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FINAL REPORT

BEST MANAGEMENT PRACTICES FOR STORAGE OF HISTORIC METAL TRUSS BRIDGES

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Best Management Practices for the Storage of Historic Metal Truss Bridges

by

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16. Abstract: As part of a 2002 agreement with the FHWA, GDOT has committed to consider storing metal truss bridges of historic value in lieu of demolition, until a recipient could be located. This research addresses the most effective processes for storage of historic metal truss bridges until a reuse can be determined. The design and material integrity of the bridge must be retained. The report first reviews the conditions leading to the decision to replace a historic bridge including the determination of the feasibility for reuse, discusses the cases in which metal truss bridges are commonly stored in situ versus being removed and stored at an off-site location, then addresses the early tasks to be undertaken once the decision has been made to store a bridge. These activities are referred to broadly as the evaluation and stabilization of the bridge. This is followed by an assessment of best practices in the areas preservation, documentation, marketing, disassembly, transportation, and cost estimation as these pertain to storage. The research concludes with a case study that analyses the marketing and storage of a historic metal truss bridge in Griffin, Georgia, which was replaced in 2012.

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EXECUTIVE SUMMARY

A popular bridge type from the late 19th through the early 20th century, metal truss bridges are reminders of Georgia's early transportation history. The expansion of the rail lines and the need for better vehicular roads called for inexpensive bridges that could be fabricated at bridge plants, shipped to the site, and quickly erected by local laborers. Since most metal truss bridges predate the inauguration of the Highway Department of Georgia in 1916, each is distinctive, which reflects the experimentation and competition among the various bridge building companies. After the Highway Department assumed responsibility for the state road system, bridge design became more permanent and standardized. The reinforced concrete bridge was used to replace deficient wood and metal bridges, and the market for steel truss bridges began its decline. It was common practice, however, to reuse metal truss bridges whenever possible. It was easy to dismantle and reassemble these bridges over another creek on a less traveled route. Their use could even be changed from carrying rail traffic to carrying vehicular traffic. While other buildings, objects, and structures might loss significance when moved from their historic context, their inherent portability and reuse potential lends significance to the metal truss bridge. Because of their distinctive geometric design, these bridges often serve as community landmarks. In a town, they are as much of a monument as one could find on the courthouse square. In a rural setting, they juxtapose the natural beauty of a meandering stream with an angular edifice from the industrial age.

In 2002, the Federal Highway Administration (FHWA) and Georgia Department of Transportation (GDOT) formed an agreement that historic metal truss bridges would be marketed to municipalities and other entities for reuse when their sufficiency rating warranted replacement. Truss bridges were considered to have good reuse potential because of their size and ability to be dismantled and reconstructed. It was assumed that these bridges would be rehabilitated for pedestrian usage in most cases. Prior to this agreement, many truss bridges were closed and bypassed when the replacement bridge was constructed.

GDOT has had challenges with this effort, due in part to funding and scheduling factors. The scheduled replacement date of the bridge often does not coincide with the identification of a

recipient, or with the recipient's readiness to reuse them. In some cases, the replacement date has been delayed due to funding or other issues during which time the recipient loses interest.

A review of current and past truss bridge surveys points to the rapid extinction of these bridges as many approach and exceed 100 years of age. As part of the 2002 agreement, GDOT also committed to investigate the temporary storage of historic metal truss bridges, in lieu of demolition, until a recipient could be located. Because of their rapidly declining numbers, GDOT's commitment to preservation, and the experiences with marketing truss bridges since 2002, this research was begun.

The objective of this report is to determine the most effective processes for storage of historic metal truss bridges until a reuse can be determined. The design and material integrity of the bridge must be retained. The report first reviews the conditions leading to the decision to replace a historic bridge including the determination of the feasibility for reuse, discusses the cases in which metal truss bridges are commonly stored in situ versus being removed and stored at an off-site location, then addresses the early tasks to be undertaken once the decision has been made to store a bridge. These activities are referred to broadly as the evaluation and stabilization of the bridge. This is followed by an assessment of best practices in the areas preservation, documentation, marketing, disassembly, transportation, and cost estimation as these pertain to storage. The research concludes with a case study that analyses the marketing and storage of a historic metal truss bridge in Griffin, Georgia, which was replaced in 2012.

The key findings of this research are as follows:

1) The 2013 Georgia Historic Bridge Survey (GHBS) database lists a total of 54 metal truss bridges, 44 of which are eligible for inclusion in the National Register of Historic Places (NRHP). This number reveals a reduction from 155 historic metal truss bridges identified in the 1981GHBS. It was found that the majority of the State's historic metal truss bridges are located in the middle to northern regions of the state, north of the fall line in the state which could lend itself to a centralized storage location in that portion of the state.
2) There has been a wide range of efforts pertaining to preservation of historic metal truss bridges throughout the United States. The nature and scope of these activities in other

states was investigated and summarized. No other states have sought to develop best practice guidelines for storage, highlighting the value of this research study.

3) A large number of the historic metal truss bridges in Georgia are off-system and are effectively stored in place. This option is cost effective. In addition, the historic setting is retained which may be important to the current owner or community. However, leaving a historic metal bridge closed to traffic but left on site had never been studied as a storage option, so it was not known whether or not this practice is a suitable treatment of a valuable historic resource. In addressing indoor versus outdoor storage, in place storage was addressed since it is essentially the same as outdoor storage.
4) If the decision is made to leave a bridge on site, approaches to extending the life of the bridge should be considered. Key activities associated with the stabilization of historic metal truss bridges left on site include restricting access to the structure and making necessary repairs to address safety concerns and to preserve the structure's historic integrity.
5) Key rehabilitation activities needed prior to storage were also identified. Various rehabilitation activities may be deferred until the bridge has been placed in storage. The rehabilitation activities may include heat straightening of members, repair or shortening of slack members, use of welding to build-up members exposed to section loss, removal and replacement of deteriorated pins and rivets, removal and replacement of loop eyebars, and pack rust and paint removal. Bridge components which typically are not preserved by other states were also identified.
6) A summary was provided on the science of corrosion supporting the non-essential nature of painting prior to storage if the structure has been adequately cleaned. However, it was found that it is important to paint in the vicinity of areas containing crevices or metal surfaces that have been repaired from pack rust damage.
7) The research assessed the use of technologies such as terrestrial laser scanning, photo- or videogrammetry, and unmanned aerial vehicles (UAV)). The study recommends that this technology be included in the standard documentation of historic metal truss bridges. Size of the bridge, accessibility, and cost should be considered before a technology is selected. All of these technologies result in point clouds that can be processed further for 3D modeling.

8) Emerging Bridge Information Modeling (BRIM) solutions can be used for marketing and conceptual designs, and can even be used in the bridge repair to reproduce deteriorated bridge components.
9) The research team identified efforts by various states as well as private organizations involving the marketing and reuse of historic metal truss bridges. Several recommendations were developed for improved marketing of these structures, emphasizing a web-based marketing presence in addition to the direct contact approach already in use. The researchers also reviewed transfer agreements developed by other states and provided some basic recommendations for these documents.
10) General considerations for disassembly of historic truss bridges were discussed, as well as the advantages of moving the bridges intact or partially intact. The research team recommended that disassembly of the structure consider the extent of necessary replacement or repairs which may require disassembly. The extent of disassembly is often a transportation consideration as well. The least harm to the historic integrity of the bridge occurs when as much of the structure is left intact as possible. The research summarized notable relocation and rehabilitation efforts by Virginia DOT and Oregon DOT involving large historic metal truss bridges.
11) If disassembled for any reason, the importance of clearly marking historic metal truss bridges was emphasized and recommendations for marking and other documentation were provided.
12) Basic considerations for transporting historic metal truss bridges were discussed and several notable examples are summarized.
13) Recommendations for the size, location and type of facilities for off-site storage were provided. Specific recommendations were provided for stacking, supporting, inspecting, and maintaining a bridge in storage.
14) Estimates of the cost for rehabilitation, storage and reuse of a bridge are provided. The research team found that the estimator may want to use multiple sources to estimate costs. Some of the activities can require specialized equipment, techniques, and materials to preserve or repair character-defining features. Due to the limited number of skilled professionals able to perform the work, such tasks might significantly add to the cost. For such reasons, recommendations were given that cost estimators may consider the use of

past bid tabulations, cost-estimating manuals, and local engineering, architectural, and construction contractor resources. It was also recommended that site visits be performed to evaluate the disassembly, reassembly, and preservation of the unique features of the bridge.

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1. Introduction

1.1 Problem Statement

In 2002, the Federal Highway Administration (FHWA) and Georgia Department of Transportation (GDOT) formed an agreement that historic metal truss bridges would be marketed to municipalities and other entities for reuse when their sufficiency rating warranted replacement. Truss bridges were considered to have good reuse potential because of their size and inherent ability to be dismantled and reconstructed. It was agreed that historic truss bridges could either be marketed for rehabilitation in place or moved to a new location. The assumption was that, in most cases, these bridges could be used for pedestrian use

According to the this agreement, GDOT would determine: 1) a bridge’s capacity for being rehabilitated without destroying its historic integrity; 2) the requirements to rehabilitate and relocate the bridge; and 3) the total cost for this undertaking. Federal regulations required that only the cost of demolishing the bridge could be used for preservation purposes. It was expected that the demolition cost would cover only the cost of the bridge relocation. Therefore, the costs associated with rehabilitation, site preparation, maintenance, etc. would need to be assumed by the recipient of the bridge.

GDOT has had challenges with efforts to reuse historic metal truss bridges, primarily due to funding and scheduling factors. The replacement date of a bridge often does not coincide with the identification of a recipient, or with the recipient’s readiness to reuse it. In some cases, the replacement date has been delayed for funding or other reasons, causing the recipient to lose interest or consider another alternative such as the use of a non-historic substitute in their project plans.

The numbers and condition of truss bridges are in rapid decline. It is important to identify all potential tools that could aid in their reuse and preservation.

As part of the 2002 agreement, GDOT also committed to consider storing metal truss bridges of historic value in lieu of demolition, until a recipient could be located. At the issuance of this report, no other state Department of Transportation has initiated a similar stewardship program.

1.2 Objective

The objective of this report is to determine the most effective processes for storage of historic metal truss bridges until a reuse can be determined. The design and material integrity of the bridge must be retained. The report first reviews the conditions leading to the decision to replace a historic bridge including the determination of the feasibility for reuse, discusses the cases in which metal truss bridges are commonly stored in situ versus being removed and stored at an off-site location, then addresses the tasks to be undertaken once the decision has been made to store a bridge. These activities are referred to broadly as the evaluation and stabilization of the bridge. This is followed by an assessment of best practices in the areas of preservation, documentation, marketing, disassembly, transportation, and cost estimation as these pertain to storage.

Each of these practices is discussed in a main chapter of the report. The sequence of the chapters follows the sequence of the activities commonly associated with the storage of these types of structures. However, these activities do not typically occur in a simple linear sequence; rather, some of them can be intertwined and some may need to be revisited.

1.3 Background

The State of Georgia has a significant number of historic metal truss bridges. According to the Georgia Historic Bridge Survey (GHBS), 44 are eligible for inclusion in the National Register of Historic Places (NRHP) (GDOT 2012). This current number is a reduction from the 155 historic metal truss bridges identified in the GHBS conducted in 1981. Many of these bridges were replaced prior to the 2002 agreement between GDOT and the FHWA and were left on site having various ownership and maintenance arrangements negotiated with local governments.

The number of metal truss bridges currently listed in the GHBS for each county within the state is shown in Figure 1. In effect, many of these bridges are stored on site.

Figure 2 shows the locations of 24 bridges out of the above 54 for which complete information regarding the maximum span length, the width and the total length of the bridge is available. The maximum span length is less than, or equal to, 150 ft. and the maximum total bridge length is less than or equal to 370 ft. These bridges are considered to be the most representative of the historic truss bridges in the State of Georgia. Seventeen of these structures are pony truss bridges, with maximum span lengths between 16 and 112 ft., six are thru truss bridges with maximum span lengths ranging from 100 to 150 ft., and one is a deck truss bridge with a maximum span length of 112 ft.

Figure 2 shows that all of the 24 bridges are located north of the fall line in the state. The small number of metal truss bridges south of the fall line is due to the flatness of the terrain in this part of the state. Due to this flatness, the rivers tend to be wide and shallow. The most economical bridge over shallow waterways is a trestle or stringer, not a truss. Metal trusses were often favored at deep or swift rivers, which are most often located in the northern part of the state (GDOT 1981).

Along with location and dimensions, the other bridge attribute is the truss type. Although the type of metal truss might not impact *how* to store the bridge, the rarity of the type might add to its historic significance and therefore, inspire the storage of the bridge until it can be reused. Bridge type also offers a common vocabulary when discussing the bridge with historians, preservationists, engineers, and bridge enthusiasts. The extant metal truss bridges in Georgia can be categorized as three types: a thru truss, pony truss, and deck truss.

A thru truss is a structure that allows the traveler to pass through it (see Figures 3 through 6). The vehicle or pedestrian passes between the metal trusses and underneath the top lateral members and sway bracing members, which stabilize the two trusses within each span laterally. The trusses work together in supporting vertical and lateral loads on the structure. Each of the vertical members of the bridge trusses supports a floor beam which spans across the width of the bridge between the trusses and underneath the bridge deck. These floor beams in turn support members that are typically referred to as joists or stringers, which span between the floor beams along the length of the bridge. The joists or stringers in turn support the bridge deck.

In contrast, the primary distinctive feature of a pony trusses is that the roadway passes between the main trusses of the structure, similar to a thru truss, but the trusses are typically smaller in span and do not have any top chord lateral bracing (see Figures 7, 8 & 9).

The deck truss, which places its supporting framework below the road, was used in cases where enough room existed below the bridge for its truss. This type was used where builders desired a more open bridge, without the confining side panels of a thru or pony truss. The thru truss, pony truss, and deck truss have subtypes with names like “Parker”, “Warren”, and “Pratt”, these generally refer to the individual who applied for the patent.

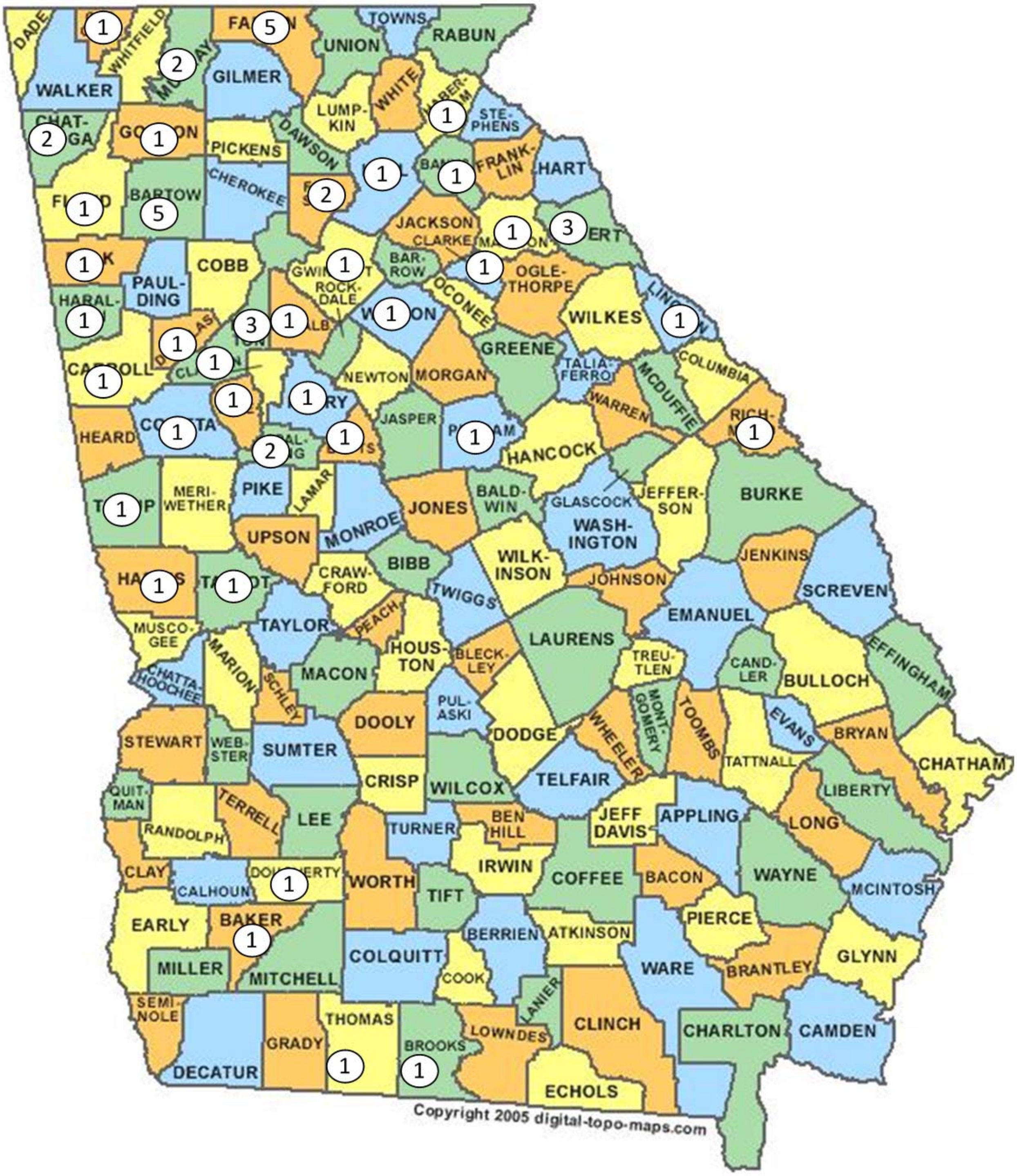

Figure 1. Location and number of historic metal truss bridges in the GHBS per county (map courtesy of Digital-Topo-Maps.com).

Figure 2. Location and number of historic metal truss bridges in the GHBS per county which have available dimensions (map courtesy of Digital-Topo-Maps.com).

The following are provided as representative examples to illustrate the historical importance and context of the metal truss bridge in Georgia.

One of the most beautiful and well regarded restored metal truss bridges is Hermi's bridge in Vinings, Georgia (**Error! Reference source not found.**). Hermi's bridge is an outstanding example of what can be done when individual, community, county and state interests, and capabilities converge to achieve the retention and restoration of a historic metal truss bridge. This bridge, constructed in 1904 by the Cotton States Bridge Construction Company, is a thru truss, meaning that the roadway (or now the pedestrian walkway) passes through the structure. Hermi's bridge has two identical 140 ft. spans of its main trusses.

When Fulton County announced plans to demolish this bridge and replace it with a new one in 1972, Cecil and Hermi Alexander urged the Fulton County Commission to save the bridge. Cecil, a prominent architect in the Atlanta area, convinced the county commission that it would be more cost effective to simply leave the old bridge in place and build a new one alongside of it. After Hermi was killed in an automobile accident, Fulton County passed a resolution in 1984 to rename the bridge in her honor, a tribute to her active role in the Civil Rights movement and her contributions as the first female jury commissioner in Fulton County history.

By 2006, Hermi's bridge had deteriorated to the point that it was deemed unsafe for usage and closed. Cecil engaged the PATH Foundation, the City of Atlanta, and Cobb County, in an effort to raise $1 million in funds to restore the bridge to its former grandeur. The restoration included replacing rotted wood decking and repainting the structure. Much of the cost of the restoration was devoted to encapsulating the bridge to ensure that paint chips did not contaminate the river when the old lead based paint was stripped. The restoration of the bridge was completed and the bridge was opened for pedestrian use in November of 2010. A more detailed description of the history of Hermi's bridge can be found at
<http://www.reporternewspapers.net/2010/02/25/hermi%E2%80%99s-bridge-a-love-story/>
and at <http://www.buckheadheritage.com/our-work/restoration/hermis-bridge>.

(a) Perspective view of Hermi's Bridge from the banks of the Chattahoochee River

(b) Elevation view

Figure 3. Hermi's bridge in Vinings, Fulton County.

(c) End portal

(d) View from the bridge deck

Figure 3 (continued). Hermi's bridge in Vinings, Fulton County.

Another distinction among historic metal truss bridges is the way that the members are connected. The members are either pin-connected or riveted. In a pin connected bridge, a cylindrical metal bar joins the truss members together. This connection method required holes in the ends of each member that were then aligned together, so that the pin could be driven through all the holes to form a structural connection. Most pin connected bridges were constructed before 1900. At the end of the 19th century most bridge manufactures had migrated from pin-connections to riveted connections.

Figures 4 through 6 show several additional examples of historic thru truss bridges within the state. These bridges are all documented in the GHBS (GDOT 2012). The pin connected Camelback thru truss shown in Figure 4 is the Milam Bridge located in Bartow County and is the longest bridge of this type within the state. Constructed in 1912 by the Converse Bridge Company in Chattanooga, this bridge was closed to traffic in the 1970s. By perusing the GHBS as well as the web sites of private organizations that promote historic bridge preservation, such as HistoricBridges.org (Historic Bridges 2014) and BridgeHunter.com (Bridge Hunter 2014), more than a few bridges can be identified that are essentially stored in situ, although efforts to restore the bridges may or may not be continuing.

Figure 4. Camelback (pinned) thru truss in Bartow County, Bridge 015-9992 (GDOT 2012).

A 100 ft. span Pratt thru truss with pinned connections, built circa 1900 is located in Thomas County, east of US 19 / SR 3, near Dawesville, in a setting of planted pines (Figure 5). The bridge historically carried U.S. Highway 84 over the Ochlockonee River but was bypassed and moved five miles to this location in 1929 to carry U.S. Highway 19/SR 3. In 1959, the bridge was again bypassed and a new concrete bridge was built nearby to carry U.S. Highway 19/SR 3 over the river. The bridge's approach spans have been removed. One can see the disheveled wood stringers underneath the wood plank deck in the photo (Figure 5), supported by the floor beams spanning between the main trusses. Although the Pratt thru truss bridge type is relatively common, the location of this bridge, south of the fall line, is rare.

Figure 5. One-hundred ft. span Pratt (pinned) thru truss located in Thomas County, Bridge 275-9991 (GDOT 2012).

A beautiful Pratt thru truss that is still in service carries a one-lane cemetery road over the Oconee River in downtown Athens, GA (Figure 6). It is ranked by the GHBS as one of the “most complete” pin connected thru truss bridges in the state. In addition to its design integrity, it is a contributing feature of the surrounding historic Oconee Hill Cemetery, an outstanding example of a Victorian cemetery. The bridge was constructed in 1899 by the Geo. E. King Bridge Company of Des Moines, Iowa. It has a number of striking ornamental features on its end portals.

Figure 6. Pratt (pinned) thru truss Clarke County, Bridge 059-9991 (GDOT 2012).

The primary distinctive feature of a pony truss bridge is that the roadway passes between the main trusses of the structure, but it does not have any top chord lateral bracing. The 77 ft. Warren pony truss shown in Figure 7 is located in Catoosa County is owned by the National Park Service. It carries a one-lane road over a stream at a boundary of the Chickamauga National Military Park. Built ca. 1907 by the War Department, this bridge was erected as part of the development of the Chickamauga Battlefield and the nation’s first national military park. Its floor beams are set above the truss bottom chords. All of its connections are riveted and the members are riveted built-up sections. The bridge has significant amounts of impacted rust on its built-up top chord and end posts. It still has its original lattice railings (the elements on the inside of the trusses intended to protect the main trusses from collision damage and help block users of the bridge from inadvertently exiting the sides of the bridge), but its approach pipe railings have been lost. This bridge was rehabilitated in 2011.

