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THE PHOTOGRAMMETRIC RECORDING OF HISTORIC TRANSPORTATION SITES

by

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Research Engineer

Photogrammetric Field Work

Directed by

Fred Bales
Photogrammetric Engineer

(The opinions, findings, and conclusions expressed in this report are those of the author and not necessarily those of the sponsoring agencies.)

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ABSTRACT

The purpose of this study was to evaluate the applicability and accuracy of documentation drawings prepared from close-range terrestrial photogrammetry and to compare them with the results of traditional documentation techniques which depend on hand measurements. The photogrammetric research was organized to coincide with equipment resources available within the Virginia Department of Highways and Transportation.

The sites studied on a case-by-case basis illustrate the types associated with transportation improvements that are likely to be affected by federal requirements which demand documentation of certain historically significant sites. The variety of sites also demonstrates the adaptability and limitations of the photogrammetric method.

Documentation drawings executed by the photogrammetric method are presented in several stages of completion to illustrate the process. These drawings are considered successful documentation delineations, with certain limitations inherent in the process.

The results of the photogrammetric technique were analyzed from two perspectives. A comparison was made between documentation drawings produced by the photogrammetric method and those made by the traditional hand measured method. An analysis also was made of the dimensional accuracy of the photogrammetric results by comparison with hand measurements taken at the sites. A few photogrammetric models were studied to determine what additional types of dimensional information can be obtained from the stereoscopic models of these sites. The degree of accuracy, both dimensionally and in the representation of deteriorated areas, was found to be more than adequate for the demands of site documentation.

1962

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ENGINEERING NEEDS FOR PHOTOGRAMMETRIC DOCUMENTATION METHODS

Federal legislation of the 1960's has made site analysis for engineering structures far more complex and time-consuming than it was previously. Executive Order 11593, Section 106 of the National Historic Preservation Act and Section 4(f) of the Department of Transportation Act have imposed significant restrictions upon the use of federal funds for engineering projects. It is now necessary for appropriate consideration to be made of all historic sites affected by a federally funded or licensed project. As defined by legislation, these historic sites can have either national, state, or local significance. Thus, historically significant sites could include a wide range of places; anything from Monticello to a local Civil War skirmish site could interfere with federal funding of transportation projects. When one of these sites is on or eligible for the National Register of Historic Places, proper measures must be taken to minimize harm to it. Often, after all alternatives have been considered, it is not possible to avoid harming the site. In many cases, for safety or economy, the only acceptable course of action is demolition of a structure or relocation of an object. In these cases, before the project may proceed, mitigation agreements often require that a recordation of the structure be made in accordance with stringent standards.

At present the documentation often required consists of the time-consuming and expensive method of hand measured drawings. Not only are field measuring techniques tedious but the standard drawing requirements are such that for the typical highway engineering draftsman hours of unfamiliar drawing are necessary.

In addition to the federal requirement to document historic sites adversely affected by proposed transportation projects, a recent federal mandate strongly encourages all state transportation departments to develop a program to inventory their historic bridges.(1) Such an inventory was appreciated in Virginia as not only a step in historic bridge conservation but also as a planning tool instrumental for avoiding the delays inherent in projects which suddenly uncover an impacted historically significant site. Thus, in 1973 the Research Council initiated a statewide inventory of structures built prior to 1932. The Surface Transportation Act of 1978 recognized the need for such inventorying by allowing the use of Highway Bridge Replacement and Rehabilitation Program funds to inventory bridges for historic significance. The development of statewide programs is accelerating, encouraged in 1980 by Federal Highway Administration policies to promote completion of inventories. The issue of a bridge's historical significance was addressed in 1982 by the FHWA with a provision for a historical significance entry on the National Bridge Inventory.

The Commonwealth of Virginia has continued the initiative through the Research Council, and is nearing completion of its inventory of bridges built prior to 1932, assuming a national lead in surveying its bridges. Still, many more bridges need to be inventoried and in other states the situation is critical. In August 1981, the U. S. Department of Transportation published a summary of the status of the various states' inventories.

When these two pressing areas of federal regulations are coupled with the national focus on the need to strengthen or replace existing bridges, the implications are serious for state highway departments. Conflicting priorities create a tension between the issue of historical significance and replacement program needs. Often project planners do not appreciate the time required for traditional historical documentation research. Therefore, the capability to survey and document historic transportation sites efficiently and satisfactorily would best be located within the structure of state highway departments.

PURPOSE AND SCOPE OF RESEARCH

The purpose of this study was to evaluate the applicability and accuracy of documentation drawings prepared from close-range terrestrial photogrammetry and to compare them with the results of traditional documentation techniques. The research was organized to coincide with specific equipmental and software resources available within operating divisions of the Virginia Department of Highways and Transportation in order to examine the feasibility of carrying out such recordations when federal mandates require them. The only equipment not already available was the camera, which was purchased by the state subsequent to the recommendations of this research project. In addition to the production of documentation drawings from photogrammetric methods, the potential for additional applications of the photogrammetric data such as condition assessment, determination of member sizes, etc., were examined. This secondary phase of the study focused particularly on the potential to measure cross-sectional dimensions from the photogrammetric models. A more extensive report on the project was presented by the author as a master of science thesis at the University of Virginia School of Engineering and Applied Science.(2)

APPROACH TO RESEARCH

Case studies of a variety of sites were made. The specific cases examined were chosen to represent —

1. a cross section of transportation sites likely to be impacted by highway projects,

2. a selection of various types of materials and construction techniques which would test plotting capabilities, and

3. a wide range of field conditions which would test the photogrammetric procedure

Numerous sites were visited and studied, and the structures and objects listed in Table 1 and Table 2 were chosen to satisfy these requirements.

It was initially hoped that several prehistoric sites would be included in this study in order to test the applicability of these photogrammetric techniques to archaeological sites, but because of the lack of available archaeological sites affected by Virginia highway projects during the research period, it was not possible to include this category in the study. Subsequent to this research, the Virginia Department of Highways and Transportation has conducted several successful archaeological documentation projects under the direction of Fred Bales.

1966

Table 1

Transportation Structures

Material	Type	County/City	Route	No. Spans	Length, ft.*
Metal	Pratt Truss	Nelson	653	1	138
Metal	Thacher Truss	Rockingham	1421	1	133
Metal	Pratt Truss	Shenandoah	758	3	359
Concrete	Arch	Richmond	1 & 301	16	3,290 (arch spans)
Wood	Covered Truss	Alleghany	Nr. 60	1	108
Metal	Bedstead Pony Truss	Augusta	683	1	75
Concrete	Arch	Frederick	608	1	50
Metal	Bascule	Portsmouth		1	56
Brick & Wood	Beam	Nansemond	634	1	30

*1 ft. = 0.3048 m.

Table 2

Industrial and Historic Road Sites

Type	Material	County
Industrial Sites:		
Mill	Brick, stone, concrete	Prince George
River navigation lock	Random stone	Fluvanna
Crozet railroad tunnel	Cut stone	Augusta
Railroad culvert	Cut stone	Augusta
Historic Road Sites:		
Road trace		Albemarle
Road marker	Stone	Fluvanna
Bremo rest area	Stone	Fluvanna
White Post	Wood	Clarke

Phases of Research

The research was divided into several phases:

I. Data Acquisition

a) reconnaissance
b) photographic field work
c) field measurement

II. Data Reduction

a) photographic laboratory work
b) stereoplotting

III. Data Analysis

a) comparative documentation
b) dimensional information

Data Acquisition

Initially, it was necessary to find sites within the state which were appropriate for the study. Each of the numerous sites visited had to be evaluated before the photogrammetric field work was done. Considerations were:

1) accessibility of site

2) visibility of site, and necessity for preliminary preparation

3) orientation of site, and determination of optimal photography time

4) requirements for special equipment, and

5) determination of desirable views to be photographed

The second phase of data acquisition was the photographic field work. This part of the study was under the direction of Fred Bales of the Location and Design Division of the Virginia Department of Highways and Transportation and employed a state-rented metric terrestrial photogrammetric camera. Only the camera would not normally be available in a modern transportation department.* The essential steps in the field were —

1) placing targets (reference points) on the object,

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*Based upon the results from this study, the Virginia Department of Highways and Transportation subsequently purchased the camera.

2) setting up camera stations on a line parallel with the object

3) photographing the object, and

4) recording distances between targets and elevations of discrete points on the object.

(Field information on individual sites is given in the Appendix.)

The third phase of data acquisition was the field measurement of several structures. The structures chosen were representative of the problems encountered in this type of field work. Areas to be measured were, for the most part, inconvenient to reach; sometimes it was impossible to reach an entire portion of a structure. Wading through streams, climbing on bridge members and abutments, and precariously positioning one's self for reading a dimensional measurement add time and the potential for inaccuracy to these measurements. Sites located in urban areas add the additional inconvenience and danger of vehicular traffic.

Standard tools were used for these measurements, namely, rules, steel tapes, and calipers.

Data Reduction

The exposed photographic plates were taken to the lab for development. The results were positive prints on transparent material, or diapositives, which were positioned between two glass plates for use on the stereoplotter. The objects were delineated from a three-dimensional model created by viewing the two images simultaneously.

The plotting of the objects from these films initially proved to be time-consuming because the stereoplotting technicians were unaccustomed to this sort of "mapping." Until this project, the stereoplotting machines had not been used for close-range photogrammetric mapping. It was necessary to work with the stereoplotting technicians on several of the sites to clarify what information was to be conveyed on the "map", or plotted drawing. This problem of unfamiliarity corrected itself when a second attempt at similar sites was executed.

Data Analysis

The drawings emerged from the stereoplotter in rough form. Some were left in this rough stage and some were sent to the drafting section for refinement. The drawings were prepared to illustrate the development of a photogrammetric drawing. Each stage in the drawing process is represented in the presentation of photogrammetrically produced documentation drawings.

Several site drawings were then chosen to be closely studied and compared with results of the traditional hand measured method.

In addition to examining the potential for accurately and acceptably documenting structures by photogrammetric techniques, the potential to make broader applications of the photogrammetric field work was examined. Once the field work was completed, a three-dimensional record of the structures studied was on file for reference. Additional information which might be needed in the future could potentially be derived from the photogrammetric plates. For example, an extremely time-consuming element in the field inspection of structures, particularly of metal truss bridges, is measuring the cross-sectional area of individual members. To test the potential of using the photogrammetric method for this type of measurement, several sites were chosen for close analysis of the dimensional accuracy. The thickness of random areas of the structures was measured photogrammetrically and by hand. The photogrammetric dimensions were obtained from the same models used for the documentation drawings, with no additional preparation of the sites. Elevation readings of the points in question were made and compared with hand measurements of the same points to determine the accuracy of reading dimensions of depth from photogrammetric models.

ADDITIONAL APPLICATIONS OF THIS RESEARCH

While in the evaluation emphasis was placed on structures and objects of the type likely to be impacted by proposed transportation projects, the concept is applicable for many other types of structures, such as dams, power plants, and buildings, and has in fact been used for such documentation of a variety of objects.[3,4] Recordation is only a small facet of potential photogrammetric applicability; not only is it possible to document existing intact structures but damaged structures of potential historic significance can be accurately recorded without resorting to approximate methods. This is particularly significant for structures made of nonstandard components. Several of the sites chosen for this study verify this assumption.

Of course, photogrammetric study is not restricted to historically significant sites. The present emphasis on bridge replacement and rehabilitation forces examinations of the load-carrying capacity of older bridges which may not necessarily be historically significant. The photogrammetric acquisition of data essential for structural analysis would have numerous advantages over tedious field measurement.

Close-range terrestrial photogrammetry can also have obvious uses in modern structural failure analysis. Since measurements are not restricted to a finite number of points moving only in one component of direction, it is possible to measure deformation in walls or individual members from the perspective of the whole structure. Suspect structures could be monitored without the use of strain gages. Also, initial field examination of damaged structures due to be reconstructed could be supplemented in the office with detailed examination of the photogrammetric studies.

These additional applications are beyond the scope of this research project and are being addressed in another Virginia Highway and Transportation Research Council study, in which the measurement of deflections by close-range photogrammetric analysis is being evaluated.(5) However, the field methods developed in this study and the determination of the system's accuracy are relevant for other applications.

ESSENTIALS OF PHOTOGRAMMETRIC DOCUMENTATION

Introduction

Photogrammetry is defined as the science of taking measurements from photographs. The term "photogrammetry" was first used in 1855 by a European geographer.(6) The naming of this science coincided with the beginning of rapidly accepted photogrammetric experimentation in Europe.

Although photogrammetric applications were not widely used until the late nineteenth century, the principles involved were understood in the Renaissance. Practical field applications awaited the development of photographic equipment. In the 1800's optical prisms replaced the pinhole camera, fixing solution was found to keep photographic images from fading, light sensitive negatives were used, and a stereoscope was made.(7) With the capability to permanently reproduce an image photographically, photogrammetric field applications quickly emerged, both on land and in the air.

The field of photogrammetry is still broken down into two broad divisions: aerial photogrammetry and terrestrial photogrammetry. The most commonly recognized modern use of photogrammetry traditionally has been topographic mapping. In the past few decades, however, the application of photogrammetric techniques has ranged widely from macroscopic to microscopic measurements. A division within the terrestrial photogrammetry category has developed to accommodate the need for microscopic measurements. Close-range terrestrial photogrammetry applies to objects up to 300 meters (984 ft.) from the camera station while terrestrial photogrammetry handles distances greater than 300 meters (984 ft.).(6)

Close-range terrestrial photogrammetry is widely applicable in today's highly technical world. Within the last decade many research projects have been done showing the feasibility of using close-range terrestrial photogrammetric techniques in "micro" measuring such things as widely varied as rock deformations in mines and craniofacial mapping of bones, teeth, and soft tissue. In general, there are three broad categorizations of close-range applications: architectural, biomedical, and industrial photogrammetry.(6) Architectural photogrammetry can be traced back to the beginning of the discipline; the others are new developments.

Close-range terrestrial photogrammetry has been satisfactorily used to study architectural monuments throughout Europe from the mid-nineteenth century. Among the numerous modern European studies is a French project of the 1970's in which the extremely detailed facades of historic churches were closely examined through stereophotogrammetry.(4) Within the past few decades documentations of architectural monuments have been made in the United States. In 1977 the National Park Service Office of Archeology and Historic Preservation produced a guide to photogrammetric recording of resources.(3) Several examples of photogrammetrically recorded architectural sites are illustrated in that publication.

The use of close-range photogrammetric procedures for architectural surveys, then,is widely recognized. The 1980 edition of the American Society of Photogrammetry's Manual of Photogrammetry states: "More recently, the field of architectural application of photogrammetry has undergone considerable expansion both in scope and diversity." Types of architectural surveys possible using these techniques are listed as —

1) rapid and relatively simple,

2) accurate and complete, and

3) very accurate.(6)

The rapid and relatively simple surveys provide sufficient information for historical inventories and other preliminary studies. Accurate and complete surveys provide information that is much more detailed than the first type. This type of information would be necessary to document intricate details and areas of deterioration on historical structures. Very accurate surveys require accuracy in the order of 0.1 mm (3.9×10^{-3} in.) to 1 mm (3.9×10^{-2} in.). Only very close investigation of surfaces or movement would warrant such detailed study.

Producing Photographs of the Sites

The photographic work for non-topographic, architectural, or structural photogrammetry projects can be done with either metric or non-metric cameras, the difference being that metric cameras are designed specifically for use in photogrammetry. Metric cameras can be either single or stereometric. The former is composed of two main parts, a mount to support the camera and a tilting metric chamber, which are separable for ease of transport and designed for easy attachment to a tripod. The stereometric camera consists of two cameras separated by a bar and attached to a tripod as a unit. The camera available for this project was a Zeiss Jenoptik UMK 10/1318, a single metric type. The focal length of this camera is 99 mm. (3.90 in.) and the film used is 13 cm. (5.1 in.) x 18 cm. (7.1 in.) x 1.5 mm (0.06 in.) glass plates, type B Kodak tri-x panchromatic plate. Glass plates are used to avoid the image distortion, through temperature changes and shrinkage associated with film.

Three types of photographs are used in photogrammetric studies, as defined by the camera and object orientation. When the optical axis, or camera axis, is vertical, the photographs are vertical, and when the optical axis is horizontal, the photographs are horizontal. When the optical axis deviates from being either horizontal or vertical, the photographs are oblique; they can be low oblique (small angle) or high oblique (large angle) photographs.

All three types of photographs were made in this study. Vertical photographs taken from a cherry picker were used for plan views and horizontal photographs on the ground were used for elevation views. The several oblique photographs taken while documenting elevations would require restitution using special universal or analytical stereoplotters to make accurate representations of the objects photographed. The restitution process was outside the current equipment capabilities of the department. A limited number of oblique photographs were taken in the event that such equipment might subsequently become available. All vertical and horizontal photographs, however, were easily handled on available equipment.

Stereoplotting the Sites

The delineation of the objects from these horizontal and vertical photographs is executed from a mechanically reproduced, three-dimensional image of the object. In order to create a three-dimensional model of the object to be studied a pair of photographs, or a stereopair, of the object is taken. When these two photographs are aligned in the stereoplotting machine in a way that reproduces the relationship of the camera field stations precisely, the object can be viewed in three dimensions and an accurate reproduction can be made. To align the photogrpahs correctly it is necessary to know where the optical axis for each photograph was located at the time of photography. The optical axis passes through the center of the lens and is perpendicular to the image plane. This point of intersection between the optical axis and the image plane is the principal point. It is not automatically obvious on the negative or film positive. For this reason four fiducial marks are photographically recorded on the image at the moment of exposure, and the principal point is the intersection of these four marks when opposite marks are connected.

When film positives, or dispositives, of the object are used, as was the case with the system available for this project, the principal points are located and centered on the plate holders, the focal length of the camera is reproduced in the instrument, and the space coordinates of the two camera stations are reproduced on the instrument.

For this project the plotting of the objects was done on a Galileo Officine Stereosimplex G5 stereoplotting instrument. A "freehand" planimetric compilation from the model was executed by means of a linear pantograph operated by the stereoplotter while examining the model through the binocular viewer. The pencil on the pantograph is automatically depressed and moved by controls on the main body of the instrument. Various scales of drawing which magnify the photograph scale are possible by manipulation of the pantograph triangulation.

When viewed through the binocular viewer of the stereoplotting instrument a three-dimensional image of the object is observed. Within the field of vision of each eyepiece is a black dot. When the controls are manipulated to fuse these two dots, both dots mark precisely the same point on the respective photographs and the dot that results appears to float as it is moved over the surface plane. It is the movement of this floating mark over the object plane that is recorded on the plotted drawing. The point of the pantograph and the floating mark correspond to the same point on the object model. In the same way spatial coordinates on surfaces of the model can be determined by manipulations of the mark.

Just as binocular vision allows depth in the field of vision when compared with monocular vision, stereophotographing an object allows three-dimensionality in the image reproduction. This is accomplished by fusing two separate but overlapping perspective images into one three-dimensional representation of the object. Thus, to reproduce a three-dimensional image of the object photographed it is necessary to overlap photographic coverage of the object. A model of the object, or portion of the object, is then created in the stereoplotter using the two overlapping photographs. Generally, there is a 60% overlap of the areas on sequential photographs.

This requirement for overlapping photographic coverage determines the number of photographs necessary at each site.

EXECUTED DOCUMENTATION DRAWINGS

As stated previously, the techniques used for this study were confined to those which could be accomplished using equipment and expertise available within the Virginia Department of Highways and Transportation.

The reduced drawings which follow show the variety of structure types and site conditions chosen for the study. Information sheets discussing the peculiarities of photographing each site are contained in the Appendix. The drawings are of the planimetric rather than the topographic type. Because the type of photogrammetric projects was quite different from that required for topographic mapping, the resourcefulness of the stereoplotting technicians was important. It was necessary for the research personnel to work closely with the stereoplotting technicians to communicate what the drawing should illustrate and how they should delineate certain portions of a few structures. The preparation and plotting time for these drawings was affected considerably by the unfamiliarity of the technicians with close-range mapping techniques.

It was decided to document the existing condition of the structures involved in this study to test (1) the resulting documentation of material deterioration and structural condition, and (2) the limits of the accuracy of the photogrammetric method. In the event that "as-built" drawings of a structure were preferred rather than "present condition" drawings, the documentation drawings produced to show existing condition could be altered. It would be an easy task to remove documented knicks and bends and replace missing material on the accurately dimensioned photogrammetric drawing.

The drawings included in this section of the report illustrate various stages in the compilation of the documentation drawings.

The structure documentation first emerges in roughest form from the stereoplotter's delineation of the three-dimensional photographic model. Several drawings illustrate this initial stage. The very light pencil lines made by the stereoplotting instrument are defined next by the simple application of an ink outline. Some drawings need to have surfaces clearly delineated with a straightedge at this point. Several drawings illustrate this intermediate stage. Finally, the stereoplotted drawing goes to the draftsman for refinement. Several drawings illustrate this final stage. A case-by-case evaluation of these drawings will show advantages and disadvantages of this system.

Bremo Stone Marker

The stone road marker on the Bremo estate marks an early Virginia road. It is located in Fluvanna County at the fork of a dirt road and is practically hidden by trees and shrubs. It is one of a small number of early road markers remaining in Virginia.

The nearly 4-foot tall marker is chipped, pockmarked, and weathered, which gives its surface the very rough appearance captured by the stereoplotted drawing (see Figure 1). All lines follow the precise contours of the marker. Planar surface changes are shown where the large chips appear. The lettering lines show exactly what is carved in the stone and the ground line literally follows the ground.

This drawing is an example of a literal representation of an object and illustrates the initial stereoplotted drawing of an irregularly shaped object. From this bare minimum delineation of the marker, the drawing would next go to a draftsman for a refinement of the rendering.

The photographic field work was straightforward, with only minor clearing of the site being necessary. Two photographs were exposed, making it necessary to use only one stereoscopic model to plot this site.

White Post

This wooden road marker was built in 1921 to replace the original, which was erected in 1751. It is in remarkably good condition and is located at the intersection of two secondary roads, on the road proper, in Clarke County.

1076

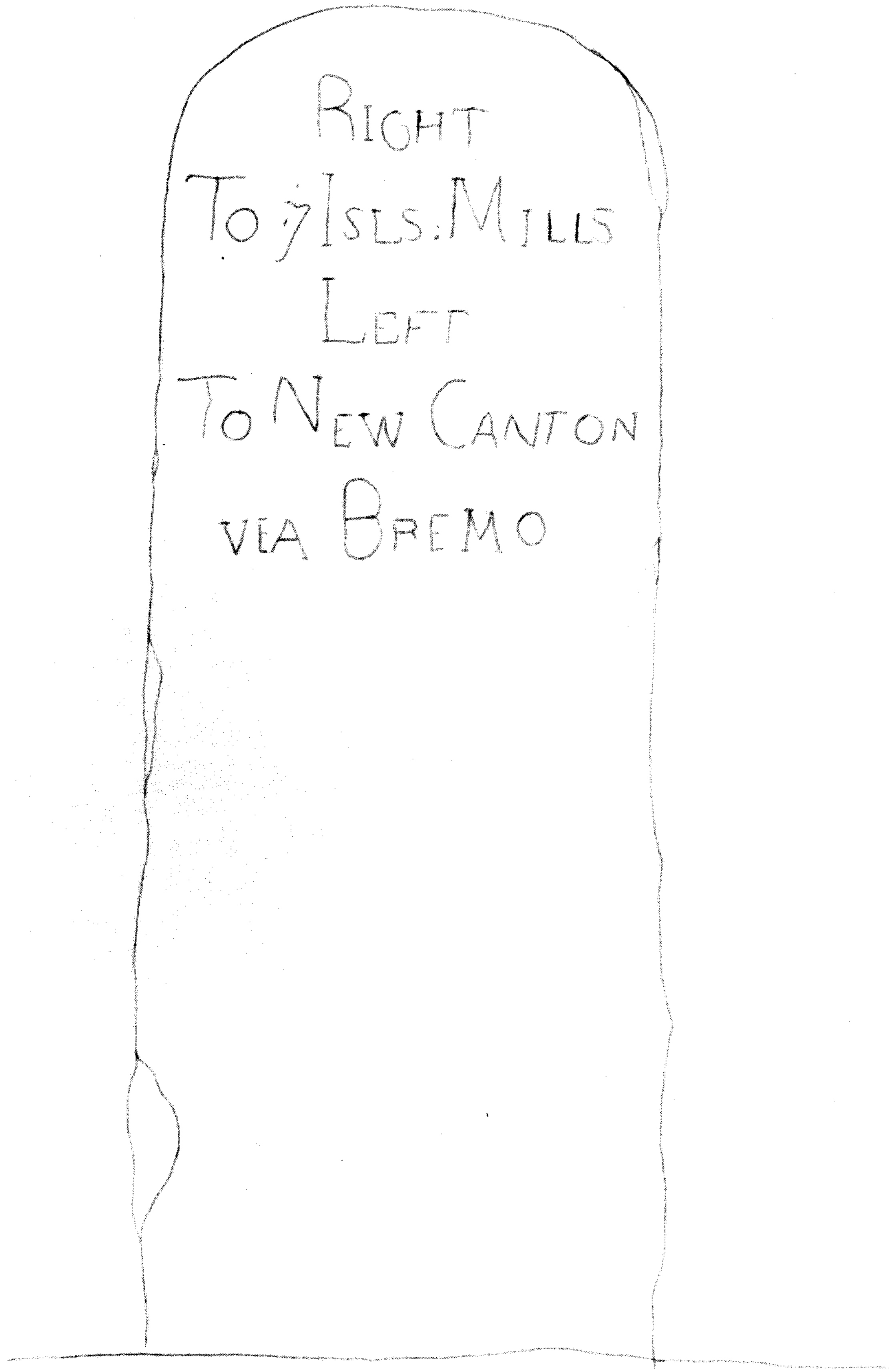

Figure 1. An early stage photogrammetric documentation drawing of the Bremo Stone road marker.

