grammatical usage or constructions.

Sometimes, terminology might reflect the combination of several defined terms. For example, *"design flood for bridge scour"* describes and uses the terms *scour* and *design flood*.

1.2 REGULATORY BASIS

This TechBrief will provide State Departments of Transportation (State DOTs) with additional context and information to understand the FHWA's regulations in 23 CFR. The FHWA requires compliance with 23 CFR and other regulations for a project to be eligible for Federal-aid or other FHWA participation or assistance [23 CFR § 630.112(a)].

The following FHWA regulations apply to highway projects and actions interacting with and within waterways and floodplains (paraphrased for brevity):

23 CFR part 625 – Design Standards

a. National Highway System (NHS) projects must follow hydrologic, hydraulic, and *scour* related sections of the AASHTO LRFD Bridge Design Specifications [§ 625.3(a)(1) and § 625.4(b)(3)].
b. Non-NHS projects must follow State DOT drainage and/or bridge standard(s) and specifications [§ 625.3(a)(2)].

23 CFR 650 subpart A – Location and Hydraulic Design of Encroachments on Flood Plains

a. All Federal-aid projects, whether on the NHS or Non-NHS require Hydraulic Design Standards. Neither State, local, nor AASHTO standards may change or override the §650.115 design standards. The design standards require development of a "Design Study" or certain analyses for each action in an encroachment (§ 650.115(a)).
b. Content of Design Studies [§ 650.117]. This regulation requires studies to contain the hydrologic and hydraulic data and design computations [§ 650.117(b)]. As both hydrologic and hydraulic factors and characteristics lead to *scour* formation, such data and computations apply to *scour* as well. Project plans must show the water surface elevations of the *base flood* (i.e., 100-year flood) and *overtopping flood* [§ 650.117(c)].

23 CFR 650 Subpart C – National Bridge Inspection Standards

a. Defines *Scour* and *Scour Critical Bridges* [§ 650.305].
b. Requires identification of "*...bridges ... that are scour critical*" [§650.313(e)].
c. For those *scour critical* bridges, requires preparing "*...a plan of action to ... address critical findings*." [§ 650.313(e)(3)].

1.3 UPDATED MATERIALS

This TechBrief provides updated and improved information for:

1. Hydraulic Engineering Circular (HEC) No. 18, "Evaluating Scour at Bridges," 5th edition, (HEC-18) (FHWA, 2012). Specifically:
   a. TechBrief Section 2.4.3 and 2.4.6 are scenarios depicting low tailwater conditions, provides further clarification to include 'low tailwater controlling conditions' in the guidance provided in HEC-18, Chapter 2, Section 2.1, Page 2.2, 2nd paragraph and Section 2.5.2, Page 2.16, 3rd paragraph.

This TechBrief does not update, change nor supersede any other information in the HEC-18 document nor other FHWA materials.

1.4 GLOSSARY

This TechBrief uses and references the following terms obtained from FHWA regulations and AASHTO LRFD Sections, Articles and Definitions. Only the definitions contained in FHWA regulations or in AASHTO LRFD Sections that are incorporated by reference into those regulations are legally binding. The Glossary also includes several TechBrief specific terms to aid in readability and context. Finally, this Glossary provides the relevant citation of each source:

23 CFR §650.105 [Definitions]

Base Flood *– Shall mean the flood or tide having a 1 percent chance of being exceeded in any given year.*
Design Flood *– Shall mean the peak discharge, volume if appropriate, stage or wave crest elevation of the flood associated with the probability of exceedance selected for the design of a highway encroachment. By definition, the highway will not be inundated from the stage of the design flood.*
Overtopping Flood (Q_{OT}) *– Shall mean the flood described by the probability of exceedance and water surface elevation at which flow occurs over the highway, over the watershed divide, or through structure(s) provided for emergency relief.*

23 CFR § 650.305 [Definitions]

Scour *– Erosion of streambed material due to flowing water; often considered as being localized around piers and abutments of bridges.*
Scour Critical *– A bridge with a foundation element that has been determined to be unstable for the observed or evaluated scour condition.*

AASHTO LRFD § 1.2 - Definitions

Design Life *– Period of time on which the statistical derivation of transient loads is based: 75 years for these Specifications.*
Extreme Event Limit States *– Limit states relating to events such as earthquakes, ice load, and vehicle and vessel collision, with return periods in excess of the design life of the bridge.*
Factored Load *– The nominal loads multiplied by the appropriate load factors specified for the load combination under consideration.*
Factored Resistance *– The nominal resistance multiplied by a resistance factor.*
Limit State *– A condition beyond which the bridge or component ceases to satisfy the provisions for which it was designed.*
Load and Resistance Factor Design (LRFD) *– A reliability-based design methodology in which force effects caused by factored loads are not permitted to exceed the factored resistance of the components.*
Load Factor *– A statistically-based multiplier applied to force effects accounting primarily for the variability of loads, the lack of accuracy in analysis, and the probability of simultaneous occurrence of different loads, but also related to the statistics of the resistance through the calibration process.*
Nominal Resistance *– Resistance of a component or connection to force effects, as … by permissible stresses, deformations, or specified strength of materials.*
Resistance Factor *– A statistically-based multiplier applied to nominal resistance accounting primarily for variability of material properties, structural dimensions and workmanship, and uncertainty in the prediction of resistance, but also related to the statistics of the loads through the calibration process.*

