ASSESSMENT OF THE NCHRP ABUTMENT-SCOUR PREDICTION EQUATIONS WITH LABORATORY AND FIELD DATA

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Abstract. The U.S. Geological Survey, in cooperation with the National Cooperative Highway Research Program (NCHRP) is assessing the performance of several abutment-scour prediction equations developed in NCHRP Project 24-15(2) and NCHRP Project 24-20. To accomplish this assessment, 516 laboratory and 329 field measurements of abutment scour were compiled from selected sources and applied to the new equations. Results will be used to identify strengths, weaknesses, and limitations of the NCHRP abutment-scour equations, providing practical insights for applying the equations. This paper presents some preliminary findings from the investigation.

INTRODUCTION

Scant situations of hydraulic engineering are more complex than those associated with scour in the vicinity of a bridge abutment, especially one located in a compound channel. Accordingly, few situations of scour depth estimation are as difficult (Ettema and others 2005).

The complexity of abutment-scour processes has made it difficult to formulate prediction methods, and few would dispute the above assessment by Ettema and others (2005). In order to advance the state-of-the knowledge and practice for predicting abutment scour, the National Cooperative Highway Research Program (NCHRP) recently sponsored several projects for the development of new abutment-scour prediction methods in cohesive and non-cohesive sediments, including NCHRP Project 24-15(2): Abutment Scour in Cohesive Materials (Briaud and others 2009), and NCHRP Project 24-20: Prediction of Scour at Bridge Abutments (Ettema and others, 2010). These investigations represent extensive efforts to develop conceptual models for abutment scour in cohesive and non-cohesive sediments, collect laboratory data, evaluate that data, and develop new methods for predicting abutment scour. With the completion of these projects, there is a need to evaluate their performance.

PROJECT OBJECTIVES AND METHODS

The objective of this investigation is to evaluate the performance of these newly developed abutment-scour prediction methods under field conditions by using selected field measurements of abutment scour. To assist in verifying the prediction patterns observed in the field data, the equations also will be evaluated with selected laboratory data. The performance of these equations will be evaluated by using comparisons of predicted and observed scour, along with relations of prediction residual with respect to selected explanatory variables. This analysis will help identify strengths, weaknesses, and limitations associated with the newly developed scour-prediction methods, and will provide guidance to the practitioner for the application of these methods. Only limited preliminary results associated with the field are presented in this paper.

DATA

The selected field data (table 1) used in the analysis included 329 measurements collected by the U. S. Geological Survey (USGS) in South Carolina (Benedict, 2003), Alabama (Lee and Hedgcock, 2008), Maine (Lombard and Hodgkins, 2008), and the USGS National Bridge Scour Database (NBSD; USGS, 2001). Ninety-two measurements in the Piedmont region of South Carolina and the 23 Alabama measurements are associated with cohesive sediments, with the other data primarily associated with non-cohesive sediments. These data represent a large and diverse database that can be used to provide insights into equation performance. Because of the complex and harsh field environments, field measurements of abutment scour typically will not have the same degree of accuracy as those obtained in the controlled environment of the laboratory. Potential sources of error in the USGS abutment-scour field data include, (1) grain-size estimates based on limited sediment samples, (2) hydraulic properties estimated from one-dimensional flow models, and (3) scour-depth measurements at locations with complex field conditions. These potential sources of error should be kept in mind when reviewing the results of this analysis. While the limitations of the USGS abutment-scour field data are acknowledged, currently (2014) they comprise the best available set of field data, and the large number of measurements (329) should be sufficient to gain insights into the general trends of abutment scour in the field setting. To assist in verifying the prediction patterns observed in the field data, 516 laboratory data from previously published investigations also were used to evaluate the performance of the equations.

PRELIMINARY RESULTS FOR NCHRP 24-15(2)

The NCHRP 24-15(2) abutment-scour prediction method was originally developed for predicting abutment scour in cohesive sediments, but was extended to include abutment-scour prediction in non-cohesive sediments (Briaud and others, 2009). The method provides two procedures for predicting abutment scour including (1) a time-dependent estimate requiring detailed site information (primarily for cohesive sediments) that provides a refined estimate of scour, and (2) the maximum scour-depth estimate requiring less detailed data (for cohesive and non-cohesive sediments). The laboratory and field datasets used in this investigation do not have the information required to evaluate the time-dependent method and therefore, the evaluation of the method was limited to use of the maximum scour-depth equation, as shown below.

$$^{y_s}/_{y_1} = K_1 K_2 K_L K_G K_p 243 \mathrm{Re}_{f2}^{-0.28} \left(1.65 Fr_{f2} - Fr_{fc}\right) \quad (1)$$

where y_s is the abutment-scour depth, in feet (ft), y_1 is the approach flow depth, in ft, Fr_{f2} is the flow Froude number at the abutment, Fr_{fc}, is the sediment critical Froude number, Re_{f2} is the flow Reynolds number at the abutment, and the K values are correction factors for abutment shape, abutment skew, channel geometry, abutment location with respect to the main channel, and pressure flow, respectively.

