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# REAL TIME MEASUREMENT OF SCOUR DEPTHS AROUND BRIDGE PIERS AND ABUTMENTS

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## SUMMARY

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# **REAL TIME MEASUREMENT OF SCOUR DEPTHS AROUND BRIDGE PIERS AND ABUTMENTS**

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## **Overview**

Scour around bridge piers and abutments is the primary reason for bridge failures. Bridge failures have substantial effects on local economies and human lives. About 60% of all bridge failures in the United States can be attributed to scour. Therefore, both accurate measurement of scour depth and real time monitoring of scour are of great importance for scour countermeasures. This report reviews the state of the art in scour measurement, shows the varying susceptibility of the selected scour measuring devices, and presents the development of a novel scour measurement method. In addition, the selected scour measuring devices and the novel method have been evaluated through laboratory experiments and field deployment. This report will be useful for making conclusive decisions in selecting a scour measurement instrument that is best suited to field conditions at a particular site.

## **Background**

Scour around bridge piers and abutments occurs when high velocity flows impinge on the riverbed, leading to the removal of bed material, which undermines the structural stability of the bridge. The damage to bridge infrastructure due to scour is costly to repair, and bridge failures can result in the loss of lives. Several bridge failures have been directly attributed to scour including the I-90 Bridge over the Schoharie Creek in New York in 1987, the U.S. 51 Bridge over the Hatchie River in Tennessee in 1989, and the I-5 Bridge over the Arroyo Pasajero River in California in 1995. Additionally, the United States Geological Survey (USGS) reported that the number of bridges damaged during flood events ranged from 17 in the U.S. Northeast in 1987 to more than 2,500 in the Midwest during the 1993 flood season, and during 1961-1974, 46 of the 86 major failures of bridges in the U.S. were due to scour, more than any other cause. Furthermore, 68 bridges in the U.S. were damaged due to scour from 1996 to 2001. Overall, scour is estimated to be the primary cause of bridge failure, accounting for approximately 60% of all failure events. Thus, an adequate methodology for monitoring the formation of scour holes around bridge structural elements is essential. The objectives of this project are to provide the knowledge required in order to deploy a sustainable and robust scour monitoring system. To serve this purpose, a comprehensive review of the state of the art in scour monitoring is reported. Based on the review, a comparison of sensitivity and susceptibility of the instruments to various environmental factors is reported. In addition, a novel scour measurement device is developed which exploits natural turbulence of the channel to determine scour depth. This novel method is then optimized and tested under various channel conditions along with the best in class scour measurement devices. In the final phase, instruments are deployed at two field sites to evaluate and compare their performances.

## Results

The review of the state of the art in scour measurement devices reveals that the two most suitable instruments for scour monitoring are sonar and TDR. A novel method is developed in response to common weaknesses in the existing scour monitoring methods. The vibration-based turbulent pressure sensors (VTP) will vibrate at significantly higher amplitudes when placed in a turbulent flow compared to the sensors buried in the bed. The concept is validated in the laboratory test using variety of shapes, thickness, size, and material for the membrane. Neoprene rubber of circular shape is selected as a sensing membrane. The size and thickness of the sensor are optimized to improve the response and resolution of the device for field deployment. The final radius and thickness are found to be 0.787 inch and 0.063 inch, respectively. The center to center spacing between the sensors is 4 inches, which means that the device will have a resolution of 4 inches in measuring scour depth. The performance of sonar, TDR, and VTP devices is evaluated for various channel conditions including salinity, temperature, turbidity, bed topography, flow alignment, flow velocity, and bed sediment type, where applicable. For the sonar device, changes in temperature (41 to 104°F) can result in relative errors of up to 6% in channel depth. Salinity (up to 35.5 ppt) can lead to relative errors of up to 3%. The temperature and salinity can be measured in the field to apply appropriate corrections to the sonar readings, if needed. The concentration of suspended particles minimally affects the sonar results in still water. For dynamic turbidity, uniform as well as stratified, the relative error in bed level measurements can be significant. The results indicate that measuring the standard deviation of the recorded signal is important to verify the quality of the recorded signal. Lastly, for variable bed topography, the sonar measures the shallowest depth. Therefore, the location of the sonar above the bed and the beam angle are critical for measuring scour depth accurately. For the TDR device, the channel temperature can affect the measured depth of a scour hole. The relative errors can be of the order of 5% for temperature variation ranging from 44.6 to 104°F. This effect, however, can be mitigated by monitoring the channel temperature in addition to the TDR waveform. Distinct features of TDR waveform to detect the sediment/water interface are lost when salinity is greater than 0.5 ppt. It is recommended to install the TDR only in freshwater conditions. Turbidity in the channel flow has no measurable effect on the TDR. The VTP device is not affected by temperature, salinity, or turbidity of the channel flow. In addition, for flow angles up to 90 degrees relative to the VTP, the sensor in the flow and that in the bed can be clearly distinguished based on their energy content. Thus, the bed can be located accurately even in highly misaligned flows. The bed sediment type (clay, sand, etc.) does not influence the energy content of the sensors in the bed and hence the ability of the VTP device to locate the bed is not affected. The VTP device was tested for velocity as low as 0.48 ft/s. The response from a VTP in the flow was an order of magnitude greater than a VTP in the sediment, indicating adequate performance even at low flow velocity. Based on the study, for shallow stream without salinity effects, the TDR may be the best choice. However, if temperature variations are large, it may be necessary to record the temperature independently and apply corrections to the TDR and sonar. The VTP device is ideally suited for shallow streams in coastal areas as it is not affected by salinity. The sonar needs to be submerged in the water and must be installed at least 2 ft above the river bed. For deep rivers, where TDR and VTP installation may be difficult, sonar can be easily installed by attaching it to a rod. The rod can then be lowered so as to situate the sonar close to the bed.

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