A later example of a pony truss bridge is located in Fannin County and was built in 1938 (Figure 8). This bridge has been bypassed and a new bridge constructed beside it. Its main span is a Warren truss with verticals, and its top chords are rolled H sections. The field connections in the bridge are bolted and all the other connections are riveted. One can observe from the photo that the bridge deck has been removed, and the approaches are mostly obliterated to limit unauthorized access to the bridge.

Last, Figures 9 and 10 show an excellent example of a pin-connected Pratt pony truss bridge. This is one of only a few of these specific types of bridges remaining in the state. The bridge is a 79 ft. span carrying a one-lane road over a stream in a sparsely developed area in Eton, near the Chattahoochee National Forest. This bridge retains its original lattice railings.

Figure 10a illustrates the pin and eyebar member details at one of the joints on the bottom chord of the main trusses of this bridge. A floor beam is framed into the truss vertical member below the pinned connection. The verticals in this bridge are built-up from three channel (C shaped) rolled sections using rivets. The eyebar heads were fabricated by ending the bars to make a loop and then forge welding the end of the bars into a notch in the straight section of the bar.

One can observe that the top chord is composed of two rolled channels on its sides, a plate riveted to the tops of the two channels, and batten plates and lacing riveted to the bottoms of the two channels. The top chord, the diagonal eyebars, and the verticals are connected together by a single pin at the center of the joint (Figure 10b).

Figure 10c shows the detail where the end post connects into a concrete abutment at one of the ends of the bridge.

Ideally, a state would endeavor to retain examples of all truss types. Once the locations, dimensions, and types are inventoried, priorities can be established for preservation. They could be left in place, stored for future use, or rehabilitated for pedestrian use.

(a) Perspective view

(b) End view

Figure 7. Warren (riveted) pony truss located in Catoosa County and owned by the National Park Service, Bridge 047-5004 in the GHBS (GDOT 2012).

Figure 8. Pony Warren truss located in Fannin County, Bridge 111-9992 in the GHBS (GDOT 2012).

Figure 9. Seventy-nine ft. span Pratt (pinned) pony truss in Murray County, built in 1918 by the Champion Bridge Co., Wilmington, OH, Bridge 213-5007 in the GHBS (GDOT 2012).

(a) Pin and eyebar member detail at a bottom chord joint, with a floor beam framed into the truss vertical member at the joint.

(b) Detail at top chord joint

Figure 10. Bridge 213-5007 details.

(c) End post detail at the bridge abutment showing some loss of the cross-section due to corrosion

Figure 10 (continued). Bridge 213-5007 details.

1.4 Research Approach

This study was conducted by reviewing the literature on the management and preservation of historic bridge structures, and by interviewing GDOT personnel and DOT personnel in other states as well as contractors, fabricators and engineering consultants that have experience with the preservation of metal truss bridges. In addition, the research team investigated documentation technologies, evaluated current historic metal truss bridge marketing efforts, and collected best practices pertaining to the disassembly, transportation, and actual storage of historic metal truss bridges. Some guidance pertaining to cost estimation for historic metal truss bridge rehabilitation and relocation also were addressed.

2. Evaluation and Stabilization Prior to Storage

2.1 Introduction

This chapter provides a brief overview of the typical activities leading up to the storage of a bridge. These include determining the feasibility of reuse, a discussion of storing a bridge in place versus moving it to a storage facility, stabilization of the bridge for storage and potential reuse, and other preservation activities to consider prior to storage.

The bridge preservation team may consider applying some of the preservation activities to the structure during its storage, when there may be fewer project time constraints. Some of the activities described in the subsequent chapters, i.e., certain documentation tasks, may need to occur before completing the preservation activities. As noted in Section 1.2, the ordering of the chapters of this report is not intended to convey a strict linear sequence of activities.

2.2 Decision to Replace and Reuse a Bridge

The decision to replace a historic metal truss bridge often starts as the result of periodic safety inspections which indicate that the bridge becoming structurally deficient. Structural deficiency means that the bridge is deteriorating to the point that its capacity for carrying traffic loads is becoming limited.

In addition to deterioration, historic metal truss bridges often do not meet today's traffic demands and safety standards. Various constraints that may impact the ability of the bridge to meet the transportation need include inadequate vertical clearance under or on the bridge, inadequate railing, deficient width, or low load capacity. If the vertical clearance under the bridge is not adequate, metal truss bridges themselves can sometimes be raised to address the problem. However, this requires lengthening the bridge approaches to the extent that raising the bridge may not be a viable option. In addition, improving the vertical clearance is usually not the only concern.

A historic railing can be augmented or replaced to meet current design standards. For example, Mort (2008) describes the preservation work performed on the Murray Van Wagoner Bridge in Morenci, Michigan. The problem of retaining the bridge's railing as a character defining feature versus the need to install a new up-to-code railing was addressed by installing a modern railing next to the bridge's travel lanes to meet current safety requirements, while retaining the historical railing on the outside to maintain the bridge's historical profile. In another example, the Silverdale bridge in Koochiching County, Minnesota (Bremer 2011) was reused as a pedestrian bridge on the Gateway State Trail, and an equestrian railing was added on the inside of the trusses as part of its new deployment. However, these types of changes may not always be feasible. Increasing the width of the roadway or the vertical clearance on the bridge is not an option for historic metal truss bridges in which the roadway passes within the structural system without substantially changing the structure. In addition, rehabilitating the structure to provide adequate load capacity may require extensive modifications. In cases where the structure or the design criteria cannot be acceptably modified to meet requirements, the bridge must be replaced.

In certain cases, the bridge may be too severely damaged or deteriorated, funds to rehabilitate it might be limited, the community might not be interested in its preservation, or there could be no opportunities available for reuse. However, even in the cases where storage and reuse are not possible, it can be worthwhile to salvage certain components of the bridge that may have high historical value and reuse potential. As discussed by Mort (2008), "The portal of its truss may be [sic] serve as an entranceway into a park. A side may be mounted on a brick wall as an exterior decoration. Critical pieces may be saved as spare parts for other restoration projects."

2.3 In Place versus Off-Site Storage

There are instances when a bridge can serve a useful purpose at its present location as part of a pedestrian walkway, cycling path, horse trail or other use. If funds are not readily available to rehabilitate the bridge to serve such a purpose, it may be cost effective to leave the bridge in place until rehabilitation efforts can be funded. If a bridge must be replaced and removed, the only storage choice is off-site. This would occur when the new bridge must be constructed in the footprint of the old bridge.

In summary, when the roadway can be realigned to leave a bridge in place, it can be a good preservation practice as long as the necessary stabilization is performed.

2.4 Stabilization

Stabilization is defined as the tasks needed to maintain or protect the structural integrity of a bridge. The goal of these tasks is to ensure the public safety and to minimize harm or damage to the structure. Most stabilization activities are necessary regardless of whether the bridge is to be stored in place or off-site.

Once the bridge is closed to traffic, these items should be addressed:

1) Restrict access to the structure. If the trusses are being moved, the bridge deck should be removed. If left in place, the deck may also be removed as a method of limiting access. However, depending on the condition of the deck, it may be advantageous to leave the deck in place either as part of the future adaptive reuse of the structure, or to facilitate the marketing of the bridge.

   Vandalism is common for closed bridges. Graffiti on the bridge can damage its historic value. Bridge plates can be removed or lost. Measures should be taken for protection. Security cameras can be installed for remote monitoring. Heat-rise sensors and water sprinkler systems can be installed. These methods are effective and low-cost. Local police should be alerted so that the bridge can be patrolled periodically.

2) Perform immediate repairs. The team addressing the storage of the bridge should identify damage to any components that poses a direct safety hazard or may lead to a significant loss of historic value of the structure. This would include the securing of loose identification plates or ornamental items on the bridge that could be removed by unwanted visitors to the site.

2.5 Evaluation

Early in the storage decision process, it is essential that an engineer develop a list of deficiencies, with input from a historian, on elements that should be retained if possible. This evaluation should be done when making the initial decision on the feasibility of storing and reusing a bridge. However, subsequent, more detailed evaluations can be required once more specific storage and reuse plans are developed.

As explained by Hatfield (2001), historic metal truss bridges were designed to support uniformly distributed loads in addition to, or in lieu of, concentrated axle loads. This was to ensure safety for lines of wagons or automobiles, livestock, and crowds of people, the latter typically being the governing distributed load. In general, the published design loads for old highway bridges exceed the current requirements for pedestrian bridges, although bridges with long spans and designed for rural service may be exceptions (Hatfield 2001). However, in some extreme cases, the damage to portions of the structure may be severe and the capacity of the bridge may be compromised. This may be the case if the bridge has already been out of service and effectively abandoned for some time. It is essential to check the bridge for loads associated with any selected rehabilitation operations, as well as disassembly and transportation.

This detailed structural evaluation requires a field inspection to collect additional information beyond that gathered during routine safety inspections. The specific tasks associated with this inspection should include:

- Identifying the bridge materials.
- Determining the general dimensions of the bridge and of the proposed site, including any significant variances due to shifting of the structure from its design position. The existing geometry of the bridge could be deformed relative to its nominal design geometry due to various factors such as collision, corrosion damage, or traffic loading which could bend one or more of the truss members. These changes in the shape of the structure should be documented. One should obtain specific condition and section dimensions of the truss members and components, particularly at locations subjected to significant section loss (i.e., the loss of thickness of the cross-section plates) due to corrosion.
- Looking for evidence of fatigue and fracture damage in the truss members and components.
- Identifying the nature and locations of any additional supports required on the in situ structure, i.e., in certain cases, the bridge may be shored or supported at certain locations to ensure stability. In some cases, historic metal truss bridges have been reused in a manner where the bridge is supported by introducing intermediate piers or a second supporting structure, thus essentially removing the primary structural demands on the bridge. As noted by Haberling and Leary (2004), the introduction of a substitute secondary structure for the final disposition of the bridge should be considered as a last resort and done in a way to minimize the removal of the historic fabric. This technique can visually overwhelm the historic bridge and reduce its trusses to ornamental fixtures on a modern looking bridge.
- Determining the extent of disassembly required for rehabilitation, transportation and storage. Assess the specific loads induced on the structure and its components during these operations. This is discussed further in the subsections below.

2.5.1 Identification of Bridge Materials

Identification of the bridge materials is important in determining the capabilities of the structure. Advances in available materials played an important role in the development of the truss bridge in the 19th century. Cast iron was the first ferrous metal to be used in large amounts in truss bridges. Though strong in compression, it is relatively weak in tension. Cast iron is most often found in early metal truss bridges (pre-1894) for cast connecting pieces and compression members. It was also used for railings, railing posts and bosses (ODOT 2010). The all-metal truss bridge became possible only after wrought iron, which is strong in both tension and compression, became available in relatively large quantities at low cost. The development of a number of truss designs in the middle decades of the 19th century coincided with the availability of wrought iron and the expansion of railroad networks (GDOT 1981).

Steel began to replace iron as the Bessemer process to make steel began around 1865. However, iron remained dominant for structural applications until the 1890s because of brittleness problems with steel, caused by high carbon, excess phosphorus or excessive temperature during rolling or too rapid a rate of rolling. Open hearth steel was first manufactured in Cleveland in 1886 and rapidly replaced wrought iron for structural applications by 1890 (Misa 1995).

When evaluating a historic metal truss bridge, it is important to identify the type of materials used for the bridge members. A visual inspection of the surface of the material after it has been thoroughly cleaned can be used to aid in determining if the material is wrought iron or steel. Procedures for the identification of wrought iron are discussed in several sources (Bowman and Piskorowski 2004; VJM Metal Craftsman, LLC 2013; Real Wrought Iron Company 2014). Chemical and mechanical testing is also desirable, if possible, to determine specific material properties. Bowman and Piskorowski (2004), and Hatfield (2001) provide specific data on typical material properties of wrought iron important for structural assessment. Interestingly, wrought iron has the highest resistance to corrosion of all ferrous metals other than special alloy steels. Section 2.2 of Bowman and Piskorowski (2004) provides an extensive review of the 19th century technical literature on structural properties and design with wrought and cast iron. They report that the lower second standard deviation for the tensile strength of wrought iron, from historical sources, is 40,000 psi and recommend this as a conservative estimate for wrought iron in historical bridges.

2.5.2 Development of a Deconstruction or Disassembly Plan

If the bridge is slated for off-site storage or is being relocated for reuse, then some deconstruction of the structure will be necessary. For small pony truss bridges, this may involve only the removal of the deck and the addition of temporary bracing needed for transportation of the intact structure. Keeping the structure intact as much as possible minimizes any potential loss of its historic integrity. After repairs are made, the structure, along with any temporary supports and bracing, should be able to resist any unusual loads induced during the disassembly. For instance, if the entire bridge is to be lifted off of its supports as one unit, (along with any temporary bracing, or other reinforcement provided for the deconstruction operations) it needs to be able to withstand the associated stress. Chapter 5 addresses specific considerations involved with the deconstruction of metal truss bridges, which can range from full disassembly to lifting of the structure intact from its supports. In all cases, the deconstruction plan must be evaluated and approved by a qualified professional engineer.

2.5.3 Development of a Transportation Plan

If transportation to off-site storage is required, a plan should be developed that ensures that the move can be achieved while maintaining the structural and historic integrity of the bridge. If large units of the bridge are to be shipped and stored intact, the plan would include the construction of sufficient supports for these units at the off-site location. Chapter 5 also addresses specific considerations associated with transportation of metal truss bridges. In all cases, the transportation plan must be evaluated and approved by a qualified professional engineer.

2.6 Preservation Activities Prior to Storage

Prior to discussing any preservation activities, it is useful to review the US Secretary of the Interior's Standards for treatment of historic properties. The next section provides a brief summary of these definitions. This is followed by a discussion of bridge elements typically not considered as important historical elements. Generally, cleaning of the structure is a necessary, high-priority and relatively inexpensive treatment that should be applied to all historic metal truss bridges that are being evaluated for storage. Therefore, this preservation activity is discussed first. This is followed by a discussion of other preservation activities. The importance of the other preservation treatments depends in large part on the condition of the bridge. The priority will vary depending on the need. As noted above, depending on the specific bridge conditions, some of these activities may be best deferred until specific future reuse decisions are made.

2.6.1 Secretary of the Interior's Standards for Treatment of Historic Properties

The Secretary of the Interior's Standards for the Treatment of Historic Properties (NPS 1995) are commonly used as a guide for preservation of historic metal truss bridges. The goal, as with any historic resource, is to retain its distinctive materials, features, design, and construction techniques as much as possible. These standards include the following four options:

- **Preservation:** Preservation is defined as "the act or process of applying measures necessary to sustain the existing form, integrity, and materials" (NPS 1995). In the context of storage of historic metal truss bridges, preservation mostly entails basic maintenance work done during the process of readying the bridge for storage and repair of historic materials rather than replacement and new construction. The Standard's guidance for preservation recommends first identifying the important historic features so that their characteristics can be retained. Second, protection and maintenance are recommended. Protection and maintenance may include cleaning, paint removal, applying protective coatings, and installing barriers to minimize access to the bridge.
- **Rehabilitation:** Rehabilitation is defined as "the act or process of making possible use for a property through repair, alterations, and additions, while preserving those portions or features which convey its historical, cultural, or architectural values" (NPS 1995). Rehabilitation differs from preservation in the sense that it focuses more on repair and replacement of deteriorated features than basic maintenance.
- **Restoration:** Restoration is defined as "the act or process of accurately depicting the form, features, and character as it appeared at a particular period of time" (NPS 1995). While preservation and rehabilitation focus on maintenance, repair and replacement, restoration's goal is to make the bridge appear as it did in the past. Restoration could remove features that had been added over time and repaint the bridge so that its appearance matches the historic paint. Missing features can be replaced based on historical research.

- **Reconstruction:** Reconstruction is defined as "the act or process of depicting, by means of new construction" so that the bridge would replicate "its appearance at a specific period of time and in its historic location" (NPS 1995). Within the scope of this report, reconstruction is the least applicable since the bridge is to be stored and reconstructed at a different location. Possible reconstruction of portions of the bridge, where needed, would likely occur later at the time of reuse. Reconstruction is outside the scope of this report, other than the fact that certain components of a bridge may need to be reconstructed depending on the attributes of the eventual reuse. However, within the context of best management practices for storage, the reuse has not yet been determined and therefore, specific reconstruction plans would not yet have been identified.

The essential theme of all of the above treatment options is that, when performing work on a historic structure, one must aim to retain and not adversely affect the features that make the structure historically significant.

2.6.2 Features that are Typically Not Rehabilitated

The identification of the key features of a historic metal truss bridge that need to be preserved requires research and review by a qualified historian. After a review of preservation efforts by other states, it was noted that it is common practice not to make efforts to rehabilitate certain components when they are severely deteriorated. These components include:

- **The bridge deck and stringers.** These elements are often the weakest elements in the bridge. Basic replacement with a new deck and stringer system increases the structure's capacity significantly. In some cases, required load capacities can be accommodated by replacing the existing deck with a lighter weight deck.
- **The bridge rails.** The bridge rails themselves can be an important historic feature. Railings can be decorative and useful in identifying the period of a bridge's construction. However, it is common to replace the rails.
- **The bridge bearings.** Deteriorated bearings are typically difficult to repair. However, they are often replaced with the same type of bearing, e.g., a pin connected bearing or rigid bearing. This element should be researched by the historian to determine its significance.

2.6.3 Specific Preservation Treatment Activities

This section discusses several specific treatment activities. These activities may or may not need to be undertaken depending on the state of the particular bridge.

2.6.3.1 Cleaning

Removal of accumulated debris is possibly the single most important immediate stabilization task for a metal truss bridge that is being placed into storage. Accumulated debris tends to accelerate material deterioration. Expansion joints, bearings and bridge seats should be cleaned of debris to ensure their proper function.

There are various opinions about the most appropriate cleaning of bridge metal surfaces. If lead-based paint is not present, hand cleaning and power washing is recommended. This should include all horizontal surfaces, such as abutment seats at the bearings, flanges of stringers and floor beams, and chords. Panel points often accumulate debris; and thus, should receive special attention.

Some states discourage chemical or physical treatments, such as sandblasting, on historic structures. If the decision is made to paint the structure, the components should be cleaned to a “white metal” condition to ensure the best adhesion of the paint. Hand cleaning and power washing, followed by application of a penetrating sealer that bonds any remaining paint and rust to the base metal, and finally the application of one or two top coats of paint is considerably less expensive, but does not last as long.

Section loss on the various metal components is most easily assessed after the structure has been cleaned.

Rust can also occur between rivet- and bolt-connected members, a condition known as impacted rust or pack rust. Pack rust is usually characterized by buckling in one or more parallel metal plates as shown in Figure 11. If pack rust is not treated, the corrosion process may actually accelerate. Pressure washing or sandblasting will not remove the corrosion in inaccessible areas. The active corrosion cells are located within the crevices and include water, oxygen and hydrochloric, nitric, and sulfuric acids. This rust must be removed. Section 2.6.3.8 discusses its removal.

Figure 11. Pack rust (Mesler 2007a)

2.6.3.2 Heat Straightening

Members of historic trusses may be damaged and distorted by overload and vehicular and environmental impacts. This damage is particularly debilitating to a metal truss bridge. Trusses depend on the fundamental structural form of various connected triangles for their structural efficiency and strength. The primary elements of a truss, i.e., any of the sides of the triangles, transfer force (through compression or tension) from one point to another. If any of these elements is bent or distorted, the fundamental form of the truss has been damaged, and the integrity of the bridge can be significantly compromised.

Heat straightening may be applied to member distortions to restore the shape of the members. The technique involves application of repetitive heating and cooling cycles and restraints to produce a gradual straightening of the metal. It is economical and does not require removal of the member from the system. Often, it is useful to heat straighten damaged members as an early step in stabilization of the structure. Heat straightening may be the only option available to allow the continued use of components that would otherwise need to be discarded and replaced.

Bowman and Piskorowski (2004) indicate that, when repairing a bent wrought iron tension member, it is essential to utilize heat to minimize the reduction in ductility and strength of the member. Cold bending of the member back to its original shape can severely impact the member's structural integrity; heat straightening, when done properly, can be performed to restore the member to its straight geometry without negative effects.

When the metal is heated locally, it wants to expand in volume, but is restrained by the surrounding unheated material. The surrounding material acts like a vise, forcing the heated metal to effectively expand into itself in the directions of the constraint. Metal fabricators refer to this process as "upsetting." When the metal cools, its contractions pull the surrounding metal into a new shape determined by the pattern of contraction the heat has caused.

The only viable alternatives to heat straightening of bent members are either the full replacement of the member by new steel, or cutting out the damaged length of the member and splicing in a new section of steel to the member. This splicing is typically done by welding.

It is essential that heat straightening repairs be evaluated and monitored by a structural or materials engineer with expertise in working with historic metals. Key controls on the process include the following:

1) Support of the structure to maintain its stability during the repairs. The parts being heat straightened must be free of external forces during the process. In most situations with metal truss members, it is best to remove the member from the bridge for heat straightening.
2) Keeping the metal below its transformation temperature at which the crystalline microstructure of the metal is fundamentally changed. The metal should be heated to no more than 1150^{o} F (620^{o} C) as measured by temperature-indicating crayons, liquids, or bimetal thermometers.
3) The metal should be cooled gradually after heating. After the metal cools naturally to 600^{o} F (315^{o} C), the Contractor may use air-mist spray cooling.
4) Inspection by an engineer after straightening. The engineer should carefully inspect the metal surface for any evidence of fractures and for general acceptability.

2.6.3.3 Repair of Elongated or Slack Members

Another problem that commonly occurs in historic metal truss bridges is that the eyebars and diagonal members can become elongated, slack or loose due to heavy use. When members become slack their carrying capacity is reduced; other members may be forced to carry greater loads than they were originally designed for. This can reduce the overall structural safety of the bridge.

Shortening the loose or slack members in a metal truss bridge is a feasible solution to this problem. Some bridges already have turnbuckles that were designed to correct the shortening. In these cases, the turnbuckle may be rotated to bring the ends of the member closer together. It is important not to rotate the turnbuckle too much since this can induce unnecessary strain in the member. If turnbuckles are corroded, it can be beneficial to apply a small amount of heat as an aid in rotating the turnbuckle. This operation should be approved and monitored by a qualified professional engineer. In addition, the threaded region of the rod should be inspected for section loss and potential cracking.

2.6.3.4 Metal Fatigue and Replacement of Fractured Members

Fatigue in metals is the process of initiation and growth of cracks due to repetitive load. If crack growth is allowed to continue, failure of the member or component can result.

Assessment of the fatigue life of historic metal truss structures is an advanced technical task. Kuhn et al. (2008) have provided one of the most recent guides to the art of fatigue assessment. The remaining fatigue life is generally a function of three variables: 1) the number of cycles of loading, 2) the range of service load stresses experienced (i.e., the difference between the maximum and minimum stress), and 3) the initial size of a flaw. All of these factors can only be estimated.

All components of a historic metal truss structure should be inspected thoroughly for cracks. When investigating the capacity of pin connections of historic metal truss bridges, it is essential to investigate the strength of the connections at the ends of the eyebars, particularly those in the bottom tension chord. These eyebars are typically fracture critical members and should be thoroughly checked for any sign of distress due to fatigue cracking or corrosion. It is recommended that fractured members be replaced in their entirety, due to a likely loss in ductility related to the fracture of the member (Bowman and Piskorowski 2004). The practice of reusing fractured members by removing damaged sections and splicing with new material is not recommended.

