AHTD TRC TRANSPORTATION RESEARCH COMMITTEE

TRC0802

A Case Study of Laser Scan Produced Measured Drawings for Abandoned Historic Bridges

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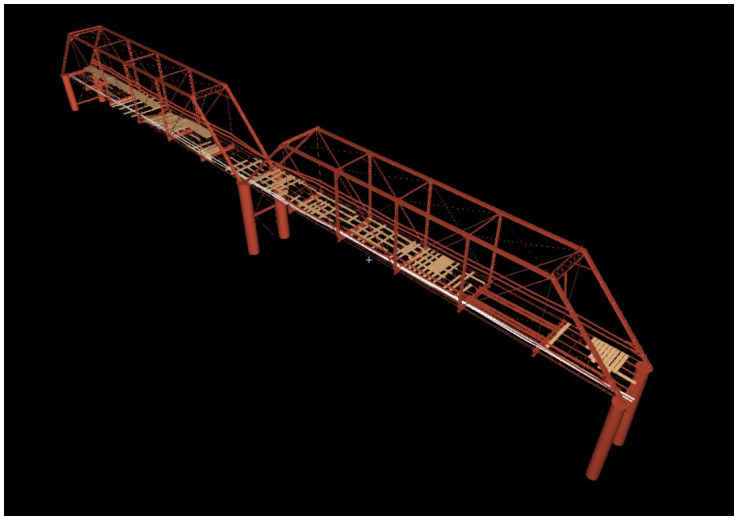

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Abstract

Some of Arkansas' most historic bridges lie abandoned and deteriorating with no historic documentation available. While photographic and written documentation can be produced for these bridges, their deteriorated condition does not allow architects to take the physical measurements necessary to produce measured drawings. This project was an attempt to find an alternate method to requiring architects to physically take the measurements necessary to produce measured drawings on abandoned and deteriorated historic bridges. Two bridges were selected, an abandoned historic bridge and a previously drawn bridge, to determine if measured drawings could be produced from laser scans of the abandoned historic bridge and to determine the accuracy by comparing the drawings created from scanning the previously drawn bridge to those created by the National Park Service for the bridge. These bridges were scanned over three days in September and five days in December-January in 2007/2008. The point clouds generated by the laser scanner were then sent to a consultant and the resulting measured drawings were submitted for review and acceptance by the Historic American Engineering Record of the National Park Service. The drawings were accepted by the National Park Service in October 2009. The project found that the use of a laser scanner is a safe and cost effective alternative to collecting physical measurements on an unsafe historic bridge and that a laser scanner can acquire measurements equal to those done by hand from a distance of at least 100 feet. In addition it can substantially reduce the field time necessary to collect the data and by using the point cloud produced from scanner; measured drawings can be produced in less time and for less cost than using traditional survey and drafting techniques.

Introduction

One of the goals of any historic bridge program is to document all of its bridges to the highest standards possible. Generally the Historic American Engineering Record (HAER) documentation conducted by the National Park Service (NPS) is considered the best documentation. This documentation consists of written histories, black and white photographs and measured drawings. Unfortunately, in most cases this is not possible due to financial constraints and most programs find themselves reserving this documentation effort for their most significant bridges. Even in the cases where the program can afford to produce all the documentation, they may find themselves unable to complete the measured drawings portion of the documentation due to the safety issues related to architects taking measurements on an abandoned and deteriorated historic bridge. This project was an attempt to find an alternate method to requiring architects/surveyors to physically take the measurements necessary to produce these measured drawings.

Previous NPS HAER projects

Three NPS HAER Level I documentation projects had been sponsored by AHTD between 1988 and 2007. The first in 1988 cost $40,000, with four bridges drawn, plus written histories and photographs for 20 bridges and took one year and six months to complete. The second project in 2004 cost $52,000, with three bridges drawn, plus written histories and photographs for 10 bridges and took nine months to complete. The third project in 2007 cost $62,000, with one bridge drawn, plus written histories and photographs for 12 bridges and took nine months to complete.

Problem Statement

A problem statement was submitted to the Arkansas Transportation Research Committee (TRC) in the fall of 2006 proposing to study the possibility of using a laser scanner to produce the required measurements:

> "One of the goals of the Arkansas State Highway and Transportation (AHTD) Historic Bridge Program is to document all of the historic bridges in the state to Historic American Engineering Record (HAER) standards. These standards set by the National Park Service (NPS) include producing a detailed history of the bridge, archival black and white photographs and a set of measured drawings. While a detailed history and photographs of a bridge can be accomplished from a distance, the design drawings require detailed measurements of the bridge. These measurements can only be accomplished by accessing the deck and with metal trusses the upper and

lower cords. A number of Arkansas' oldest, most important bridges do not have design plans or measured drawings. NPS Architects are unable to access the bridges due safety issues raised by their deteriorated conditions, which have resulted from these bridges being abandoned. This design information is a critical part of the HAER documentation and is an important component for the accurate documentation of the history of bridge construction in the State.

