Measurement of
Bridge Deck Layout Prior to Concrete Placement

By

Dr. Jim Richardson
Dr. Sriram Aaleti
Dr. Wei Song
Mr. Thomas Moat
Department of Civil, Construction, and Environmental Engineering
The University of Alabama
Tuscaloosa, Alabama

And

Dr. Keith Williams
Department of Mechanical Engineering, College of Engineering
The University of Alabama
Tuscaloosa, Alabama

Prepared by

UTCA
University Transportation Center for Alabama
The University of Alabama, The University of Alabama at Birmingham, and
The University of Alabama in Huntsville

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Prepared by

Dr. Jim Richardson*, Associate Professor
Dr. Sriram Aaleti, Assistant Professor
Dr. Wei Song, Assistant Professor
Mr. Thomas Moat, Graduate Student

Department of Civil, Construction, and Environmental Engineering, College of Engineering
The University of Alabama

Dr. Keith Williams, Associate Professor
Department of Mechanical Engineering, College of Engineering
The University of Alabama

* Principal Investigator. P.O. Box 870205, Tuscaloosa, AL 35487-0205
Tel: 205-348-1709, Fax: 205-348-0783
Email: jrichardson@eng.ua.edu

UTCA

University Transportation Center for Alabama
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### Abstract

The main objective of this research was to develop a method of measuring and producing as built bridge drawings. This was the first step in the feasibility assessment for automated bridge deck paving. The research goes to show the standard methods used to capture large amounts of data quickly in the field.
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Executive Summary

The main objective of this research was to develop a method of measuring and producing as built bridge drawings. This was the first step in the feasibility assessment for automated bridge deck paving. The research goes to show the standard methods used to capture large amounts of data quickly in the field.

Two main methods were used to evaluate the effectiveness of current technologies in the field. First, an established surveying company was consulted to provide expertise on current practices in the field of large data capture. Data was collected on the I-65 Corridor X site in Birmingham, AL using Topcon equipment operated by employees of the surveying company. Initial scan processing was done by the consultant before turning over the data to UA; the data was then further processed to replicate the design drawings. During this time UA contacted software company (FARO) for help with the processing. Subsequent conversations with FARO technical support staff identified problems with the current bridge data set.

UA formed a partnership with FARO and was able to borrow equipment to scan another bridge in Gadsden, AL. This second time around, a different method of data capture was used that was developed by UA with input from FARO. Using a new cutting edge scanner, a new data set was produced by UA. The processing then followed a similar path to try and replicate the design drawings.

While the results were a good match, several problems were revealed in the technology and process. The largest issue was the amount of time the data processing took after scanning. In order to solve problems with rebar placement or clearances, the data would need to be processed in less than half a day to not hold up the next step in the construction process. However, UA found this process will take two to four days from start to finish after obtaining the scan data. Also, the number of scans and scan length were not quick averaging around three hours per construction process.

Because of the adverse outcomes of the project, UA recommends ALDOT revisit the topic in approximately five years to see if the technology has progressed sufficiently to accomplish the project goals.

On another note, components of stringless paving could likely be used to “automate” the bridge deck layout procedure. An on-site computer with a 3-D deck design that was connected to a robotic total station could guide the contractor while placing forms, rebar and screed supports. This would eliminate many calculations currently made by the contractor and likely improve the accuracy of the layout.
Chapter 1: Introduction

1.1 Background

Preparation for placing concrete for a reinforced concrete bridge deck consists of the following basic steps.

- Measure the elevation profile of the top of each bridge girder. Subtract the anticipated dead load deflection from these elevations.
- Attach metal stay-in-place forms between the girders, and on brackets cantilevered outside of the exterior girders.
- Place the bottom and top rebar mats.
- Adjust the screed supports and the screed profile between supports. Screeds can be supported on longitudinal rails along the cantilevered deck forms (e.g. Bidwell screeds), or on transverse bulkheads (e.g. Shugart screeds).
- Check the distances between the bottom of the screed and the deck and the top rebar using a tape measure during a “dry run” of the screed.

Errors in any of the steps above can lead to an uneven riding surface, inadequate reinforcement cover, or insufficient deck thickness.

