Evaluation and Prediction of Bridge Pier and Contraction Scour of Cohesive River Sediments in Tennessee

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Synopsis of the Research Problem

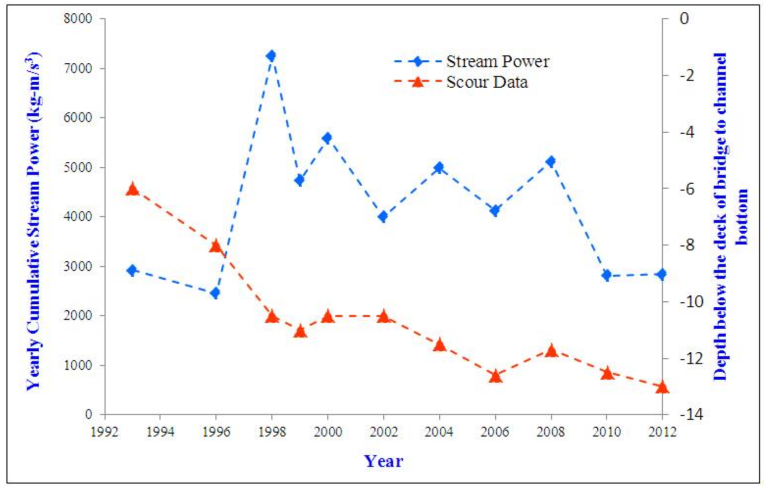
Approximately 450 scour critical bridges are maintained by TDOT across the state, many of which are located in river or stream beds with cohesive sediments, particularly in western Tennessee. In the Hydraulic Engineering Circular No. 18 (2012) by the Federal Highway Administration, existing equations for predicting scour depth at bridge piers and contractions in river beds with non-cohesive, coarse-grained sediments tend to perform well. However, when cohesive, fine-grained sediments lie on the river bed, the HEC-18 equations tend to over predict scour depth. Prediction of scour depth in cohesive sediments (e.g., consolidated clay with silt) is more complex than for non-cohesive gravel-sand riverbed sediment. Erosion behavior of cohesive sediments is dependent on its geophysical properties, and under fluvial shear stresses failure occurs as aggregates of clay-silt that break off from the boundary (river bed and bank). Because scour in cohesive sediments is a time-dependent variable and episodic under varying river flow stages over time, a hydrological analysis at bridges need to be conducted examining flood history and scour depth measurements over time per site. Lack of predictive capability of the maximum scour depth in cohesive river bed sediments remains a critical engineering problem for TDOT bridge engineers. Scour prediction is necessary in order to identify bridges in danger of foundation instability and failure; and conversely, in rivers with high hydraulic resistance where bridge piers and abutments may be overdesigned, increasing project construction costs.

Project Objectives

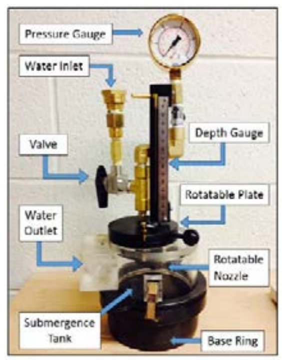
The overall project goal is to develop bridge scour relationships for erodibility and critical shear stress specific to geophysical properties of cohesive sediment among the four TDOT regions. The task objectives include: 1) compile bridge information and historic scour data at bridge sites across Tennessee; 2) conduct a hydrologic analysis and develop cumulative shear stress and stream power duration curves; 3) field survey scour patterns at piers and contractions at bridge sites, classify bed/bank sediment/soils, measure *in situ* τ_c and erodibility with the jet tester, analyze sampled cohesive sediment for geotechnical properties; 4) conduct a statistical analysis correlating measured scour depth with hydrological analysis data and measured geotechnical properties; and 5) develop predictive relationships for scour depths.

Project Description and Current Outcomes

Twenty-one bridge sites were selected for the project, including 3 in TDOT Region I, 2 in Region II, 3 in Region 3, and 13 in Region IV. Design information on bridge piers and abutments for these sites were compiled. A hydrological analysis using HEC-HMS and available climate data were completed where daily stream flows were simulated over the life period of the bridge. Cumulative shear stress and stream power duration curves were computed and compared with scour depth. See example plot for one site to the right. In this example, it is observed a rapid decline in scour depth initially after the bridge was constructed, and a potential scour response to a major flood in 1998, after which more moderate scour occurred and did not correspond to annual stream power.



To date, a major contribution has been advancing the application of a jet test device (JTD) used to estimate critical shear stress (τ_c) and the erodibility coefficient (k_d) for cohesive soils. It was originally developed at the USDA National Sedimentation Laboratory. Photos of the JTD are shown to the right. Research to improve the accuracy of this device has included varying test pressures and assessing multiple computational procedures for estimating τ_c and k_d. In addition, field JTD results have been compared with estimates from a specially-constructed conduit flume at the UT's Hydraulics and Sedimentation Laboratory. The research associated with this JTD is fundamental, and our research team is involved with academic colleagues nationally on how to improve measuring procedures, data analysis, and the multivariate factors that affect field estimates of erodibility of cohesive soils.



JTD tests were conducted at the 21 bridge sites, the same bridge sites in which the hydrological analyses were conducted, and field soil samples collected. Extensive geotechnical/geophysical testing was completed on sampled sediment consisting of 23 parameters. A statistical analysis was completed developing predictive relationships for τ_c and k_d based on the 23 parameters. The significant outcome of this analysis was that each TDOT region, with its unique geology and parent material for soil genesis, had unique predictive equations. The importance of this research is how equation independent variables are dominantly related to geology. Studies prior to this one had always been conducted in the same geological region, and published works have reported multiple prediction equations lacking predictive precision. This work is a significant contribution to developing a useful predictive model for bridge pier/abutment scour.

Project Status

The five project objectives tasks have been completed and efforts now include report writing and manuscript preparations for publication. Further advancement of the fifth objective is being proposed, in which the plan is to build an open channel and scaled physical model of bridge pier with a cohesive soil bed to test the predictive equations developed from field studies. The project is scheduled to be fully completed by July 31, 2018.