AASHTO LRFD § 2.2 – Definitions

***Check Flood for Bridge Scour** – Check flood for scour. The flood resulting from storm, storm surge, tide, or some combination thereof having a flow rate in excess of the design flood for scour, but in no case a flood with a recurrence interval exceeding the typically used 500 years.*
***Design Flood for Bridge Scour** – The flood flow equal to or less than the 100-year flood that creates the deepest scour at bridge foundations. The highway or bridge may be inundated at the stage of the design flood for bridge scour. The worst-case scour condition may occur for the overtopping flood as a result of the potential for pressure flow.*
***Design Flood for Waterway Opening** – The peak discharge, volume, stage, or wave crest elevation and its associated probability of exceedance that are selected for the design of a highway or bridge over a watercourse or floodplain. By definition, the highway or bridge will not be inundated at the stage of the design flood for the waterway opening.*

AASHTO LRFD § 3.2 – Definitions

***Load** – The effect of acceleration, including that due to gravity, imposed deformation, or volumetric change.*
***Nominal Load** – An arbitrarily selected design load level.*

HEC-18 – Definitions

***Hydraulic Design Flood** – is equivalent to AASHTO LRFD definition of Design Flood for Waterway Opening*
***Scour Check Flood** – is equivalent to AASHTO LRFD definition of Check Flood for Bridge Scour*
***Scour Design Flood** – is equivalent to AASHTO LRFD definition of Design Flood for Bridge Scour*
***Scour Depth or Depth of Scour** – The vertical distance a streambed is lowered by scour below a reference elevation.*
***Total Scour** – The sum of long-term degradation, general (contraction) scour and local scour.*

Specific TechBrief Terminology (non-regulatory)

***Foundation Element** – A footing, pile, or other type of foundation associated with a bridge (or culvert).*
***Incipient overtopping** – The point at which overtopping is beginning to occur*
***Low Tailwater Flow** (Q_{LT}) – This condition occurs if high flow from a channel enters a low water boundary condition, in relatively close proximity, downstream of a structure.*
***Worst Case Scour Depth** – The conditions (e.g., discharge, velocity, depth, tailwater, geometry, orientation, type of foundation, etc.) that would produce the maximum scour depth at a particular foundation element.*

1.5 Influencing-Element Examples in Determining Worst Case Scour Depth

Figure 1 illustrates the relationship between flood discharge, tailwater and the associated *scour depths*. Specifically, Figure 1 depicts the *worst-case scour depth*; with several aligned illustrations and plots used to convey various elements. Figure 1's top left plot depicts how *scour depth* varies with increasing flow rate at various tailwater levels (TW). This top left plot includes the critical depth line (y_{c-line}) demonstrating the lower bounds of TW depth.

The top right illustration represent a color ramp scale of *scour depth*; with the deepest blue colors represent the shallowest *scour depth* and the darkest red the deepest *scour depth*.

The two illustrations on the bottom of Figure 1 depict the *scour* progression versus discharge at the y_{c-line}. The bottom left plot shows how some specific tailwater level (TW_i) generates the *worst-case scour depth* ($y_{S,max}$), which is the deepest *scour* within the range of considered discharges and possible tailwater levels. For Figure 1, this *worst-case scour depth*, $y_{S,max}$, occurs at Q_j and TW_i.

The bottom right illustration depicts a profile view of the waterway, bridge, bridge foundation and scour hole; designating $y_{S,max}$, Q_j and TW_i.