2.6.3.5 Use of Welding to Build-Up Members Exposed to Section Loss

It is common to find severe corrosion near the joints of the structure. Eyebars and diagonals should be checked thoroughly for section loss from corrosion. When the section loss is severe, it may be necessary to replace or repair the member. Bowman and Piskorowski (2004) recommend two procedures to repair corroded members. The first recommendation is to grind the corroded areas to clean metal and use a filler weld repair procedure to build up the cross-section. The second recommendation is to remove the corroded section entirely and weld a new length of the member using a full penetration groove weld. Bowman and Piskorowski conducted experimental tests of both these repairs. Both tests failed in the shank of the eyebar, indicating that the repairs did not reduce the strength of the eyebar.

Figure 12, from Bowman and Piskorowski (2004), shows a corroded eyebar at its end connection, and Figure 13 shows this member after the above filler weld repair procedure was been completed on this member. A detailed discussion of the above filler weld processes can be found also in (Mort 2008), where the process is referred to as padding.

Figure 12. Eyebar end connection showing heavy corrosion (Bowman and Piskorowski 2004)

With both of the above procedures, it is particularly important to give due attention to the welding process. Welders with experience and knowledge in welding historic metals should be used, and the process should be approved by a qualified professional engineer. It should be noted that these procedures are relatively obscure. The authors of this report were not able to locate any formal specifications for the processes in their literature search. Mort (2008) refers to Lincoln Electric Company (1933) and Jefferson (1990) for guidance on the welding processes. He indicates that successful repairs have been conducted by using low welding currents and fast travel speeds for steel with high phosphorus and by using low-hydrogen electrodes on steels with high sulfur.

Figure 13. Eyebar end connection after repair by the filler weld procedure (Bowman and Piskorowski 2004)

2.6.3.6 Removal and Replacement of Deteriorated Rivets and/or Pins

In cases where rivets are corroded and need to be replaced, a common practice in many states is to replace the rivets by high strength bolts. Button head bolts can be used that have a similar appearance to the rivet on the side of the button head. The installation of rivets in steel construction is largely obsolete and few engineers and contractors are trained in the process of riveting. However, there are a number of organizations within the US that have experience in riveting. Vermes (2011) provides a succinct review of rivet technology, including recommended rivet removal procedures. The corresponding Lansing Community College website contains videos demonstrating rivet installation and removal. Mort (2008) explains that re-riveting as part of the preservation activities on a historic metal truss bridge should not be dismissed. He discusses several resources for riveting as well as the experiences with riveting by construction teams at the Calhoun County Historic Bridge Park in Michigan.

Substantial corrosion and section loss at truss pins, as shown in Figure 14, can result in an irregular cross-section that makes their removal difficult. Jacking may be necessary to separate members at the panel points if heavy corrosion has occurred. In some cases, it has been necessary to pierce the pins through their centers with a torch and collapse them (Figure 15). Care must be taken to support the remaining members after the removal of the pin.

Figure 14. Example of a heavily corroded pin (VDOT 2006).

Figure 15. Piercing the center of a pin (VDOT 2006).

2.6.3.7 Removal and Replacement of Loop Eyebars

Historic metal truss bridges often use loop or loop forge welded eyebars (Figure 16) as tension members. These members were formed by bending the bar to form a loop and welding the end into a notch in the straight section of the bar. Failure of these types of members has been noted during inspections of historic truss bridges (VDOT 2006), and their design use has long been prohibited (Urquhart 1930). There are no current standards to guide the assessment of these member types. Because of the uncertainty, Virginia DOT replaced all of the loop eyebars in its preservation of the Goshen Bridge (VDOT 2006). However, Hatfield (2001) points to research by Ellerby (1976), in which fatigue tests were conducted on these types of bars that suggested that they could have remained in highway service for many more decades. Nevertheless, these researchers found that fracture may occur at a forge weld rather than in the body of the bar, sometimes at a load much less than the design strength of the bar. The investigators speculated that repeated flexing of the loops was a critical factor and noted the deleterious effect of a poor fit of the pin. Hatfield (2001) recommends the practice of inspecting eyebars and forge welds visually and by ultrasonic and dye penetrant methods, grinding out cracks, and building back bars to their original profile by filler welding. He points to Ellerby (1976) for evidence that this process restores the full strength.

Figure 16. Forge welded loop eyebars from the City of Griffin 6th St. Bridge.

2.6.3.8 Pack Rust Removal

Special procedures for removal of pack rust are discussed by Mesler (2007a) and by Mort (2008). These methods involve applying heat to the buckle and then using a rivet hammer to drive out the rust from the buckle and then flattening the plates. To control distortion, the heating and hammering are sequential. Mort (2008) provides a more detailed description of the method used to avoid damage to the members during this process:

(1) The fabricator blunted the end of the rivet gun and fabricated a plate with a handle to serve as a buffer between the hammering of the rivet gun and the buckle, to avoid scarring the plate.

(2) Approximately 750^{o} F heat was applied to the buckles. This temperature is well below the 1,200^{o} F transformation range of the steel to avoid any problems in creating hard or brittle areas.

(3) To prevent distortion, the heating was sequenced.

Mort (2008) points out that this procedure does not remove all of the rust from between the plates, and that it is important to paint the cleaned exterior surface in the vicinity of the repair to seal the joint from oxygen and thus inhibit the progression of further rusting.

It is recommended that any specific procedures employed in practice should be evaluated and monitored by a qualified professional engineer.

2.6.3.9 Replacement of Deteriorated Members

Where deteriorated members need to be replaced, it is important to replace them with new steel members or with other identical members that have been salvaged from a similar bridge. It is important that either salvaged or new members maintain the original pinned or riveted (bolted) connection details. This not only preserves the appearance and historic context of the bridge, but also maintains the bridge's structural integrity. Pinned and riveted connection designs have different internal stresses. For example, a failed eyebar on a pin connected bridge could be replaced with a modern steel rod with end eyes that fit around the original pin. This allows the bridge to continue to accommodate stresses. Conversely, welding new or replacement members to a pin, or welding the pin itself, creates a rigid connection that will introduce forces for which the members were not originally designed.

2.6.3.10 Removal of Lead Paint

The presence of lead paint can be a major cost factor that can severely impact the reuse of a historic metal truss bridge. It is essential that the structure be assessed for the presence of lead paint. The lead paint should be removed. Also, the bridge is more marketable without lead paint, since lead paint removal is costly. Environmental Protection Agency (EPA) standards should be consulted for guidance on how to remove lead paint.

During the paint removal, the existing structure should be evaluated to determine what paint color was used historically.

2.6.3.11 Repainting of the Structure

Once the structure has been cleaned, including the removal of active corrosion products, the rate of further corrosion is low even if the bridge is left unpainted. Corrosives, such as weed control chemicals, must be kept away from the metal structure, however.

Repainting of the structure may be beneficial to marketing of the bridge for reuse, simply because this improves the appearance of the bridge; however, rusting of the newly exposed metal surfaces of the bridge is not cause for immediate concern. A somewhat higher rate of corrosion can be expected in crevices of a historic metal truss bridge. In addition, when pack rust has been repaired, it is essential to paint the cleaned exterior surface in the vicinity of the repair to seal the joint from oxygen and thus inhibit the progression of further rusting, as noted in Section 2.6.3.8,.

2.6.3.12 Other Re-Painting Considerations

Clean metal structures which have little water accumulation and are located away from industrial areas and coastal areas, exhibit slow rates of corrosion. There are various documents useful to understanding the factors that lead to the corrosion of ferrous metals, including Kogler (2012) and Corus (2004 and 2005). The following is a synthesis of the discussions from these references, with an emphasis on findings most relevant to the corrosion of unpainted historic metal truss bridges stored within the State of Georgia.

Most corrosion of steel is an electrochemical process that requires the simultaneous presence of water and oxygen. The principle factors that affect the rate of corrosion in air are:

- **Time of wetness:** This is the total time during which the surface is wet, due to rainfall, condensation, etc.
- **Atmospheric pollution:** This is the type of atmospheric pollution and contaminants, e.g., sulfates, chlorides, dust, etc.

In external or wet environments, the design features of the structure also have an important bearing on the corrosion. In dry, heated interiors, corrosion rates are essentially negligible.

Atmospheric corrosivity in noncoastal regions of Georgia range from C2 (low – exterior atmospheres with low level of pollution: mostly rural areas) to C3 (medium – exterior urban and industrial atmospheres, moderate sulfur dioxide pollution: moderate salinity) based on BS EN ISO 12944 Part 2 (ISO 1998). For this range of environments, the thickness loss in low-carbon steel after the first year of exposure varies from 1.3 μm (5.1 x 10^{-5} inches) to 50 μm (0.0020 in). Therefore, with the exception of the increase in corrosion at crevices, a metal truss bridge that is clean and stored outside should not see any significant section loss over a number of years.

Numerous metal bridge structures have survived in outside environments for many years without having been repainted. As an example, the Old Cedar Avenue Bridge, which is presently owned by the City of Bloomington, Minnesota, was originally constructed in 1920; it was repainted in 1959 (Gates 2013). Since 1959, the bridge has had only some minor spot painting. According to Rathke of Mead and Hunt (2013):

> *"The structure currently has an intact top chord, top chord bracing, and web members with only minor surface corrosion. The lower chord is primarily in fair condition except for span 5 that has significant corrosion. There is pack rust present in some, but not all, lower chord joints…. There is very little section loss of the main truss members except in those areas that*

have experienced continuous moisture contact and/or exposure to salts such as the floor system and lower chord lateral bracing…. With replacement of the floor system, lower chord lateral bracing and the span 5 lower chord, the superstructure would be intact and capable of supporting the expected loads going forward as a pedestrian bridge, with minimal future maintenance… in considering the use going forward as a pedestrian bridge, it would be realistic to expect that this bridge will not be subject to deicing salts… Given the absence of a painting program for this bridge and the fact that there is not significant section loss to the majority of the main truss members, a conclusion could be drawn that the afore mentioned corrosion rate would be consistent with the observed condition of the bridge it the bridge remained unpainted."

Wrought iron by its very chemical makeup is rust resistant. Steel used in the construction of bridges before the 1920s had a high phosphorous content, which makes it more rust-resistant than modern-day steel.

2.6.3.13 Other Types of Protective Coatings

One less common method that has been used in Virginia to rehabilitate and preserve pin-connected trusses (VDOT 2006) is to dismantle and hot-dip galvanize the members. The bridge is then re-erected and new steel pins are used. This method of protecting the bridge is sensitive to preservation because the bridge is not significantly modified. The galvanization also addresses lead paint removal issues, since the lead paint removal is handled by the galvanizing contractor. This eliminates the high cost and environmental dangers of lead paint removal on site. While galvanization is expensive, it is well-suited to small truss bridges or large truss bridges that are assembled from small elements, since small elements are most easily galvanized. Galvanizing also has the advantage of providing an extremely maintenance-free bridge for future reuse.

One potential negative point pertaining to galvanizing is because of its resulting dull silver appearance, the historic color of the bridge is compromised.

2.7 Summary

When a historic metal truss bridge needs to be replaced and is being considered for reuse, the bridge needs to be stabilized and a list of its deficiencies should be developed by an engineer. These deficiencies should be discussed with a historian in order to prioritize the elements that can be retained. Various preservation activities may then be pursued, the least expensive and most important first activity being the cleaning of the structure to remove accumulated debris and facilitate access to the structure. If lead paint is present, it should be removed if at all possible as part of the bridge replacement project, to remove the toxicity of the lead paint and to eliminate the high cost of subsequent lead paint removal (which could be a major hindrance to the marketing of the bridge for subsequent reuse). Repainting is recommended to seal areas where rust has been repaired in the vicinity of crevices, or where pack rust has been repaired. However, otherwise, the environmental conditions in Georgia typically are conducive to storage without the necessity of painting.

3. Documentation to Facilitate Reuse

3.1 Introduction

The Secretary of the Interior's Standards for Architectural and Engineering Documentation (NPS 2013) list requirements for the content, quality, material, and presentation of documentation of historical bridges and structures for inclusion in the Historic American Building Survey (HABS) and Historic American Engineering Record (HAER) collections at the Library of Congress. These standards have been adopted by state agencies for the documentation of historic bridges determined eligible for the NRHP. However, these standards focus on collecting and developing materials for archival purposes rather than reuse considerations. Stabilization measures, marketing, and storage demand accurate and comprehensive data that reflects the condition of the bridge.

This chapter addresses key considerations pertaining to the documentation of truss bridges. The importance of thorough documentation is discussed as well as the introduction of three technologies that can be used to help document the structure in its current condition. An example that explains the advantages and limitations of the technologies follows. Finally, recommendations are provided for data collection pertaining to documentation for storage and reuse.

3.2 Documentation of the Current Bridge Condition

Data on the current condition of a bridge is essential in determining the structural rehabilitation and restoration potential. The data provides geometry and connectivity information of structural members critical to maximizing the efficiency and minimizing the damage during disassembly and transportation. Photographs and 3D models can be useful for marketing the bridge. The positioning of a 3D model of the bridge at various alternatives for relocation or at a given modified site if the bridge is left in place, can provide useful visual images for future users. Integration of a point cloud 3D model into a conceptual or detailed Bridge Information Modeling (BRIM) system can be especially valuable.

3.3 Documentation Technology for Storage and Reuse

Laser scanning technology has drawn much attention from state DOTs and other agencies. Laser scanners can accurately record geometric data of objects in a fast and nondestructive manner. Scanners emit a laser beam more than 50,000 times per second, measuring 3D point cloud data from reflected light. The equipment can take associated photographs (i.e., color values) of the structure at the same time. By measuring the travel time of the laser beam in every laser emission, laser scanners generate the 3D image. The scan results are presented as a closely spaced grid of points, namely a point cloud, which is analyzed using various types of computer software to generate a final detailed image or 3D model of the scanned objects (Figure 17). Laser scanners have been successfully applied to record, digitize, and reconstruct objects, ranging from small artifacts to large and complex structures such as bridges, buildings, and landscapes. Point clouds from laser scans can be converted to 3D models, as shown in Figure 17.

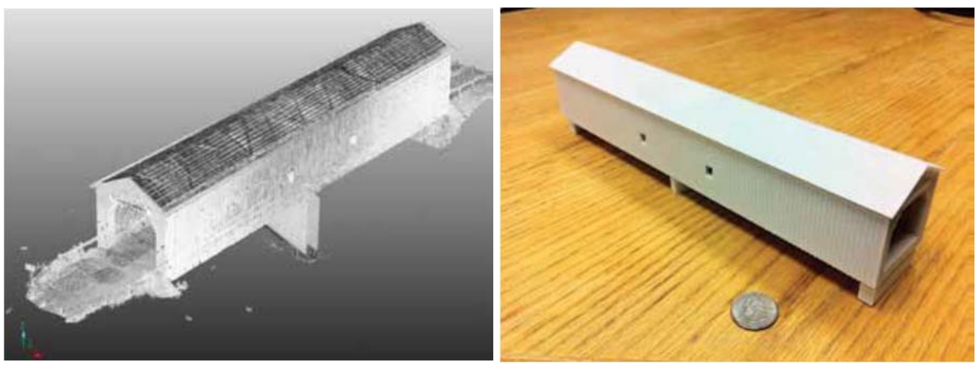

Figure 17. Point cloud image and scale model of the Zumbrota Bridge (Ross et al. 2012)

An initial study pertaining to the use of laser scanners for historic bridge documentation was completed in 1999 by the Pennsylvania DOT (Foltz 2000). This study compared the traditional method (i.e. loop closure and network adjustment processes) to laser scanners and estimated an overall time savings of more than 100 man hours using laser scanners. Based on this assessment, the Pennsylvania DOT purchased two laser scanners in 2000.

Another assessment, conducted by Jaselskis et al. (2003), indicated that laser scanners could be used cost effectively for preliminary surveys for the development of triangular network meshes of roadway surfaces and to measure bridge beam camber safely and quickly. This study recommended that the Iowa Department of Transportation rent or purchase laser scanners and post-processing software.

Recently, a research project was led by the Arkansas State Highway and Transportation Department (AHTD) to determine if laser scanners could produce the measurements necessary to produce HAER-level measured drawings for historic bridge documentation. The results indicate that using laser scanners for documentation reduces the data collection field time as well as the time and cost of producing drawings.

The major benefits of using laser scanners include high accuracy, a large survey range (up to about 200 meters), a high density of data, and a high rate of data acquisition (currently, thousands of points per second). Since laser scanners record every surface within the scanners field-of-view, data is easier to obtain (Lavoie and Lockett 2012). In addition, the point cloud (Figure 17) is capable of revealing small deflections, cracks, and other deficiencies in the structure that photographs taken from a few single locations cannot easily detect. A 3D printer can quickly and accurately produce a scaled model of the bridge (Ross et al. 2012), as shown in Figure 17.

Lavoie and Lockett (2011) state the primary disadvantages of laser scanners are:

- They cannot cover the areas obscured by adjacent objects (e.g., vegetation, other structures) or spaces beyond the scan range.
- Because they rely on the reflectivity of the scanned objects, laser scanners cannot easily detect darkly colored objects.

Because of these limitations, Lavoie and Lockett recommend that laser scanners should be used in conjunction with other survey methods to obtain comprehensive and well-informed data.

Although point clouds from laser scanners can be collected easily and in little time, they often require multiple set up locations. Such manual surveying is labor-intensive, can be costly, and potentially exposes the surveyor(s) to road hazards. For these reasons, photogrammetric range point cloud data acquisition techniques using inexpensive photo or video cameras (Dai et al. 2013) and Unmanned Aerial Vehicles (UAV) (Seibert and Teizer 2013) may be better options. Figure 18 shows sample photogrammetry and videogrammetry data. Since photos or videos are routinely taken on projects, generating point clouds from such devices adds little additional cost. Some of today's computer algorithms provide point cloud data at low error rates. The results of many photo or videogrammetric data acquisition and processing techniques provide accuracies within a few centimeters, but these are sufficient for many tasks in documenting historic bridges. Similar to laser scanning, point cloud values in photogrammetry and videogrammetry are always colorized. Figure 18 shows multiple colorized point clouds generated by different software. The choice of software and its corresponding output is dependent on the needs of the user.

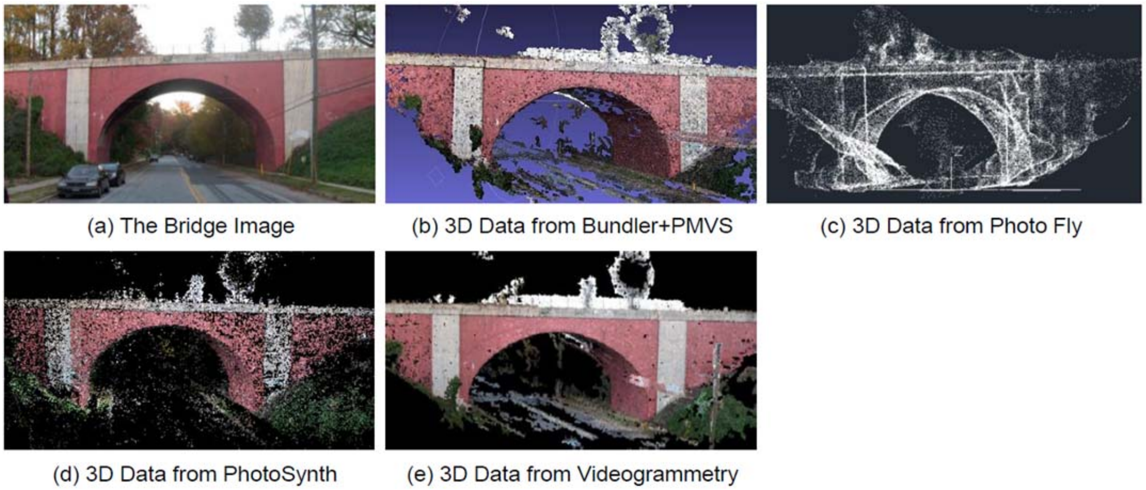

Figure 18. Photogrammetry and videogrammetry as point cloud data acquisition approach (Dai et al. 2013)

A high-resolution project monitoring camera was used to document the replacement of Atlanta's 14th Street bridge (Bohn and Teizer 2010). A photo was taken every few minutes over the entire duration of the bridge project (Figure 19).

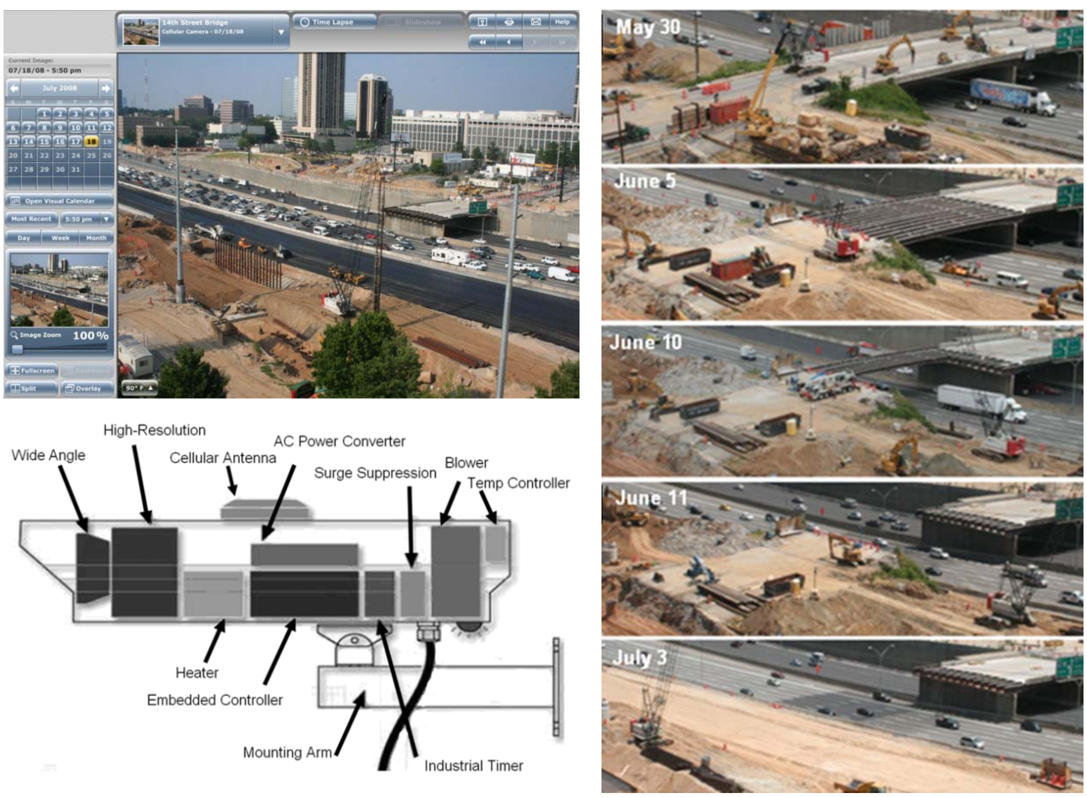

Figure 19. Project monitoring by a high-resolution camera during the replacement of Atlanta's 14th Street bridge (Bohn and Teizer 2010)

3.4 Example of Current Condition Documentation, Minnesota Bridge No. 5721

Minnesota Bridge No. 5721 has an overall structure length of 378 feet and an out-to-out width of 18 feet. The main span is a 162-foot, simple-span, pin-connected, Parker thru truss, fabricated of wrought iron. In 1998, this bridge was listed on the NRHP as one of the 24 bridges on the MnDOT list of historic bridges. The bridge was originally built in 1877 as a wood-deck, wrought iron truss bridge (Figure 20a) to carry pedestrians over a river in Sauk Center, Minnesota. In 1937, the bridge was disassembled and moved to serve as Minnesota Highway 65 crossing the Little Fork River in southeastern Koochiching County (Figure 20b). The traffic load, which included heavy logging trucks, eventually became too much for the bridge. In the fall of 2009, the bridge was disassembled and transported to Maplewood, Minnesota (Figure 21), and stored until the summer of 2010, when it was rehabilitated and reassembled as an equestrian and pedestrian bridge for the Gateway Trail in Washington County (Figure 20c). The county paid $100,000 of the approximately $2.8 million cost for relocating the bridge (Bremer 2011).

