A GUIDANCE MANUAL FOR ASSESSING SCOUR POTENTIAL USING THE SOUTH CAROLINA BRIDGE-SCOUR ENVELOPE CURVES

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Abstract. The U.S. Geological Survey, in cooperation with the South Carolina Department of Transportation, conducted a series of three field investigations of bridge scour in order to better understand regional trends of scour within South Carolina. The studies collected historic-scour data at approximately 200 riverine bridges including measurements of clear-water abutment, contraction, and pier scour, as well as live-bed contraction and pier scour. These investigations provided valuable insights for regional scour trends and yielded bridge-scour envelope curves for assessing scour potential associated with all components of scour at riverine bridges in South Carolina. The application and limitations of these envelope curves were documented in three reports. Each report addresses different components of bridge scour and thus, there is a need to develop an integrated procedure for applying the South Carolina bridge-scour envelope curves. To address this need, the U.S. Geological Survey and the South Carolina Department of Transportation initiated a cooperative effort to develop an integrated procedure and document the method in a guidance manual. In addition to developing the integrated procedure, field data from other investigations outside of South Carolina were used to verify the South Carolina bridge-scour envelope curves.

INTRODUCTION

Bridge scour is the erosion of streambed or bank material around bridge abutments or piers that occurs because of rapidly flowing water during floods. Equations to estimate bridge-scour are presented in the Federal Highway Administration's guidance manual, Hydraulic Engineering Circular No. 18 (HEC-18; Arneson and others, 2012). These equations reflect the current state-of-the practice for predicting scour at bridges and provide an important resource for assessing scour potential. However, there is a measure of uncertainty when applying them to field conditions. Various laboratory researchers (Melville and Coleman, 2000; Arneson and others, 2012) have acknowledged the uncertainty and limitations associated with the current equations. Additionally, various field investigations (Mueller and Wagner, 2005; Benedict and others, 2006; Benedict and Caldwell, 2006; and Benedict and Caldwell, 2009) have highlighted the uncertainty by demonstrating how the equations often provide excessive overpredictions, with some equations providing frequent underpredictions.

Because of this uncertainty, HEC-18 (Arneson and others, 2012) recommends that engineers evaluate the computed scour depths obtained from the equations and modify them if they appear unreasonable. One way to evaluate the reasonableness of predicted scour is by comparing it to field measurements of historic scour. Historic scour measurements are similar to post-flood measurements and represent the maximum scour that has likely occurred over the life of the bridge. Such field data show scour depths resulting from high flows, and provide a reference for evaluating predicted scour. However, it is rare that such data are available at or near the site of interest making the evaluation of predicted scour in comparison to field data difficult if not impossible.

Realizing the value of historic scour measurements, the U.S. Geological Survey (USGS), in cooperation with the South Carolina Department of Transportation (SCDOT) conducted a series of three field investigations (Benedict, 2003; Benedict and Caldwell, 2006; Benedict and Caldwell, 2009) with the goal of collecting historic scour measurements in order to better understand regional trends of scour within South Carolina. The studies collected historic scour data at approximately 200 riverine bridges including measurements of clear-water abutment, contraction, and pier scour (scour that occurs on the bridge overbank), as well as live-bed contraction and pier scour (scour that occurs in the main channel). These investigations have provided valuable insights for regional scour trends and have yielded bridge-scour envelope curves for assessing all components of scour at riverine bridges in South Carolina. The application and limitations of these envelope curves are documented in four reports. Each report addresses different components of bridge scour and there is a need to develop an integrated procedure for applying the envelope curves to help assess scour potential at riverine bridges in South Carolina. In addition to developing the integrated procedure, field data from other investigations outside of South Carolina were used to verify the South Carolina bridge-scour envelope curves. This paper will provide an overview of the project objectives and present preliminary findings regarding the verification of selected envelope curves.