The objective of the project is to determine if it is possible to produce measured drawings for a selected abandoned bridge that is unsafe for the NPS Architects to access for safety reasons, by using a laser scanning device to collect the data at a distance from the bridge.

We propose to use the abandoned Old River Bridge over the Saline River in Saline County as the test bridge. We would contract with a company or university that has experience with laser scanning of structures to scan the Old River Bridge, merge the scans into a point cloud and then create drawings acceptable the NPS HAER unit. The process is estimated to take eight months, with the field scanning taking around a week, the point cloud development around a month to two months and creating the drawings around four to six months."

The project was approved by the TRC in December of 2006 with a budget of $119,600.00. A TRC Subcommittee was then created to determine the whether the project should be conducted by a contractor or produced in-house, what specifications the NPS HAER section would require to accept measured drawings from a laser scanner and what type of laser scanner should be used to scan the bridge.

Contractor or In-house

Initially, the project Subcommittee decided to investigate the opportunity to make this an "in-house" project due to the AHTD's continuing need to document and record historic bridges. Unique to this project is the method of using a laser scanner to acquire the measurements thus negating the safety concerns of concerns of performing physical measurements on historic bridges in extremely poor condition and the fact that NPS HAER specifications have not been fully developed regarding measurement accuracies through laser scanner methods. After discussions with NPS HAER it was determined that a resolution of a quarter inch would be acceptable. To meet these requirements, a review of manufacturer's specifications indicated that only those laser scanners priced above $100,000 were capable of acquiring these precision measurements.

Since the project's budget was not enough to pay for a laser scanner and subsequent investigations did not find another similar and safe method of acquiring these precision measurements without purchasing a laser scanner, the only recourse left was to consider subcontracting the project to an experienced engineering firm or university which would furnish little or no training for AHTD personnel and would probably commit the AHTD to contracting all future projects that included measured drawings for deteriorated bridges. However, during this time the Surveys Division of AHTD expressed an interest in purchasing a laser scanner for use to survey busy intersections in addition to using it for this project.

Approval for Surveys to purchase the scanner for use with the project was received from AHTD's Administration with the project's Subcommittee overseeing all aspects of the research project including training and scheduling.

Selecting the Laser Scanner

Two types of laser scanners (time-of-flight and triangulation) were investigated for use by the project.

The time-of-flight laser scanner is an active scanner that uses laser light to probe the subject. At the heart of this type of scanner is a laser rangefinder. The rangefinder determines the distance of a surface by timing the round-trip time of a pulse of light produced by the laser. The scanner scans its entire field of view one point at a time by changing the range finder's direction of view to scan different points. Typically a time-of-flight laser scanner can measure 10 to 15 points every second.

The triangulation laser scanner is also an active scanner that uses laser light to probe the subject. The triangulation laser shines a laser on the subject and uses a camera to look for the location of the laser on its surface. Typically, this uses a laser stripe to scan the object instead of a dot.

The time-of-flight laser scanner is able to operate over long distances 100-250 meters with accuracies in the millimeter range. While the triangulation laser scanner will only operate at limited ranges possibly as high as 5 meters, but with accuracies in the micrometer range (Katsushi, 2010).

Both laser scanners were reviewed with the requirements of the project in mind. After the review was completed, the Subcommittee determined that the time-of-flight laser scanner was the right choice due to the distances required to scan a large object such as a bridge and that the differences in the accuracies was minimal.

Selection of Test Bridges

During Subcommittee discussions it was determined that in addition to the selection of an abandoned historic bridge, a bridge that had already been drawn by the NPS HAER should be selected to evaluate the accuracy of the scanner. After reviewing numerous bridges the Subcommittee selected the Old River Bridge in Saline County for the abandoned bridge and the Ward's Crossing Bridge in Yell County as the control bridge.

Figure 1. The Old River Bridge

Old River Bridge is located in Saline County over the Saline River in the town of Benton. It was abandoned in the mid 1970s after a truck feel through the deck. It is an excellent example of a pin-connected Pratt through truss built in 1891 by the Youngstown Bridge Company of Youngstown, Ohio. The bridge consists of two 130-foot Pratt trusses with six panels each and a single lane for traffic. The bridge was abandoned before the AHTD Historic Bridge Program was created and was not included in any work by the NPS HAER and the original plans had been lost.

Figure 2. The Ward's Crossing Bridge

The Ward's Crossing Bridge is located in Yell County over the Fourche LaFave River. It is an excellent example of a pin-connected Camelback through truss built in 1905 by the Converse Bridge Company of Ridgedale, Tennessee. The bridge consists of one 162-foot Camelback truss with seven panels and a single lane for traffic. The bridge was drawn by the NPS HAER in 2005.

