NCHRP Project 24-48, "Develop a Formula for Determining Scour Depth Around Structures in Gravel-Bed Rivers"

Implementation of Research Findings and Products of NCHRP Project 24-48

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More information is available in *NCHRP Research Report 1031: Determining Scour Depth Around Structures in Gravel-Bed Rivers*, which can be found on the National Academies Press website (nap.nationalacademies.org).

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Brief summary of research

A new system of bridge pier scour equations was calibrated and tested for live bed and clear water conditions in coarse bedded rivers (median grain size > 2 mm) with a range of different pier shapes (cylindrical, round, sharp-nose, square). The equations require measurements of the undisturbed flow depth, undisturbed flow velocity, undisturbed channel slope, pier shape and configuration, flow angle of attack, grain size sorting parameter, bed sand content, and bed median grain size. Other general results from the research, which were incorporated into the new equation design, were that bridge pier scour in coarse bedded rivers is controlled by the: 1) impacts of grain size distribution sorting and bed sand content on the critical shear stress, 2) changes to the scour depth between clear water and live bed flow conditions, 3) decrease in the applied shear stress in the scour hole as scour progresses vertically, 4) differences between shear stresses at the pier and those for undisturbed conditions, and 5) need to use easily measurable undisturbed flow variables to predict scour while incorporating the mechanics of sediment motion within the scour hole.

Implementation and impediments

Conversations with seven state DOT were used to help identify the largest impediments to potential implementation of this research as well potential methods to best put this research into practice. In each the subsection below, we combine the topics of: a) how to best implement the research products, b) potential issues with implementation of the research and possible ways to mitigate for these issues.

Application of the new set of bridge pier scour equations: The system of equations requires iteration to solve and is therefore more difficult to implement than the current HEC-18 equations. To address this impediment, we developed a simple and easy to use excel spreadsheet that performs all the scour calculations for practitioners. If the excel spreadsheet proves useful to practitioners, then incorporating the new system of equations into the FHWA Hydraulic Toolbox or a having formal linkage between the excel spreadsheet and the Hydraulic Toolbox should be considered. Such a formal linkage would likely increase use of the new system of equations given that most state DOT use the FHWA Hydraulic Toolbox.

Importance of bed grain size distribution measurements for new scour equations and for predicting scour in general: Grain size distributions of the bed material were found to control both the measured scour depth and the critical shear stress for the onset of motion in laboratory experiments. These grain size distributions require estimates of the fraction of sand on the bed, and the D_{16}, D_{50} and D_{84} of the grain size distribution (where the subscript number denotes the percentile of the distribution). The new set of bridge pier scour equations requires bed grain size distribution data that may be more than many state DOT currently collect or have readily available. However, although the new set of scour equations was developed using very detailed grain size information, the field calibration and testing of these equations used less precise data. Specifically, we had to make some assumptions about the sand fraction, which was not reported, at each field site using only the measured D_{16}, D_{50} and D_{84} of the entire bed grain size distribution. Despite these assumptions, the new equations still accurately and reliably predicted scour in all tested rivers. Therefore, extremely detailed bed grain size information may not be needed to use this new system of equations. Some state DOT interviewed discussed the lack of general standards, uncertainty in where and how to sample grain sizes, and/or potential difficulty in obtaining samples. We provided general sediment sampling recommendations as an Appendix of the Final Report of this project to help address this problem. Future work could focus on developing grain size sampling standards and best practices for use of grain size measurements in bridge pier scour estimates for coarse bedded rivers. If a standard set of procedures were developed, this could be not only beneficial to the application of the new scour equations developed here but also for bridge pier or other structure analysis in general.

Importance of bed grain size distributions of different sediment layers: The grain size distributions of different sediment layers (e.g. armor vs subsurface) were also found to control measured scour depths in the conducted laboratory experiments. This implies that more accurate scour estimates, regardless of the equation employed, will likely result from having measured grain sizes in different layers. The effects of layers were therefore incorporated into the development of the new bridge pier scour equation. However, most interviewed state DOT do not sample the grain size distribution of different sediment layers. To address this problem, the new set of equations was directly calibrated and tested using field data in which only one layer of sediment was reported. This demonstrates that although sampling of different sediment layers is ideal, the new bridge pier scour equations provide reliable and accurate estimates of scour even if only one sediment layer has been sampled. Similar to our general recommendation for grain size measurements, future work could focus on developing easy to use methods and standards for measuring the grain size distributions of different sediment layers.

Lack of scour data in coarse bedded rivers with complex channel configurations or complex bridge pier configurations: Limited databases exist of measured bridge pier scour in coarse bedded rivers for complex pier configurations or complex channel topographies and morphologies. Although the new system of scour equations was developed using pier configurations with multiple columns, very few field data were available to fully assess the reliability of the new equations and the HEC-18 equations for these types of piers. In our interviews, some state DOT also discussed the problems of applying any bridge pier scour equations to the much more complex field environments that are typically encountered in coarse bedded rivers. Therefore, we recommend that future work may focus on compiling existing scour measurements for complex pier configurations or complex channel configurations. Future work could also focus on new scour measurements in these environments using the temperature sensor probes presented in Chapter 2 of our Final Report or other similar instruments that continuously measure scour. Such data could then be used to further develop or modify the new system of bridge pier scour equations.

Incorporation of local shear stresses from 2D models into new system of scour equations: Many interviewed state DOT are using 2D hydraulic models to estimate the near-pier flow conditions (e.g. velocities and shear stresses) to help inform their estimates of scour. The new scour equations developed as part of this report incorporate near-pier shear stresses directly into a system of general equations that calculate: 1) the difference between near-bed shear stresses at the pier to those for undisturbed conditions, and 2) conversions between near-bed shear stresses and total shear stresses at the pier, which are needed for comparison to critical shear stresses (measured using total shear stresses) to calculate scour. This set of shear stress equations was developed using the near-bed and total shear stresses in the specific laboratory experiments and 3D numerical models of the project. Although these new equations are generally applicable, the near-pier shear stresses for any bridge pier will depend on the actual complex flow field around a particular pier in a given river, which is why 2D models are being used by many state DOT. Future research could therefore focus on methodologies to directly incorporate the depth-averaged near-pier shear stresses from a given 2D model (developed by state DOT) into the new system of shear stress equations (developed in this research) for transforming local depth-averaged shear stresses into reach-averaged total shear stresses. This would allow more site specific and detailed 2D hydraulic information to be readily and directly used in the new set of bridge pier scour equations. We expect that the use of these site specific data would further improve scour predictions at each location. Such modifications would be relatively simple to accomplish as long as a standard procedure was established for obtaining the near-pier shear stresses (e.g. definition of near pier, use of mean near-pier shear stress for zero scour conditions) from any 2D models.

Possible leadership institutions in applying the research and measuring impacts associated with implementation

Implementation of the new system of scour equations and application of knowledge from the general results of this research partly hinge on awareness of this work. Beyond publishing this report and spreadsheet, future efforts could focus on presenting the results of the project at conferences and meetings. A group of state DOT (AK, CA, ID, NC, OR, WA and WY) are already aware of this research and its general findings from the presentations and interviews conducted as part of this project. They have also already seen draft versions of the scour equations and the excel file for implementing the equations as well as provided valuable feedback for equation development and implementation. Some of these state DOT (or others) could undertake training on the new equations and spreadsheet with the University of Idaho. These states could then test the equation implementation for practical scour predictions. If this test group finds the new scour equations useful, then a broader outreach program for training other state DOT and government agencies could take place.