The outline of this object was rectilinear and very regular, and it was plotted with the aid of drafting triangles. This drawing is another example of a first stage photogrammetric documentation drawing (see Figure 2). It has come directly from the stereoplotter without refinement by a draftsman.

The photographic field work was straightforward, with no clearing of the site required. Conditions were perfect and the field work was completed in 20 minutes.

Masonry Culvert

The small masonry culvert shown in Figure 3 is located about a mile west of the Crozet railroad tunnel in Augusta County, under the same railroad bed. It is a carefully constructed, highly detailed structure for a simple culvert, with rusticated masonry, a carefully defined arch, carved keystone, and curving coping stones.

The site is easily accessible from a major highway. It was overgrown with vines and needed considerable cleanup work, but the photographic work was straightforward and was completed in 1½ hours. Site conditions required coverage of the structure with four photographs and two models. This was necessary, despite the small scale of the structure, because the area immediately behind the camera station line was thick with trees and the work was done at a closer than optimal range.

Figure 3 illustrates a drawing barely beyond the initial stage of stereoplotting. A few edges (for example, the keystone, the ledge at the spring point of the arch, and the coping stones) have been defined with a straightedge. The drawing would next be sent to a draftsman for refinement.

The unfamiliarity of the stereoplotting technicians with planimetric representational drawings is well characterized by this example. A quick examination of the coping stones shows the confusing representation of missing areas of stone and odd looking joint lines in the horizontal stones. The joint lines on the upper face appear vertical because these lines recede in space directly behind the joint lines on the front face. When the floating mark of the stereoplotting instrument follows the surface of these joints it moves straight back and the linear representation of that receding movement is a straight vertical line. These problems are not serious, however, as they could be rectified by the draftsman in the refinement of the drawing.

This structure was chosen for detailed comparative analysis and will be discussed in greater depth in the next section.

1978

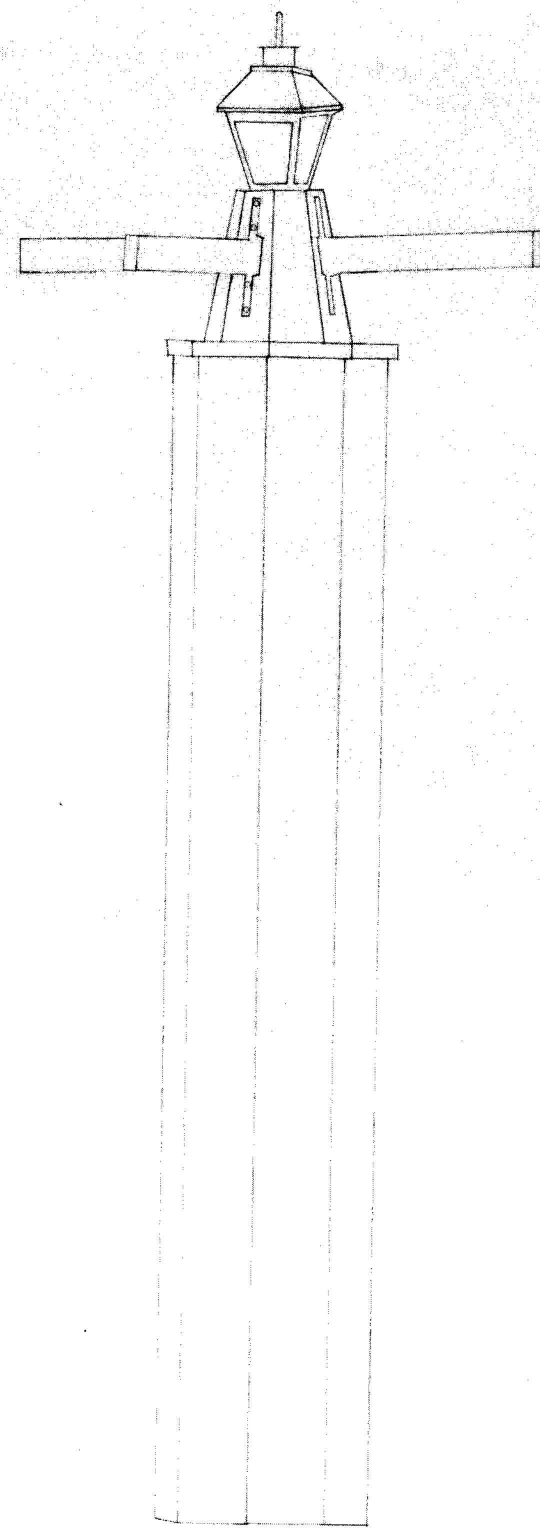

Figure 2. An early stage photogrammetric documentation drawing of the White Post road marker.

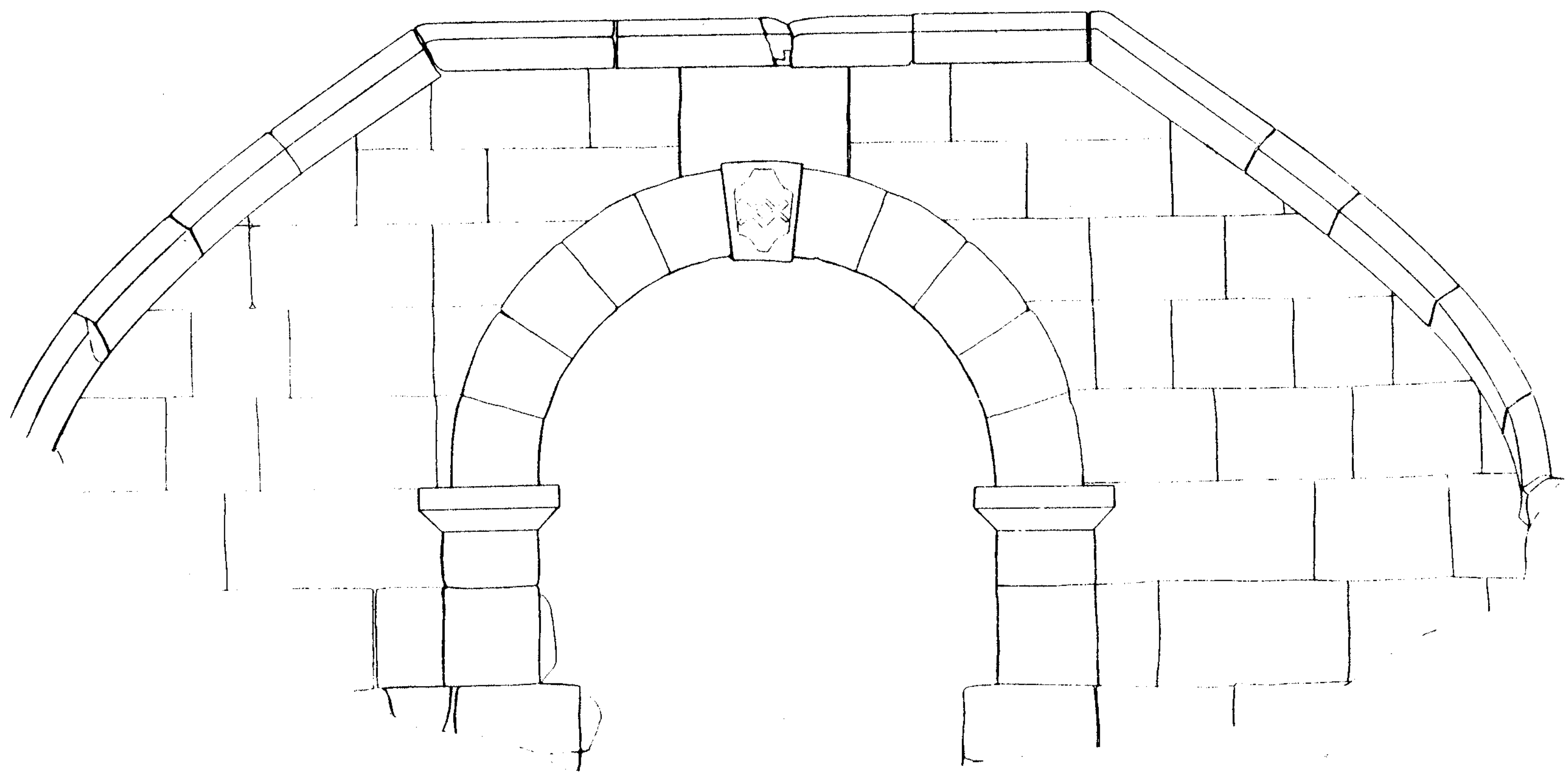

Figure 3. An early stage photogrammetric documentation drawing of a masonry arch culvert.

Rivanna River Navigation Lock

This structure was uncovered at the site of a bridge replacement project. It is a nineteenth century stone masonry navigation lock on the Rivanna River in Fluvanna County.

The aerial view of the extant portion of the lock was photographed from the existing bridge when the water level was low and most of the existing structure was exposed. The remaining parts of the timber gate are shown, as well as the exact location of all stones. This capability to precisely locate irregularly shaped objects without the use of field measurement and surveying techniques is a most useful application of close-range terrestrial photogrammetry, particularly for the documentation of archaeological sites.

The Rivanna River lock drawing illustrates the initial stage of photogrammetric documentation wherein all parts of the structure have been delineated (see Figure 4). The drawing would be given to a draftsman for definition of edges and refinement of the drawing.

Luten Concrete Arch Bridge

This simple, one-span concrete bridge located in Frederick County, is of a type designed by Daniel Luten, and is typical of a number of small span highway bridges built throughout the United States in the early years of the twentieth century.

The structure is clearly delineated. Projecting surfaces are obvious from the perspective of the model view and the relationship of angled wing walls to the bridge structure is clear.

The Luten arch bridge drawing is an example of a well developed intermediate phase drawing (see Figure 5). Surfaces have been very clearly delineated in the application of ink outlines. Differentiation of planes and surfaces by varying line weights would be executed by the draftsman in the final refinement stage.

Pratt Truss Bridge

This bridge was built in 1882 and is one of the oldest metal truss bridges in Virginia and is listed on the National Register of Historic Places. It is located in Nelson County over the Southern Railroad. Metal truss bridges are comprised of steel or iron components riveted together to make individual members, which are often connected at the panel joints by nuts and bolts. Because of this intricate configuration the advantages of photogrammetric documentation of structures can be seen clearly in metal truss bridge examples. In this drawing the location of all rivets and the configuration of all joints is delineated precisely.

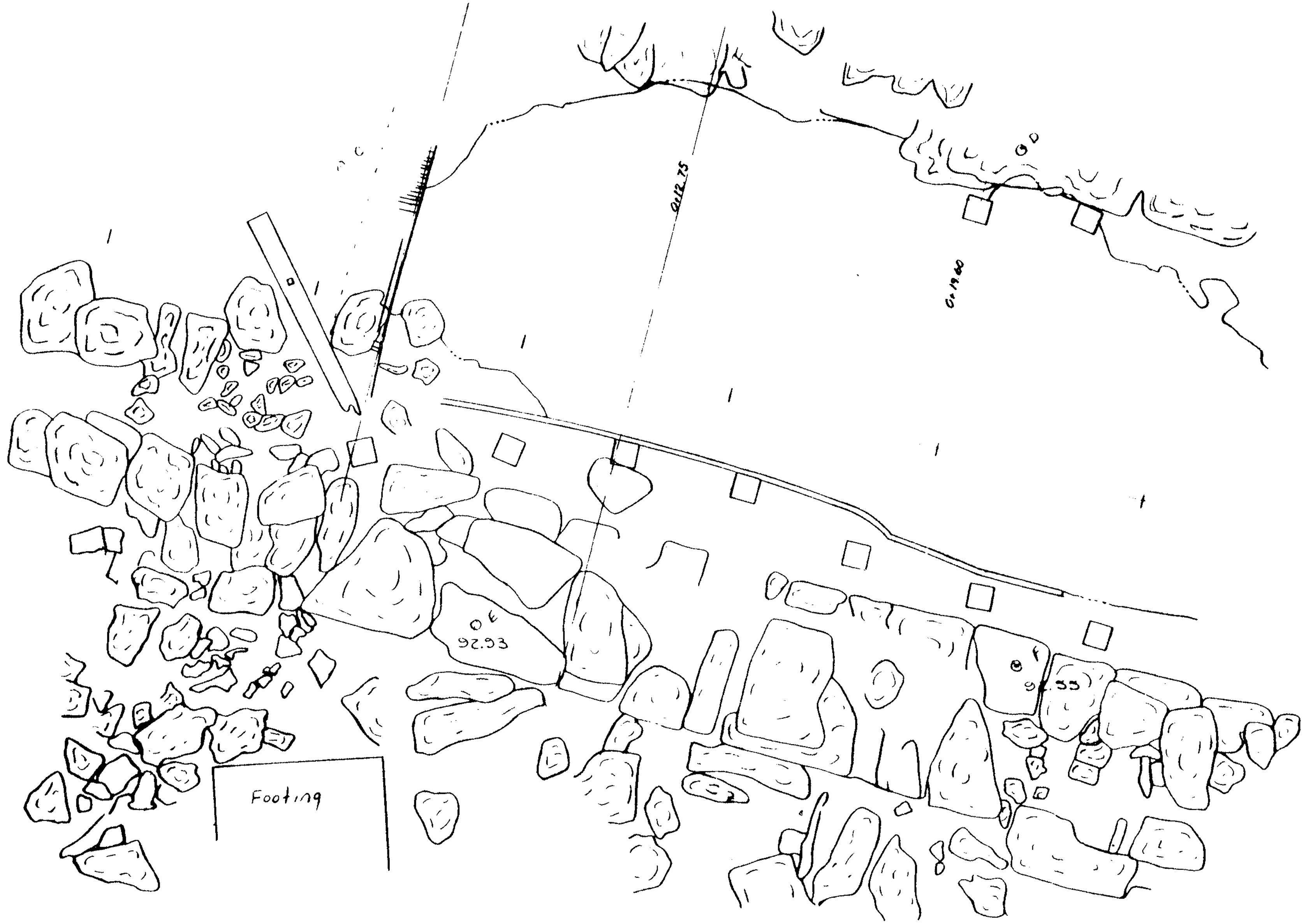

Figure 4. An early stage photogrammetric documentation drawing of a Rivanna River navigation lock.

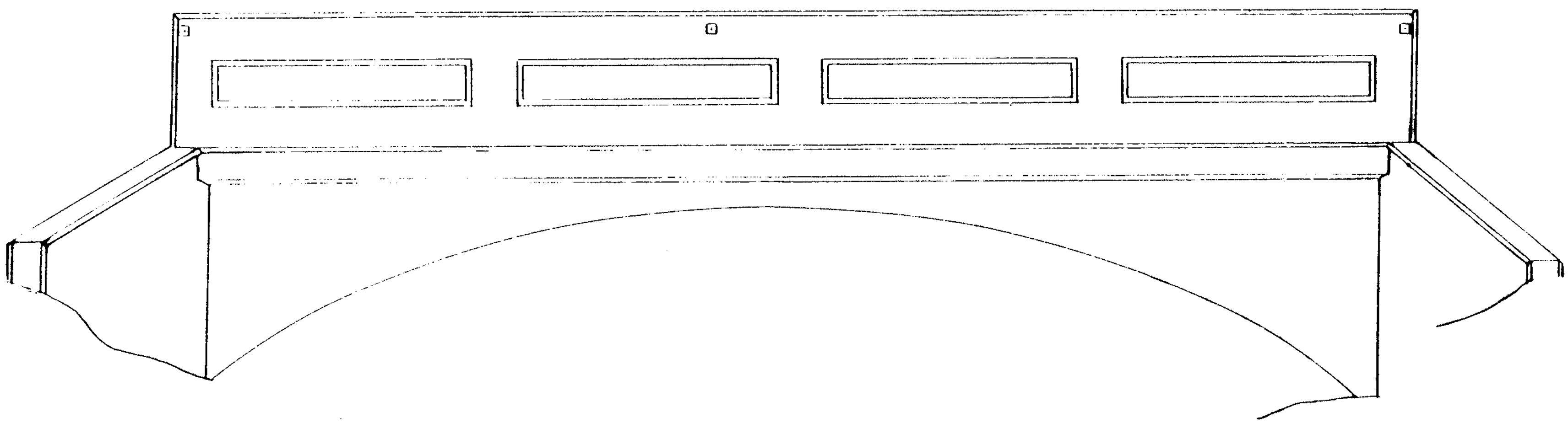

Figure 5. A late stage photogrammetric documentation drawing of a Luten concrete arch bridge.

The Pratt truss bridge drawing is an example of an early final stage drawing (see Figure 6). All truss members have been delineated and the process of edge definition has been started. Additional definition by varying line weights would next be added by the draftsman.

Thacher Truss Bridge

This bridge, built in 1898, is the only Thacher truss in Virginia and is listed on the National Register of Historic Places. It is located in Rockingham County over the Linville Creek.

Several views of this bridge were photographed: a side elevation, an elevation of the portal end, and a close-up detail of the L-3 joint connection. (This joint designation uses the conventional engineering system of numbering where U = upper chord connections, L = lower chord connections, and the sequence begins with 1 at the left side.) Each is presented at a different scale, showing the amount of structural detail possible by varying parameters in the field and in the lab. The decision as to how much detail is necessary depends on the requirements of the documentation. The advantages of a photogrammetric documentation of historic structures are highlighted after close examination of these three views. All cables, rivets, pins and other components are precisely located on the structure. Locating all these by hand would take far more time, ingenuity, and agility than was required for the photogrammetric field work on this bridge.

This site required clearing foliage in order to expose end posts and bearings; it also required maneuvering around barbed wire fences and through a shallow stream to set up the camera stations. All of these are typical problems encountered when documenting historic transportation structures.

The Thacher truss drawings represent different stages in the photogrammetric documentation process (see Figures 7, 8, and 9). The elevations of the side and portal have been defined with a straightedge and outlined with ink. A further refinement of these two views by a draftsman would be required. The joint detail drawing is a final stage documentation drawing which has been refined by a draftsman. The level of detail illustrated on this view (threads are visible on bolts) would be especially helpful in the rehabilitation analysis of a bridge or the reconstruction of transportation structures.

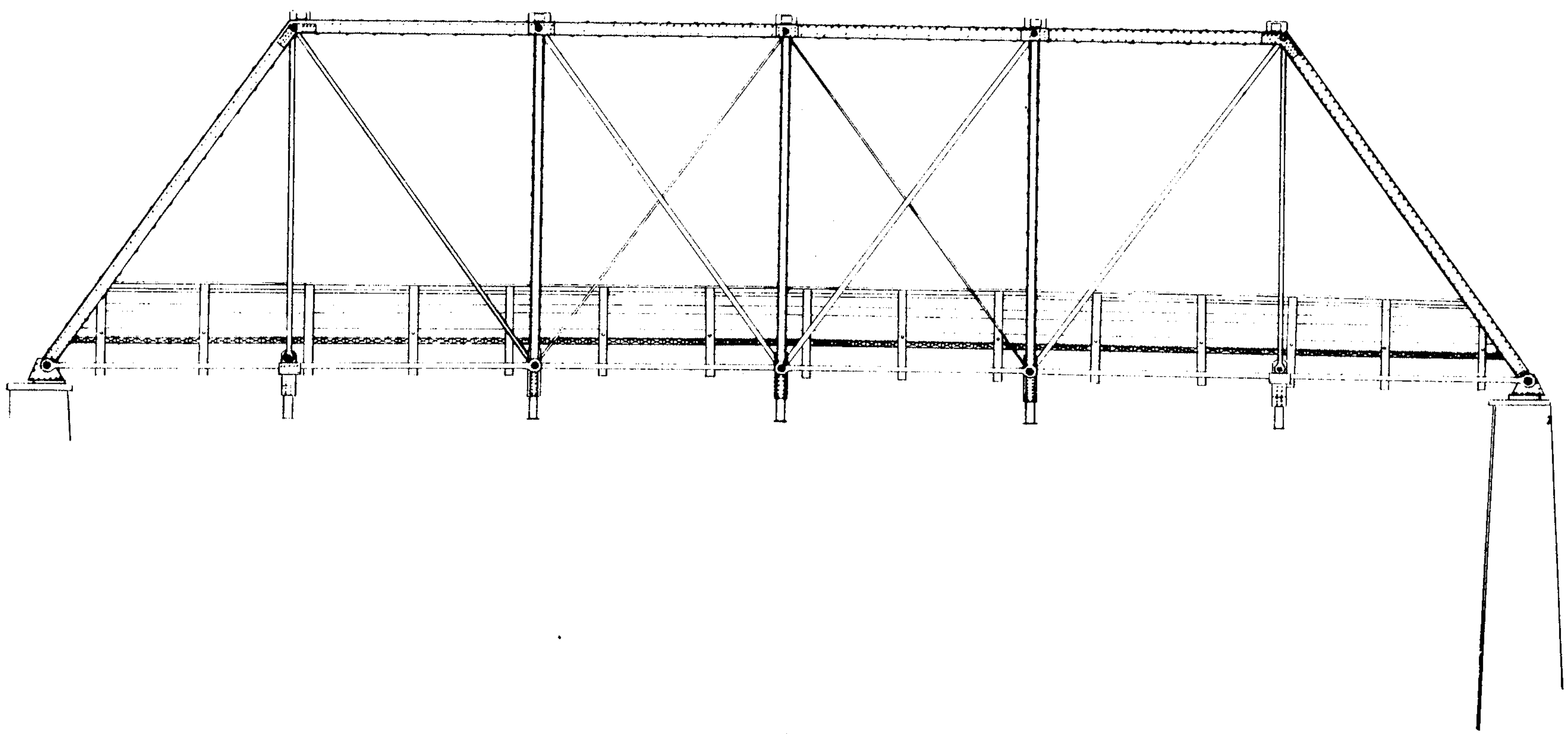

Figure 6. A late stage photogrammetric documentation drawing of the Nelson County 1882 Pratt truss bridge.

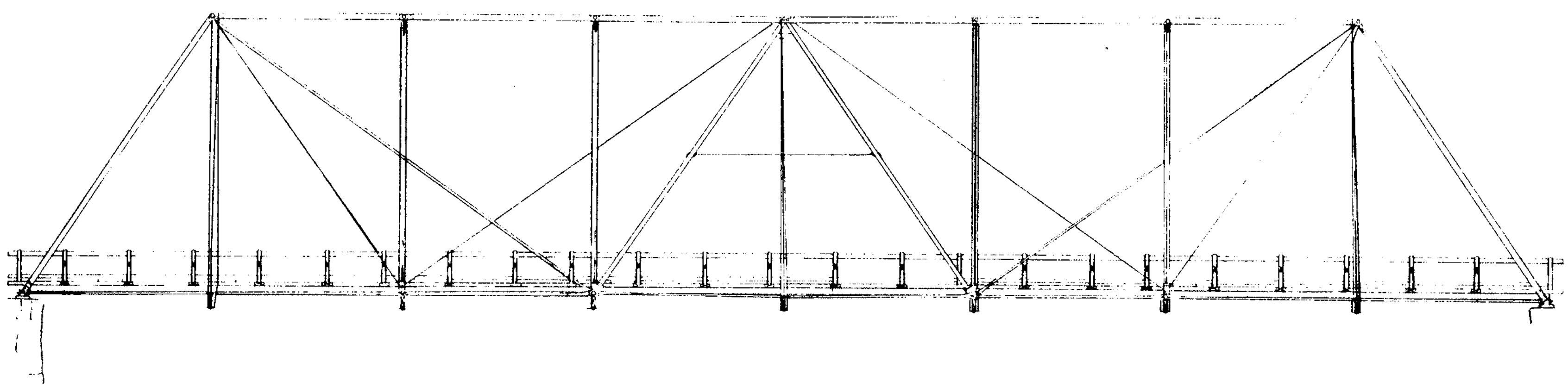

Figure 7. An intermediate stage photogrammetric documentation drawing of Virginia's only Thacher truss bridge, built in 1898.

