

FINAL REPORT
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BEST PRACTICES FOR THE REHABILITATION AND MOVING OF HISTORIC METAL TRUSS BRIDGES



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<p>Abstract</p> <p>The Virginia Department of Transportation and the Department of Historic Resources are responsible for the management of about 30 historic truss bridges. All too often, these structures do not meet today's traffic demands or safety standards. Their general deterioration requires disassembly and relocation, rehabilitation and re-erection, or storage. The technology and materials used to build them are no longer in use, and many of the people with practical experience are no longer working. Little information is readily available on safely and effectively identifying and performing necessary operations.</p> <p>VDOT's Knowledge Management Division and the Virginia Transportation Research Council interviewed active and retired engineers, consultants, field personnel, environmental specialists, and architectural historians to collect best practices related to pin-connected and riveted truss bridges. The report is organized using the process followed for the recent rehabilitation of a historic truss in Goshen, Virginia, and discusses the issues faced by those moving and rehabilitating historic metal truss bridges.</p>				

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Virginia Transportation Research Council
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PREFACE

Any knowledge management study is a cooperative effort. The collection and documentation of knowledge in any area, in this case the rehabilitation and moving of historic metal truss bridges, require contributions from those who have the necessary experience and expertise.

Knowledge management as applied in this study composed the collection and documentation of information obtained from several sources. The authors are pleased to recognize the major contributors listed here, who had so great a part in the preparation of this document.

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The authors are also indebted to them and many other colleagues for their contributions, critical reviews, guidance, and assistance.

The decision to rehabilitate a truss bridge at Goshen, Virginia, using his team at the Staunton District Bridge Office instead of a consultant was made by Park W. Thompson, P.E., the District Structure & Bridge Engineer. In interviews with the design team, it became clear that the great amount of engineering research, design, and planning that was devoted to the project should be documented for guidance to others facing similar projects in Virginia and elsewhere. Park and Robert W. Saufley, Jr., who became a member of the research team, gave us extensive interviews, answered endless questions, and gave us access to file documents and the complete photographic record of the work. We found a presentation made to the Transportation Research Board by Keith P. Weakley, P.E., Assistant District Structure & Bridge Engineer, to be a most helpful document in providing a timeline that organized the field operations in our minds.

It was also clear that much of the ultimate success of the Goshen rehabilitation was due to an excellent working relationship with the general contractor, Allegheny Construction Company, Inc., of Roanoke, Virginia. A. Wade Douthat III, President; John W. Douthat, Vice President; and Allegheny's superintendent, W.T. Carder, worked closely with VDOT personnel in an effective partnership. Their cooperation extended to this study. Wade Douthat loaned all of his files, his photographic record of the operations, and a reference text to the research team during the study. Without these insights, this report would have been of much more limited value.

Also of great value to the final report was the background information provided by those retired VDOT bridge engineers interviewed early in the study and by R. Wayne Schwartz, P.E., President of Schwartz and Associates. Each of the bridge engineers, John E. Andrews, P.E., Former Assistant State Structure & Bridge Engineer; Larry L. Misenheimer, P.E., Former Staunton District Structure & Bridge Engineer; William L. Sellars, P.E., Former Lynchburg District Structure & Bridge Engineer; Robert H. Morecock, P.E., Former Fredericksburg District Structure & Bridge Engineer; and Frank L. Prewoznik, P.E., Former Culpeper District Structure & Bridge Engineer, had decades of experience with a variety of bridges, including metal truss structures. Mr. Schwartz is a leading consultant in the inspection, evaluation, repair, and rehabilitation of old truss bridges. His experience, shared freely with his former colleagues, is particularly appreciated. The background information gained during this early phase of the study provided its foundation.

Guidance throughout the course of the study was provided by a Project Panel, VDOT's Historic Structures Task Group, and the Virginia Transportation Research Council's (VTRC) Environmental Research Advisory Committee. Each of these groups played a distinct role in the course of the research, leading to a more useful final document. Critical reviews were provided by Antony F. Opperman, Preservation Program Manager, and Edward D. Wallingford, Engineering Program Manager, Environmental Division, who provided guidance and text for the section on environmental concerns and regulations, and by John E. Wells, Richmond District Preservation Program Coordinator, an architectural historian who provided guidance on the utility of the document to cultural resource personnel.

Administrative guidance and enthusiastic support were provided by Maureen L. Hammer, Ph.D., Administrator of VDOT's Knowledge Management Division; Amy A. O'Leary, Ph.D., Associate Director for Environmental and Business Practices, VTRC; and Jose P. Gomez, Ph.D.,

Associate Director for Structural, Pavement, and Geotechnical Engineering, VTRC. Invaluable assistance in the timely preparation of this document was provided by our Administrative Assistant, Betty A. Sevachko. We happily recognize the formidable skills and somewhat abused patience of VTRC's Editor, Linda D. Evans, and her colleagues in our Media Center. In its final form, this document will owe much of its utility to her and to F. Randy Combs, who developed the graphics, and Edward J. Deasy, who formatted the many pictures in the report.

ABSTRACT

The Virginia Department of Transportation and the Department of Historic Resources are responsible for the management of about 30 historic truss bridges. All too often, these structures do not meet today's traffic demands or safety standards. Their general deterioration requires disassembly and relocation, rehabilitation and re-erection, or storage. The technology and materials used to build them are no longer in use, and many of the people with practical experience are no longer working. Little information is readily available on safely and effectively identifying and performing necessary operations.

VDOT's Knowledge Management Division and the Virginia Transportation Research Council interviewed active and retired engineers, consultants, field personnel, environmental specialists, and architectural historians to collect best practices related to pin-connected and riveted truss bridges. The report is organized using the process followed for the recent rehabilitation of a historic truss in Goshen, Virginia, and discusses the issues faced by those moving and rehabilitating historic metal truss bridges.

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INTRODUCTION

Metal truss bridges were first developed in the 1840s and 1850s, although they did not appear in many areas of Virginia until the 1870s. The earliest use of these structures was as railroad bridges. The use of metal truss bridges for vehicular use seems to have begun in Virginia after the Civil War, and metal truss bridges began to supersede traditional wooden trusses in Virginia during the last quarter of the 19th century. Numerous bridge companies arose throughout the United States and often employed regional representatives to sell their company's products to local counties. Since most varieties of wooden bridges, even covered bridges, needed constant maintenance, and uncovered wooden bridges deteriorated quickly, metal truss bridges were promoted as a more long-lasting solution. Although they were indeed more durable than wooden truss bridges, metal truss bridges had several major drawbacks: in addition to their greater initial construction costs over those of timber trusses or steel beam bridges, they required periodic maintenance, particularly painting, and the cost of upkeep was often perceived as a drain on county budgets. It was common practice among county governments to delay or ignore

what should have been routine maintenance on metal bridges in an effort to stretch dollars, with resultant deterioration and damage to the bridges (Miller and Clark, 1997).

Metal truss bridge plans were standardized in Virginia after 1909. By this time, reinforced concrete bridges were beginning to be used as a more maintenance-free and long-lived alternative to wooden and metal truss bridges. The use of concrete bridges increased through the first several decades of the 20th century until concrete superseded metal trusses as the dominant type of medium to larger bridge in Virginia. Construction of new metal truss bridges continued through the 1940s, and a few new trusses were built after 1950, but metal trusses became increasingly a less-favored and more specialized form of bridge design. By the mid-20th century, the moving and re-erection of older metal truss spans was much more common than new metal truss construction. Older truss bridges on major highways were often replaced by more modern bridges as traffic increased and the roads were improved; still-serviceable truss spans were frequently relocated to less-traveled back roads (Miller and Clark, 1997).

For the most part, these aging truss bridges, often functionally obsolete, were not perceived as being important historic resources. They were regarded by both transportation professionals and local and state government offices as being merely “old,” not “historic.” Deteriorating with age and, in many cases, overuse, and in need of increasingly expensive painting, repairs, and maintenance, such bridges were scheduled for replacement as funding allowed. Since it was assumed that the bridges would be replaced, little additional maintenance was done.

The spread of the historic preservation movement in America, beginning during the 1960s and 1970s and continuing to increase since then, brought a new appreciation of early bridges, particularly metal truss bridges. Along with this appreciation came increasing demands from the public and preservation organizations for the preservation of at least some of these picturesque examples of earlier engineering practices. Studies of early truss bridges (Virginia’s initial studies in the 1970s and 1980s were the first in the nation) identified a number of important early examples (Diebler, 1975; Miller and Clark, 1997). Later historic bridge studies in the 1990 (cited in Miller, Clark, and Grimes, 2001) were followed by the development of the Virginia Department of Transportation’s (VDOT’s) Management Plan for Historic Bridges in Virginia (Miller et al., 2001). In this plan, older metal truss bridges and other types of bridges across Virginia were surveyed and their significance as historic structures was weighed. The plan, which ensures a consistent and rigorous review of all older bridges, yields management options that range from repairing the structure and maintaining it for vehicular use through documentation and demolition. Unfortunately, by the time their potential historic significance was recognized, many early truss bridges had deteriorated badly.

On Virginia’s primary and secondary highway systems are approximately 30 metal truss bridges judged to be historically significant; that is, they are eligible for inclusion or are listed in the Virginia Landmarks Register or the National Register of Historic Places. Management of these important structures may involve rehabilitation in place or disassembly and relocation to a more favorable site. Either action requires knowledge of the design and behavior of pin-connected and riveted truss bridges, some of which are relatively frail, and an awareness of the

notable features of the structures that must be preserved. Today's engineers who work only infrequently with a smaller population of old bridges do not easily obtain such knowledge.

Relatively little written material exists from the 19th and early 20th centuries regarding the disassembly of truss bridges and their reconstruction at another site, although the portability of these structures was a significant advantage. Disassembled, the bridges were moved easily from place to place on railways and roads as needs and priorities changed, and railroad bridges were occasionally transferred to road agencies as rail loadings increased. Successful completion of these operations, which were more practical than theoretical in nature, depended on the empirical knowledge and skill of builders and their engineers.

In VDOT, all aspects of the maintenance of old truss bridges, including their disassembly and relocation, were directed by engineers in VDOT's Structure & Bridge Division and, since the late 1950s, by district structure and bridge engineers. Many of the most experienced of these professionals, both engineers and senior field personnel, have retired, taking with them a wealth of practical experience.

Although the need to manage these old bridges continues, the description of practices necessary to do so have not been consolidated in one place, and neither the technology nor many of the materials (and therefore experience with them) continue in use—therefore, the potential for knowledge loss was significant. Because of the importance of preserving and sharing the experiential knowledge gained by current staff nearing retirement and by retired staff, VDOT's Knowledge Management (KM) Division sponsored the current research.

PURPOSE AND SCOPE

The purpose of this research effort was to create a reference for use by engineers and historic resource personnel involved in the dismantling and reassembly of truss bridges. The scope of the study was limited to pin-connected and riveted metal truss bridges. The question to be answered was: "How did they design them, build them, take them down, move them, and reassemble them?"

Although the primary emphasis was the structural engineering aspects of the question, guidelines for the rehabilitation of historic structures in a manner that would preserve their integrity and the associated operational and environmental issues were also considered.

Carefully structured interviews with regard to the design, construction, evaluation, disassembly, moving, and rehabilitation of historic structures combined with documentary research formed the foundation of this study of best practices. The process involved in the refurbishing of a truss bridge crossing the Calpasture River in the town of Goshen, Virginia, was used as a detailed case study to present the many issues that must be addressed during the dismantling and restoration of a historic truss bridge

When the project was initiated, the KM Division attempted to set up an on-line team room that would allow VDOT and non-VDOT practitioners in this area to communicate and maintain a library for future use. However, because of the recent (at that time) implementation of a new VDOT intranet, the technology was not yet ready to accommodate this objective. However, this project collected and will maintain in the Virginia Department of Transportation Research Library a collection of old (1940s or earlier) texts concerning truss bridges, thus providing access in a single location for practitioners.

METHODS

As stated previously, carefully structured interviews with regard to the design, construction, evaluation, disassembly, moving, and rehabilitation of historic structures combined with documentary research formed the foundation of this study of best practices. The research approach combined the knowledge management and structural engineering disciplines.

The study began with discussions involving a relatively small group of current and former VDOT employees to establish the information gathering process, guided by VTRC personnel and prefaced by a presentation of the nature of the project and its goals. Further interviews included participants representing the private and public sectors, including engineers, contractors, field personnel, and architectural historians. Combined, the participants presented several decades of experience in all facets of bridge engineering and the evaluation and disposition of historic truss bridges. The interviews with older and retired bridge engineers, contractors, and associated individuals yielded a great deal of general information from their many years of practical field experience.