(a) (b) (c)

Figure 20. Bridge 5721 in its (a) original (Talbot 2012), (b) second, and (c) current locations (Bremer 2011).

(a) (b) (c)

Figure 21. Relocation of Bridge 5721 in its (a) disassembly, (b) transportation, and (c) reassembly stages (Talbot 2012).

The lack of original drawings and specifications creates a challenge for the rehabilitation of any century-old bridge. The bridge was scanned with a 3D laser scanner prior to disassembly.

Surveyors set up the scanner at nine different locations prior to the disassembly of the structure. After two and a half days of scanning, the team used software to create a registered point cloud consisting of 13 million points, each with x, y, and z coordinates (Figure 22). In addition, a point cloud fly-through video of the bridge was created.

The detailed representation of the bridge was used for both engineering work and historical records. To provide information on the fastener patterns, the team scanned each major truss member as it was removed. These operations took place on a scanning table before the pieces were loaded onto a truck and moved to the storage site. This allowed for detailed evaluations of the geometry of the structure, allowing the team to isolate specific members.

In the process of replacement and rehabilitation, the project team replaced two floor beams at each end of the bridge. To ensure that they could fit the original connections, new beams were fabricated based on detailed drawings developed by the laser scan data. Because the weight of a conventional concrete deck would have required reinforcement of the truss members, the team replaced the original timber deck with a lightweight concrete deck, which created an alteration of the look and the historic character of the bridge. In addition, to closely match the 1877 configuration, the team changed the portal height clearance from 16 to 14 ft. Also, they removed lead-based paint on the reused components and applied a new four-coat paint system to the bridge.

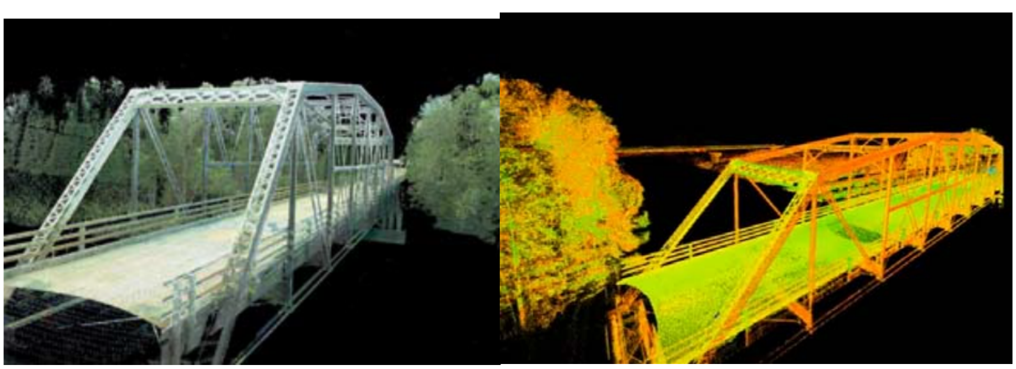

Figure 22. Laser scan images of Bridge 5721: point cloud (Talbot 2012) (left) and flythrough video (right) (Krichels 2012).

3.5 Summary Recommendations

3.5.1 Documenting the Current Condition

The data from a historic bridge can be used to determine the need of stabilization, rehabilitation or other treatments. Data collection using laser scanning, photogrammetry and videogrammetry are recommended and described in the following sections.

3.5.2 Laser Scanning

Laser scanners can accurately and rapidly collect geometric data of scanned objects. Depending on the size of the bridge, a time-of-flight (TOF) vs. phase-based laser scanning method needs to be selected. While the phase-based measurement method tends to have a higher data rate due to the character of continuous wave modulation, its measurement range is shorter than the pulse-based method. For bridges in the bright outdoor environment, most likely TOF laser scanning yields the best results. After the scanning has been completed registered point clouds and 3D models can be generated from the data for presentation. A detailed workflow for laser scanning of bridges is explained by Tang and Akinci (2012).

Key guidelines for the use of laser scanners are:

- The scan team should generate a scan plan with the estimation of scan number and survey duration, the selection of scanner positions, and the sequence of scans.
- The scan plan should guarantee that the entire bridge is covered after all the scans and enough targets are set up on the structure and around the site.
- The scanner resolution should be set according to the desired level of accuracy, detail, level of the scan, and the available time for scanning.
- A mobile power supply (e.g., portable generator, vehicle power output) is recommended to minimize the scan time by providing ready access to power.
- A long crossover cable is necessary to connect some scanners to either the power supply or computer. All the cables should be protected from damage, moisture, and tripping.
- Laser scanning should not be used exclusively for visual records, but rather as a complement to photography.

3.5.3 Photogrammetry and Videogrammetry

Terrestrial (ground-based) or aerial photogrammetry and videogrammetry are similar to laser scanning. Multiple images of the bridge from all sides and numerous angles are captured. The time required for each image is only a few seconds, making it a fast approach for gathering the as-built geometric data. However, typically, the resolution for capturing the geometric details is not as accurate as laser scanning. Commercially available software packages (e.g., Agisoft Photoscan) are available to stitch the individual photos together. The two-dimensional photographic images of an object from different angles can be registered automatically to a 3D point cloud for further processing. Registration is the process of transforming different sets of data into one coordinate system. Various technical papers explain the workflows and methods of photogrammetry and videogrammetry as they apply to infrastructure and bridges, e.g., papers by Dai et al. (2013), Golparvar-Fard et al. (2009), and Golparvar-Fard et al. (2011). Bohn and Teizer (2010) also focus on the cost-benefit analysis of high-resolution photo cameras for construction project monitoring. Such time-lapse photo-capturing technology can be very useful for precisely documenting the disassembly and/or assembly of a historic metal truss bridge.

3.5.4 Potential Cost

The overall cost of documentation using the technologies discussed above includes the purchase, maintenance, and rental of sensing equipment such as laser scanners, photo- or video cameras, and unmanned aerial vehicles (UAV). Other costs include surveying accessories, the labor costs of a surveyor or data collector, and a point cloud to modeling expert who may also create a 3D information model from the point cloud; and the bridge information modeling (BRIM) software license. As these technologies have developed, the costs have declined.

The cost of laser scanning, photogrammetry, videogrammetry, and the data processing will depend on the size of project, the scope of work, and the detail required. Prices may start at a few thousand dollars.

4. Marketing for Reuse

4.1 Introduction

This chapter reviews websites of various agencies and private organizations related to historic bridge marketing. Recommendations include marketing prioritization, marketing methods, and transfer agreements. In addition, a flowchart illustrates the major tasks in marketing historic bridges. A prototype website is included to demonstrate one possible approach to marketing historic bridges using the internet.

4.2 Overview of Historic Bridge Marketing Programs

Marketing bridges for reuse has been a popular option for state agencies to preserve and extend the value of their historic bridges. Eleven states have developed dedicated programs to promote their historic bridges and to search for potential recipients. While some agencies post the information for available historic bridges on their websites, others actively seek potential recipients simply by direct contact.

To locate a potential recipient of a historic bridge, one approach has been to develop a contact list of current owners and relevant state and local agencies with jurisdiction over trails, parks, and historic sites (Haberling and Leary 2004). The Tennessee Department of Transportation (TDOT), for example, has a marketing program to advertise the availability of historic bridges that are scheduled for replacement (TDOT 2012). TDOT mails the information to approximately 100 groups that might be interested in either preserving the bridge in place or adaptively reusing the structure at a new location. In the State of Indiana, when a historic bridge is bypassed or replaced, the bridge is offered to any group or individual that wants to take ownership of the bridge (INDOT 2014a). The North Carolina Department of Transportation (NCDOT) donates bridges, provides assistance with disassembly and relocation, stores bridges in a bridge yard until a new owner can be identified, and preserves in place (NCDOT 2014). Colorado (CDOT 2012), Maine (MaineDOT 2014), Montana (MDT 2014a), Ohio (ODOT 2014a & b), and Pennsylvania (PennDOT 2005 & 2014b) have similar programs. The programs have led to the successful preservation or adaptive reuse of many valuable historic bridges throughout the United States.

In the process of marketing historic bridges, funding for relocation is a common issue. Relocation costs usually exceed the demolition costs since relocation often involves disassembly, transportation, preservation, and temporary storage. Consequently, most historic bridge marketing programs- Colorado, Maine, and Montana- specify that the recipient is responsible for relocation expenses. For example, the Colorado DOT offers historic bridges free to a new home, but the recipient has to pay for the disassembly, relocation, reassembly, and other related costs (CDOT 2012). A detailed estimate of the costs and time required to complete the relocation is an essential component of a relocation proposal submitted by those interested in owning a bridge. In a number of cases, the state agency has fully (Kentucky Transportation Cabinet 2012), or partially (PennDOT 2014a & b; KDOT 2007) funded the removal and relocation costs.

Criteria for bridge recipients developed by the Oklahoma DOT require that a relocation proposal identify the location of the new site, the use of the bridge at the new site, and the specific procedure for disassembling, moving, and rebuilding the structure (OKDOT 2012). Bridge Relocation Proposal Guidelines, developed by the Indiana DOT, require that relocation proposals contain comprehensive information about the new site (INDOT 2014b). The required information includes:

1) Unobstructed and high resolution photos and maps of both the site at which the bridge is currently located and the relocation site,
2) Renderings illustrating what the bridge would look like at its new site, and
3) Documentation of coordination with historians to determine what work is necessary to preserve the historic context of the bridge at the new bridge site.

4.3 Overview of Websites for Historic Bridge Marketing

Twenty-five state DOTs have developed websites for their historic bridge programs. Most of these websites include a general introduction of their respective historic bridge programs and an inventory of their state-owned historic bridges. Of the twenty five websites reviewed, eight have specific web pages for the marketing of historic bridges. Three of these eight web pages provide little detail about the available bridges or the bidding guidelines for the potential recipient to follow. The five web pages that have more detailed information are:

- Historic Bridges Marketing Program – Indiana Department of Transportation (INDOT 2014a) <http://www.in.gov/indot/2532.htm>

- Historic Bridge Available For Adaptive Reuse – Maine Department of Transportation (MaineDOT 2014) <http://www.maine.gov/mdot/env/bridgesau.htm>
- Historic Bridge Adoption – Montana Department of Transportation (MDT 2014a) <http://www.mdt.mt.gov/business/bridge_adoption.shtml>
- Historic Bridges Available for Reuse – Ohio Department of Transportation (ODOT 2014b) <http://www.dot.state.oh.us/Divisions/Planning/Environment/Cultural_Resources/BRIDGE_STATUS/REUSABLE_BRIDGES/Pages/default.aspx>
- Bridge Marketing: Wanna Buy A Bridge? – Pennsylvania Department of Transportation (PennDOT 2005) <http://www.dot.state.pa.us/Internet/Bureaus/pdCulturalResources.nsf/CultResHomepage?OpenFrameSet&Frame=main&Src=%2FInternet%2FBureaus%2FpdCulturalResources.nsf%2Fbridge%2520marketing%3FOpenForm%26AutoFramed>

The structure and content of these websites can be summarized as follows:

- **General Introduction to the Program:** All of the reviewed web pages contain general introductions of their historic bridge marketing programs. The introductions typically include the motivations for marketing historic bridges, the current inventory of historic bridges, and the basic criteria that the potential recipients must satisfy.
- **Information Pertaining to Available Historic Bridges:** The Ohio DOT's web page, "Historic Bridges Available for Reuse" (ODOT 2014a & b), lists historic bridges that are currently available for marketing. The information provided for these bridges includes a bridge's history, historic significance, structural type, span length and width dimensions, current condition, and photos. In addition, contact information is provided for each bridge. In addition to the above information provided by ODOT, each page provides further information such as alterations to the bridge, the current ownership, and the specific requirements for the purchase of the bridge. Similarly, the PennDOT (2005) web page, "Bridge Marketing: Wanna Buy a Bridge?" classifies available bridges into state-owned, and county and municipally-owned bridges. It has separate web pages for each linked to the main page.

- **Advertising Formats:** All the reviewed web pages advertise the available historic bridges in text and photos. There are no 3D bridge models or videos provided in any of the reviewed web pages.
- **Criteria for Selection of a New Owner:** Since the intent of marketing historic bridges is to maintain their historic integrity to the greatest extent possible, some web pages contain detailed criteria for selection of new bridge owner. At its web page, Montana Department of Transportation (MDT 2014b) asks anyone interested in adopting a bridge to submit an application addressing the following questions:

  1) Who will be the owner of the bridge?
  2) What will be the intended use of the bridge?
  3) Who will use the bridge?
  4) Where will the bridge be located?
  5) How do you intend to move the bridge? Please be fairly specific about how the bridge will be transported, which route will be used and obstacles that may be encountered.
  6) Are you willing to sign an agreement holding the State and County harmless for use of the structure and lead paint on the structure and to maintain the historic integrity of the bridge?
  7) How do you intend to install the bridge at the new site? Will permits be required? How will the substructure be designed/constructed? How will the roadwork be accomplished?

  If the bridge is to be left in place:

  1) How will access & right of way be provided?
  2) A non-governmental entity will be required to post a cash bond or bond in the form and amount to be determined by the state to cover the cost of future demolition. Are you able to provide such a bond?
  3) Provide evidence that you have the assets and income to insure long-term maintenance and upkeep of the bridge.
  4) If the bridge is to be open to the public what is the anticipated cost of liability insurance? Which insurance company provided this quote?

If two or more entities express an interest in the bridge, the selection of new owner is by the following priorities:

1) Adoption by a government agency.
2) Adoption by an established civic group.
3) Adoption by a non-incorporated group.
4) Adoption by an individual.

- **Successful Marketing Efforts:** The Montana DOT web page (MDT 2014b) provides a link describing a previous marketing efforts and the current status of the corresponding bridge.

4.4 Private Organizations

The preservation of historic bridges has drawn increasing attention from the general public. There are a number of public and private organizations dedicated to the promotion, preservation, and documentation of historic bridges in the United States. In many cases, these organizations prepare and post additional information that supplements and complements the bridge information found on state databases. Such information can include: a bridge's history, location, and historic and current photographs. Several of these organizations are highlighted below. More can be found in "Links to Bridge-Related Websites" on the HistoricBridge.org website (Historic Bridges 2014).

- **HistoricBridges.org** (Historic Bridges 2014)**:** HistoricBridges.org offers professional photo-documentation and information on the dimension, history, and condition of all types of historic bridges in the United States and Canada. Many of the bridges promoted by the website are metal truss bridges. In addition, this website introduces viewers to the world of historic bridges through informative presentations with photos and diagrams, as well as the terminology, construction, and configuration of historic bridges.
- **Historic Bridge Foundation** (Historic Bridge Foundation 2013)**:** The Historic Bridge Foundation is a national advocacy organization for the preservation of historic bridges in the United States. It offers support to people interested in bridge preservation through 1) service as a clearinghouse for information on the preservation of historic bridges via a website, electronic newsletters or alerts, and directory of consultants; 2) identification of and communication with individuals and groups interested in the preservation of historic

bridges; 3) consultation with public officials to devise reasonable alternatives to demolishing or adversely affecting historic bridges; and 4) development of educational programs to promote awareness of historic bridges.

- **BridgeHunter.com** (Bridge Hunter 2014)**:** BridgeHunter.com is one of the largest bridge websites on the Internet, and relies heavily on bridge photo contributions from viewers. It covers numerous states and is rapidly expanding. Although their inventory covers all types of bridges, including modern and historic structures, a large number of historic metal truss bridges are presented along with extensive documentation.
- **VJM Metal Craftsman** (VJM Metal Craftsman, LLC 2013)**:** This website contains articles, research, and workshops pertinent to the restoration of historic metal truss bridges. A strong focus is placed on the restoration of metal truss bridges, with attention paid to retaining original materials or exactly replicating worn parts of a truss bridge.

Direct programmatic involvement of these organizations with state DOTs was not found.

4.5 Summary Recommendations

Considerations for the selection of historic metal truss bridges for marketing are discussed, and two active advertising methods are introduced, the basic contents of a transfer agreement, and the criteria for selection of a final recipient, are recommended in this section.

4.5.1 Selection of Historic Bridges for Marketing

Bridge marketing can be a long-term endeavor, and the resources and funding for it can be limited. Advertising efforts should give priority to bridges with historical significance, high reuse potential, urgent stabilization or rehabilitation needs, and ease of relocation. Three main aspects should be addressed on an individual basis:

- **Bridge Significance:** Priority should be given to bridges with high intrinsic significance. The significance includes rareness of bridge type, unique structural features, and/or association with major historic events or persons.
- **Bridge Dimension and Type:** Bridge dimension and type have a great influence on the transportation and re-erection of the bridge. Specifically, the best candidates for relocation are pony and thru truss bridges because, typically, these are less than 90 feet long.

- **Bridge Condition:** Bridges whose state of deterioration is so serious that the bridge requires immediate treatment to stabilize the structure against further damage or deterioration may require an immediate decision as to whether the bridge, or portions of it, should be saved or demolished.

4.5.2 Marketing Methods

Dissemination of information about the availability of historic bridges increases the chances of success in marketing. Presented below are methods that optimize the outcome of historic bridge marketing:

- **Direct Contact:** To maximize the effectiveness of the marketing program, the marketing team should actively contact potential recipients to inform them of the availability of historic bridges and solicit their interest in receiving and using historic bridges. To locate a potential recipient of a historic bridge, a contact list of current owners and relevant state and local agencies with jurisdiction over trails, parks, and historic sites should be prepared.

  Guidelines for the marketing process, transfer agreements and requirements should be readily available.
- **Website for Historic Metal Truss Bridges:** Agencies or individuals who are interested in reuse of historic bridges can easily find a historic bridge marketing website through internet search engines. In addition, the information on a website can be presented in various ways - videos, interactive 3D models, and links to external sources.

  An effective historic bridge marketing website should contain more than a general introduction to the marketing program and information on available bridges. A survey report with the structure's type, critical dimensions, and history should be provided. The website should include the following content:

  1) **Introduction to the Program:** A general introduction of the historic bridge marketing program including background and purpose of the program, current inventory of historic bridges, and the criteria for eligibility of the recipients.
  2) **Information Pertinent to Available Bridges:** This should include a brief introduction to the bridge's history, structural type, span length and width

dimensions, historic significance, and current condition. In addition, a point of contact should be provided for each bridge.

3) **Guidelines for Marketing, including a Sample Transfer Agreement:** Additional discussion of transfer agreement requirements is provided in 4.5.3.
4) **Discussion of Previous Historic Bridge Successes** in reuse to provide a "lessons learned".

4.5.3 Transfer Agreements

A transfer agreement specifies a reuse plan for a historic truss bridge and clarifies the responsibilities of the parties involved in the process. A transfer agreement should also transfer responsibility for maintenance and operation to the new owner. The states of Indiana, Missouri, Texas, and Kansas have developed transfer agreements to assess recipients early in the process. Each of these states requires potential recipients to submit the agreement together with other documents prior to transfer. Although specific items to be included in the agreement should be considered on an individual project basis, these items should be considered:

- Special requirements for the reuse of the bridge (e.g., pedestrian railing geometry and capacity restrictions),
- The scope of work to be performed on the bridge, including modifications, restoration, and preservation, and identify parties responsible for such work,
- A description of any new construction needed to accommodate the bridge at a new site, and the parties responsible for such work,
- Environmental clearances or permits required,
- A proposed schedule for completing the bridge relocation and rehabilitation,
- A disclosure of hazardous material, and/or implementation of a survey to determine if the bridge includes products such as lead-based paint, and
- A transfer of existing documentation.

4.5.4 Prototype Website

A prototype website was developed as a part of this research. Sample pages from this site are presented in the Appendix.

5. Disassembly and Transportation

5.1 Introduction

Historically, metal bridges were often designed by bridge companies, fabricated at their plants, and then shipped to the local site for erection. Only a few skilled workers were required for their construction.

Metal trusses have been disassembled, moved to another location with relative ease, and reassembled for continued used on the nation's railway and highway systems during their life. This characteristic makes them particularly amenable to storage and future repurposing and reuse once they have reached the end of their useful service on the state's road system.

The best candidates from bridge relocation are truss and girder bridges (ConnDOT 1991) due to their design and fabrication. More specific, the best candidates for relocation treatment are pony and thru truss bridges (NYSDOT 2002; Haberling and Leary 2004), such as illustrated in Figure 23.

Figure 23. Relocation of the 7th Street Bridge in Coudersport, Pennsylvania (Larson Design Group 2011).

This chapter addresses key considerations pertaining to the deconstruction or disassembly of metal truss bridges. Factors that influence the extent of disassembly of these structures and a broad overview of the process are presented. This is followed by a discussion of two representative examples in Sections 5.4 and 5.5. The essential problem of marking for disassembly and eventual reassembly is also discussed.

5.2 Extent of Disassembly

In 1995, Texas DOT devised Special Specification Item 4220 for historic truss bridges. This item was titled "Remove and Relocate Existing Historic Truss Bridge". This specification, included as part of a construction contract, requires the following (Texas DOT 1995):

1. The existing bridge should be removed and relocated in accordance with the engineering plans or as directed by the Engineer of Record.
2. Flame cutting of members is disallowed unless approved by the engineer.
3. The bridge shall be detached from its foundations, and moved intact, to its new location.
4. Before moving the existing bridge, the new foundations at the relocation site shall be complete and ready to accept the bridge.
5. A bracing and moving plan needs to submitted and approved prior to removal.
6. Careful consideration must be taken when lifting the truss from the existing abutments, transporting the bridge to the new site, and placing the bridge on the new foundations. The document states, "If both ends of the bridge are lifted at once, all four corners of the bridge shall be lifted simultaneously and symmetrically. If only one end of the bridge is lifted at a time, then both corners shall be lifted simultaneously and symmetrically."

The above specification focuses on leaving the entire metal truss bridge intact and moving it as one unit to an alternative location. Many small truss bridges can be handled in this way and there are records of bridge spans with lengths slightly larger than 100 ft. being relocated intact. Figure 24 shows an example of a rare Fink truss bridge in Virginia before it was taken out of service. Virginia DOT relocated this 52.5 ft. long, 13 ft. wide, and 7.5 ft. deep bridge, intact, to a nearby park (Figure 25) by removing its deck and railings, and supporting the bridge on stanchions on a flatbed trailer (Figure 26).

