Close-Range Photogrammetry for Bridge Measurement

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ABSTRACT

Studies have been conducted to determine the applicability of close-range photogrammetry for the measurement of bridges. Included are steel-beam deflection measurement, records of deck deterioration, and drawings for the documentation of historic structures. Measurement and documentation by photogrammetric methods are of sufficient accuracy for a variety of measurements involving structures. When structures are measured by the traditional hand-measurement method, particularly for as-built and historic documentation, the field work becomes the most labor-intensive phase. The photogrammetric method can be effective by reducing the manual labor, scaffolding, and other support equipment required to accomplish such measurement by hand. It can also minimize interruption to the flow of traffic.

Close-range photogrammetry is another precise tool in the arsenal of measuring techniques now available to the highway and transportation profession. Any time that the simultaneous recording of a large number of points is required, close-range photogrammetry can become most effective in minimizing interruption to traffic. It is also helpful in cases where heavy traffic makes ordinary survey techniques unsafe and inefficient.

This technology, sometimes referred to as nontopographic photogrammetry, has been used in Europe for several decades in the architectural field for the documentation of historic structures and monuments and for accident investigations. The academic community in the United States has been active in close-range photogrammetric projects for a number of years, as have various industrial groups such as the aircraft, automobile, and shipbuilding industries. Unfortunately, photogrammetry has been slow to attain recognition in the transportation field (1-3).

BACKGROUND

It was not until the director of the Virginia Highway and Transportation Research Council (VHTRC), Howard Newlon, became aware of work being accomplished at the Miami-Dade Community College by Joel Kobelin that the potential of close-range photogrammetry was recognized by Virginia. It appeared to have possibilities for the measurement and preparation of drawings as required by the National Historic Preservation Act of the 1960s and subsequent federal-aid highway acts of the late 1960s and 1970s.

Close-range photogrammetry has been approached with guarded optimism. The first attempt in 1979 at taking close-range photography was through the use of a camera owned by the Virginia Department of Highways and Transportation (VDHT), a World War II surplus Fairchild F-56 aerial camera. This camera produced a negative 7 x 7 in. and was equipped with a long-focal-length lens of 210 mm.

The camera was rather unwieldy and had to be hand held in a horizontal position, supported on the top of a stepladder, and leveled in a crude fashion. Single photographs were taken; the camera then was repositioned over another point. By doing so, overlapping pairs of photographs suitable for stereoscopic viewing were exposed. Because of the long-focal-length lens, the camera had to be positioned some distance from the object being photographed in order to obtain sharp focus. This increased the likelihood that obstructions such as trees, utility poles, embankments, buildings, railway cars, and automobiles would block the line of sight. Of course, this photography revealed the potential of a close-range photogrammetric system but was lacking in image quality so essential for the preparation of adequate structure drawings. However, it was discovered from these early experiments that a fairly large-format camera (large negative size) and a fairly short-focal-length lens (distance from lens to film) are needed, particularly when conventional stereoscopic mapping instruments such as those now available to most departments of highways and transportation are used.

VDHT has a completely equipped and fully staffed aerial photogrammetric section, which has worked cooperatively with the VHTRC to develop and implement a close-range photogrammetric system to meet new and expanding needs.

Research projects were approved for Highway Planning Research funding by FHWA during the fall of 1980 to study the application of close-range photogrammetry to the measurement of highway- and transportation-related structures. A search was initiated at that time for a metric camera to meet the necessary criteria.

Actually, there are a limited number of manufacturers of close-range cameras worldwide, and few are willing to rent their equipment on a short-term basis. The U.S. representative of Zeiss Jena was willing to rent a metric camera, the UMK 10/1318, equipped with a lens of 100-mm focal length and with variable focus for exposures as close as 12 ft (camera to object). The camera produces a negative 5 x 7 in. on glass plate for image stability, flatness, and enhanced accuracy.

During the course of this research effort, a variety of transportation-related sites were photographed. Twenty-four sites were photographed, not all of which were bridges. There were unique highway markers, a tunnel portal, a cut-stone masonry culvert, and archaeological sites. A test beam was also measured in the civil engineering laboratory at the University of Virginia.

