Multi-Beam Sonar Infrastructure Mapping Research

Prepared by:

Petronella DeWall, P.E.
Nicole Bartelt, P.E.
Minnesota Department of Transportation

Garrett Owens, P.E.
Barritt Lovelace, P.E.
Collins Engineers, Inc.

EXECUTIVE SUMMARY

In the fall of 2012, the hydraulics unit in MnDOT’s bridge office applied for a research grant to develop in-house underwater acoustic 3D imaging capabilities. The research report presents both stationary and mobile scanning techniques, outlines the setup of both systems, discusses field operations, summarizes the data analysis and post-processing of images, and reviews lessons learned. It can be found at:

http://www.dot.state.mn.us/bridge/hydraulics/Waterways/Multi-Beam%20Sonar%20Infrastructure%20Mapping%20Research.pdf

Several case studies frame a discussion of the capabilities and limitations of 3D acoustic imaging for underwater bridge inspection. The case studies provide examples of different applications of this technology. The primary case studies include the following bridges:

- Bridge 2440 – Third Avenue
- Bridge 4654 – Stillwater Lift
- Bridge 67805 & Bridge 67806 – Luverne
- Bridge 9040 – Red Wing

The variety of applications explored in these case studies include the documentation of large-scale underwater defects, construction inspection confirming as-built conditions, rapid condition assessment following a flood event, determination of scour extents and foundation exposure, as-built and site conditions for construction pre-planning, and diver safety and efficiency improvements for challenging dive conditions.

Underwater acoustic imaging has been shown to have real value to bridge inspectors and owners for a variety of applications.
CHAPTER 1: INTRODUCTION

In the fall of 2012, the hydraulics unit in MnDOT’s bridge office applied for a research grant to develop in-house underwater acoustic imaging capabilities. As part of this effort, MnDOT purchased a multi-beam sonar from Teledyne Technologies, Inc.

According to the 2016 National Bridge Inventory data, Minnesota has 13,355 bridges, 11,183 of these structures span waterways, and 306 are scour critical. Approximately 585 bridges in the state’s inventory require an underwater bridge inspection. The use of underwater acoustic imaging is becoming more common as bridge inspectors and owners use this technology to supplement the current requirements of the National Bridge Inspection Standards (NBIS) with regard to underwater inspections.

1.1 RESEARCH OBJECTIVES

The objective of this research is to outline the steps taken to establish the in-house underwater acoustic 3D imaging capability of the MnDOT bridge office’s hydraulic unit. The published research report presents the setup of the system, discusses field operations, presents the data analysis and post-processing of images, and summarizes lessons learned. Several case studies will frame a discussion of the capabilities and limitations of 3D acoustic imaging for underwater bridge inspection. In particular, this discussion will present examples of this technology in use including: documentation of large-scale underwater defects, construction inspection confirming as-built conditions, rapid condition assessment following a flood event, determination of scour extents and foundation exposure, as-built and site conditions for construction pre-planning, and diver safety and efficiency improvement for challenging dive locations.

1.2 PROJECT ACTIVITIES

For the sonar technology, the unit used was the Teledyne Blueview BV5000 multi-beam sonar. The system functions by mechanically rotating a sonar head and combining vertical sonar slices into a final 3D point cloud. In addition to this hardware, Blueview Proscan software was used in the collection of field data. Some basic hardware specifications for this model include:

- Operates at 1350 kHz
- 256 beams with 45° view
- Beam width = 1°
- Beam spacing = .18°

The system can be deployed in two distinct modes: stationary and mobile. Both modes typically require the use of a boat. Although for the stationary method the unit can be deployed using drops from the bridge deck or from an articulated arm of a vehicle from the roadway above. This discussion will be limited to the boat deployment method for both modes. The MnDOT bridge office’s boat, a 20’ long
Kann aluminum flat bottom work boat with twin 50-hp mercury motors, was used for the entire project and will be referred to throughout this report as the boat.

Regardless of the deployment method, the sonar data should be calibrated to the sound velocity conditions present at the site during the time period of the scanning. This is typically accomplished with the use of a sound velocity probe.

1.2.1 Stationary Scanning System Setup and Field Data Acquisition

When performing stationary scans, the sonar needs to be used in conjunction with a mechanically scanning pan and tilt unit. This pan and tilt unit allows the sonar to rotate through the full range of angles with precisely known positioning at all times.

For stationary scanning, there are three basic deployment methods: tripod, metal plate, and boat-mounted surface. Each method was used during the course of the project. The existing setup of the boat was used without significant modification. Refer to Figure 1-1 for an annotated view of the boat illustrating existing aspects of its design useful in the application of this technology.

Figure 1-1: MnDOT Bridge Office’s Boat Overview for Stationary Scanning
A summary of the required hardware and software for stationary scanning is listed below.