1986

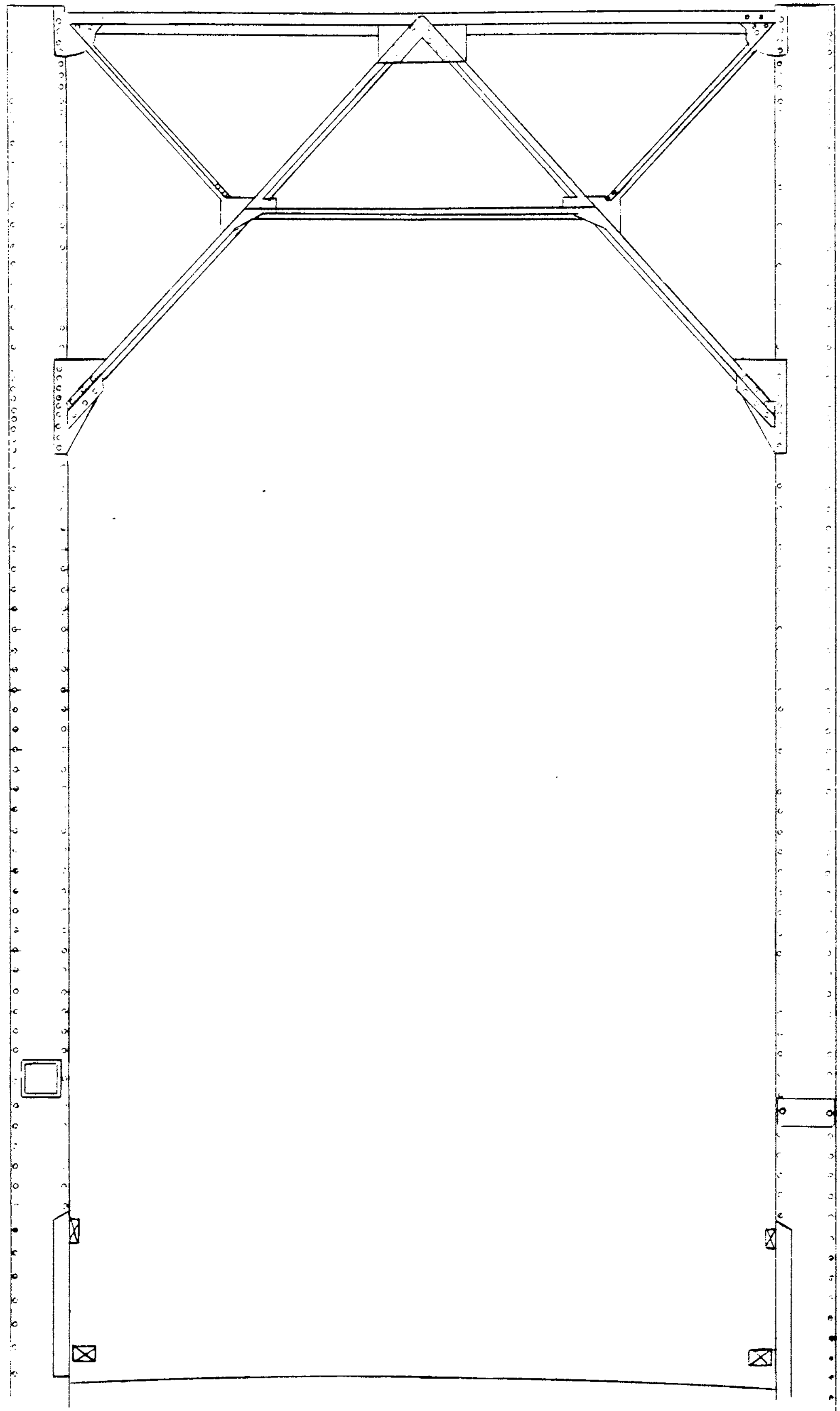

Figure 8. An intermediate stage photogrammetric documentation drawing of the portal view for the Thacher truss in Figure 7.

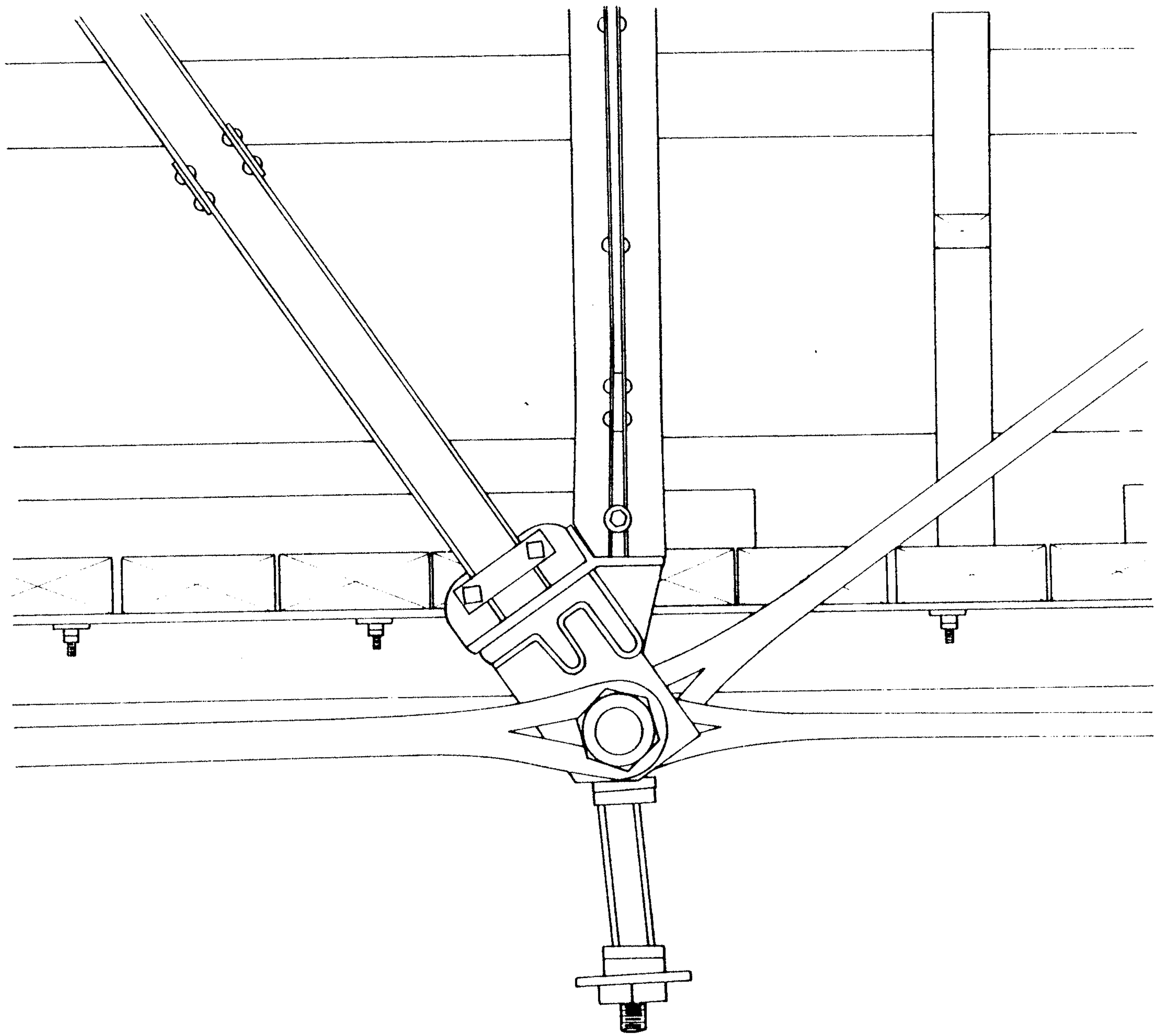

Figure 9. A final stage photogrammetric documentation drawing of a joint detail from the Thacher truss in Figure 7.

Bedstead Pony Truss Bridge

The Augusta County bedstead pony truss bridge is one of the few remaining true bedstead truss bridges in Virginia. The date of its erection is undocumented since the bridge date plate is missing, but the manufacturer is identified as the Champion Bridge Company of Wilmington, Ohio.

Two elevation views and a very close-range joint detail view of L-1 were photographed. (This joint designation L-1 uses the conventional engineering system of numbering where U = upper chord connections, L = lower chord connections, and the sequence begins with 1 at the left side.) As with the Thacher truss bridge documentation, each view was presented at a different scale, showing the potential for illustration of detail by this method. All components of this bridge are accurately represented as they appear; i.e., the rivets, turn buckles, bolts are exactly located. An attempt has been made on the portal view elevation drawing to illustrate the precise location of corroded areas. The photogrammetric method of documentation has the advantage of not only pinpointing these areas and details but of storing this information for future reference. A detail which might seem irrelevant at the time of field inspection may be overlooked on first inspection. With photographic plates storing all views of the structure, necessary details can be recovered by a stereoscopic inspection in the office.

The bedstead truss documentation drawings illustrate intermediate stages of the photogrammetric documentation process (see Figures 10, 11, and 12). The elevation of the entire structure represents a slightly more refined stage, where the structure has been delineated in ink and further defined with a straightedge, and some line weight variation has begun. The portal elevation and the joint detail views are examples of drawings which have been delineated by a straightedge and ink, with no accentuation treatment by a draftsman, as was done in Figure 9.

The bedstead truss bridge was chosen for the comparative analysis and will be discussed in greater detail in the next section.

Hodges Ferry Bascule Bridge

The Hodges Ferry bridge is located in Portsmouth. It is comprised of beam spans and one bascule span which is one of the few remaining movable spans in Virginia. It is also the only Scherzer rolling lift highway bridge known to remain in the state.

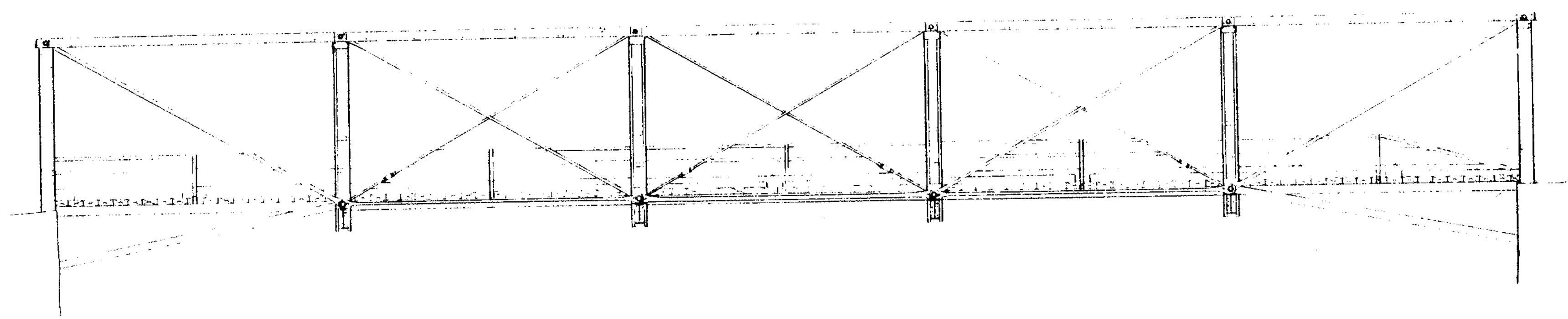

Figure 10. An intermediate stage photogrammetric documentation drawing of a bedstead pony metal truss bridge.

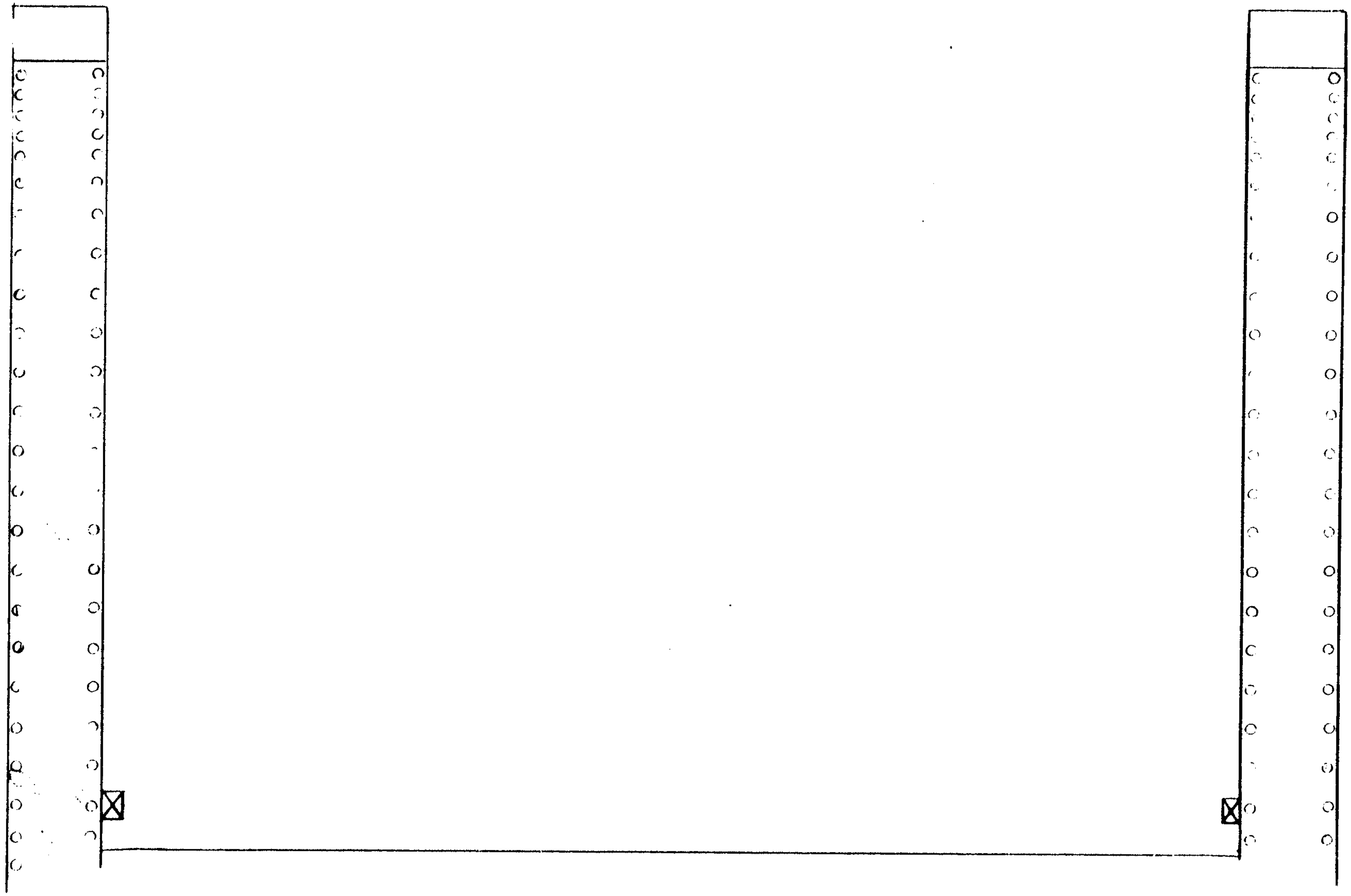

Figure 11. An intermediate stage photogrammetric documentation drawing of the portal view of the bedstead truss bridge in Figure 10.

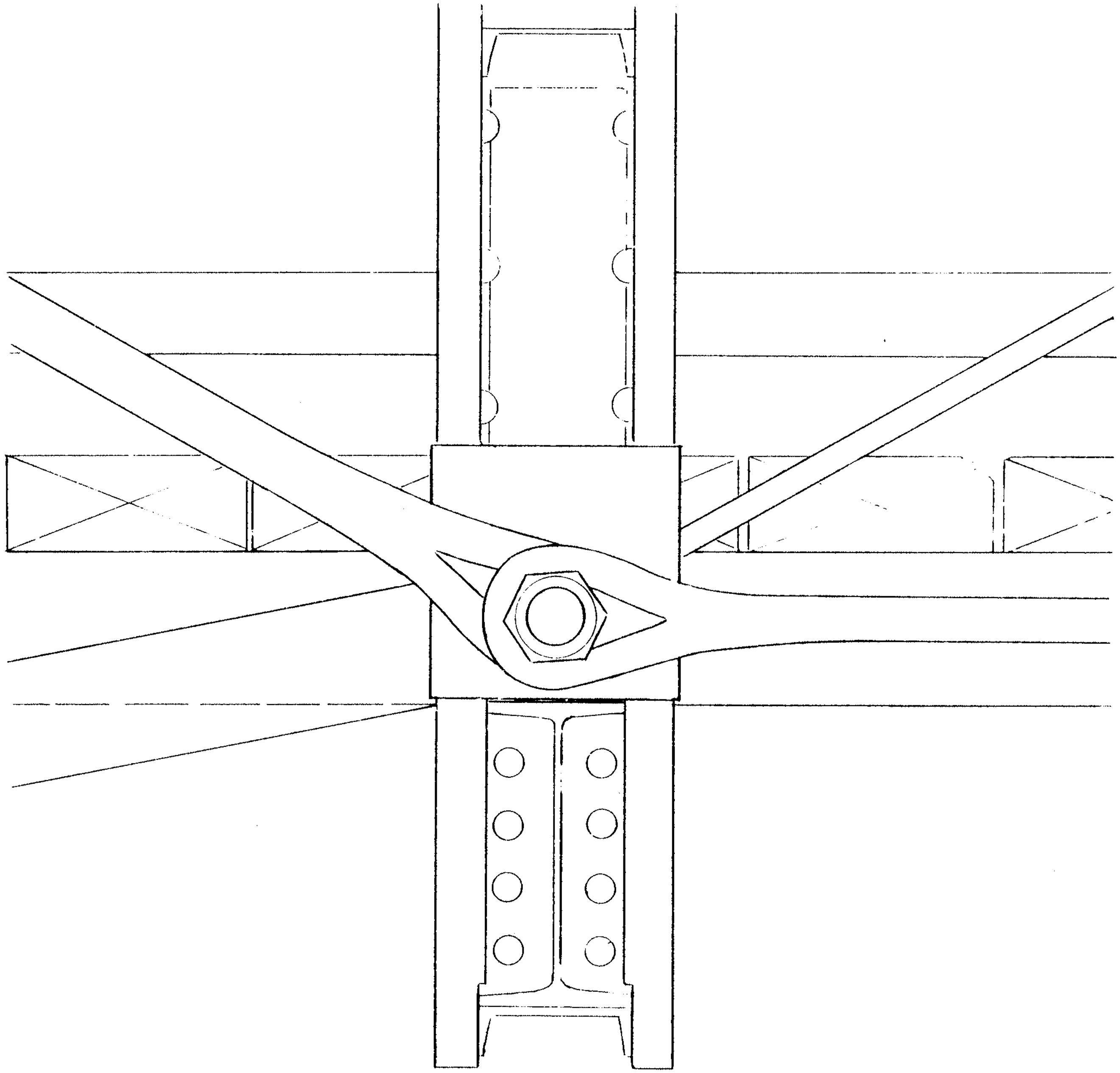

Figure 12. An intermediate stage photogrammetric documentation drawing of a joint detail from the bedstead truss bridge in Figure 10.

The Scherzer rolling lift portion of the Hodges Ferry bridge was chosen for the photogrammetric study. Two views of the bascule are illustrated in this section. Figure 13 is an elevation of the entire lift span photographed from a boat at rest in the river. Figure 14 is a close-range view of the moving portion, which consists of a circular, segmental, built-up girder, a counterweight, track, gears, and chain. It was photographed from the bridge deck.

Both drawings illustrate the second stage of photogrammetric documentation drawing, where edges have been outlined and clearly defined with straightedges. The drawings would be given to a draftsman for further refinement as the last stage in the documentation of this portion of the bridge.

Site conditions are hazardous for this bridge, which is located in a congested suburban area. The dangers are twofold: vehicular traffic is heavy and areas of this section of the bridge are difficult to reach. The photographic field work was completed within 1/2 hour. Hand measurements of all the intricate details of this mechanism would be far more precarious and time-consuming and probably impossible. Consider what would be involved in order to obtain hand measurements information to produce a dimensionally correct drawing like Figure 14.

The Hodges Ferry bridge rocker arm portion (Figure 14) was chosen for comparative analysis and will be examined in greater detail in the following section.

Lake Cohoon Bridge

The Lake Cohoon bridge, located in Nansemond County, is a nineteenth century wooden deck bridge on brick abutments and wing walls. It was not originally included in the structures to be studied in this project. It reemerged from the middle of Lake Cohoon in the summer of 1980 during the severe drought of that year after having been submerged since construction of the adjacent dam in 1915.

The unusual circumstances of recording this site highlight some advantages of the photogrammetric documentation method. The exposure of this site was time-dependent since a change in weather conditions would submerge the bridge again in Lake Cohoon. With only a few hours of field work all the data necessary to record the structure were obtained. The small structure took longer to document than was expected because site conditions were unstable. The lake bed was composed of silty mud and was extremely difficult to maneuver in and the weather was unpredictably rainy.

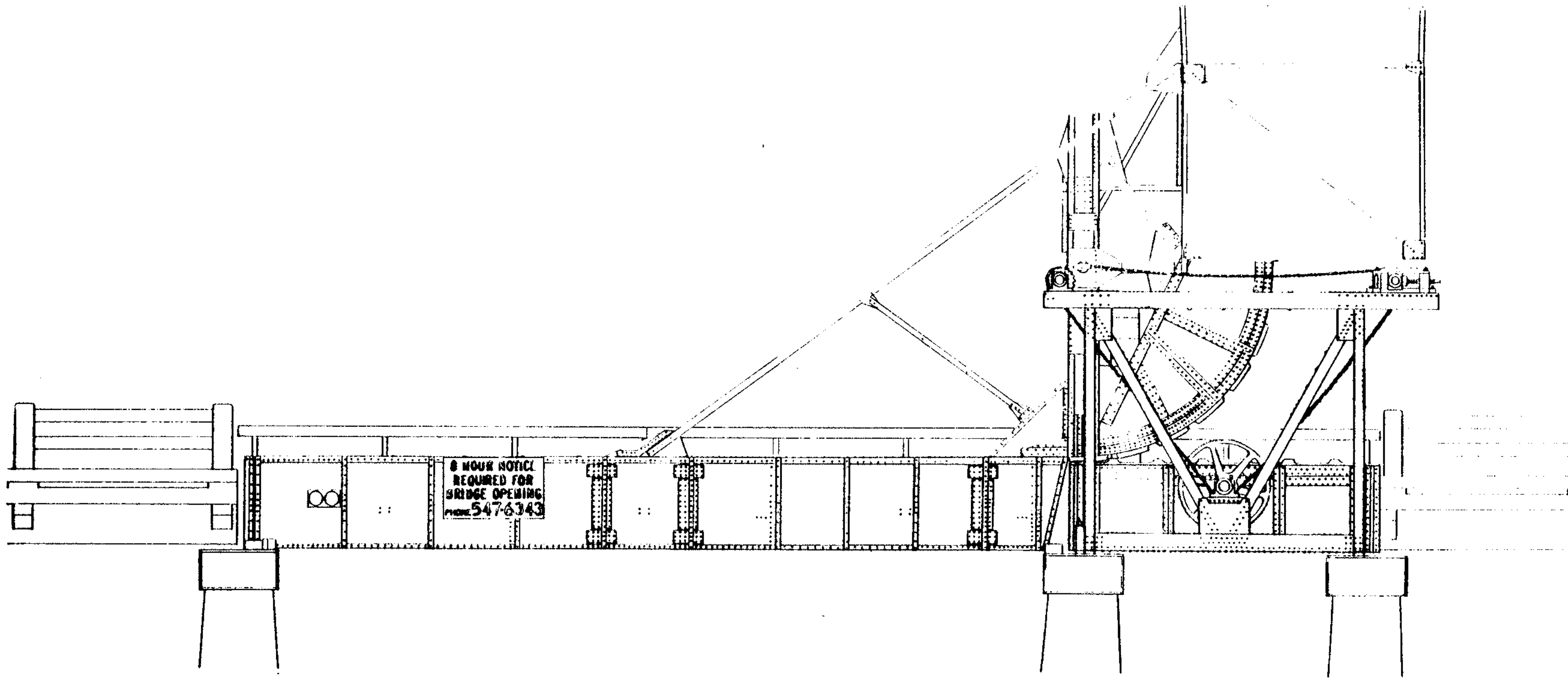

Figure 13. An intermediate stage documentation drawing of the Hodge's Ferry bridge bascule span, photographed from the water.

