The paper was published in the proceedings of the 1st International Conference on Scour of Foundations and was edited by Hamn-Ching Chen and Jean-Louis Briaud. The conference was held in Texas, USA, on November 17-20 2002.

Portable Scour Monitoring Research

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Abstract

Scour monitoring can be completed by either fixed or portable instruments. Fixed instruments are those that are installed and left at the bridge. During the last ten years, significant research and progress has been made with fixed instrumentation. However, fixed instrumentation is not suitable, practical, or cost effective for all bridges. In many cases portable monitoring may be a better solution, and yet, not much research has been completed to improve this type of technology.

Recognizing this limitation, the National Cooperative Highway Research Program (NCHRP) funded project 21-07, "Development of Portable Scour Monitoring Equipment." The objective of this research was to improve deployment, positioning, and data collection procedures for portable scour monitoring work. These improvements will facilitate data collection under adverse conditions, and will allow more successful monitoring at a wide range of bridges under flood flow conditions. The research was conducted recognizing the need to provide solutions that are easily used and affordable by state and local bridge owners.

The research concentrated on developing a truck mounted articulated crane to quickly and safely position various measurement devices. Collection of position and scour data is automated and a data file is written that allows plotting channel section or scour hole bathymetry.

Introduction

Monitoring and measuring the scour conditions at a bridge can be completed by a variety of instrumentation. Fixed instruments are those that are installed and left at the bridge and typically involve a sensor for making the scour measurement, a power supply and a data logger. More recently, telemetry has become a common component of many fixed instrument systems. During the last ten years, significant research and progress has been made with fixed instrumentation, both through research activity, commercial development and field installations, often completed by state DOT's. However, fixed instrumentation is not suitable, practical, or cost effective for all bridges. In many cases portable monitoring during a flood is a better solution, and yet, not much research has been completed to improve this type of technology.

Physical probing has been used for many years as the primary method for portable scour monitoring by many DOT's. More recently, sonar has seen increased use, in part due to the technology transfer provided through FHWA's Demonstration Project 97, Scour Monitoring and Instrumentation (FHWA, 1998). However, probing and sonar techniques both have limitations during flood events when the flow depth and/or velocity are high. Low flow monitoring during the 2-year inspection cycle with this type of technology has been effective and is used by many DOT's; however, critical decisions on bridge safety during flood flow conditions have been hampered by the limitations of the existing equipment and its application. As a result, some bridges have been closed unnecessarily, causing traffic delays and increased expenses, while other bridges that should have been closed were not, resulting in increased risk and liability.

Research Objective and Criteria

Recognizing these concerns, the National Cooperative Highway Research Program (NCHRP) funded project 21-07, "Development of Portable Scour Monitoring Equipment." The objective of the research was to develop improvements and/or alternatives to existing portable scour monitoring equipment and techniques for measuring stream bed elevations at bridge foundations during flood conditions. The equipment and techniques developed should be operational under the following conditions:

1. Flow velocities exceeding 3.5 m/s
2. High sediment concentrations
3. Floating debris
4. Ice accumulation
5. Limited clearance
6. Pressure flow
7. Overhanging or projecting bridge geometries
8. Bridges with decks more than 15 m above the water
9. Air entrainment
10. Easily used and affordable by state and local bridge owners
11. Transportable by pickup, van, or similar vehicle
12. Accuracy of 30 cm +/-

Research Tasks

Given these conditions, which represent the real world conditions that bridge inspectors must often work under, it is unlikely that one instrument or device will meet all the desirable criteria. To address the research needs, the project was divided into two Phases. The purpose of Phase I was to complete literature review and identify alternative technologies, allowing development of a detailed work plan for Phase II. Phase II included prototype development, extensive field testing, and documentation of the results.

A significant part of the Phase II research was the development of a truck mounted articulated crane to quickly and safely position various measurement devices. Articulated cranes, also known as knuckle boom or folding cranes, are commonly used in the construction and building materials industry. The following sections summarize the work completed related this research task.

