Adequate Selection of Design Flood Frequencies for the Evaluation of Scour and Scour Countermeasures of Critical Bridges, and their Impact on the Puerto Rico Highway and Transportation Authority's Bridge Program

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Abstract

Federal regulations require all bridges, over waterways, to be designed for scour resistance and all existing bridges to be evaluated for scour vulnerability. Scour evaluations are typically based on the hydraulic design flood frequency of a 100-year flood event. Existing bridges determined to be unstable due to observed scour or assessed high potential for scour are deemed **scour critical**. When designing a new bridge or evaluating a scour critical bridge to determine the total scour depth, the selection of a hydraulic design flood frequency is one of the most important parameters. Various equations to evaluate scour are available, however many of them are considered conservative and leading to overestimation of the scour total depth. This overestimation could have an impact on the Puerto Rico Bridge Program, which has almost **500 scour critical bridges**, all requiring flood monitoring and, consequently, greater resources.

Introduction

Bridge scour is the removal of soil material around the abutments and/or piers of bridges, caused by the flowing water. Moreover, bridge scours are the most common cause of bridge failures [1]. Federal regulations require that all bridges over water have a documented evaluation of scour vulnerability and that bridges determined to be scour critical have a Plan of Action (POA) prepared to monitor them in accordance with said POA. Empirical methods have provided derived equations for the estimation of scour depth around bridge elements, which are often considered conservative and leading to overestimation of the depths [2].
The adequate selection of the hydraulic design flood frequencies and the engineering judgment when selecting parameters and scour equations are of the upmost importance when determining the scour total depth.

Background

The most common cause of bridge failures is from floods scouring bed material from around bed foundations [1]. Bridge scour is the result of the erosive action of flowing water, which excavates and carries away the material from around the piers and/or abutments of bridges. Evaluating bridge scour is complex due to the nature of the acting variables. Bridge scour depends on whether it is occurring at **clear-water condition**, where there is no transport of bed material from upstream of the bridge; or **live-bed condition**, where there is transport of bed material from upstream. Bridge total scour considers three primary components: **Long-term Degradation, Contraction Scour, Local Scour,** refer to Figures 1,2, 3 &4 [1]. The need to minimize bridge scour has resulted in a number of publications seeking to provide guidance in the evaluation of scour, one of which is the **FHWA Evaluating Scour at Bridges (HEC-18)** [1], whose guidance on the development and implementation of procedures for evaluating bridge scour.
In 2010, the U.S. Congress recommended that FHWA apply risk-based and data-driven approaches to its bridge program goals, which include the Scour Program. Risk-based approaches factor in the importance of the structure and are defined by the need to provide safe and reliable waterway crossings and consider the economic consequences of failure. Bridge foundations should be designed to withstand the effects of scour caused by hydraulic conditions from floods larger than the design flood, refer to Tables 1 & 2 [1]. A bridge is considered scour critical if the abutment and/or pier foundations are coded unstable due to either observed scour or an assessed high potential for scour, refer to Figure 5 [3].

Problem

The main objective of this article is to create awareness on the adequate selection of design flood frequencies for the analysis of scour and scour countermeasures of scour critical bridges. Furthermore, this article seeks to invite the professional community to understand how its selection impacts the evaluation of bridges in Puerto Rico.

Methodology

This project was developed in three phases:

- Review of literature and manuals about bridge scour, bridge scour countermeasures and bridge inspections.
- Performed interviews to water resource engineers to know their process and considerations when performing bridge scour studies.
- Performed an interview to a former PRHTA employee and who is currently leading a bridge program in the private practice.