Certain field measurements are needed for control of horizontal and vertical scale within each stereoscopic overlapping pair of photographs and for use in the orientation of the photography in a mapping instrument. Small contrasting black-and-white targets 5 x 8 in. large have served adequately for marking horizontal and vertical control positions within the region being imaged (Figure 1). They have been printed on card stock by using either diazo equipment or a printing press. These were tacked or taped to wood or taped to steel structures. Others have been printed on adhesive-backed material and placed on steel beams, and still others have been placed on steel beams by using magnets. On some concrete bridges where the surface would not accept adhesives, a template was used and the target was spray-painted on.

Inasmuch as VDHT is using conventional optical-

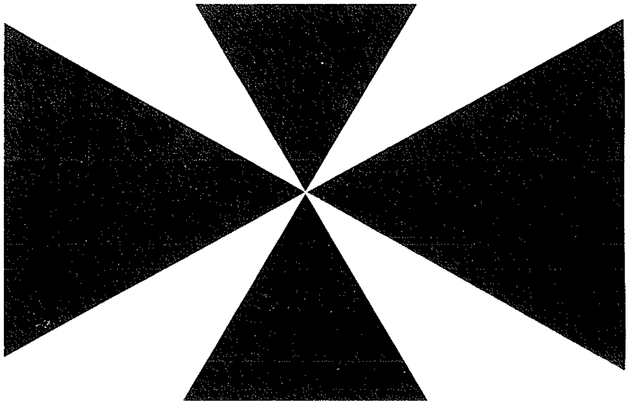

FIGURE 1 Targets used to mark horizontal and vertical control positions.

mechanical stereoscopic mapping equipment, certain constraints are imposed by the design of the instruments. The close-range camera movement is limited to about 5 degrees of tip and tilt. Stated in photogrammetric terms, this is 5 degrees of omega, phi, and kappa along the three rotational axes of the instrument. It is also necessary to position the camera along a line essentially parallel with the object being photographed. Otherwise, a condition is created similar to an aircraft's losing altitude between aerial camera exposures.

Close-range photogrammetry is a little different in many respects from aerial photogrammetry. Its reliability must be proven by comparing the results obtained with an acceptable, time-honored conventional method of measurement.

Structures were photographed under a variety of weather and lighting conditions. Most were taken under excellent lighting conditions, but some were taken under overcast skies. Several sites were photographed through light rain, and one structure was photographed at night with floodlights. The camera platforms varied from creek bottoms, with the photographer standing in waist-deep water, to a special cherry-picker mount and a boat moved on a line parallel to the bridge by using lines and anchors.

This report will be confined to the methodology for measuring deflections on a laboratory test beam, measuring deflections for one bridge, recording one bridge deck, and historic documentation for two bridges.

METHODOLOGY

Test Beam

The hydraulically actuated test bench at the University of Virginia was located within a convenient distance from a flat stationary wall. This wall in the laboratory was suitable for the placement of targets for photogrammetric control measurements (Figure 2).

Control was arranged in a quadrilateral with all sides and diagonals chain measured. Close-range photographs were taken with the camera positioned 25 ft from the test I-beam and also were taken under various loading conditions from two camera stations. Dial gauges reading to 0.001 in. were used to physically measure the test I-beam deflection.

Image positions were measured on the photographs by using a comparator that had 1-micron accuracy for use in an analytic aerotriangulation computer program. Manual and photogrammetric measurements were

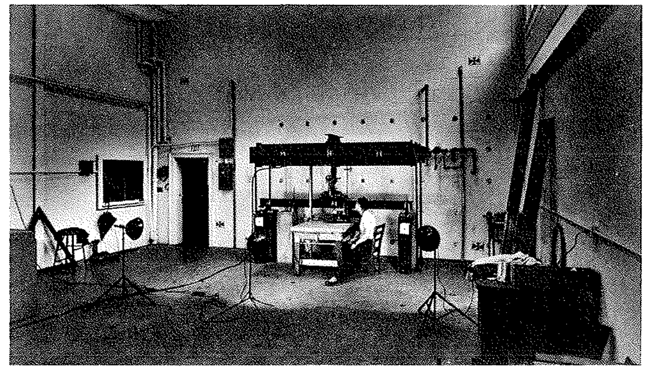

FIGURE 2 Set-up to photograph test beam.

in close agreement. The beam with maximum loading deflected 0.408 in. The disagreement between close-range photogrammetry and measurement by the conventional method was 0.040 in.