The knowledge of various practical aspects of bridge work gained in the interviews pointed the way to additional sources of information such as files, drawings, photographs, and older textbooks and treatises on bridge construction. A list of the most helpful of these texts is provided later in this report. The information gained from all of these sources was used to develop the text of this report at the appropriate locations.

The process of the refurbishing of a truss bridge crossing the Calfpasture River in the town of Goshen, Virginia, was used as a detailed case study to organize the document and presents the many issues that must be addressed during the dismantling and restoration of a historic truss bridge. This report documents the complexities of the process from the initial evaluation, the decisions that had to be made, and the care that had to be taken to effect the desired restoration. Information derived from interviews and other contacts with experienced engineers were incorporated into the framework of the Goshen Bridge process to provide more complete guidance as to the best practices for the disassembly, rehabilitation, and moving of historic metal truss bridges. Guidelines for the rehabilitation of historic structures in a manner that preserves their integrity and the operational and environmental issues attendant to the rehabilitation work are also addressed.

THE GOSHEN BRIDGE

One metal truss bridge included in VDOT's Management Plan for Historic Bridges in Virginia (Miller et al., 2001) is the two-span Pratt through truss that carries Route 746 over the Calfpasture River in the Town of Goshen in Rockbridge County, Virginia. As noted on the management recommendation sheet provided in Appendix A, the Goshen Bridge, which was built in 1890 by the Groton Bridge Company, was in poor condition with widespread corrosion and section loss in some of the structural members. Its roadway had been reduced to a single lane sometime prior to 1948. The bridge, shown before its restoration in Figure 1, was posted for a load limit of 6 tons, and thus it was unable to accommodate the passage of various emergency and service vehicles to approximately 12 homes in a section of Goshen that had no other means of access. As is the case with many other older metal truss spans, costly maintenance activities had been deferred with the aim of eventually replacing the Goshen Bridge with a modern structure. This might well have occurred but for the interest in transportation history within VDOT, the appointment of a Virginia Historic Structures Task Group, and the adoption of the management plan.

Several factors contributing to the historical significance of the Goshen Bridge and its listings in the Virginia Landmarks Register and the National Register of Historic Places are noted on the recommendation form in Appendix A. These, combined with strong local pressure both to preserve the bridge as an important landmark and to keep it in service, resulted in VDOT's decision to rehabilitate the structure completely with two lanes of vehicular traffic to design it for the American Association of State Highway & Transportation Officials (AASHTO) H20-44 standard truck loading (AASHTO, 2002).



Figure 1. Route 746 Bridge Over Calfpasture River at Goshen, Virginia

VDOT then made the decision to perform the project engineering work in the Structure & Bridge Section at its Staunton District Office to preserve the knowledge and skills developed in the process within VDOT. The rehabilitation included the disassembly of the bridge, the replacement of those members that were weakened by section loss and those not fabricated to meet modern design specifications, the galvanizing of the members to provide lasting protection, and the reassembly of the restored substructure. Fortunately, the general contractor awarded the job, Allegheny Construction Company, Inc., of Roanoke, Virginia, was both talented and interested in contributing to the complex process. The result was a smoothly operating partnership that accomplished the goals of the project. Nevertheless, the Goshen rehabilitation is not without controversy. It was expensive, more expensive than replacing it with a modern structure would have been. Many of the members had to be replaced to construct a bridge that would carry today's loads, preserving, in the words of a VDOT historian, "the technology rather than the artifact" (Newlon, 2003).

Regardless of the final goal in the disassembly and reassembly of a metal truss bridge and the nature of the rehabilitation and member replacement required or desired, the steps in the process and the decisions that must be faced are the same as those encountered in the restoration of the Goshen Bridge.

UNDERSTANDING THE TRUSS BRIDGE AS A STRUCTURE

A detailed discussion of the analysis and design of truss bridges is beyond the scope of this report, but a basic knowledge of the manner in which such structures carry loads is essential. Figure 2 shows the various members that comprise a typical truss bridge, in this case a common Pratt truss. The load path is easy to trace. Loads on the bridge are transmitted by the deck to the

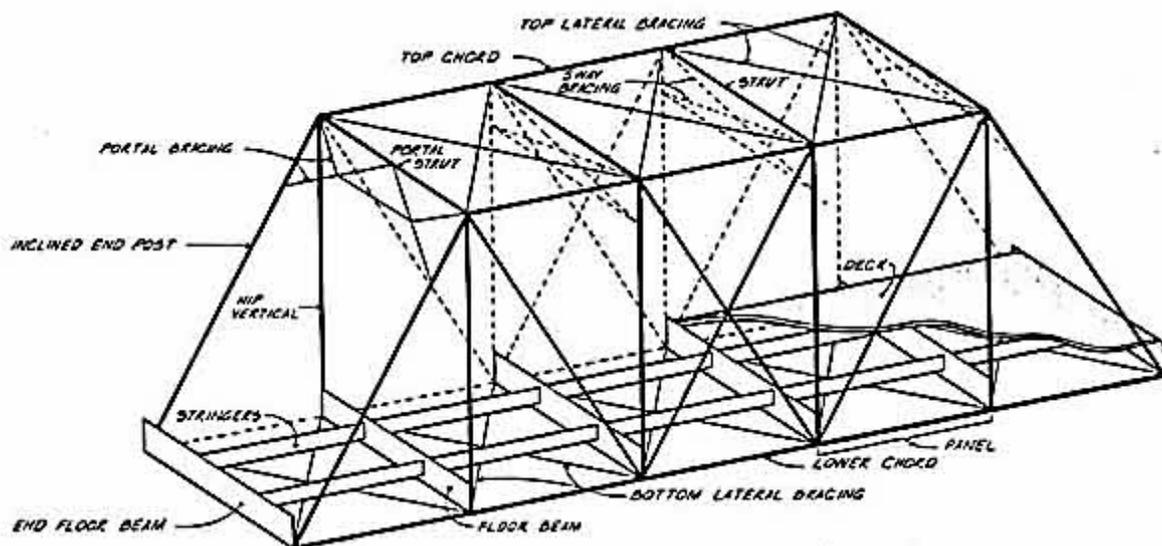


Figure 2. Components of a Typical Truss Bridge. *Source:* Historic American Engineering Record. Trusses: A Study by the Historic American Engineering Record. HAER T1-1. (Poster). National Park Service, Washington, DC, 1976. Reprinted with permission.

longitudinal stringers, to the floor beams, and then to the two trusses at each panel point, i.e., the point at which the members intersect at a pin or riveted gusset plate. Pin-connected truss members form triangles, since this structural configuration remains stable under load. Vierendeel trusses, composed of rectangular panels, maintain stability under load through sufficient rigidity at the joints to accommodate bending moments.

Trusses can be envisioned as deep I-beams with triangular openings in their webs, as shown in Figure 3, carrying the loads on the bridge (its live load) and the weight of the structure itself (dead load) to abutments at either end. The top chord corresponds to the upper flange of the beam, and the lower chord to the lower flange, with the members between the chords forming the web.

Under the load shown in Figure 3, the beam deflects downward, placing the top flange in compression and the bottom flange in tension. Similarly, the end posts and top chords of a truss are in compression while the bottom chords are in tension. The forces in the web members depend on the configuration of the truss.

Figure 4 shows the members of a Pratt truss and indicates those subjected to compressive and tensile forces when the structure is loaded. The compression members (shown darker on the diagram) are more substantial members and are braced by the lateral struts (shown in Figure 1) to resist buckling under load.

In the design of a truss such as that shown in Figure 4, the dead load of the structure is taken to be concentrated at the panel points. The weight of the floor system is carried by the bottom panel points, and the weight of the trusses and bracing is distributed equally between the top and bottom panel points. The total dead load is distributed as vertical forces equally between the bearings at either end of the trusses.

Particular computer software packages, such as AASHTO's Bridge Analysis and Rating System (BARS) (AASHTO, 1994), can be used for the structural analysis of pin-connected trusses, and graphical methods have long been used. Often, however, the analysis is performed by hand using the method of joints, in which the analysis proceeds by balancing the tension and compressive forces joint by joint throughout the truss, or the method of sections, a more

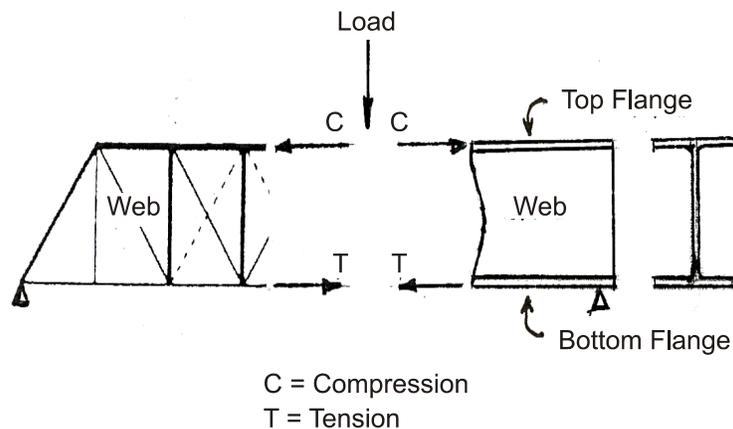
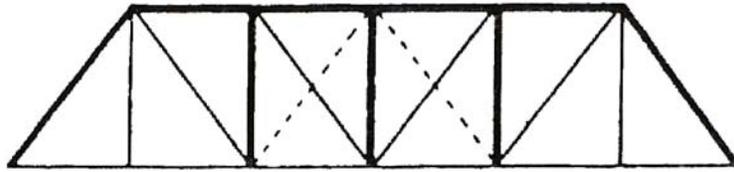


Figure 3. Truss-Beam Analogy



PRATT

1844 - 20th Century

Diagonals in tension, verticals in compression, (except for hip verticals adjacent to inclined end posts)

Length: 25 - 150 feet
0 - 45 meters

Figure 4. Pratt Truss. *Source:* Historic American Engineering Record. Trusses: A Study by the Historic American Engineering Record. HAER T1-1. (Poster). National Park Service, Washington, DC, 1976. Reprinted with permission.

streamlined procedure that investigates the equilibrium of selected sections of the truss. The horizontal and vertical components of the forces in the members at each joint must be equal, and a “free body” of the entire truss or any section of it must be in equilibrium to avoid collapse. Although it is not within the scope of this report to teach truss analysis or design, a brief description of the application of these two methods to the truss in Figure 4 will facilitate an understanding of the behavior of such structures under load.

The Pratt truss in Figure 4 is shown under its dead load in Figure 5. Since the loads are distributed symmetrically at the upper and lower panel points as explained earlier, the end

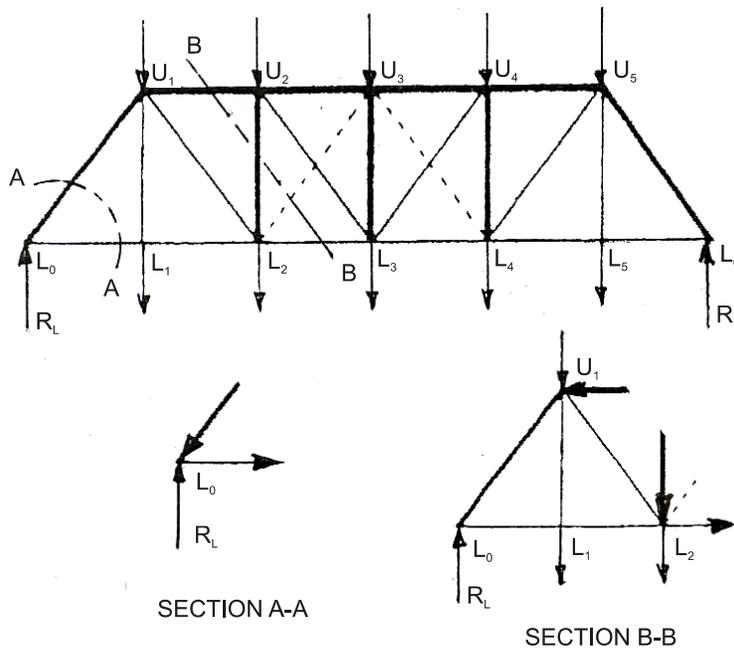


Figure 5. Procedures for Analysis of Truss Under Dead Load

reactions R_L and R_R are equal. The method of joints is most easily demonstrated at the left end of the truss, section A-A. For the algebraic sum of the vertical forces to equal zero, the upward reaction, R_L , must be balanced by the vertical component of the downward (hence, compressive) stress in the end post, $L_0 U_1$, since member $L_0 L_1$ has no vertical component. Similarly, the stress in the horizontal member $L_0 L_1$ must be equal to the horizontal component of the stress in the end post $L_0 U_1$. For equilibrium, the member $L_0 L_1$ must be in tension.