1003

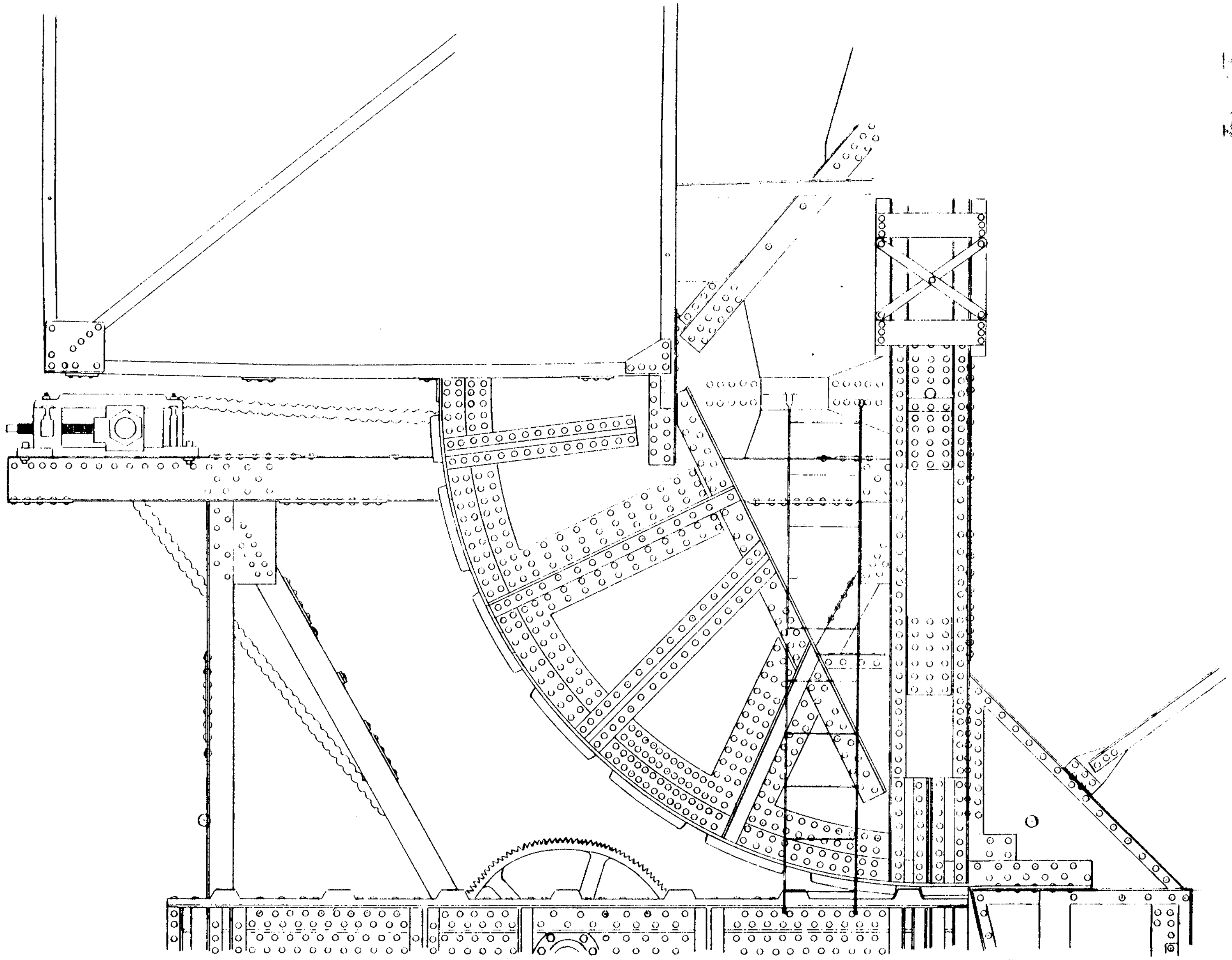

Figure 14. An intermediate stage photogrammetric documentation drawing of the moving portion of the Hodge's ferry bascule bridge, photographed from the bridge deck.

The photogrammetric documentation drawing is illustrated in Figure 15. It represents an intermediate photogrammetric documentation drawing and would be sent to a draftsman for further refinement. The condition of the wooden beams and planks is precisely documented. Inspection of Figure 15 shows areas of deterioration in the wood and the bricks.

Lee Bridge

The Robert E. Lee Bridge is located in Richmond. It is a concrete arch structure, built in 1934, which spans the James River, two railroads, two streets, and a canal. There are 16 open spandrel, double ribbed, reinforced concrete arches whose total length is 3,209 feet (978 m), and a series of concrete beams on the approach ends of the bridge. The entire Lee Bridge is 3,710 feet (1,131 m) long.

The James River consists of two channels separated by Belle Isle at this site. The length of Lee bridge and the conditions of this site made it one of the most difficult sites to document. The depth of the James River prohibited the use of waders and forced manipulation in a boat. Portions of the bridge were obscured by very large trees and buildings, particularly on Bell Isle. Because of the experimental nature of this report it was decided to document nine of the arches in two parts. A portion of the four-arch section of Lee bridge north of Bell Isle is reproduced here as Figure 16, which is a well developed intermediate stage photogrammetric documentation drawing. All edges are clearly defined and the bridge's profile is well represented. The pierced parapet wall made this drawing a tedious and time-consuming subject for the stereoplotting technician. The end result, at this stage, is satisfying in quality and economy of time as hand measurement of this long span bridge would have been far more time-consuming. This drawing would be further refined by a draftsman to complete the final stage documentation drawing.

Hopewell Mill

The remains of this mill, located east of Hopewell, are documented in Figure 17. This early stage documentation drawing shows the brick and concrete foundation walls and a few remaining wooden parts of the mill. Archaeological research showed that this mill was originally built in the seventeenth century, damaged and rebuilt during the Civil War years, and in continual use until the early twentieth century.

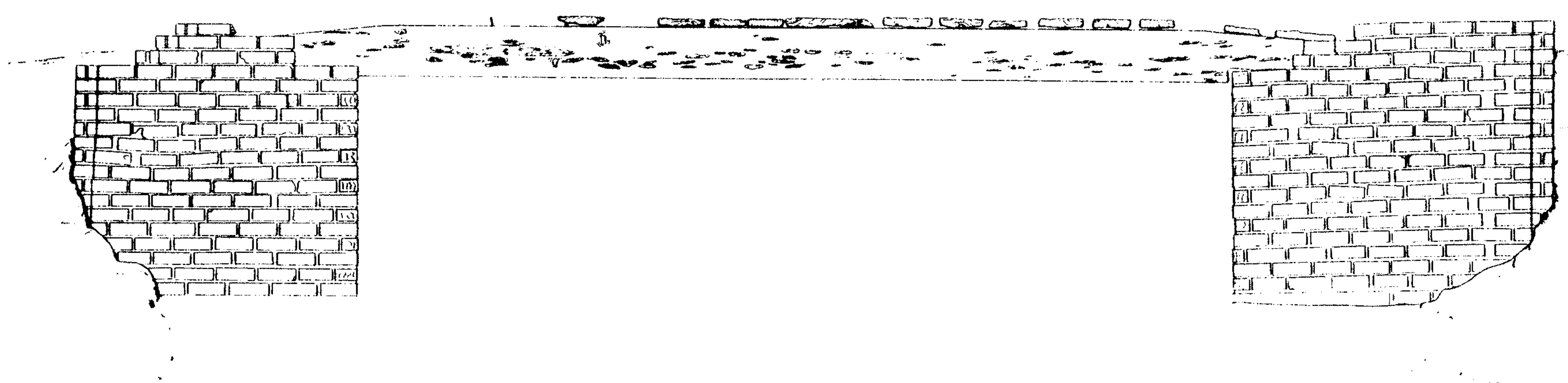

Figure 15. An intermediate stage photogrammetric documentation drawing of the Lake Cohoon bridge which emerged from Lake Cohoon during the 1980 drought.

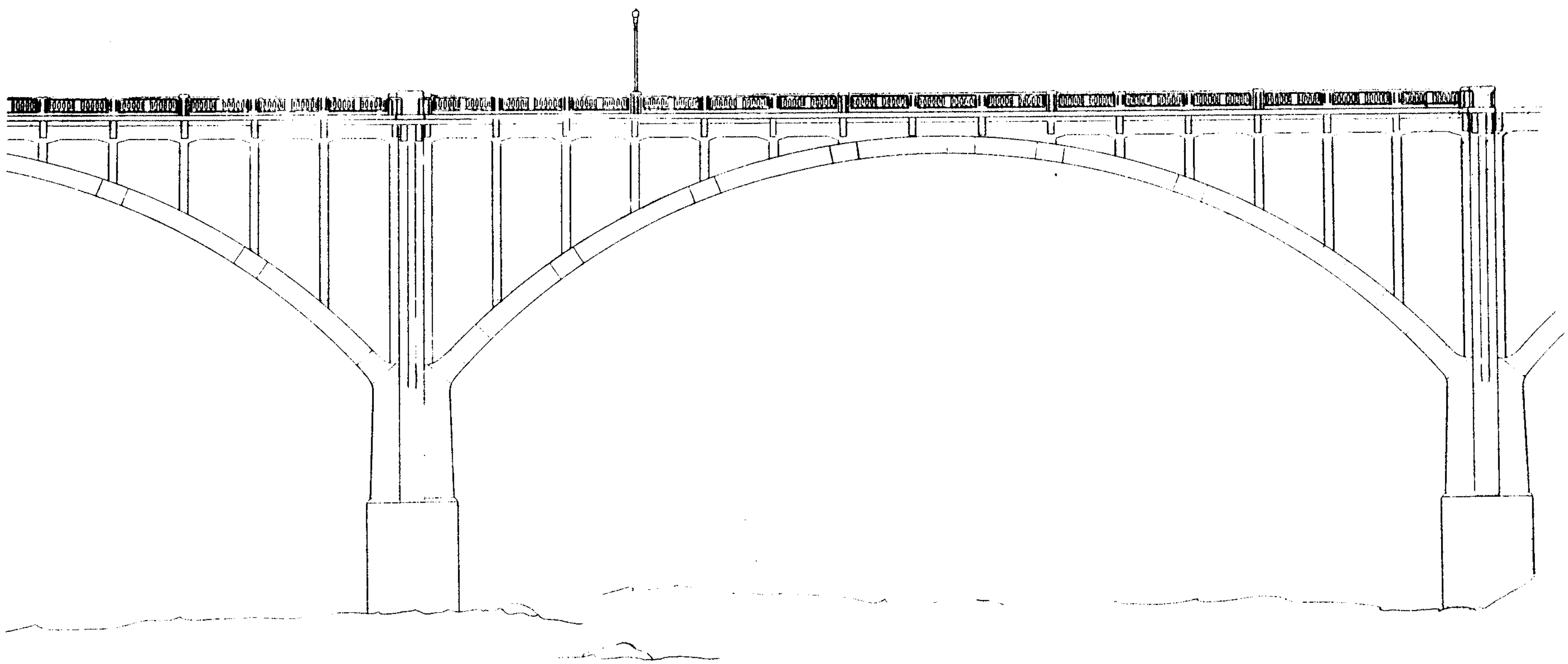

Figure 16. A refined intermediate stage photogrammetric documentation drawing of a portion of the Robert E. Lee Bridge in Richmond, Virginia.

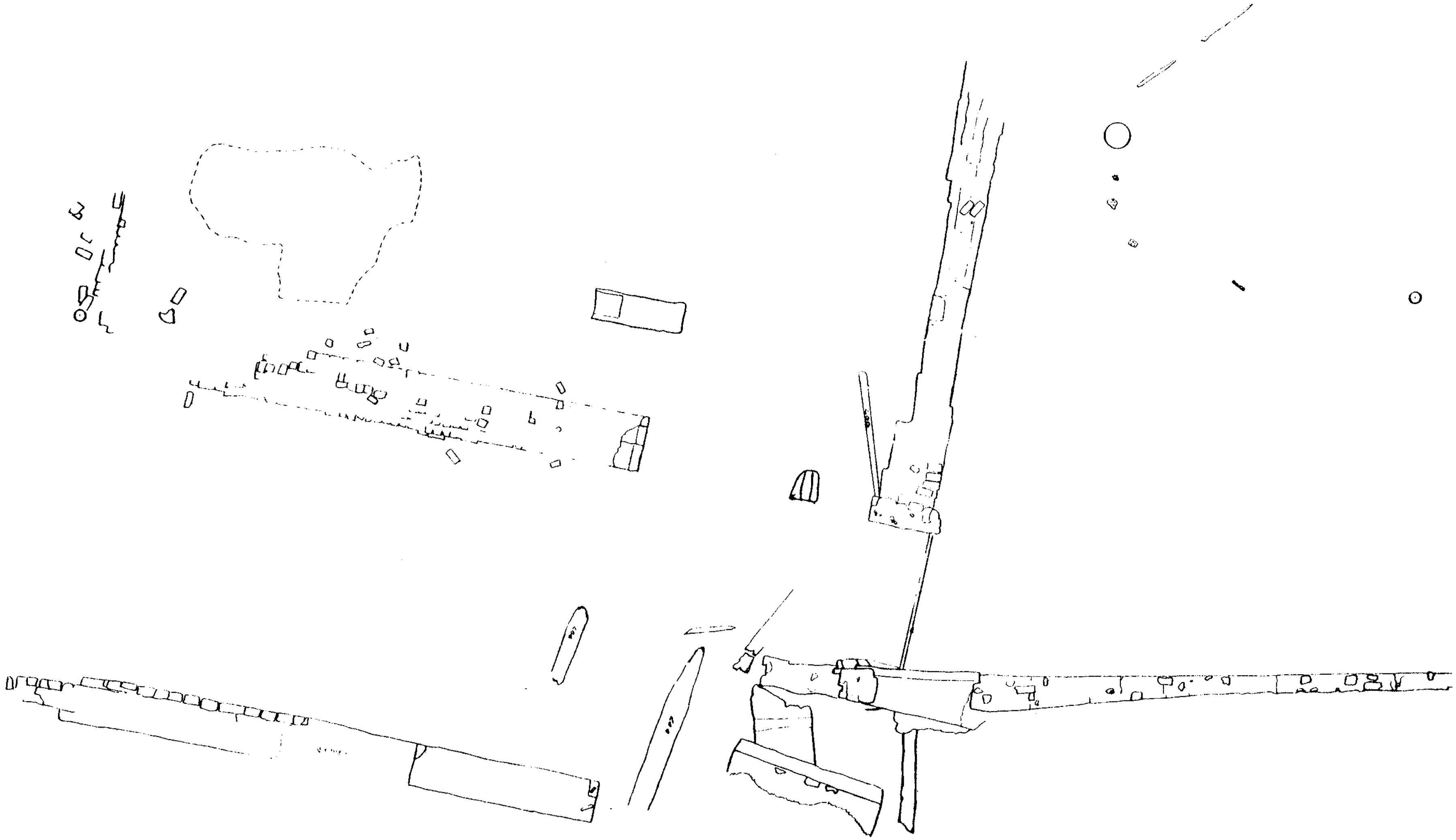

Figure 17. An early stage photogrammetric drawing of a mill site in Hopewell, Virginia.

Although this is a very early stage drawing, with little refinement, it marks the precise location of the remains of the mill. Viewed from a cherry picker, the documentation of this archeological site with scattered remains and uneven terrain was completed in the field in a few hours. Field time was extended by the need to manipulate the cherry picker around live electrical wires. This documentation drawing would be given to a draftsman for a clearer definition of edges and refinement.

Humpback Covered Bridge

The Humpback covered bridge near Covington is one of the few remaining covered wooden truss bridges in Virginia and purportedly one of only two "Humpbacks" in the United States. It was the only wood structure chosen for this study.

The documentation of the Humpback Bridge focuses on the three views which were photographed and drawn: an elevation of the portal end, an elevation of the entire structure, and a close-range detail of the interior. Each view is shown in sequence, with the photogrammetric delineation following the traditional one. Figures 18 and 19 illustrate the portal end elevation, and Figure 20 shows the stereopair related to Figure 19. Figures 21-24 illustrate the structure elevation and interior detail.

The site conditions were typical of the bridges studied for this project. Several trees obstructed the view of the entire structure and it was necessary to cut away foliage which covered portions of the bridge. One camera station required maneuvering in a shallow stream to set up the equipment. Weather conditions were good and the photographic work was straightforward. The interior view was experimental, no additional lighting was introduced and the interior was quite dark. The interior photographs were exposed for 5 seconds and the resulting model produced a very good representation of the structural components of the wooden truss.

The documentation drawings of this bridge are very successful in illustrating the advantages of the photogrammetric documentation of historic structures. First, they illustrate the extensive coverage possible in one day of field work. Second, they illustrate the detail which can be accurately shown without precarious and time-consuming field measurements. Third, they document the existing condition of the structure and show all areas of deterioration. This last observation is only necessary in an accurate and complete survey or for rehabilitation or restoration purposes. It does, however, show the capacity for study and documentation of details by close-range terrestrial photogrammetry.

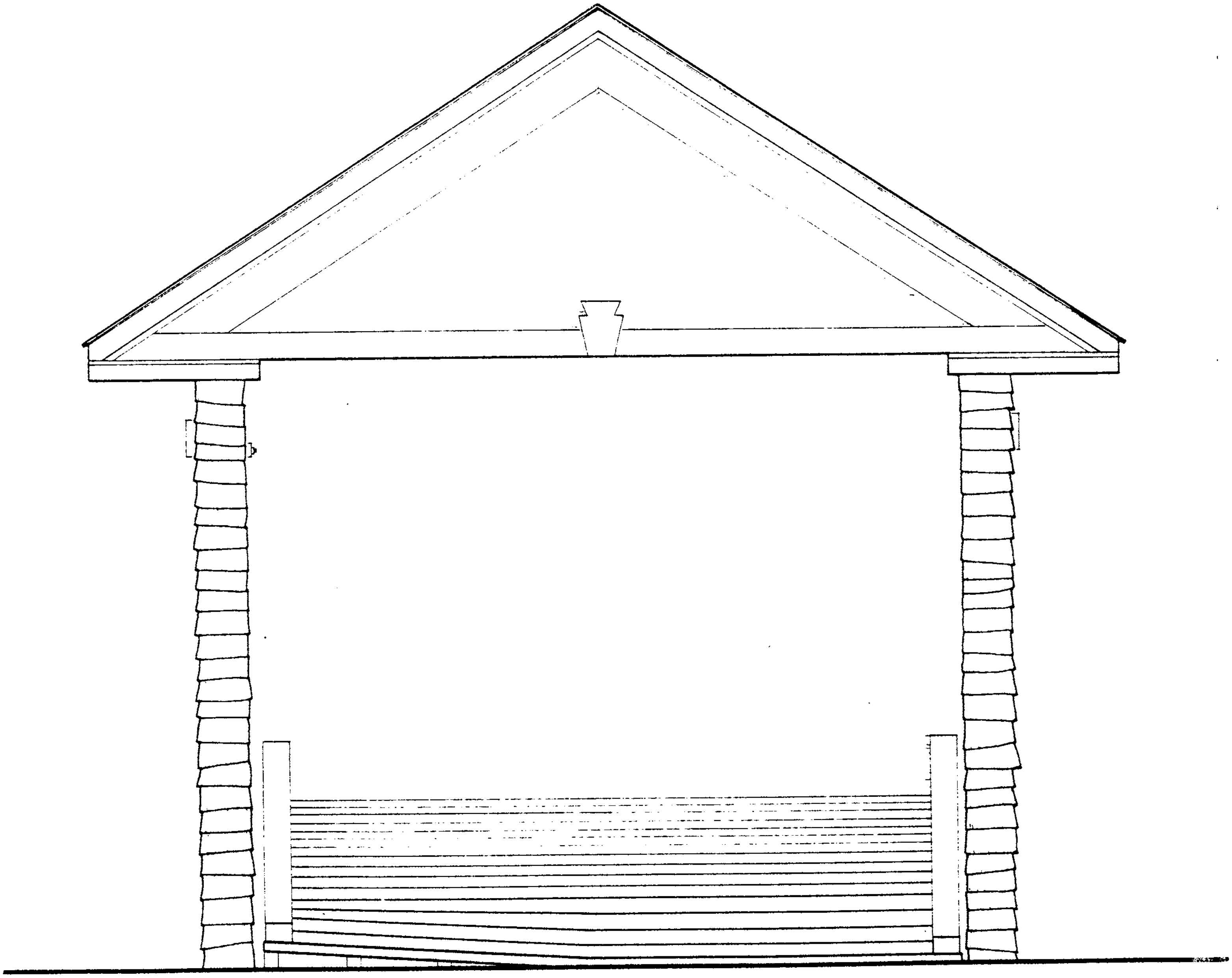

Figure 18. The HAER documentation drawing of the Humpback Covered Bridge, portal view, executed by the traditional technique using hand measurements.

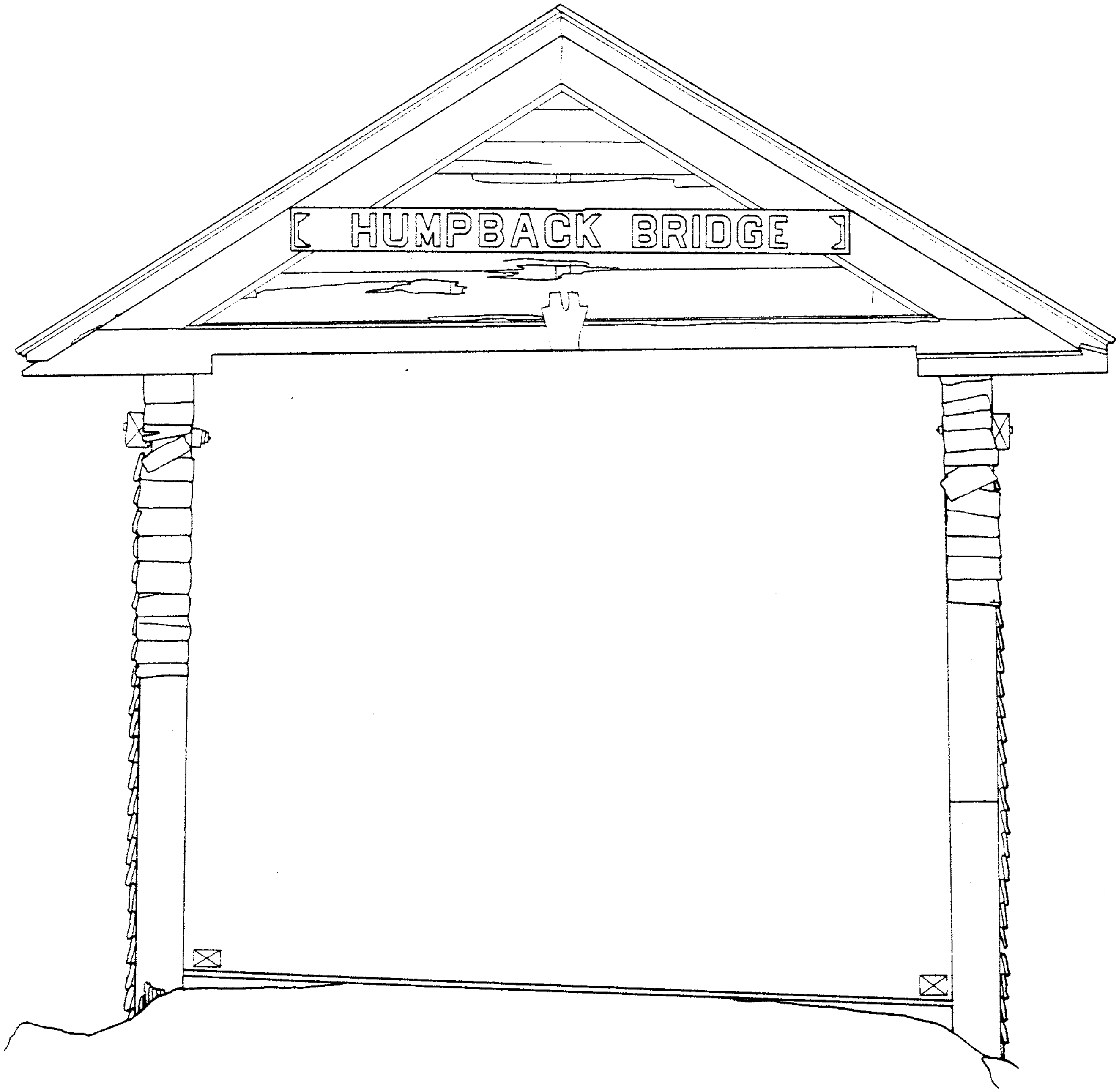

Figure 19. The documentation drawing of the Humpback Covered Bridge, portal view, executed by the photogrammetric technique. This is a late stage photogrammetric documentation drawing.

