1D and 2D Hydraulic Modeling to Estimate Bridge Scour Depth
A Case Study

Kettsy García-Santiago, EIT
Christian A. Villalta Calderón, PhD.
Department of Civil and Environmental Engineering and Land Surveying

Abstract

Scour is the effect of erosion of soil surrounding a bridge foundation due to fast-flowing water. This dynamic phenomenon can be categorized as the most common cause of bridge failures. Therefore, scour depth at piers and abutments should be estimated during the preliminary bridge design phase. This project will compare scour depth values for an existing bridge's foundation applying 1D and 2D hydraulic modeling. The bridge to be evaluated is located in the Municipality of San Germán, Puerto Rico and crosses the Rosario River. The 1D hydraulic model was performed using the U.S. Army Corps of Engineer's computer program, Hydrologic Engineering Center's River Analysis System, and for the 2D hydraulic model, the community version of Surface-water Modeling System from Aquaveo was used. The result of this project indicates that the use of 2D hydraulic models is the best approach to estimate scour depth in bridges

Introduction

The depth of the scour hole is an integral part of the bridge foundation design, and it is mostly used to determine what depth should be ignored as vertical and horizontal resistance of the piles [1]. 1D and 2D hydraulic modeling were applied in this project to appreciate the difference between scour depth magnitudes. The US Army Corps of Engineer's computer program, HEC-RAS, is the most common software to performed 1D hydraulic calculation despite its limitations which are mostly based on the simulation assumptions. Application of 2D hydraulic modeling is rapidly becoming the preferred analytical approach, specially for bridge scour studies. For the 2D simulation project, the community version of SMS from Aquaveo was used.

Background

The fifth edition of the Federal Highway Administration, Hydraulic Engineering Circular-18- from 2012, presents the state-of-the-art in scour calculations methods and equations. This new version include updated material as a result of the continued research performed by the National Cooperative Highway Research Program.

Problem

There is an enigma among engineers as to what type of hydraulic model use when predicting bridge's scour depth. In the past, assembling a two-dimensional model took a lot of time in addition to special computers, which led to having to decide if the situation really justified its application. One-dimensional models such as HEC-RAS include an interface to estimate scour depth with velocity and depth data resulting from hydraulic simulation, but based on assumptions that included, but are not limited to, the direction of flow, areas of ineffective flow, and flow expansion/contraction through a bridge. These assumptions can lead to erroneous estimate of scour depth, an important parameter when designing a bridge. This project reflects the differences between using one model or another to predict this depth of erosion around the foundation of a bridge.

Methodology

One-dimensional hydraulic simulation was performed using HEC-RAS 6.0 Beta 3 and a two-dimensional hydraulic simulation was performed using SMS 13.0.14. The scour depths results from the two models were compared.