Uneven riding surfaces caused by small errors setting the elevations of the screed supports or the screed itself could potentially be eliminated using so-called “stringless” paving techniques currently used for asphalt and concrete roads, parking lots and airport runways. Stringless techniques use modern surveying equipment and controllers to position the screed in real time at the elevation of the design surface as communicated by a computer on site.

Benefits of stringless paving include improved precision of the riding surface, elimination of human error during the survey operation, and reduced material costs when used in conjunction with laser-guided subgrade preparation. Bridges involving transitions from superelevation to normal crown could especially benefit from the precise control of the bridge deck surface afforded by stringless paving techniques. One complication for stringless bridge deck placement is the supporting girders deflect during the paving operation under the weight of the concrete, although this can likely be accommodated using the bridge engineer’s estimated dead load deflections.

Although improved “ridability” could likely be achieved by stringless bridge paving, the other benefits of stringless roadway paving (elimination of surveying errors and material savings) would not directly apply to bridges. Preparation of a bridge “subgrade” is a labor-intensive operation involving placing girders, welding forms between girders and erecting cantilever forms on the outside of the exterior girders. It seems possible, however, that a robotic total station linked to an on-site 3-D bridge model could guide workers setting bridge forms and screed supports. This would eliminate the need for the workers to add/subtract an offset from a measured elevation and then measure it using a hand rule.
The approach to improve the quality control of bridge deck construction proposed for this project was to measure the top surface of the girders, the forms, the two layers of reinforcing steel and the bottom of the screed (during a dry run) using state-of-the-art laser scanners and a total station. Possible project outcomes included:

- Improved quality control of deck thickness, rebar placement and concrete cover.
- As-built drawings that could potentially be used to guide deck widening and other bridge rehabilitation jobs. For example, every rebar would be located within a fraction of an inch, eliminating the need for ground-penetrating radar or other techniques for measuring rebar locations in existing structures.

1.2 Project Objectives

The objective for this project was to test the feasibility of measuring bridge deck layouts using modern surveying equipment (robotic total stations and laser scanners). The two primary questions were:

1. Can the bridge deck layout (forms, rebar and bottom-of-screed) be measured with sufficient accuracy to serve as a quality control prior to concrete placement?
2. Can the measurements be performed and the data reduced in a timely matter during typical bridge deck construction? Timely means the scanning can be accomplished with minimal interruption to construction, and the data can be reduced to useful measurements (e.g. deck thickness) before the concrete is placed.

1.3 Review of State-of-the-Practice

The first step undertaken for this project was to solicit a loan of surveying equipment (a robotic total station and a laser scanner). The Alabama Leica representative was interested initially but was unable to obtain approval from the Leica main office.

Bruce Carlson of Carlson Software was contacted next. Carlson Software is used to collect surveying data, design grading plans, and interface with machine control. Mr. Carlson said that 3-D control of bridge paving is definitely doable, although the deflection of the girders due to the dead load of the slab presented a complication. He referred me to Brad Phipps, an engineer who used Carlson Software to create 3-D design surfaces for earth-moving contractors.

Brad Phipps, of Laser Specialists in Olathe KS uses Carlson software to set up 3-D grading and paving jobs for local contractors. He also thought 3-D control of bridge paving was very feasible, and spoke of using procedures similar to those used for highway paving but with an offset to account for girder deflection due to deck weight. He referred me to Gomaco Inc., makers of concrete paving equipment, including bridge pavers.

Chad Shaeding, of Gomaco Inc., in Ida Grove Iowa, knew exactly what we were trying to do. He indicated that Gomaco had used equipment similar to bridge deck finishers to pave the transition from linear sloped to parabolic superelevation for an auto test track (see Figure 1).
Figure 1. Gomaco 3-D laser-guided concrete finisher.
Chapter 2: Measurement of Corridor-X Bridge Deck Layout

After exhausting all leads for donated equipment, an agreement was made with Earl Dudley Inc. to lease equipment and software to UA for the project and to provide technical assistance. The equipment consisted of a Topcon GLS-2000 scanner, a Sokkia Net05 robotic total station, and Topcon Scanmaster software. One of the bridges under construction for the Corridor X and Interstate 65 interchange was identified as a test span.