Both bridges were selected due to their relative closeness to the AHTD Central Offices in Little Rock and the presence of open areas with light overgrowth around the bridges which would facilitate the scanning.

Project Benchmarks

After the decision was made to manage the project in-house and the selection of the scanner and test bridges were completed, the Subcommittee developed six benchmarks for the project.

These benchmarks were:

- Purchase equipment and receive training.
- Scan Ward's Crossing Bridge.
- Scan Old River Bridge.
- Acquire proposals from consultants for creation of measured drawings.
- Select consultant to produce measured drawings.
- Submit drawings for NPS HAER approval.

Equipment and Training

Two time-of-flight laser scanners were selected as candidates for purchase by AHTD Surveys Division. These were the VX Spatial Station by Trimble and the Scanstation by Leica. The price of both was comparable at around $100.000. The two scanners were comparable in most technical aspects except vertical scanning. The Trimble required the scanner to be repositioned from vertical to horizontal to scan above 80 degrees. The Leica was constructed with a second vertical window to allow scanning above 80 degrees without repositioning the scanner. In addition, while the Trimble and Leica laser scanners had comparable resolution, a side-by-side comparison of point clouds generated by the scanners revealed that the Scanstation had the best point cloud coverage of the two.

After review the Surveys Division selected the Leica Scanstation for purchase, due to the better resolution and its ability to scan vertically without repositioning. The purchase included the laser scanner and accessories, one floating license for Cyclone software, one license for Cloudworx software for Microstation and training to use the scanner and software. The total cost for the purchase was $163,419.49, which was paid for from the Surveys Division budget.

After the purchase of the Leica Scanstation, the Subcommittee working in coordination with Surveys Division scheduled training for January 8–11 of 2007 which would be conducted by Leica. This training would involve learning how to scan a bridge, register the point clouds and produce 3-dimensional features. Part of this training involved hands on training, during which a bridge on Interstate 630 in Little Rock was scanned and the point clouds registered. Additional training was later scheduled in March which would concentrate on working with features created from the point clouds.

Figure 3. Leica Scanstation

Scanning of Test Bridges

The first bridge to be scanned was the Ward's Crossing Bridge which was scanned over three days in September 2007. No problems were encountered during the scanning, although it was discovered that the bridge deck carried vibrations easily. This caused the scanner to have a problem with stability if the bridge was walked on during scanning.

The Old River Bridge was then scanned over five days in December 2007 and January 2008. The scanning days were stretched between the end of December and early January due to the Christmas and New Year holidays and a significant flood event that occurred during the December scanning (Figure 4).

Both bridges required between seven and ten individual setups, which were scan locations. Numerous scans of the bridge were taken from each setup. The setups were designed to allow the scanner to access most areas of the bridge from many angles. Generally, three angles for any point on the bridge was the goal. For the single truss Ward's Crossing Bridge the setups included the portals, both sides, underneath and on the deck. Since the Old River Bridge included two trusses the same setups were used except

for the deck (which was gone) on each truss. The scanner setups were configured to cover each side of both trusses.

Most scans were set at a resolution of 1/4" inch in the horizontal and vertical at the actual distance to the bridge. Selected areas of each bridge (upper and lower chord pin-connections and bearings) were scanned at a higher resolution of 1/8" inch in the horizontal and vertical at the actual distance to the bridge. These scans were limited to small areas on each bridge due the time required to scan at the higher resolution. This was done to include as much detail as possible from areas which proved difficult to scan.

Figure 4. Scanning the Old River Bridge

After the bridges were scanned, the Surveys Division registered the point clouds and sent them to the Subcommittee for review. The point clouds were found to be very detailed, although some areas of the bridges proved impossible to scan, such as the interior of the pin-connections in the center of the trusses on the upper and lower chords on the Old River Bridge. In these cases, the contractor was asked not to attempt to draw these areas.

Figure 5. Point cloud from Ward's Crossing Bridge scans.

