THE UPPER BOUND OF PIER SCOUR DEFINED BY SELECTED LABORATORY AND FIELD DATA

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Abstract The U.S. Geological Survey, in cooperation with the South Carolina Department of Transportation, conducted several field investigations of pier scour in South Carolina and used that data to develop envelope curves defining the upper bound of pier scour. To expand upon this previous work, an additional cooperative investigation was initiated to combine the South Carolina data with pier-scour data from other sources and evaluate the upper bound of pier scour with this larger data set. To facilitate this analysis, a literature review was conducted to identify potential sources of published data on pier scour, and selected data were compiled into a digital spreadsheet consisting of 569 laboratory and 1,858 field measurements. These data encompass a wide range of laboratory and field conditions and represent field data from 23 states within the United States and six other countries. This extensive database was used to define the upper bound of pier-scour depth, with respect to pier width, encompassing both laboratory and field data. The envelope curve provides a simple but useful tool for assessing the potential maximum pier-scour depth for pier widths of about 30 feet or less.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the South Carolina Department of Transportation (SCDOT), collected 179 field measurements of clear-water pier scour and 141 measurements of live-bed pier scour in South Carolina (Benedict and Caldwell, 2006; 2009), with nominal pier widths ranging from 0.8 to 9 feet (ft). These data were used to develop field-derived envelope-curves that reflect the upper bound of clear-water and live-bed pier scour for bridges in South Carolina, using pier width as the primary explanatory variable. To expand upon this previous work, the USGS and SCDOT initiated an additional cooperative investigation to combine the South Carolina data with pier-scour data from other sources and evaluate upper-bound relations within this larger data set. A literature review was conducted to identify potential sources of pier-scour data, and selected data were compiled into a database consisting of 569 laboratory measurements and 1,858 field measurements from 23 states within the United States and six other countries (Benedict and Caldwell, 2014). These data substantially extended the nominal pier-width range (0.05 to 64 ft) and spatial extent associated with the South Carolina data. They provide a means to develop an improved upper-bound pier-scour envelope curve having broad application. Pier width has been noted by various investigators (Laursen and Toch, 1956; Melville and Coleman, 2000; Mueller and Wagner, 2005; Ettema and others 2011; and Arneson and others 2012) to be a primary variable that influences pier-scour depth, and therefore, pier width was the only explanatory variable used in the envelope curve. This paper presents preliminary findings providing a brief description of (1) the laboratory and field database, (2) the upper-bound envelope curve of pier-scour based on the compiled database, (3) the comparison of this upper-bound curve with the South Carolina pier-scour envelope curves, and (4) conclusions.

LABORATORY AND FIELD DATABASE

Benedict and Caldwell (2014) developed a digital pier-scour database, called the 2014 USGS Pier Scour Database (PSDb-2014), consisting of 569 laboratory and 1,858 field measurements compiled from selected authors. The laboratory data are measurements taken from 17 previous investigations and originally compiled by Sheppard and others (2011). Through a screening process that included data review and statistical analysis, Sheppard and others (2011) identified 441 of the laboratory measurements, with no skew to flow, that approximated equilibrium scour depths for the given flow, pier geometry, and sediment characteristics. These screened laboratory data provide a reliable source for evaluating the upper-bound relations of pier scour and were used in the current (2015) investigation to initially determine a pier-scour envelope curve. The field data were compiled from 32 previous publications and reflect measurements collected in 23 states within the United States and six other countries. A subset of 727 field measurements included in the PSDb-2014 was previously screened by Sheppard and others (2011), and identified as likely approximating equilibrium scour depths. From this subset of screened data, 410 field measurements with pier skews equaling zero degrees, or with adequate information to evaluate the influence of pier skew, were selected and used to corroborate and extend the pier-scour envelope curve defined by the laboratory data. An additional 558 pier-scour data, measured during high flows and having the previously noted selection criteria, were chosen from the remaining PSDb-2014 field measurements, and used as validation data to verify the pier-scour envelope curve defined with the screened laboratory and field data. [Note: Field measurements used in this investigation with piers skewed to flow were adjusted by dividing the scour depth by the pier-skew coefficient as determined from Arneson and others (2012).] Additional information regarding the PSDb-2014 and its associated report (Benedict and Caldwell, 2014) is available at the following web address: http://pubs.usgs.gov/ds/845.