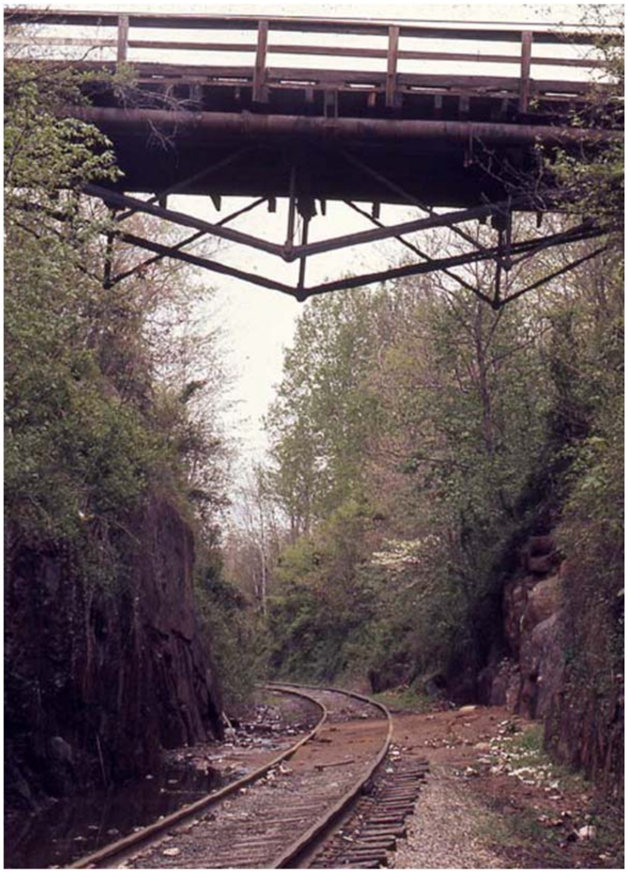

Figure 24. Fink truss railroad overpass in Virginia prior to moving the bridge (VDOT 2006).

Figure 25. Fink truss relocated as an exhibit in a park (VDOT 2006).

Figure 26. Transportation of Fink truss (VDOT 2006).

Figure 27 shows a 106 ft. span Pratt thru truss bridge, also from Virginia DOT (VDOT 2006). It was lifted from its bearings using two cranes and placed nearby for dismantling. Its deck was removed and the rigging, shown in Figure 28, was placed at its hip joints for lifting of the structure. Temporary struts were added to the lower-chord tension members in this bridge to handle the compressive forces induced in the members by the lifting. A conventional structural analysis of the action of this type of bridge under gravity load indicates that the lower chord is always in tension when the bridge is supporting gravity load. Hatfield (2001) provides an interesting discussion of the fact that the upper chord and end posts of this type of bridge can act as an arch in resisting the gravity loads if the connections provide sufficient continuity of the chord rotations at the truss joints. He goes on to point out that lifts similar to that shown in Figure 27 have been conducted without reinforcement of the bottom chord. However, this relies on significant bending resistance of the top chord, the hip joints, and the end posts. In Figure 28, it is evident that the connection at the hip joint in this bridge is a true pin, and as such, the "secondary" resistance would likely be negligible in this case.

Figure 27. Lifting of a 106 ft. span Pratt truss (VDOT 2006).

Figure 28. Lifting apparatus at hip joint of 106 ft span Pratt truss (VDOT 2006).

Figure 29 shows another example of moving a Pony truss bridge intact (VDOT 2006). The temporary struts have been placed between the trusses at the level of the top chord to prevent the potential of the top chords essentially folding inward during the lifting. In addition, the bottom chord has been reinforced by temporary struts for the lifting and moving operation. As previously discussed, lifting the bridge by rigging attached at the hip joints induces compressive forces in the lower chords.

Figure 29. Moving of a pony truss bridge intact (VDOT 2006).

Another option is to disassemble the truss bridge into each of the component members between its panel points (assuming that the chords are not continuous across the panel points). As noted in Section 2.6.3.13, Virginia DOT has used this approach when they have selected to hot-dip galvanize the truss members prior to reuse. If the condition and size of the historic truss bridge permits relocation of the structure intact, usually this will disturb the historic integrity of the structure the least and be the most cost effective method of storing the bridge. An engineer needs to evaluate the structure and develop a construction plan that ensures the safety and integrity of the structure.

5.3 Disassembly Process and Design for Disassembly

The disassembly of a historic metal truss bridge can be conceptualized as the reverse of the process by which these structures were built. The Virginia DOT report on "Best Practices for the Rehabilitation and Moving of Historic Metal Truss Bridges" (VDOT 2006) provides a succinct discussion of typical erection procedures for these types of bridges in the 19th and early 20th centuries, as well as a summary of key references from this time period. The basic steps of the deconstruction process for a historic metal truss bridge are as follows:

1) Remove the deck.
2) Remove the stringers.

3) Erect falsework to support of the trusses during the disassembly. In many situations, the bridge is supported by bearing of the floor beams on moveable falsework placed at panel points of the trusses.
4) Starting at one of the abutments, support the trusses by a combination of falsework and cranes within the span, and disconnect the members at the end joint. Care must be taken to support each of the members connecting into a joint when the pin or rivets (or bolts) are removed at the joint.
5) Dismantle the joints of each panel point beginning at the start abutment and proceeding to the end abutment, remove the truss and floor beam members.

Factors such as the original design features of the bridge, subsequent alterations, soil conditions, access restrictions, the intersection of railways or streams, and the degree of deterioration of the different components need to be addressed while planning the deconstruction. For very small truss bridges with little damage or deterioration, the disassembly plan usually can be simple and straightforward. However, for larger truss bridges with substantial damage or deterioration to certain components, a more elaborate disassembly plan may be required.

5.4 Notable Disassembly Example, Virginia DOT's Goshen Bridge

In October of 2001, Virginia DOT began renovation of its historic Goshen Bridge, which carried State Route 746 over the Calfpasture River in Goshen, Virginia. This bridge is a two-span Pratt thru truss and provides the only means of access to one section of Goshen that has approximately 12 homes (VDOT 2006). The bridge, built in 1890 by the Groton Bridge Company, had been in poor condition with widespread corrosion and section loss in its members. Its roadway had been reduced to a single lane prior to 1948 and the bridge had been posted for a load limit of 6 tons.

The bridge's listing in the NRHP, combined with a strong local pressure to preserve the bridge as a landmark and keep it in service, led VDOT to completely rehabilitate the structure to provide for two lanes of vehicular traffic (AASHTO 2002).

Because of the extensive deterioration of the structure and the need to increase its load capacity to meet the current design standard of the time, it was decided to completely disassemble the structure and replace more than 100 of its members, including all of its end posts, hip verticals, upper chord members, counters, and pins. The floor beams, stringers, and deck also were scheduled for replacement. Button head high strength bolts were used in the reconstruction of the structure. In addition, the complete disassembly of the structure permitted galvanizing of all of the members for the renovated bridge, which addressed lead paint removal. Because of the extensive in-kind replacement of the structural components of the bridge, the VDOT report quotes one of its historians as saying that they preserved "the technology rather than the artifact."

Because the Calfpasture River at Goshen carries runoff from a substantial mountainous drainage area, the river flows rapidly and floods frequently, carrying debris that posed a hazard to any temporary supports located in the river or the adjacent flood plain. For this reason, the VDOT design team decided to basically build a two-span, three-girder rolled beam bridge above the floor beams of the historic truss to serve as the falsework for the disassembly of the truss bridge. This continuous-span falsework bridge was supported on blocks on the floor beams of the truss bridge and then on temporary bents placed adjacent to the abutments and the middle pier. Figure 30 shows the Goshen bridge just prior to its disassembly, Figure 31 shows the installation of the three beams of the two-span continuous falsework bridge, and Figure 32 shows the temporary bent at the middle pier of the truss structure (three H-piles on concrete footings founded on firm material (1.5 tons/ft^2), and one pile beneath each of the beams of the falsework bridge). The two-span continuous falsework bridge was constructed with various cross-frames between its girders as well as a top flange lateral system, as can be seen in Figure 31.

Figure 30. Goshen Bridge, Route 746 Bridge over the Calfpasture River at Goshen, Virginia (VDOT 2006) prior to disassembly.

Figure 31. Installation of the beams for the internal two-span continuous falsework bridge used for the disassembly of the Goshen Bridge (VDOT 2006).

Figure 32. Temporary bent at the middle pier of the Goshen Bridge, with two lines of the falsework beams in place, from (VDOT 2006).

The floor beams of the historic truss bridge were supported from the girders of the falsework bridge by a hanger arrangement as shown in Figure 33. The hangers were tightened to a snug fit before any loads were transferred to the falsework, and they were adjusted as necessary to remain snug during the dismantling and subsequent re-construction operations. The influence of the loads on one span on the vertical deflections in the opposite span of the two-span continuous falsework bridge during the disassembly and re-erection had to be considered. The re-erection of the bridge was performed symmetrically, working outward from the center pier toward the two abutments, to minimize these effects.

The three-girder falsework bridge was designed to support a moveable platform and walkway for access to the bridge during the disassembly and reassembly operations. The contractor was allowed to submit an alternate platform subject to limits of 50 pounds per square ft. (psf) for dead load and 50 psf for construction live load. The suggested platform was approximately 8 ft wide by 15 ft long, but other configurations not exceeding 120 ft^2 were allowed.

Extra details of the historic structure were included in the plans provided to the contractors bidding the job. These included an expanded general note describing the special requirements; a schedule of quantities that noted the members scheduled for replacement; a layout plan showing the existing location of the bridge, which had shifted after shearing its abutment anchor bolts; and detailed drawings of the existing trusses, with connection details and a complete description of the members (VDOT 2006). In addition, complete details of the replacement members and new bearings were included, and a suggested sequence of construction, was provided as guidance for the contractors. Last, the contract documents provided for any additional replacement of members beyond those anticipated at the time of the advertisement of the project. Payment for this work was on a per item basis rather than a lump sum basis to facilitate negotiations for any unforeseen work.

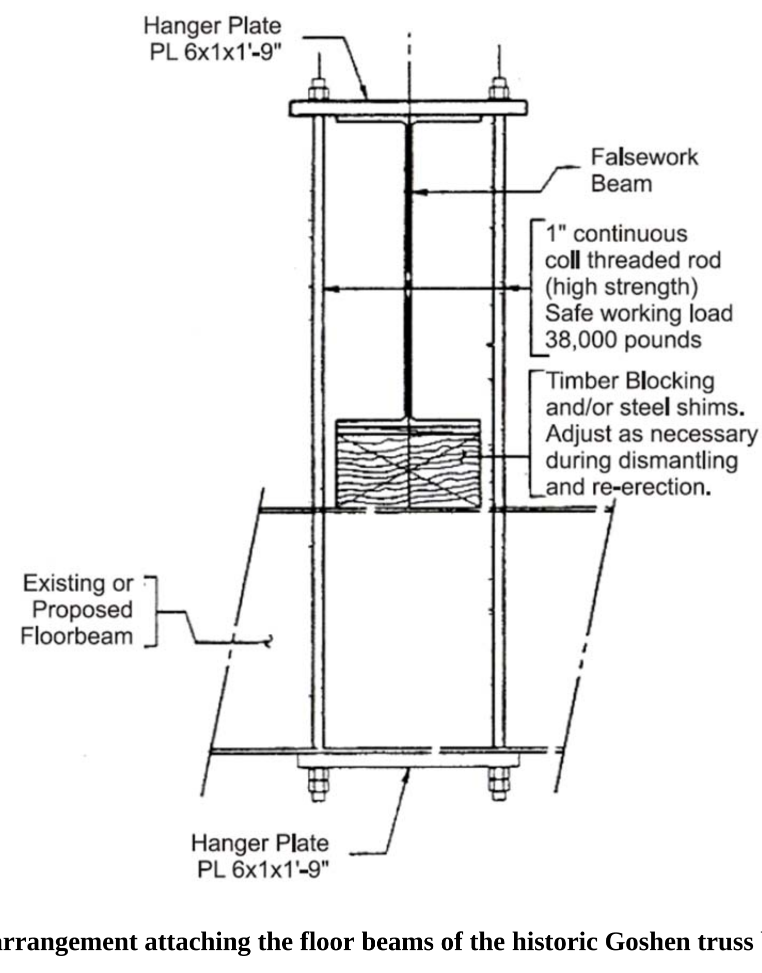

Figure 33. Hanger arrangement attaching the floor beams of the historic Goshen truss bridge to the girders of the falsework bridge (VDOT 2006).

Two cranes, one on the causeway and the other at the abutment nearest the work, were used for the disassembly and re-erection operations. In addition, the contractor used light electric-powered man lifts for workers access to the bridge, during both the disassembly and the re-erection. Once the railing, deck, and stringers of the truss bridge were removed, the pin elevations at each of the panel points of the trusses were recorded for later use in checking the correct cambers of the spans during re-erection. The trusses were generally dismantled in sections composed of several members, followed by disassembly into the individual members elsewhere on the site. Care was taken to support the different members upon removal of the pins at the joints.

The truss members were marked with paint to denote their locations prior to disassembly. All of the members were subsequently labeled with die marking before shipment to the galvanizing plant. The VDOT report emphasized that permanent marking is essential. The VDOT team also emphasized that due to the uniqueness and special characteristics of historic bridges, "it typically takes about 50% more time to disassemble them than that to disassemble a conventional steel-girder bridge" (VDOT 2006).

The members that were selected for replacement were stored on sheeting at a staging area at the job site until the dimensions of their replacements were determined. The members that were retained in the rehabilitated structure were shipped to the galvanizer after their die markings were prepared.

5.5 Notable Disassembly Example, Oregon DOT's Conduit 2/4 Bridge

The removal of the Conduit 2/4 Bridge over the Sandy River in Oregon provides other useful insights pertinent to best management practices for storage of historic metal truss bridges. The 300 ft. main span of this bridge was constructed in 1893 and is comprised of a steel pin-connected modified Pratt truss, approximately 16.5 ft. wide (Figure 34). The bridge carried the water supply for the City of Portland across the Sandy River. Several bridge issues were identified that placed the City's water supply at some risk. As such, the conduits were removed from the bridge and placed in a tunnel underneath the Sandy River. Also, the bridge was to be removed and stored for potential reuse.

Figure 34. Conduit 2/4 Bridge over the Sandy River in Oregon (Parsons Brinckerhoff 2008).

Temporary shoring was installed to transfer the dead load from the truss to the shoring (Portland Water Bureau 2007). This shoring significantly reduced stresses at the pins. The members could then be removed with relative ease. The report suggested three removal options:

1. **Component by Component Removal**: As members were gradually removed from the bridge, load paths and stresses would change in each member. Some members were designed only for tension. Thus, a load reversal resulting in compression could buckle the members. The report required that a careful study of the removal sequence would need to be carried out before any work was performed. The contractor would need to choose the removal sequence to maintain stability.
2. **Removal in Sections**: Removal in sections can accelerate the dismantling process. However, this was not necessarily possible for the Conduit 2/4 Bridge due to stability considerations. The original pin design of the bridge required that the members had to be removed in the opposite order of the erection sequence. In addition, the upper pinned connections were incapable of transferring any significant tension across the joints. As a result, a section removal resulting in tension in the top chord would lead to instability.
3. **Removal of Entire Truss in a Single Section**: Depending on the equipment and the size of the bridge, removal of the entire truss can be accomplished to expedite the dismantling

process. The entire truss then can be disassembled component by component on the ground, or in some cases, the entire structure can be stored intact. This process is safer than doing so with the bridge above the ground or over the water as in the case of the Conduit 2/4 Bridge. However, removing the entire truss may present challenges since large cranes and special equipment are required. The Sandy River Crossing Bridge was 300 feet long and needed to be supported at both ends. Due to the heavy weight of the conduits, the report recommended that the conduits be removed before relocating the truss. However, it was recommended that other members not be removed since doing so would reduce the stiffness of the truss.

The presence of lead paint was also a concern in the Sandy Crossing River bridge relocation project. Although the paint was in good condition, there were several minor areas of deteriorated paint. As such, a containment system was installed beneath the bridge to prevent any paint that flaked off during removal from entering the river.

5.6 Marking for Reassembly

This section addresses the need for marking of bridge components for disassembly, transportation, storage, and reassembly. Radio Frequency Identification (RFID) is introduced as a potential aid for historic metal truss bridge storage management. This section discusses its principal and current applications. The benefits and limitations of implementing RFID for historic metal truss bridge storage are discussed. In addition, other methods of marking components for disassembly, and eventual reassembly, are discussed.

5.6.1 Marking of Bridge Components

For the ease of transportation and rehabilitation, a historic metal truss bridge may be disassembled into hundreds of components before being transported to a storage facility. Those disassembled components need to be organized in a proper way so that later in the storage or reassembly work, engineers and erectors understand the exact function and position of each bridge component. Each component to be disassembled will be assigned a unique identification number. Prior to disassembly, workers commonly paint the IDs on the corresponding components; they will also be marked on bridge drawings. Alternatively, permanent die markings or conventional metal tags can be used. Despite the common use of the painting-based, die, or conventional metal tag marking methods, it is time-consuming to manually and visually traverse the entire inventory to find a single bridge component.

5.6.2 Radio Frequency Identification (RFID) Technology

Radio Frequency Identification (RFID) is a method of communication that uses radio waves. The system is composed of a tag, which is read by an RFID Tag reader, and a computer that receives the data from the reader. The tags can be active (battery powered), semi-passive or semi-active (battery-assisted), or passive (no battery). The transponder and transceiver (reader) gather and transmit the information to a RFID tag wirelessly, without necessarily needing to be in the direct line-of-sight to the tags. First, the reader sends a radio frequency signal to the tag. The tag then sends the signal back to the reader along with any information or data stored on it, such as an identification number. Upon receiving this information, the reader sends it to the computer where it is stored and analyzed. The information sent to the computer includes items such as the time at which the signal was received, which reader received it, and with what strength.

RFID technology is improving rapidly, helping to track materials, workers, and equipment in real time, as well as produce a visual of the locations and resources on a construction site. The use of RFID technology has been found to be a significant improvement over manual tracking (Ross et al. 2009). Ross et al. found that this technology, compared to the limited bar code system that requires line of sight read range, provides significantly greater read-ranges and can be utilized in both outdoor and indoor conditions, ranging in temperatures from −40°C to 200°C

The drawbacks to RFID technology include: 1) there are no self-reporting capabilities, 2) the read range typically is limited to up to ten meters, and 3) using RFID in environments exposed to either multipath or metal surfaces are at risk of experiencing signal attenuation due to the metal surfaces and the signal bouncing (Vogt and Teizer 2007).

5.6.3 RFID Technology and Historic Truss Bridge Storage Projects

Once the laser scanning of a bridge is completed, the point cloud data can be automatically generated and manually converted to a BRIM model, which holds information such as identification number, dimension, material, connection type for every bridge component. Then, unique identification numbers are assigned to both the bridge component in the BRIM model and a passive RFID tags. Prior to disassembly work, the project team sticks passive RFID tags on the corresponding bridge components so that the real bridge components can be linked to massive information held in the BRIM model to further describe the tagged bridge components. Such information can be made easily accessible to users, such as a disassembly engineer, a transportation coordinator, or a storage manager.

The RFID technology enables easy inquiry of bridge member information throughout the entire project process. Passive RFID tags are believed to be sufficiently durable such that they can still function after a number of years of use in various outdoor environments. However, field trials of testing such technology in preservation projects still need to be conducted to verify that this technology is a reliable and viable solution.

5.6.4 Recommendations for Marking

Although RFID tag marking is a promising new technology, it is recommended to use the RFID technology together with the more traditional painting-based or die-based marking methods to identify truss components and their locations and positions in the structure, until further verification of the technology in preservation projects can be conducted. Some combination of these traditional marking methods along with RFID tag marking could be explored, to also take advantage of the benefits of RFID technology. A marking plan should be included in the contract documents for removal and relocation of a historic metal truss bridge.

The following recommendations provided by Mort (2008) are valuable and practical:

"Use a dependable marking system. Old bridges have a way of bending and stretching over time. What was once a perfectly symmetrical and tight-fitting structure may today be a jigsaw-puzzle nightmare waiting to happen. Each piece of the bridge should be sensibly marked so that someone else could easily understand how to put it back together at a later date. The marks should be indelible enough to withstand transportation, outdoor storage, and time. An accompanying marking system key should be created and kept in the bridge's paperwork file. Whatever the marking system you choose – metal tags or colored numbers – make sure that you use it religiously."

5.7 Transportation Considerations

McKeel (VDOT 2006) describes some experiences in transporting historic bridges. With the availability of modern technology, bridges can be transported with little or no dismantling. Engineering assessment is needed to determine the deconstruction sequence, lifting points, etc. Limits and regulations controlling the size of the bridge members or subassemblies that can be transported on the highways and local roads must be addressed.

5.8 Notable Transportation Examples

5.8.1 Use of Self-Propelled Mobile Transporters

The Illinois DOT successfully moved a 400-foot long steel truss in Chicago in 2012 (Figure 35). This is the largest steel truss Illinois DOT has moved intact to date (Weiss 2012). The project contractor used four Self-Propelled Mobile Transporters (SPMTs) to relocate the bridge from its assembly site to its erection site. A SPMT is a vehicle with large wheels that can move heavy bridges with precision. The use and implementation of SPMTs for relocating bridges is the top recommendation by a 2004 international observation team supported by FHWA (FHWA 2007). FHWA published a manual that provides details on using SPMTs to remove or install bridges. It addresses all aspects regarding moving bridges, including technical specifications on lifting equipment, overall benefits, and implementation costs. The manual also provides example calculations, diagrams, and plans for moving bridges (FHWA 2007).

Figure 35. A SPMT moving the Torrence Avenue truss bridge into its erection site in Chicago, Illinois (Transportation Nation 2012).

5.8.2 Use of Helicopters

Constructed in 1879, the Hale Bridge is a pin-connected, bowstring thru truss bridge spanning across the Wapsipinicon River in Hale, Iowa. Because of flooding in 1993, the bridge was significantly damaged and closed in 1997. In 1998, the bridge was nominated for the National Register of Historic Places as the longest-standing bowstring arch bridge in Iowa, and in 2003, the bridge was dismantled. Its three spans were moved into storage for refurbishment, restoration, and the future construction of the new Hale Bridge (Figure 36). In 2006, after its three-year long restoration was completed, the Hale Bridge found its new home (non-traffic use) in the Wapsipinicon State Park as shown in Figure 36c (NTAC 2014).

(a) (b) (c)

Figure 36. Hale Bridge (a) moved, and (b) placed by Chinook helicopters, and (c) existing in its new location (NTAC 2014).

Two spans of the Hale Bridge are 85 feet long and weigh 16,500 pounds. The main span is 100 feet long and weighs 19,600 pounds. The relocation of the bridge spans was unusual not only because each span was moved in one piece but also because Chinook helicopters from the Iowa Army National Guard were used to lift and move them (Figure 36a and Figure 36b). The History Channel featured the bridge relocation as part of a television program called "Mega Movers."

5.9 Summary

Metal trusses can be disassembled and transported with relative ease due to the nature of their design. However, excessive and unnecessary disassembly can impact the integrity and historic significance of the bridge. In general, the disassembly of historic metal trusses should be minimized. In some cases, constraints in transportation such as the vehicle capacity and road clearances require the trusses to be disassembled. In addition, if the rehabilitation work requires disassembly of the trusses to reinforce or replace members, the trusses can be disassembled in advance to minimize the transportation difficulty. It is essential that the disassembled components of a bridge be marked extensively and clearly to ensure that the parts can be reassembled in their correct 3D position and orientation within the bridge structure. A marking plan should be included in the contract documents for removal and relocation of a historic metal truss bridge.

6. Specific Storage Considerations

6.1 Introduction

This chapter provides a review of the practices of storing historic metal truss bridges in other states. This is followed by recommendations pertaining to off-site storage based on the various factors that have been discussed in the other chapters of the report.