A series of five visits were made to the bridge site. On the first visit, personnel from Earl Dudley and UA met with ALDOT construction inspector Jacob Hudson to determine a suitable bridge to measure. Ramp ESX65, a curved continuous span steel plate girder bridge over the NSP Railroad and a creek was selected.

2.1 Measurement of Bridge Deck Components

In order to obtain a full 3-D model of the deck layout, a plan was formulated to measure each component of the deck separately, before the next component was placed above it (see Table 1).

Table 1. Plan for measuring Corridor-X Bridge deck layout

<table>
<thead>
<tr>
<th>Bridge Deck Component Measured</th>
<th>Construction Stage</th>
<th>Measurement Equipment</th>
</tr>
</thead>
<tbody>
<tr>
<td>Forms</td>
<td>After stay-in-place forms are placed but before rebar is placed</td>
<td>Laser Scanner</td>
</tr>
<tr>
<td>Bottom layer of rebar</td>
<td>After the bottom layer of rebar is placed but before the top layer of rebar is placed</td>
<td>Laser Scanner</td>
</tr>
<tr>
<td>Top layer of rebar</td>
<td>After the top layer of rebar is placed</td>
<td>Laser Scanner</td>
</tr>
<tr>
<td>Bottom of screed</td>
<td>During the “dry run” of the Bidwell screed</td>
<td>Robotic Total Station</td>
</tr>
</tbody>
</table>

The first step was to establish benchmarks to align each of the four separate measurements described in Table 1 above. We used an existing construction benchmark and established four additional benchmarks. The benchmark locations are indicated with red circles in Figure 2. The scanner was set up over the two benchmarks at the bridge abutment.

The five benchmarks described above were located relative to the state-wide coordinate system using the Topcon GPS unit. Prior to scanning, the scanner was set up over one of the two benchmarks adjacent to the bridge abutments. The scanner was then used to measure the location of at least one of the three remaining benchmarks before scanning the bridge deck.

The first three bridge deck components listed in Table 1 were measured on three separate
days. The scans required approximately two hours each day, during which construction activities were halted on the portion of the bridge that was scanned. Due to the steep super elevation and the curve in the bridge, two scans were performed for each component and overlaid to get the most complete point cloud and to limit reflections and dead zones.

Three scans of the stay-in-place deck forms (pans) are shown in Figure 3(a), 3(b) and 3(c). Figure 3(a) shows the scan data with the scanner located on the east side of the abutment, Figure 3(b) shows the scan data with the scanner located on the west side of the abutment, and Figure 3(c) shows the two point clouds overlaid.

Blank spaces in the point cloud data are evident in the individual scans (Figures 3(a) and 3(b). Note that when combined (Figure 3(c), many but not all of the blank spaces go away. Also, the data shown in Figure 3 has already been clipped to only include the bridge portions. The procedure for clipping the data is covered in a later section.

A similar procedure was followed two weeks later to measure the bottom layer of reinforcing steel. A week later, a third scan was performed to measure the top layer of rebar. The elevation profile of the scree rails was also obtained in this scan.
Figure 2. Benchmark locations (shown with red circles) at the bridge site.
Figure 3. Scan of deck pans with scanner set up over (a) east side of abutment and over (b) west side of abutment. Figure (c) is superposition of scans in Figures 3(a) and 3(b)
To measure the future bottom of slab, a laser target was attached to the Bidwell scree that will be used to finish the concrete (Figure 4). The vertical distance and horizontal offset from the target to the scree were measured and a robotic total station was set up near the bridge abutment. After backsighting to a reference point, the total station recorded target locations every 1/10 of a second while an operator moved the scree laterally across the bridge, then longitudinally down the bridge (Figure 5). The resulting zig-zag path (see Figure 6), while more exaggerated (spread out) than during the actual pour allows for the final top of slab surface to be found.

Figure 4. Laser target mounted on screed (inside red circle).
Figure 5. Measurement of bottom of screed using robotic total station
Figure 6. Data for bottom of screed from dry run
2.2 Data Processing Procedure

This section describes the procedure used to process the scan and total station data to yield useful information.