Bridge Deflections

One of the structures on which the deflections was measured was a new bridge under construction. It was of the continuous-beam design with a total length of 464 ft. The distance between piers of the span measured was 170 ft (Figure 3). The camera was positioned under the center of the span with the lens axis pointing upward. Distance from the bottom of the beams to the three camera stations required at this site was 36 ft.

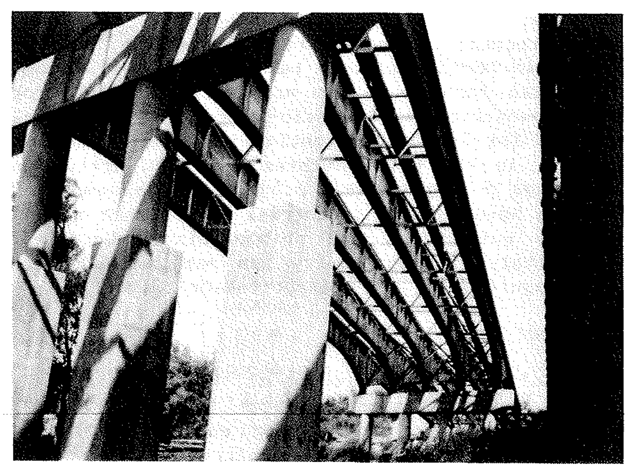

FIGURE 3 Fifth Street Bridge, Lynchburg, Virginia (under construction).

Control targets were placed on the beams by using adhesive-backed targets. The horizontal and vertical positions on the targets were measured with a precision theodolite by using the triangulation method from a measured baseline. The deflection of the beams was also measured by differential leveling.

Two sets of photographs were taken, one set at the time of placement of the steel beams and the other set after the pouring of the concrete deck (Figures 4 and 5). Here again the comparator with an accuracy of 1 micron and the analytic aerotriangulation method were used for the computation of position.

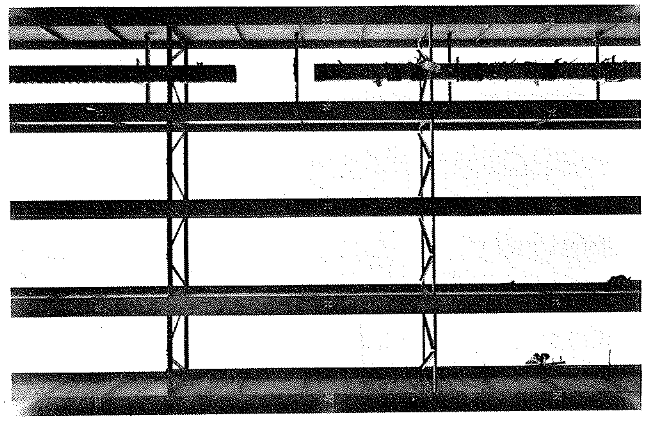

FIGURE 4 Fifth Street Bridge after placement of steel beams.

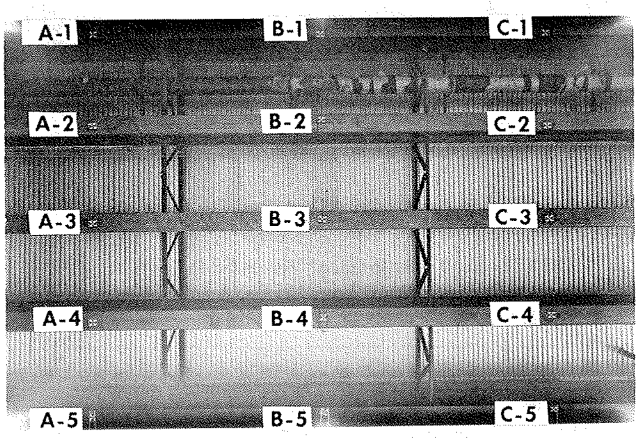

FIGURE 5 Fifth Street Bridge after pouring of concrete deck.