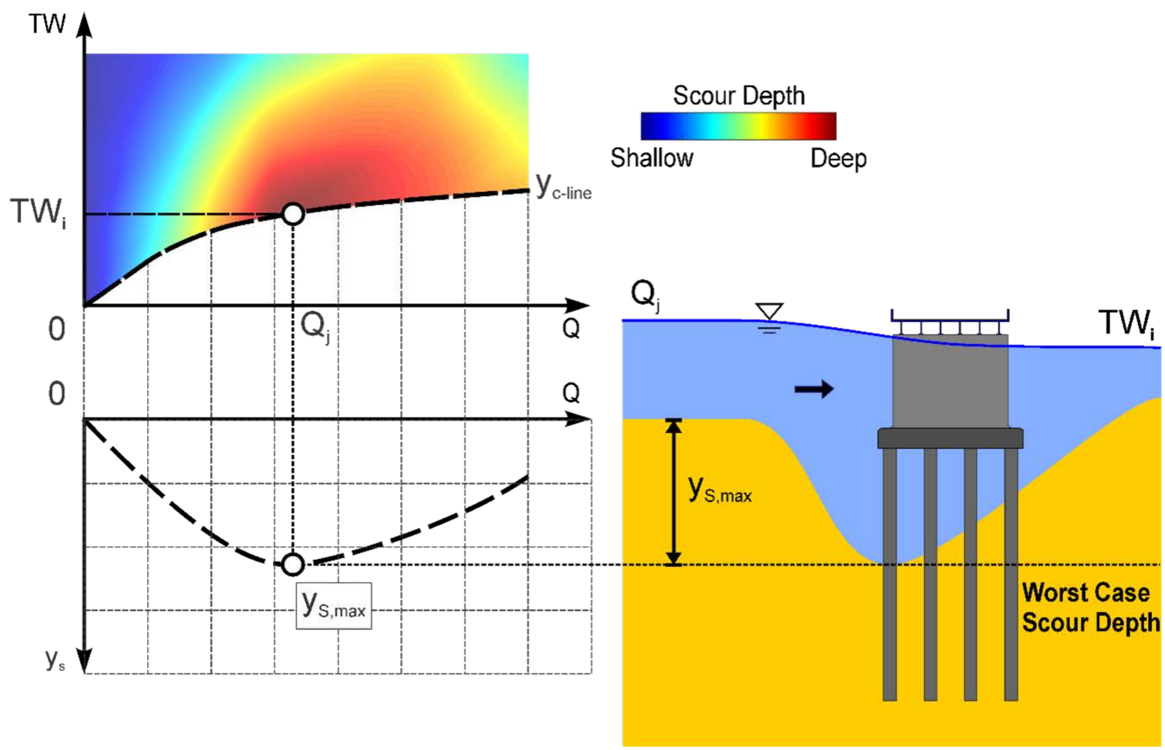

Figure 1. *Worst-case scour depth*.

This TechBrief will attempt to describe and depict other potential concepts and scenarios within AASHTO LRFD and FHWA approaches.

2 FOUNDATIONS & SCOUR WITHIN THE CONTEXT OF AASHTO LRFD

The FHWA regulation 23 CFR § 625.4(b)(3) [Design Standards] requires use of the "AASHTO LRFD Bridge Design Specification" for projects on the National Highway System (NHS).

Additionally, under their § 625.3(a)(2) authorities, many State DOTs adopt this document for use on non-NHS projects as well.

As a result, this TechBrief focuses on the interaction of foundations and *scour* within the context of AASHTO LRFD. In doing so, this section of the TechBrief provides more detailed explanations of the *scour*-related AASHTO LRFD articles and their relationship to foundations. Unless specifically cited with a regulation, these TechBrief discussions only represent technical considerations and processes.

Note, this Tech Brief does not distinguish how AASHTO LRFD specifications address deep foundation and shallow foundations. The figures in this TechBrief incorporate deep foundations for illustration purposes only.

2.1 AASHTO LRFD Foundation Design

In the design of a foundation, AASHTO LRFD requires the consideration of structural and geotechnical conditions, and the load combinations specified in Service, Strength, and Extreme Events *limit states*.

The LRFD design methodology uses *load factors* to account, primarily, for the variability of loads, the uncertainties in load evaluation, and the probability distribution for potential combinations of different loads, but also related to the statistics of the resistance through the calibration process. It uses *resistance factors* to account for, primarily, uncertainties in material properties, geometric variation from fabrication process, and capacity analysis, but also related to the loads through the calibration process.

The combination of *factored loads* (i.e., the sum of products of *nominal loads* and *load factors*) cannot exceed the *factored resistance* (i.e., *nominal resistance* of the component multiplied by a *resistance factor*). If it does, the bridge or bridge component no longer satisfies the specific *limit state* and therefore, no longer fulfils the target reliability embedded in AASHTO LRFD.

2.2 LRFD Application to Scour Design

While the foundation scenario described above where LRFD applied *factored loads* and *factored resistance*, this is not the case for how LRFD accounts for *scour*.

Essentially, there are several circumstances and reasons why LRFD accounts for scour in a different manner than structural and geotechnical approaches:

- Bridge hydraulic practice essentially looks at two types of design situations (i.e., waterway opening and scour) and applies two discrete discharges (i.e., *design flood for waterway opening (hydraulic design flood),* and *design flood for bridge scour (scour design flood)*). Distinctions include:
  - The *hydraulic design flood* focuses on flooding, backwater, and overtopping issues while *scour design flood* focuses on conditions affecting foundation integrity.
  - The concept of a "check event" only applies to the *scour* design, not the waterway opening design (i.e., there is no explicit check condition for the waterway opening)

  Such distinctions may introduce conflicting design constraints (i.e., the design constraints for flooding may not be the same for *scour*).
- *Scour* develops as a result of hydrostatic and hydrodynamic forces upon the waterway bed material; eroding that material, and potentially exposing foundation elements.