The laser scanners performed 360-degree scans. A typical scan is shown in Figure 7 below. Each scan was clipped to just keep the bridge sections to be investigated. This was done easily by using the select polygon feature in the Scanmaster software by Topcon. Once the data to keep was selected, the function invert was used to select the point not to keep. Finally the delete function was used to remove the excess points. The resulting point cloud look is shown in Figure 8.

Figure 7. 360 degree scan data.
As noted above, due to the super elevation and curve of the bridge, scans on the test bridge were taken from both the east and west side of the abutment. Figure 8 shows just the scan from the east side. Once this data reduction was performed for the scans from both the east and west side, they were both turned on in the view. Next the data extents that were used in both scans were selected and a new cloud was created. This separate cloud was then be exported as an ASTM E57 file type. This was done by navigating to the recently created cloud in the left navigation pane, right clicking and choosing “export cloud”. The file type was selected as ASTM E57 before saving.
The process described in the paragraph above was repeated for the scans of the bottom reinforcing layer, and for the scans of the top reinforcing layer.

Once all scans were turned into clouds and exported, they were combined into a new Scanmaster file. This was done by opening a new blank project, and then finding the cloud file notation in the left navigation window. Right clicking on the cloud notation gave the option to import. Once all clouds were imported in this manner, each cloud layer was renamed. The bottom of pan was named Bridge A, the bottom mat of rebar was named Bridge B, the top mat of rebar was named Bridge C, and the top of slab as named Robo Data.

Each of the scans (pan, bottom rebar mat, and top rebar mat) were assigned to different levels and different colors. Figure 9 shows the data from all three scans, each scan represented by a different color (yellow, blue and green).
Figure 9. Scan data of pan (yellow), bottom rebar (green) and top rebar (blue).
The next step was to export selected scan data to AutoCAD for the purpose of displaying transverse deck cross sections. The command extract single section was used to cut a transverse slice of the scan data at a particular longitudinal location on the bridge. Trial and error was used to select slice parameters (shown in Figure 10) that produced acceptable results.

Figure 10. Parameters controlling slice of scan data representing transverse section of bridge deck.

Parameters were defined as (in feet):
- Slice Thickness- Distance perpendicular to the drawn cross section, controls how much data in the longitudinal direction is included in the slice.
- Edge Length- Maximum separation between points to join with a line segment.
- Smoothing- Maximum separation between points in an area to smooth by creating a rolling average (makes the line straighter by looking at all points in this specified distance).

Once these parameters were set, a starting and end point were selected for creating the cross sections. For this project, cross sections were cut approximately every eight feet along the bridge. Figure 11 shows the cross section obtained using the following parameters from Figure 10: 0.3, 0.04, and 0.02, from top to bottom. The result consists mostly of points where individual rebar are located.

Figure 12 shows a cross section created using smoothing. The data cloud for each component (pan, bottom layer of rebar and top layer of rebar) was processed separately to avoid intermixing the data during the smoothing operation. The smoothed lines were then recombined to yield the cross section. The profile of the pan, bottom layer of rebar and top layer of rebar are shown in yellow, green and blue, respectively.

Longitudinal deck cross section were also extracted from the data, as shown in Figure 13. Due to the length and curve of the bridge, the longitudinal section was cut into three parts. The section was cut parallel to and approximately midway between the girders.
Figure 11. Transverse slice of scan data to show deck cross section.

Figure 12. Smoothed transverse slices of pan data (yellow), bottom rebar layer (green) and top rebar layer (blue)

Figure 13. Longitudinal slice of scan data.
The 16 transvers cross sections and the four longitudinal sections were superimposed on the pan, bottom rebar and top rebar scan data in Figure 14. Figure 15 shows just the transverse and longitudinal cross sections.

The scan data needs to be organized into layers to avoid losing data during the procedure to export it to AutoCAD. Figure 16 shows the organization of the levels. The scan data for each component (deck, bottom rebar and top rebar) were placed in the first three levels (Bridge A, Bridge B and Bridge C). The smoothed cross sections for each component were also placed in these levels. The 16 unsmoothed cross sections were placed in the next 16 levels, and finally the longitudinal sections were placed in the level labeled “90 degree”.