THE UPPER BOUND OF PIER SCOUR IN LABORATORY AND FIELD DATA

Figure 1 displays the relation of pier-scour depth with respect to pier width using the 441 screened laboratory measurements identified by Sheppard and others (2011). A log-log scale is used to better display the upper bound of the data. With only two exceptions, the upper bound displays a well-defined relation as shown by the line in figure 1. The two data points that slightly exceed the line are associated with high Froude numbers (1.2 and 1.5). Jain and Fischer (1979) note that the flow conditions associated with these two measurements were very turbulent and unsteady, making the measurements questionable. Therefore, these two data points were excluded in defining the upper bound of the data. If the laboratory data in figure 1 are capturing the upper bound of pier-scour depth that is expected in the field, it would be reasonable to expect that the upper bound of the field data would conform to the extension of the line in figure 1.

Figure 2 shows the relation of scour depth and pier width for the 410 screened field data, previously described, using the same format as figure 1 with an extension of the envelope curve derived from the laboratory data. While there is more scatter in the upper bound of the screened field data than that of the laboratory data, it conforms well to the envelope curve of the laboratory data, indicating that the laboratory envelope curve provides a reasonable definition of the upper bound of pier scour in the field as well as the laboratory. There are two field measurements that exceed the envelope curve with exceedance values of 0.3 and 2.5 ft. The

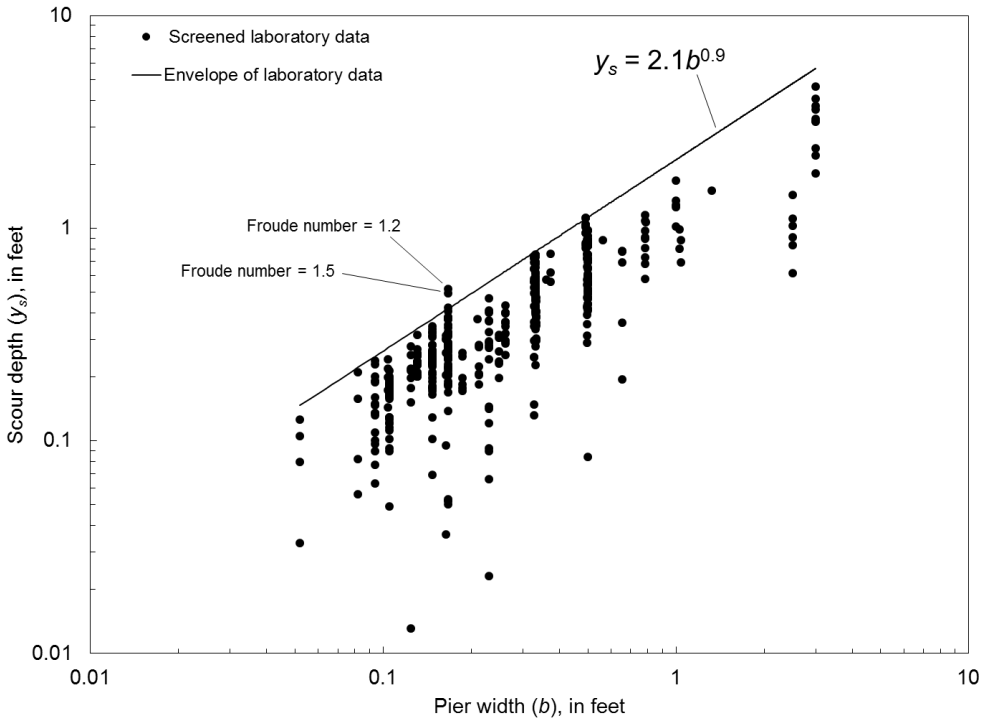

Figure 1 Relation of scour depth to pier width for the screened laboratory data.