Articulated Arm Crane Research Results

There are various manufacturers of articulated arm cranes, each with a variety of models that differ by their reach and lifting capacity. For purposes of this research, a smaller crane with a long reach, but not much weight lifting capability was desired. The long reach was necessary to be able to work off of higher bridge decks, and the size of the crane was important to improve maneuverability, as well as to minimize lane closure and traffic control issues.

After researching the available models and evaluating reach capabilities and cost, a Palfinger model PK 4501 C crane was selected (Figure 1). This crane has a maximum reach of 36 feet with a lifting capacity at this distance of 600 Lbs. In 2001, the base price for this crane was $14,500, with an installation cost of $1,800. This crane is small enough to be installed on a Ford F-450 truck or equivalent.

The most common location for a crane is immediately behind the cab of the truck. An alternative location is at the back of the truck, behind the rear axle. A rear mount puts more load at the back of the truck, and can cause weight distribution problems if the truck is also carrying substantial weight on the flat bed. The advantage of the rear mount is better clearance around the truck, since the cab is not in the way. For purposes of scour monitoring, with no substantial weight being transported on the truck bed, a rear mount seemed advantageous.

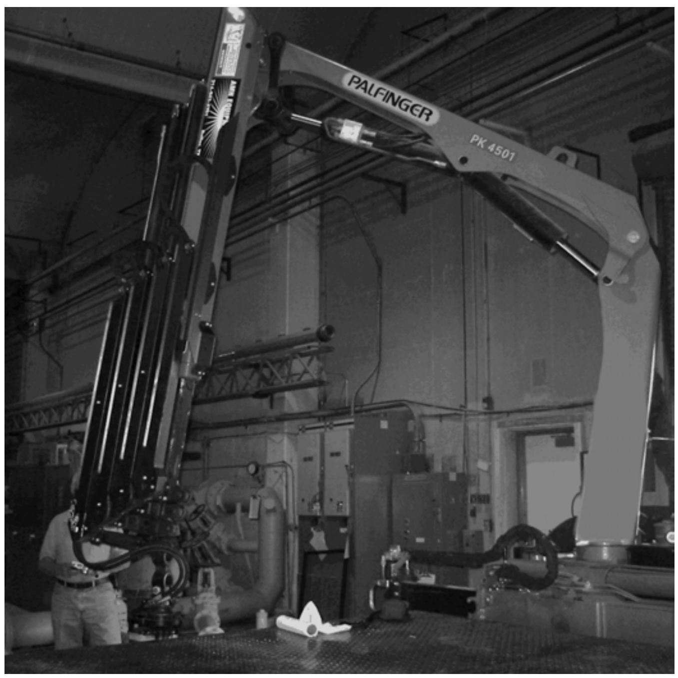

Figure 1. Palfinger PK4501C crane.

Based on the reach of the PK4501C crane, mounted with an offset to the center of the truck, the PK4501C has the capability to reach 6.5 m (21.25 ft) below the bridge deck when the truck is a maximum of 0.3 m (35 in) from the edge of the bridge. A hydraulic rotator was added to the end of the crane to provide better ability to position and control instrumentation. In addition to the rotational ability at the end of the crane, the rotator itself was attached to a custom fabricated mounting bracket that provided an additional articulation at the end of the crane arm. With the rotator mounting bracket the total reach of the crane below the bridge deck was 7.0 m (23.0 ft).

Instrumentation Installed on Crane

A variety of sensors were installed on the truck and crane to allow geometric calculation of the position of the end of the rotator. Tilt meters were used to measure the vertical deflection angle of the crane arm and the rotator arm. A draw wire was used to measure the linear extension of the arm, and a draw wire around the circumference of a circle attached to the base of the crane was used to measure crane rotation. The azimuth of the rotator was measured with a potentiometer through a gear and sprocket mechanism. An acoustic stage sensor was used to measure the distance to the water surface. Tilt data for the crane and rotator, the azimuth of the rotator, and the linear extension of the arm are transmitted by a radio modem from an instrument box at the end of the crane, that also transmits sonar data. The data is pre-processed with a Campbell CR10 data logger prior to transmission to the computer on the truck. A second CR10 is used to process truck data, which includes the azimuth of the crane, distance to the water surface, distance traveled across the bridge deck, and winch data when using cable suspended methods.