According to the design calculations, the maximum dead-load beam deflection should have been 2 in. However, by both photogrammetric analytic aerotriangulation and differential-leveling techniques, the maximum deflection was determined to be only 3/8 in. (see Table 1).

Bridge Deck

The bridge deck selected for this study is near Harrisonburg where VA-33 crosses Interstate 81. Close-range photography was taken following the conventional bridge inspection team. While the travel lanes were still cordoned off for the normal bridge inspection, the photographic crew moved in with the cherry picker to take vertical photography. The necessary horizontal and vertical control as required for the photogrammetric work had been pre-marked on the bridge deck just before photography.

The inspection team had made the normal survey, including the use of drag chain, to determine delamination. The delaminated regions were marked by using chalk on one section and spray paint on another for ease of identifying them with the close-range photography (Figure 6). Figure 7 shows the photogrammetric record of the delamination shown in Figure 6.

A bridge deck could be photographed rapidly if it was not for mandatory safety rules that require the boom of the cherry picker to be returned to a

TABLE 1 Summary of Elevation Measurements on Fifth Street Bridge, Lynchburg, Virginia

	No Load (September 18, 1981)		Loaded (April 21, 1982)		
Point	Differential Leveling (ft)	Photogrammetry (ft)	Differential Leveling (ft)	Photogrammetry (ft)	Ground Triangulation (ft)
A-1	714.88	714.85	714.86	714.85	714.85
A-2	714.65	714.64	714.66	714.66	714.65
A-3	714.49	714.49	714.51	714.51	714.49
A-4	714.31	714.32	714.34	714.34	714.32
A-5	714.13	714.14	714.14	714.12	714.13
B-1	715.02	715.02	714.99	714.99	714.98
B-2	714.80	714.80	714.79	714.79	714.78
B-3	714.63	714.62	714.64	714.64	714.62
B-4	714.45	714.46	714.46	714.46	714.44
B-5	714.27	714.27	714.27	714.27	714.23
C-1	715.11	715.08	715.09	715.09	715.07
C-2	714.90	714.90	714.89	714.89	714.89
C-3	714.73	714.73	714.73	714.73	714.73
C-4	714.55	714.55	714.54	714.54	714.53
C-5	714.35	714.36	714.33	714.33	714.30

neutral position before it is moved to the next camera station. Even with all the precautionary measures, exposures were taken at intervals on an average of 8 min.

Historic Documentation

The two structures selected for inclusion in this paper to show historic documentation illustrate measurements and drawings prepared under favorable and unfavorable conditions. As mentioned earlier, the close-range photographs were taken under a variety of weather and lighting conditions. A bedstead pony truss bridge was photographed under overcast skies in a drizzling rain with a fairly large object-to-camera distance (Figure 8). This is the type of condition to be avoided if at all possible. The drawing of this bridge, a side elevation, was prepared to a scale of 1 in. = 3 ft (Figure 9).

Hand measurements of the actual bridge were compared with dimensions taken from the photogrammetric drawing by using an engineer's scale. In making such a comparison, it should be remembered that even the width of a pencil line on the drawing can represent a measurement as large as 1 in. Paint and corrosion build-up on the bridge sometimes amount to as much as 3/8 in.

Some of the hand measurements differed by as much as 3/4 in. from the scaled measurements. The results are favorable when considered as a percentage of the total dimensions. Of the 15 points checked, 60

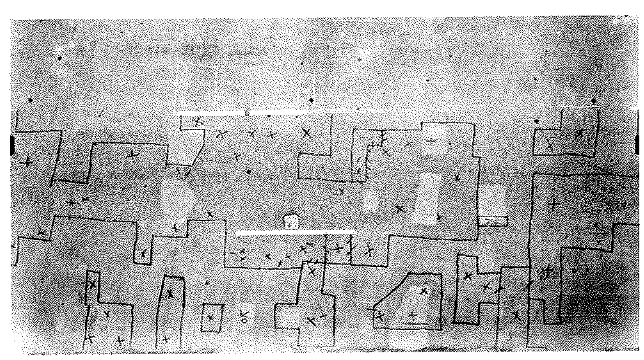

FIGURE 6 Bridge over I-81, Harrisonburg, Virginia, showing regions of delamination.