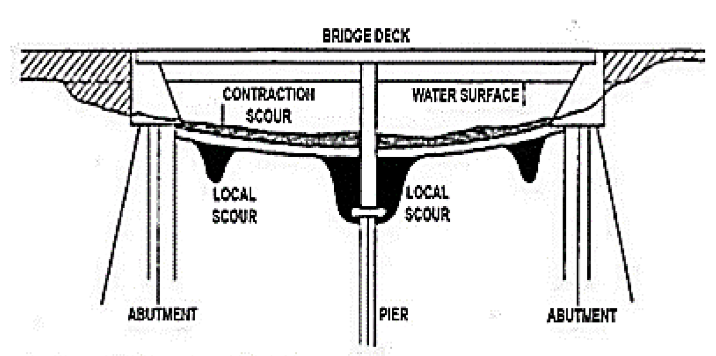

Figure 1: Bridge Elements with Components of Scour

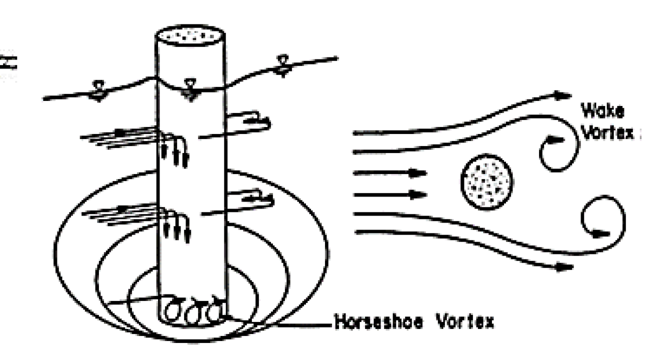

Figure 2: Horseshoe and Wake Vortices of Local Scour

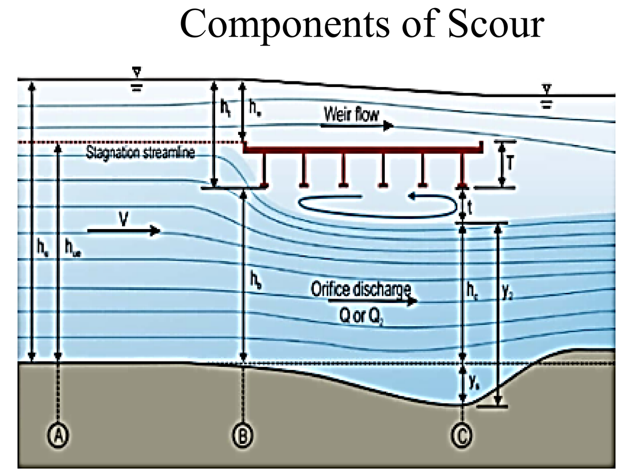

Figure 3: Vertical Contraction Scour

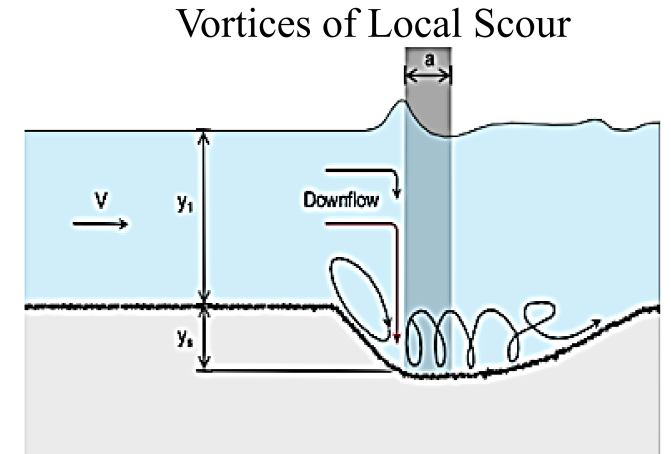

Figure 4: Local Scour at Pier

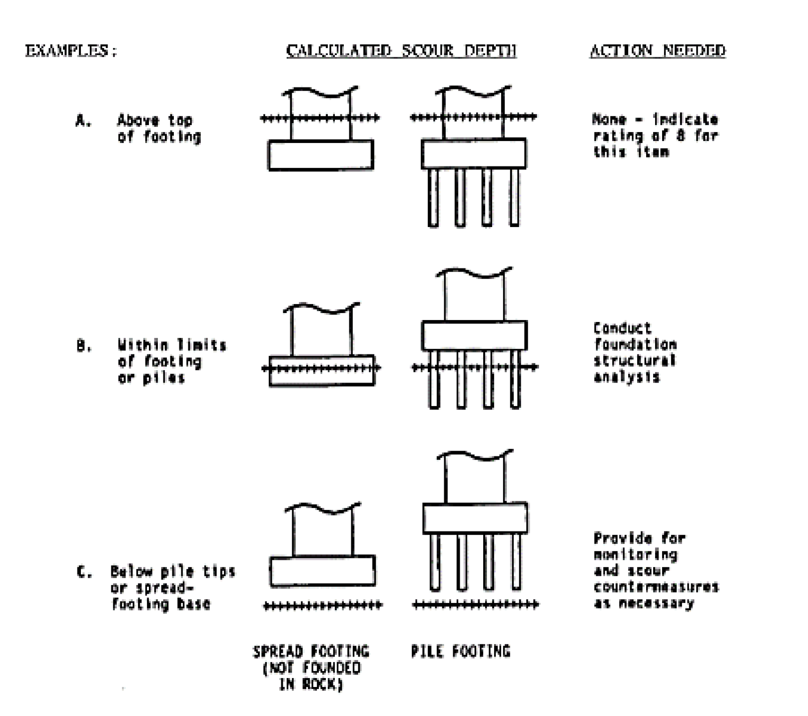

Figure 5: Item 113 – Scour Critical Bridges Rating

Results and Discussion

When designing a new bridge or evaluating a scour critical bridge to determine the total scour depth, the selection of a hydraulic design flood frequency is one of the most important parameters.
The hydraulic design flood frequency has a direct impact in the scour total depth determination because many of the scour equations rely on the magnitude of discharges generated by the flood frequencies presented in Table 1 and Table 2 [1], including overtopping. With these discharges and the use of one-dimensional or two- dimensional computer model, the water-surface profiles and many of the input variables such as the discharge, velocity and depth needed for the scour calculations can be determined.