It is convenient to use the method of sections to calculate the force in member U_1-U_2 . With regard to the free body, section B-B in Figure 5, equilibrium requires that both the horizontal and vertical forces acting on the section and the moments (the product of the external forces acting on the section and the distances of those forces from the point about which the moments are taken) be balanced. If moments are taken about joint L_2 , the external forces in truss members U_2-L_2 and L_2-L_3 are eliminated since they pass through joint L_2 , the center of moments. For equilibrium, the algebraic sum of the moments attributable to the known external reaction R_L and the loads at panel points U_1 and L_1 and the sought force in U_1-U_2 must equal zero, making the latter force easily computed. Sections can be chosen to facilitate the determination of forces in other truss members.

Redundancy must be considered when disassembling a truss. *Redundancy* refers to the availability of a redundant load path, the presence of other members capable of supporting the structure if a member should fail. In a bridge, load path redundancy exists if there are more than two longitudinal members, such as girders or trusses in a span. Thus, each of the two trusses supporting a span in the Goshen Bridge is non-redundant. Further, all truss tension members, pins, and the hanger assemblies connecting the floor beams to the trusses are non-redundant and considered fracture critical, meaning that their failure could seriously affect the stability of the structure. Failure to consider the lack of redundancy in a structure could result in a dangerous situation.

Although it is not the point of this exercise to teach the analysis of trusses, the importance of individual truss members to the equilibrium of the entire structure should be apparent. Thus, a truss cannot be disassembled unless it is supported at every panel point by either external bents or an interior support system. The application of interior supports is illustrated in the detailed discussion of the disassembly of the Goshen Bridge later in this report.

THE DISASSEMBLY, MOVING, AND REHABILITATION OF TRUSSES: DECISION POINTS IN THE PROCESS

Decisions regarding the disposition of any historic bridge begin with an assessment of its suitability for continued service in the transportation system and its evaluation as a historic property. Two complementary resources that provide a basis for these decisions in Virginia are the Bridge Safety Inspection Reports, required by federal regulations to be completed by VDOT and other bridge owners every two years (every year for fracture-critical structures), and the Management Plan for Historic Bridges in Virginia (Miller et al., 2001), described earlier in this report and completed for every structure that is eligible for inclusion or is listed in the National

Register of Historic Places and the Virginia Landmarks Register. Choices, beyond leaving the structure as is, include documentation and demolition of the bridge, preservation or restoration in place or at a more appropriate location, or rehabilitation to meet current system needs. The decision process that follows is complex, involving an interaction of many engineering, environmental, and historic factors, in combination with contractor expertise and the availability of funding.

The Disposition of a Historic Structure

The decision as to the disposition of a historic bridge usually results from the findings of the periodic safety inspections that indicate the structure is structurally deficient (deteriorated to the point that it is no longer safe) or functionally obsolete (i.e., of a design that can no longer sustain the loads of today's vehicles or carry the volume of traffic it must serve). Historic significance is determined on the basis of the National Register criteria as established by federal regulation (36 C.F.R., Part 60). In the case of old trusses, which are costly to maintain and difficult to strengthen or widen, the engineering decision is often to demolish the structure and replace it with a modern bridge. This decision may be tempered by the findings of an evaluation of the historic importance of the truss. *A Management Plan for Historic Bridges in Virginia* (Miller et al., 2001) is a valuable asset in this regard, providing a consistent basis for the decision and a prioritized list of management options for the disposition of the bridge. Input from community leaders and citizen groups is also considered and may overrule the decision to replace a structure.

As noted previously, the decision was made to rehabilitate the Goshen Bridge, which, though severely deteriorated, was historically significant and enjoyed strong support as a local landmark. Engineering considerations, however, dictated the disassembly of the bridge and the replacement of many of the members of the trusses to serve current traffic loads. It was recognized that this unprecedented course of action would be costly, and it was possible only with the allocation of special funds.

Given this decision, preserving the historical integrity of the Goshen Bridge became an important consideration. The project involved a large through truss with significant deterioration, which would have to be disassembled, reassembled, and rehabilitated not only to continue to serve vehicular traffic but also to handle increased loads. This situation contrasted with that of two important truss bridges that in the 1970s had been saved from demolition through the efforts of VDOT's historic resource and engineering personnel. The first of these, a small bowstring pony truss, the oldest truss then existing in Virginia, had been relocated and rehabilitated to serve as a pedestrian bridge in a rest area, and the second, a rare Fink deck truss, was removed from service and relocated to a walking trail in a park setting (see Figure 40). In these two cases, the structures were in relatively good condition and maintaining historical integrity was not a problem. As mentioned previously, keeping the Goshen Bridge in service did result in substantial replacement of members, but the original configuration of the bridge was maintained.

Planning for the Goshen Bridge project was done in accordance with *The Secretary of the Interior's Standards for Treatment of Historic Properties* (Weeks and Grimmer, 1995). This document should be used to guide any work being planned for a historic bridge, and an interpretation of the *Secretary's Standards* for bridge-related projects is included as Appendix B.

Field Inspection of the Existing Structure

If an old truss is to be taken down, the first step in the operation must be a detailed field inspection of the condition of the truss members and the general dimensions of the bridge and its site. This will indicate the nature and locations of supports required during the disassembly of the trusses and the type of equipment required. It serves to ensure both the safety of workers and the successful preservation of the structure during dismantling operations. Environmental issues related to the presence of lead-based paint, the presence and preservation of wetlands, and the protection of the waterway can affect several aspects of the operations, such as the location of cranes to stabilize the trusses during disassembly and the storage of members after removal. The construction of containment structures to collect the coating during removal or measures to prevent the release of coatings during dismantling operations and the secure storage of hazardous wastes may be particularly challenging aspects of the project.

If the operation includes the reassembly of the truss with the replacement of members, the inspection also must include detailed measurements of the dimensions of every member in the bridge so that the loads and stresses in the truss members can be computed. Since the Goshen Bridge, for which original plans were unavailable, was being rehabilitated to carry current loads, the inspection was particularly thorough and comprehensive. It involved members of the design team, bridge safety inspectors, and bridge maintenance personnel. Precise information was obtained on the alignment of the trusses; the configuration and condition of each member; and, as much as possible given the extensive deterioration of the structure, the dimensions of the members. The field inspection verified and complemented the data recorded during the safety inspections and expanded upon them. Numerous photographs documented the findings and the state of the structure.

Measurements of the trusses on either side of the spans were complicated by the layout of the structure, which was skewed at approximately 35 degrees, and by the discovery that the bridge had sheared the anchor bolts at the Goshen abutment and drifted slightly downstream. Severe section loss in several members, indicating the extent of member replacement required, was documented during the inspection, and camber in the trusses, the upward curvature of the trusses to avoid sagging after construction and during the passage of vehicles, also was disclosed. Camber is a common feature of truss designs that must be considered in the case of member replacement. Old texts and specifications indicated that camber often was provided in truss bridges by making the lengths of the top chords slightly longer than those of the lower chords. This approach, discussed later, was used successfully to provide camber in the reconstructed trusses on the Goshen Bridge.

Structural Analysis, Design, and Plan Preparation

In the simplest terms, the procedure for disassembling a truss is merely the reverse of the construction procedure. Often, supports are placed beneath the floor beams at each panel point, and the truss is dismantled panel by panel, followed by the deck, the stringers, and finally the floor beams. In practice, however, factors such as the original design features of the bridge (and any subsequent alterations), soil conditions, the nature of the stream flow, the degree of deterioration of the trusses themselves, and environmental restrictions all tend to complicate the process.

Complete rehabilitation of a historic truss is accomplished through a complex design process that begins with the determination of a methodology for supporting the trusses during their disassembly and includes an analysis of the forces in the truss members, the selection and design of those members that must be replaced, and then the actual dismantling and reassembly of the bridge in the field. A wide variety of resources are used, including engineering texts and specifications in use at the time of the original construction of the bridge and the current AASHTO bridge specifications (AASHTO, 2002). Engineering expertise and field experience on the part of the contractor are required to ensure success.

In addition to the computation of member forces in truss bridges, other elements must be considered in the analysis or design of truss members. This is essential in determining which truss members will have to be replaced. The following action list, although not comprehensive, should be checked routinely as part of any analysis and checked for compliance in each case with current AASHTO specifications (AASHTO, 2002).

- Compute bearing stress of all connected parts to ensure that areas are sufficient to ensure that bearing contact surfaces do not fail or crush. This is particularly important in all pin connections and bolted connections
- Check shear stresses and moment carrying capacity (flexural strength) of truss connection pins.
- Check fatigue properties for non-redundant load path members and loading cycles that will reduce allowable stresses.
- Compute the eccentricity between the “geometric centers” (the centerline through the center of the pins) of pin-connected truss members and the computed center of gravity of built-up members with cover plates. This eccentric distance is used in the computation of allowable column loads.
- Check to see if the ends of compression members have been milled to bear against each other. This will determine the member end conditions in the computation of allowable column loads.
- Check spacing of lacing bars in built-up compression members for spacing to meet current AASHTO specifications.

- Check spacing of rivets or bolts in the end of built-up members to ensure terminal development in cover plates.
- Measure all eye bar dimensions to ensure that the physical shape will meet the current AASHTO specification for net area). In addition, check bearing stresses for the computed forces in these members.
- Check all threaded members (normally counter members in pin-connected truss bridges) for “upsetting” of the threaded portion. In addition, determine if the threads have been rolled or cut. These factors will determine if the net section or gross section will govern in the load-carrying capacity of a tension member.
- Loop-welded ends of tension members are no longer permitted. These members will have to be replaced so that the load-carrying capacity of the truss bridge will be adequate.
- Check all members for rusting and loss of section when load-carrying capacities are computed.
- In accordance with current AASHTO specifications, check wind loads on the superstructure and wind loads on the live load to determine if adequate lateral bracing is available in the current structure.
- If possible, perform testing of existing materials to determine steel yield strengths and welding compatibility (if a member is to be repaired).
- If existing members are to be galvanized, ensure the compatibility of the metal with galvanizing process.

The Calfpasture River at Goshen flows rapidly, carrying runoff from a substantial mountainous drainage area. During frequent floods, the river carries significant amounts of debris that would pose a threat to temporary supports located in the river or the adjacent flood plain. For this reason, the Staunton design team decided to use beams available in a district storage yard to construct a specially designed interior falsework beam system, shown in Figure 6, consisting of three lines of continuous girders as a primary means of support throughout the job. The falsework beams were supported on blocks on the floor beams of the bridge and on three temporary bents, two at the abutments and one at the pier. They were designed with splices as required to form a continuous beam across the bridge, and a heavier section was used to resist negative moment over the pier. Between the lines of falsework beams, cross frames resisted torsion in the support structure during disassembly, and lateral bracing supported the compression flanges of the girder lines. Drawings and other information on the support system, including the design of the steel falsework bents, and other structural details and procedures described elsewhere in this report can be found on the project plans (VDOT, 2000a).



Figure 6. Falsework Beams during Installation

Falsework hangers (Figure 7) support the floor beams at their intersections with the falsework beams. They had to be tightened to a snug fit before any loads could be transferred to the falsework beams and adjusted as necessary to remain snug during dismantling and re-erection operations. Once the hangers were tightened and the loads transferred, the two simply supported (independent) truss spans acted as a two-span beam continuous over the central pier. Thus, loads on one of the spans have an effect on the deflection of the other, and this had to be considered during operations to unload or reload the bridge. Re-erection of the restored trusses was performed symmetrically from the center pier toward the two abutments.

Use of the internal falsework system on the Goshen Bridge was influenced by concerns about the possibility of high water and the availability of the necessary structural members. Under different conditions, other systems providing supports at the panel points might have been attractive. Waddell (1889) mentions timber cribbing using timbers from the joists and floor beams for the construction of low falsework and provides a design procedure and a drawing of a taller and more elaborate structure. Today it is possible to use other structural elements to configure innovative falsework systems. One such approach using rental scaffolding for both support and worker access is shown in Figure 8. The system offers the capability of bridging short sections of the stream, but it would not be feasible if the possibility of high water presented a hazard.