- Deployment of choice (boat mount, tripod, plate)
- Pan and tilt unit
- Field computer
- Sound velocity probe (or other instrument to measure sound velocity indirectly)
- Sonar software (to operate the sonar unit)

1.2.2 Mobile Scanning System Setup and Field Data Acquisition

For mobile scanning, the boat requires precise setup and mounting of additional hardware. In addition to the sonar head, this technique requires a significant amount of additional software and hardware beyond the requirements for stationary scanning, including the following:

- Stable mount that can scan at fixed head angles
- Hypack Software or equivalent multibeam software
- Motion Reference Unit (MRU)
- Dual Antenna GPS unit (location and heading)
- Pulse Per Second Timing Box (PPS) – optional, dependent on sonar unit
- Power source (Generator)
- Wifi or other internet connection
- NTRIP or other software for GPS correction (if connecting to a real-time GPS correction data site)
- GPS Base station (ONLY if correcting the GPS signal in real-time with a base station)

Note: Some of this equipment can be purchased together as units, such as a combination GPS and MRU unit.

Refer to Figure 1-2 for a schematic of the mobile scanning setup.
Figure 1-2: Mobile Scanning Setup Schematic
1.3 OVERALL LESSONS LEARNED

The following are overall best practices and suggestions from the research project experience:

- Power source is key. A small generator is now used to power the equipment. MnDOT selected Honda EU1000i inverter generator, which is quiet and powerful enough to run all of the necessary equipment.
- Complete all data processing for both stationary and mobile scanning in one set of units (metric or english).
- Attend Hypack or other training available for underwater imaging. The learning curve is steep, especially for mobile (multibeam) data collection and processing.
- 3D imaging results are hard to show in a report. Recommend doing video reports to show the complexity of the finished product and where any problems are.
CHAPTER 2: CASE STUDIES

2.1 BRIDGE 2440 – THIRD AVENUE

Bridge 2440 is an open spandrel concrete arch which carries 3rd Avenue over the Mississippi River upstream of Upper St Anthony Falls in Minneapolis, MN. During the 2012 underwater inspection of the bridge a previously unnoted area of undermining was discovered at the upstream end of Pier 5. The undermining was noted as a cavity measuring up to 3 feet high with a maximum penetration of more than 14 feet. The reinforced concrete piers of the bridge have spread footing founded on bedrock. Given the discovery of this defect during the routine underwater inspection and the foundation type, a special in-depth underwater investigation was required to determine next steps and possible repair options.

With the MnDOT bridge office, Teledyne Blueview scanned Pier 1 and Pier 5 of the bridge on February 26th and again on March 18th, 2014. Evidence of the undermining and concrete deterioration was confirmed with these initial scans. Figure 3-1 shows a view of the 3D point cloud from these initial scans of Pier 5.

Figure 3-1: Bridge 2440 Pier 5 Initial Scan

The link below redirects to a video outlining the initial application of underwater imaging at this site.

https://www.youtube.com/watch?v=g1-ZssO04D8

In the summer of 2015, underwater imaging was utilized to assist in repairing the undermining and concrete deterioration. Additional scanning activities were used to confirm proper construction of the
repairs and to document as-built conditions as shown in Figure 3-2. Scans were completed using the tripod mount, with the tripod placement done by divers.

![Figure 3-2: Bridge 2440 Pier 5 Post Repair Colorized Point Cloud](image)

The link below redirects to a video outlining the post-construction application of underwater imaging at this site.

[https://www.youtube.com/watch?v=U2_0pZ1hffw](https://www.youtube.com/watch?v=U2_0pZ1hffw)

### 2.2 BRIDGE 4654 – STILLWATER LIFT

The Stillwater Lift Bridge is a 10-span bridge with six steel through truss spans and one vertical lift span which carries State Highway 36 over the St. Croix River, in Stillwater, MN. The 2013 underwater inspection report noted the full footing height (4 feet vertically) of Pier 8 was exposed around the entire perimeter, and the seal was exposed at the upstream nose.

On October 13, 2015 the MnDOT bridge office scanned Pier 8 using all three stationary deployment techniques. The underwater imaging of Pier 8 is an example of using this technology to determine the extents of scour and footing exposure.
Figure 3-3: Bridge 4654 Pier 8 Colorized Point Cloud Plan View

Figure 3-4: Bridge 4654 Pier 8 Colorized Point Cloud Upstream Isometric View

The link below redirects to a video outlining the application of underwater imaging at this site.

https://www.youtube.com/watch?v=9jtVPsNuQ9M
2.3 BRIDGE 67805 & BRIDGE 67806 – LUVERNE

Bridges 67805 and 67806 are each 3 span continuous steel girder bridges carrying I-90 over the Rock River near Luverne, MN. In June of 2014, following heavy rains, an upstream damn failed essentially emptying Split Rock Lake. This wall of water eroded the streambed and overtopped I-90 closing the interstate. Bridges 67805 and 67806 were monitored during this event and it was noted that scour had occurred but not to the scour critical level.

In December of 2015 debris got caught up on the bridge and maintenance forces noticed that the erosion that occurred in 2014 had not filled back in.