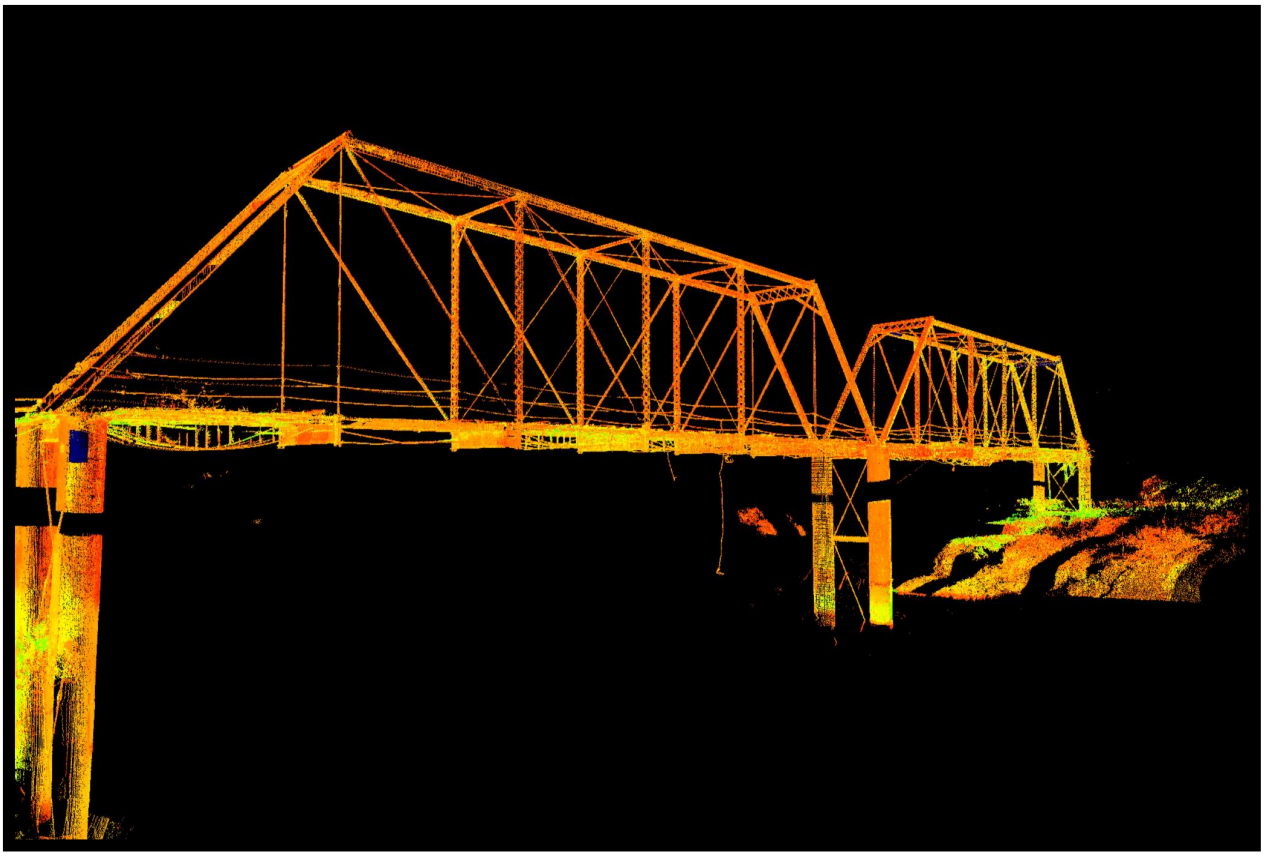

Figure 6. Point cloud from Old River Bridge scans.

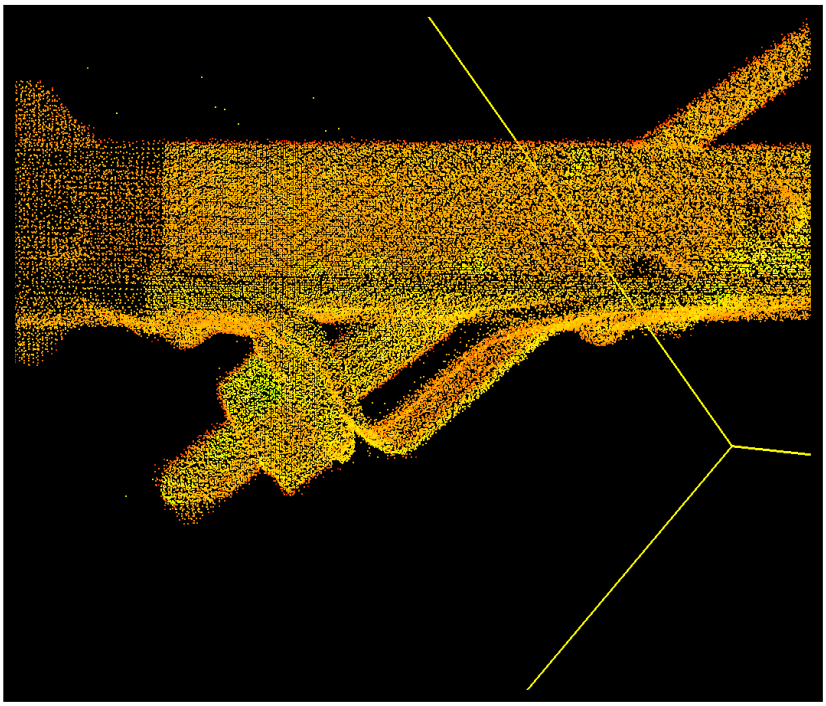

Figure 7. Scan of a sway bracing connection from the Ward's Crossing Bridge.