Given the desire to operate at flood conditions with high velocities, a streamlined probe was built to position the sonar transducer directly in the water using the articulated arm. The probe was fabricated from a section of helicopter blade, and proved to be very stable when placed in high velocity flow during field trials. The streamlined probe eliminated the vortex shedding problems of a simple cylinder shaped rod exposed to high velocity flow. The fin on the streamlined probe could freely rotate, which allowed the fin to follow the current no matter what horizontal angle the crane was positioned in. The fin was attached to a 2 m (80 in), 125 mm (2 in) schedule 80 stainless steel pipe. Given the distance the crane could reach below the bridge deck (7.0 m or 23.0 ft), the crane could reach nearly 9.1 m (30 ft) below the bridge deck for a sonar measurement.

To provide physical probing capability an extendable rod was fabricated. The rod extensions were built with 125 mm (2 in) stainless steel, Schedule 80 pipe in 1.5 m (5 ft) lengths, allowing a total length up to 4.5 m (15 ft). Threaded unions were machined to allow individual sections to be screwed together to create the longer extensions. Using the articulated crane for physical probing is most appropriate in a gravel/cobble bed, or to evaluate riprap conditions, since the strength of the crane hydraulics makes it difficult to know exactly when the channel bottom is reached.

The truck also includes two winches to allow cable suspended measurements using a sounding weight or a float based deployment of a sonar transducer. Two winches allows more control of the location and placement of cable suspended instruments (Figure 2). The float was built using a kneeboard with a wireless sonar to transmit data to the bridge deck with a modem. The kneeboard can be floated under the bridge deck to get measurements where direct measurement with the arm, or cable suspended weights are not possible.

The position of the truck as it moved across the bridge was monitored with a standard surveying measuring wheel attached to the back of the truck. Pulse counters were added to the wheel and connected to the Campbell CR10 data logger to electronically register the distance traveled. Figure 3 shows the completed articulated arm truck.

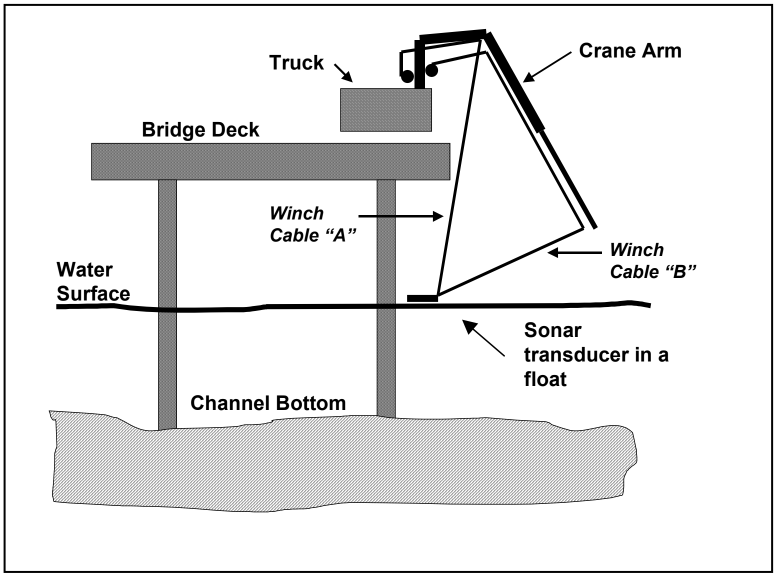

Figure 2. Two winch concept for cable suspended operations.

Figure 3. Completed articulated arm truck.