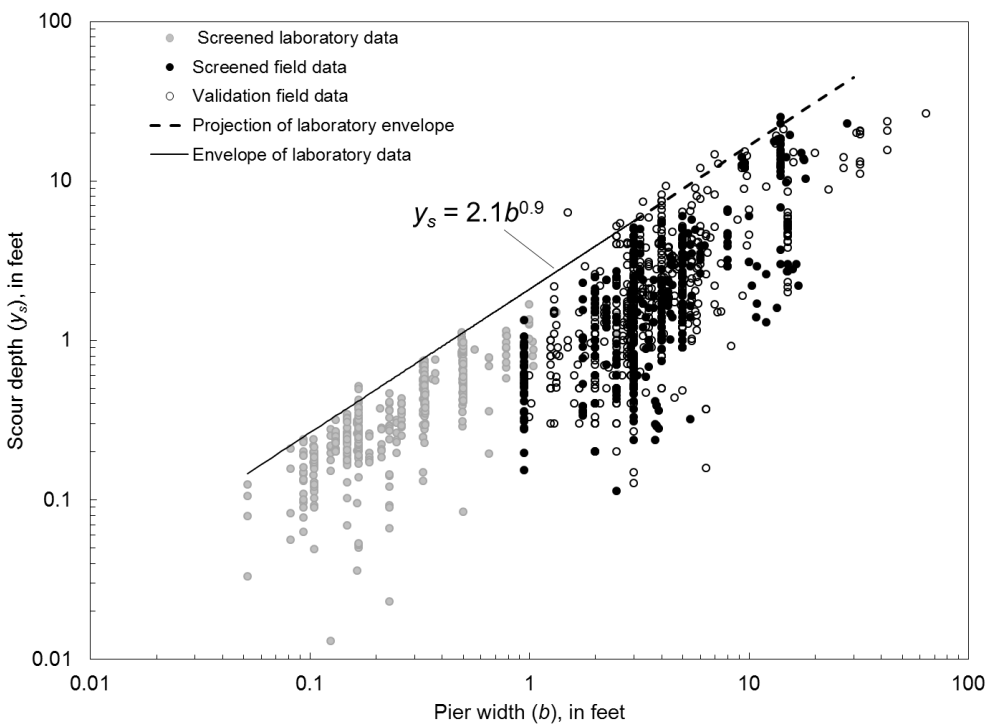

Figure 2 Relation of scour depth to pier width for the screened laboratory and field data, and validation field data.

complexities of the field, combined with the harsh measuring environment, make it difficult to measure pier scour to the same degree of accuracy as that of the laboratory, and therefore, it is expected that some field measurements may exceed the upper bound of the laboratory data. Because the exceedance values are small, no adjustment was made to the envelope curve to account for these two data points. The 558 validation field data measured during high flows as previously described, also are shown in figure 2. Only 11 of the validation data exceeded the envelope curve with small exceedance values ranging from 0.2 to 3.3 ft, with a median exceedance of 0.9 ft. The validation data provide further confirmation that the envelope curve shown in figure 2 is reasonable. The envelope curve in figure 2 represents preliminary findings for the current (2015) investigation and is subject to change.

COMPARISON WTIH THE SOUTH CAROLINA PIER-SCOUR ENVELOPE CURVES

Benedict and Caldwell (2006; 2009) developed clear-water and live-bed pier-scour envelope curves to be used as supplementary tools for evaluating the potential for pier scour at bridges in South Carolina. The format of the South Carolina pier-scour envelope curves are similar to those shown in figures 1 and 2 with pier width used as the primary explanatory variable. An objective of the current (2015) investigation is to evaluate the South Carolina envelope curves with the PSDb-2014 database to determine if they are reasonable or need modification. Figures 3 and 4 show the South Carolina pier-scour envelope curves for clear-water and live-bed scour conditions, respectively, along with the preliminary upper-bound envelope curve derived from the PSDb-2014 database. The South Carolina pier-scour envelope curves fall in close proximity to the PSDb-2014 envelope curve, indicating that the South Carolina pier-scour envelope curves

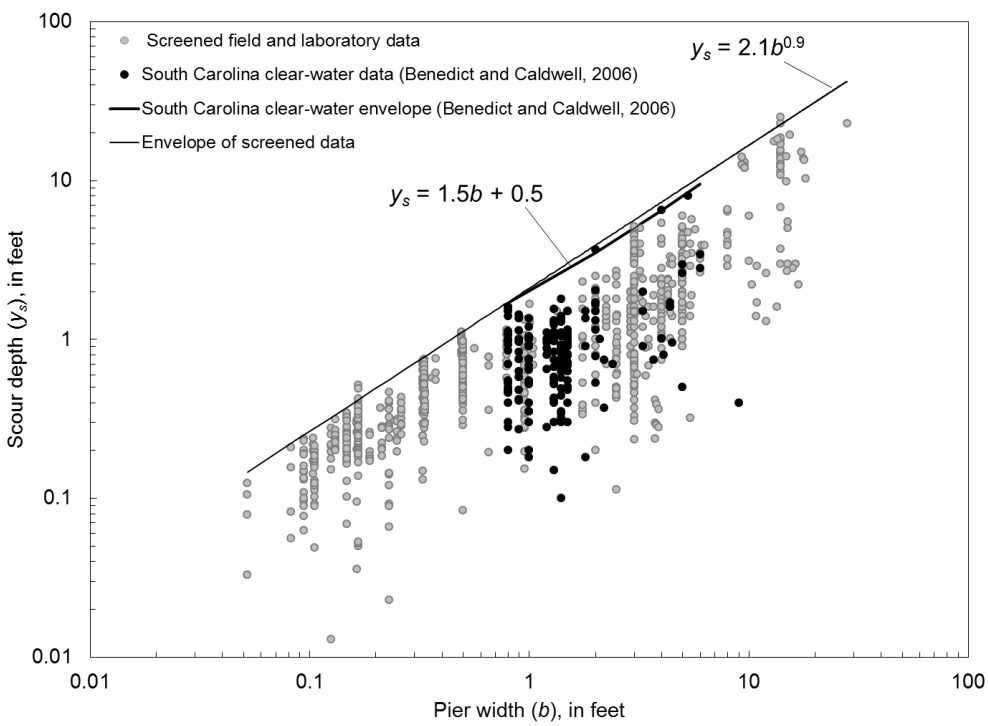

Figure 3 Comparison of the South Carolina clear-water pier-scour envelope curve to the upper-bound envelope curve derived from the screened laboratory and field data.