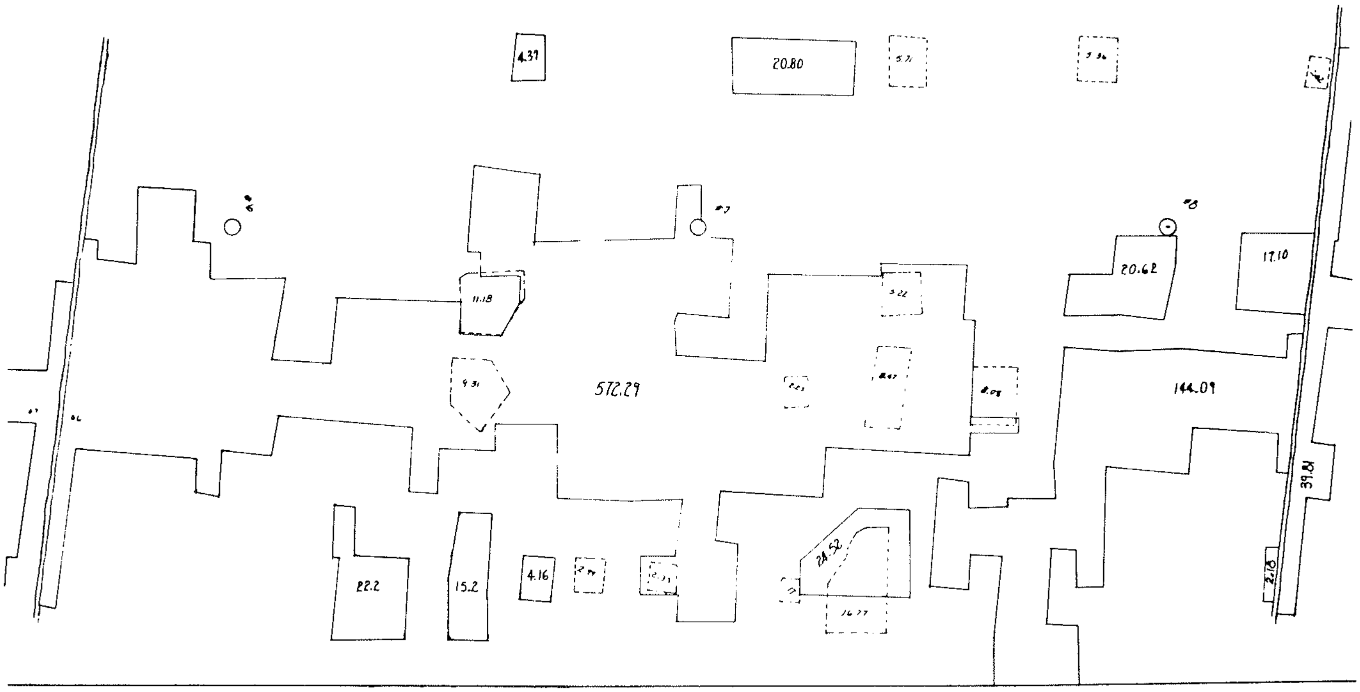

FIGURE 7 Photogrammetric record of delamination shown in Figure 6.

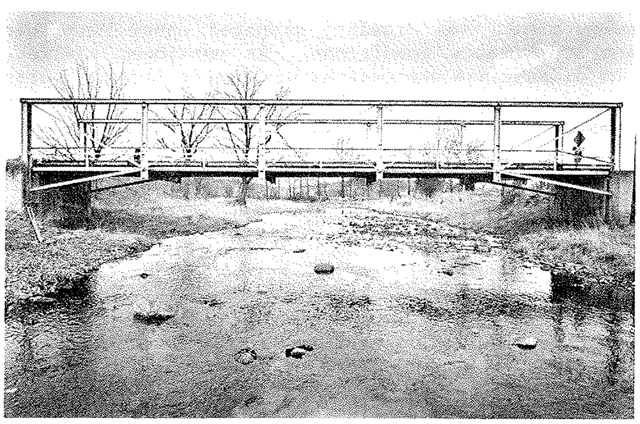

FIGURE 8 Pony truss bridge, Augusta County, Virginia.