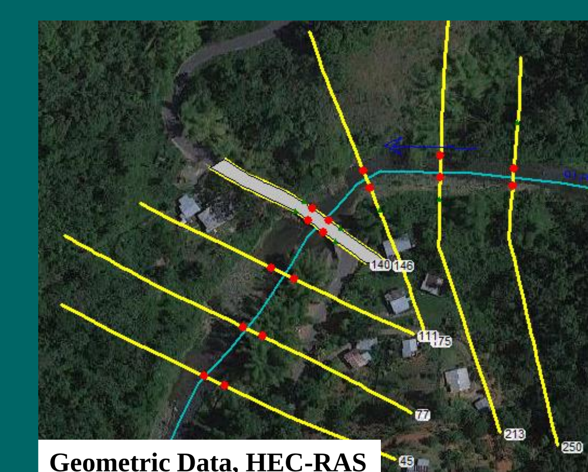

El Brujo Bridge, San Germán, PR

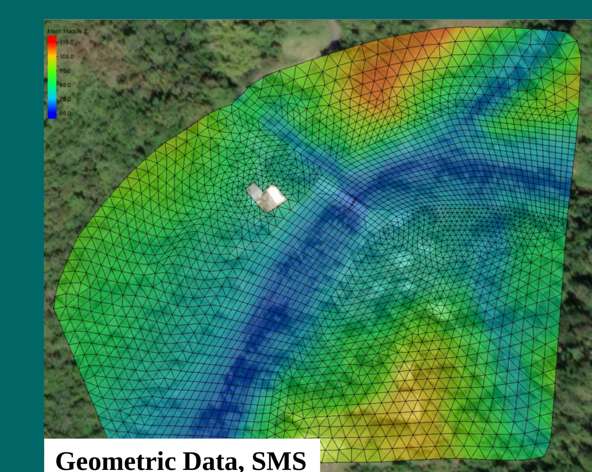
The main differences between both models are that the HEC-RAS computational procedure is only based on the solution of the one-dimensional energy equation, and the energy losses are evaluated by friction and the change in velocity head (contraction/expansion coefficients), while SMS solves the 2D dynamic wave equation for water surface elevation, water depth, and depth-averaged velocity using the finite volume numerical method.

For the assembly of the two hydraulic models there are several data that is needed to run both programs. Some of these input data are the resulting peak flows for different rainstorm events (obtained from a previous hydrologic analysis), the bridge dimensions, a particle size distribution of the streambed soil (obtained from a geotechnical study report), the topography of the area that include the bathymetry of the river (usually provided by a licensed land surveyor), the characteristic longitudinal slope of the stream, and the surface's roughness coefficients.

The estimated peak flow is 666 cms for a 100-years recurrence interval event. This river discharge value was used for both models. The flow regime was assumed as subcritical with a downstream longitudinal slope of 0.01 m/m.

The 1D hydraulic model was assembled and in the Figure 2 shown below, it can be observed a top view of the cross sections taken by a land surveyor on the river channel and its floodplain area. These cross sections contained topographic information of the river.


Geometric Data, HEC-RAS

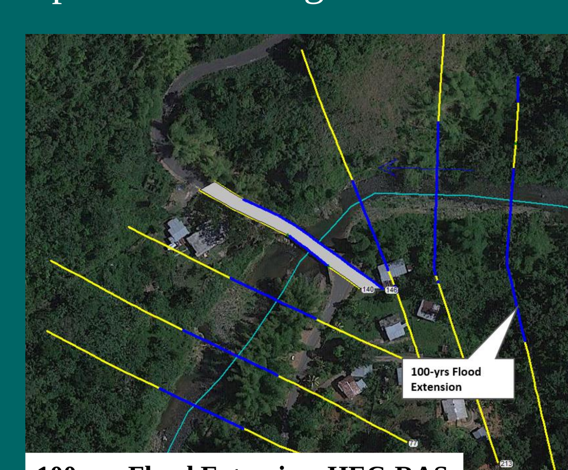

Geometric Data, SMS

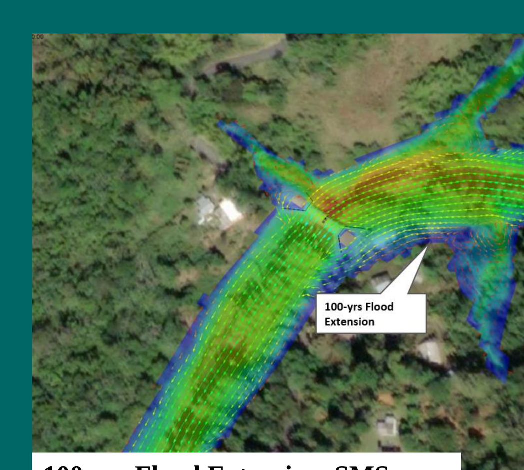
The topographic information used in the 2D simulation is the product of a merge between the ground elevation points took by the land surveyor and points from a U.S. Geological Survey LiDAR DEM from 2018. With this information and the surface's roughness information the mesh for the 2D model was completed.

After all these data was enter in the programs and once it is run, resulting values of water depth and water velocities are used to estimate bridge scour depth with the HEC-RAS Hydraulic Design Function and the FHWA Hydraulic Toolbox program.