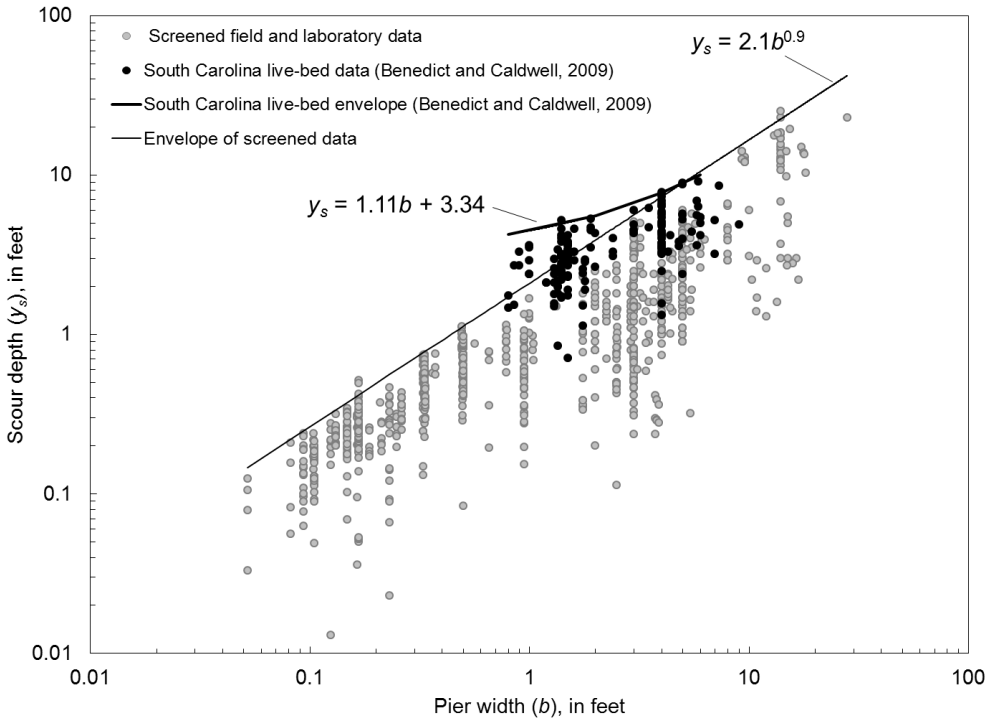

Figure 4 Comparison of the South Carolina live-bed pier-scour envelope curve to the upper-bound envelope curve derived from the screened laboratory and field data.

are reasonable. The small exceedance of the live-bed envelope curve (figure 4) can be attributed to the use of ground-penetrating radar that tends to have a larger measurement uncertainty (Benedict and Caldwell, 2009), which can lead to overestimates of scour. Current guidance and limitations for using the South Carolina pier-scour envelope curves can be found in Benedict and Caldwell (2006; 2009).

CONCLUSIONS

Current methods for predicting pier-scour depth have some uncertainty, and therefore, should be assessed for reasonableness. One way to make such assessments is by comparing predicted scour to historical field measurements. The recent investigations of pier 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 preliminary pier-scour envelope curve based on the PSDb-2014 database indicates that the South Carolina bridge-scour envelope curves are reflecting a reasonable upper bound of pier scour under field conditions in South Carolina. The preliminary PSDb-2014 pier-scour envelope curve (figure 2) includes a larger range of pier widths and is therefore likely applicable to a broad range of pier widths. The South Carolina pier-scour envelope curves can be used as supplementary tools for assessing potential maximum pier-scour depth in South Carolina, and the preliminary PSDb-2014 pier-scour envelope curve likely will be applicable to a broader range of pier widths, inside as well as outside of South Carolina. Because of the complexity of scour, caution and judgment should be used in the application of the envelope curves presented in this paper, and they should not be relied upon as the only tool for assessing pier-scour potential. One can best assess anticipated scour by

compiling and studying the available information for a given site, bringing sound engineering principals to bear on the final estimate of anticipated pier-scour depth. Additional guidance and limitations for using the South Carolina pier-scour envelope curves can be found in Benedict and Caldwell (2006; 2009).

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