- Current methods for assessing *scour depth* apply observations or predictive evaluations.
- For observed *scour*, current hydraulic methods often are not able to deconstruct the flow conditions that produced the *scour depth*; thus being unable to capture the associated exceedance probability.
- For predictive *scour*, evaluations may not consider the geotechnical properties of the bed material; instead applying conservative assumptions (i.e., non-cohesive material extending throughout the geological strata) and quasi-empirical equations.
- The current foundation design in AASHTO LRFD does not take into account the combined effect of variability of foundation element resistance and variability of *scour depth*. As a result, there are no statistically-based factors dedicated to the effects from *scour*.
- The FHWA provisions and AASHTO LRFD provisions related to *scour* use discharge (i.e., flood or flows) as a (at least) third order surrogate for determining *scour* depth. For each waterway, practice uses the discharge to estimate resultant flow depths and velocity (i.e., second order surrogates); which in turn estimate *scour* depth. In other words, specifying a discharge may not capture the different erosion forces and load vectors and components acting on the soil at bridge foundations.
- *Scour depth* does not necessarily increase with discharge. Therefore, applying a *scour check flood* associated with Q_{500} that is greater than the *scour design flood* associated with Q_{100} may not yield an increased *scour depth* nor represent the *worst case scour*.
- Applying discrete discharges neglects that *worst case scour* formation may NOT occur at those discharges.[1] The *worse-case scour depth* at some bridge *foundation element* may occur at a discharge with an exceedance probability less than the *design life* or even the *hydraulic design flood*. Alternatively, *worst case scour* may occur at flood exceedance probabilities larger than such discrete discharges.

Since LRFD considers scour not as a force but as a change of foundation condition, i.e. loss of bed material, the following sections describe how scour is addressed in the LRFD methodology.

2.3 Scour Design Flood & Scour Check Flood

LRFD seeks to provide a buildable, serviceable bridge, capable of safely carrying design loads for a specified *design life*. This translates to satisfying various *limits states,* of which each consists of a unique combination of permanent, transient or extreme loads and/or conditions. Another way to look at this approach is that bridges must satisfy normal operational needs, but also address situations such as seismic events or vessel collisions. AASHTO LRFD accomplishes some of these such needs by designing at multiple *limit states*. For example, Strength III checks for a very high wind speed (design wind) condition, while Strength V prescribes a moderately high wind speed that allows normal operation.

AASHTO LRFD applies this concept to *scour* design as well. The *scour design flood*, associated with the flood with an 1% annual exceedance probability (i.e., 100-year return period, or, Q_{100}), represents the "normal" scour depth condition. The *scour check flood*, associated with the 0.2%

[1] The 1962 *scour* induced I-29 Big Sioux River bridge collapse occurred at approximately the *waterway opening design flood* (i.e.., 50-year exceedance discharge for an Interstate Highway Bridge) (FHWA, 1963).

annual exceedance discharge probability (i.e., 500-year return period or Q_{500}), represents the “check” condition.

AASHTO selected these 100-year and 500-year flood discharges based on recommendations from FHWA and in alignment with the National Bridge Inspection Standards (NBIS) regulation (23 CFR § 650 subpart C). Specifically, in the late 1980s, when developing the FHWA Scour Program, the FHWA recommended use of 100-year and 500-year exceedance discharges as the *scour design flood and scour check flood.*[2]

2.4 Scenarios Depicting Different Situations Covered by LRFD & Scour

AASHTO LRFD recognizes that the *worst case scour depth* may not occur at the highest flow rate that the *scour design flood* or *scour check flood* may have (i.e., Q_{100} and Q_{500} events). So, the *scour design flood* might consist of some flood magnitude less than the Q_{100} that causes greater *scour* at the bridge. If so, the specifications require using that discharge as the *scour design flood*. Similarly, if there is a flood event less than the Q_{500} that causes the *worst case scour depth* at the bridge, it should be used as the *scour check flood*. Another way of stating the above is that the *scour design flood* should be the *worst-case scour* for all floods up to and including Q_{100}. Likewise, the *scour check flood* should be the *worst-case scour* for all floods up to and including the Q_{500}.

For the bridge design considering *scour*, AASHTO LRFD Section 2.6.4.4.2 has the following requirements:

> For the *design flood for scour*, the streambed material in the *scour* prism above the *total scour* line shall be assumed to have been removed for design conditions.
> The design flood storm surge, tide, or mixed population flood shall be the more severe of the 100-yr events or from an *overtopping flood* of lesser recurrence interval.

AASHTO LRFD Section 2.6.4.4.2 also requires:

> For the *check flood for scour*, the stability of bridge foundation shall be investigated for scour conditions resulting from a designated flood storm surge, tide, or mixed population flood not to exceed the 500-yr event or from an overtopping flood of lesser recurrence interval. Excess reserve beyond that required for stability under this condition is not necessary. The extreme event limit state shall apply.