Results and Discussion

The models, 1D and 2D, estimates the 100 years storm event flood extension. These models also calculated the water depth, and the velocities of the river. These data is applied to calculate the scour depths in the bridge.


100-yrs Flood Extension, HEC-RAS

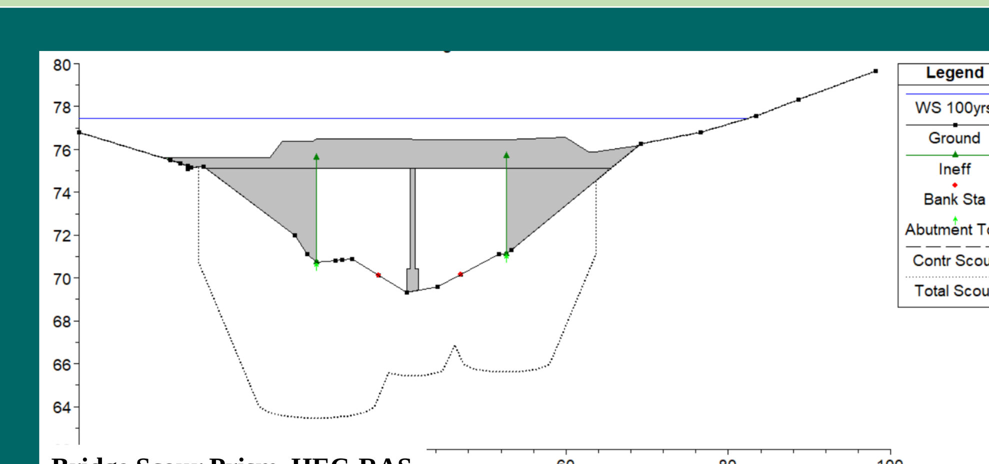

100-yrs Flood Extension, SMS

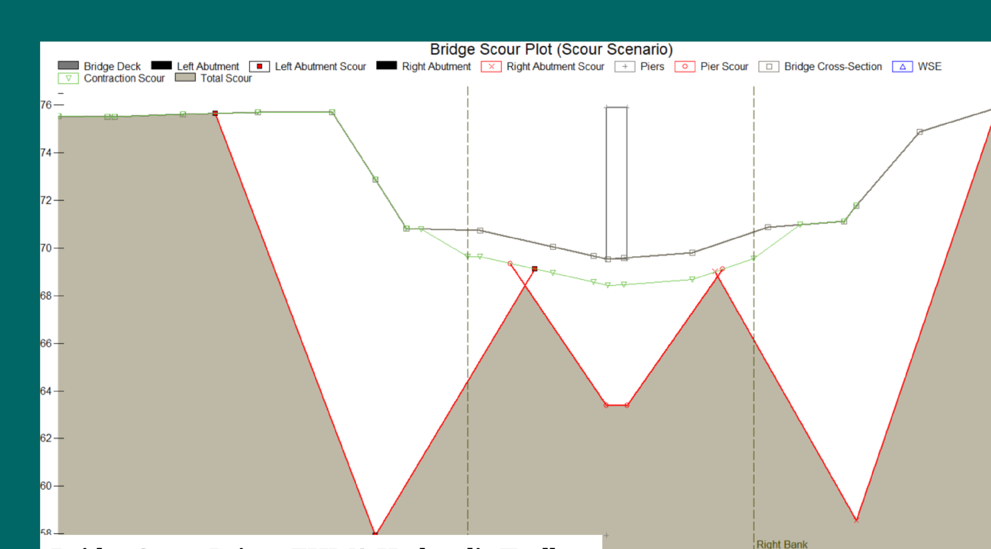
The values obtained for contraction and local scour, with the HEC RAS Hydraulic Design Function (1D) and with the Hydraulic Tools (with the data extracted from the SMS model), are presented in the table below.