For new bridges, scour evaluations are typically based on a hydraulic design flood frequency of a 100-year event. So, they can be designed and re-designed to comply with the standards and requirements established by the owner. But for scour critical bridges, PRHTA does not have a clear interpretation on the selection of the hydraulic design flood frequency for scour evaluation and countermeasure design as stated in Table 2. The common practice by designers is to select a hydraulic design flood frequency of a 100-year event and to use engineering judgement. With this approach, design professionals tended to be on the conservative side and without considering risk-based evaluation which can result in the overestimation of the scour total depth.

There are almost 500 scour critical bridges in the Puerto Rico National Bridge Inventory. Many of them exceed their design service-life. Moreover, considering the climate-change and the increase in precipitation values after Hurricane María, their hydraulic design flood frequencies are probably exceeded too. Today's hydraulic design flood frequencies are higher than in the past. Hence, when evaluating a scour critical bridge and taking advantage of the computer models, the actual hydraulic design flood frequency for the bridge can be determined by reducing the discharges to determine the flood event that can be accommodated through the bridge prior to overtopping. By using this approach, a hydraulic design flood frequency can be assigned and recommended frequencies on Table 2 be used for scour evaluation and countermeasure design.

Hydraulic Design Flood Frequency, Q_D	Scour Design Flood Frequency, Q_S	Scour Check Design Flood Frequency, Q_C
Q_{10}	Q_{25}	Q_{50}
Q_{25}	Q_{50}	Q_{100}
Q_{50}	Q_{100}	Q_{200}
Q_{100}	Q_{200}	Q_{500}

Table 1: Hydraulic Design, Scour Design, and Scour Design Check Flood Frequencies

Hydraulic Design Flood Frequency, Q_D	Scour Design Flood Frequency, Q_S	Scour Countermeasure Design Flood Frequency, Q_{CM}
Q_{10}	Q_{25}	Q_{50}
Q_{25}	Q_{50}	Q_{100}
Q_{50}	Q_{100}	Q_{200}
Q_{100}	Q_{200}	Q_{500}

Table 2: Hydraulic Design, Scour Design, and Scour Countermeasure Design Flood Frequencies

Conclusions

PRHTA does not have a clear interpretation on the selection of the hydraulic design flood frequency for scour evaluation and countermeasure design for scour critical bridges as stated in Table 2. Furthermore, PRHTA and designers are not implementing risk-based analyses when evaluating scour critical bridges.
The PRHTA has limited resources and a great quantity of bridges, and more to come. An overestimation of scour total depth may result in expensive and unnecessary countermeasures to protect the bridge foundations.
The adequate selection of the hydraulic design flood frequencies and the engineering judgment when selecting parameters and scour equations are of the upmost importance when determining the scour total depth.

Future Work

As a next step for this project, a series of seminars and /or webinars could be created for the professional community and PRHTA to raise awareness in the importance of the adequate selection of the hydraulic design flood frequencies and the risk-based approach.

In addition, in order to maximize the use of resources, it would be recommendable that PRHTA:

- Establish and implement a Risk-Based approach for the design of new bridges.
- Establish and implement a Risk-Based approach for the design of countermeasures for scour critical bridges.
- Establish, implement, and maintain a Web-Based GIS with the available data of all bridges to monitor, manage and record the design and scour evaluation parameters used. Furthermore, it could help in creating evacuation and access routes in case a bridge fails or collapses.

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References

[1] L. A. Richardson, L. W. Zevenbergen, P. F. Lagasse, and P. E. Clopper, "Evaluating Scour at Bridges 5th Edition", Federal Highway Administration, Washington D.C., Report No. FHWA-HIF-12-003 HEC-18, 2012.

[2] L. Brandimarte, P. Paron, and G. Di Baldassarre, "Bridge Pier Scour: A Review of Processes, Measurements and Estimates", Institute for Water Education, Delft, NL, Environmental Engineering and Management Journal Vol. 11, No. 5, 975-989, 2012.

[3] Office of Engineering, "Recording and Coding Guide for the Structure Inventory and Appraisal of the Nation's Bridges", Federal Highway Administration, Washington D.C., Report No. FHWA-PD-96-001, 1995.