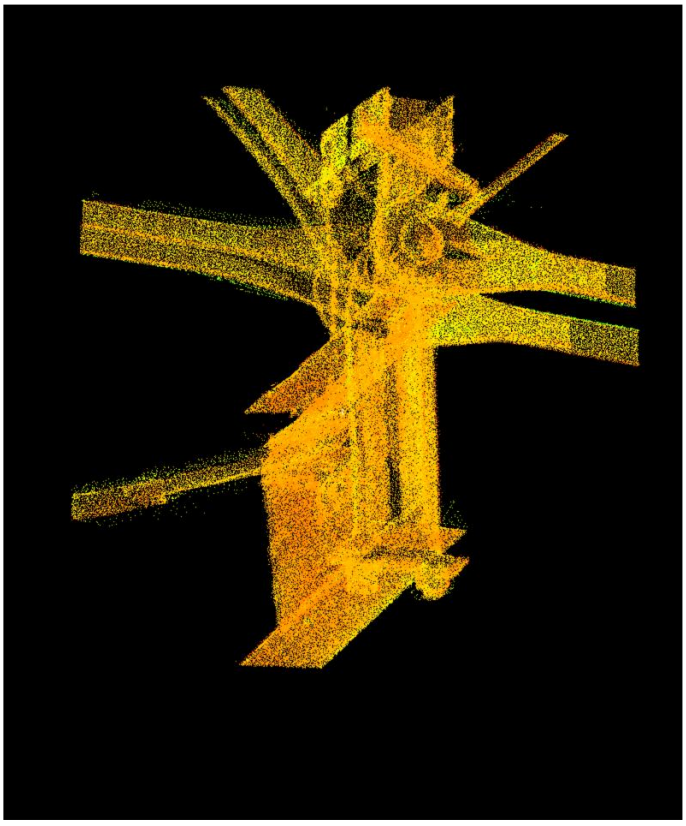

Figure 6. Scan of a pin-connection in the lower chord from the Old River Bridge.

Measured Drawings Specifications

After the bridges were scanned the NPS HAER was contacted for a copy of the *Secretary of the Interior's Standards and Guidelines for Architectural and Engineering Documentation: HABS/HAER Standards* which contain the Level I documentation specifications for measured drawings. In addition to the standards required for Level I documentation additional requirements were added by the Subcommittee. These requirements included that the scale of all drawings would be 1 to 1 and it would be drawn "as found". Also that the contractor will provide a 3-D wire-frame of the bridges and will submit finished electronic copies of the drawings in Microstation design file ".dgn" format along with two sets of the completed drawings created using NPS HAER standards to AHTD.

Selection of Consultant to produce Measured Drawings

When the specifications were completed the Subcommittee began the search for companies and universities with the experience to complete the project. Seven companies and one university were identified that potentially had the required experience. Four of the companies did not return messages from AHTD, but three of the companies and the university were contacted. All the potential consultants had experience with laser scanning and producing drawings from point clouds. The potential consultants were then provided with the measured drawing specifications as well as point clouds from both bridges to base their proposals on. The Subcommittee subsequently received proposals from all four potential consultants. These proposals ranged from $10,000 to $69,000.

An attempt was made to find companies within the state with the experience to handle the project; unfortunately none existed at the time. Although the Center for Advanced Spatial Technologies (CAST) at the University of Arkansas at Fayetteville had experience with laser scanning it was unable to submit a proposal due to a heavy work schedule.

These consultants are listed below from lowest to highest bid with projected completion time:

- GDM Inc. of Fairview, Tennessee - $10,010 (1 month)
- PMC of Dearborn, Michigan - $15,000 (3 - 4 weeks)
- ArrowScan of Eagle, Idaho - $30,516 (3 months)
- Texas Tech, College of Architecture in Lubbock, Texas - $68,685 (7 months)

The Subcommittee then reviewed all proposals, which were found to be comparable in scope and adherence to the requested specifications. After this review the

Subcommittee selected GDM Inc. as the contractor for producing the measured drawings. The company was selected due to the lowest cost and shortest projected completion time as well as its proximity to Arkansas.

Measured Drawings

Once the selection of a consultant was finalized a work order was issued in the fall of 2008 for the consultant to begin work. During this time AHTD contacted NPS HAER for the template used for measured drawings. This template along with digital pictures of the bridge in general and the pin-connections specifically were sent to the consultant as per their request.

The initial creation of the 3-dimensional model and first draft of the measured drawings created from the model took a little over a month. The consultant then submitted the first draft of the drawings to AHTD for review. Along with the draft the consultant submitted a list of question regarding; creating 3-dimesional elements for certain pieces of the bridge that AHTD was unable to scan and concerning line weights, fonts and scales listed in the NPS HAER standards for measured drawings.

