HISTORIC SCOUR DATA COLLECTED AT SELECTED BRIDGES IN SOUTH CAROLINA

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Abstract. The U.S. Geological Survey, in cooperation with the South Carolina Department of Transportation, is currently investigating live-bed contraction and pier scour in South Carolina using historic scour measurements collected in the main channel of 78 bridges. These data were collected using ground-penetrating radar. A brief description of data-collection techniques and limitations is included. These data will be used to evaluate scour-prediction equations and develop regional envelope curves to help assess live-bed scour potential in South Carolina.

INTRODUCTION

The U.S. Geological Survey (USGS), in cooperation with the South Carolina Department of Transportation (SCDOT), conducted several studies to investigate clear-water abutment-, contraction-, and pier-scour depths on the flood plains of 168 bridges in the Piedmont and Coastal Plain physiographic provinces of South Carolina (Benedict, 2003; Benedict and Caldwell, 2006). (Note: Clear-water scour conditions exist when flow velocities are too low to move sediments along the bed. This type of scour typically occurs on stream flood plains.) The objectives of these studies were the following: (1) collect field measurements of historic bridge scour; (2) evaluate scour-prediction equations with that data; and (3) develop regional envelope curves that show the trend and upper limits of the field data for the Piedmont and Coastal Plain regions of South Carolina. The evaluation of the existing scour-prediction equations with the field data indicated that they often do not perform well, highlighting the need for improved methods to assess scour. To supplement existing scour-prediction equations, the collected field data were organized into regional envelope curves. While the regional envelope curves have limitations, they can be used to help assess the potential for clear-water scour at streams in South Carolina.

Based on the success of the clear-water bridge scour studies, the USGS, in cooperation with the SCDOT, began a field investigation in 2004 to study live-bed contraction and pier scour. (Note: Live-bed scour conditions exist when flow velocities are sufficiently large to move sediments along the bed.) Because live-bed scour primarily occurs in the main channel of South Carolina streams, rather than the flood plain, data collection focused on this part of the bridge opening. The objectives of the live-bed bridge-scour investigation are similar to the previous studies with a primary goal of developing regional envelope curves to help assess the potential for live-bed contraction and pier scour in the Piedmont and Coastal Plain of South Carolina. If regional envelope curves for live-bed contraction and pier scour can be developed, then a full series of envelope curves for the primary components of bridge scour (clear-water and live-bed) will be available to help engineers assess bridge-scour potential in South Carolina.

APPROACH

This project focused on the collection of historic occurrences of live-bed contraction and pier scour that were created by past flood events during the life of a given bridge. To provide some assurance that measured scour reflects scour resulting from high flows, a strategic sample of data-collection sites was selected that included older bridges that likely have undergone a large flood and sites where large floods are known to have occurred. Sixty-one of the 78 selected bridges are at or near USGS streamflow gaging stations providing a means to estimate historic peak flows at those sites.

Live-bed bridge scour holes that occur in the main channel are typically inundated and are partially or totally refilled with sediments, making field measurement of the scour problematic. Therefore, to measure historic live-bed scour, one must use some type of subsurface investigation such as coring or a geophysical technique. For this investigation, a ground-penetrating radar (GPR) system deployed by boat was considered the most appropriate tool for collecting the live-bed scour data. Ground penetrating radar has been used successfully to locate and estimate scour depths associated with historic live-bed scour (Placzek and Haeni, 1995; Webb and others, 2000) and the shallow (6.1 meters or less) freshwater granular bottom streams of South Carolina provide a favorable environment for this system.