2002

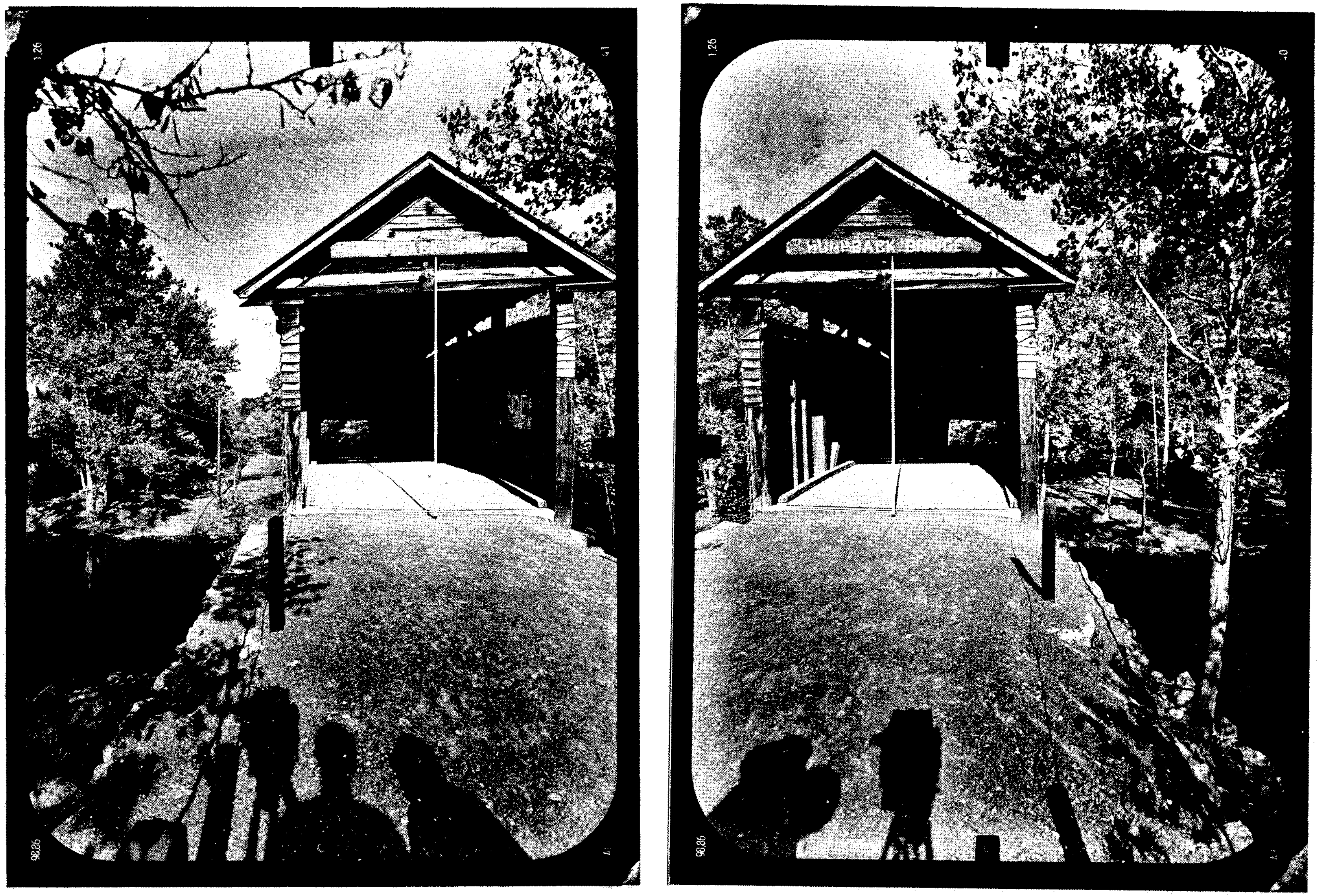

Figure 20. The stereopair photographs used for the photogrammetric recordation of the Humpback Covered Bridge portal view.

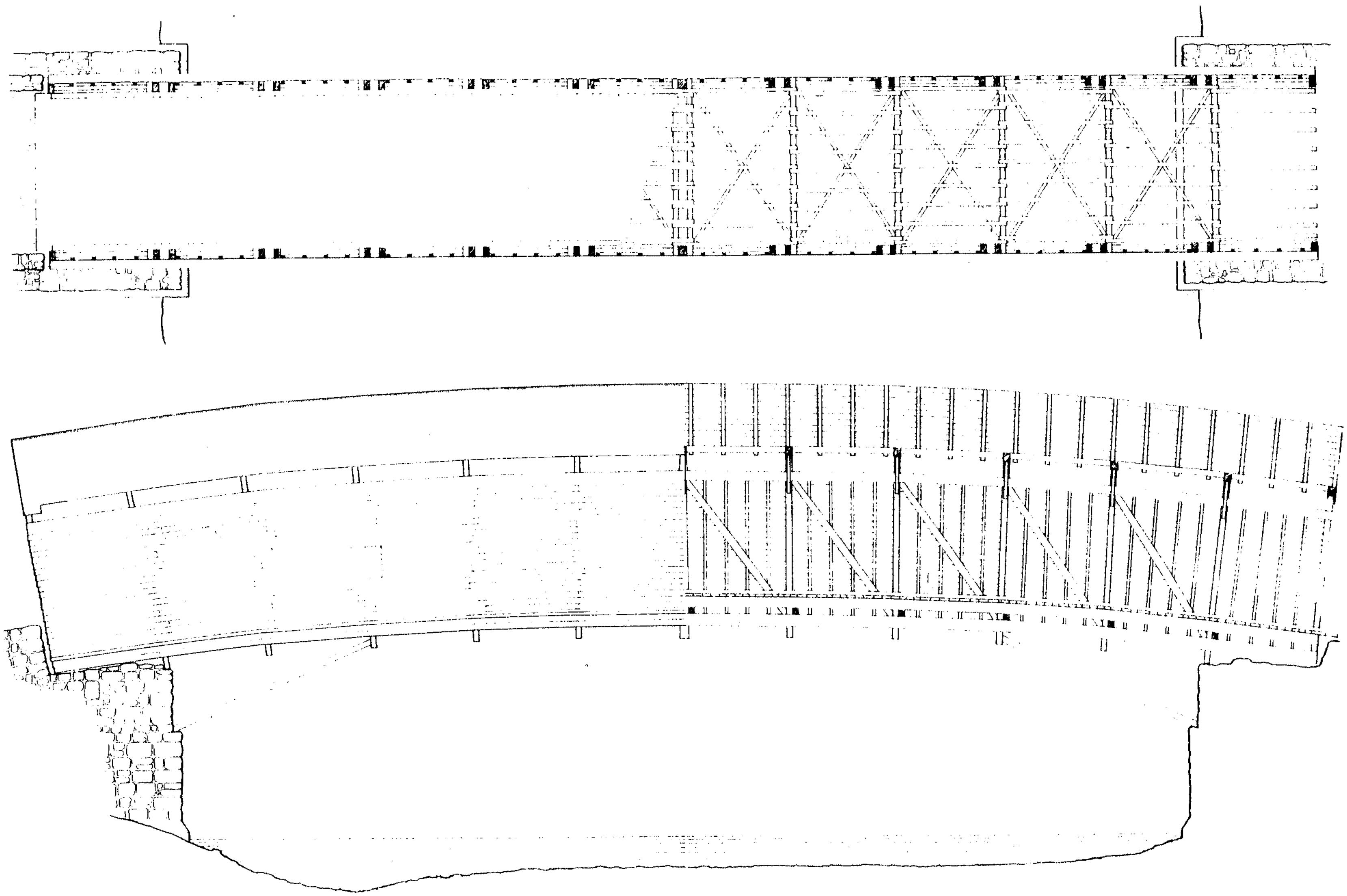

Figure 21. The HAER documentation drawing of the Humpback Covered Bridge, south elevation, executed by the traditional technique using hand measurements.

2003

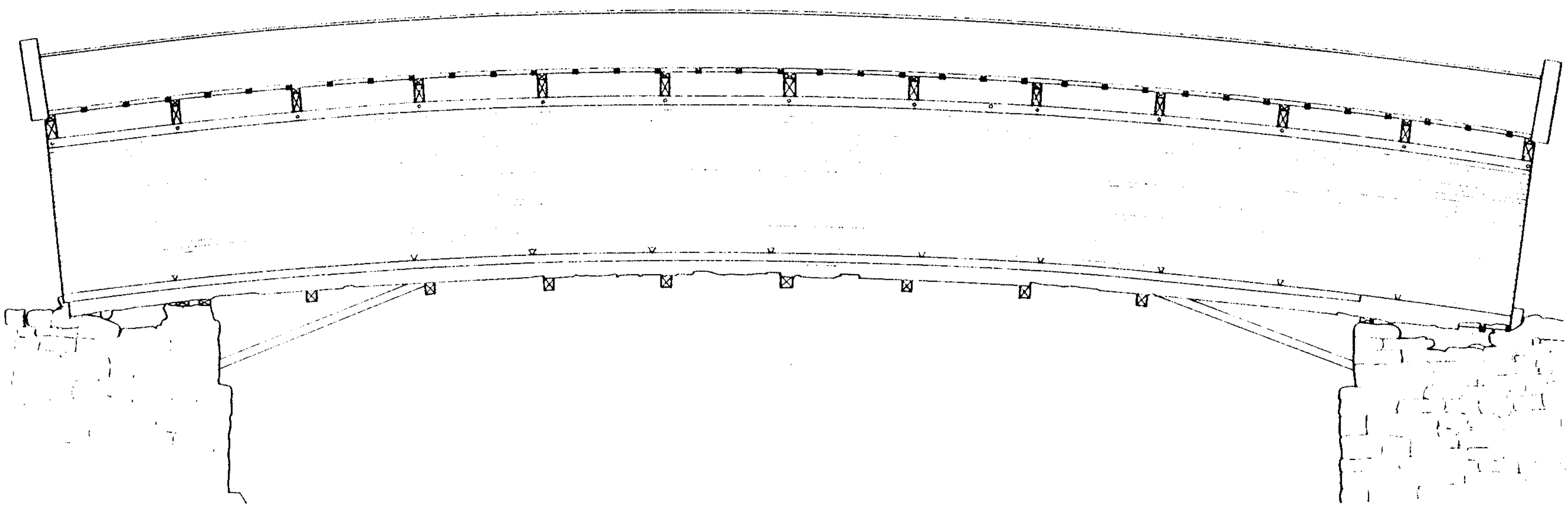

Figure 22. The documentation drawing of the Humpback Covered Bridge, south elevation, executed by the photogrammetric technique. This is a late stage photogrammetric documentation drawing.

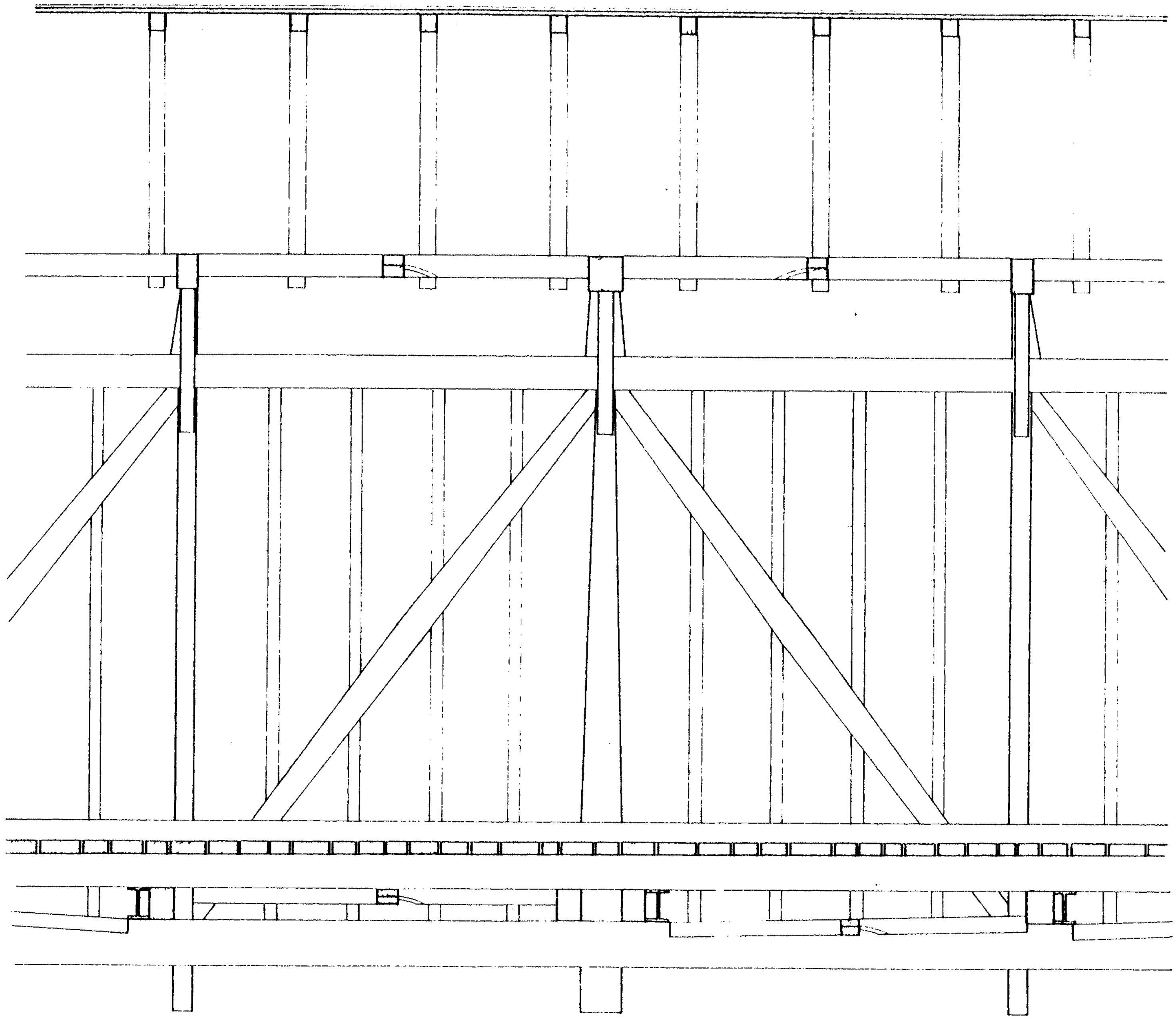

Figure 23. The HAER documentation drawing of the Humpback Covered Bridge, interior structural detail, executed by the traditional technique using hand measurements.

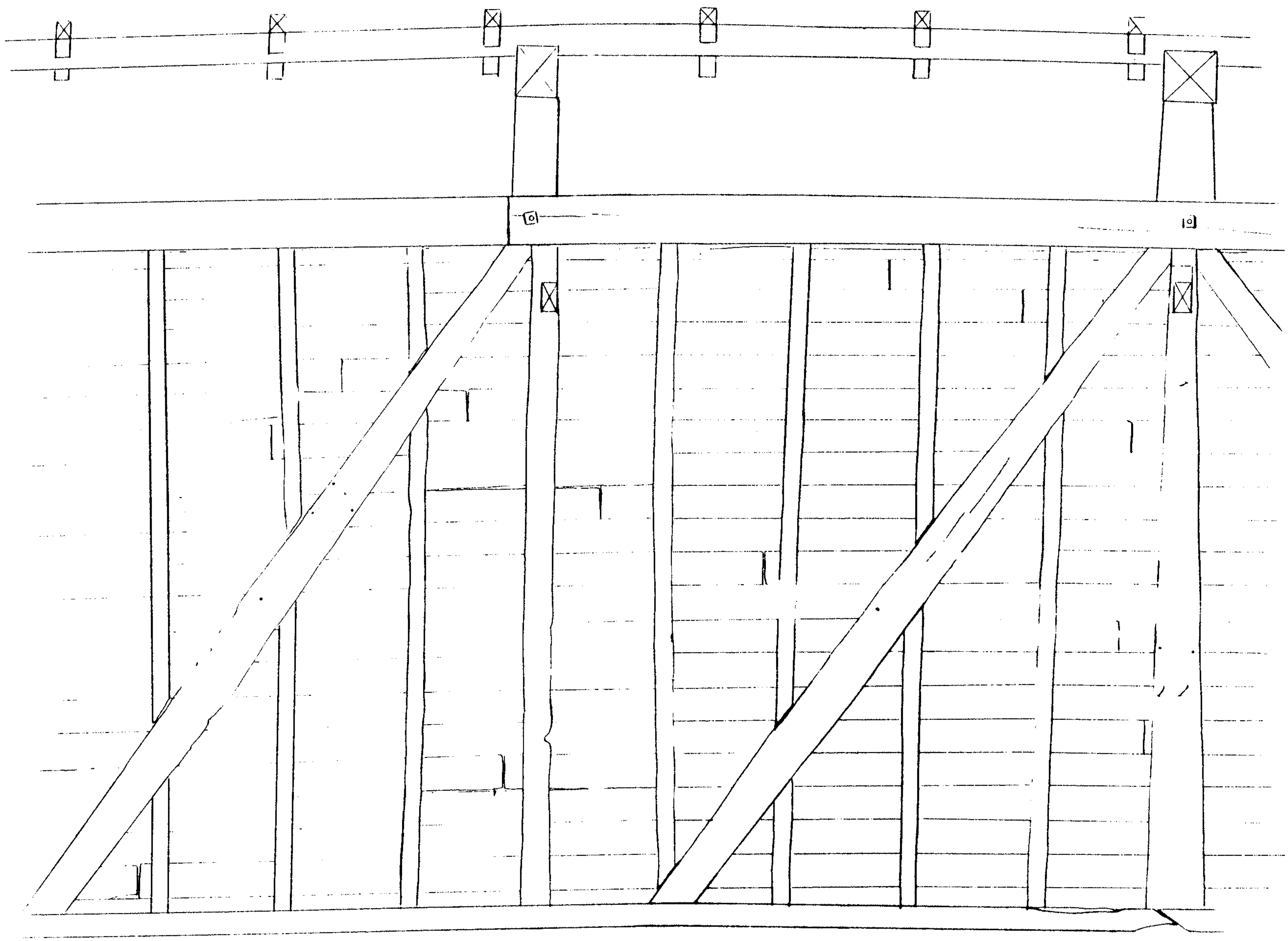

Figure 24. The photogrammetric documentation drawing of the interior structure of the Humpback Covered Bridge. This is an early state photogrammetric documentation drawing.

The three views of the bridge also illustrate different stages in the process of delineating photogrammetric documentation drawings. Both the portal and side elevations are in the beginning of the refinement stage. Surfaces and edges are very clearly defined by the use of ink and straightedge, where appropriate. A more refined rendition of these two views would require greater definition of surfaces and a clearer distinction in line weight qualities. The interior view of the truss structure is just barely beyond the initial stage in the documentation process. It is a literal representation of the object as seen in the three-dimensional model viewed in the stereoplotter. The light pencil lines of the drawing have been outlined and a few edges of members have been clarified with the use of a straightedge. All gouges and rough edges in the wood are apparent.

The Humpback Covered Bridge was chosen for comparative analysis and it will be discussed in greater detail in the following section.

Crozet's Blue Ridge Railroad Tunnel

This railroad tunnel in Augusta County was constructed between 1850 and 1858 for the Blue Ridge Railroad Company, under the direction of Chief Engineer Claud Crozet. It is a narrow, single-track tunnel, now superseded and accessible only by foot.

This drawing shows the west face of the tunnel. (See Figure 25 in the following section.) On the interior it is lined with brick. The exterior face consists of cut stone with the arch accentuated by bevelled, protruding voussoirs, some of which are showing signs of deterioration and destruction. The tunnel has been subjected to both weathering and vandalism.

The field work time for this site was lengthened by the inaccessibility of the site and the need to clear obstructing growth. Several hours were spent pulling honeysuckle vines and weeds so the outline of the structure could be delineated. It was then necessary to carry all equipment to the site by hand. The actual setup and photography time was 1½ hours. The site configuration required the use of three photographs, a two-model coverage of the tunnel, despite the narrowness of the structure. This was done to expose the surface of the tunnel face, which abutted the rough rock wall. Since the approach rock wall protrudes in front of the intersection of the tunnel face and rock, it was desirable to have the widest coverage possible.

The drawing of the tunnel illustrates the intermediate stage of photogrammetric drawing. Surfaces have been outlined from the three-dimensional model in the stereoplotter and then some edges have been delineated and accentuated with ink and straightedge. An attempt has been made on this drawing to show major cracks and chipped and missing stones. All surfaces, including rock edges and ground lines, are literal.

This drawing would next go to a draftsman for rendering which would more clearly define the various planes and edges of the tunnel face.

The Crozet tunnel was chosen for the comparative analysis and will be discussed in greater detail in the next section.

COMPARATIVE AND DIMENSIONAL ANALYSIS

The results of the photogrammetric documentation technique used in this study were analyzed from two perspectives. First, a comparison was made between documentation drawings produced by the photogrammetric method and the traditional hand measured method. Then, an analysis was made of the dimensional accuracy of the photogrammetric results. In this dimensional analysis comparisons were made between photogrammetric and hand measurements, both in the photographic plane of the object and perpendicular to that plane. A few photogrammetric models were studied in this manner to determine what types of dimensional information could be obtained from the stereoscopic models of these sites. The results of these detailed analyses are presented in the following two sections.

Comparative Analysis

In the previous section examples of documentation drawings were illustrated. These examples showed the progression of stages in the production of photogrammetric documentation drawings.

Two sites were chosen for a comparative analysis of photogrammetrically and traditionally produced drawings. The traditional drawings were produced by Historic American Engineering Record (HAER). These sites are the Humpback covered bridge and Crozet's Blue Ridge Railroad tunnel. Three views of the Humpback covered bridge (side elevation, portal elevation, interior structure) and one view of Crozet's Blue Ridge Railroad tunnel (elevation) were compared.

The Humpback Covered Bridge: Portal/West Elevation

The most striking difference in the two drawings of this view is that the traditionally drawn view (Figure 18) portrays the structure as it was built, newly completed and in perfect condition, while the photogrammetrically drawn view (Figure 19) documents the structure in its present condition, which is verified by the photograph (Figure 20). The present condition includes missing shingles and molding, large deteriorated areas of wood, and termite damage in the lower left corner. The detailed documentation possible on a drawing of this scale (1" [25 mm] = 1' [300 mm]), with photographs taken from a distance of approximately 25 feet (7.6 m), is illustrated particularly well by the termite damaged area of the left end post and the nailhead positions shown over the entire structure.

This type of drawing probably would be considered too literal a representation of the structure by HAER, an organization whose responsibility is to document important American engineering and industrial sites. This agency uses traditionally produced drawings. The January 1981 HAER Field Instruction Manual[8] states:

> ...drawings are generally considered to show the "as is" condition of a structure when it is drawn. Consequently, any portion of a drawing that fills in missing parts of a structure, or which partially reconstructs or restores a structure to anything other than its present condition, should be clearly noted, and the source or basis of such a construction should be cited as a footnote printed directly on the drawing.

These instructions are qualified later in the Manual with comments on several drawings:

> Precisely delineated, but too literal in recording the existing state of the structure. It's safe to assume the building wasn't built with holes in the floor and nothing important to the structure is communicated by recording the dilapidation in drawings (photographs can do that). One of the advantages of a measured drawing is the ability to "restore" a site to its full integrity using adequate evidence and/or common sense....
>
> Avoid the "Romantic Ruin" syndrome. Don't be so literal in recording a site that you end up drawing in broken windows, blown shingles and piles of junk. If the mullions remain in the window sashes, put the glass back in them in the drawings, etc. More extensive "restorations" should only be done where clear evidence can be cited....

Thus, if highway department mitigation agreements for impacted historically significant transportation sites required documentation to HAER standards, delineation of the structures in question would require some cosmetic restoration or replacement of deteriorated or missing materials on the drawing. This would demand far less time from the draftsman than drawings like this Humpback covered bridge portal drawing demanded. It would be a simpler task to delineate the structure in perfect condition than to show the precise location of damage and the exact size of irregularly shaped materials, like shingles, as was done in the execution of this drawing. The capability to produce either literal or non-literal drawings is certainly available with the photogrammetric method. For example, most of the metal truss bridges and the concrete arch bridge in this study were delineated as they were built, since deterioration was minimal. (See illustrations in the previous section.)

The Humpback Covered Bridge: Side/South Elevation

The advantages of the traditional hand measured drawing method are more clearly illustrated by this comparative example. With the siding removed on half the bridge the truss structure is exposed on the traditionally produced drawing (Figure 21). Since this drawing is a compilation from hand measured field notes, the combination of these two views into one drawing is only slightly more time-consuming than would be a single view. On the other hand, a composite view like this would require far more work from the photogrammetric method, and the photogrammetric drawing shows only the exterior (Figure 22). The only way to photograph the truss structure is from the interior (see Figure 23). Figure 23 illustrates barely two truss panels. This small model required two photographs because the camera-to-object distance was only 11 feet (3.4 m) and the camera coverage was, therefore, restricted. Documenting half the structural system would necessitate many setups, both with the camera in the field, and on the stereoplotter with stereopair photographic plates. In addition, a composite drawing made from models at the different scales which would result from differing object-to-camera distances would be very confusing and difficult to execute.

The plan view shown on the hand measured sheet would present the same problems in the field as documenting the interior structure would. The camera-to-object distance (this time to the bottom of the bridge from the water, with a vertical view) would be small enough to require numerous setups for documenting the humpback covered bridge floor plan.

Although the elevation of the entire bridge would necessitate far less field work by the photogrammetric method than by the traditional method, the nature of this site would require a combination of both methods for the efficient recording of the floor plan and half the truss structure.

