

Project Title

Flood Hydrograph Generation for Predicting Bridge Scour in Cohesive Soils

University

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Principal Investigators

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Research Needs

The method currently used by South Dakota Department of Transportation (SDDOT) for designing bridge foundation assumes that the bed material is sand and designs for a single (worst-case) flood event such as the 100-year or 500-year flood using the peak flow magnitude. Many bridges in South Dakota are founded on cohesive soils consisting of silts and clays (Niehus, 1996). Since silts and clays scour more slowly than sands, using the traditional methods for evaluating scour at bridges may over predict the extent of scour. This could result in over design of new bridge foundations or installation of unnecessary scour countermeasures at existing bridges. Furthermore, bridges that are classified as scour critical may in fact be safe. With reliable methods for predicting scour in cohesive soils, SDDOT could save significant time and money on bridges built over waterways.

The Scour Rate In Cohesive Soils (SRICOS) method (Briaud et al., 1999, 2001) is included in the current edition of Hydraulic Engineering Circular No. 18 (HEC-18; Arneson et al., 2012) as an alternative approach for predicting bridge scour in cohesive soils. The SRICOS method uses site-specific measurements of soil erosion rate to predict scour depth as a function of time. For soils that erode slowly, the final scour depth predicted by the SRICOS method could be significantly less than the equilibrium scour depth in sand. However, a hydrograph is required in order to use the SRICOS method. Various models have been developed by researchers to generate a continuous hydrograph over the design life of bridges (e.g., Brubaker et al., 2004; Brandimarte et al., 2006). These time series models require a great deal of effort to construct and are difficult to apply routinely by engineers. There is no guidance in HEC-18 on how to generate a hydrograph for using the SRICOS method. It is unclear what level of detail (e.g., a continuous hydrograph for multiple years with an annual flooding cycle, a series of design floods) is required in the temporal record of flows to correctly predict the final scour depth in cohesive soils. It is also unclear how to apply the SRICOS method to small watersheds and ungauged streams where historical flow records are lacking. SDDOT needs guidelines to define the site

conditions in which the SRICOS method is more appropriate and more cost effective than the traditional methods, and to select a hydrograph generation method for using the SRICOS method.

Research Objectives

This research has three main objectives. First, select three bridge sites in South Dakota with long stream flow records (> 50 years) to compute the scour histories using the SRICOS method. The results will be analyzed to understand the relationship between time sequence of flows, rate of scour, and final scour depth to answer the fundamental question of how the characteristics of a hydrograph such as flood magnitude and duration, and the order of occurrence of floods would influence scour development in cohesive soils. Second, develop a decision tool to identify the types of field situations where the SRICOS method will be appropriate and beneficial. Third, provide guidelines for hydrologic analysis and hydrograph generation for using the SRICOS method based on the site conditions and project requirements.

Research Methods

We hypothesize that even for highly erosion resistant cohesive soils, it is not necessary to predict scour using a continuous hydrograph that covers the service life of a bridge. Due to pre-existing scour, most of the floods in a hydrograph will not achieve their maximum scour potential. Therefore, a sequence of design floods should be all that is needed to predict scour over the project life. This hypothesis will be tested by analyzing the recorded hydrographs from the three bridge sites to determine how the characteristics of a hydrograph such as the magnitude and duration of floods, and their order of occurrence influence the time development of scour. To expand the data set to include soil types other than those found at the three bridge sites, a sensitivity analysis will be conducted by varying the soil critical shear stress and slope of erosion-rate-versus-shear-stress curve over a range of values representative of cohesive and non-cohesive soils. The findings from these analyses will be synthesized to develop a decision tool with a series of screening process flow charts to allow the engineer determines whether use of the SRICOS method is beneficial for a given project.

We will develop several approaches for predicting bridge scour in cohesive soils based on the SRICOS method to be used with the decision tool. Each approach will involve a different level of complexity in hydrograph generation, with quantifiable risks. The basic framework will be a series of maximum annual floods (Ting et al., 2011). A frequency analysis is first performed on historical flow data to determine the peak flow magnitudes and recurrence intervals of the individual floods. The peak flow magnitudes are then used to calculate the parameter values (e.g., mean and standard deviation) of an assumed probability distribution (e.g., Log Pearson Type III distribution). The probability distribution is then sampled (randomly or in some prescribed manner) to create a flood series that satisfies the parameters of the distribution. A set of equally probable future hydrographs will be generated and used with the SRICOS method to compute the final scour depth. The distribution of computed final scour depths is then used to determine the risk values associated with different project lives of bridge and design values of scour depth. Note that in addition to flood magnitude, flood duration also needs to be specified for the individual floods in order to predict scour. Flood durations will be determined for the individual floods in the maximum annual series from historical flow records at the bridge site.

For gauged streams, the drainage-area ratio method will be used to transfer stream flow data from a gauging station or stations to the bridge site. For an ungauged stream, daily stream flow data will be transferred from a gauging station on a nearby stream to the bridge site using the QPPQ method (Archfield et al. 2013). If hourly stream flow data are required, the stream flow disaggregation scheme by Straub and Over (2010) will be used to estimate average hourly discharges from the estimated daily discharges. The computed probability distribution of scour depth produced by the maximum annual series can then be used to assess the risk levels of other, simplified methods, such as using a recorded hydrograph with the SRICOS method to predict future scour; running the SRICOS method with the 100- or 500-year peak flow for a certain number of days; or running the SRICOS method with a time series of flow values generated by a forecasting model.