To ensure the safety of the bridge against overloading during removal and re-erection operations, the plans also included the suggested movable platform and walkway for worker access, shown in Figure 9. Alternate methods could be submitted for approval by the contractor subject to limitations of 50 pounds per square foot for dead load and 50 pounds per square foot for construction live load. The suggested work platform was approximately 8 feet wide by 15

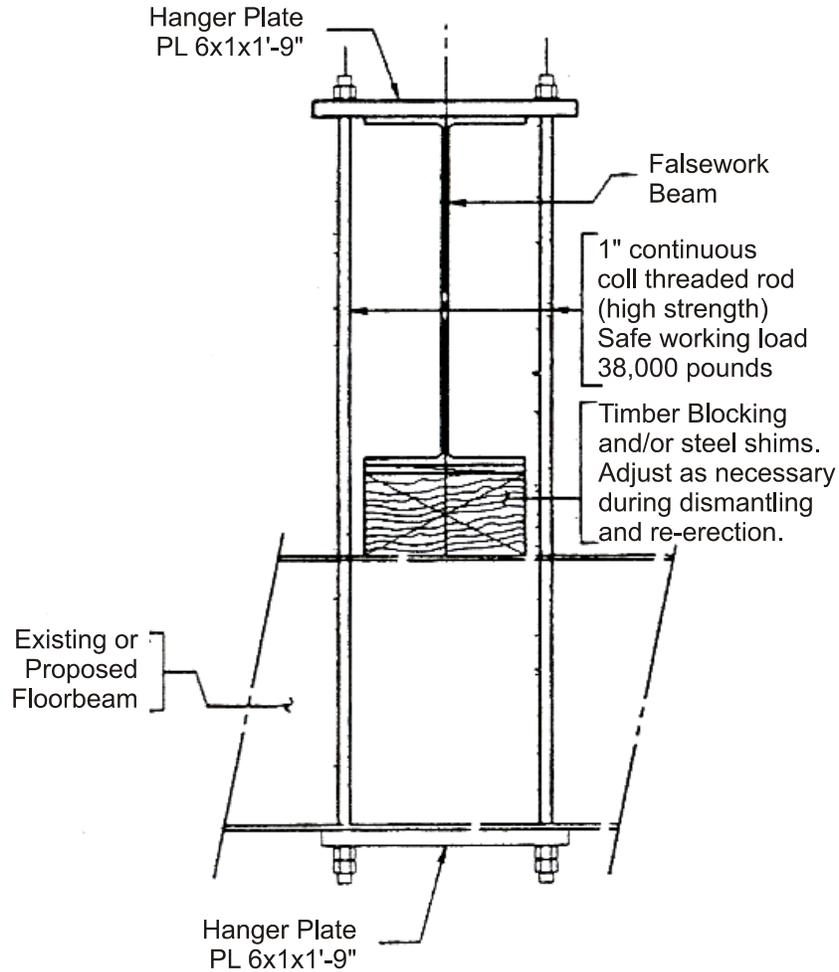


Figure 7. Falsework Hanger

feet long, but other configurations not exceeding 120 square feet in area were allowable. In fact, an entirely different alternative was proposed by Allegheny Construction Company, Inc., and approved by the district bridge engineer. Nevertheless, the inclusion of limitations on the size and weight of any alternative access systems may be warranted to preserve a deteriorated structure.

In addition to the details of the falsework required to support the bridge and the worker platform, considerable extra detailing of the existing structure was included in the plans to assist the contractors in bidding the job. These included an expanded general note describing special requirements; a schedule of quantities that noted the members scheduled for replacement based on the field inspection; a layout plan showing the existing location of the bridge, which had drifted after shearing its abutment anchor bolts; and detailed drawings of the existing trusses with connection details and a complete description of the members. Complete details of the replacement members and new bearings were included, and a suggested sequence of construction was provided for contractor guidance.



Figure 8. Falsework System Supporting Each Panel Point

Contract documents (VDOT, 2000b) supplemented the plan set in providing needed flexibility. For example, provision was made for any additional replacement of members beyond those anticipated at the time of advertisement of the project; these were to be paid for on a “per each” basis as opposed to inclusion in a “lump sum” item, facilitating negotiations for any unforeseen work.

Condition Assessment and Replacement of Members

The widespread serious deterioration of the trusses combined with the requirement to ensure that the reconstructed Goshen Bridge would be adequate to carry a standard highway loading necessitated the replacement of many structural members. Based on findings of section loss, active corrosion, and pack rust during field inspection, the design team decided at the outset to replace more than 100 members, including all end posts, hip verticals, upper chord members, counters, and pins. Radiographic and ultrasonic testing was required to ensure the suitability of those fracture-critical tension members designated for reuse in the reconstructed trusses. The floor beams, stringers, and deck also were scheduled for replacement. Tension control (round head) bolts, placed with the round head on the visible face of the structure, were to be used in the reconstruction of the structure. All of the structural steel, including the bolts and bearings, was to be galvanized.

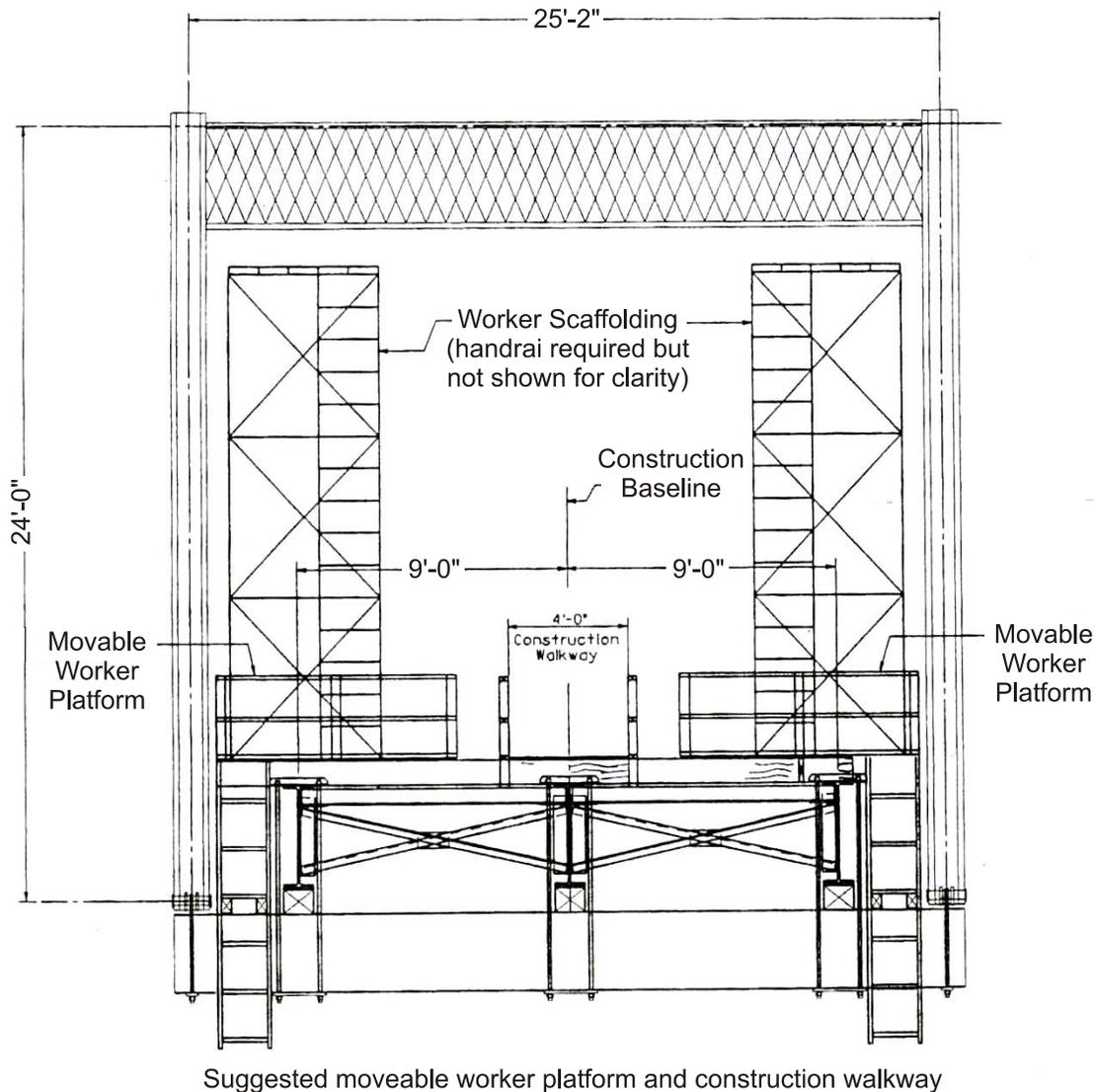


Figure 9. Suggested Platform for Worker Access Travels Along the Three Falsework Beams. Falsework hanger assemblies supporting floor beams are also shown.

Inspection of the trusses revealed steel from at least three manufacturers. The latter part of the 19th century was a period of transition between wrought iron and steel as the predominant material. Until the founding of the American Society for Testing and Materials (ASTM) in 1898, there was no effort to develop a standard specification for structural steel. Since there was no uniform system of mill analysis at the time of construction, samples taken from several members, including beams, stringers, and a hip vertical, were tested to obtain strength data in an effort to determine their suitability for retention. Replacement of deteriorated ends of some vertical members necessitated testing of the suitability of the steel for welding. Although the test results for the steel samples were acceptable, magnetic particle tests on the fracture-critical lower chord tension members disclosed several surface defects as noted here (Wingfield and Ackerman, 2001):

During this inspection, several surface defects were noted in the fracture-critical members. Most of the long surface seam indications can be classified as stringers of non-metallic inclusions. These indications follow the grain flow in forgings. Several cracks were noted on the inside diameter wall in the pinhole area. These cracks have originated from laminar type defects and have progressed to the surface of the part. These indications are a concern for the inspector and may increase in magnitude during the 900°F zinc coating galvanizing process. This inspection was performed in accordance with ASTM A275 Standard Test Method for Magnetic Particle Documentation of Steel Forgings.

A diagram and description of the defects disclosed in eye bar 93 during the magnetic particle tests are provided in Figure 10, and photographs of defects in the bar are shown in Figures 11 through 13. Similar defects were found in eye bars 99 and 100, as shown in Figures 14 through 16.

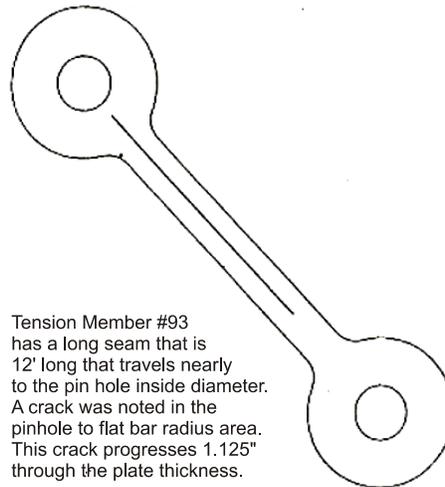


Figure 10. Defects Disclosed in Lower Chord Eye Bar 93 During Magnetic Particle Testing



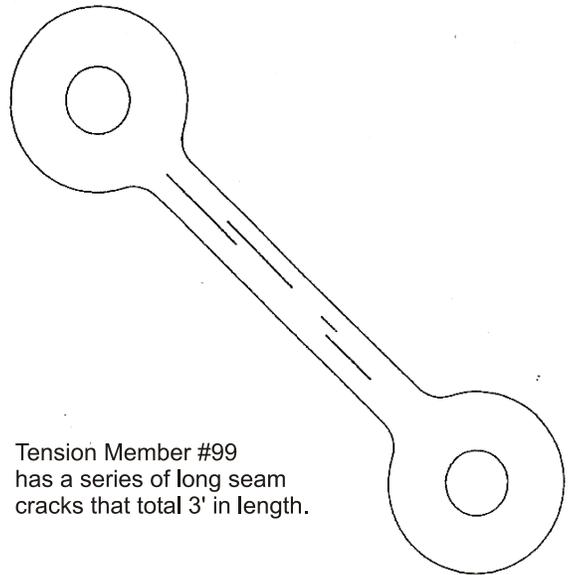
Figure 11. Longitudinal Seam Edge of Bar 93



Figure 12. Crack (at Tip of Pointer) in Transition Radial Area on Edge of Bar 93

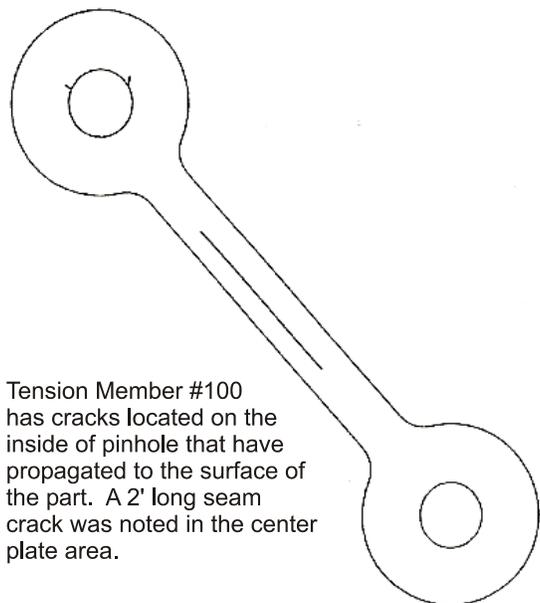


Figure 13. Seam in Surface of Pin Hole, Eye Bar 93



Tension Member #99 has a series of long seam cracks that total 3' in length.