While field conditions generally are favorable for the success of GPR in South Carolina, the field complexities and bridge to stream orientation at a given site may limit the ability of the system to discern subsurface interfaces and historic scour. Additionally, the interpretation of the GPR data includes some subjectivity which may reduce scour measurement accuracy and increase uncertainty. While the limitation associated with GPR scour measurements cannot be removed, if a large sample of field data is collected, the regional range and trend of live-bed scour can be approximated, providing useful information for assessing scour potential. For the South Carolina investigation of live-bed scour, GPR data was collected at 78 bridges, yielding a relatively large data sample for approximating the regional range and trend of live-bed scour. Additionally, data collected in this investigation will be compared with live-bed scour data from the USGS National Bridge Scour Database (NBSD) (http://water.usgs.gov/osw/techniques/bs/BSDMS/index.htm, accessed November 30, 2006). Much of the scour data in the NBSD were collected during high-flow events and can be used to help assess whether the South Carolina live-bed scour data collected with a GPR system are reasonable.

DESCRIPTION OF STUDY AREA

The investigation of live-bed scour has yielded data at 78 bridges in South Carolina with 46 located in the Coastal Plain physiographic province and 32 in the Piedmont physiographic province. Because the streams of these provinces have regional characteristics, data-collection sites were strategically selected within these provinces in an attempt to capture regional scour trends. While each data-collection site has unique characteristics (soil, stratification, channel geology and morphology), there are general trends within these regions; a general description of regional stream characteristics of the Coastal Plain and Piedmont follows.

The Coastal Plain of South Carolina comprises approximately 63 percent of the State and is characterized by sandy surface soils, relatively flat stream slopes, wide densely vegetated floodplains, and relatively long flood-flow durations. A unique feature of the channels of many Coastal Plain streams is that they generally are cut into older geologic formations formed of marine sediments. The channels typically consist of a relatively thin layer (commonly 3 meters or less) of sand overlying older marine sediments. When scour occurs at these sites, it often cuts into the marine sediments and the scour holes partially or totally refill with loose sand. The electrical properties of the refilled sand and marine sediments typically differ, and the interface is readily visible in GPR data, allowing a reasonable assessment of historic scour. (Note: Sites in the Coastal Plain, with only 3 exceptions, had no tidal influence.)

The Piedmont of South Carolina comprises approximately 35 percent of the State and is characterized by clayey soils, moderately steep stream slopes, incised channels, narrow floodplains, and relatively short flood-flow durations. As with the Coastal Plain, the channels of Piedmont streams are cut into older geologic formations (saprolite) that are typically composed of clays, silts, and disintegrated rock. The channels consist of a relatively thin layer (commonly 3 meters or less) of sand overlying the saprolite. When scour occurs at these sites, it often cuts into, or is limited by the clayey, saprolitic soils and the scour holes refill with loose sand. Where scour cuts into the saprolitic soil an interface is commonly visible in the GPR data. However, if the saprolitic soil limits the scour it may be difficult to discern the historic scour with the GPR system.

DATA-COLLECTION TECHNIQUES

During this project, GPR data were collected using a RAMAC/X3M radar control unit and a 100 Megahertz shielded antenna manufactured by MALA GeoScience[1] (MALA Geoscience, 2003). Data were viewed and stored on a laptop computer connected to the radar control unit. For access to points within a river channel, the GPR system was deployed by using variously sized inflatable boats. The antenna was placed in the bottom of the inflatable boat so that its radiating surface was as close to the air-water interface as possible. In non-wadeable streams, a 3.7-meter-long boat propelled by a motor was used to carry two crew members and the GPR system. In wadeable streams, a small inflatable boat that carried only the GPR system was pushed or towed by hand. In the largest rivers, the small inflatable boat with the GPR system was tied to the side of a larger boat to facilitate maneuvering in the strong currents.

To determine the depth and areal extent of contraction and pier scour at a given site, numerous longitudinal and cross-sectional GPR traces were collected within the channel. Particular focus was given to the collection of

[1] The use of trade or product names is for identification only and does not constitute endorsement by the U.S. Government.

GPR traces at the bridge faces and along the bridge piers. When water depths were approximately 1 meter or greater, a Lowrance[1] model X-16, 192-kHz black and white chart-recording fathometer was used to mirror the data collected by the GPR system. The fathometer traces served as a verification of the channel bathymetry shown by GPR and assisted in the interpretation of the GPR data. After GPR data were collected, bed-material samples were taken for grain-size distribution analyses within the areas of observed scour and refill and at midchannel upstream from the unscoured areas. Pictures, sketches, and a general description of the site were made as needed.