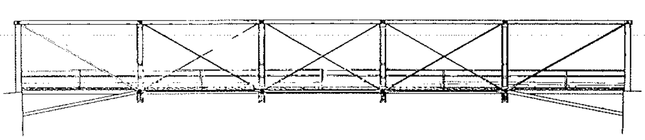

FIGURE 9 Intermediate-stage photogrammetric documentation of pony truss bridge.

percent differed less than 2 percent; 87 percent differed less than 5 percent; and only 2 readings out of 15 were greater than 5 percent in error (Table 2).

The cross-sectional measurements (those measured perpendicular to the elevation plane) fared somewhat better. Of 17 readings, 4 were difficult to read by photogrammetry as well as by manual methods. Rust and paint build-up apparently caused erratic readings, and the largest error of these four was as great as 1/4 in. All other errors were less than

TABLE 2 Hand Measurement Versus Scaled Dimensional Comparison, Pony Truss Bridge, Augusta County, Virginia

Location	Hand Measurement (in.)	Scaled Measurement (in.)	Difference (in.)
1	71.376	71.400	0.024
2	11.184	10.800	0.384
3	90.120	90.000	0.120
4	90.240	90.600	0.360
5	90.480	90.000	0.480
6	90.120	89.400	0.720
7	90.480	89.700	0.780
8	6.312	6.000	0.312
9	5.064	4.800	0.264
10	6.372	6.600	0.528
11	7.188	6.900	0.288
12	9.564	9.600	0.036
13	6.000	5.700	0.300
14	56.880	56.700	0.180
15	183.480	183.600	0.120

1/8 in. There were 4 other points of the 17 that were in error by only 1/64 in. (Table 3). Actually, on a percentage basis, 65 percent of the cross-sectional measurement was less than 3 percent in error; 85 percent was less than 5 percent in error.

Results similar to those for the overall elevation of the bedstead pony truss were experienced in checking the elevation of the joint detail of this bridge (Figures 10 and 11). The results were better, in most part because of a shorter object-to-camera distance. From a percentage standpoint, 67 percent of the errors in measurement were less than 1/16 in. and 92 percent were less than 1/8 in. (Tables 4 and 5).

Despite the unfavorable conditions encountered on this bridge, the comparative results from hand and scaled measurements were favorable. The engineers concluded that drawings produced by photogrammetric methods for this site were as accurate as a hand-

TABLE 3 Cross-Sectional Dimensional Comparison, Pony Truss Bridge, Augusta County, Virginia

Location	Photogrammetric Reading (in.)	Hand Measurement (in.)	Difference (in.)
1	2.172	2.187	0.015
2	1.692	1.813	0.121
3	1.224	1.375	0.151
4	2.328	2.313	0.015
5	2.292	2.250	0.042
6	1.296	1.359	0.063
7	4.260	4.250	0.010
8	3.528	3.469	0.059
9	3.960	3.750	0.210
10	2.040	2.000	0.040
11	0.972	1.000	0.028
12	2.316	2.375	0.059
13	12.000	12.016	0.016
14	0.888	0.906	0.018
15	2.772	2.875	0.103
16	1.620	1.688	0.068
17	6.792	6.875	0.083

FIGURE 10 Pony truss bridge: joint detail.

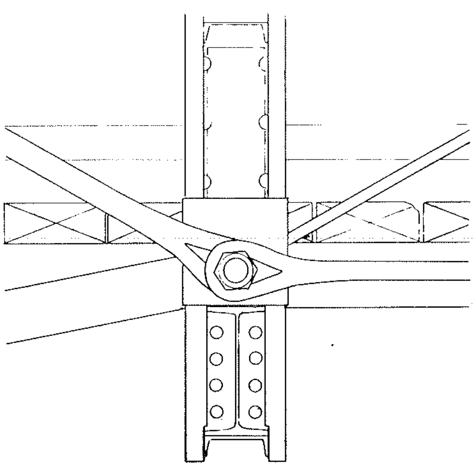

FIGURE 11 Intermediate-stage photogrammetric documentation of joint detail of pony truss bridge.

measured documentation drawing, given a reasonable scale drawing and a short object-to-camera distance. The lesson to be learned is never to photograph a site under conditions that are less than ideal.