The Subcommittee advised the consultant to avoid creating elements for bridge pieces that were not scanned. There was concern that these elements would alter the "as found" aspect of the drawings. The majority of the areas not scanned consisted of the interior of the upper and lower pin-connections in the center of the spans of both bridges.

There did appear to be some issues with the transition of the consultant from the creation of typical engineer drawings to the creation of the historic preservation influenced engineering drawings of the NPS HAER. This mainly manifested itself in the use of line weight, fonts and scales. A series of emails between the consultant, AHTD and NPS HAER provided the consultant with guidance in regards to these questions.

After review of the draft AHTD provided the consultant with comments. The consultant then incorporated these comments and submitted a second draft for review. A review of this draft found a few minor corrections, but was otherwise acceptable to the Subcommittee. AHTD then forwarded the second draft to NPS HAER for their initial review.

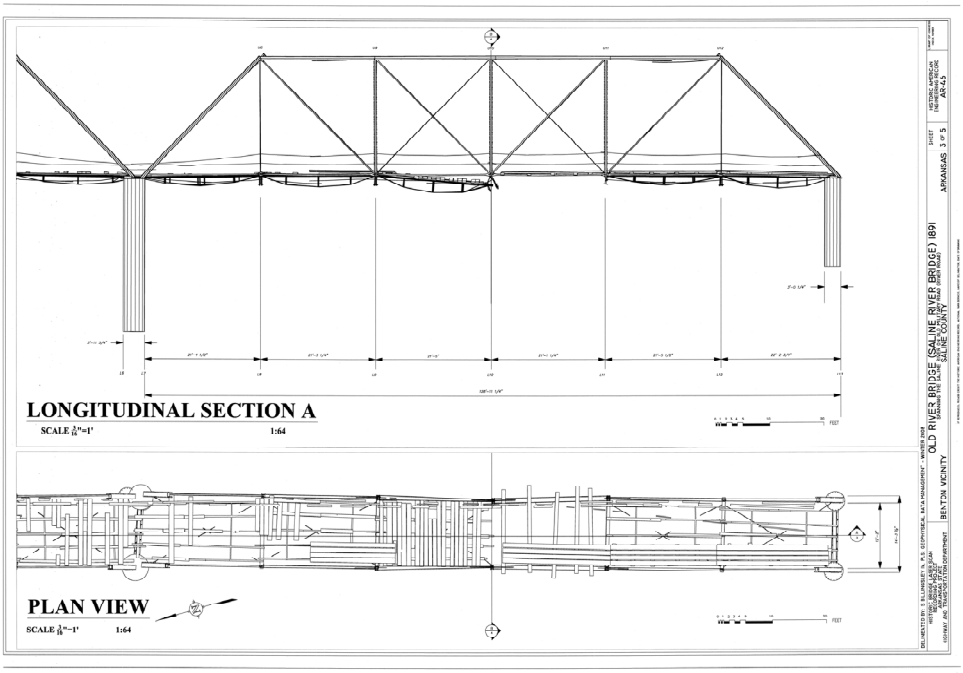

Figure 7. Measured Drawing produced from Old River Bridge point cloud.

After reviewing the drawings, NPS HAER sent comments to AHTD which were mainly concerned with line weight, font, scale and some measurements. But that over all the NPS HAER felt that the drafts were good and that with a few changes would be acceptable. The comments were forwarded to the consultant, who after consultation with Subcommittee addressed the comments. The drawings with the comments incorporated were sent to NPS HAER, who noted a few minor corrections to be made, but stated that with the incorporation of these minor changes the drawings should be ready to submit to NPS HAER for official acceptance. The changes were incorporated and submitted to the NPS HAER for acceptance in the spring of 2009. Official acceptance by NPS HAER was received in October of 2009.