To illustrate some (but not all) of the different situations covered by AASHTO LRFD and scour, this TechBrief will cover several different scenarios.

For the sake of clarity, the TechBrief places each scenario on a separate page.

[2] AASHTO incorporated these into pre-LRFD bridge standards and specifications. When developing the LRFD, AASHTO essentially kept these prior approaches.

2.4.1 Scenario 1: Scour design flood equals the Q_{100} flood

Figure 2 illustrates the *scour* progression versus discharge that generates the worst-case scour depth, relative to the bridge foundation. The maximum scour depth is on the upstream side of the bridge structure.

In this scenario, the *worst-case scour depth* ($y_{S,Q_{100}}$) as depicted in the left-side plot and profile illustrations, occurs at Q_{100} and serves as the *scour design flood*.

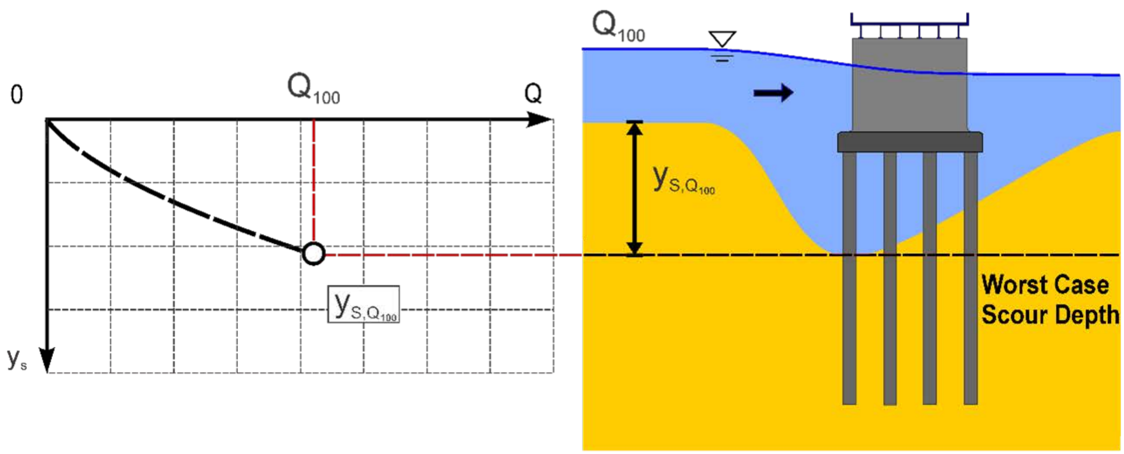

Figure 2. *Worst-case scour depth* for ≤ Q_{100} used for *scour design flood*.

2.4.2 Scenario 2: Scour design flood equals the Q_{OT} flood

Figure 3 depicts an alternate scenario where *incipient overtopping flood* at the roadway approaches occurs, and the *worst-case scour depth* does not occur at Q_{100}, but rather at the *incipient overtopping flood*, labeled as Q_{OT}.

In this scenario, there is hydraulic relief provided at Q_{OT}, so that Q_{100} causes a shallower *scour depth*, as reflected in the plots on the left.

The left plot and profile illustrations depict the *worst-case scour depth* ($y_{S,Q_{OT}}$) for this scenario.

The flood discharge in this scenario shows the water level is higher relative to the bridge structure. For this case, the *scour design flood* uses the Q_{OT} condition.

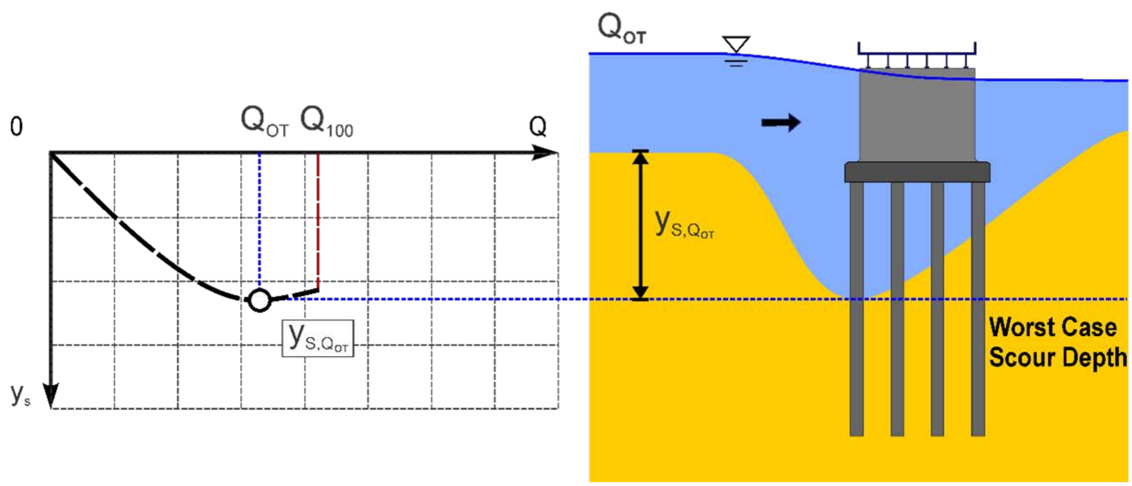

Figure 3. *Incipient overtopping flood* generates the *worst-case scour depth* for the *scour design flood*.