Figure 14. Defects Disclosed In Lower Chord Eye Bar 99 During Magnetic Particle Testing



Tension Member #100 has cracks located on the inside of pinhole that have propagated to the surface of the part. A 2' long seam crack was noted in the center plate area.

Figure 15. Defects Disclosed in Lower Chord Eye Bar 100 During Magnetic Particle Testing



Figure 16. Longitudinal Seams in Face of Lower Chord Eye Bar 100

It is likely that the seams in the eye bars resulted from the techniques used to fabricate the bars. Ketchum (1912) described two ways of forming the eyes:

The eyes may be formed (a) by upsetting and forging, or (b) by piling and welding. By the first method the bar is upset and the head is forged in a die, after which the bar is reheated and annealed and the pin hole is drilled. By the second method a “pile” of iron bars is placed on the end of the bar, the pile is heated and the head is forged in a die. The bar is then reheated and annealed and the pin hole is drilled. Steel eye bars should always be made by upsetting and forging.

It was surmised that the laminar defects in the wall in the pin hole were indicative of fabrication by piling and welding. The resulting cracks in the pinhole wall were troubling, and the presence of those and other defects in the fracture-critical lower chord members, combined with heavier loads on the reconstructed bridge, led to a decision to replace all of the lower chord members.

Designing replacement members was a process involving complex design and detailing decisions to meet modern specifications and ensure proper fitting of the members during reconstruction. As one example, all design specifications recognize that truss spans should be designed with camber, an upward curvature sufficient to offset sagging under live load deflections. This can be achieved by either lengthening the upper chord member or shortening the lower chord members. Although the deflections can be computed or determined graphically, some old references (Ketchum, 1912; Urquhart and O’Rourke, 1930) recommended, as a rule of thumb, that the upper chords be lengthened $3/16$ inch for each 10 feet of horizontal projection. This approach was taken by the contractor on the Goshen Bridge.

AASHTO specifications allow the use of eye bars that meet prescribed dimensions at the eye (AASHTO, 2002). Structural Steel Products of Clayton, North Carolina, employed numerically controlled plasma cutters to fabricate replacement eye bars from a single plate to match exactly the dimensions of the original bars. Minor differences in the bars are not apparent to the casual observer. The design and detailing of other members, those in the end posts and upper chords, are quite complex, and a thorough familiarization with the provisions of the specifications is recommended.

Replacement of the counters, secondary diagonals shown as dotted in Figure 2, was required for compliance with the AASHTO specifications (AASHTO, 2002). Counters are adjustable diagonal members that serve to add rigidity to the truss. They are loaded only by the passage of the live load and prevent stress reversal in tension members. Usually, counters are formed from square or round bars and terminate with eyes at the pin connections. Loop, or loop-welded, eyes, such as those from another structure shown in Figure 17, are formed by bending the bar to form a loop and forging (welding) the end into a notch in the straight section of the bar. Failure of loop bars at that point has been noted during inspections of historic truss bridges, and their use has long been prohibited (Urquhart and O'Rourke, 1930). The eyes in the replacement counters, Figure 18, were formed by welding the end of the counter into a notched plate in which the pin hole is drilled.



Figure 17. Typical Loop Bar Counters Showing Advanced Corrosion



Figure 18. Replacement Counters

Replacement of the truss hanger assemblies (Figure 19), also designed as fracture-critical members, presented both a procurement and a fabrication problem. Details of the hanger, as shown in Figure 19, required the bending of a square bar (a round bar developed high bearing stresses) to fit around the pin, but one with a round cross-section with upset threads at its ends. Upset threads are those that extend beyond the outer dimensions of the bar, as opposed to being cut into the bar. Upset threads necessitate that the ends of the bar be round and of a diameter large enough to accommodate the threads. It was difficult to find a fabricator interested in producing the assemblies, which are not common today. The Haydon Bolt Company of Philadelphia produced the assembly by machining the central section of a 2-inch-diameter rod to produce a 1 $\frac{3}{8}$ -inch square bar with the required upset threads at its ends, cold bending it, heating it to relieve residual stresses, rebending it, and galvanizing it (Douthat, 2001).

The reconstructed assembly of the truss members at a lower panel point is shown in Figure 20. The pin holes in the truss members were oversized by 1/8 inch to allow for the thickness of the two layers of galvanizing on the members and the pins.

Modern components were used in other portions of the bridge. The existing rail system, which consisted of pipes attached to the truss with U-bolts, was replaced with a substantial metal railing to protect the truss better. Because of anticipated corrosion problems with roller bearings, laminated elastomeric pads were substituted in the expansion bearings. Glued laminated timber deck panels replaced the original plank deck.

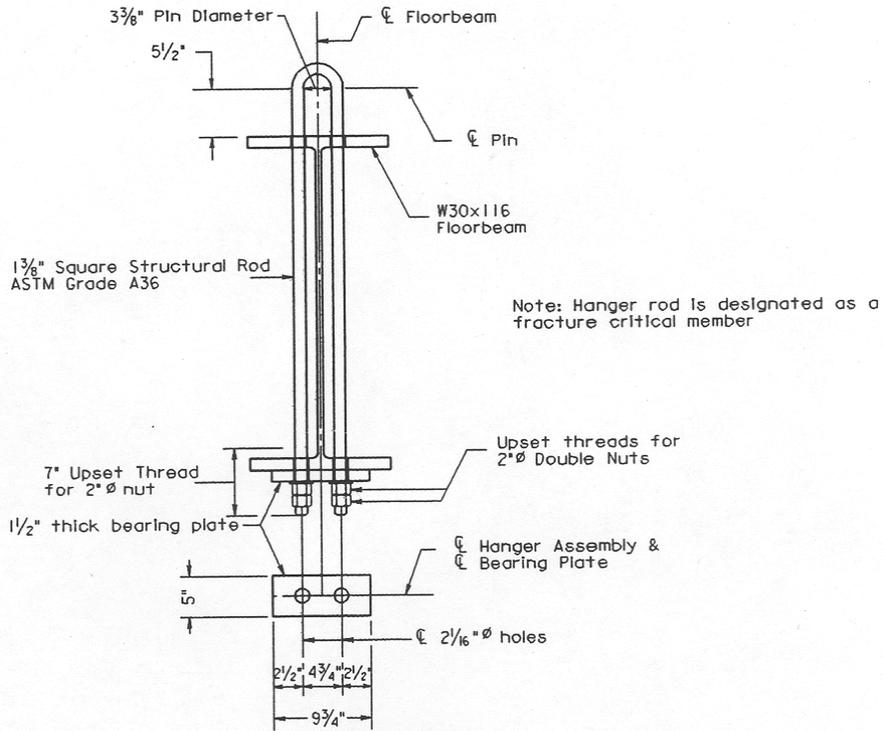


Figure 19. Replacement Truss Hanger Assembly



Figure 20. Final Truss Member Assembly at Lower Panel Point

Some reconstruction of the bridge seats on the pier and abutments was required with the use of a concrete mix that closely matched the color of the existing stone masonry. The masonry abutments and pier were blast cleaned and repointed. Repointing of the mortar required the services of a contractor, Moran Construction of Abingdon, Virginia, experienced in restoration work. Although a 100 percent lime mortar mix had been developed based on analyses of samples of the original mortar, the contractor recommended a stronger, more weather-resistant mortar containing both lime and white portland cement. It was noted that a 100 percent lime mortar is seldom used today except in areas not subjected to moisture. Instead, an 8-2-1 mix (8 parts sand, 2 parts lime putty, 1 part white portland cement) was recommended for backfill and a 6-2-1 mix for pointing the stone masonry in the pier (Moran, 2001).

Environmental Considerations

In the repair or restoration of a historic metal truss bridge, environmental considerations are as important and can affect operations as much as the structural configuration of the bridge and preservation issues. Compliance with the regulations of several local, state, and federal agencies is mandated. Government environmental specialists should be consulted before any operations begin, and the employment of an experienced consultant to prepare the required documents might be considered. Contract documents should require those measures necessary to protect the environment.

One of the primary environmental concerns is the removal of lead-based paint from these old metal structures. Such coatings provided excellent corrosion protection and, as such, were very commonly used on bridges. However, lead is extremely toxic to humans, animals, and plants. When it is removed from a structure, it becomes a designated hazardous waste subject to the federal Resource Conservation and Recovery Act and Virginia's hazardous waste regulations. The removal practices for lead-based paint themselves are subject to federal Occupational Safety and Health Administration (OSHA) regulations and Virginia regulations as administered and enforced by the Virginia Department of Labor and Industry. The lead paint must be captured and contained during coating removal or dismantling operations to ensure that it is not released to the air, soil, or water. Further, it must be securely contained while it is awaiting proper disposal and then conveyed by a licensed hazardous waste transporter to a licensed hazardous waste disposal site.

In addition to the requirements imposed by these statutes and regulations, VDOT, for example, has its own specifications and special use provisions, listed here, for lead-based paint removal:

- VDOT *Road and Bridge Specifications*, 2002, as amended, Sections 107.01 and 411.08
- Resource Conservation and Recovery Act and regulations (40 C.F.R. 240-281)
- Occupational Health and Safety Act and regulations(29 C.F.R. 1926.62, Lead in Construction Standard)

- *Code of Virginia* 40.1-51.20 and regulations (16 VAC 25-35-10 et seq.).

The specifications and provisions require, among other things, that Environmental Protection Plans (EPPs) be developed for the individual project that detail the contractor’s plans for managing the material in a way that protects the public health, worker safety, and the environment. The EPP must be approved by a Certified Industrial Hygienist or an individual defined as a “*Competent Person*” in accordance with the Society for Protective Coatings (SSPC) and submitted for review several weeks prior to beginning the project. Violation of these statutes and regulations can result in the imposition of severe civil and criminal penalties; there is also the prospect of tort and common law liabilities stemming from injuries or property damage incurred as the result of an improperly executed project.

Waterway, stream bed, and wetland protection, including erosion and sedimentation control measures, requires permits from governing authorities at the state and federal levels. A plan detailing these measures must be submitted, and compliance with regulations may restrict contractor access to the waterway or environmentally sensitive areas of the site. Details such as the permitted locations of cranes and other construction equipment and the storage of members and other materials in the waterway or elsewhere on the site may dictate aspects of the planning of dismantling and re-erection operations.

As an example of the permit application process, the Goshen Bridge contract documents required compliance with the following VDOT special provisions, accompanied by a map locating the project area and detailed permit application sketches showing the locations and nature of any temporary causeways proposed by the contractor.

- Special Provision for Virginia Marine Resources Commission’s Virginia General Permit (VGP) for Projects Undertaken In, On, or Over State-Owned Subaqueous Lands (Waterways and Tidal Wetlands) Within the Commonwealth—Conditions and Limitations Issued to Virginia Department Of Transportation
- Special Provision for Nationwide Permit 14—Road Crossings to Discharge Dredge or Fill Material in Waters of the United States Pursuant to Section 404 of Clean Water Act—Conditions and Limitations Issued to Virginia Department of Transportation
- Special Provision for Nationwide Permit 33—Temporary Construction, Access and Dewatering to Discharge Dredge or Fill Material in Waters of the United States Pursuant to Section 404 of Clean Water Act—Conditions and Limitations Issued to Virginia Department of Transportation
- Special Provision for 107A—Erosion and Siltation Control.

Planning the Dismantling and Re-Erection of Trusses

Considerable thought must be devoted to the dismantling and re-erection of a historic truss by engineers, historic resource personnel, and the contractor prior to beginning any work in

the field. Old texts, such as those cited previously, can provide information on the original designs, and the results of thorough field inspections disclose the condition of the existing structure.