PROJECT OBJECTIVES

The primary objective of this project is to develop an integrated procedure for assessing scour potential at riverine bridges in South Carolina utilizing the regional bridge-scour envelope curves developed in the three previous field investigations (Benedict, 2003; Benedict and Caldwell, 2006; Benedict and Caldwell, 2009). To accomplish this objective, the following steps will be taken: (1) a literature review of selected publications that are currently used for guidance in scour prediction and to identify other sources of field data for verification of the South Carolina bridge-scour envelope curves, (2) verification/modification of the South Carolina bridge-scour envelope curves with other field data identified in task 1, (3) development of an integrated procedure for applying the envelope curves; (4) development of the 500-year flow envelope-curve coefficients, (5) development of a spreadsheet to automate the integrated procedure, (6) development of a site-comparison database by merging the three existing databases, and (7) the documentation of the integrated procedure in a guidance manual.

VERIFICATION OF THE SOUTH CAROLINA PIER-SCOUR ENVELOPE CURVES

Benedict and Caldwell (2006, 2009) used 179 field measurements of clear-water pier scour and 141 measurements of live-bed pier scour to develop clear-water and live-bed envelope curves to be used as supplementary tools for evaluating the potential for pier scour at bridges in South Carolina. Pier width is known to be a strong explanatory variable for pier-scour depth (Melville and Coleman, 2000, Arneson and others, 2012), and was used as the primary explanatory variable in these envelope curves. One objective of the current investigation (2014) is to verify these envelope curves by evaluating them with previously published data. A literature review was made to identify potential sources of pier-scour data, and selected data were compiled into a database consisting of 569 laboratory and 1,858 field measurements of pier scour. These data were published in Benedict and Caldwell (2014). The field data consist of measurements from 23 States within the United States and 6 other countries. These data were analyzed for the upper bound of pier scour and a verification envelope curve was developed from this larger dataset. The South Carolina pier-scour envelope curves fell in close proximity to the verification envelope curve, indicating that the South Carolina envelope curves are reasonable. For illustration, figure 1 shows the South Carolina clear-water pier-scour envelope curve in comparison to the verification envelope curve. Current guidance and limitations for using the South Carolina pier-scour envelope curves can be found in Benedict and Caldwell (2006, 2009).

VERIFICATION OF THE SOUTH CAROLINA ABUTMENT-SCOUR ENVELOPE CURVES

Benedict (2003) used 209 field measurements of clear-water abutment scour to develop envelope curves for the Piedmont and Coastal Plain of South Carolina to be used as supplementary tools for evaluating the potential for abutment scour at bridges in South Carolina. The embankment length blocking flow, measured from the edge of the floodplain to the abutment toe, and the geometric contraction ratio, a dimensionless variable that reflects the severity of the geometric contraction created by the bridge, with 0.0 being no contraction and 1.0 being 100 percent blockage, are known to be strong explanatory variables for abutment-scour depth (Melville and Coleman, 2000; Benedict, 2003) and were used as the primary explanatory variables in these envelope curves. As with verification of the pier-scour envelope curves, a literature review was made to identify potential sources of abutment-scour data, and 329 field measurements of abutment scour were compiled into a database. All of the data were collected by the USGS and included 15 measurements from the USGS National Bridge Scour Database (NBSD; USGS, 2001), 198 measurements from South Carolina (Benedict, 2003), 93 measurements from Maine (Lombard and Hodgkins, 2008), and 23 measurements from Alabama (Lee and Hedgecock, 2008). In addition to the USGS field data, two abutment-scour measurements at Interstate 70 crossing the Missouri River (Parola and others, 1998), associated with the 1993 flood also were included. The Missouri River data are perhaps the largest measured abutment-scour depths in the United States (30 and 56 feet) and were strongly influenced by a levee breach located approximately 350 ft upstream from the abutment. Additionally, the site has a drainage area of 500,000 square miles. In contrast, the maximum drainage area for the South Carolina data is 8,830 square miles with a median value of approximately 100 square miles. The adverse flow conditions and significantly larger drainage area contribute to the larger scour depths than those of the South Carolina data. While the Missouri River data do not represent typical abutment scour, they were included in the analysis for perspective.

All of the field data were plotted with the South Carolina abutment-scour envelope curves and most of the data fell within the curves, indicating that they are reasonable. As an example, figure 2 shows the abutment-scour envelope curve with respect to the geometric contraction ratio. For scale, only the 30-foot Missouri River scour depth was included in this figure. The exceedance of the Missouri River data can be attributed, in part, to the levee breach and the much larger drainage area, and highlights the importance of limiting the application of the South Carolina bridge-scour envelope curves to site characteristics similar to the South Carolina data used to develop the curves. The one Maine data point that exceeds the envelope curve was measured with ground-penetrating radar, which tends to provide conservative estimates of scour depth (Benedict and Caldwell, 2009), giving some explanation for its exceedance. Current guidance and limitations for using the South Carolina abutment-scour envelope curves can be found in Benedict (2003).