DATA INTERPRETATION

The electromagnetic data collected with a GPR system typically has a high degree of accuracy; however, the interpretation of those data is not a precise science and will introduce some error into the assessment of historic bridge-scour depths. Each bridge site has unique features, such as sediment characteristics, geology, and river morphology that will affect the difficulty and accuracy of the interpretation of scour depths. Although it is difficult to determine error limits associated with the interpretation, it is surmised that many sites will have an error of less than 1 meter, which is acceptable for field investigations of scour.

Soil boring data from bridge plans constitute a valuable resource to assist in the interpretation of bridge-scour data collected with a GPR system. The borings can be used to identify subsurface materials and the locations at which soil characteristics change, which often correspond to changes in the reflection patterns of the GPR data. As noted previously, live-bed scour in the channels of South Carolina streams commonly cuts into older geologic formations. The scour holes are partially or totally refilled with loose sands, forming a soil interface that is readily distinguished in the GPR data. This scour and refill pattern, in conjunction with the bridge plan borings, can be helpful in data interpretation. Figure 1 shows a sample GPR longitudinal profile at a bridge identifying the contraction scour depth.

PLANNED ANALYSES

The analysis of the field data will consist of two phases. The first phase will be the development of one-dimensional flow models and the computation of predicted live-bed scour for each site. U.S. Geological Survey streamflow gaging stations located at or near many of the sites, will be used to estimate the historic maximum flood that has occurred during the life of the bridge. The maximum historic flood will be used in the flow models to estimate hydraulic variables that may have created the observed scour. These variables will be applied to commonly used scour-prediction equations and computed scour will be compared with the field measurement of scour to assess the equation performance. Although the approximated hydraulic variables will introduce error into this comparison, making it less than ideal, the large amount of scour data used in the assessment will show the general trend of the scour-prediction equations.

The second phase of the analysis will involve the compilation of a database that will include field data, modeled hydraulic data, and predicted scour data. These data will be used to investigate relations that may help