Waddell's (1889) chapter on the erection of truss bridges is written in the context of construction technology in the latter part of the 19th century. For the most part, truss construction made use of pulleys and levers, and the sequence of erection of the various truss members was governed by the need to maintain the riveters' access to connections. Much of the material is devoted to tables, drawing plates, and formulas, practical advice to aid in the detailing and construction of timber falsework bents for sites where the distance from the stream bed to the lower chord exceeds 18 feet. If the distance is less than 18 feet and there is no danger of sudden high water with a swift current, the floor and joists can be used for falsework. Unless a soft stream bed requires piles, the bents are founded on mud sills. During erection, the top and bottom chords of the two trusses are supported on beveled wooden camber blocks nailed lightly to the bents.

Only a brief summary of Waddell's detailed description of the construction process is provided here as a guide to the dismantling and re-erection of trusses. The nomenclature used is that of the typical truss shown in Figure 2.

Starting at the far end of the bridge from the storage area for the truss members and preferably at a fixed bearing, the work progresses as follows:

1. Lay out and mark the centerline of the bridge on the bents, and locate those of the trusses on the camber blocks.
2. "Pack" both the top and bottom chords, i.e., arrange the individual members in their positions to form the chords.
3. Using pulleys, hoist the two batter braces (end posts) into position and pass the anchor bolts through the shoe plate of the bearing, fixing the location of the batter braces, which are supported, as well, by blocks attached to the bent.
4. Place the portal strut, lower lateral strut, and the lower lateral rods. The lower strut and lateral rods are secured by the end pins, which also connect the chord bars.
5. Hoist the end sections of the top chord and the end diagonals into position and attach them temporarily at the hip, the far end of the chord section resting on its camber block. The hip vertical is omitted at this time for convenience later in the construction process.
6. Place the first vertical posts with their upper ends supported in the open ends of the chord sections.
7. Begin riveting at the portal. The riveting gang will follow up the erection as it progresses.

8. Raise the second sections of the top chord; temporarily bolt them in place; and run the pins through the posts, diagonals, and fillers.
9. Place the second posts, the third sections of the chords, the third set of main diagonals, and the first set of counters as before, and continue in this fashion to the end of the span.
10. When the span is half erected, placing those members that were omitted begins, and the upper lateral bars are placed just before the rivet gang completes its work.
11. Couple the bottom chords to the bearings at the ends of the bridge.
12. Knock out the upper chord camber blocks, and take down the upper portion of the falsework.
13. Gradually knock out the lower chord camber blocks all together to swing the bridge with minimal impact.
14. Run out the floor beams, swing them into position, attach them to the trusses, and bolt up the lateral struts.
15. Screw up every adjustable rod to proper tension, and check the tension by tapping the bars with a hammer.
16. Install the joists, floor, and railing system.

A truss bridge would be taken down in much the same order, starting at an abutment after the falsework is placed. It seems likely that the floor beams, rather than the trusses, would bear on the falsework and would remain in place with the floor to serve as a work surface during the dismantling of the trusses. Support of the truss members by cranes or other means would be required during the operation.

Modern construction equipment allowed modification of the dismantling and erection processes at the Goshen Bridge, including the use of the internal falsework beam system described earlier instead of falsework bents at every panel point. In an effort to clarify the process for prospective bidders, a suggested "Sequence of Construction" was included in the plans. Deviations from the suggested sequence were permitted, subject to the approval of the engineer, except as noted. The sequence, which covers all site operations, including both the dismantling and the reassembly of the bridge, is presented in its entirety in Appendix C.

NOTES ON FIELD OPERATIONS FOR THE GOSHEN BRIDGE

Annotated photographs of the field operations of Allegheny Construction Company, Inc., at the Goshen site are intended to complement the construction sequence. Those instances in

which the contractor chose an alternative method are referenced to the appropriate items in the sequence.

Negotiations with a private landowner to permit temporary access to those homes normally dependent on the Goshen Bridge allowed closure of the structure during its restoration. A temporary causeway was constructed in the river using concrete traffic barrier sections to support a deck of heavy timbers that was removed during periods of high water. Two cranes, one on the causeway and the other at the abutment nearest the work, were used during dismantling and re-erection (Figure 21).



Figure 21. Crane Locations During Re-erection of Trusses

Light electric-powered man lifts (Figure 22) were used for worker access and as light cranes on the bridge instead of the worker platform shown in Figure 9 during both dismantling and re-erection. Dismantling of the trusses could begin at either abutment, progressing from one span to the next, but re-erection began at the center pier and progressed outward to the abutments.

The three falsework bents (Figure 23), one at each abutment and the third at the center pier, were constructed before the falsework beams shown in Figure 24 were placed. Three H-piles on concrete footings founded on firm material (1.5 tons/square foot) supported the three lines of falsework beams, one pile beneath each beam. The footings were left in place and graded over upon completion of the project.



Figure 22. Light Electric Lifts During Re-Erection of Truss



Figure 23. Falsework Bent at Pier with Two Lines of Falsework Beams in Place



Figure 24. Placing Falsework Beam

Falsework bents at each panel points would serve as well at a site where high water was not a consideration, but the chosen configuration must be designed to provide secure support to the bridge before dismantling begins.

Construction of the network of falsework beams followed completion of the bents. Individual segments comprising each of the three falsework beam lines were placed on the bridge and connected. Connection of the lateral bracing and diaphragms completed the falsework system. Once the railing, deck, and stringers were removed, the trusses were subject to the loading they will experience after re-erection, and the recording of pin elevations at this point (step 2-I) confirms the existing camber of the trusses, providing information vital to their reassembly. Tightening all connections between the falsework beams and the floor beams prior to removing any truss pins or connections also was essential.

Jacking, shown in Figure 25, may be necessary to separate members at the panel points if heavy corrosion has occurred. Heavy corrosion and metal loss, such as that on the pin from another bridge shown in Figure 26, result in an irregular cross section that makes the removal of the pin difficult. After several tactics including the use of jacks and the application of lubricants failed to dislodge the pins on the Goshen Bridge, it became necessary to pierce them through their centers with a torch and collapse them (Figure 27).

The electric lifts shown earlier provided access to the panel points, allowing the dismantling of the trusses in sections composed of several members, as shown in Figure 28. Disassembly of the sections was completed elsewhere on the site. As shown in Figure 29, care was taken to support remaining members after the removal of pins. Those members selected for replacement were stored on sheeting at the site until the dimensions of their replacements were



Figure 25. Jacking Truss Members Apart on Goshen Bridge



Figure 26. Heavily Corroded Pin; Section Loss Makes Removal Difficult



Figure 27. Piercing Center of Pin



Figure 28. Cranes Remove Sections of Truss



Figure 29. Supporting Diagonal After Pin Removal

verified. The members to be retained were shipped to Galvan Industries of Harrisburg, North Carolina, for galvanizing. After sandblasting to remove lead paint, the members were further cleaned to remove oil and contaminants, and the surfaces prepared for the zinc coating. No disassembly of individual members was required. Some minor difficulty was experienced, at times, in achieving proper adhesion, but the final results obtained (Figure 30) promise excellent durability.



Figure 30. Original Vertical Member After Cleaning and Galvanizing

Galvanizing, although costly, was feasible because disassembly of the trusses was required to allow the replacement of deteriorated members. Otherwise, removal of the lead paint on the intact trusses followed by either painting or metallizing (the process in which a protective coating of zinc or aluminum is sprayed on the blast-cleaned steel surface for corrosion resistance) might have been considered. These alternatives would have been expensive. Metallizing, although very effective, is costly, and removal of lead paint would have required the shrouding of the entire bridge to provide complete containment of the toxic waste products. Galvanizing the individual members provided the advantage of enhanced corrosion resistance, as the faces within the connections were coated.

As shown in the photographs, members were marked with paint to denote their locations prior to disassembly. All were labeled with die marking before shipment to the galvanizing plant. Permanent marking is essential. Bridge engineers interviewed as part of this study reported instances in which trusses had been reconstructed with members in the wrong locations.

After dismantling of the trusses was complete, re-erection began as the existing floor beams were removed and replaced with new members, one panel point at a time, across the bridge (Figure 31).

As noted earlier, the use of an internal falsework beam system converted the two simply supported trusses into a two-span continuous structure. Thus, loads in one span will cause an upward deflection in the adjacent span. Balanced construction was necessary to maintain equal deflections, beginning at the center pier and progressing concurrently toward abutments, as shown in Figure 32. Construction can begin at the ends of the spans if falsework supports are located at each panel point.



Figure 31. Floor Beam Replacement



Figure 32. Re-erection of Trusses

Care must be taken during re-erection to ensure that the members are not only in their correct locations between panel points on the truss but also in their proper positions on the pins at the panel points. Photographs of the proper orientation of members in the joints were provided to the inspector. Placing the pins can be an intricate process requiring manipulation of the truss with the cranes and jacks and the use of lubricants. Driving the pins was permitted on the Goshen Bridge, but the use of a rubber hammer was required to protect the galvanizing. Members and pins had been detailed to allow for the thickness of the coating.

At the completion of the truss erection, the falsework hangers were loosened (Figure 33), slowly transferring the loads to the trusses to minimize impact, to swing the restored Goshen Bridge. Repointing of the mortar joints in the pier and abutments had been accomplished during the dismantling and re-erection of the superstructure.

The falsework beams were removed after the transfer of loads to the trusses, and the stringers (Figure 34), glued laminated timber deck panels (Figure 35), and rail system (Figure 36) were installed. Final grading to the original contours and the placement of a repainted plaque and new decorative spires completed the refurbishing of the Goshen Bridge shown in Figure 37. There are plans to place a bronze tablet near the bridge to note the date of its restoration and to credit the entities that contributed to its successful restoration.



Figure 33. Loosened Falsework Hangers at Completion of Truss Erection



Figure 34. Installation of Stringers



Figure 35. Glued Laminated Timber Panel Installation



Figure 36. Modified Illinois Rail Protects Truss



Figure 37. Rehabilitated Goshen Bridge, 2002

THE LIFTING AND MOVING OF INTACT BRIDGES

Modern construction equipment may allow the removal of a structure from its site and its transport with little or no dismantling, depending on the size of the structure and the extent of the movement required. Often this will allow the disassembly of a fairly large stream-crossing structure on dry land adjacent to the site. Recent newspaper coverage has described the moving of historic bridges by cranes and, in at least one instance, by a large helicopter (Field Under the Bridge, 2006).

Virginia's rare Fink deck truss bridge (Figure 38) cited earlier in this report was taken out of service and moved after removal of its deck and railings (Figure 39) from its site over a railroad to a nearby park (Figure 40). The structure, which was 52 feet, 6 inches long by 13 feet wide by 7 feet, 6 inches deep was supported on stanchions on a flat bed trailer to avoid disassembling the truss members.

A larger Pratt through-truss bridge, 106 feet in length, built over the Rappahannock River in 1879 by the King Iron Bridge and Manufacturing Company of Cleveland, Ohio (Figure 41), was lifted from its bearing using two cranes and placed nearby for dismantling. Surveyed in 1974, it was in "imminent threat of replacement" (Diebler, 1975). Its deck was removed, and lifting points (Figure 42) were placed at the hip joints. Lower chord tension members required reinforcement by the addition of temporary struts to sustain compressive forces generated during lifting.

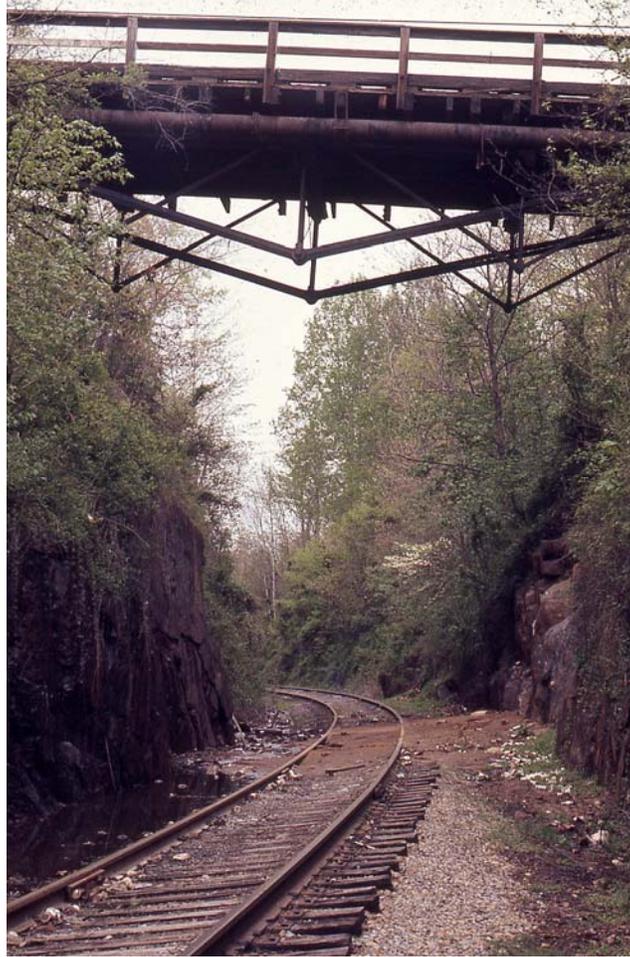


Figure 38. Fink Truss Railroad Overpass Bridge



Figure 39. Moving Fink Truss



Figure 40. Fink Truss as Exhibit in Park



Figure 41. Lifting 106-foot Pratt Truss



Figure 42. Lifting Apparatus at Hip Joint, 106-foot Truss

Supplemental struts for the lower chord members and between the trusses were required for stability when the light pony truss shown in Figure 43 was moved. Lifting a bridge by attachments at the hip joints induces compressive forces in the lower chords of the end panels.