A structure photographed under ideal weather conditions is a bascule span, which is one of the few remaining movable spans in Virginia and the only Scherzer rolling lift highway bridge known to remain in the state. Two views were taken of this bridge, known locally as the Hodges Ferry Bridge (Portsmouth, Virginia). The first view, consisting of two overlapping pairs of photographs, was exposed from a motorboat anchored in the river. The boat was moved 59 ft with anchors along a line parallel to the side of the bridge. The photograph and drawing are shown in Figures 12 and 13.

The second view is of the rocker-arm detail, which was used for dimensional analysis. It was

TABLE 4 Hand Measurement Versus Scaled Dimensional Comparison, Pony Truss Bridge: Joint Detail

Location	Hand Measurement (in.)	Scaled Measurement (in.)	Difference (in.)
1	2.3125	2.3	0.0125
2	3.9375	3.9	0.0375
3	0.2500	0.3	0.0500
4	1.7500	1.7	0.0500
5	5.1875	5.3	0.1125
6	2.375	2.3	0.0750
7	9.500	9.45	0.050
8	6.000	6.05	0.050
9	0.375	0.40	0.025
10	14.500	14.5	0
11	5.625	5.4	0.225
12	2.167	2.05	0.117

TABLE 5 Cross-Sectional Dimensional Comparison, Pony Truss Bridge: Joint Detail

Location	Photogrammetric Reading (in.)	Hand Measurement (in.)	Difference (in.)
1	1.032	1.000	0.032
2	1.944	1.969	0.025
3	0.456	0.375	0.081
4	2.1096	2.2125	0.015
5	7.2876	7.250	0.0376
6	1.4496	1.406	0.0436
7	0.336	0.3125	0.0235
8	0.462	0.500	0.038
9	2.352	2.375	0.023
10	8.844	8.875	0.031

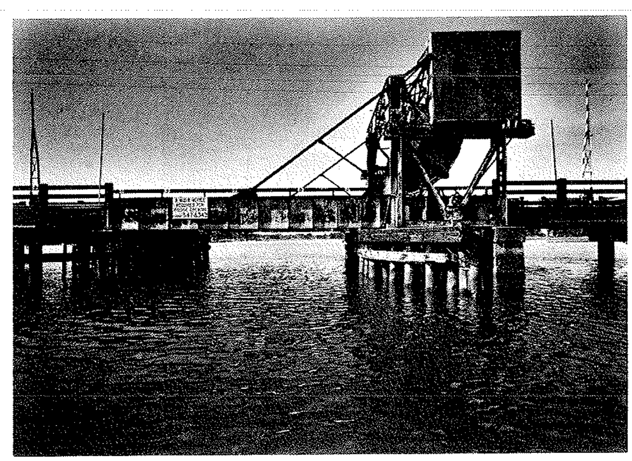

FIGURE 12 Hodges Ferry Bridge, Portsmouth, Virginia.

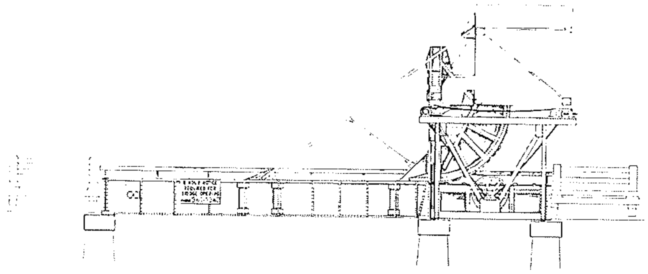

FIGURE 13 Intermediate-stage photogrammetric documentation of Hodges Ferry Bridge.

selected as an example of a site that would be prohibitively time-consuming to hand measure, to say nothing of the dangers involved (Figures 14 and 15). The high traffic volume on the narrow bridge and its height above the water made hand measurements hazardous.