2.4.3 Scenario 3: Scour design flood equals the Q_{LT} flood

Figure 4 depicts a *low tailwater flow* condition case.

In this scenario, a low flow generates higher velocities at the bridge structure for low TW conditions, while higher flows reduce velocities at bridge structure due to increasing TW.

For example, a bridge structure is located at a tributary stream close to a river confluence. During a storm event, flow from the tributary goes through critical depth ($y_{c\text{-line}}$) before entering the receiving stream with low tailwater (low flow depth) generating high velocities at the bridge structure. As the storm progresses, the depth in the receiving stream increases, creating higher tailwater conditions for the tributary and reducing velocities at the bridge structure.

In this case, the *worst-case scour depth* occurs at a *low tailwater flow* condition (Q_{LT}) and TW_i, which occurs for flows lower than the Q_{100}. Figure 4 designates this *worst-case scour depth* as $y_{S,Q_{LT}}$ (as depicted in the bottom plot and profile illustrations). Q_{LT} is used as the *scour design flood*.

Conditions in this scenario are similar to those that occurred in the April 1962 flood events that led to the I-29 Big Sioux River bridge collapse.

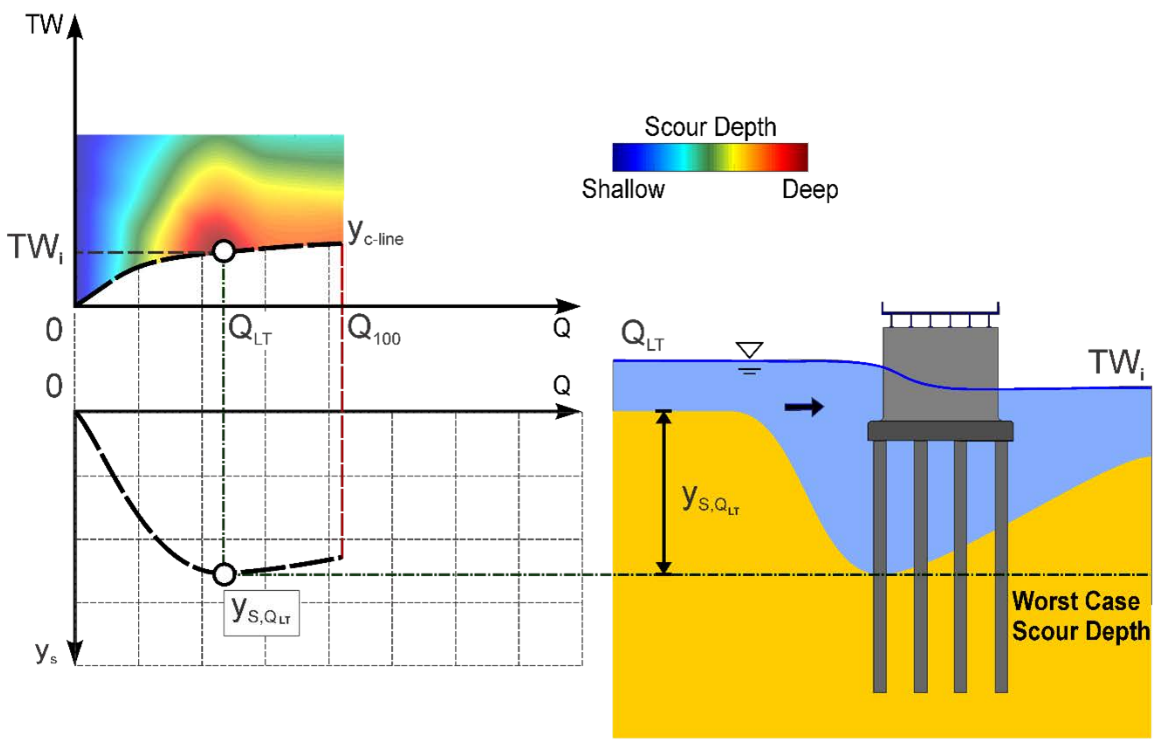

Figure 4. *Low tailwater flow* generates the *worst-case scour depth* for the *scour design flood.*

2.4.4 Scenario 4: Scour check flood equals the Q_{500} flood

While Figures 2 thru 4 showed the *worst-case scour depths* related to Q_{100}, the following three figures depict similar scenarios, but for Q_{500}.