Figure 43. Moving Pony Truss Bridge

Although the ability to move an intact bridge certainly simplifies dismantling operations, it also presents complications, as the state of stress in particular members can be reversed or new stresses induced during lifting. In light of this possibility, the inspection and engineering analysis required must be as rigorous as that described earlier. After being moved, the structure must be placed on level temporary bearing surfaces on firm material to facilitate its disassembly.

REFERENCES FOR FURTHER INFORMATION

Further information on the analysis and design of old trusses can be found in several textbooks dating from the late 19th and early 20th centuries. References used in this study included *Design of Highway Bridges* (Ketchum, 1912), *Design of Steel Structures* (Urquhart and O'Rourke, 1930), *Theory of Simple Structures* (Shedd and Vawter, 1941), and *The Designing of Ordinary Iron Highway Bridges* (Waddell, 1889). Similar texts are available in the libraries of many educational institutions.

Many of the old texts on truss bridges do not address the erection of the structures, but Waddell's (1889) highly regarded text does include a chapter on their erection and maintenance. This is a practical "treatise upon bridge designing, and not one upon stresses," "written for engineers, students, and, to a certain extent, county commissioners," and intended to "supplement the books generally use by classes in engineering schools." It provides tables and plates showing member sizes and configurations that are valuable references in understanding the design, detailing, and erection of today's historic trusses. A helpful glossary and references to other texts for those who wish to study stresses are provided. It is a particularly useful introductory reference for those historic resource personnel who are not trained in engineering.

More recent publications with valuable information on truss repair include *Repair and Strengthening of Old Steel Truss Bridges*, prepared by a Task Committee on Strength of Old Truss Bridges of the American Society of Civil Engineers' Technical Committee on Structural Safety and Reliability of the Structural Division (American Society of Civil Engineers, 1979), and *National Cooperative Highway Research Program Report 222, Bridges on Secondary Highways and Local Roads—Rehabilitation and Replacement* (Transportation Research Board, 1980). The first is a text devoted to guidelines on the inspection, evaluation, structural analysis, and repair procedures for old truss bridges, and the latter contains practical examples of procedures for the repair and replacement of truss members provided by transportation agencies. Another useful reference is the technical leaflet *Bridge Truss Types: A Guide to Dating and Identifying* (Comp and Jackson, 1977).

As noted, various early texts concerning truss bridges were collected as part of this project. These volumes, as well as materials on other historic bridge types and other historic transportation structures, are maintained in the Virginia Department of Transportation Research Library as the Historic Structures Project. Additions are made regularly to this collection.

CONCLUSIONS

- *The rehabilitation or restoration of a historic metal truss bridge is a costly and complex process that is best based on safety inspection data indicating the suitability of the structure to continue to remain in service and a rational assessment of its historic significance.* Once these decisions are made, the disposition of the bridge, whether its rehabilitation or restoration or some other option, can be decided. Most of the options will require structural engineering services in addition to cultural resource expertise, as most demand structural analysis and design.
- *Assumptions are dangerous when dealing with the dismantling and re-erection of old pin-connected metal truss bridges.* There may be displacement of the spans because of anchorage failures and instances of severe deterioration or localized failure. In bridges built before the beginning of the 20th century, the steel in various members may have come from different suppliers and may display widely varying strengths and other characteristics. Members may have flaws resulting from early fabrication methods, and occasionally members have been found in the wrong locations in the trusses. A detailed inspection of the bridge and the site always is in order as a first step to disclose the state of the bridge, the dimensions of members for structural analysis, and the presence of lead paint. Lead paint is an extremely hazardous material, and its handling has a great effect on any rehabilitation or restoration effort.
- *Although the degree of effort in design and planning varies with the option selected, a structural analysis of each structure that will carry either vehicles or pedestrians is required, regardless of the eventual ownership of the bridge.* The falsework system must be designed to support a truss properly even if it is to be discarded after disassembly to ensure worker safety during the field operations. Preparation of plans that cover each aspect of the project can greatly facilitate its success.
- *Historic significance often is a well-established factor in the evaluation of today's bridge populations, and a management system can disclose those older structures of real historic significance.* Application of the principles of preventive maintenance to these truly significant bridges will minimize their deterioration and, thus, the costs of their restoration, preserving important historic properties for future generations.

RECOMMENDATIONS

The applicability of the best practices developed in this study to any particular truss bridge rehabilitation project will depend on the condition of the structure and the plans for its disposition. Obviously the degree of effort in design and planning will vary with the option selected from those described in this report to the simple elimination of access to a discontinued or abandoned structure. Although these measures are based on Virginia's experience and framed in the context of a deteriorated bridge that was rehabilitated to carry modern loads, we believe the issues are relevant to any rehabilitation or restoration project.

1. *The disposition of an old truss will depend on its suitability for continued service in the transportation system, as indicated by the biennial bridge safety inspections (annual inspections in the case of fracture-critical bridges), and its evaluation as a historic property, but the effect of local support cannot be ignored.*
2. *Historic metal truss bridges such as the Goshen Bridge are classified as fracture-critical structures because the failure of a single element could lead to the collapse of the bridge. Successful restoration or rehabilitation of a historic truss is, thus, best accomplished through a partnership that includes historic resource personnel, bridge engineers, and the contractor.*
3. *The Secretary of the Interior's Standards for Treatment of Historic Properties should be used to guide any work being planned for a historic bridge.*
4. *Funding for a rehabilitation or restoration project must be in place to ensure its success. Rehabilitation of the Goshen Bridge to carry modern loads cost much more than would a conventional replacement structure, requiring funds beyond those available for normal maintenance replacement.*
5. *The first step in the dismantling of an old truss must be a detailed field inspection of the condition of the truss members, the presence of lead paint, and the general dimensions of the bridge and its site. If the operation includes the reassembly of the truss with the replacement of members, the inspection also must include detailed measurements of the dimensions of every member in the bridge so that an analysis of the loads and stresses in the truss members can be determined.*
6. *A detailed inspection and structural analysis of each structure that will carry either vehicles or pedestrians is required, regardless of ownership, and, to ensure worker safety, sufficient care must be exercised in properly supporting a truss that is to be rehabilitated or merely demolished. Guidance as to the design process for the rehabilitation of old metal truss bridges is provided by the action list in this report.*
7. *Project plans should include those items needed to facilitate bidding and ensure proper completion of the project, possibly including a suggested sequence of construction, details of the falsework system, any limitations on the size and weight of worker access systems, and any needed information on the layout of the existing bridge, in addition to details of the rehabilitated structure.*
8. *In the case of bridges constructed prior to the development of standard specifications for structural steel, testing of samples from the truss members should be considered to provide data on the strength and, if necessary, the weldability of the steel. The steel may have been supplied by more than one manufacturer.*
9. *Members in the rehabilitated bridge must comply with any AASHTO specifications, including those for pedestrian loading, applicable to their planned use. Techniques used in the fabrication of members may limit the suitability of truss members.*

10. *Compliance with environmental regulations of several local, state, and federal agencies is mandated for all field operations.* Government environmental specialists should be consulted and approval of required plans sought well ahead of the beginning of operations, even if the structure is to be demolished.
11. *Falsework to support the structure during the dismantling of the trusses can be an internal beam system as described, a system of individual supports, or another approach suitable for the site, but each must be designed to carry safely the loads transferred from the trusses, and each must be in place to support the trusses completely prior to beginning operations.* Supplemental support must be provided throughout disassembly and re-erection operations when the trusses are unstable.
12. *Members must be marked in place as to location in the truss before dismantling begins and permanently die marked prior to any treatment, including lead paint removal if performed after dismantling.*
13. *Modern construction equipment may allow the removal of a structure from its site and its transport with little or no dismantling, depending on the size of the structure and the extent of the movement required.* Lower chord tension members may require reinforcement by the addition of temporary struts to sustain compressive forces, and the location of lifting points and design of connections will require engineering services.
14. *Application of the principles of preventive maintenance to those bridges determined to be truly significant will minimize their deterioration and, thus, the costs of their restoration or rehabilitation, facilitating the preservation of important historic properties for future generations.*

BENEFITS AND COSTS ASSESSMENT

The primary benefit of this knowledge management study is that it meets a need expressed by cultural resource personnel involved with the dismantling and re-erection of historic metal truss bridges. Documentation of the design and construction aspects of the Goshen Bridge project will be useful as a guide for structural engineers in Virginia and elsewhere involved with the rehabilitation and restoration of old truss bridges. That information and the input of others who contributed their expertise will comprise a useful guide for those working to preserve historic metal truss bridges.

Implementation of the recommendations in this report should impose no additional costs, and the benefits will accrue primarily through increased efficiency in dismantling and re-erection operations and enhanced worker safety.

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APPENDIX A

MANAGEMENT PLAN FOR THE GOSHEN BRIDGE

(From Miller, A.B., K.M. Clark, and M.C. Grimes. 2001. *A Management Plan for Historic Bridges in Virginia*. VTRC 01-R11. Virginia Transportation Research Council, Charlottesville)

Rockbridge County (81)

VDOT Structure No. 6145

VDHR Inventory No. 226-5001

Name: Goshen Bridge

Location: Route 746, crossing Calfpasture River

National Register Status: Listed

Description: Rockbridge County Structure No. 6145 is a two-span Pratt through truss, built in 1890 by the Groton Bridge Co, carrying Rt. 746 crossing Calfpasture River. This structure is approximately 261 feet long overall; the trusses are approximately 139 and 121 feet long. Constructed for the planned industrial community of Goshen, this bridge has a number of points of significance: it is one of Virginia's earliest multi-span truss bridges; it is built on a skew; and it is an early multimodal bridge. As originally designed, the structure included a lane for vehicular traffic, a lane for streetcars, and a cantilevered sidewalk.

Evaluation: Rockbridge County Structure No. 6145 was placed on the Virginia Landmarks Register in 1977 and on the National Register of Historic Places in 1978.

Documentation: Rockbridge County Structure No. 6145 was included in the initial metal truss survey report prepared by VTRC (Deibler/Spero 1975-1982) and the more recent update (Miller and Clark 1997). It was also recorded to Historic American Engineering Record Standards (HAER No. VA-102).

Condition: The current inspection report indicates that this structure is in poor condition. There are numerous areas of corrosion and section loss to steel members. The piers are missing mortar and substructure stones in various locations. The roller bearing devices are frozen, and some are displaced. In addition, debris is present on the bridge seats, on the connections, and between the stringers. Only one lane is open to vehicular traffic; the other lane, which was originally planned as a streetcar lane, has not had decking for at least 50 years; there is attendant corrosion of the exposed members. A rehabilitation of the structure is planned.

Posted Restrictions: The structure is posted at 6 tons.

ADT: 55.

Right-of-Way Ownership: Because of the structure's location on a portion of a secondary roadway that has undergone no substantial improvement projects since the creation of the

secondary system in 1932, the approaches are presumed to be constructed on prescriptive easement.

Recommended Treatment: A full rehabilitation of this structure has been in the planning stage by the Staunton District Structure & Bridge Office over the last several years. Planning is now complete. The stone piers will be repaired and repointed as needed, using compatible mortar. The truss will be disassembled, and the members repaired as needed and galvanized. The truss will then be reassembled and restored for two lanes of vehicular traffic. The task group concurs with this plan. Attempts to fund this rehabilitation substantively with enhancement grant monies were unsuccessful until the present (2000) grant cycle, when \$25,000 was received in a TEA-21 grant (\$250,000 was requested).