Data Collection Software

A windows based software package was developed to automate the data collection process. Data collection and processing occurs with a laptop computer equipped with two serial ports, one for the boom data, and one for the truck data, as sent by the two Campbell CR10 data loggers. The program includes a calibration menu that allows calibrating all sensors. Four programs were created: one for direct probing with the end of the crane, one for sonar measurements with a wireless sonar mounted on the articulated arm, one for measurements completed with the kneeboard, and one for cable suspended operations. All programs produce an x,y,z data file that can be read by other programs for contouring and plotting. The coordinate system for the x,y,z file is referenced to the profile line for the bridge, as typically shown on bridge plans, to allow easy comparison with elevation and station data for the bridge. The software for sonar measurements with the crane allows point measurements, or continuous recording as the crane is either driven across the bridge, or with the truck in a stationary position and sweeping the crane in an arc.

Field Testing

The objective of field testing was to evaluate the performance of the articulated arm truck at a variety of sites, representing a range of bridge and site conditions. The purpose of this testing was to validate the performance of the prototype devices and/or procedures under real world conditions, as implemented by highway personnel. Ideally, detailed testing would occur during flood conditions to evaluate the performance of the articulated arm relative the twelve criteria established as part of the research objective. In particular, this included a range of bridge conditions (high bridge decks, limited clearance, etc) and flow conditions (high velocity and sediment concentrations, floating debris, ice, pressure flow and air entrainment). The drought conditions during 2002 throughout much of the United States limited the opportunity to test the truck in flood conditions, but ultimately, ten bridges in seven states were visited. The following paragraphs present the results from two of these test sites.

Colorado I-70

Initial field testing was completed at the I-70 bridge over the Colorado River near DeBeque Canyon in western Colorado. The bridge has three piers on pile caps with 12 H-piles under each pile cap. The bridge was designed for a 50-year discharge of 900 m^3/s (32,000 cfs), and experiences velocities in excess of 3 m/s (10 fps), even at low flow. The channel bed material is primarily gravels and cobbles. The bridge has been rated scour critical based on observed conditions (Item 113, rating 2). The upstream channel bend has migrated, creating a skewed alignment into the bridge opening, and causing a large scour hole at pier 2, that extends through the bridge opening to the downstream side. Prior to extensive riprap placement in mid- march 2002, a 6 m (20 ft) scour hole had developed, exposing about 3 m (10 ft) of pile.

Figure 4 shows the flow conditions between pier 2 and the right abutment. At about mid-span the velocities were about 3.5 m/s (11 fps), and the flow depth was about 2 m (6.5 ft). Data was collected at both the upstream and downstream side of the bridge sweeping multiple arcs with the articulated arm and using a sonar mounted on the end of the crane (Figure 5). Results of the data collection indicated that the recently placed riprap has generally filled the scour hole back to the streambed elevation. As part of a cooperative effort with NCHRP Project 24-07, *Pier Scour Countermeasures*, this bridge will be monitored on a regular basis over the next 2-3 years to evaluate the performance of the riprap.

Figure 4. Flow conditions between the right abutment and Pier 2.

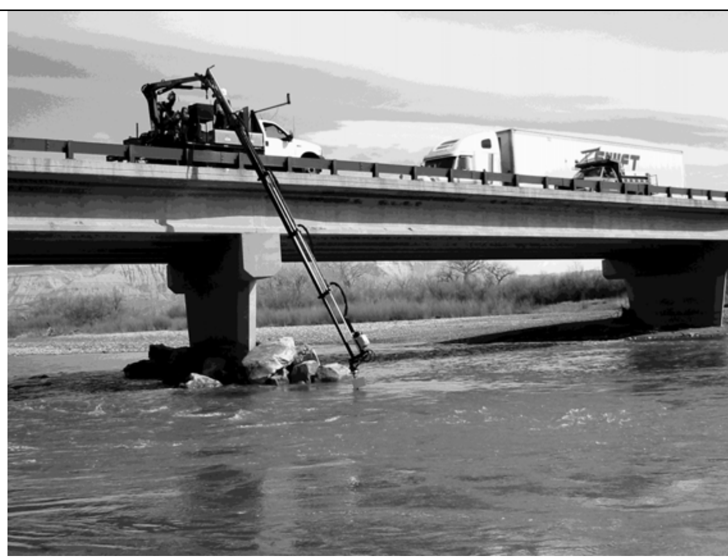

Figure 5. Using the articulated arm to sweep arc's around recently placed riprap.