Expected Outcomes

The expected outcomes of this project will be an alternative approach to evaluation of bridge scour in cohesive soils. The results of this proposed research will be directly applicable to practice, first by giving the design engineer detailed guidelines to identify bridge sites where the SRICOS method may be useful and, second, by providing step-by-step instructions and worked examples on how to generate flood hydrographs for scour prediction using the SRICOS method. When use of the SRICOS method is advisable, substantial savings in foundation costs may result and this can be measured by the dollars saved in SDDOT projects.

Relevance to Strategic Goals

The proposed project and its expected outcomes are related to the following strategic goals of the MPC: State of Good Repair, Safety, and Economic Competiveness. SDDOT currently uses methods developed for non-cohesive soils to evaluate bridge scour. The SRICOS method could reduce foundation costs in cohesive soils and increase confidence level of foundation designs for some bridge sites and projects. The SRICOS method would also be useful for predicting scour produced by extreme events where the duration of floods is not sufficient to generate equilibrium condition.

Educational Benefits

One graduate student will work on this project and complete a Master of Science (MS) thesis. The student will attend and present his/her work at an annual Transportation Research Board (TRB) Meeting. Conference and journal papers will be published to disseminate the results of this project widely to the practitioners. The information developed by this project will also be used for presentations and term projects in hydraulic engineering classes taught by the principal investigator.

Work Plan

The project will include the following 14 tasks. Table 1 provides a graphical presentation for the identified tasks.

- 1) Meet with the project technical panel to review project scope and work plan.
- 2) Review literature on recent advances in predicting bridge scour in cohesive soils and methods for constructing flood hydrographs.
- 3) Conduct a national survey on methods and practices used by state DOTs to evaluate bridge scour in cohesive soils, including use of the SRICOS method and types of projects.
- 4) Through consultation with SDDOT and the United States Geological Survey (USGS), select three bridge sites with long stream flow records and compute the scour histories using the SRICOS method.
- 5) Perform scour analysis (pier, contraction, and abutment, depending on the characteristics of each site) using the predicted scour histories to determine the influence of time sequence of flows on rate of scour and final scour depth to answer the fundamental question of how the characteristics of a hydrograph influence scour development in cohesive soils.
- 6) Submit a technical memorandum and meet with the project technical panel to present the results of Tasks 2-5.
- 7) Analyze the sensitivity of the scour analysis in Task 5 by varying the soil critical shear stress and slope of erosion-rate-versus-shear-stress curve over a range of values representative of cohesive and non-cohesive soils. For the different soil erodibility values, determine the level of detail needed to be retained in the hydrograph to predict the same final scour depth as predicted by the complete recorded hydrograph.
- 8) Identify the site conditions and design requirements—including soil characteristics, hydraulic and hydrologic conditions, and design life—where use of the SRICOS method would be beneficial and develop a decision tool for identifying these projects.
- 9) Develop guidelines for selecting a hydrograph generation method based on the site conditions, project type, and acceptable risk. These methods will include hydrograph generation for small watersheds and ungauged streams.
- 10) Submit a technical memorandum and meet with the project technical panel to present the results of Tasks 7-9.
- 11) Develop procedures and provide at least three worked examples on the use of the decision tool and hydrograph generation methods in Tasks 8 and 9. Perform laboratory testing to determine the critical shear stress and slope of erosion-rate-versus-shear-stress curve of soil samples collected for use in the examples.
- 12) Submit a technical memorandum and meet with the project technical panel to present the results of Task 11.
- 13) Prepare a final report summarizing the research methodology, findings, conclusions and recommendations.
- 14) Make an executive presentation to the SDDOT Research Review Board at the conclusion of the project.

Table 1 Task Time Schedule

TASK	YEAR/MOHTH	2017												2018												2019	
		3	4	5	6	7	8	9	10	11	12	1	2	3	4	5	6	7	8	9	10	11	12	1	2		
1. Meet with technical panel		█																									
2. Conduct literature review		█	█	█																							
3. Conduct national survey					█	█	█	█																			
4. Select bridge sites and compute scour histories					█	█	█	█	█																		
5. Perform scour analysis					█	█	█	█	█																		
6. Submit 1st technical memorandum and meet with technical panel									█																		
7. Conduct scour analysis with a range of soil erodibility values									█	█	█																
8. Develop decision tool for using the SRICOS method												█	█	█	█	█											
9. Develop guidelines for hydrograph generation												█	█	█	█	█											
10. Submit 2nd technical memorandum and meet with technical panel																█											
11. Provide worked examples on use of decision tool and hydrograph generation methods																█	█	█	█								
12. Summit 3rd technical memorandum and meet with technical panel																			█								
13. Prepare Final Report and publications																					█	█	█	█	█	█	█
14. Make executive presentation to SDDOT Research Review Board																											█

Project Cost

Total Project Costs: \$139,672
 MPC Funds Requested: \$ 64,135
 Matching Funds: \$ 75,537
 Source of Matching Funds: South Dakota Department of Transportation

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