CONCLUSIONS

Current methods for predicting scour have some uncertainty, and therefore, should be assessed for reasonableness. One way to make such assessments is by comparing predicted scour to field measurements of historic scour. The recent investigations of scour in South Carolina demonstrate how a strategic sample of historic field data can be used to develop regional bridge-scour envelope curves for assessing scour potential. The verification of these envelope curves with field data from other sources indicates that the South Carolina bridge-scour envelope curves are reflecting the upper bound of scour under field conditions in South Carolina. The findings presented in this paper will be included in a report that documents the development, application, and limitations of the South Carolina bridge-scour envelope curves.

REFERENCES

Arneson, L.A., Zevenbergen, L.W., Lagasse, P.F., and Clopper, P.E., 2012, Evaluating scour at bridges. Hydraulic Engineering Circular No. 18, 5th Ed., Federal Highway Administration, Publication FHWA-HIF-12-003, 340 p.

Benedict, S.T., 2003, Clear-water abutment and contraction scour in the Coastal Plain and Piedmont Provinces of South Carolina, 1996-99, U.S. Geological Survey, Water-Resources Investigations Report 03-4064, 137 p.

Benedict, S.T., and Caldwell, A.W., 2006, Development and evaluation of clear-water pier and contraction scour envelope curves in the Coastal Plain and Piedmont of South Carolina, U.S. Geological Survey Scientific Investigations Report 2005–5289, 98 p.

Benedict, S.T., and Caldwell, A.W., 2009, Development and evaluation of live-bed pier and contraction scour envelope curves in the Coastal Plain and Piedmont provinces of South Carolina, U.S. Geological Survey Scientific Investigations Report 2009-5099, 108 p.

Benedict, S.T., and Caldwell, A.W., 2014, A pier-scour database—2,427 field and laboratory measurements of pier scour: U.S. Geological Survey Data Series 845, 22 p.

Benedict, S.T., Deshpande, Nikhil, Aziz, N.M., and Conrads, P.A., 2006, Trends of abutment-scour prediction equations applied to 144 field sites in South Carolina: U.S. Geological Survey Open-File Report 2003-295, 150 p.

Lee, K. G., and Hedgecock, T. S., 2008, Clear-water contraction scour at selected bridge sites in the Black Prairie Belt of the Coastal Plain in Alabama, 2006, U.S. Geological Survey Scientific Investigations Report 2007–5260, 56 p.

Lombard, P.J., and Hodgkins, G.A., 2008, Comparison of observed and predicted abutment scour at selected bridges in Maine: U.S. Geological Survey Scientific Investigations Report 2008–5099, 23 p.

Melville, B.W. and Coleman, S.E., 2000, Bridge Scour: Highlands, Colorado, Water Resources Publications, 550 p.

Mueller, D.S., and Wagner, C.R., 2005, Field observations and evaluations of streambed scour at bridges, Federal Highway Administration, Publication FHWA-RD-03-052, 122 p.

Parola, A.C., Hagerty, D.J., and Kamojjala, S., 1998, Highway infrastructure damage caused by the 1993 Upper Mississippi River basin flooding, National Cooperative Highway Research Program, NCHRP Report 417, 172 p.

U.S. Geological Survey, 2001, National bridge scour database, accessed April 15, 2014, at http://water.usgs.gov/osw/techniques/bs/BSDMS/index.htm.