Indiana State Route 61

Indiana S.R. 61 crosses the White River southeast of Vincennes, Indiana. The bridge has 5 spans on piers with pile caps with steel H piles driven to approximate refusal. At the time of inspection, the river was at flood stage and the southern part of the state was experiencing the wettest May on record. The bridge has not had any major scour problems, but has had a large sand bar in the bridge opening that had been contracted for removal. In addition to potential pier scour during the recent high flows, Indiana DOT was particularly interested to see if the sand bar was still present.

Testing at this bridge provided the opportunity to work at flood stage with relatively high velocities (about 2.1 m/s or 7 fps). The bridge had large grate inlets that required positioning the truck away from the barrier for a cross section measurement. This had not been tried before, but worked fine since the crane could still be articulated into position. Figure 6 shows the truck as it is driving across the bridge collecting cross section data. A wireless sonar in the sounding weight was also tested at this bridge (Figure 7), and was found to track the current and remain in a steady position, which had been a problem with earlier versions of the modified sounding weight.

Figure 8 illustrates typical results available with the articulated arm truck. The x,y,z data collected from these measurements along with bridge plan information were used in Microstation to create the plots shown in Figure 8. The top drawing shows the limits of the cross section data collected, and the arc's that were taken at piers 3 and 4. The middle part of the figure shows the cross section plotted, and at the bottom of the figure are the contour plots developed for each pier.

Conclusions

As a result of this research improved measurement devices and deployment procedures have been developed that will more successfully allow portable scour monitoring at a wide range of bridges under flood flow conditions. The adverse flow conditions that exist during flooding, including high velocities and debris, make these type of measurements difficult and can limit the success rate, even when properly applied, or applied to the best ability of the inspector.

The articulated arm developed under this research, with its automated data collection and multiple sensor capability, provides improved capability to collect data during flood conditions. Given the complexity of flood flow monitoring, including both difficult bridge conditions and difficult flow conditions, more than one measurement procedure is required to address as many situations as possible. The articulated crane should be a valuable addition to the inspectors "tool box" that will facilitate flood based scour monitoring.

References

Federal Highway Administration (FHWA), 1998. *Scour Monitoring and Instrumentation,* Publication No. FHWA-SA-96-036.

Figure 6. Collecting cross section data while driving the truck across the bridge.

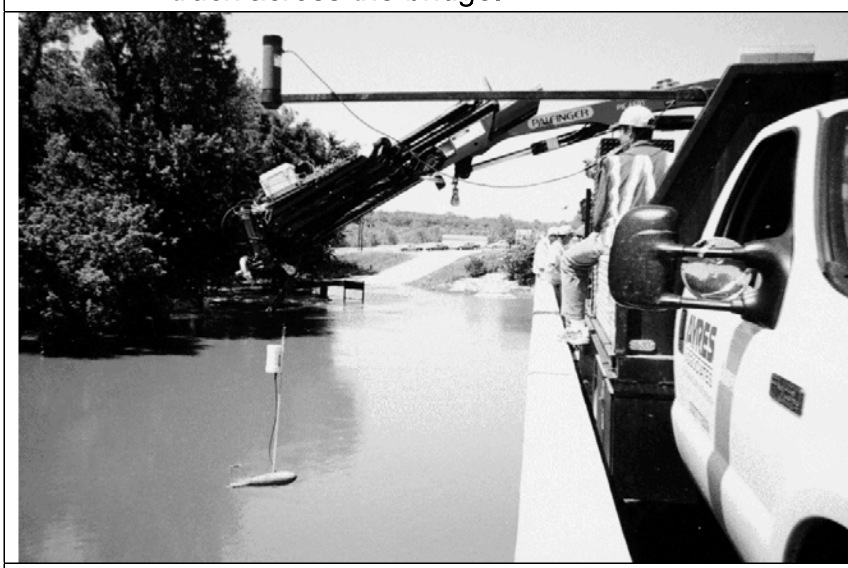

Figure 7. Wireless sonar in a sounding weight.