Following the application guidance in Briaud and others (2009), the laboratory and field data were applied to the NCHRP 24-15(2) prediction method. Preliminary results for the field data (subject to change) are shown in table 1, and figure 1 shows the data grouped by cohesive and non-cohesive sediments. As previously noted, the NCHRP 24-15(2) method was developed for cohesive sediments and therefore, the better performance with the cohesive sediments (South Carolina Piedmont and Alabama data), as shown on figure 1, and in the prediction residuals in table 1, would seem reasonable. Minor adjustments to equation 1 along with better estimates of flow velocity from a two-dimensional flow model will likely improve equation performance. A detailed analysis of the equation will be presented in the final report.

PRELIMINARY RESULTS FOR NCHRP 24-20

The NCHRP 24-20 abutment-scour prediction method was developed for predicting abutment scour in non-cohesive sediments (Ettema and others, 2010). The method assumes that abutment scour is a function of contraction scour as represented by the following equation:

$$Y_{MAX} = \alpha Y_C \quad (2)$$

where Y_{MAX} is the maximum flow depth at the abutment-scour area, in ft, Y_C is the mean flow depth of the contraction scour, in ft, and is determined by the Laursen (1960, 1963) contraction-scour equations, and α is an amplification factor that accounts for additional scour (beyond the contraction scour) at the abutment. The abutment-scour depth is determined from equation 3 below:

$$y_s = Y_{MAX} - y_1 \quad (3)$$

with all variables previously defined.

The Federal Highway Administration’s guidance manual, Hydraulic Engineering Circular No. 18 (Arneson and others, 2012) provides application guidance for the NCHRP 24-20 method, and following that guidance, the laboratory and field data were applied to the NCHRP 24-20 prediction method. Preliminary results for the field data (subject to change) are shown in table 1, and figure 2 shows the data grouped by cohesive and non-cohesive sediments. The NCHRP 24-20 method was developed for non-cohesive sediments and therefore, the better performance with the non-cohesive sediments, as shown on figure 2 and in table 1, would seem reasonable. Better estimates of flow velocity from a two-dimensional flow model will likely improve equation performance. A detailed analysis of the equation will be presented in the final report.

CONCLUSIONS

The NCHRP 24-15(2) and NCHRP 24-20 investigations represent extensive efforts to develop new methods for predicting abutment scour providing a valuable resource to the practitioner. Preliminary results for evaluating these new methods indicate that the NCHRP 24-15(2) method, originally developed for predicting abutment scour in cohesive sediments, will likely perform better in cohesive rather than non-cohesive sediments. Similarly, the NCHRP 24-20 method, originally developed for predicting scour in non-cohesive sediments, will likely perform better in non-cohesive rather than cohesive sediments. A detailed analysis of these equations will be presented in the final report.

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Table 1. Range of selected variables for abutment-scour measurements in the South Carolina, Maine, Alabama, and National Bridge Scour Databases

[ft, feet; ft/s, feet per second; mm, millimeters; <, less than]

Range value	Average abutment approach velocity (ft/s)	Average abutment approach depth (ft)	Embankment length blocking flow (ft)	Median grain size (mm)	Observed abutment -scour depth (ft)	NCHRP 24-20 [a]prediction residuals (ft)	NCHRP 24-15(2) [a]prediction residuals (ft)
South Carolina Piedmont (92 measurements – primarily cohesive sediments)							
Minimum	0.17	2.19	18.4	0.003	0.0	-5.0	-3.7
Median	0.96	5.90	268	0.029	1.2	13.3	6.5
Maximum	3.57	15.60	1,669	0.447	18.0	55.9	14.5
South Carolina Coastal Plain (106 measurements – primarily non-cohesive sediments)							
Minimum	0.05	2.00	86.7	0.005	0.0	-16.5	-20.5
Median	0.48	4.91	610	0.179	7.0	2.3	-2.0
Maximum	0.96	16.04	7,440	0.782	23.6	17.3	12.8
Maine (93 measurements – primarily non-cohesive sediments)							
Minimum	0.18	1.11	0.0	0.25	0.0	-6.5	-5.0
Median	1.04	7.06	40.1	45	0.0	2.6	14.8
Maximum	5.62	15.25	808	109	6.8	29.0	42.9
Alabama (23 measurements – primarily cohesive sediments)							
Minimum	0.18	3.21	43.0	0.001	1.4	-0.2	-5.8
Median	0.62	5.00	400	0.009	4.7	5.9	-0.1
Maximum	1.31	9.34	1,141	0.170	10.4	17.5	5.5
National Bridge Scour Database (15 measurements – primarily non-cohesive sediments)							
Minimum	0.49	3.95	15.0	0.001	0.0	-2.1	-0.1
Median	0.71	8.81	560	0.150	4.5	4.6	7.9
Maximum	3.37	36.56	3,522	35	18.0	22.4	16.9

[a] Negative value is underprediction and positive value is overprediction.