6.2 Off-Site Storage Examples

The *Connecticut Historic Bridge Inventory Final Report: Preservation Plan* requires that storage conditions should be amenable to minimum deterioration of trusses or disassembled parts (ConnDOT 1991). Assuring the long-term retention of the integrity of bridges necessitates continued inspection and maintenance of the stored bridges. In addition, the mitigation of further corrosion is a critical treatment for the storage of historic metal trusses. The Minnesota Department of Transportation Management Plan (MnDOT 2006) states that good practices for mitigating corrosion include:

1. Storing trusses in positions that promote free drainage to avoid the ponding of moisture,
2. Painting trusses or truss members prior to storage,
3. Keeping them off the ground, and
4. Inclining them to enable the free drainage of moisture.

Storage of bridges until a reuse is determined, or funding is available, is an option that has been employed by numerous states within the U.S. Unfortunately, in many states, the practice of storage appears to have undermined the value of the bridges, due to the storage methods and neglect once the bridges have been placed into storage.

A review of the current state of historic bridges in storage shows that most bridges are being stored outdoors. Significant deterioration of the bridge components is evident in certain cases. Although the specific condition of these bridges at the onset of their storage is not known, it is noted that preservation activities were applied to some of the bridges at the time of storage, including repainting.

Without an active management and effective reuse plan, the stored bridges can be forgotten and become overgrown with vegetation. Figure 37 emphasizes the important need for vegetation control at any outside storage location, either by placing the structure on concrete or providing some type of vegetative barrier.

Figure 37. The Big Slough Bridge in storage in Bartholomew County, IN (Bridge Hunter 2013).

Compared to being placed in basic storage facilities, the historic bridges in Calhoun County Historic Bridge Park in Michigan are well preserved by effectively rehabilitating and storing them as park attractions that provide enjoyment and education to visitors (Historic Bridges 2013). The park currently houses five metal truss bridges and a stone arch bridge. Instead of randomly placing the bridges on the ground, designers of the park located them at sites that demonstrate their original engineering and historic beauty. More information about this historic bridge park is provided in the section below.

6.3 Calhoun County Historic Bridge Park

The Historic Bridge Park in Calhoun County, Michigan, is the first and currently the only historic bridge park in the United States (Figure 38). This park is the home of five historic truss bridges which could no longer be used in their original locations. These bridges are listed in Table 1.

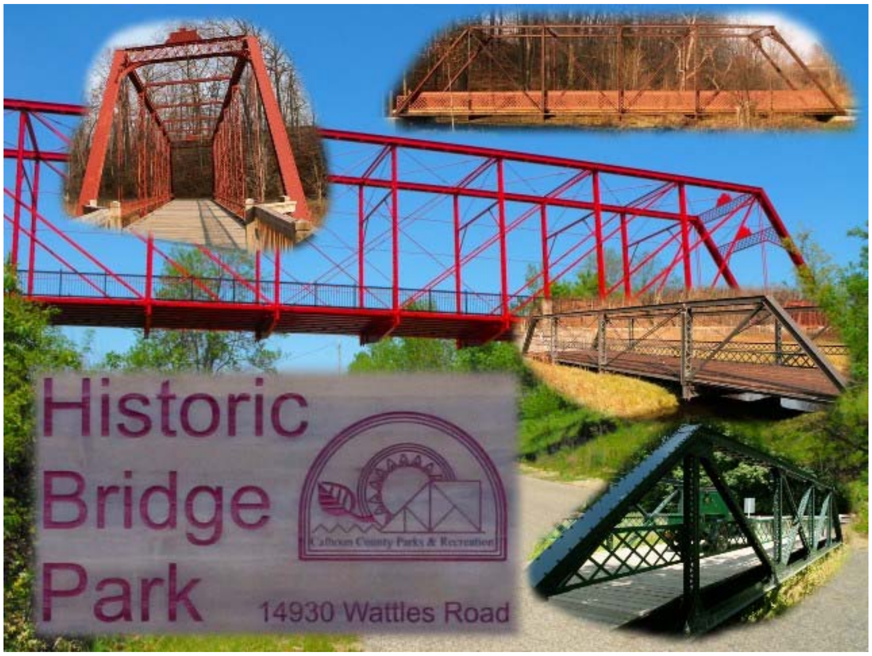

Figure 38. Calhoun County Historic Bridge Park (Historic Bridges 2013).

The restored bridges are placed in the park to serve as part of pedestrian paths and as hands-on exhibits of Michigan's significant history in transportation and metal fabrication industries. The objective of restoring historic trusses in the park was to maintain as much of the original bridge material as possible and to replicate any parts that required replacement. In addition to providing the historic trusses for the enjoyment and education to visitors, the Historic Bridge Park is a fully functional park with running water, restroom facilities, picnic and playground areas, and paved trails for pedestrians and bicyclists.

Table 1. Truss bridges in the Calhoun County Historic Bridge Park (Historic Bridges 2013).

Name	Structure Type	Span	Width
20 Mile Road Bridge	Pony truss, Revit-connected	64 feet	15.4 feet
133rd Avenue Bridge	Pony truss, Pin-connected	66 feet	14 feet
Bauer Road Bridge	Thru trusses, Pin-connected	89 feet	16 feet
Gale Road Bridge	Thru trusses, Pin-connected	118 feet	14.4 feet
Charlotte Highway Bridge	Thru trusses, Pin-connected	173 feet	14.4 feet

One of the bridges located in the park is the Charlotte Highway Bridge. This bridge was built by H.P. Hepburn Engineering and Construction of Cleveland, Ohio, in 1886. It is a 173-foot single span wrought iron thru truss with pinned connections, and it is one of Michigan's three remaining Pratt (Whipple) thru trusses, having its diagonals crossing two truss panels. In 2001, the Charlotte Highway Bridge was removed from its original location in Portland, Michigan. This bridge was in good condition; the only major rehabilitation required was the replication of ten riveted floor beams. In 2005, the Charlotte Highway Bridge was moved to the Calhoun County Historic Bridge Park, and in 2007 it was reassembled at the park entrance as the fifth historic truss bridge (Figure 39).


(a)

(b)

(c)

Figure 39. Charlotte Highway bridge (a) At its original location, (b) During reassembly, and (c) In its current location (Historic Bridges 2009).

In addition to the five bridges situated in the park, the park has acquired several historic truss bridges for storage. These bridges are now stored in a specific storage area in Marshall, Michigan, as shown in Figure 40. The disassembled structures are stored outdoors.

Figure 40. Historic bridge storage area in Marshall, Michigan (Mesler 2007b).

6.4 Summary Recommendations

The selection of a storage facility for metal trusses should consider the type, dimensions, and location of the bridges, and the attributes of the roads from the current location to the facility, and from the facility to the potential reuse location.

Possible storage facilities include warehouses, yards, maintenance facilities, airports, and parks. These candidate locations can be categorized into indoor and outdoor facilities. In most cases, a truss bridge or truss members can be stored outdoors after proper stabilization (Section 2.4). Providing a roof over the metal components can be beneficial to reducing the amount of time that the metal surfaces are wet.

The distance and conditions of the road from a bridge's current location and from its storage facility, is critical to the selection of potential storage facilities. As the distance increases, transportation costs, and the probability of damage to the bridge, will likely increase. Road conditions such as width and clearances may be a factor in determining the required extent of disassembly of the bridge. As shown in Section 1.3, the majority of Georgia's historic metal truss bridges are in the middle to northern regions of the state, above the fall line. Many of these bridges are in rural locations. Any centralized state-provided location(s) should be positioned in these areas of the state. If there is a possibility that state maintenance workers could conduct needed preservation, locating the trusses at or near maintenance facilities could be advantageous.

If the relocation of a historic metal truss bridge is predetermined, it would be desirable to store the bridge at a facility close to the new site.

Based on the assessment of the metal truss bridges documented in the GHBS (GDOT 2012), storage facilities generally need to accommodate pony truss bridges up to 112 ft. in span thru and deck truss bridges up to 150 ft. in span. For the large span thru and deck truss bridges, it is likely that at the structures would need to be partially disassembled.

Metal trusses in storage can be jeopardized for various reasons. Pooling of water on the members and components of trusses can cause serious corrosion. Trusses covered by tarps, or stored in an indoor facility with bad ventilation, are susceptible to corrosion. Many chemicals that might be used in or near storage facilities, such as herbicides and pesticides, are corrosive to metal. In addition, improper stacking and support may damage the bridge components. Loading and stacking truss members on uneven surfaces or terrain, especially when the truss members are long and heavy, can exceed the elastic state of the members.

6.4.1 Minimizing Corrosion

The following recommendations are aimed at minimizing corrosion during the storage process.

- Trusses or truss members must be stored on a slight slope to allow free drainage of water and to prevent pooling of water on the truss members and components.
- Trusses or truss members should be supported by placing on blocks to keep them off the ground for a minimum distance of 12 inches, with adequate airflow and ventilation around each member.
- Trusses should rest on concrete or other vegetative barriers. If such barriers cannot be arranged, periodic inspection and proper measures for vegetation control is necessary.
- Minnesota DOT recommends that if storage is for more than 5 years, components should be painted (MnDOT 2006).
- Placing a tarp over trusses during storage is not recommended. It is better to allow free air flow around the steel.

- Chemicals should not be spread around the stored trusses or truss components for control of vegetation. Many of these chemicals are corrosives that can be very damaging to the metal components.

6.4.2 Support Techniques

In order to maintain design integrity, the following measures are recommended during the storage process.

- Trusses or truss members should not be unloaded on uneven surfaces or terrain that could cause damage to the truss.
- Each bridge member should be supported by blocking to ensure that components are not stressed.
- Where feasible, it is recommended that a historic metal truss bridge be reassembled into its intact configuration and located on temporary bearing supports at the storage site. Having the structure stored intact can facilitate marketing of the bridge, and also helps eliminate the potential problem of the components of the bridge going missing.
- Necessary work to prevent further damage or deterioration during storage should be considered on a case-by-case basis.

6.4.3 Inspection and Maintenance

Continued periodic inspection and maintenance to assure long-term retention of the bridge's integrity is necessary. Vegetation growing at the storage site should be cut on a regular basis. Trusses and truss members in storage should be inspected at least every two years, to ensure that the storage conditions are stable. If any corrosion and damage is identified, repairs should be made as soon as possible. The results of inspection should be documented and reported to the owner or potential recipients.

6.4.4 Sunset Clause

It is recommended that a sunset clause be part of the contract to store a given historic truss structure. When the clause expires, the disposition of the bridge should be revisited.

7. Cost Estimation

The cost to rehabilitate and relocate a historic bridge is one of the first issues discussed with a potential owner. Costs can vary and change as the relocation/rehabilitation project progresses. This variance is related to (a) rehabilitation needs, (b) relocation requirements, or (c) storage availability. Since the 2002 agreement between FHWA and the state DOTs states that only the cost of demolishing a bridge be used for preservation purposes, it can be expected that the demolition cost may cover only a portion of the total cost of bridge relocation and rehabilitation. In fact, relocation costs usually exceed the demolition costs since it involves disassembly, transportation, and temporary storage. Therefore, the other costs for rehabilitation, site preparation, reassembly, maintenance, etc. would need to be assumed by the recipient of the bridge. A detailed estimate and time required to complete the relocation is an essential component of a relocation proposal, but the new owner may also need to project costs in order to select the most desirable location for the historic bridge.

7.1 Cost Estimates

A cost estimator or engineer may use multiple sources to estimate the costs for the rehabilitation and relocation of a bridge. Some activities (e.g., stabilization, rehabilitation, and repair) can require highly specialized equipment, techniques, and materials to preserve or repair character-defining features. For example, the use of rivets or button-head bolts adds expense due to the limited number of skilled professionals able to perform the work (MnDOT 2006). Customized activities required for the disassembly, reassembly, storage, and preservation of a historic metal bridge structure can be more costly than repairs to a non-historic bridge because the efforts require unique skills and are often more labor intensive. Cost estimators often rely on past bid tabulations, cost-estimating manuals, and local engineering, architectural, and construction contractor resources.

Cost estimates for disassembly, reassembly, and rehabilitation require detailed plans. Site visits by an estimator and a structural engineer are necessary to determine the specific needs of the bridge. The development of preliminary plans based on fieldwork (e.g., surveying, site visits) will improve the precision of cost estimates. Actual costs may vary significantly from early cost estimates due to unforeseen circumstances. It is important to account for risk. Contingency funds for unanticipated costs, such as replacing lost parts or damage encountered during disassembly or reassembly, should be established.

7.2 Cost Categories

Relocating a historic bridge can be divided into four major activities: disassembly at the current location; transportation to the new site, or to temporary storage; rehabilitation; and site preparation and reassembly at the new location.

Disassembly is part of the bridge replacement project and should be included in the construction contractors' bids for the replacement bridge. In most cases, the new owner will not be responsible for these costs since it is part of the bridge replacement project. The disassembly should include costs for hoisting and bracing, removal of lead-based paint, and the marking of the truss members, and documentation before and during disassembly. In addition to these costs, transportation to storage or to the new site could be included in the construction contract. The contractor may be able to include the transportation cost in the bid for the construction of the new bridge if the bridge is small and the storage site is nearby. Since contractors specializing in heavy construction such as bridges routinely transport large beams, girders, and columns, they have expertise at planning and implementing this work. The second activity is transportation to the new site or to temporary storage. The transportation, either to storage or to the new site, cannot be included in the contract or if a second move out of storage and to the final location is planned, some cost that considers distance and the equipment needed to erect the truss using the documentation prepared during disassembly should be assigned. In addition, a storage fee may be required. If the new owner is a municipality with access to an area considered adequate, no costs for the storage would be expected.

Rehabilitation of the bridge may be done during any phase of the project. For example, it is prudent to thoroughly clean the structure during disassembly and to reconstruct the deck after the bridge has been moved to the new site. Rehabilitation will also vary dependent upon its future use. Rehabilitation could include pack rust removal, the replacement of fractured or damaged members, welding, replacement of rivets or pins, and applying a protective coating. Costs for labor and materials for each of the proposed rehabilitation activities should be considered.

The final activity is the site preparation and re-erection of the bridge at the new location. This cost can vary due to right of way or easement costs, utility relocation, equipment needed for the re-erection, environmental permitting, and construction of new use facilities. Bridge access, ADA compliance, lighting, sidewalks, grading, drainage, erosion control, and traffic control should be considered.

Very little detailed cost estimation data has been published that can be applied to historic metal truss bridges. Each bridge has its own criteria, making it very difficult to rely on another bridge estimate. Inflation and advances in technology also make it difficult to prepare an estimate that relies upon previous estimates. It is also possible to separate the costs and activities to "pay as you go". This approach relies on having a suitable storage location until funding has been secured.

7.3 Example of Rehabilitation Costs

7.3.1 Weighing the Alternatives: Rockcastle River Bridge, Kentucky

Only three Pennsylvania Petit steel truss bridges remain in Kentucky. One of these is the Bridge across Rockcastle River in London, Kentucky (Figure 41). It is located on a rural, low volume road (200 ADT). The bridge, constructed in 1921, is 205 feet long and 18-20 feet wide. Its sufficiency rating before the repair was 38.7, and it had a 3-ton weight limit. The bridge is a habitat for endangered mussels and that it is located on the Sheltowee Trace National Recreation Trail. Any bridge closure would cause a 22-Mile detour for traffic.

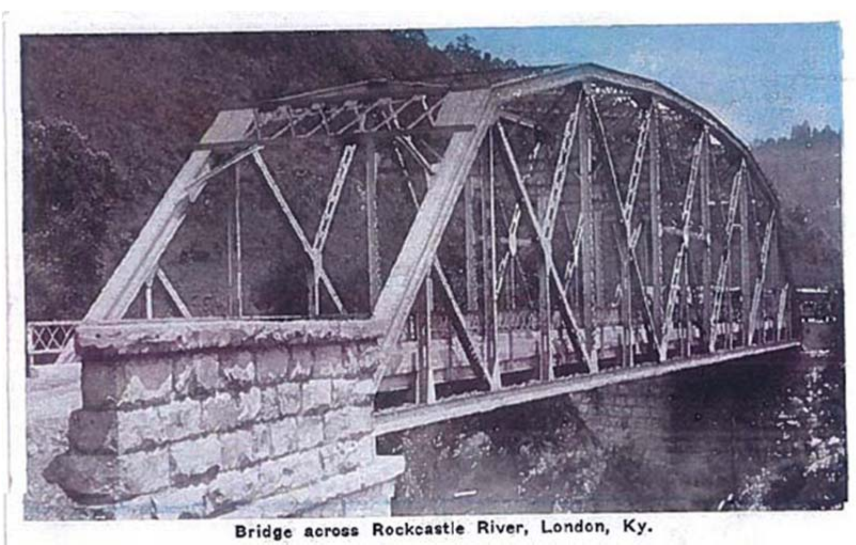

Figure 41. Bridge across Rockcastle River, London, Kentucky (Kentucky Transportation Cabinet 2012)

The bridge required repainting, end post plates replacement, and repairs to the vertical members and gusset plates. The estimated replacement cost in 2006 was estimated at $1.8M. This sum included right-of-way (ROW), utility, and construction work. A detailed bridge repair plan was created (Figure 42). The engineer's estimate for the alternative, paint and repair, was $913,000. Four bids were received to perform the work, ranging from $465,000 to $696,000. Since all plans were developed in-house, and the lowest bid received was $465,000, significant money was saved by leaving the historic bridge in place. Leaving the bridge in place, with continued service or modified service, can be a cost effective option.

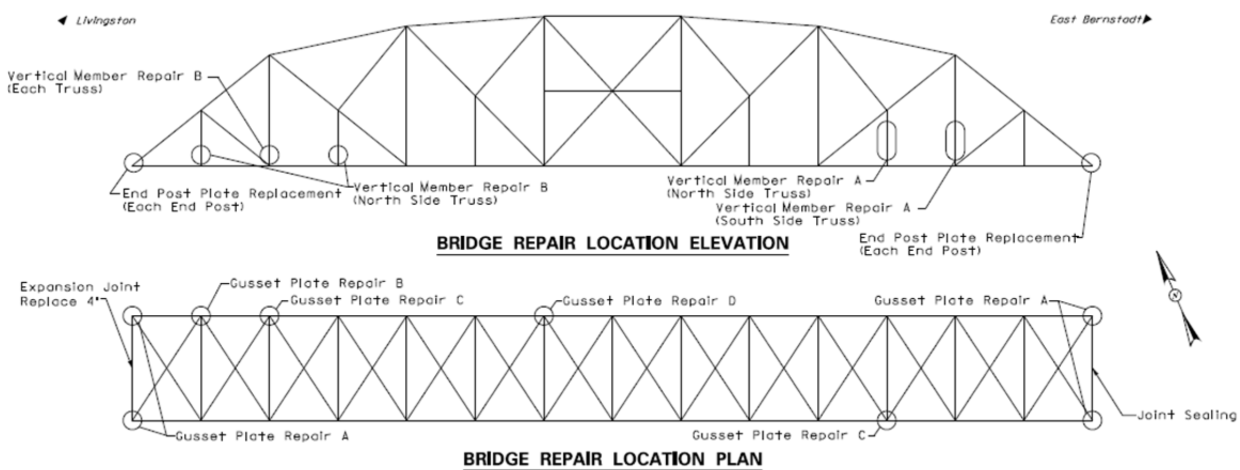

Figure 42. Bridge repair location plan used to estimate cost (Kentucky Transportation Cabinet 2012)

The total construction time took two months, during which the bridge had only one lane open. The bridge was completely closed for 5 days during October 17-21, 2011, and the work was completed on December 5, 2011. It is estimated that the bridge will not require another major repair for another 20 or more years. After the repairs were completed, the bridge's weight limit was increased to 15 tons.

7.4 Summary

Four major activities can be assumed when relocating a historic bridge for reuse. They include disassembly at the current location; transportation to the new site or to temporary storage; rehabilitation and site preparation; and reassembly at the new location. Cost estimates for these activities require detailed development of the associated plans. The development of preliminary plans for each of these activities should be based on fieldwork (e.g., surveying, site visits) and will improve the precision of cost estimates. Actual costs may vary significantly from early cost estimates as unforeseen events can occur. The inclusion of contingency funds for unanticipated costs, such as replacing lost parts or damage encountered during disassembly or reassembly, is recommended.

8. City of Griffin 6th Street Bridge Case Study

8.1 Introduction

In 2012, the 6th Street Bridge (GDOT Bridge No. 255-0048-0) located in Griffin, Georgia was disassembled, moved, and stored for future reuse as a pedestrian bridge. A decision to replace the bridge was made because it was determined to be structurally deficient and functionally obsolete. Because the bridge spanned a railroad and the vertical clearance was insufficient, it had to be removed and a new bridge constructed in its place.

The 6th Street Bridge structure consisted of two parallel pin-connected, Warren truss bridges with spans of approximately 100 feet. It was located in the Griffin Commercial Historic District which was listed on the National Register of Historic Places in 1988. The bridge also maintained a strong community identity as a local landmark. The 6th Street Bridge was considered to have good reuse potential because of its size and ability to be dismantled and reconstructed. After several years of coordination between GDOT, the City of Griffin, and other concerned parties, it was agreed that once construction began on the replacement bridge, the existing bridges would be disassembled, moved, and stored. The decision to store both bridges rather than reuse them was a product of scheduling. The replacement date and the need to remove the old bridge did not coincide with the municipality's readiness to reuse it. The trusses have been stored at the Griffin-Spalding County Airport since 2013.

The challenges encountered during this undertaking prompted the initiation of this research by GDOT. Because the later stages of the 6th Street Bridge project occurred concurrently with this study, it offered an opportunity for analysis of the methods used to determine if additional steps could have been taken to preserve the historic integrity of the trusses during their disassembly, rehabilitation, and, storage. It also allowed the research team to interview design engineers, field personnel, and architectural historians regarding the challenges that were faced.

8.2 Storage Decision

As discussed in Chapter 3, storage in place is the most cost-effective and least disruptive way to preserve a historic bridge, although it is not always a possible alternative. This was not possible with the 6th Street Bridge. Because the bridge had insufficient vertical clearance and inadequate travel lane width for vehicular traffic traveling across the bridge, it had to be either demolished or relocated.

In the early planning stages of the bridge replacement, efforts were made to market the historic bridge. In spite of its age, the bridge was in relatively good condition and was believed to have potential as a pedestrian bridge at a different location. Initially, the City of Griffin was not interested in reusing the old bridge and supported the efforts made by GDOT to look to other communities for potential reuse. However, input from community leaders renewed the city's interest in retaining the structure in 2008. At this time, Atkins, an engineering and design consulting firm, was hired by GDOT to develop reuse alternatives. After reviewing the alternatives, the city elected to retain the trusses and provide a place for storage. The development of alternatives and transportation to the storage location was performed as mitigation for the finding of adverse effect to the historic district as a result of the project.

8.3 Stabilization of Structure

In the case of the 6th Street Bridge Griffin, the stabilization activities were relatively minor since the bridge was in good structural condition. The metal components were cleaned and painted after they were moved to the storage location. No other maintenance was done.

8.4 Documentation of Structural Features and Historic Context

Because of the 6th Street Bridge's initial use as a rail-carrying bridge, GDOT had no construction plans on file for the old bridge. Before the bridge replacement project could begin, Historic American Engineering Record (HAER) documentation of the bridge was completed and submitted to the Library of Congress. Additionally, some laser scanning was conducted prior to its disassembly for the purpose of historic and engineering documentation. Various phases of the disassembly process were also documented with a video camera. The aforementioned documentation of the bridge was part of the mitigation for the loss of the historic resource and was aimed at documenting the engineering and design of the bridge. This effort was directed by the GDOT historian.