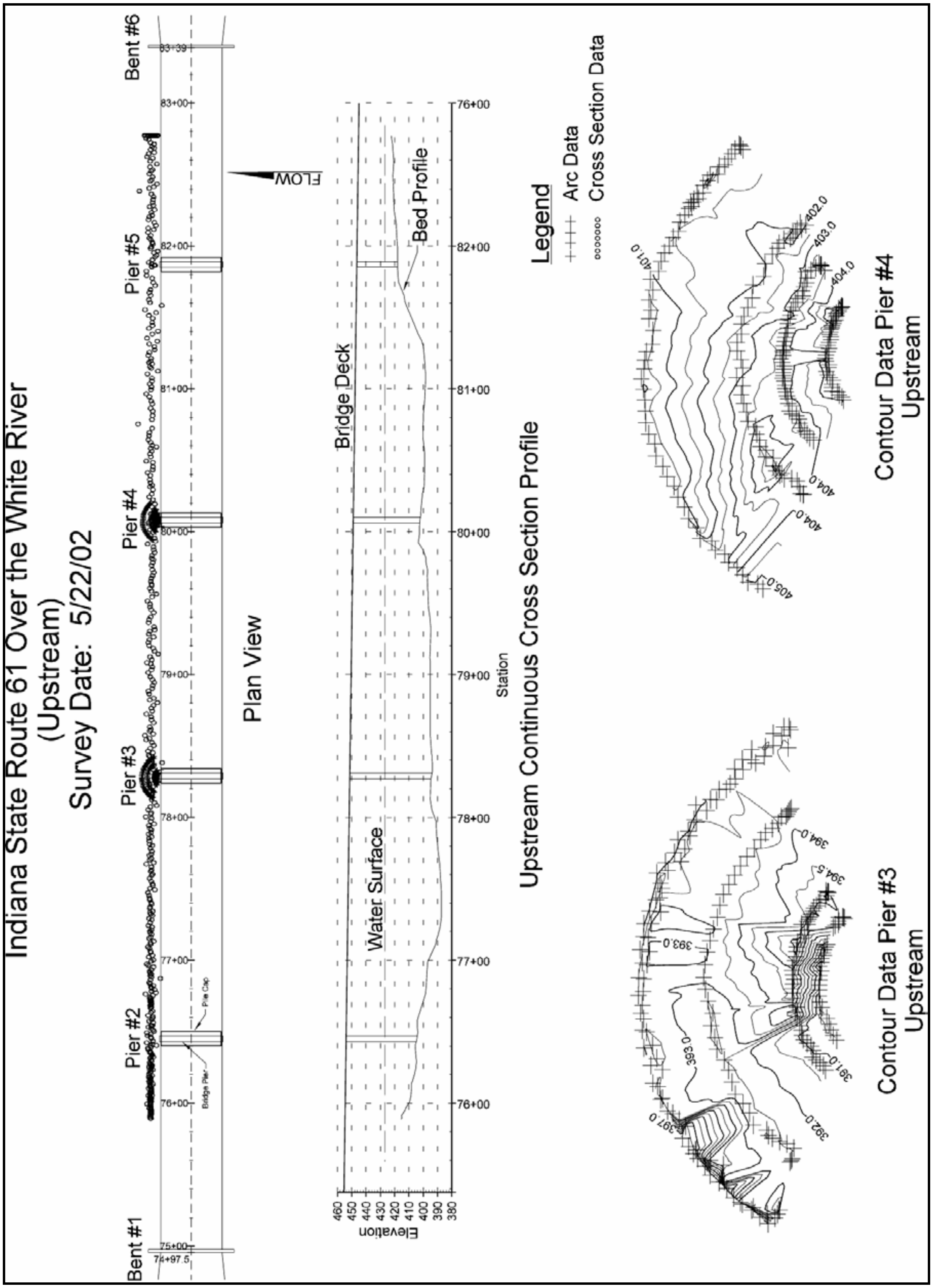

Figure 8. Typical results obtained with the articulated arm.