The final step was to turn on only the cross sections, as shown in Figure 15, and export to AutoCAD. Care was taken to export to the appropriate format for our version of AutoCAD.
Figure 14. Combined scan data. Pan data in yellow, bottom rebar layer data in green, and top rebar layer in blue. Transverse cross section approximately every eight feet, longitudinal cross sections approximately midway between girders.
Figure 15. 16 transverse cross sections and four longitudinal cross sections
The data from the robotic total station tracking the location of the bottom of the screed during the dry run was loaded into AutoCAD. Care was exercised to reference the data to the same benchmarks used to reference the scanner data. The elevation of the screed support rails were also measured. This data is shown in Figure 17.

Each cross section was then loaded into AutoCAD. A base point of 0, 0, 0 and a rotation of 0 were specified since all data was georeferenced.

A triangulated surface was created for the zig-zag screed data for the purpose of measuring the future top of concrete. The cross section data and triangulated surface are shown in Figure 18.
Figure 17. Bottom of screed during dry run with screed. Screed support rails are also shown (darker vertical lines in figure).
Figure 18. Triangulated surface from bottom of screed data.
2.3 Data Interpretation

The idea was to compare deck cross sections from the scan data with the deck cross section specified in the plans. A typical transverse deck cross section is shown in Figure 19. The bottom of the screed is not shown due to difficulty picking points on the triangulated surface in line with the cross section.

A dimensioned partial deck section is shown in Figure 20 and the deck cross section from the bridge plans is shown in Figure 21.

**Figure 19.** Typical deck cross section showing pan, bottom layer of rebar and top layer of rebar.

**Figure 20.** Dimensioned partial deck section, showing pan, bottom layer of rebar and top layer of rebar.

**Figure 21.** Deck cross section from bridge plans.

From the bridge plans, the distance from top of pan to the middle of bottom rebar should be (1 inch clear cover) + ½ (5/8 inch bar diameter) = 1 5/16 inches.
The dimensioned cross section from the scan data shows this distance to be $= 2\ 3/8$ inches.

Also from the bridge plans, the distance from the bottom of pan to the middle of the top rebar should be $(7.25$ inch concrete thickness $) - (2$ inches of clear cover $) - ½ (5/8$ inch bar diameter $) = 4\ 15/16$ inches.

The dimensioned cross section from the scan data shows this distance to be $= 6\ 7/8$ inches.

These results were obviously disappointing. Although closer matches to the dimensions in the bridge plan could have been found, our conclusion was that the processed scan data was not sufficiently accurate to be used to check the deck layout. Also, at this point in the project, we knew that the process to reduce the scan data to meaningful information was much too time consuming to be practical.

While we were processing the data for the Corridor X bridge, we were offered the use of a high resolution scanner by a company specializing in 3D measurement technology called FARO. Wishing to improve on the time to capture data in the field, the time to process the data, and the accuracy of the final result, we accepted the scanner and set up visits to another bridge under construction.
Towards the end of the processing of the Corridor X bridge data, the FARO corporation was engaged in order to use a plug in tool bar they had developed for AutoCAD. This plug in, called Pointsense Pro, was used in the final editing of data. During a training session for the software with FARO, members of their team noticed problems with the data from the Topcon scanner. UA entered into an agreement with FARO to borrow a laser scanner (FARO Focus X330) and data processing software, and to receive training for the scanner and software.

A second bridge under construction was located in Gadsden AL. This bridge was an 85-foot-long prestressed girder bridge carrying Tuscaloosa Ave over Black Creek. Much like the first bridge, data was collected via four trips to the bridge. At each of the first three visits to the bridge (to measure the pan, the bottom rebar layer and the top rebar layer), four scans were performed, one from each corner of the bridge deck.

For the last visit, the scanner was set up on the outside edge of the bridge near midspan (Figure 22). Three scans were captured showing the Shugart screed in three positions (Figure 23). The time to complete a FARO scan was only about eight minutes, much faster than the Topcon scanner. The scans caused very little interruption to construction.