Once the contract for the construction of the new bridge was awarded to E. R. Snell Contractor, Inc., Structural Engineering Solutions LLC was hired by Snell to produce a set of drawings to aide in the deconstruction process resulting in a Bridge Removal Plan produced in October 2011.

3D point cloud data using a terrestrial laser scanner was collected specifically for this case study to examine and discuss the effectiveness of 3D modeling. In addition, a Bridge Information Model (BRIM) was generated. Based on a consideration of the laser scan data for the 6th Street Bridge, several important observations can be made regarding the duality of 3D modeling in BRIM.

The two facets of this duality are BRIM as a visualization tool and BRIM as a constructability tool. As a visualization tool, a 3D model can be created relatively quickly to display a photo-realistic model with the general shape and dimensions of a bridge. This basic shell acts as a 3D image that is most useful as an aide in the decision making process. The model in Figure 43 shows the range point cloud that modern laser scanners collect. Laser scanning a bridge may take from about a few hours to a few days depending on the size of the object to be scanned. Laser scanning the 6th Street Bridge was done from multiple scan locations that were scanned and referenced within one day.

As a tool for documenting the current condition, a 3D model can be created to display the exact dimensions, components, and materials of a bridge. Creating a 3D model of the structure is time-consuming. However, this is most useful during design, planning, and construction. Disassembly and reconstruction of a bridge are two of the activities where BRIM can be very useful. Structural BRIM software (e.g., Trimble, Tekla Structures, Nemetscheck) can show the level of detail bridge component fabricators need to know if they need to refabricate a bridge element with highest level of detail, for example, the location of bolts. In this case study, a 3D model was created and utilized as a visualization tool. The point cloud, which served as the reference model for the 3D model discussed in Section 8.4.2, is displayed in Figure 44.

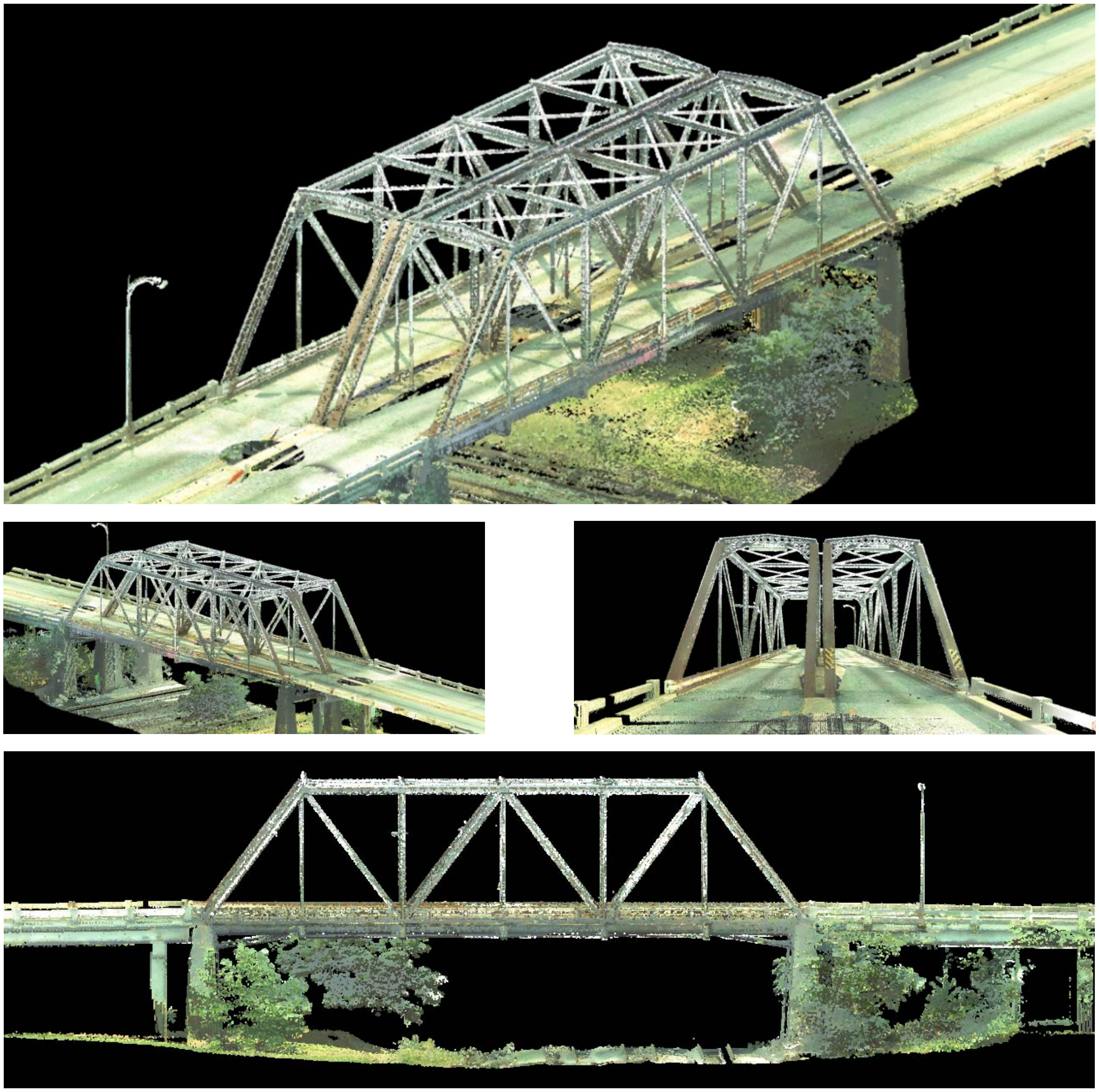

Figure 43. Photo-realistic TOF point cloud laser scan of the 6th Street Bridge (Courtesy of Sharman Southall, GDOT).

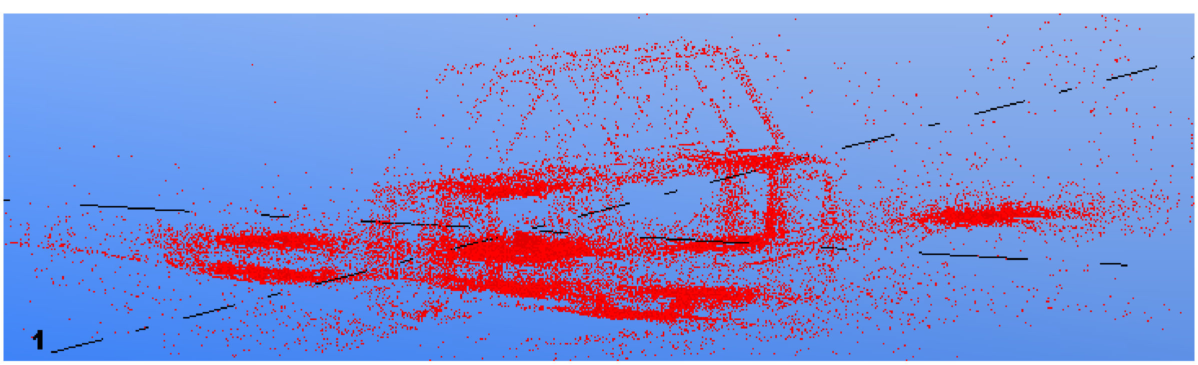

Figure 44. Raw data of a phase-based scan of the 6th Street Bridge used as a reference model.

8.4.1 Visualization Tool

When deciding how best to repurpose a bridge, a basic 3D sketch can help in the visualization of its new use at the new location. 3D sketches can also be integrated into photographs to help stakeholders visualize the sizing, placement, community impact, and overall aesthetic appeal of different options. Atkins prepared seven reuse options for the 6th Street Bridge in January 2011. The seven reuse options were compared on the basis of the evaluation criteria discussed in the study. Included in each option was a visualization comparison. Figures 45 and 46 show an example of the visualization presented to the City for one of the seven options.

Figure 45. Taylor Street and 5th Street (PBS&J 2011).

Figure 46. Taylor Street and 5th Street with 3D sketch of bridge added (PBS&J 2011).

All reuse options included in the report incorporated similar before/after comparisons showing how quickly and effectively a 3D sketch can be utilized as a visualization tool. A basic 3D sketch can be further used as a marketing tool on a website describing available truss bridges within the state. A 3D sketch of this kind that can be quickly created will aide potential users in a more meaningful way than photographs and drawings. The ability to manipulate and implant a 3D sketch into different locations and settings will help stakeholders understand and assess the various options.

8.4.2 Tool for Documenting the Current Condition

A second visualization tool is a 3D Bridge Information Model (BRIM). A BRIM in this study was generated from the range point cloud. It was, however, not utilized for more extensive documentation of the current condition of the structure on the 6th Street Bridge project. Creation of the data for this application takes considerably more time to create than the generation of the data basically for a 3D sketch. This type of application requires greater detail and information than a model used solely for visualization purposes. A BRIM further yields advantages that are technical in nature. A 3D model of this kind is most useful to the designers, engineers, and contractors that collaboratively work during bridge disassembly and reconstruction. Although the small size and simplicity of the 6th Street Bridge made the creation of a model less necessary, 3D models can, in general, save considerable amounts of time and money, particularly on larger scale projects. A BRIM of the 6th Street Bridge is shown in Figure 47.

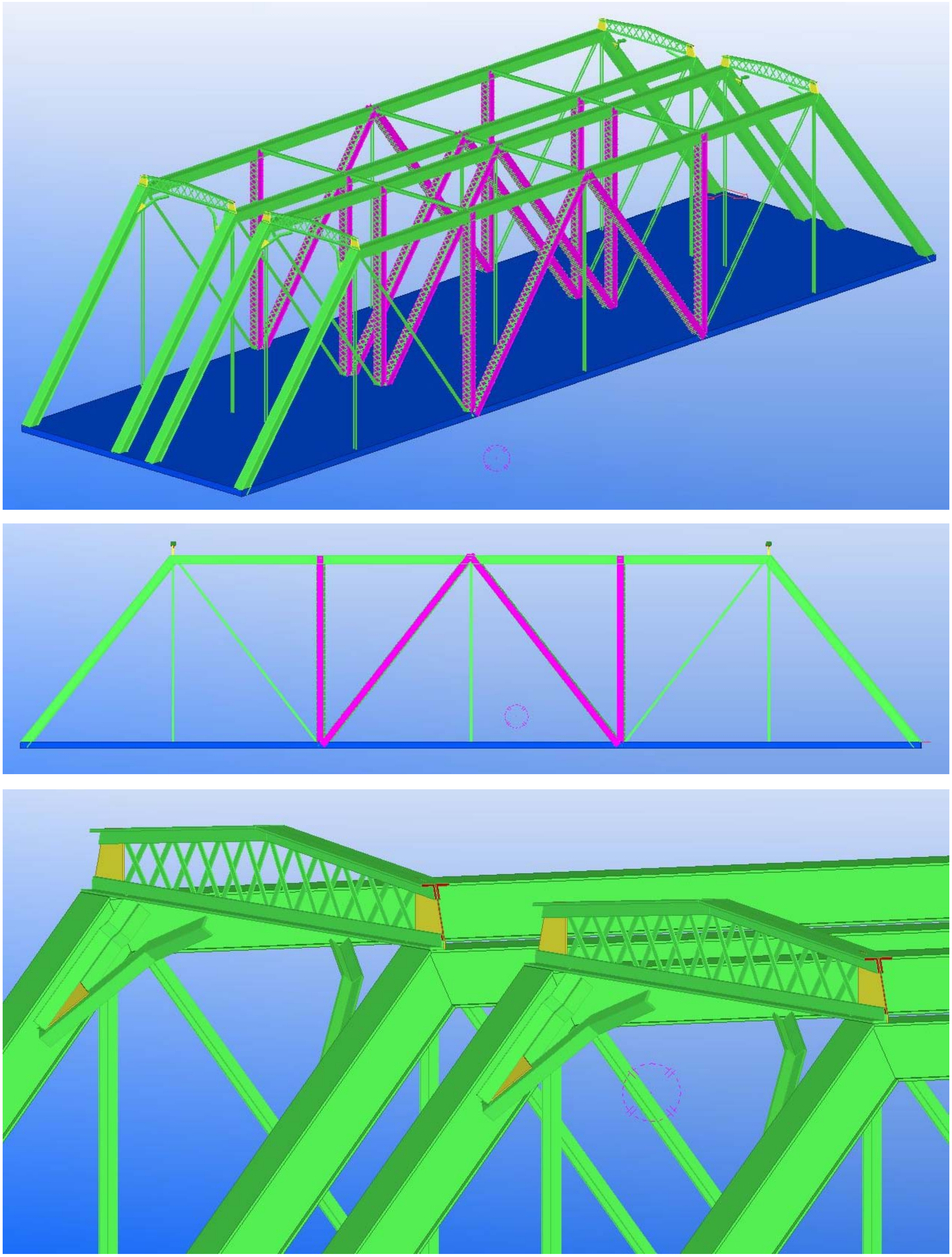

Figure 47. 3D Model of the 6th Street Bridge in Griffin.

8.5 Marketing

Marketing efforts for the 6th Street Bridge began in 2002. After the Regional Development Commissions had been contacted, a municipality with a planned pedestrian trail was located. However, after some time elapsed, the municipality could not wait for the replacement contract (the 6th Street Bridge was in use up until the time that it was replaced) and had a new bridge fabricated. As an alternative, the City of Griffin decided to retain the bridge and sought candidate relocation sites for it. Atkins (formerly PBS&J) was hired by GDOT to evaluate alternatives for use of the structure as a pedestrian bridge. The alternatives were developed by a group including the city manager, the public works director, the city planner, and the historic preservation commissioner. Despite the extensive evaluation of potential reuse options prepared by PBS&J (2011), the 6th Street Bridge has not yet been assigned to a new home. However, the City of Griffin has selected a potential location and hopes to obtain a funding that will enable its reuse as a pedestrian bridge in the future. Rehabilitation

The rehabilitation that took place on the 6th Street Bridge was a straightforward, two-step process. Before being transported to the offsite storage location at Griffin-Spalding County Airport, the truss members were sand blasted to remove rust and smooth the outer surface of the metal. Although little of the paint was left from its last application in 1958, that which remained contained lead and was removed and contained according to Georgia Environmental Protection Division regulations. After arriving at the storage location, the truss members were then sprayed with a primer coat to impede further rusting.

Although the piece marking of the bridge components was specified as a general requirement in the job specifications, the various truss components were either not marked prior to disassembly, or the marks were painted over after the truss was moved to the storage location.

It is important to note that while the rehabilitation on this bridge was a relatively simple process, it was by far the most expensive step of the overall process. This expense is discussed in greater detail in Section 0.

8.6 Disassembly

The 6th Street Bridge was disassembled in the following seven phases:

1) Removal of approach spans to allow immediate construction of new wider approach spans (Figure 48);

Figure 48. New construction approach spans (Courtesy of Sharman Southall, GDOT).

2) Removal of concrete deck as well as the timber stringers below (see Figure 49);

Figure 49. Removal of concrete roadway and timber stringers (Courtesy of Sharman Southall, GDOT).

3) Adding lateral and horizontal bracing to the frame at the upper chord truss members to accommodate the crane lift points (Figure 50);

Figure 50. Lateral and horizontal bracing at the upper chord to accommodate the crane lift points (Courtesy of Sharman Southall, GDOT).

4) Lifting of each thru truss span off of the concrete column bents with one crane on each end for control and safety, as shown in Figure 51;

Figure 51. Two cranes working together to lift the 100 feet span (Courtesy of Sharman Southall, GDOT).

5) Placement of the ends of each thru truss span on cribbing to ensure that the five central truss verticals remained elevated (Figure 52);

Figure 52. Trusses placed on cribbing at each of the four corner supports to ensure that the five truss verticals remained elevated (Courtesy of Sharman Southall, GDOT).

6) Removal of lateral and horizontal bracing and components; and
7) Placement of the individual planar trusses onto a modified truck for transportation to storage.

Due to its light weight and good condition, the removal of the 6th Street Bridge was a relatively straightforward and simple task for the contractor. Adequate temporary storage space was available close to the bridge's original location. A major concern in the disassembly was safety and railroad right-of-way access, since the bridge spanned over rail road tracks. Proper planning and communication among the involved stakeholders resolved all the concerns.

8.7 Transportation

As described in Section 8.6, the 6th Street Bridge was disassembled into four planar trusses. These planar trusses were transported separately to the Griffin-Spalding County Airport, approximately two miles away. Figure 53 shows one of the planar trusses in-transit to the offsite storage location.

Figure 53. Transportation of one of the planar trusses on S. Hill Street, Griffin, GA, in route to the storage site at the Griffin airport (Courtesy of Sharman Southall, GDOT).

8.8 Off-Site Storage

The 6th Street Bridge was placed into storage at Griffin-Spalding County Airport on March 26, 2012 (Lightner 2012). Two of the four trusses were stored intact on their sides at the airport storage site as shown in Figure 54. The trusses are elevated off of the ground on wood blocking to facilitate drainage and minimize corrosion. The bridge floor beams are also elevated on wood blocking (Figure 55). As observed in other instances involving the storage of historic bridges, lack of vegetation control could lead to damage to the bridge members. Proper measures of vegetation control such as periodical inspection and clearance are necessary.

Figure 54. Planar trusses resting on their side on wood blocks at the Griffin-Spalding County airport storage site.

Figure 55. Floor beams in storage at the Griffin-Spalding County airport storage site.

8.9 Cost Estimation

The cost estimation shown in Table 2 was prepared as part of the report given by PBS&J (2011). These estimates do not include disassembly and transportation to the storage site. These estimated costs were prepared for the City of Griffin to assist them in planning. It does not include costs of maintenance, environmental permitting, engineering, right of way, and easement acquisition.

Table 2. Example of the rehabilitation cost for the Griffin 6th Street Bridge (PBS&J 2011).

Rehabilitation cost for one bridge:		Rehabilitation cost for both bridges at the same location:	
Removal and erect	$ 20,000	Removal and erect	$ 20,000
Disassembly	$ 30,000	Disassembly	$ 40,000
Bracing	$ 10,000	Bracing	$ 20,000
Transportation	$ 3,000	Transportation	$ 6,000
Reassemble	$ 30,000	Reassemble	$ 40,000
Rehabilitate	$ 12,000	Rehabilitate	$ 24,000
Paint	$200,000	Paint	$200,000
TOTAL	$305,000	TOTAL	$550,000

8.10 Lessons Learned

The case study points to several problem areas in the relocation and storage of metal truss bridges. They are the potential loss of marking during repainting, the need for vegetation control if stored outdoors, and the value of laser scanning and BRIM as a means of documentation.

Tracking of individual metal truss members with barcode or RFID technology, or with any other clear markings that identify the location and orientation of the pieces was not effectively done for this project. If the bridge pieces had been marked during disassembly, these markings were hidden by the repainting of the structure. It is absolutely essential that extensive markings be provided on disassembled structures like the 6th Street Bridge, to facilitate the eventual reassembly of the structure.

There is a potential for vegetation to grow around and through the trusses and other components in their current storage location. Some type of barrier should be placed under these components, or the vegetation growth needs to be periodically controlled without the use of weed control chemicals which are extremely corrosive to metal.

It has been concluded that 3D modeling is an effective method of documentation and can also be used as a visualization tool. The renderings of historic bridges can serve as visualization tools for stakeholders, as educational tools for students and scholars, and as historical records for the general public. In addition, the range point cloud information that a laser scanner provides can be used at any time, allowing additional 3D modeling for other reuse scenarios to occur in the future. Due to the accelerated schedules and relatively simple procedures involved in deconstructing the 6th Street Bridge, the time and cost it takes to create a comprehensive model of the current bridge condition outweighs the benefits of doing so.

For bridges that have more complex geometry or when a massive number of structural or architectural members need to be replaced, a more extensive 3D model of the bridge could be used for extensive structural analysis and planning, and eventually fabrication of replacement pieces. If a model of the current bridge condition was available to the future reconstruction contractor with exact dimensions, structural analysis capabilities, comprehensive inventories of parts and components, and other pertinent information collected and recorded during disassembly, a considerable amount of time and money could be saved in the consideration of various potential reuse options. Although some up-front investment would be necessary (scanning effort and time for modeling) such a model would essentially jump start the reconstruction process and help to ensure that the bridge would not be deemed too difficult or expensive to re-erect.

Marketing structures, such as the 6^{th} Street Bridge, via a website can broaden the reach of efforts to achieve a beneficial reuse of the structure.

9. Conclusions

This study has identified various best management practices pertaining to the storage of historic metal truss bridges in Georgia. The study was conducted by reviewing the literature on management and preservation of historic bridge structures, and by interviewing GDOT and other state DOT personnel as well as contractors, fabricators and engineering consultants with experience in preservation and storage of historic metal truss bridges. The research team also investigated the state-of-the-art of various preservation technologies as well as documentation (measurement) technologies pertinent to the subject, conducted detailed web-based searches and evaluation of current historic metal truss bridge marketing efforts in various states, and collected best practices pertaining to deconstruction, transportation and actual storage of metal truss bridges. Best practices pertaining to cost estimation for historic metal truss bridge storage also were addressed.

The recommendations from this research may be summarized as follows:

1) The majority of the State's historic metal truss bridges documented in the Georgia Historic Bridge Survey (GHBS) are located in the middle to northern regions of the state, north of the fall line in the state. As such, this region of the state should be considered for a storage location if a centralized storage is developed. Most of these bridges range from 16 to 112 ft in span, and hence would be relatively easy to transport and store at an off-site location.
2) In-situ storage is indeed a viable option in many cases, and in fact, a large number of the historic metal truss bridges in Georgia are currently off-system and are effectively being stored in place. If the decision is made to leave a bridge on site, activities should be undertaken generally to address safety and to preserve the structure's integrity. These include restricting access to the structure and implementing measures such as heat-rise sensors and water sprinkler systems to discourage vandalism. Loose identification plates or ornamental items that could be removed by unwanted visitors should be secured. Cleaning of the structure is recommended as a common necessary, high-priority, and relatively inexpensive task.
3) Various rehabilitation activities often may be deferred until a bridge has been placed in storage. Key activities that may need to be undertaken either before or during storage

include heat straightening of members, repair (shortening) of slack members, use of welding to build-up members exposed to section loss, removal and replacement of deteriorated pins and/or rivets, removal and replacement of loop eyebars, pack rust removal and paint removal.