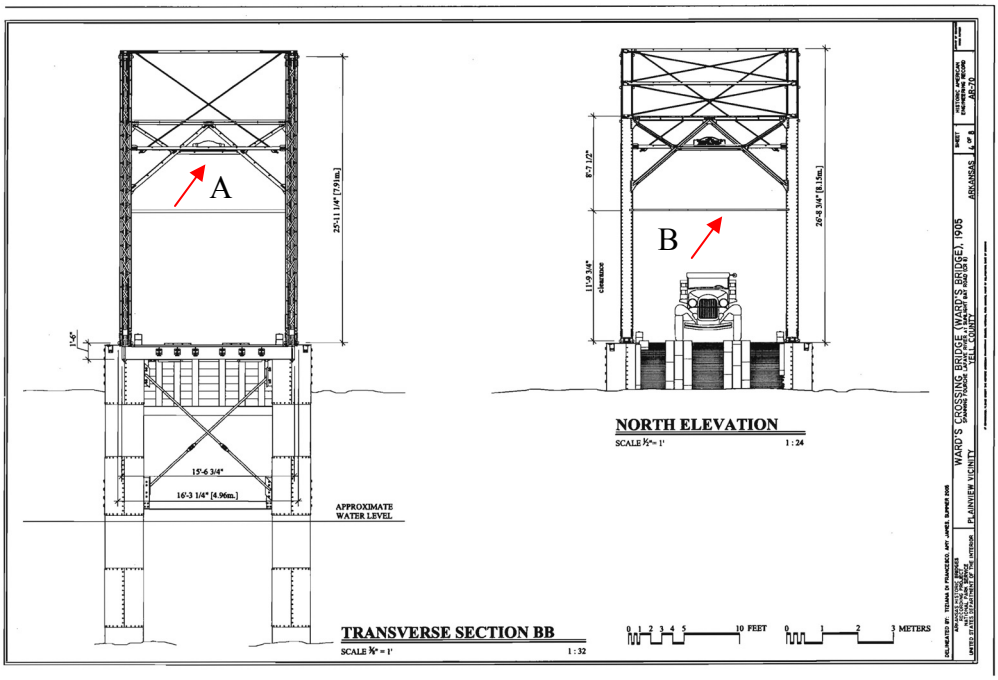

Figure 8. Transverse Section from 2005 NPS HAER Ward's Crossing Bridge drawings.

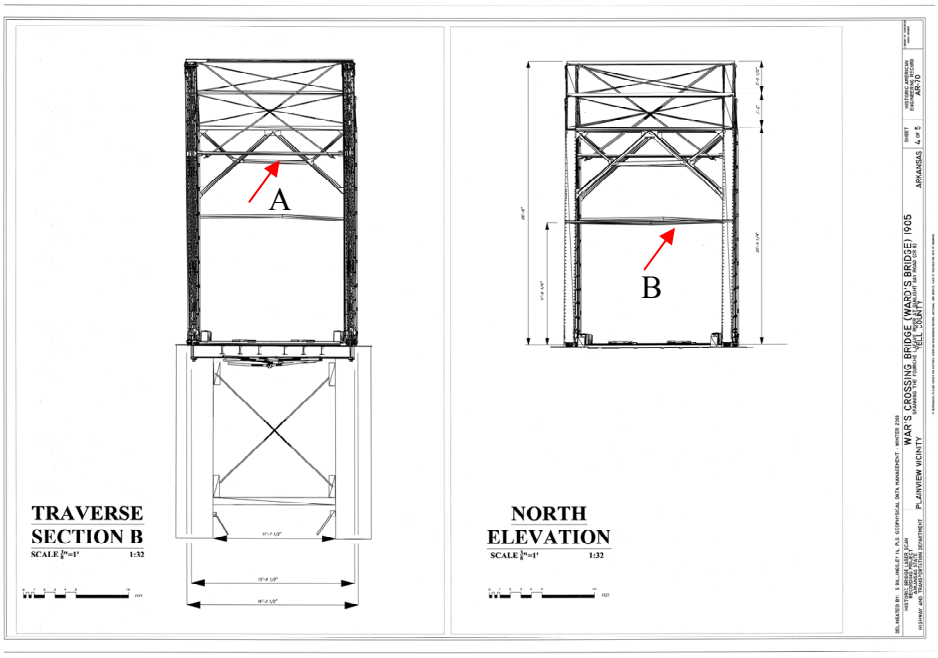

Figure 9. Transverse Section drawings created from the Ward's Crossing Bridge point cloud.

3-Dimesional Models

During the creation of the measured drawings, a 3-dimensional model of the bridge is developed from the point cloud. The model is then used to create the actual drawings. After the project was completed AHTD requested a copy of the models for the Old River and Ward's Crossing Bridges. These models were then used to create 3-dimensional fly-through video files of the bridges which were placed on the AHTD website.