The Humpback Covered Bridge: Interior Structural Detail

The interior structural detail comparative example shows disadvantages in the photogrammetric method, as did the previous view. The portions that are illustrated are very well documented in the photogrammetric drawing (Figure 23), but because the deck obscured the view below and the camera view prohibited including the roof structure, the structural detail is far more complete in the hand measured drawing (Figure 24). It would be necessary to supplement the photogrammetric field work with hand measurements to document the portions of the interior structure which could not be covered by photogrammetry alone.

The advantages of structural detail documentation produced by the photogrammetric method are better realized with analytical use than for archival purposes. To correctly analyze a truss the area of least cross section must be known. With the bird's-eye view available on an executed photogrammetric drawing, the smallest cross sections can be quickly and accurately pinpointed and the structural analysis can proceed with significantly less field time than traditional hand measurement would require.

The advantages of the photogrammetric system, however, are illustrated again by this example in the quality of the detail which can be precisely reproduced on a drawing. This can be seen in the nailheads protruding from members and in the gouges shown in the wood. The irregularity of the hand-hewn members also shows in the photogrammetric drawing.

Crozet's Blue Ridge Railroad Tunnel

The west elevation of this mid-nineteenth century railroad tunnel is illustrated in Figures 25 and 26, the photogrammetric and traditional drawings, respectively. The photogrammetric rendering again shows the literal condition of the face of the structure. It has not been refined by a draftsman and suffers in the comparison if viewed without the understanding that it represents an early stage drawing in the photogrammetric method. The photogrammetric drawing has the distinct advantage of representing the exact curve of the arch and locating the masonry courses precisely and not be approximation, as is typically done in the traditional hand measured method. What is assumed to be a weephole in the upper right of the tunnel face is not shown in the traditionally produced drawing, Figure 23, neither is it clear if the plaque above the arch is missing, as is obvious in Figure 25. The reliability of the photogrammetric drawing, based upon an objective mechanical documentor, would certainly be the last to be questioned, and it would be far easier to refer to stored photographic plates than to field notes taken by hand to clear up any potential problems.

The obvious advantage of the hand measured method is the capacity to draw plans from field measurements. In the present comparison this advantage is not valid. The tunnel is brick lined, several layers thick, but the distinction in materials between the stone face and the brick lining is not indicated in the plan view. Thus, it seems that the photogrammetric rendering of the Crozet tunnel is far superior to the conventionally produced drawing. It could, however, be refined by a draftsman to show the tunnel's as-built qualities and the character of the site, as shown in Figure 27.

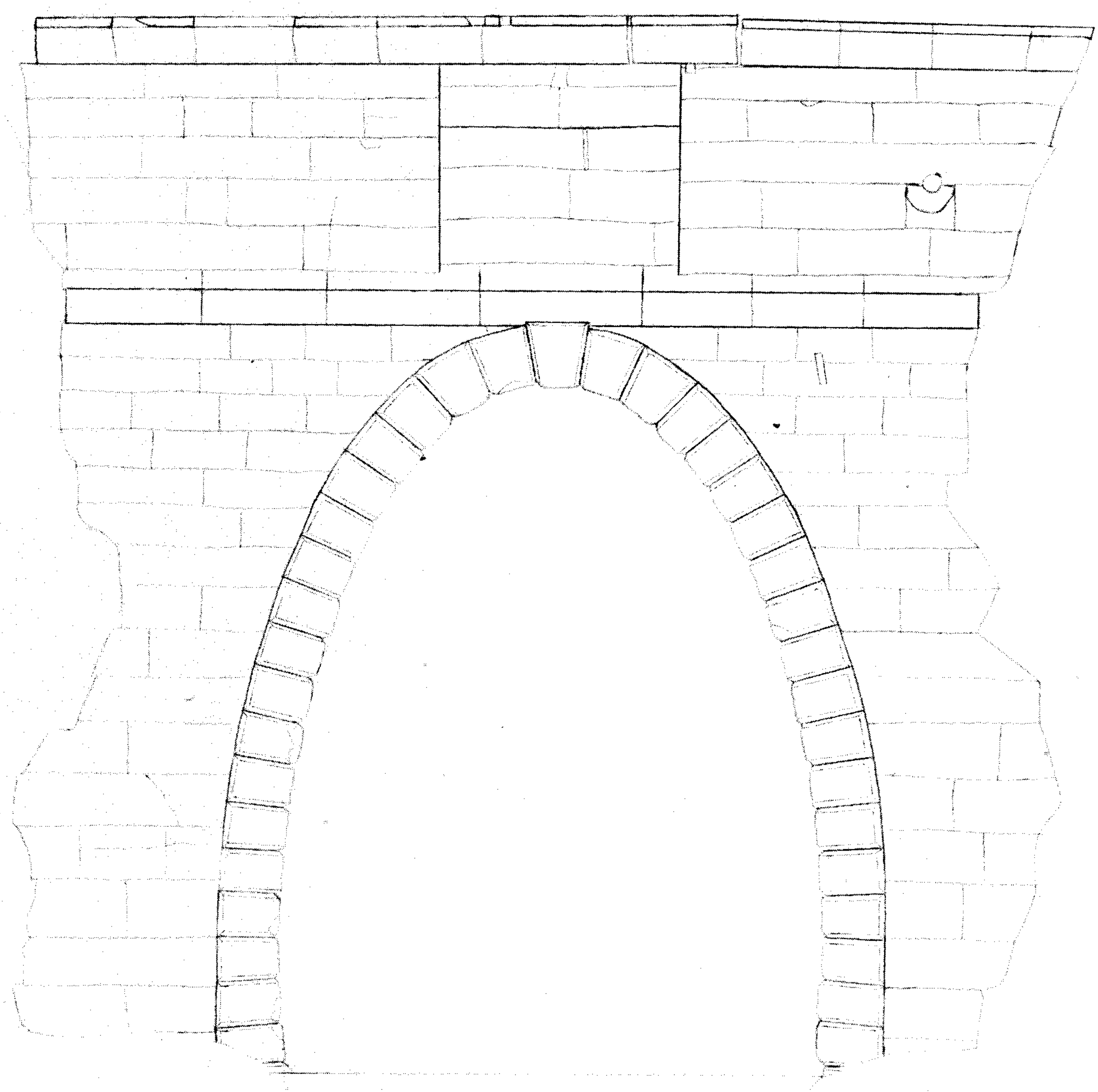

Figure 25. The photogrammetric documentation drawing of the west portal of Crozet's Blue Ridge Railroad Tunnel. This is an early stage photogrammetric documentation drawing.

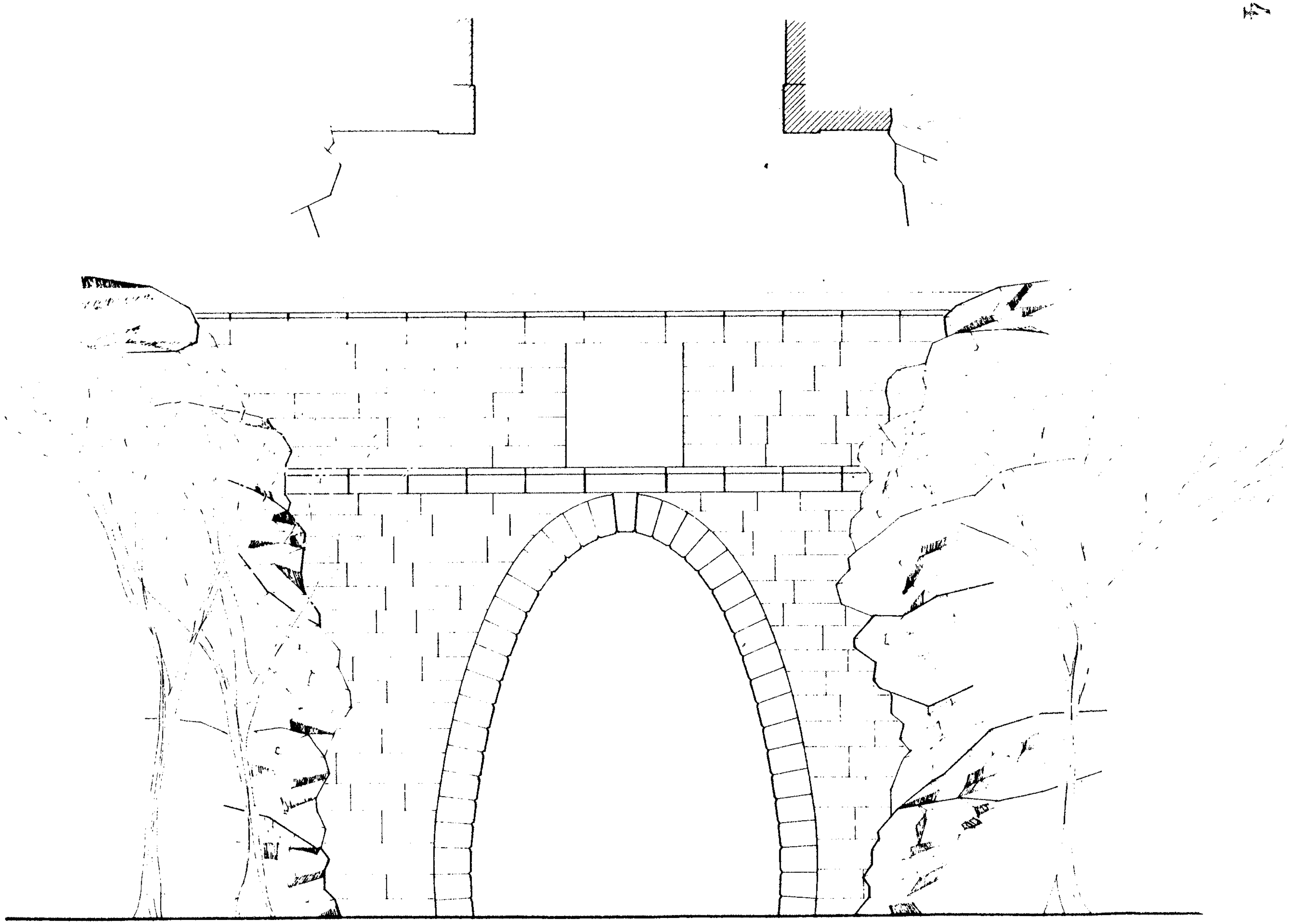

Figure 26. The HAER documentation drawing of the west portal of Crozet's Blue Ridge Railroad Tunnel, executed by the traditional technique using hand measurements.

2014

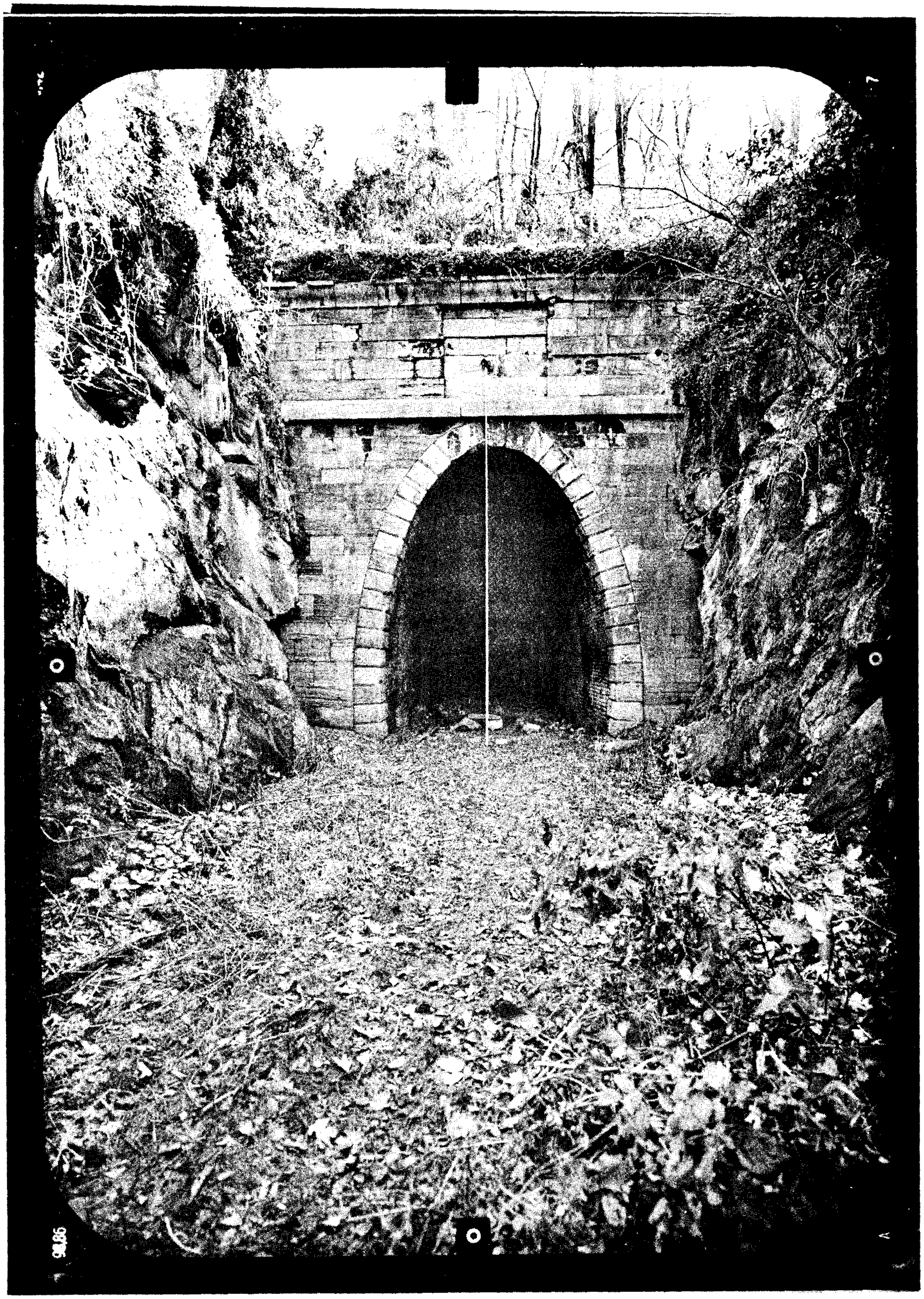

Figure 27. One of the photographs taken with the metric camera for the documentation of Crozet's Blue Ridge Railroad Tunnel.

Dimensional Analysis

The dimensional accuracy of the photogrammetric documentation method was examined on a case-by-case basis. Measurements of portions of the structures were compared both in the photographic or surface plane of the objects and perpendicular to this plane, in the depth of the objects. The photographic plane dimensions were scaled directly from the photogrammetric drawings and compared with hand measurements taken in the field. The perpendicular plane dimensions were read from the photogrammetric models as elevation readings and compared with the hand measurements. These perpendicular dimensions were studied to check the accuracy of depth measurements taken from the photogrammetric models. The capacity to accurately measure depth, in this perpendicular plane, from stereopair photographs would allow member thickness, in addition to lengths and widths, to be measured from the stereoscopic models rather than from hand measurements taken in the field. Four sites were chosen for the case-by-case study of dimensional accuracy.

Photographic Plane Dimensions

The photographic plane dimensional analysis was an examination of the dimensional accuracy of the drawings themselves. This segment of the study compared measurements in the photographic plane of the objects. The sites chosen for analysis of accuracy in the photographic plane of the structure are listed below

1) Bedstead pony truss bridge
    - a) side elevation
    - b) joint detail
2) Masonry culvert
    - a) elevation
3) Luten concrete arch bridge
    - a) elevation

The comparative results for these site measurements are found in Tables 3 through 6. Hand measurements taken in the field are listed in the first column of Tables 3 through 6, scaled measurements taken from the completed photogrammetric documentation drawings are listed in the second column, and the differences between the two are listed in the last column. The difference in dimensions derived by both techniques was also viewed as a percentage of the total dimension for each measurement taken. It was necessary to consider this relative error in measurement since there was a large dimensional differential among these sites. As with the perpendicular plane measurements, a 1/4-inch (6 mm) error in a 2-inch (50 mm) measurement is far more significant than a 1/4-inch (6 mm) error in a 300-inch (7.6-m) measurement.

The data from the photogrammetric documentation drawings were obtained directly with an engineer's scale. A problem encountered in this dimensional analysis and not in the following perpendicular dimensional analysis was due to the different scales at which the drawings were executed. Scaled measurements from a large structure, drawn at a scale to accommodate the structure on a standard drawing sheet, could be in error due to the thickness of a drawn line. This factor is probably the most significant cause for error in the following results, which are discussed site by site.

Augusta County Bedstead Pony Truss, Table 3

Table 3 shows the comparative results from hand and scaled measurements on the side elevation of this truss bridge. The initial reaction to the large errors, in contrast to the errors found in the perpendicular dimensions, is that the results show large inaccuracies in the drawings. Some of the hand and scaled measurements differ by as much as 3/4 inch (19 mm), as compared with the largest error of approximately 1/4 inch (6 mm) in perpendicular plane dimensional comparisons. When the larger difference of 3/4 inch (19 mm) is considered as a percentage of the total dimension, and in light of the scale at which the drawing was executed, the results are better.

This elevation was drawn at a scale of 1" = 3' (25 mm = 900 mm). At this scale the thickness of a pen line can measure as much as 1 inch (25 mm). This single factor could certainly account for the larger order of error found in these dimensional comparisons.

From an error percentage perspective, the results are also favorable. Nine of 15 measurements (60%) show errors of less than 2%; 13 of 15 measurements show errors of less than 5%. The 2 measurements with errors greater than 5% are measurements of very small dimensions and could be in error due to the thickness of a pen line.

The errors in this comparative dimensional analysis would probably be reduced if the bedstead truss elevation drawing was executed at a larger scale, as is the detail drawing in the following example.

Augusta County Bedstead Pony Truss Joint Detail, Table 4

The order of error in the Augusta County joint detail view is less than in the Augusta County bedstead truss side elevation drawing. These results are listed in Table 4, which shows that differences in hand and scaled measurements ranged from no difference to the largest at 1/4 inch (6.35 mm). The only inordinately large difference is a 20% error, although it appears insignificant (0.05 inch [1.27 mm]) in the Table 4 listing. As discussed in numerous examples, measurements of the order of this one, i.e., less than 1 inch (25.4 mm), were not reliably determined by the photogrammetric technique with the equipment used in this project. In other examples, this error was primarily due to corrosion and paint buildup of up to 3/8 inch (9.5 mm). For this site detail drawing, small measurements are also unreliable due to reading error from the thickness of the line that defines the detail. The scale at which the joint detail is drawn is 2" = 1' (50 mm = 300 mm). At this scale, the thickness of a pen line can measure as much as 0.15 inch (3.8 mm). Thus, the potential for error in a small dimension is obvious.

For measurements of larger dimensions the results are good. The portion that measured 14.5 inches (368 mm) registered as precisely 14.5 inches (368 mm) in both hand and scaled measurements. Sixty-seven percent of the errors in measurement were less than 1/16 inch (1.6 mm); 92% of the errors in measurement were less than 1/8 inch (3.2 mm).

The dimensional comparative results from hand and scaled measurements were favorable in this case, even though the photography was poor due to weather conditions. The documentation drawing produced by the photogrammetric method, then is as accurate as a hand measured documentation drawing, given a reasonable scale drawing and a small camera-to-object distance.

Masonry Arch Culvert, Table 5

The field conditions at the masonry arch culvert were good and the photographs produced were excellent. The camera-to-object distance was small (19 feet [5.79 m]) and the drawing scale was large enough (1" = 1' [25 mm = 300 mm]) for this small structure to show good detail. This condition ideally would produce good results based on the conclusions drawn in the above example.

Comparative dimensions in the plane of the arch were very good, resulting in less than 1% error. When dimensions on the curving wing walls were compared, the results were poor, as expected. The walls curve away from the arch and toward the viewer and thus are foreshortened on the drawing. All hand measurements of these areas are larger than the dimensions of the same foreshortened areas in the drawing, as would be expected.

For dimensions parallel to the plane of the photograph the comparative results from hand and scaled measurements at this site were very good. As with the previous truss bridge, the photogrammetric drawing of the masonry structure is as accurate as a hand measured drawing would be.

Table 3

Hand Measurement Vs. Scaled Dimensional Comparison
Augusta County Pony Truss (Figure 10)

	Hand Measurement, (feet)	Scaled Measurement (feet)	Difference (inches)
1.	5.948	5.95	0.024
2.	0.932	0.90	0.384
3.	7.51	7.50	0.120
4.	7.52	7.55	0.360
5.	7.54	7.50	0.480
6.	7.51	7.45	0.720
7.	7.54	7.475	0.780
8.	0.526	0.50	0.312
9.	0.422	0.40	0.264
10.	0.531	0.550	0.528
11.	0.599	0.575	0.288
12.	0.797	0.80	0.036
13.	0.500	0.475	0.300
14.	4.740	4.725	0.180
15.	15.290	15.300	0.120

NOTE: 1 ft. = 0.3048 m
1 in. = 25.4 mm

Table 4

Hand Measurement Vs. Scaled Dimensional Comparison
Augusta County Pony Truss Detail (Figure 12)

	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

NOTE: 1 in. = 25.4 mm

Table 5

Hand Measurement Vs. Scaled Dimensional Comparison
Masonry Arch (Figure 3)

Hand Measurement, (feet)	Scaled Measurement (feet)	Difference (in.)
1. 6.3125	6.325	0.15
2. 6.9792	7.000	0.2496
3. 6.7135	6.725	0.138
*4. 2.0625	1.925	1.65
*5. 2.5521	2.075	5.7252

*foreshortened

NOTE: 1 ft. = 0.3048 m
1 in. = 25.4 mm

Table 6

Hand Measurement Vs. Scaled Dimensional Comparison
Luten Concrete Arch (Figure 5)

Hand Measurement, (feet)	Scaled Measurement (feet)	Difference (in.)
1. 27.86	27.80	0.72
2. 3.04	2.98	0.72
3. 26.25	26.14	1.32
4. 0.70	0.56	1.68

NOTE: 1 ft. = 0.3048 m
1 in. = 25.4 mm

Luten Concrete Arch Bridge, Table 6

The camera-to-object distance at this site was significantly larger than the distances in the previous few examples. The field work was done 48 feet (14.6 m) from the bridge. Because of the small span of the bridge, it was plotted, or drawn, at a scale of 1" = 1' (25 mm = 300 mm).

Comparative results for hand and scaled measurements were good, except for the measurement of a very small dimension (less than 1 inch [25.4 mm]). This 3/4 inch (19 mm) measurement was in error by 20%, while the other measurements compared at less than 2% error. As cited many times in the discussion of dimensional accuracy, for measurements of such small dimensions the error inherent in the system is far too great to give reliable results. Errors in the field can result from large corrosion and paint buildup, while errors from the photogrammetric drawing can result from the scale of the drawing and the thickness of a drawn line. A higher accuracy would certainly be expected for small dimensional measurements, if the range of photography were much closer.

Perpendicular Plane, or Cross-Sectional, Dimensions

The sites chosen for analysis of accuracy in the perpendicular plane tested the capacity to obtain depth, or thickness, dimensions. Ultimately, this technique would be used to measure cross-sectional areas of members. The three sites used for this perpendicular plane portion of the study are listed below

1) Bedstead pony truss bridge
   a) side elevation
   b) joint detail

2. Hodge's Ferry bascule bridge
   a) rocker arm detail

3. Masonry culvert
   a) elevation

The comparative results for these site measurements are found in Tables 7 through 10. Photogrammetric data are listed in the second column of the tables as machine elevation readings. Hand measurements are listed in the third column, and the differences between the two are listed in the last column as fractions of inches.

The photogrammetric data were obtained in the lab with the photogrammetric stereopair models of the sites located in the stereoplotting machine. The method used was an adaptation of the techniques used by the Location and Design Division for the production of topographic maps. Simplistically described, this technique records height differences among discrete points with respect to a referenced low point or zero elevation.

After the documentation drawings were completed the designated stereopair photographs used for that process were reoriented in the stereoplotting machine. No additional field work was necessary for this phase of the study. Thickness dimensions were derived from the stereoscopic model of the structure established by the stereopair photographs in the stereoplotting machine. The thickness of carefully specified components of the chosen structure were determined from relative elevation readings between the high (or front) and low (or back) surfaces of each designated component. These precisely located points were then measured by hand on the structures and the results were compared.

Problems were encountered in obtaining both photogrammetric and field measurements. Since the photogrammetric method is a photographic process, the quality of photography was very important for this detailed analysis. Poor conditions included overcast and rainy weather and grainy photographs resulting from a large camera-to-object distance. In some cases shadows were cast in the photographs and elevation readings were partly obscured because there was no definite point in the background to which the technician could reference. The deteriorated state of the structures was another problem. In many areas the corrosion and rust buildup was such that it was extremely difficult to get accurate readings either on the stereoscopic model or in the field. Additional problems in the field included the inaccessibility of some areas and hazardous conditions at the site.