APPENDIX B

THE *SECRETARY'S STANDARDS* INTERPRETED FOR BRIDGE REPAIR, REHABILITATION, AND REPLACEMENT SITUATIONS

(Adapted from Miller, A.B., K.M. Clark, and M.C. Grimes. 2001. *A Management Plan for Historic Bridges in Virginia*. VTRC 01-R11. Virginia Transportation Research Council, Charlottesville)

The *Secretary of the Interior's Standards for Treatment of Historic Properties* (Weeks and Grimmer, 1995) were first codified in 1979 in response to a federal mandate requiring the establishment of policies for all programs under the authority of the Department of the Interior. The *Secretary's Standards* are used in review of all federal projects involving historic properties listed on or eligible for listing on the National Register of Historic Places. Compliance with the *Secretary's Standards* provides for the preservation of the historic and architectural integrity of properties being rehabilitated. The *Secretary's Standards* were most recently revised in 1992. The Department of the Interior regulations (36 C.F.R. 67.7(b)) state that the *Secretary's Standards* are to be applied in a reasonable manner, taking into consideration economic and technical feasibility.

Since their identification, the *Secretary's Standards* have been interpreted and applied in response overwhelmingly to one type of historic resource: buildings. Although the philosophy of the *Secretary's Standards* can be applied to bridges, the fundamental differences between buildings and structures must be considered. Newlon (1985) argued that the purpose of buildings is the organization and control of space, providing for a wide and flexible range of functions. Engineering structures such as bridges are designed primarily to control loads and forces to accomplish more limited functions such as the transport of people and goods on roads and bridges, retention of water by dams, or support of cables by towers. The more restrictive function of engineering structures is reflected in their design and construction, and this imposes limitations on continued or alternative uses that do not apply in the same degree to buildings.

The following wording of the *Secretary's Standards* addresses the unique requirements of historic bridges. This text closely follows the similar section that appeared in *A Management Plan for Historic Bridges in Virginia* (Miller et al., 2001).

1. *Every reasonable effort shall be made to continue a historic bridge in useful transportation service. Primary consideration shall be given to rehabilitation of the bridge on site. Only when this option has been considered shall other alternatives be explored.*

Bridges are designed to carry roadways over obstructing conditions: ravines, waterways, and other roadways. Bridges are best suited for this type of use. The first priority should always be retention of a bridge in its existing location and in its existing function. In many instances, contemporary vehicular traffic demands may exceed the capacity of an old bridge, and programmatic modifications, such as reduced transportation service, should be considered. Limiting the loads and types of vehicles that may use a bridge will require minimal change to the defining characteristics of the bridge.

Under some circumstances, bridges may be suitable for adaptive re-use. Zuk, Newlon, and McKeel (1980) described some approaches for adapting metal truss bridges for alternative uses, including housing, commerce, etc. Alternative uses may be considered for bridges left in their original locations and for bridges that are re-located. Some metal truss bridge types were designed so that relocation would be readily achievable, and many smaller trusses have served at several locations in Virginia. One example is a Fink Truss located in Lynchburg. This bridge, when taken out of service, was relocated to a park, where it is visible, accessible, and presented in context with a locomotive and other transportation resources.

2. The original character-defining qualities or elements of a bridge, its site, and its environment should be respected. The removal, concealment, or alteration of any historic material or distinctive engineering or architectural features shall be avoided.

The character-defining features of a historic bridge must be identified so that these physical features can be retained and preserved. The bridge surveys completed by the Virginia Transportation Research Council (see, for example, Miller and Clark, 1997) are the primary means of identifying important bridges and their character-defining features.

3. All bridges shall be recognized as products of their own time. Alterations that have no historical basis and that seek to create a false historical appearance shall not be undertaken.

4. Most properties change over time; those changes that have acquired historic significance in their own right shall be retained and preserved.

5. Distinctive engineering and stylistic features, finishes, and construction techniques or examples of craftsmanship that characterize a historic property shall be preserved.

Characteristic features, finishes, and construction techniques must be identified so that they can be preserved. In most bridges, the most important character-defining features will be the primary structural components: trusses, girders, T-beams, slabs, concrete arches, etc. Operating mechanisms for moveable spans should also be considered primary character-defining features. Secondary characteristic features may include Phoenix columns, pinned truss connections, lattice beams, cork rails, and curbs. Abutments, piers, approaches, and other features of the crossing may be identified as primary or secondary character-defining features. In many cases, decking and roadbeds will not be considered significant character-defining features.

6. Deteriorated structural members and architectural features shall be retained and repaired, rather than replaced. Where the severity of deterioration requires replacement of a distinctive element, the new element should match the old in design, texture, and other visual qualities and, where possible, materials. Replacement of missing features shall be substantiated by documentary, physical, or pictorial evidence.

The *Secretary's Standards* recommend retention and repair of existing historic features, rather than replacement. They also acknowledge the limited life-span of most building materials. When bridge components are deteriorated beyond a reasonable prospect of retention and repair,

replacement can be considered. Although replacement in kind is generally recommended, alternative materials can be considered.

Modern metals with superior resistance to deterioration (stainless steel, for example) may be used to replace missing or severely deteriorated historic members provided they are galvanically compatible with the surviving original members.

7. Chemical or physical treatments that cause damage to historic materials shall not be used. The surface cleaning of structures, if appropriate, shall be undertaken using the gentlest means possible.

Materials typically used in bridge construction are generally selected for their ability to resist harsh conditions. Aggressive chemical or physical treatments may be appropriate for cleaning of some common bridge materials and components. In *Metals in America's Historic Buildings*, Gayle, Look, and Waite (1992) describe appropriate measures for proper surface preparation of iron and iron alloys, including flame cleaning, pickling, sandblasting, and other abrasive processes. Dismantling of truss bridges and galvanizing or metallizing the component chords is suggested as a sound means of preserving the historic features and configuration without damage.

8. Significant archaeological and cultural resources affected by a project shall be protected and preserved. If such resources must be disturbed, mitigation measures shall be undertaken.

Associated resources may include fords, abutments, piers, and other features associated with earlier crossings. They may also include structures that are adjacent to, but not culturally related to the bridge: canals, sluices, mills, raceways, shipwrecks, fish-traps, and power plants.

9. New additions, exterior alterations, structural reinforcements, or related new construction shall not destroy historic materials that characterize the property. The new work shall be differentiated from the old and shall be compatible with the massing, size, scale, and architectural features to protect the historic integrity of the property and its environment.

Structural reinforcement may be necessary to allow a historic bridge to continue in service. In extreme cases, new structural components that supersede the historic components may be necessary. Priority must be given, in all such cases, to retaining significant historic structural components, even if their load-carrying function is reduced or eliminated. New structural elements should be designed so that the historic components remain visible and so that the historic structural configuration remains evident. A valid approach is the method of superimposing structural steel arches in truss bridges, which relieves the critical historical connections and members of much of the stresses imposed by modern traffic (Kim and Kim, 1988).

10. New additions and adjacent or related new construction shall be undertaken in such a manner that if removed in the future, the essential form and integrity of the historic property and its environment would be unimpaired.

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APPENDIX C

SUGGESTED SEQUENCE OF CONSTRUCTION

(VDOT Plan Set 280-84, P. 3 of 34)

1. Close Existing Bridge:

- A. Close bridge to all traffic after temporary detour (by VDOT) is opened.
- B. Erect Type III Barricades.
- C. Construct and maintain all items of erosion and sediment control shown in the environmental documents and shown in this contract.
- D. Construct Temporary Construction Causeway.

2. Erect Falsework System:

- A. The purpose of the falsework beam system detailed in these plans is to provide a means of dismantling and subsequent re-assembly of the truss while minimizing the number of falsework bents in the stream. An alternate contractor plan adding any more falsework supports will not be allowed.
- B. Construction vehicles and/or materials exceeding the posted restriction (6 tons) will not be allowed on the existing bridge.
- C. Construct Temporary Falsework Bents.
- D. Remove existing railing and curb.
- E. Layout falsework beams within prism of existing bridge. As an alternate, falsework beams may be assembled and “launched” together as a unit complete with crossframes and lateral bracing. Route 39 traffic near the North end of bridge may be detoured and re-routed for a four week period during each stage of erection and dismantling of falsework system for this alternate. Additional Type III Barricades will be required. Detour signing will be provided by VDOT for this alternate method.
- F. Remove remainder of existing railing, deck and stringer system.
- G. Position falsework beam as shown on Sheet 7 of 34. [Sheet 7 contains details of the falsework framing plan.]
- H. Connect all falsework beam diaphragms and lateral bracing.

I. Run pin elevations to confirm existing truss cambers. Record information for use in re-assembly. Cost included in Construction Surveying.

J. Install falsework hanger rods and snug fit existing floorbeams to falsework beams using timber blocking and steel shims prior to removing any truss pins or connections.

3. Install Worker Access and Work Platforms:

A. Erect temporary construction walkway full length of bridge. Starting at Abutment A end of bridge, construct movable worker platforms. The length of these platforms shall be limited to 15 Feet subject to the loading provisions shown on Sheet 8 of 34.

B. In addition to this method of access, a cable system of worker access from the bottom of the bridge will be allowed provided no additional loading is added to the existing truss or falsework system. This is not a substitute for the falsework system detailed in these plans. Any additional worker access is subject to the approval of the engineer. Also, a crane may be positioned on the temporary construction causeway to aid in the removal of the truss members panel by panel point. The removal of the crane, cable hung worker access and portions of the causeway are subject to the provisions shown in the environmental sketches for flood warnings.

4. Dismantle Existing Truss Bridge:

A. Additional temporary bracing may be required for stability of the existing truss bridge during dismantling and subsequent re-assembly. Cost of an additional bracing shall be included in the respective bid items for Remove Portion of Existing Structure No. 6145 and Erect Structural Steel.

B. Starting at the Abutment A end of the bridge, start dismantling the bridge removing the portal sway frame and lateral bracing, connection pins, truss members for one panel bay (17'-3").

C. Continue with the step shown above, removing only one panel at a time in a sequential manner until moving on to the next.

D. Care shall be taken to remove only the rivets necessary for dismantling. Connector plates are to remain attached to the portal frames and sway frames. Pin plates shall remain attached to the truss members.

E. Member ends shall be heavy "die-stamped" and tagged. See Sheet 18 of 34.

F. Members not designated for reuse in the rehabilitated bridge shall be placed in storage until project is complete. This area shall be accessible to the project engineer and the fabricator's personnel for the purpose of preparing shop drawings and verification of member dimensions if required.

5. Rehabilitate Existing Members and Fabricate New Components:

A. After dismantling is complete, ship truss members and components to be reused in the rehabilitated bridge to the galvanizing plant for initial clean-up and removal of existing paint. These members shall then be sent to the structural steel fabricator for repairs and inspection.

B. After all structural steel components are repaired and new members fabricated, the entire lot of structural steel components shall then be sent back to the galvanizer for final clean-up and galvanization.

C. After galvanization, all members shall then be inspected for finish, sweep, twist and squareness. Any deviation from AISC specifications for tolerance shall be corrected by the fabricator prior to shipment to the field for erection.

6. Prepare Site and Rehabilitate Substructure:

A. Proceed to substructure repair. Remove portions of existing abutments and pier as shown on the plans. Re-point existing masonry. Construct abutment and pier caps.

B. Perform grading and borrow material fill on Abutment A end.

7. Re-Erect Truss Bridge:

A. After existing truss members are rehabilitated re-erect truss generally in the reverse order of dismantling. Care shall be exercised in the handling of galvanized members in order to not damage the surface finish.

B. Snug fit new floorbeams to the falsework beams using timber blocking and steel shims prior to erection of the truss members.

C. After truss is re-erected a geometry check shall be made to check for sweep and camber. This check shall be made after load is released from falsework beam system.

D. Counter members shall be free of load at this point.

E. Remove falsework supporting system. Geometry and camber shall be approved by the fabricator and by the Engineer.

8. Complete New Superstructure Items:

A. Erect new stringer, glu-laminated deck and railing system. Install glu-laminated deck panels from the centerline of pier and working towards each abutment.

B. Once rail and deck are installed, all pairs of tension members shall be evaluated for balanced (equal) loading. Any loose members shall be adjusted to equal loading with its

mate by heat shrinking and/or other methods recommended by the Fabricator and approved by the Engineer.

C. Counter members shall be adjusted to a light load as directed by the Engineer.

9. Finish Project:

A. Complete all remaining contract items including grading, guardrail installation and paving. Final surface treatment of glu-laminated deck panels shall be performed by VDOT.