Figure 5 illustrates the relationship between flood discharge and the associated *scour depth* up to Q_{500}.

The illustrations below show the *scour* progression versus discharge that generates the *worst-case scour depth* relative to the bridge foundation.

In this scenario, the *worst-case scour depth* occurs at the upstream side of the bridge structure at the Q_{500}; designated as $y_{S,Q_{500}}$ (as depicted in the plot and profile illustrations).

These conditions would constitute the *scour check flood*.

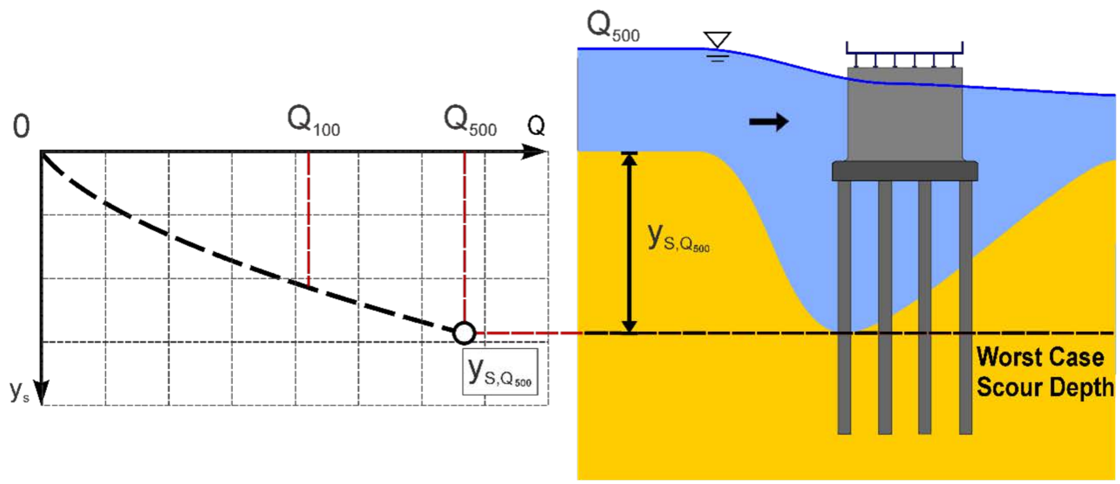

Figure 5. Q_{500} generates the *worst-case scour depth* for the *scour check flood*.

2.4.5 Scenario 5: Scour check flood equals the Q_{OT} flood

Figure 6 shows the alternate scenario where *incipient overtopping flood* occurs.

The *worst-case scour depth* does not occur at Q_{500}, but rather at a lesser *incipient overtopping flood* (greater than Q_{100}). Figure 6 labels this flood as Q_{OT}.

Figure 6 designates this *worst-case scour depth* as $y_{S,Q_{OT}}$ (as depicted in the plot and profile illustration).

For this case, the Q_{OT} is used as the *scour check flood*.

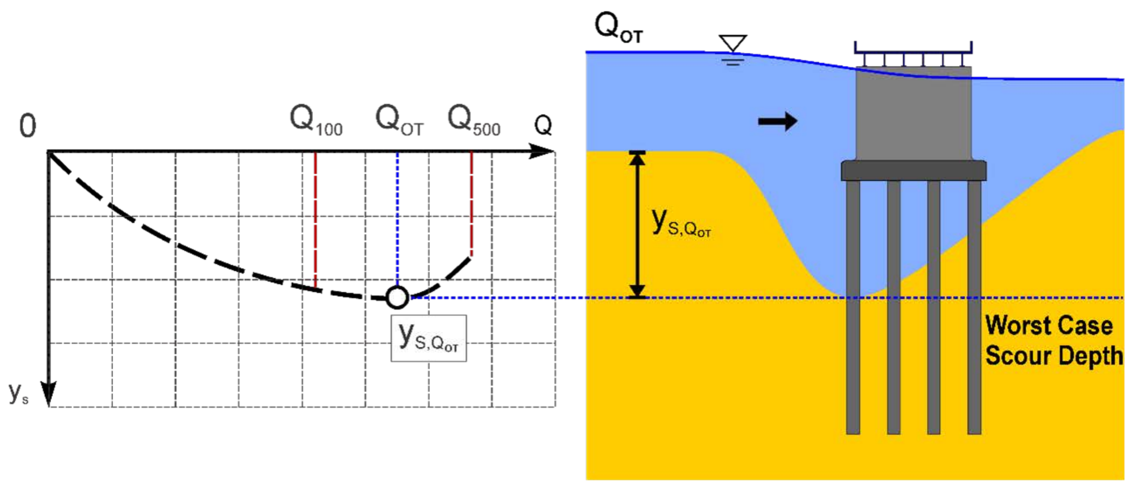

Figure 6. *Incipient overtopping flood* generates the *worst-case scour depth* for the *scour check flood.*

2.4.6 Scenario 6: Scour check flood equals the Q_{LT} flood

Figure 7 once again depicts the special case (see scenario 3), a *low tailwater flow* condition. In this scenario, the *worst-case scour depth* is at the Q_{LT} and TW_i, which occurs for flows greater than Q_{100} and lower than the Q_{500}, should be used as the *scour check flood*.