<u>Augusta County Bedstead Pony Truss, Table 7</u>

The limits of the photogrammetric method were tested most by this site. Field conditions for the photogrammetric work were poor. The sky was very overcast during the photographing of the side elevation; the photographs suffered from a dark sky and from a large object-to-camera distance. These side views were photographed from 55 feet (16.8 m). The result was a stereoscopic model on which detailed readings were difficult. Elevation readings were taken to 1/1000 inch (0.0254 mm), but the reading for the last decimal place was largely estimated. Comparative measurements were made at seventeen randomly distributed locations.

Considering the field conditions, the results were quite good. Four of the 17 readings were difficult to read in the lab and in the field due to rust and paint buildup. These were at locations 2, 3, 9, and 15. The largest error in this group is almost 1/4 inch (6.35 mm), which is a considerable error on a measurement of 3-3/4 inches (95.25 mm). Aside from these 4 erratic readings, all other errors are below 1/8 inch (3.18 mm), or 0.125 inch (3.18 mm). On a structure which has areas of corrosion buildup over 1/4 inch (6.35 mm), it would be unreasonable to expect greater accuracy. The very best readings on this site were accessible and easy to read both in the lab and in the field. These were for locations 1, 4, 7, and 14, with errors of about 1/64 inch (0.40 mm). These 4 readings cluster near 1% error, when the difference in dimensions derived by both techniques is considered as a percentage of the total dimension. Fourteen of 17 (82%) of the readings were below 5% in error and 11/17 (65%) of the readings were below 3% in error.

<u>Augusta County Bedstead Pony Truss Joint Detail, Table 8</u>

The problems encountered during the field work for the side elevation discussed above were compounded in the joint detail by a rainstorm which began as setup for the detail view started. Despite the fact that the camera-to-object distance was significantly smaller (12.72 feet [3.88 m]), the weather conditions were worse and resulted in very poor quality photographs. The readings on a site with such a small camera-to-object distance should have been extremely good. Obscured areas on the detail accounted for one very poor reading, which was off by almost 22%, and some otherwise erratic readings. Since this was a close-up of a truss joint detail, dimensions considered were generally far smaller than in the previous example. Some measurements were as small as 3/8 inch (9.52 mm). Thus, errors of 1/8 inch (3.18 mm) are significantly greater in this example than in the side elevation of the truss. On first inspection, Table 8 shows excellent comparative results, with all but one difference in measurements being less than 1/16 inch (1.59 mm). From a strictly analytical perspective, these results are less acceptable when considered as error percentages. One reading is 22% in error, two others are approximately 7% in error. At the same time, 70% of the readings are 3% or less in error.

With field conditions at the Augusta County bedstead truss site presenting the problems described above, the results of the comparative dimensional analysis, although complicated by erratic readings, show that the photogrammetric technique has promise in its potential for taking cross-sectional area measurements.

Hodge's Ferry Bascule Bridge, Table 9

The rocker arm detail of the Hodge's Ferry movable bascule span was selected for the dimensional analysis because it is an example of a site which would be prohibitively time-consuming to hand measure. This view was illustrated in Figure 14. This section of the bridge is made up entirely of riveted components and would involve many tedious hand measurements.

Field conditions for the photogrammetric work were good. The weather was perfect and camera-to-object distance was only 24.6 feet (7.5 m). The major problem was that the bridge was heavily travelled by vehicular traffic and the work required setting up the camera on the span itself. This heavy traffic also posed additional problems in the field work for the hand measurements. Hand measuring this site required maneuvering on beams with no bridge deck cover, as well as being on the bridge with fast moving, frequent vehicular traffic. Also, corrosion buildup was a problem in some portions of the bridge.

From a strictly technical perspective the photogrammetric field conditions were excellent and resulted in very good quality photographs and accurate readings. Because the model was so clearly defined it was easy to specify the precise points to be measured and compared. Just as the Augusta County pony truss tested the limits of the system under poor conditions, this example tested the limits under good conditions.

As seen in Table 9, data points from two locations were rejected; one because it was impossible to measure by hand as the member projected over the water with no support near it (9) and the other because the point was in shadow and so difficult to read on the stereopair model that the reading was unreliable (10).

Table 9 lists comparative results in measurements. The hand and photogrammetric measurements are very close. Using the valid data points, all measurements show under 1/8 inch (3.18 mm) difference between hand and machine measurements. Of these 18 data points, 8 show less than 1/64-inch (0.40 mm) difference, 3 show less than 1/32-inch (0.79 mm) difference, and 6 others show less than 1/16-inch (1.59 mm) difference between field measurements and machine readings.

An examination of the data on an error percentage basis shows 16/18 (89%) of the data points below 4% error in measurement. The two points which are over 4% error are measurements of very small dimensions (3/4 inch [19.05 mm] and 3/8 inch [9.52 mm]) and the fractional errors are considerable, even though they are only 0.054 inch (1.37 mm) and 0.033 inch (0.84 mm), respectively.

The comparative measurememts for components on the Hodge's Ferry bridge show that the photogrammetric method is potentially a reliable technique for making cross-sectional measurements on structures.

Masonry Arch Culvert, Table 10

The small masonry arch culvert, illustrated in Figure 3, was chosen for the dimensional analysis to test the photogrammetric method with material other than metal. Field conditions were very good for the photogrammetric work. The camera-to-object distance was 19 feet (5.8 m) and weather conditions were excellent. Field conditions were good for hand measurement work, also. The only problem was that parts of the site were awkward to reach for hand measurements.

Cross-sectional dimensional comparisons, Table 10, show very unreliable and erratic readings. This was due to the nature of the material, which is rough, "rock-face with draft-line" ashlar masonry. The surface of the stones is roughly finished and protrudes very unevenly. It was extremely difficult to get reliable comparative readings on this site. A lateral displacement of 1/8 inch (3.18 mm) in a measurement of a stone could make a difference of 1/2 inch (12.70 mm) in the depth measurement. It was difficult to be sure that field readings and lab readings precisely coincided because of the random nature of the stone surface treatment.

The photogrammetric technique of depth measurement is not appropriate for irregularly surfaced structures like the masonry arch culvert, because of the unreliable nature of the data produced from both elevation readings and hand measurements.

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Table 7

Cross-Sectional Dimensional Comparison
Augusta County Pony Truss (Figure 10)

Location No.	Machine Elevation 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

NOTE: 1 in. = 25.4 mm

Table 8

Cross-Sectional Dimensional Comparison
Augusta County Pony Truss
Joint Detail View (Figure 12)

Location No.	Machine Elevation 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

NOTE: 1 in. = 25.4 mm

Table 9

Cross-Sectional Dimensional Comparison
Hodges Ferry Bascule Bridge (Figure 14)

Location No.	Machine Elevation 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.	2.496	impossible to reach	
* 10.	5.064	4.84375	0.22025
11.	9.036	9.0625	0.0265
12.	5.604	5.5625	0.0415
13.	4.848	4.750	0.098
14.	59.964	59.96875	0.00475
15.	5.520	5.500	0.020
16.	2.736	2.6875	0.0485
17.	0.300	0.3125	0.0125
18.	0.408	0.375	0.033
19.	0.684	0.6875	0.0035
20.	1.092	1.125	0.033

*data rejected

NOTE: 1 in. = 25.4 mm

Table 10

Cross-Sectional Dimensional Comparison
Masonry Culvert (Figure 3)

Location No.	Machine Elevation Reading, (in.)	Hand Measurement (in.)	Difference, (in.)
1.	2.5224	2.5625	0.0401
2.	2.2008	2.375	0.1742
3.	0.7968	0.90625	0.10945
4.	0.672	0.90625	0.23425
5.	3.84	3.90625	0.06625
6.	4.164	4.25	0.086
7.	0.1164	0.1875	0.0711
8.	3.9084	4.00	0.0916
9.	4.29	4.375	0.085
10.	0.9876	1.09375	0.10615
11.	3.8268	4.03125	0.20445
12.	5.4648	5.500	0.0352
13.	2.3304	2.15625	0.17415
14.	1.896	1.6875	0.2085
15.	4.1796	4.0625	0.1171

NOTE: 1 in. = 25.4 mm

SUMMARY AND DISCUSSION

The documentation drawings illustrated in the previous sections clearly show that the ability to produce documentation drawings by a photogrammetric procedure is within the capability of the Virginia Department of Highways and Transportation if a proper camera is available. These drawings of representative historic sites demonstrate all stages in the photogrammetric drawing production technique by illustrating varying degrees of refinement in the drafting process. Several drawings show literal representations of the photogrammetric models of the structures. These drawings were reproduced as they were completed from the stereoplotting machine, with no attempt to make them into presentation drawings. The documentation drawings of other sites were delineated by a draftsman to varying degrees of refinement, thus demonstrating the process from beginning to end.

This study has shown numerous advantages of the photogrammetric method. Information recorded on photographs is stable and comprehensive. Since the method is a precise photographic technique, all the information ever potentially desired from a site is permanently stored with the exposed photogrammetric plates. This fact would allow flexibility in the planning of a survey or documentation program for historic highway structures since the drafting and other labor intensive operations could be scheduled to avoid peak work loads. With minimal field work, rapid and relatively simple inventories of structures can be completed while storing the potential to document or analyze in detail the structures inventoried. Traditional methods for inventories and documentation drawings require many man-hours of field work initially to obtain hand measurements of the structures. In a climate of reduced manpower, this capability is particularly significant. Also, the supplementary photographic coverage normally used in the traditional hand measured methods can be minimized.

The discussion of the executed documentation drawings in the previous two sections set forth a satisfactory comparison between photogrammetrically and traditionally produced documentation drawings. It was shown in these comparisons that the recordation of a structure in whatever form desired is possible. Examples like the Humpback covered bridge portal elevation illustrate literal "as is" representations of a structure. Although this literal form of recording may not be desirable from an aesthetic point of view, from an engineering perspective and for highway department use, the ability to document the literal condition of a structure would be very valuable. A literal representation of the three-dimensional photogrammetric model allows damaged areas to be precisely pinpointed with minimal field work.

The dimensional comparison in the last section showed that additional information can be obtained from the stereoscopic models created from stereopair photographs. In that section a preliminary analysis of the potential for reading cross-sectional areas of members from these models showed positive results. For highway department use this damage and dimensional information would be valuable in the analysis and maintenance of historically significant sites, as well as for other types of structures.

On the other hand, if the documentation of a deteriorated structure required an "as built" drawing, delineation of the structure in question would not be literally recorded from the photogrammetric model. Instead, deteriorated or missing materials could be modified on the drawing by the draftsman, while the information of the literal condition of the structure would remain in storage on the photogrammetric plates. In cases of extreme historic significance, the photogrammetric delineation could certainly provide the skeleton for a more aesthetically pleasing and sensitive drawing, if required.

The question of which type of documentation is preferred is tied up with philosophical issues in the field of historic preservation. On one side of the issue is the desire for a strong, well articulated, and aesthetically pleasing representation of the historical site in question. On the other side of the issue is the need for absolutely accurate representations of structures for analytical and rehabilitative purposes. It has been the frustrating experience of more than one engineer working on historic sites to have to return to the site to remeasure dimensions because of inaccurate or illegible hand notes of the "cosmetic" restoration in a drawing.

Because the engineering community appears to be awakening to the need to preserve its heritage, an understanding of the valid requirements of both sides of the issue is necessary and a compromise is possible. Certainly the potential for both accurate and aesthetically pleasing renditions exists using photogrammetric recording techniques.

This report has shown that with minimal time in the field the photogrammetric method produces the ability to document structures in a very precise and detailed manner, and potentially of a quality acceptable to the agency which requires the documentation.

However, in order to be able wo work within the existing structure of a highway department, several problems inherent in the use of the photogrammetric method must be addressed. These can be mitigated with additional experience, equipment, and training. Three types of problems emerged as this research progressed: those in the field work, those in the lab, and those in the structures themselves.

The sites were chosen to include a range of field conditions that would test the photogrammetric procedures. Imagination and ingenuity were required to record a number of sites. It was necessary to set up in streams, on boats, on structures accommodating heavy vehicular traffic, above the sites in cherry pickers, and in remote and inaccessible places. Obstructions often required spending time clearing a site before the photogrammetric setup could begin. The demands of the field conditions in this study could certainly coincide with field conditions in any typical survey or documentation program. Therefore, it would be extremely difficult to follow one specific procedural guideline for documenting historic sites. Flexibility in the approach to various sites would be necessary. Clearly, the ability to rectify oblique photos would mitigate this situation to some extent.

This study also showed that the photogrammetric method is weather dependent. The quality of photography was very important, particularly at close range, for the technicians to be able to delineate the photogrammetric model. Lab work on the Augusta County bedstead truss bridge site, for example, was tedious and more time-consuming because the photographs were exposed in dark, rainy weather and were not of as good quality as the photographs at other sites. This can be overcome with proper scheduling.

Additional problems became apparent in the lab. The stereoplotting technicians were unaccustomed to executing planimetric renditions of structures. It was necessary to supplement the photogrammetric coverage with close-up standard photographs of details of the sites in order for the stereoplotting technicians to delineate the structures accurately. These supplemental detail photographs were essential for successful recordation.

The last problem encountered is inherent in the nature of historic sites. Some of the structures studied were badly deteriorated. Rust and paint buildup on the metal structures were severe in areas. Stone structures were chipped and cracked and wooden structures were rotted or missing parts. This factor complicated gathering the data for the comparison of dimensional accuracy in photogrammetric and hand measured methods. Despite this, the potential to accurately obtain dimensional data from photogrammetric models, both in the photographic and perpendicular planes, was demonstrated.

It was impossible to obtain elevation readings for some metal truss members which were thin and contrasted against the sky. In order to read cross-sectional data for metal truss bridges in future uses of the photogrammetric method, black targets ought to be attached to the backs of members. This is necessary to give a reference point for reading elevations on the backs of those members with only sky behind them; it is otherwise very difficult to tell where the member ends in the perpendicular plane. These black targets could be magnetized, as could those used on the face of the structure, and the setup for photogrammetric recording would proceed with little additional work.

The precision of measurements was limited because of structural deterioration. To determine stringent limits of the dimensional accuracy in the photogrammetric method, additional tests should be conducted on nondeteriorated sites where rust and paint buildup would not complicate the determination of accuracy. Good comparative results were also limited by the size of the measurements used; very small measurements should always be supplemented by a check with hand measurements, as accuracy with measurements under 1 inch (25.4 mm was very poor with the type of equipment used in this project. If more sophisticated, microprocessor digitizer equipment had been available, results would have been more reliable.

In some cases, the unfamiliarity of the stereoplotting technicians and the draftsmen with this type of rendering made it necessary to work closely with them to communicate what the drawings should illustrate. The skills of the technicians were challenged by this project. In a few instances the standard procedures used in ordinary work — e.g., standard use of ballpoint pen — were unacceptable for the purposes of this study. For these reasons it is strongly recommended that procedural guidelines and drafting requirements be established and appropriate training be executed for the personnel executing photogrammetric documentation drawings, should additional photogrammetric recordation of historic sites be desired.

This study has shown that it is feasible to document historic structures by use of close-range terrestrial photogrammetry. This method of documentation can be successfully applied within the capability (assuming a proper camera) of local highway departments to produce very precise documentaiton drawings and, with little additional work and some modification of drafting guidelines, renderings acceptable to other agencies can be produced. If desired, the results of the photogrammetric documentaiton field work can provide additional information about the structures. Thus the applicability of the photogrammetric documentation procedure is broader than solely the production of documentation drawings.

CONCLUSIONS

Based upon this study it is concluded that:

1. Documentation by photogrammetric methods is applicable to and of sufficient accuracy for a wide variety of structures and sites and is very cost-effective by reducing man-hours required for hand measurements, traffic control, and scaffolding.

2. With the exception of the camera, and rectifying equipment, the production of documented drawings photogrammetrically is within the capacity of currently available equipment in most, if not all, departments of transportation.

3. A major advantage of the photogrammetric method is that the most critical phase (obtaining the field data) is the least labor intensive phase. By traditional methods this is the most labor intensive operation.

GUIDELINES

The following preliminary guidelines are an outgrowth of this research

I. The photogrammetric documentation team will be made up of the following:

   A. Photogrammetric engineer.

   B. Photogrammetric engineering technician.

   C. Civil or structural engineer to interpret site and determine views and details required for documentation.

   D. If none of the above are sensitive to historic transportation sites, consultant from either local SHPO or HAER.

II. The procedure for field work will follow this general outline:

   A. Site reconnaissance

      1. Visit site to determine axis orientation for optimal photography time.

2. Analyze site or structure to determine desired views, including detail coverage.
3. Analyze site to determine equipment necessary for suitable photographic coverage.

B. Site preparation

1. Clear site of obstructions
2. Place targets on object, using black as needed
3. Locate camera stations

C. Site documentation

1. Stabilize camera at designated stations
2. Photograph object
3. Record distances between targets and elevation of discrete points on the object
4. Using 35 mm camera, or Polaroid, photograph structural details which are complex or which may be confusing to stereoplotting technicians.

III. The procedure for stereoplotting will include:

A. Technicians will be briefed on information desired for each site documentation.

B. Technicians will use supplemental site photographs for potentially confusing details of structures and sites.

C. Technicians will work closely with engineer to assure recordation of site in accordance with desired documentation.

D. Technicians will complete documentation drawing only through early stage documentation.

IV. The procedure for drafting will include:

A. Early stage documentation drawings will be completed by draftsmen with familiarity of architectural drafting.*

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*This may require a special training session.

B. Delineation of drawings will proceed with the understanding that they will rarely be reproduced at full scale

   1. Thus, the need for strong differentiation of line weights in illustration of the structure.

   2. Thus, the need to avoid using faint lines and closely spaced lines.

C. Delineation of drawings will never be completed in ball point ink but will always be done with standard drafting pens and ink.

D. A standard drawing size of 24 inch x 36 inch (610 mm x 914 mm) will be adopted for all documentation drawings, and recordation of sites will be planned within this dimensional framework.

RECOMMENDATIONS

It is recommended that:

1. The Department immediately obtain, on a permanent basis, a camera such as that used in this study.*

2. Long-range consideration should be given to acquiring a universal or analytical stereoplotter that would allow the capability to compile plan drawings from convergent, oblique, or severely tilted photography.

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*While the report was in preparation, this recommendation was implemented.

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1. United States Government, Department of Transportation, Federal Highway Administration, Memorandum HNG-30, September 5, 1980.

2. Spero, Paula A. C., "The Applicability of Close Range Terrestrial Photogrammetry to the Documentation of Historically Significant Structures and Sites Associated with Transportation Projects," M. S. Thesis, University of Virginia, August 1981.

3. Borchers, Perry E., "Photogrammetric Recording of Cultural Resources." Washington, D.C.: Technical Preservation Services Division, Office of Archeology and Historic Preservation, National Park Service, U. S. Department of the Interior, 1977.

4. Agnard, Jean-Paul and Sanfacon Roland. "Photogrammetric Study of French Architecture." Proceedings of the Symposium on Close-Range Photogrammetric Systems. Falls Church: American Society of Photogrammetry, 1975, pp. 1-3.

5. Hilton, Marvin H., and Fred B. Bales, "Application of Close-Range Photogrammetry to Bridge Structures," Virginia Highway and Transportation Research Council, in preparation.

6. Slama, Chester C., ed., Manual of Photogrammetry. 4th ed., Falls Church: American Society of Photogrammetry, 1980, p. 5.

7. McNeil, Gomer T., ABC's of Photogrammetry, Part I: Fundamentals. Ann Arbor: Edwards Brothers, Inc., 1950, pp. 1.01-1.02.

8. Historic American Engineering Record, Field Instructions. Heritage Conservation and Recreation Service. Washington: U.S. Department of the Interior, 1981, pp. 34-35.

2038

APPENDIX

PHOTOGRAMMETRIC FIELD INFORMATION

SITE BREMO ROAD MARKER

LOCATION Fluvanna County

SITE DESCRIPTION 19th century monolithic stone road marker

VIEWS 1 elevation

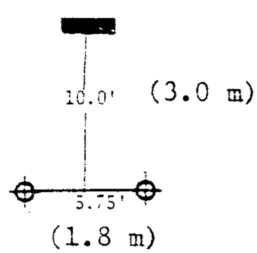
ADDITIONAL EQUIPMENT

COMMENTS Setup and photography were straightforward.

*Project completed in 45 minutes

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



SITE WHITE POST

LOCATION Clarke County

SITE DESCRIPTION Reproduction of 18th century wooden road marker

VIEWS 1 elevation

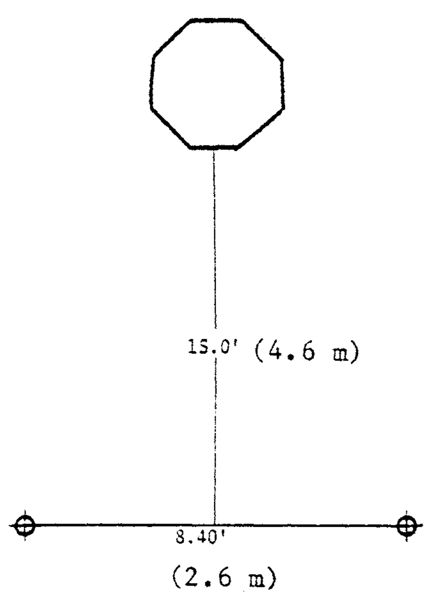
ADDITIONAL EQUIPMENT

COMMENTS The weather was perfect and no problems were encountered.

*Project was completed in 20 minutes.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



SITE MASONRY ARCH CULVERT

LOCATION Augusta County

SITE DESCRIPTION Small, cut stone masonry culvert with curving wing walls; carrier railroad to Crozet tunnel

VIEWS 1 elevation

ADDITIONAL EQUIPMENT

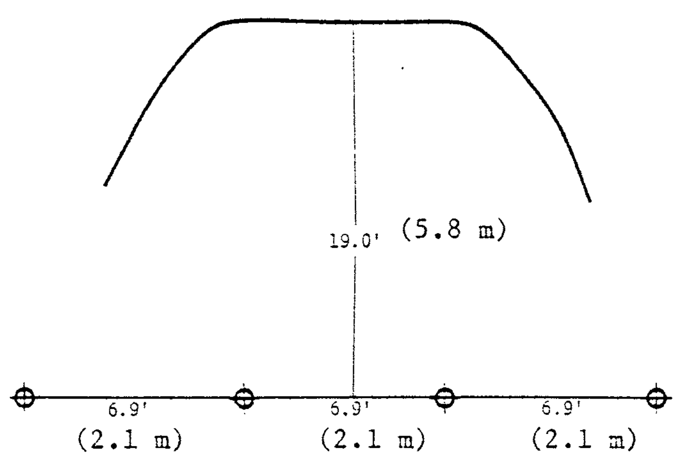
COMMENTS The site was cleared the day before photography was to be done.

Photographing culvert was straightforward; no particular problems at this site.

*Setup, photography, and recording time was 1½ hours.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



SITE — RIVANNA RIVER NAVIGATION LOCK

LOCATION — Fluvanna County

SITE DESCRIPTION — Submerged 19th century stone navigation lock

VIEWS — 1 plan

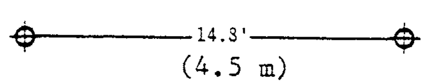
ADDITIONAL EQUIPMENT — Camera mount for bridge rail

COMMENTS — Preparing site included the cutting of small brush which obscured a portion of the lock wall

*Setup, photography, reading measurements and elevations were completed in 4 hours

*Does not include preliminary site evaluation time or travel to and from site

CAMERA STATION LOCATIONS



Camera was 30.0' from targets, vertically.
This is a plan view of the target setup.

2044

SITE | LUTEN CONCRETE ARCH

LOCATION | Frederick County

SITE DESCRIPTION | Small span concrete arch bridge built after patent by Daniel B. Luten

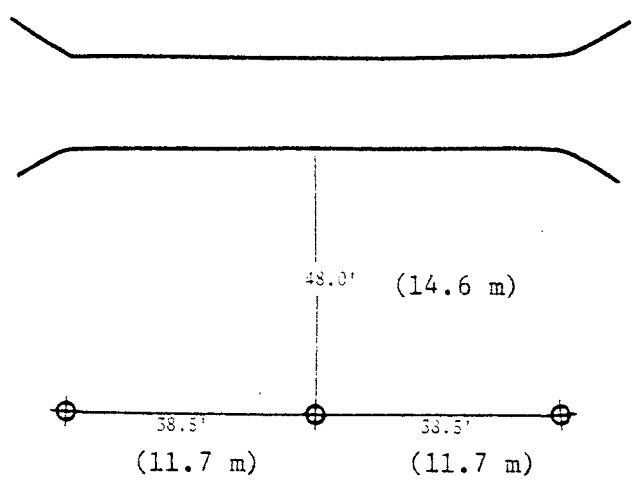
VIEWS | 1 side elevation

ADDITIONAL EQUIPMENT

COMMENTS | No site preparation was necessary. *Setup, photography reading measurements and elevations were completed in 4 hours

*Does not include preliminary site evaluation time or travel to and from site.