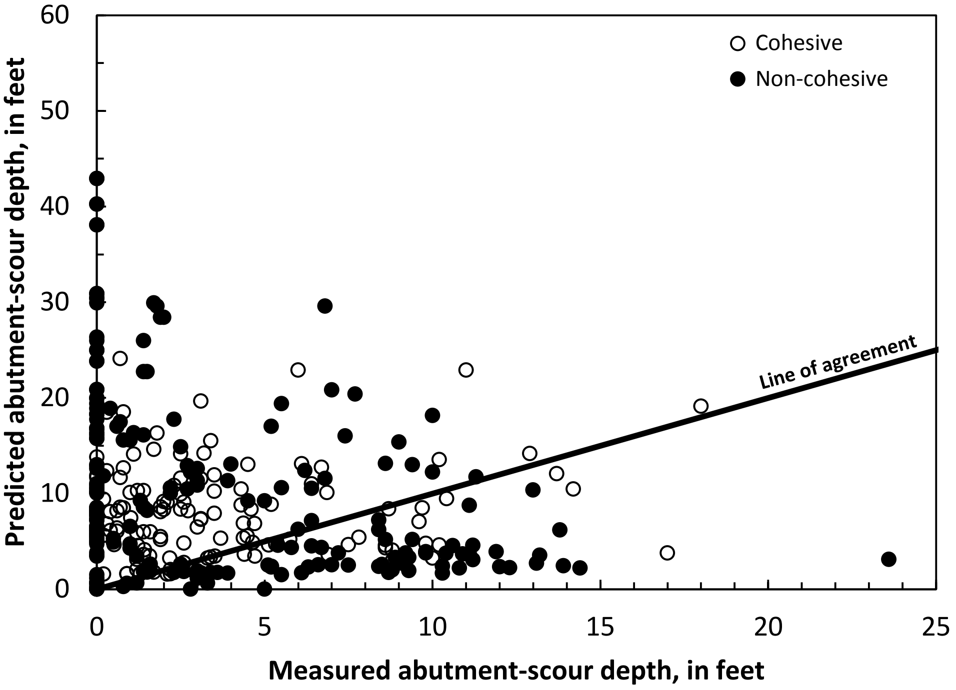

Figure 1. Relation of predicted and measured abutment-scour depth for selected field data grouped by cohesive and non-cohesive sediments, using the NCHRP 24-15(2) scour-prediction method.

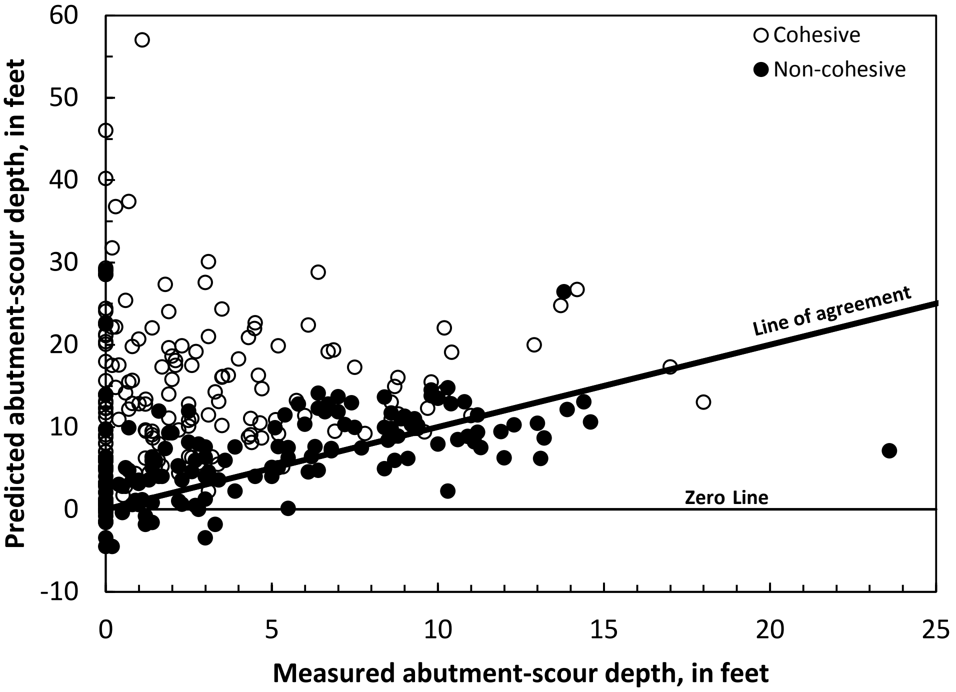

Figure 2. Relation of predicted and measured abutment-scour depth for selected field data grouped by cohesive and non-cohesive sediments, using the NCHRP 24-20 scour-prediction method.