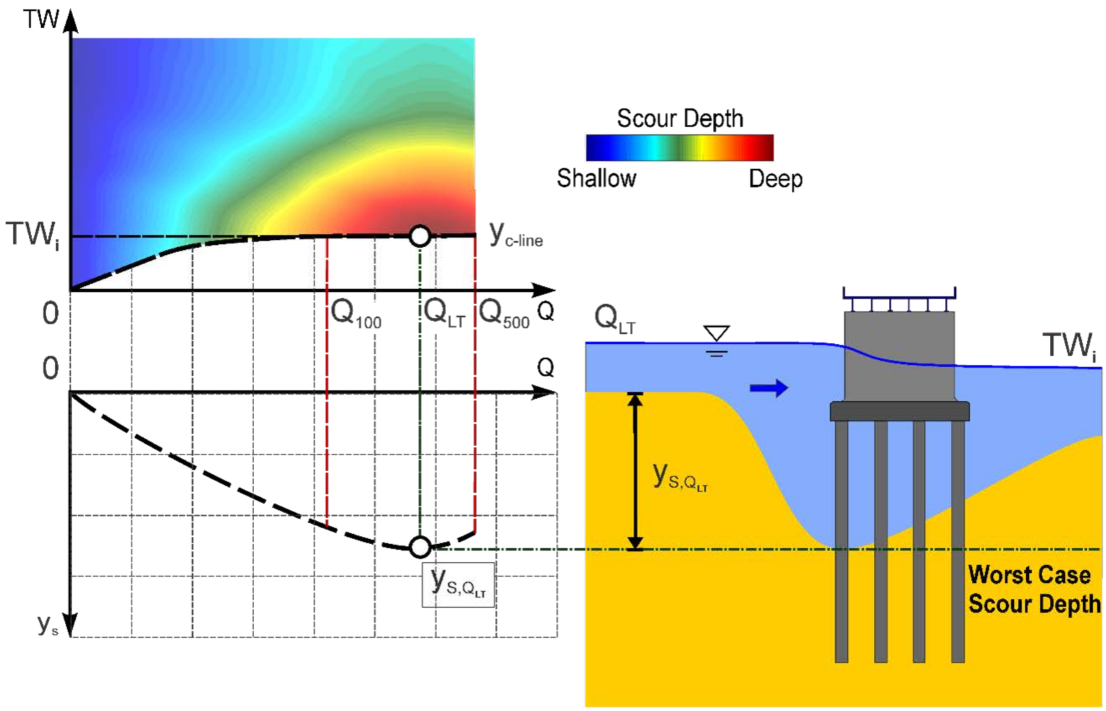

Figure 7. *Low tailwater flow* generates the *worst-case scour* depth for the *scour check flood.*

2.4.7 Other Scenarios

An important take-away is that every bridge crossing represents different hydrologic, hydraulic, geotechnical, and structural characteristics and considerations. This TechBrief provides six various scenarios. However, the scenario that generates the *worst-case scour* depth for a particular bridge may constitute some other discharge and tailwater combination(s).

The FHWA and AASHTO are working to better understand and characterize these situations with a goal to advance the practice of scour considerations.

3 SUMMARY

This TechBrief provides the following summary and take-aways for considering *scour* and AASHTO LRFD.

- The AASHTO document “Load and Resistance Factor Design Bridge Design Specifications” (LRFD) (AASHTO, 2017) forms the basis for nearly all recent highway bridge and structure design practices and standards. Under 23 CFR §625.4, the FHWA incorporates by reference the 2017 AASHTO LRFD as a design standard for bridges on the National Highway System.

- Bridge engineers factor the capacity (resistance) and demand (load) upon bridge superstructure, substructure and foundation elements for all *limit states*.
- AASHTO LRFD considers *scour* not as a force, but a change in foundation conditions. There are currently no statistically-based factors applied to *scour.*
- This document aligns the terminology in LRFD with HEC-18, i.e. 'design flood for scour' (AASHTO LRFD) equates to 'scour design flood' (HEC-18).
- The *scour design flood* should be the flood that produces *worst-case scour* for all floods up to and including Q_{100} and tailwater variation. The *scour check flood* should be the flood that produces *worst-case scour* for all floods up to and including the Q_{500} and tailwater variation.
- The FHWA and AASHTO work to improve the practice of considering scour in the context of bridge specifications, such as the AASHTO LRFD.

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Scour Considerations within AASHTO LRFD Design Specifications

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