Total Scour Depth (m)

	SMS 2D Model	HEC-RAS 1D Model	% Diff.
Pier	6.04	4.53	25
Left Abutment	10.97	7.28	34
Right Abutment	10.84	5.50	49

The resulting scour prism for both models is presented in the following figures.


Bridge Scour Prism, HEC-RAS

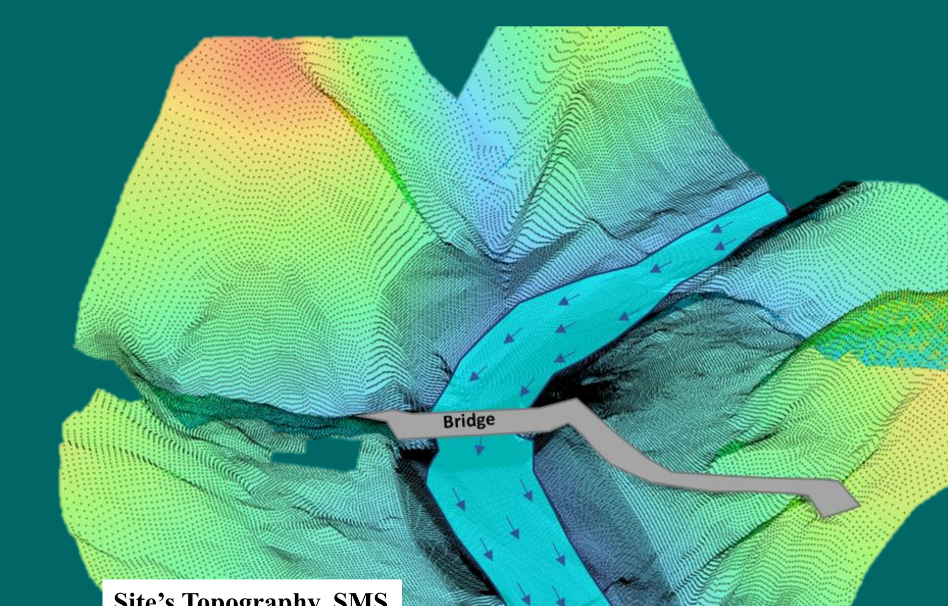

Bridge Scour Prism, FHWA Hydraulic Toolbox

From these figures it can be observed that even though they present the same behavior, it was demonstrated that the scour values can be differentiated up to 50% like the scour depth for the right abutment, especially if the equations applied in each model were different, as in this case.

Conclusions

It can be concluded after the completion of this project, that if the topographic data is available for the site being evaluated, and what is being analyzed is a hydraulic crossing, the best alternative is to assemble a 2D model. This will save the subjective interpretation of each parameter needed for the calculation of the scour hole in the bridge's foundation, which is greatly affected by the spatial distribution of flow.

In addition, the program used in this study for the two-dimensional modeling provides results applying the most recent developed equations by the National Cooperative Highway Research Program (NCHRP) for scour in bridges that are not included in the HEC-RAS program. While a formula completely based on laboratory data is applied in the one-dimensional model (HEC-RAS), the resulting data of the two-dimensional model are used in an equation that is more physically representative of the abutment scour process (NCHRP equation).



Site's Topography, SMS

Future Work

Two-Dimensional hydraulic modeling to estimate scour depths in bridge's foundation elements should become more common. There are a lot of support in the web, from truthful resources, which provide guidance to new and experience modelers. Since there has been recent advances in computers and softwares, 2D hydraulic modeling has become more accessible to engineers. Now the Federal Highway Administration Programs are promoting the application of this type of models, which can lead to make it a requirement of the local departments of transportation when presenting bridge's designs.

Acknowledgements

I want to thank my professor and mentor Christian Villalta, PH.D., for his time to answer questions and for the material provided during class over these two years of the graduate program.

References

[1] J. L. Briaud. "Scour Depth at Bridges: Method Including Soil Properties. I: Maximum Scour Depth Prediction." Journal of Geotechnical an Geoenvironmental Engineering, vol. 141, Issue 2, Feb. 2015.