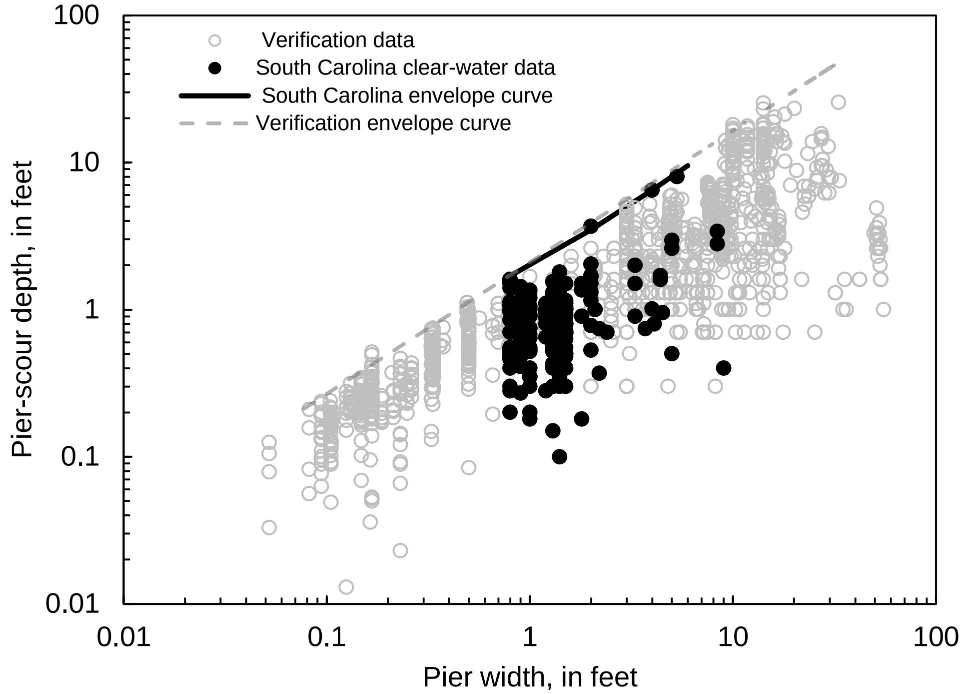

Figure 1. Comparison of the South Carolina clear-water pier-scour envelope curve to the verification envelope curve.

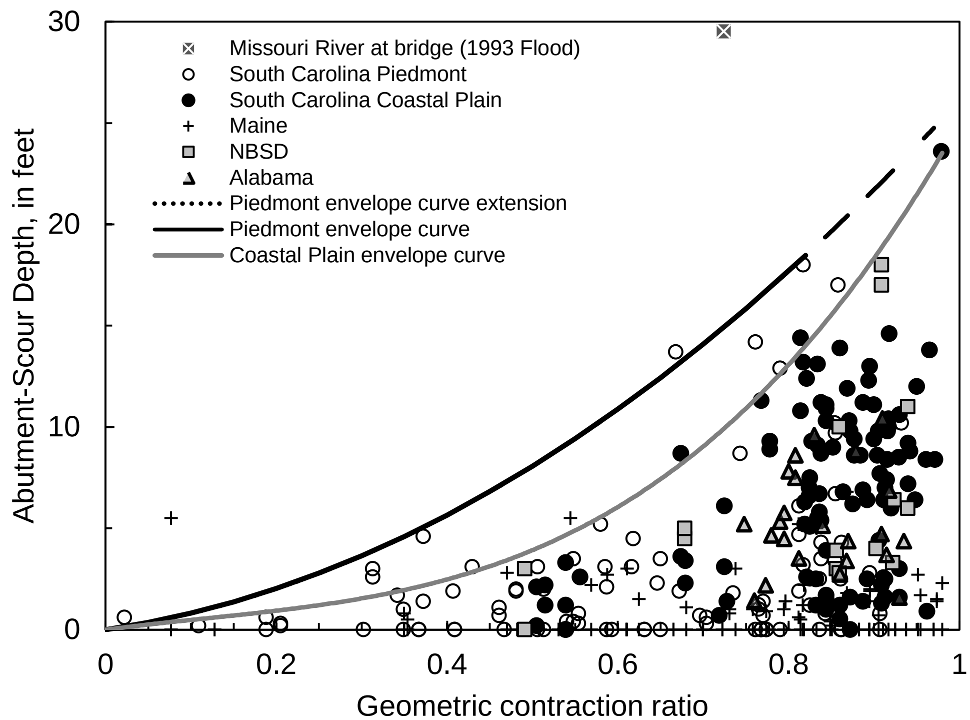

Figure 2. The South Carolina abutment-scour envelope curves with respect to the geometric contraction ratio compared with selected field data.