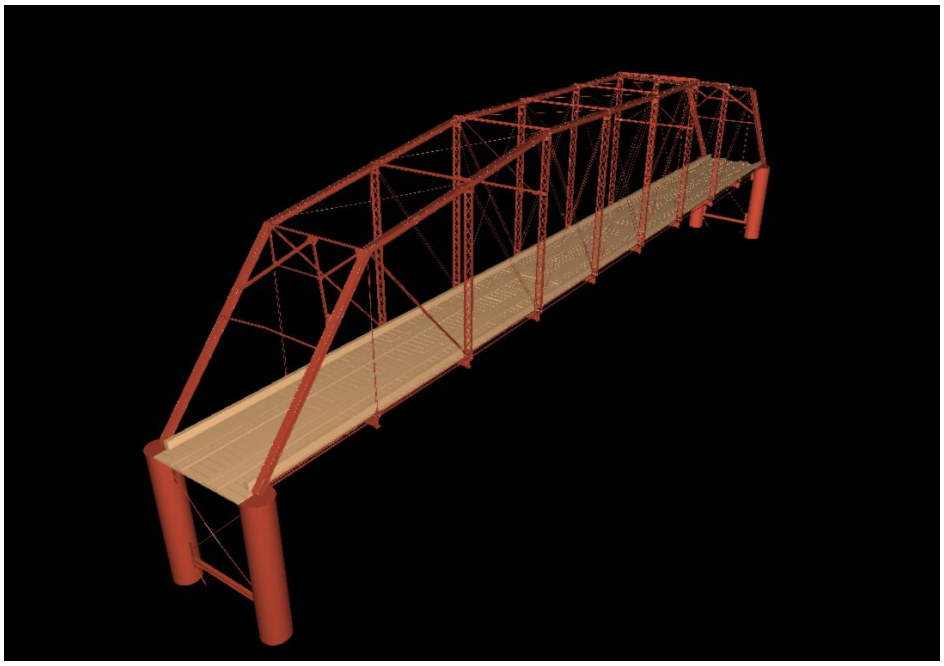

Figure 10. 3-Dimensional Model of the Ward's Crossing Bridge.

Project Results

The results of the project confirmed that laser scans taken of abandoned historic bridges would produce resolutions good enough to create measured drawings acceptable to the NPS HAER. The laser scan drawings are comparable in every way with the NPS HAER drawings. The 1/4 inch resolution allowed the scanner to pick up almost the same level of detail as physical measurements would, with the exception of the limited number of areas inaccessible to the scanner.

A comparison of transverse sections of the Ward's Crossing Bridge found that the laser scan produced drawings that accurately depicted the "as found" condition of the bridge. This can be seen by comparing the red arrows on Figures 8 & 9. Red Arrow A

contrasts the bridge portals which show a clear deformation on the laser scan drawing, but is level in the NPS HAER drawing. The same situation is seen with Red Arrow B which shows the deformation of the vertical limit bar.

Because the project was using a bridge that had previously been drawn by NPS HAER to determine the accuracy of the laser scanning, the Subcommittee decided that the cost, time and level of effort required to produce measured drawings for the bridge should be compared with the NPS HAER work conducted on the Ward's Crossing Bridge in 2005.

A comparison of the cost of producing measured drawings for Ward's Crossing Bridge using laser scanning vs. physical measurements was almost half of what the NPS HAER charged (NPS HAER - $20,000 vs. AHTD - $11,500). Also the use of a laser scanner substantially reduced the field data collection time (NPS HAER – 1 month vs. AHTD – 3 to 5 days). Finally the use of a consultant greatly reduced drawing time (NPS HAER – 9 to 18 months vs. AHTD - 4 months). Some additional benefits of using a laser scanner were that scans could be taken of a bridge and archived to be drawn at a later date and that 3-D models are created as a by-product during the creation of the drawings at no extra cost to a project.

The final cost for producing the drawings was $11,460. GMD Inc. charged $6,555 for the Old River Bridge, $3,805 for the Ward's Crossing Bridge and $1000 for two Mylar prints of the measured drawings. The 3-dimensional models were created as part of the drawing process and received at no cost. The total time from the creation of the drawings until there acceptance by the Subcommittee was four months. The drawings were created within the original time frame of one month projected by the consultant, but subsequent revisions be both AHTD and NPS HAER extended the project time.

Other costs incurred by the project included salaries and travel costs of the survey crews needed to operate the scanner - $23,706 and the purchase of computer equipment and software - $32, 103. The total costs expended from the project budget were $67,460.

The use of a laser scanner has been found to be a safe and cost effective alternative to collecting physical measurements on an unsafe historic bridge. A laser scanner can acquire measurements equal to those done by hand from a distance of at least 100 feet and substantially reduces the field time necessary to collect them. Using the point cloud produced by the laser scanner; measured drawings can be produced in less time and for less cost than using traditional survey and drafting techniques.

The Future

After completion of the project, scheduling of laser scanning for historic bridges programmed for replacement was incorporated into the AHTD Survey Division's project planning process. Fourteen historic bridges were then scheduled for scanning, with the point clouds generated from these bridge scans to be archived for future use.

The project committee then met a final time to discuss any future issues identified during the project that should be investigated. The meeting resulted in the identification of three issues needing further investigation. These issues were; determining the best format for long term archival of the point clouds, determining the most cost effective way to produce drawings from the point clouds (in-house vs. consultant), and investigating the usefulness of laser scanning to aid in the maintenance and rehabilitation of historic bridges. The committee believes that the investigation of these issues would potentially increase the cost effectiveness of the laser scanning of historic bridges as a common mitigation strategy and contribute to the effectiveness of historic bridge maintenance programs as well as historic bridges rehabilitation projects.

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