CAMERA STATION LOCATIONS



SITE: PRATT THROUGH TRUSS

LOCATION: Nelson County

SITE DESCRIPTION: Single-span metal truss bridge of Pratt type

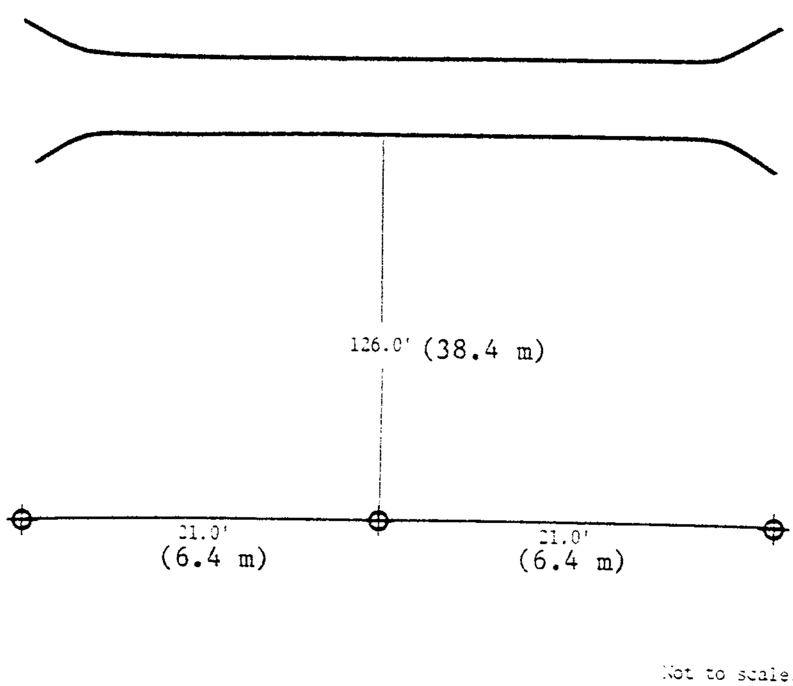
VIEWS: 1 elevation

ADDITIONAL EQUIPMENT:

COMMENTS: No site preparation was necessary

The only problem encountered was the packing of equipment down a steep embankment to the site

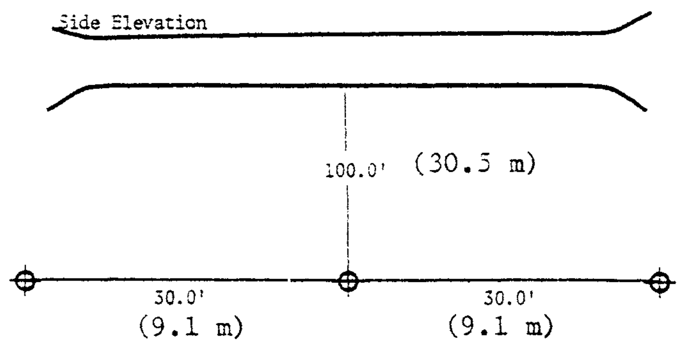
CAMERA STATION LOCATIONS

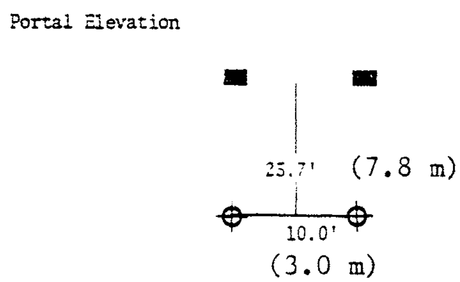


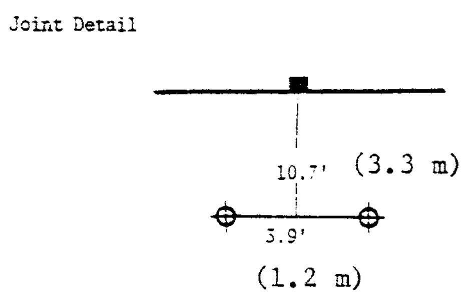
SITE	THACHER TRUSS
LOCATION	Over Linville Creek at Broadway, Virginia
SITE DESCRIPTION	Single-span, multiple intersection, metal truss bridge on masonry abutments
VIEWS	1 side elevation 1 portal elevation 1 lower joint detail
ADDITIONAL EQUIPMENT	Step ladder Tree pruner Waders
COMMENTS	Preparing site included trimming a tree which obscured the bearing and part of the truss on the right side of the elevation. The stream was shallow and it was not particularly difficult to maneuver with photographic equipment. It was necessary to take photographs early in the morning to avoid shooting into the sun. As the day progressed, it was necessary to wait for clouds to obscure intense rays of the sun. *Clearing site, setting up, photogaphing elevation, portal, and joint detail, reading measurements and elevations were completed in 7 hours. *Does not include preliminary site evaluation time or travel time to and from site
CAMERA STATION LOCATIONS	Following page

CAMERA STATION LOCATIONS

Thacher Truss Bridge





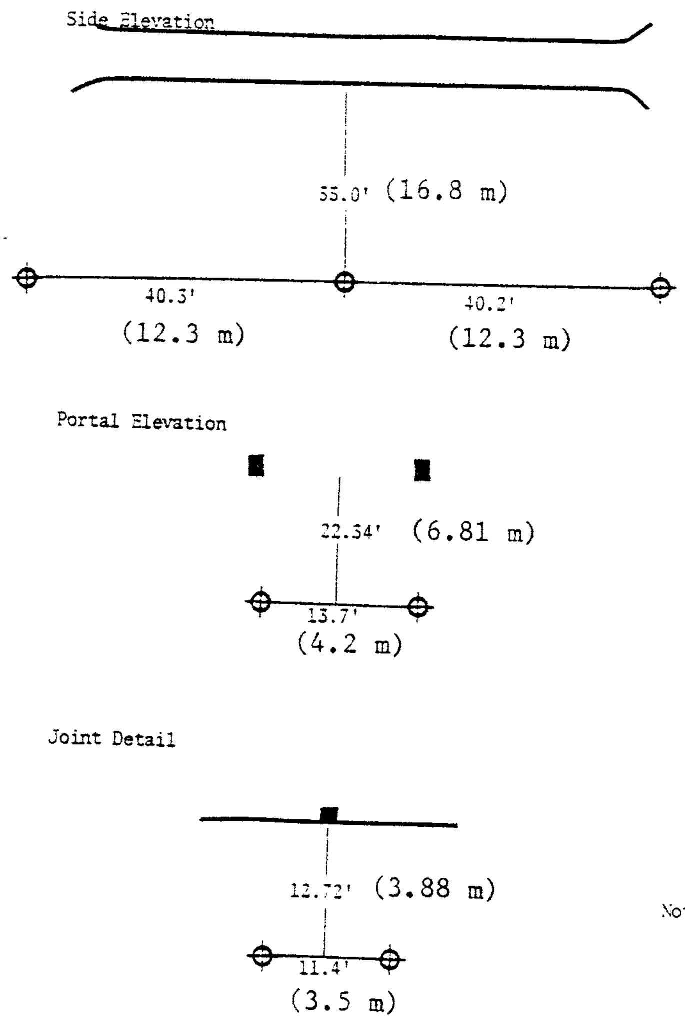


Not to scale.

SITE	BEDSTEAD PONY TRUSS
LOCATION	Augusta County
SITE DESCRIPTION	Early 20th century single-span metal truss bridge of bedstead pony type
VIEWS	1 side elevation 1 portal elevation 1 joint detail
ADDITIONAL EQUIPMENT	Waders Step Ladder
COMMENTS	No site preparation was necessary; there were no trees obscuring the view and the stream was very shallow. The only problem encountered was a quick rainstorm which moved in during the last hour of photography. *Setup, photography, and recording time was 5 hours. *Does not include preliminary site evaluation time or travel time to and from site.
CAMERA STATION LOCATIONS	Following page

CAMERA STATION LOCATIONS

Augusta County Bedstead Pony Truss Bridge



Not to scale.

SITE: HODGE'S FERRY BASCULE BRIDGE

LOCATION: Portsmouth, Virginia

SITE DESCRIPTION: Moving bascule span of a multi-span bridge

VIEWS:
1 side elevation
1 portal elevation
1 detail elevation of rocker arm

ADDITIONAL EQUIPMENT:
Motor boat
Anchors
Rope

COMMENTS:

This was one of the most difficult sites chosen to study. The river is navigable and therefore required coverage by boat.

To stabilize the boat, 2 anchors and 1 line tied to a pier were used. Timing was critical; as soon as the camera was leveled it was necessary to activate the camera or it quickly became out of level. A man on shore with a transit kept the boat on line parallel with the bridge.

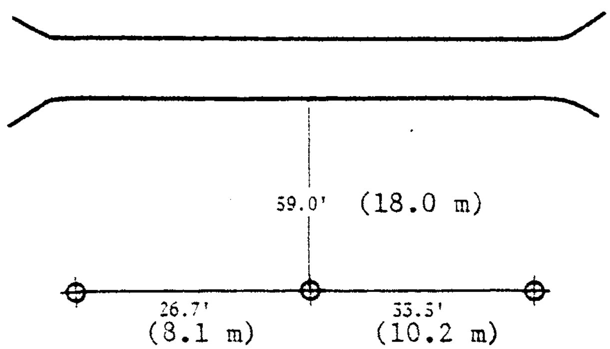
Upon return to the laboratory, all side elevation photographs were found to be of such poor quality that they had to be redone, requiring another day at the site.

CAMERA STATION LOCATIONS: Following page

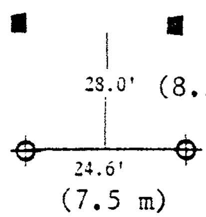
CAMERA STATION LOCATIONS

Hodges Ferry Bascule Bridge

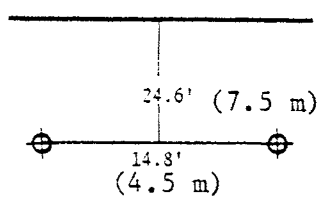
Side Elevation



Portal Elevation



Rocker Arm Detail



Not to scale.

SITE — LAKE COHOON BRIDGE

LOCATION — Lake Cohoon, Nansemond County

SITE DESCRIPTION — 19th century wooden bridge on brick abutments, hidden in man-made lake, reemerged during 1980 drought.

VIEWS — 1 side elevation

ADDITIONAL EQUIPMENT — Waders

COMMENTS — Several unanticipated problems were encountered at this site.

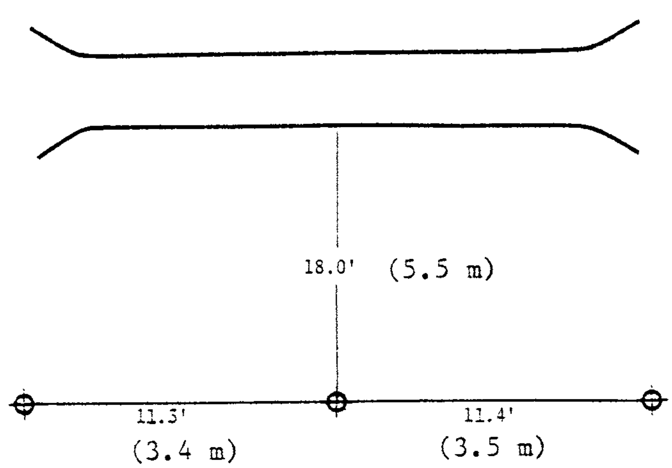
The photography was successful despite a light rain that lasted most of the morning and forced the work to stop at several points.

It was extremely difficult to maneuver on the ground surrounding the old bridge. The ground consisted of soft, deep, silty mud. There was no solid surface on which to set the tripod until a discarded piece of metal was found on the lake bed. This provided a hard, flat surface but the underlying mud affected the camera setup much like a rocking boat did. Once the camera was leveled, it was activated immediately, before movement forced the camera out of level.

*Setup and photography time was 4 hours.

*Does not include preliminary site evaluation time or travel time to and from site

CAMERA STATION LOCATIONS



SITE — LEE BRIDGE

LOCATION — Richmond, over the James River

SITE DESCRIPTION — Multi-span concrete arch, open spandrel bridge

VIEWS — 1 side elevation selected portions

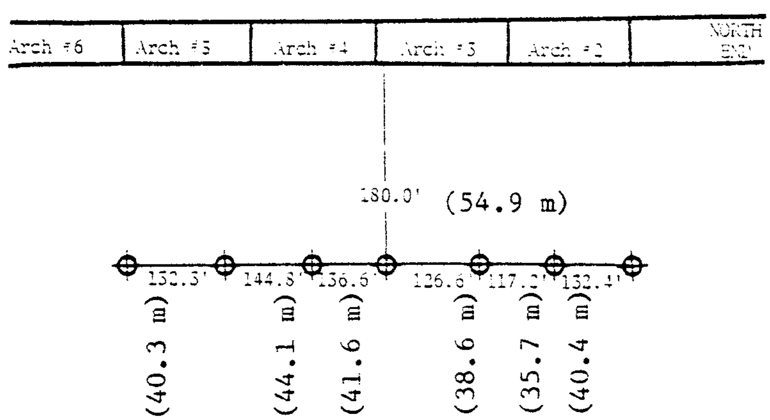
ADDITIONAL EQUIPMENT — Flat bottom boat
8' stakes
Rope

COMMENTS — Site conditions presented many problems. Deep water required use of a boat. Parts of bridge were in accessible due to buildings or large trees. On the first attempt at this site, the current was so swift that it was impossible to keep the boat on course and several photographs were taken at odd, uncalculated andles to the bridge. Reshooting these on a clear day with smooth water made the process much easier and took far less time.

It was decided to use only representative sections of this long span bridge. The time involved in recording the hard-to-reach spans was considered excessive for this project. The technique was tested and, if necessary, those spans could be done at a later date.

Arches of the northern section of Lee bridge are reproduced in this report.

CAMERA STATION LOCATIONS



2054

SITE	HOPEWELL MILL
LOCATION	Prince George County, east of Hopewell
SITE DESCRIPTION	Brick and concrete foundation walls - remains of a mill
VIEWS	Plan
ADDITIONAL EQUIPMENT	Cherry picker Camera mount for cherry picker bucket

COMMENTS

Targets were laid out and elevation readings were taken before photographing site.

Several electric wires crossed the site and extreme care in maneuvering the cherry picker was necessary. Working around the wires necessitated taking 5 photographs and using 4 models.

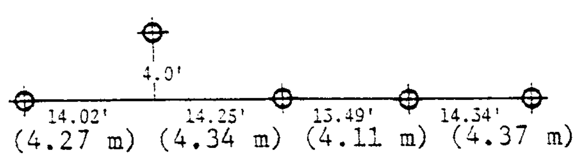
A plumb bob and string were attached to the cherry picker bucket to locate the center of the camera over the center of each target.

Site was cleared of vines and leaves in several hours on the day before photographing it.

*Setup, readings, and photography were completed in 4 hours.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



Not to scale

Camera was 25.0' from targets, vertically. This is a plan view of the target setup.

Target #4 is offset 4.0' to the west because live wires were in the way.

SITE	HUMPBACK COVERED BRIDGE
LOCATION	Covington, Virginia
SITE DESCRIPTION	Single span, wooden covered truss bridge on masonry abutments.
VIEWS	1 side elevation 1 portal elevation 1 interior panel detail
ADDITIONAL EQUIPMENT	Step ladder Tree pruner Waders

COMMENTS

Preparing the site included trimming some foliage from trees. The stream was shallow enough for waders on the side which was being photographed.

Direct sunlight on the wood siding gave a mottled appearance to the surface as it shone through the foliage. Several shots were timed to correspond to cloud cover over the sun; this added slightly to the time involved.

An experimental model was shot on the interior, which was very dark. No special lighting was used, only time exposure. Results were very good. While plotting this interior model and the portal elevation it was possible to record great detail, e.g. the projection of a staple from a wood post could be clearly delineated.

*Clearing, setting up, photography and readings were completed in 8 hours.

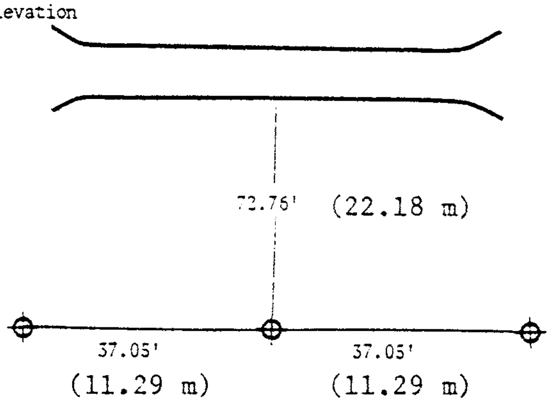
*Does not include preliminary site evaluation time or travel time to and from site.

2056

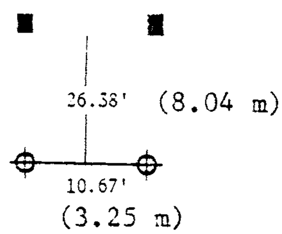
CAMERA STATION LOCATIONS

Humpback Covered Bridge

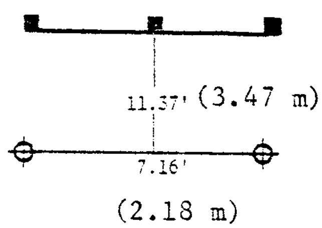
Side Elevation



Portal Elevation



Interior Structure



Not to scale.

SITE CROZET'S BLUE RIDGE RAILROAD TUNNEL

LOCATION Augusta County

SITE DESCRIPTION 19th century stone masonry railroad tunnel

VIEWS 1 elevation

ADDITIONAL EQUIPMENT
Tree pruner
Bush ax
Wheelbarrow

COMMENTS This site was very inaccessible. It was cleared the afternoon before photography was to be done. Because the tunnel is in a very deep cut, the optimal photography time was noon.

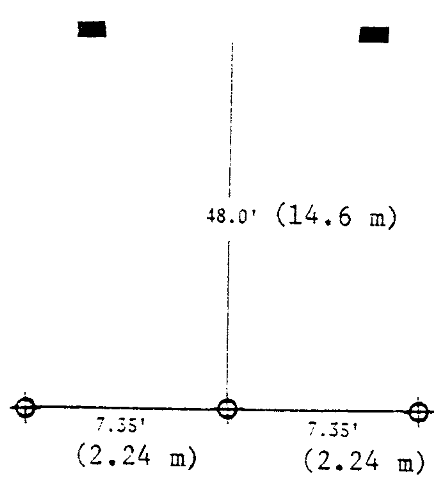
The wheelbarrow was necessary because the tunnel was far from the road and all equipment had to be carried by hand.

Because of protruding rocks on either side of the tunnel, three photographs were taken in order to see the butting of the cut stone with the mountain.

*Setup, photography, and recording time was 2 hours.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



Not to scale.

2058

SITE: SHENANDOAH TRUSS

LOCATION: NF Shenandoah River at Woodstock, Virginia

SITE DESCRIPTION: 3 span truss on lally columns — very high bridge, dam upstream, bouldery streambed. Thigh deep water in areas. Small island, with tall trees, covers 1 span.

VIEWS:
1 elevation
1 portal view

ADDITIONAL EQUIPMENT:
8' step ladder
Tree pruner
Waders

COMMENTS: This was one of the most troublesome sites encountered for the study. It was decided that the two spans not obscured by foliage be photographed while the water was low, and a return trip be made after the leaves had fallen to photograph the remaining span.

Initial site preparation included trimming some bushes, setting targets on bridge and below bridge in water.

Maneuvering with equipment down rocks, over boulders, and through water was difficult. Setting up for shots in the stream was time-consuming.

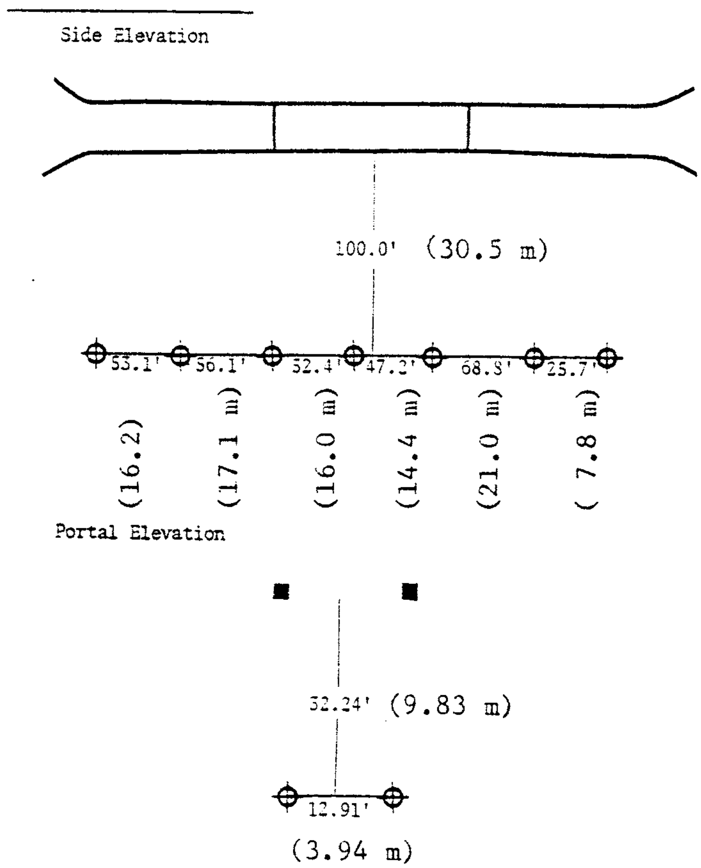
It was necessary to return twice to this site, once to reshoot several photographs which were of poor quality and once to photograph the south truss span. It was hoped that some photographs could be taken at this return time from the dam upstream. The water level was significantly higher, making it impossible to stand on the dam and difficult to maneuver in the stream. This site was not photogrammetrically reproduced in this report.

*Total time spent clearing, setting up, reading measurements and elevations and photographing this site was 16 hours.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS

Shenandoah Truss Bridge



Not to scale.

2060

SITE BREMO WAYSIDE

LOCATION Fluvanna County

SITE DESCRIPTION 19th century stone rest area on old road; spring channelled to a bowl carved in stone.

VIEWS
1 elevation, entire site
1 elevation, carved bowl

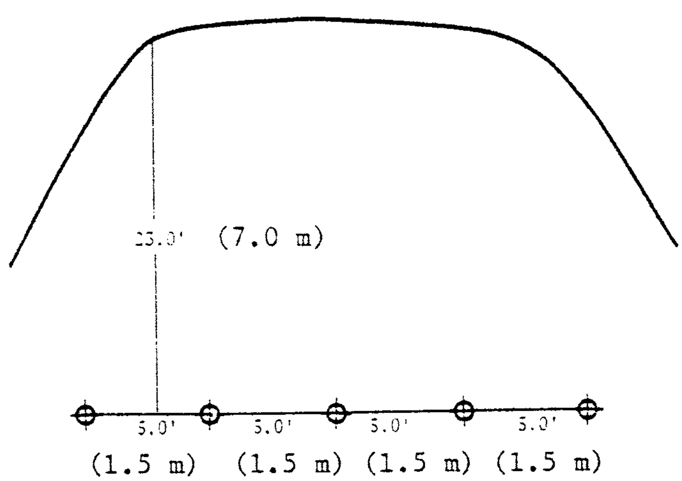
ADDITIONAL EQUIPMENT
Clippers
Broom

COMMENTS Photographing this site was unsuccessful. Many trees blocked the view and made it necessary to take an excessive number of photographs very close together. It was not possible to plot a drawing which adequately documented the wayside from elevation photographs. A plan view would have been successful but getting a cherry picker to the site was too complicated to warrant reshooting.

*Site clearing, setting up, photographing, and recording time was 4 hours.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



Not to scale.

SITE — THREE NOTCHED ROAD TRACE

LOCATION — Albemarle County

SITE DESCRIPTION — 18th Century road, now dirt secondary road

VIEWS — 1 profile

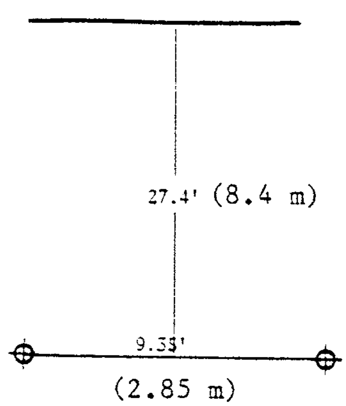
ADDITIONAL EQUIPMENT

COMMENTS — Two horizontal photographs were taken of road profile. Photogrammetric coverage of site was unsuccessful. No useful documentation drawing was possible using the models of the profile.

*Setup, photography, and recording time was 1 hour.

*Does not include preliminary site evaluation time or travel time to and from site.

CAMERA STATION LOCATIONS



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