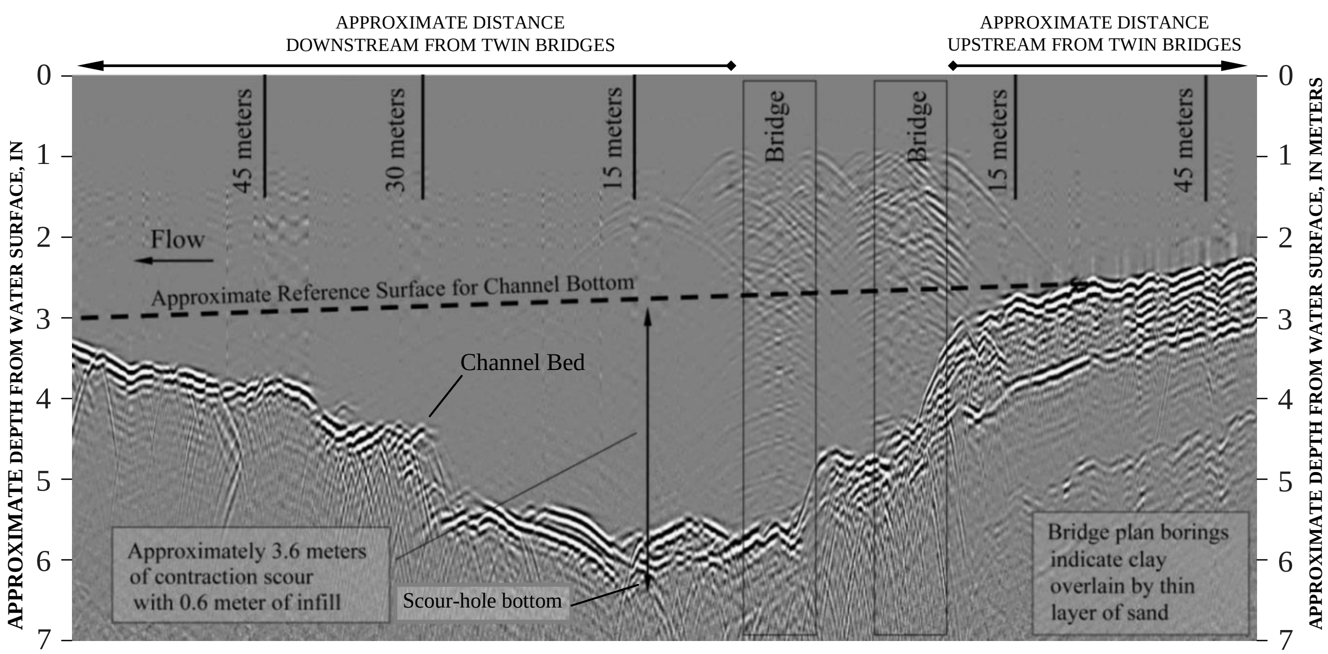

Figure 1. Example of ground penetrating radar longitudinal profile.

explain live-bed scour trends in South Carolina. If possible, regional envelope curves will be developed to help engineers assess the reasonableness of predicted scour and assess the potential for scour in South Carolina. Regardless of the results of the analysis, the collected data will give numerous examples of real-world scour in South Carolina, providing a valuable tool for engineers to develop a better understanding of scour. This understanding will build a good foundation for acquiring the often elusive 'engineering judgment,' to assess and, if necessary, modify the results of the scour-prediction equations.

PRELIMINARY FINDINGS

Preliminary interpretation of GPR data at 78 sites has been made, including 46 sites in the Coastal Plain and 32 in the Piedmont. In the Coastal Plain, contraction-scour depths ranged from 0 to 5.2 meters with infill ranging from 0 to 2.9 meter; pier-scour depths ranged from 0 to 5.2 meters with infill ranging from 0 to 2.3 meters. In the Piedmont, contraction-scour depths ranged from 0 to 6.0 meters with infill ranging from 0 to 5.9 meters; pier-scour depths ranged from 0 to 2.8 meters with infill ranging from 0 to 2.6 meters. Other preliminary findings indicate the following:

- Complete refill of live-bed scour holes occurred infrequently and remnant scour holes that identify the location and approximate depths of historic scour often were identifiable in the channel bed topography as determined by the GPR.
- Fathometer traces will often provide similar estimates of the depth of refilled sediments within live-bed scour holes.
- Scour in the channels of Coastal Plain streams will typically be classified as live-bed scour for a 100-year flow event; however, large scour holes with minimal infill were commonly observed in the channels of Coastal Plain streams. This phenomenon possibly occurs because clear-water scour conditions prevail over most of the flood hydrograph with live-bed scour conditions occurring only for a short duration near the flood peak. Therefore, sediments have little opportunity to move into the scour hole.
- While bridge-scour depths estimated from GPR data will have some associated error and at times will be unsuccessful in defining refilled scour holes, these data often can provide a valuable understanding of historic scour at a site of interest. The historic data can be of particular benefit when an existing bridge is being replaced by a new bridge at or near the same location. The historic scour at the existing bridge can provide an understanding of anticipated scour for the replacement bridge.

CONCLUSIONS

A GPR system can be a useful tool to measure historic live-bed scour depths within stream channels. Data from such a system can be used to approximate the regional range and trend for the upper limits of scour that in turn can help engineers assess the potential for scour within a region of interest. Additionally, such data can be useful for bridge replacements. Because historic scour can be a good indicator of scour that may occur in the future, field data collected with a GPR system at an existing bridge can provide valuable insights into the scour potential for the replacement bridge. Historic scour data measured with a GPR system will always have error and uncertainty associated with them, and this should be kept in mind when using these data to assess historic scour patterns.

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