The bridges were initially scanned on December 14, 2015 using a number of stationary scans, using the boat mounted scanning technique. The scans showed significant scour and undermining at all the piers of both bridges. Pier 2 of Bridge 67805 had a maximum of 8 vertical feet of undermining. Timber debris stuck in the pile group was also noted at this pier. The scanning was able to confirm that the scour critical elevations for these piers had not been reached. Figure 3-6 shows an overview of one pier from this initial scanning effort:
This example shows value of scanning for rapid condition assessment following a flood event, and its value in determining scour extents and foundation exposure. The link below redirects to a video outlining the initial application of underwater imaging at this site.

https://www.youtube.com/watch?v=KKP3qKvPIQA

It was decided that these piers should be protected as long term exposure of the piles could create problems with deterioration of the piles and debris catching on them creating scour formation. Repairs were planned for the next construction year.

On October 6, 2016 these bridges were rescanned using stationary deployment techniques as the contractor noted that changes had occurred at the site. The channel had begun filling back in so the bridge was scanned to determine changes to the plans that were drawn from the December 2015 scans. The link below redirects to a video outlining the 2016 scans:

https://www.youtube.com/watch?v=JENm_3owm7k
Figure 3-7: Bridges 67805 & 67806 Combined 2016 Scans Colorized Point Clouds

2.4 BRIDGE 9040 – RED WING

Bridge 9040 is a cantilevered through truss spanning the Mississippi River carrying U.S. 63 from Wisconsin to Red Wing, MN. As part of an ongoing replacement project, the bridge office completed 3D underwater scanning of Pier 2 and the main channel in September 2016. A new bridge is planned for the site directly upstream and adjacent to the existing bridge. The purpose of the scan was to locate the upstream edge of the Pier 2 footing and seal and provide as-built information to be used in pre-construction planning and bid documents.

After scanning and processing was completed, the upstream edge of the Pier 2 footing was located, but further investigation was needed to determine the location of the seal. Collins Engineers performed the routine underwater inspection of this bridge in November 2016. Using the 3D scan and previous plan information, the dive inspection confirmed the location of the upstream corner of the seal.

The scan and subsequent dive inspection provided valuable as-built information concerning the location of the seal. This information was useful for the construction pre-planning and generation of bid documents. The scan also provided up-to-date information about the site and was useful in dive planning, ultimately improving diver safety and efficiency.
The link below redirects to a video outlining the application of underwater imaging at this site.

https://www.youtube.com/watch?v=rfAewqzFQaA

2.5 OTHER EXAMPLES

2.5.1 Bridge 5327 - Thief River Falls

This is an example of a post construction scan. This bridge was considered scour critical. A unique scour protection plan was constructed with micro piles and riprap protection. The scan was done to verify the contractor installed the micro piles and riprap protection per the contract. The MnDOT bridge office hydraulics unit is currently advising that all scour construction projects have scans taken before the contract is closed out. Figure 3-10 shows an example of the micro piles installed, and riprap placed inside of the micro piles, as per the plan.
2.5.2 Bridge 40001 – Henderson

This is an example of a pre-construction hydrographic scan. The mapping/survey was completed to provide bathymetry for an extensive 2-dimensional (2D) hydraulic model of the Minnesota River near Henderson, MN. The model was over 32-miles long, so extremely detailed bathymetry was not required for the entire reach. The model was completed as part of the Henderson Flood Mitigation Feasibility Study. Figure 3-12 shows the bathymetry scatter set inside of the 2D model. The link below redirects to a video outlining the application of underwater imaging at this site.

https://youtu.be/zjypv7EXnMw.
2.5.3 Bridge 85851 - Winona

This is an example of a post construction scan. The new bridge crossing was built next to the existing bridge crossing. The existing bridge crossing will stay in-place, and is considered scour critical. As part of the rehabilitation project, the contractor placed geobag filters and riprap protection around two of the main channel piers to protect against scour. The post construction scan was completed to verify the placement of the scour protection, and as a baseline for future underwater inspections. Figure 3-13 is from a scan completed after partial construction, as the scour protection was staged over multiple construction seasons. The MnDOT bridge office hydraulics unit is planning a final post construction survey in summer 2017.
Figure 3-11: Bridge 85851 Post-Construction Scan

Recommendations

Underwater acoustic imaging has been shown to have real value to bridge inspectors and owners for a variety of applications, from pre-construction planning and post-construction inspection, to routine underwater inspection and post-event emergency inspections. The case studies in this report exhibited a number of these applications. The following is a list of recommendations to aid in the safe and efficient adoption of this technology in the state:

- Develop and publish MnDOT underwater imaging policy.
- Provide outreach to MnDOT districts, counties, cities and other bridge owners in the state informing of MnDOT bridge office’s imaging capabilities and expertise.
- Develop adequate post-processing capabilities and data storage of completed projects.
- Generate list of bridges suitable for underwater imaging, look for input from bridge owners across the state.
- Provide indication in bridge record that underwater imaging of bridge exists and is available for review.
- Ensure field personnel performing underwater imaging are properly trained in both bridge inspection and underwater imaging techniques.