The scan data was then brought back to UA to be processed. The scans were successfully combined by automatic registration via the FARO software SCENE. The scan data from the FARO scanner had much better imagery and pictorial presence, however the data points were less dense even though more scans where performed.
A procedure similar to the one used to process the Corridor X bridge scan data was used to slice the data into cross sections at roughly five foot intervals. These slices were then edited to compare with the design cross sections of the bridge. A typical transverse cross section is shown in Figure 24. A dimensioned section of the cross section is shown in Figure 25, and the bridge cross section from the bridge plans is shown in Figure 26. The distances between pan, rebar layers, and the top of slab are compared in Table 2.
Table 2. Comparison of component vertical spacing for scan data vs. bridge drawings

<table>
<thead>
<tr>
<th>Distance from:</th>
<th>Scan</th>
<th>Bridge Drawing</th>
</tr>
</thead>
<tbody>
<tr>
<td>Top of slab to middle of top rebar</td>
<td>2 ¼”</td>
<td>2 5/16”</td>
</tr>
<tr>
<td>Middle of top rebar to middle of bottom rebar</td>
<td>3 7/8”</td>
<td>3 3/8”</td>
</tr>
<tr>
<td>Middle of bottom rebar to middle top of form</td>
<td>2 3/8”</td>
<td>1 5/16”</td>
</tr>
</tbody>
</table>

As can be seen in Table 2, only the distance from the top of slab to the middle of the top rebar is close. These results indicate that the scan data was not sufficiently accurate to serve as a check on the contractor’s deck layout.

The poor results at this site can be attributed to this less dense data. The data collection (field scans) and the data processing were much quicker than for the Corridor X bridge. Four scans could be completed in less than 30 minutes, requiring little stoppage by the contractor.

Figure 24. Typical transverse cross section from scan data. The pan forms, bottom layer of rebar, top layer of rebar and the bottom of screed (future top of concrete) are shown.

Figure 25. Dimensioned cross section from Figure 24 data.
Figure 26. Bridge cross section from bridge plans.
Chapter 4: Summary

4.1 Conclusions

Two bridge decks were measured using laser scanners and a robotic total station for this project. The two research questions were:

1. Could the bridge deck layout (forms, rebar layers and bottom of screed) be measured with sufficient accuracy to serve as a check on the adequacy of the contractor’s work?

2. Could the measurements be taken and the data processed in a timely manner so as not to overly delay the contractor?

Since neither of the two bridges yielded measurements of sufficient accuracy to serve as a check on the contractor, the answer to Question 1 is “no”. The measurements were not wildly off, however, considering the first time nature of this work. Future bridge deck measurements would likely be more accurate.

The answer to Question 2 is also “no”. Faro produces state-of-the-art software for constructing models of building interiors from scan data. However, no software currently exists for constructing a model of a bridge deck from scan data. As a result, no special time-saving and accuracy-improving tools exists for the data processing tasks.

One of the principal data processing challenges consisted of identifying individual reinforcing bars from millions of overlapping point measurements (the point cloud). A software tool for this purpose would both speed up the process and improve the accuracy of measuring rebar mats.

4.2 Recommendations

Bridge decks on two different bridges were scanned and the data processed to provide a check on the contractor’s deck layout (forms, rebar mat and bottom of screed). While laser scanners now exist with sufficient capacity and accuracy to measure a bridge deck layout, obtaining useful information from the data was a big challenge. Probably the biggest obstacle occurred during the data processing phase: identification of individual rebar in an extensive rebar mat was difficult and time consuming.

We recommend revisiting this topic in several years after scanner and data processing technology have improved.

On another note, 3D bridge modeling capability could be linked with 3D measurement equipment to help the contractor layout the forms (especially the cantilever sections), rebar and screed supports. This would likely be an improvement in both time and accuracy over current field-calculated offsets and hand measurements.
Executive Committee

Dr. Jay K. Lindly, Director UTCA
The University of Alabama

Dr. Steven Jones, Associate Director UTCA
The University of Alabama

Dr. Fouad H. Fouad, Associate Director UTCA
The University of Alabama at Birmingham

Dr. Houssam A. Toutanji, Associate Director UTCA
The University of Alabama in Huntsville

Staff

Ms. Connie Harris, Secretary UTCA

Contact Information

University Transportation Center for Alabama
1105 Bevill Building
Box 870205
Tuscaloosa, AL 35487-0205
(205) 348-9925
(205) 348-6862 fax

utca@eng.ua.edu
http://utca.eng.ua.edu