Of the 18 points used for analysis, all measurements show less than 1/8 in. difference between hand and photogrammetric measurements. Of these, eight show less than 1/64 in. difference, three show less than 1/32 in., and six others show less than 1/16 in. difference between the two methods (Table 6). The conclusion from this site is that the photogrammetric method is potentially a reliable technique for making documentation drawings and for cross-sectional measurements on structures (4).

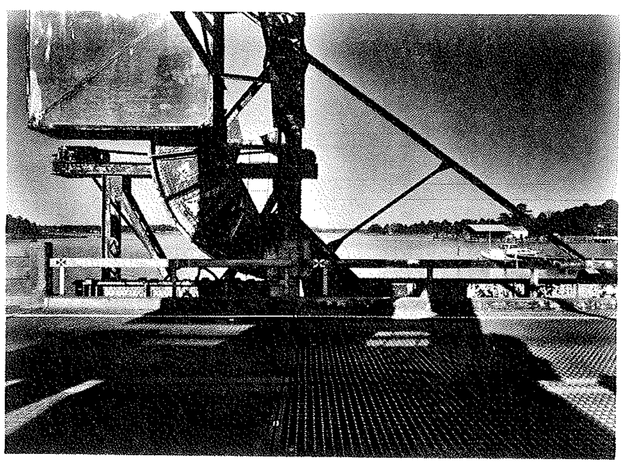

FIGURE 14 Rocker-arm detail, Hodges Ferry Bridge.

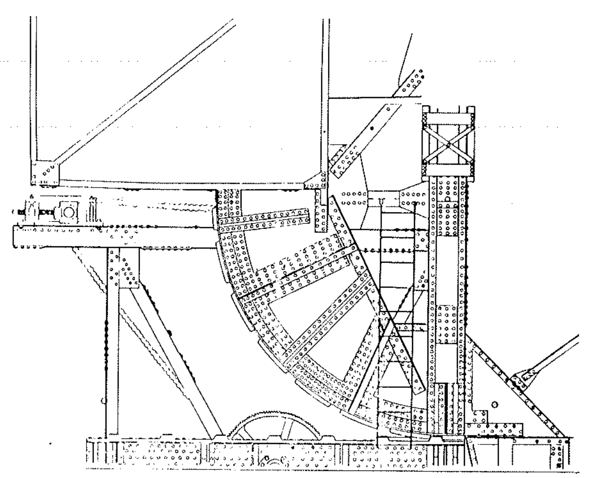

FIGURE 15 Photogrammetric documentation of rocker-arm detail, Hodges Ferry Bridge.

TABLE 6 Cross-Sectional Dimensional Comparison, Hodges Ferry Bridge

Location	Photogrammetric Reading (in.)	Hand Measurement (in.)	Difference (in.)
1	4.488	4.5156	0.0276
2	4.872	4.875	0.003
3	0.384	0.375	0.009
4	0.696	0.750	0.054
5	0.372	0.375	0.003
6	3.192	3.250	0.058
7	2.700	2.6875	0.0125
8	5.616	5.625	0.009
9	9.036	9.0625	0.0265
10	5.604	5.5625	0.0415
11	4.848	4.750	0.098
12	59.964	59.96875	0.00475
13	5.520	5.500	0.020
14	2.736	2.6875	0.0485
15	0.300	0.3125	0.0125
16	0.408	0.375	0.033
17	0.684	0.6875	0.0035
18	1.092	1.125	0.033

CONCLUSIONS

It has been demonstrated that close-range photogrammetry can provide fairly reliable measurements for a variety of applications. Close-range photogrammetry is applicable when a large number of points on a bridge need to be recorded simultaneously or in a short period of time. It is also applicable when interruption to traffic needs to be minimized or when ordinary survey techniques are unsafe, ineffective, or inefficient. It is recommended that photographs be taken only under ideal lighting conditions.

Close-range photography provides a permanent set of records for immediate or future use in the evaluation and documentation of bridges. It can be used for as-built plans for new bridge structures as well as for the documentation of historic bridges.

The results obtained from beam deflection were rather inconclusive; therefore, it is recommended that additional work be accomplished on this subject.

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