4) The presence of lead paint can be a major cost factor that can severely impact the reuse of a historic metal truss bridge. As such, removal of lead paint must be addressed deliberately and as early as possible in the project.
5) Strong arguments exist that, if the metal on the bridge is cleaned properly, repainting is not an immediate concern prior to storage. However, the painting of the structure may be of significant benefit to marketing of the bridge for reuse. If significant pack rust needs to be repaired, it is important to repaint the corresponding areas to seal the joints from further corrosion.
6) For smaller-sized bridges (e.g., lengths and widths), laser scanning offers cost- and time-efficient documentation. Laser scanning produces point clouds that can be processed further for 3D modeling. Photogrammetry and videogrammetry also can be useful to collect data for 3D modeling, but are considered more as useful options for precisely documenting the disassembly and assembly of a historic metal truss bridge.
7) Emerging Bridge Information Modeling (BRIM) solutions should be used to create object-based models that facilitate a visual and geometric understanding of the details of a bridge. These models can be used for marketing and conceptual designs, and can even be used in design (if the models are detailed enough) to reproduce deteriorated bridge components.
8) To best facilitate re-use of historic metal truss bridges, a vigorous web-based marketing presence is recommended in addition to direct contact with potential recipients. Not every bridge can be saved. Priority should be given to bridges with historical significance, high reuse potential, urgent stabilization or rehabilitation needs, and ease of relocation. In cases where storage and reuse are not possible, it can still be worthwhile to salvage certain components of the bridge that may have high historical value and reuse potential.
9) Disassembly of a historic metal truss bridge must generally be balanced with the extent of replacement or treatment of components requiring their removal as well as transportation

considerations. The least danger to the historic integrity of the bridge occurs when as much of the structure is left intact as possible. Contractors involved with deconstruction of historic metal truss bridges should be instructed to leave as much of the structure intact as possible, balanced with requirements for repair and replacement of the bridge components. Flame cutting of members should be disallowed unless approved by the engineer.

10) If disassembled for any reason, extensive and clear marking of historic metal truss bridges is essential. A marking plan should be included in the contract documents for removal and relocation of a historic metal truss bridge. Each piece of the bridge should be marked so that someone else can easily understand the specific location and orientation of the component within the overall bridge at a later date. The marks should be indelible enough to withstand transportation, outdoor storage, and time. An accompanying marking system key should be created and kept with the bridge's documentation.

11) Based on the characteristics of the historic metal truss bridges in the GHBS, the maximum size bridge that would need to be stored is essentially a 150 ft span thru truss. It is unlikely that this large a bridge could be transported to off-site storage intact unless the storage site is adjacent or very close to the original bridge site. However, large sections of the trusses potentially can be transported and stored intact.

12) An outside uncovered area is sufficient for storage, as long as the metal components are positioned in a way that allows for air flow and free drainage of water. Corrosive chemicals, such as herbicides and pesticides, must be kept away from the metal. The truss components, particularly long and heavy ones, generally should be moved and stacked on even surfaces or terrain in a way that does not induce any permanent deformation into the components. Each component should be supported by blocking.

13) The selection of a storage facility for metal trusses should consider the type, dimensions, and location of the bridges, and the attributes of the roads from the current location to the facility, and from the facility to the potential reuse location. If the relocation of a historic metal truss bridge is predetermined, it would be desirable to store the bridge at a facility close to the new site.

14) Where feasible, historic metal truss bridges should be reassembled into their intact configuration and located on temporary bearing supports at the storage site. This can

facilitate the marketing of the bridge, and also helps the potential problem of the components of the bridge going missing.

15) Trusses and truss members in storage should be inspected at least every two years, to ensure that the storage conditions are stable. If any corrosion and damage is identified, repairs should be made as soon as possible. The results of inspection should be documented and reported to the owner or potential recipients.
16) Vegetation growing at the storage site should be cut on a regular basis.
17) Contracts to store a given historic truss bridge should include a sunset clause. When the clause expires, the disposition of the bridge should be revisited.
18) The cost estimator or engineer should use multiple sources to estimate costs. Some of the activities can require highly specialized equipment, techniques, and materials to preserve or repair character-defining features. Due to the limited number of skilled professionals able to perform the work, such tasks might significantly add to the cost. Cost estimators may rely on past bid tabulations, cost-estimating manuals, and local engineering, architectural, and construction contractor resources. Site visits to evaluate the disassembly, reassembly, and/or preservation are essential as these efforts require detailed investigations and associated repair plans. It is advisable to provide contingency funds for unanticipated costs, such as replacing lost parts or damage encountered during disassembly or reassembly.

10. References

AASHTO (2002). *AASHTO Standard Specifications for Highway Bridges*, 17th Ed., American Association of State Highway and Transportation Officials, Washington, DC.

AHTD (2007). “3-Dimensional Bridge Flythroughs,” *Historic Bridge Program,* Arkansas State Highway and Transportation Department, <http://www.arkansashighways.com/historic_bridge/bridge_fly_by/3_dimensional_bridge_flythroughs.aspx> (Mar. 6, 2014).

Bellefeuille, J. and Roise, C. (2007). “Minneapolis Midtown Corridor – Historic Bridge Study,” <http://midtowngreenway.org/files/mgc/ckfinder/files/MidtownCorridorHistoricBridgeStudy5-30-07.pdf > (Mar. 6, 2014).

Bohn, J. and Teizer, J. (2010). “Benefits and Barriers of Construction Project Monitoring using Hi-Resolution Automated Cameras,” *ASCE J. Constr. Eng. and Mgmt.*, 632-640.

Bowman, M. and Piskorowski, A. (2004). “Evaluation and Repair of Wrought Iron and Steel Structures in Indiana,” <http://www.historicbridgerestoration.com/articles/bowman.pdf> (Mar. 6, 2014).

Bremer, K. (2011). “New historic gateway trail Bridge over Washington County 15 gets a third lease on life,” <http://www.rippleinstillwater.com/2011/10/new-historic-gateway-trail-bridge-over.html> (Mar. 6, 2014).

Bridge Hunter (2014). “Bridgehunter.com” <http://bridgehunter.com> (Mar. 6, 2014).

CDOT (2012). “Historic Bridge Adoption Program,” Colorado Department of Transportation, <http://www.coloradodot.info/programs/environmental/archaeology-and-history/historic-bridge-adoption-program> (Mar. 6, 2014).

ConnDOT (1991). “Connecticut Historic Bridge Inventory Final Report: Preservation Plan” *Federal Aid Project # HPR-PR-1(27),* Connecticut Department of Transportation, <http://environment.transportation.org/pdf/HistoricBridgePreservationPlan.pdf> (Mar. 6, 2014).

Corus (2004). “The Prevention of Corrosion on Structural Steelwork,” Corus Construction and Industrial Group, <http://resource.npl.co.uk/docs/science_technology/materials/life_management_of_materials/publications/online_guides/pdf/structural_steelwork.pdf> (Mar. 6, 2014).

Corus (2005). "Corrosion Protection of Steel Bridges," <http://resource.npl.co.uk/docs/science_technology/materials/life_management_of_materials/publications/online_guides/pdf/protection_of_steel_bridges.pdf> (Mar. 6, 2014).

Costin, A., Pradhananga, N. and Teizer, J. (2012). "Leveraging passive RFID technology for construction resource field mobility and status monitoring in a high-rise renovation project," *Automation in Construction*, 1-15.

Dai, F., Rashidi, A., Brilakis, I. and Vela, P. (2013). "Comparison of Image- and Time-of-Flight-Based Technologies for 3D Reconstruction of Infrastructure," *ASCE J. Constr. Eng. and Mgmt.* ,69-79.

Ellerby, H. (1976). "Service Load and Fatigue Tests on Truss Bridges," *J. Struct. Div.*, 2285-2300.

FHWA (1998). "Heat Straightening Repair for Damaged Steel Bridges: A Technical Guide and Manual of Practice," <http://isddc.dot.gov/OLPFiles/FHWA/009569.pdf> (Mar. 6, 2014).

FHWA (2000). "Guide For Heat-Straightening of Damaged Steel Bridge Members," <http://www.fhwa.dot.gov/bridge/steel/heat_guide.pdf> (Mar. 6, 2014).

FHWA (2007). "Manual on Use of Self-Propelled Modular Transporters to Remove and Replace Bridges," <http://www.fhwa.dot.gov/bridge/pubs/07022/chap00.cfm> (Mar. 6, 2014).

FHWA (2011). "Bridge Preservation Guide," <http://www.fhwa.dot.gov/bridge/preservation/guide/guide.pdf> (Mar. 6, 2014).

Foltz, L. (2000). "Application: 3D Laser Scanner Provides Benefits for PennDOT Bridge and Rock face Surveys," *Prof. Sur. Mag.*, 22-27.

Gates, J. (2013). "Old Cedar Bridge and the Minnesota River Valley State Trail," <http://www.ci.bloomington.mn.us/cityhall/dept/pubworks/engineer/streets/curr_proj/ocbc/ocbc.htm#faq1> (Mar. 6, 2014).

GDOT (1981). "Georgia Department of Transportation and Georgia Department of Natural Resources Historic Bridge Survey," Georgia Department of Transportation, Atlanta, GA.

GDOT (2012). "Georgia Historic Bridge Survey," (CD-ROM), Georgia Department of Transportation, Atlanta, GA.

Golparvar-Fard, M., Bohn, J., Teizer, J., Savarese, S. and Peña-Mora, F. (2011). "Evaluation of image-based modeling and laser scanning accuracy for emerging automated performance monitoring techniques," *Automation in Construction*, 1143-1155.

Golparvar-Fard, M., Peña-Mora, F. and Savarese, S. (2009). “Application of D4AR—A 4-dimensional augmented reality model for automating construction progress monitoring data collection, processing and communication,” *J. Info. Tech. Constr.*, 129–153.

Haberling, M. and Leary, D. (2004). “Evaluation and Rehabilitation of Historic Metal Truss Bridges: Preservation Issues,” <http://fsel.engr.utexas.edu/publications/docs/0_1741_4.pdf> (Mar. 6, 2014).

Hatfield, F. (2001). “Engineering for Rehabilitation of Historic Metal Truss Bridges,” <http://www.jflf.org/pdfs/wi301/historicbridges.pdf> (Mar. 6, 2014).

Historic Bridge Foundation (2013). “Every Bridge Tells a Story,” <http://historicbridgefoundation.com> (Mar. 6, 2014).

Historic Bridges (2009). “Charlotte Highway Bridge,” < http://www.historicbridges.org/bridges/browser/?bridgebrowser=truss/charlotte/> (Mar. 6, 2014).

Historic Bridges (2013). “Historic Bridge Park of Calhoun County, Michigan,” <http://www.historicbridges.org/info/bridgepark/> (Mar. 6, 2014).

Historic Bridges (2014). HistoricBridges.org, <http://www.historicbridges.org/> (Mar. 6, 2014).

INDOT (2014a). “Historic Bridges Marketing Program,” Indiana Department of Transportation, <http://www.in.gov/indot/2532.htm> (Mar. 6, 2014).

INDOT (2014b). “Bridge Relocation Proposal Guideline,” Indiana Department of Transportation, <http://www.in.gov/indot/files/Guidance.pdf> (Mar. 6, 2014).

ISO (1998). “Paints and Varnishes – Corrosion Protection of Steel Structures by Protective Paint Systems – Part 2: Classification of Environments,” ISO 12944-2:1998, International Organization for Standardization.

Jaselskis, E., Cackler, E., Andrle, S. and Gao, A. (2003). “Pilot study in improving the efficiency of transportation project using laser scanning (CTRE Project 02-109),” Center for Transportation Research and Education, Iowa State University, Ames, IA.

Jefferson, T. (1990). *Metals and How to Weld Them*, 2nd Ed., James F. Lincoln Arc Welding Foundation, Cleveland, 392 pp.

KDOT (2014). *Historic Bridge Relinquishment & Relocation Agreement,* Kansas Department of Transportation <http://www.ksdot.org/topekametro/pdf/Atchison%20Historic%20Bridge%20Relinquishment%20&%20Relocation%20Agreement.pdf > (Mar. 6, 2014).

Kentucky Transportation Cabinet (2012). “Truss Bridges of Kentucky,” <http://transportation.ky.gov/Highway-Design/Conference%20Presentation/A%20Bridge%20To%20The%20Past%20Truss%20Bridge%20Rehab.pdf> (Mar. 6, 2014).

Kogler, R. (2012). “Corrosion Protection of Steel Bridges,” *Steel Design Handbook,* Washington, D.C.

Kuhn, B., Lukic, M., Nussbaumer, A., Gunther, H., Helmerich, R., Herion, S., Kolstein, M., Walbridge, S., Androic, B., Dijkstra, O. and Bucak, O. (2008). *Assessment of Existing Steel Structures: Recommendations for Estimation of Remaining Fatigue Life,* JRC Scientific and Technical Report, European Commission Joint Research Centre, EUR 23252 EN, Luxembourg, 90 pp.

Krichels, J. (2012). “Bridge 5721: Historic Restoration and Relocation,” <http://blog.archpaper.com/wordpress/archives/31359> (Mar. 6, 2014).

Larson Design Group (2011). “Historic Truss finds new service life in Coudersport, PA,” <http://www.ldgblog.com/2011/09/06/historic-truss-finds-new-service-life-in-coudersport-pa> (Mar. 6, 2014).

Lavoie, C. and Lockett, D. (2012). “Producing HABS/HAER/HALS Measured Drawings from Laser Scans: the Pros and Cons of Using Laser Scanning for Heritage Documentation,” <http://www.nps.gov/history/hdp/standards/laser_procon.pdf > (Mar. 6, 2014).

Lichtenstein and TranSystems (2012). “Transportation Contexts for Georgia, From Colonial Trails to Interstate Highways,” Atlanta, GA.

Lightner, R. (2012). “Bridge to Be Moved Monday Morning,” <http://www.griffindailynews.com/view/full_story/17987259/article-Bridge-to-be-moved-Monday-morning?instance=home_news_lead_story> (Mar. 6, 2014).

Lincoln Electric Company (1933). *The Procedure Handbook of Arc Welding, Design and Practice*, Cleveland.

MaineDOT (2014). “Historic Bridge Available For Adaptive Reuse,” Maine Department of Transportation, <http://www.maine.gov/mdot/env/bridgesau.htm> (Mar. 6, 2014).

MDT (2014a). “Historic Bridge Adoption,” Montana Department of Transportation, <http://www.mdt.mt.gov/business/bridge_adoption.shtml> (Mar. 6, 2014).

MDT (2014b). “Historic Bridge Adoption,” Montana Department of Transportation, <http://www.mdt.mt.gov/business/bridge_adoption_details.shtml> (Mar. 6, 2014).

Mesler, V. (2007a). “Restoration,” <http://www.historicbridgerestoration.com/articles/packrustremovalprocedure.pdf> (Mar. 6, 2014).

Mesler, V. (2007b). “Charlotte Highway Bridge - Restoration Newsletters,” <http://www.historicbridgerestoration.com/newsletters/charlotte_2007_august_07.pdf> (Mar. 6, 2014).

Misa, T. (1995). “A Nation of Steel: The Making of Modern America 1865 - 1925,” Johns Hopkins University Press.

MnDOT (2006). “Management Plan for Historic Bridges in Minnesota,” <http://www.dot.state.mn.us/historicbridges/pdf/mgmtplan.pdf> (Mar. 6, 2014).

Mort, M. (2008). *A Bridge Worth Saving*, *A Community Guide to Historic Bridge Preservation,* Michigan State University Press, East Lansing, MI, 143 pp.

NCDOT (2014). “Bridge Reuse Program,” North Carolina Department of Transportation, <https://connect.ncdot.gov/municipalities/BridgeReuse/Pages/default.aspx> (Mar. 6, 2014).

NCHRP (2008). “Report 604: Heat-Straightening Repair of Damaged Steel Bridge Girders: Fatigue and Fracture Performance,” <http://onlinepubs.trb.org/onlinepubs/nchrp/nchrp_rpt_604.pdf> (Mar. 6, 2014).

NPS (1995). “Introduction to Standards and Guidelines <http://www.nps.gov/history/hps/tps/standguide/overview/choose_treat.htm> (Mar. 6, 2014).

NPS (2013). “Archeology and Historic Preservation: Secretary of the Interior's Standards and Guidelines,” National Park Service, http://www.nps.gov/history/local-law/arch_stnds_6.htm> (Mar. 6, 2014).

NTAC (2014). “Hale Bridge Wapsipinicon State Park, IA,” National Transportation Alternatives Clearinghouse, <http://images.ta-clearinghouse.info/6-Historic-Preservation-Rehab/Hale-Bridge-IA/9562149_ZJfK2q#!i=643178786&k=UbDK8> (Mar. 6, 2014).

NYSDOT (2002). “Historic Bridge Management Plan,” New York Department of Transportation, <https://www.dot.ny.gov/divisions/engineering/environmental-analysis/repository/historicbridgemanagementplan.pdf> (Mar. 6, 2014).

ODOT (2010). Ohio Historic Bridge Maintenance and Preservation Guidance. Ohio Department of Transportation. <http://www.dot.state.oh.us/Divisions/Planning/Environment/Cultural_Resources/HISTORIC_BRIDGES/Documents/OhioHistoricBridgePreservationManual910.pdf> (Mar. 6, 2014).

ODOT (2014a). “Historic Bridges,” Ohio Department of Transportation, <http://www.dot.state.oh.us/Divisions/Planning/Environment/Cultural_Resources/HISTORIC_BRIDGES/Pages/default.aspx> (Mar. 6, 2014).

ODOT (2014b). “Historic Bridges Available for Reuse,” <http://www.dot.state.oh.us/Divisions/Planning/Environment/Cultural_Resources/BRIDGE_STATUS/REUSABLE_BRIDGES/Pages/default.aspx > (Mar. 6, 2014).

OKDOT (2012). “Historic Bridge Marketing Program,” Oklahoma Department of Transportation, <http://www.okladot.state.ok.us/env-programs/bridges/pdfs/program.pdf> (Mar. 6, 2014).

Parsons Brinckerhoff (2008). “Sandy River Conduit 2/4 Truss Bridge: Truss Component Baseline Condition Survey,” <http://www.portlandoregon.gov/water/article/329853> (Mar. 6, 2014).

Parsons Brinckerhoff Engineering and Industrial Heritage (2005). “A Context for Common Historic Bridge Types,” <http://onlinepubs.trb.org/onlinepubs/archive/NotesDocs/25-25(15)_FR.pdf> (Mar. 6, 2014).

PBS&J (2011). “6th Street Bridge Study Report,” (CD-ROM). Atlanta, GA.

PennDOT (2005). “Bridge Marketing: Wanna Buy A Bridge?” Pennsylvania Department of Transportation, <http://www.dot.state.pa.us/Internet/Bureaus/pdCulturalResources.nsf/CultResHomepage?OpenFrameSet&Frame=main&Src=%2FInternet%2FBureaus%2FpdCulturalResources.nsf%2Fbridge%2520marketing%3FOpenForm%26AutoFramed> (Mar. 6, 2014).

PennDOT (2014a). “Pennsylvania's Historic Bridges,” <http://paprojectpath.org/penndot-crm/bridges> (Mar. 6, 2014).

PennDOT (2014b). “Project for Pennsylvania Transportation, Bridge Marketing,” <http://www.paprojectpath.org/news/bridge-marketing> (Mar. 6, 2014).

Portland Water Bureau (2007). “Sandy River Crossing Project,” <http://www.portlandoregon.gov/water/article/329865> (Mar. 6, 2014).

Rathke, J. (2013). Personal communication, January.

Real Wrought Iron Company (2014). “What is Wrought Iron?” <http://www.realwroughtiron.com/about_wrought_iron-217.html> (Mar. 6, 2014).

Recollections of a Vagabonde (2011). <http://avagabonde.blogspot.com/2011/05/blog-intermission-no-11-entracte-bridge.html> (Mar. 6, 2014).

Ross, A. D., Twede, D., Clarke, R. H. and Ryan, M. (2009). "A framework for developing implementation strategies for a radio frequency identification (RFID) system in a distribution center environment," *J. Bus. Log.*, 157-183.

Ross, R. J., Brashaw, B. K., and Anderson, S. J. (2012). "Use of Laser Scanning Technology to Obtain As-Built Records of Historic Covered Bridges" <http://www.fpl.fs.fed.us/documnts/fplrp/fpl_rp669.pdf> (Mar. 6, 2014).

Saldibar, J. (1997). "The Stillwater Road (SHEA) Bridge, Cumberland, Rhode Island," Metals Number 4, Rehabilitating a Historic Iron Bridge, *Preservation Tech Notes*, U.S. Department of the Interior, Natural Park Service Cultural Resources, Washington, DC <http://www.nps.gov/tps/how-to-preserve/tech-notes/Tech-Notes-Metals04.pdf> (Mar. 6, 2014).

Siebert, S. and Teizer, J. (2013). "Mobile 3D Mapping for Surveying Earthwork Projects using an Unmanned Aerial Vehicle (UAV) System," *Automation in Construction*, 41, 1-14.

Talbot, J. (2012). "Back on the job," <http://www.modernsteel.com/uploads/issues/january_2012/012012_back.pdf> (Mar. 6, 2014).

Tang, P. and Akinci, B. (2012). "Automatic execution of workflows on laser-scanned data for extracting bridge surveying goals," *J. Adv. Eng. Info.*, 889-903.

TDOT (2012). "Social & Cultural Office, Historic Preservation Section," Tennessee Department of Transportation, <http://www.tdot.state.tn.us/environment/historic/bridges.htm> (Mar. 6, 2014).

Transportation Nation (2012). "PICS: Largest Truss Bridge Ever Moved into Place Fully Assembled," <http://transportationnation.org/2012/08/27/largest-truss-bridge-moved-while-fully-assembled-chicago> (Mar. 6, 2014).

TxDOT (1995)," Special Specification 4220 – Remove and Relocate Existing Historic Truss Bridge," Texas Department of Transportation, <http://onlinemanuals.txdot.gov/txdotmanuals/his/specs.pdf> (Mar. 6, 2014).

Urquhart, L. (1930). "Design of Steel Structures," McGraw Hill, New York, NY.

VDOT (2006). “Best practices for the rehabilitation and moving of historic metal truss bridges,” Virginia Department of Transportation, <http://www.virginiadot.org/vtrc/main/online_reports/pdf/06-r31.pdf> (Mar. 6, 2014).

Vermes, W. (2011). “Design and Performance of Riveted Bridge Connections,” Iron and Steel Preservation Conference <http://www.lcc.edu/manufacturing/welding/ISPCConference/Newsletter/September/Performance%20of%20Rivets%20-%202011.pdf> (Mar. 6, 2014).

VJM Metal Craftsman, LLC (2013). “Working with Historic Metal Truss Bridges,” <http://www.historicbridgerestoration.com> (Mar. 6, 2014).

Vogt, B. and Teizer, J. (2007). “Sparse Laser Scanning to Improve Off-Shore Pipe-Fitting Productivity,” *Proceedings of the Construction Research Congress*, 6-8.

VTrans (2014). “Vermont Historic Bridge Program,” Vermont Agency of Transportation, <http://www.aot.state.vt.us/progdev/sections/structures%20info/vermonthistoricbridgeprogram/hbp00vermonthistoricbridgeprogram.htm> (Mar. 6, 2014).

Weiss, T. (2012). “Largest Truss Bridge Move Ever,” Modern Steel Construction, <http://www.modernsteel.com/SteelInTheNews/?p=1912> (Mar. 6, 2014).

11. Appendices

11.1 Glossary of Terms

BIMS: The Bridge Information Management System, a database in which input data from bridge inspections in the State of Georgia is collected. This system is separate from the Federally-required National Bridge Inventory (NBI), and contains data on bridge condition in addition to what the Federal government requires. The BIMS may be used to generate deficiency reports, and to access information about necessary repairs, vertical clearance and load requirements for oversize/overweight vehicles.

Fracture-critical: A fracture-critical bridge typically has a steel superstructure with load (tension) carrying members arranged in a manner in which if one fails, the bridge could collapse. Examples of fracture critical bridges are two girder bridges or truss bridges (MnDOT 2006). The classification of fracture critical does not mean the bridge is inherently unsafe.

Functionally obsolete: Bridges are considered functionally obsolete (FO) when the deck geometry, load carrying capacity (comparison of the original design load to the current State legal load), clearance, or approach roadway alignment no longer meet the usual criteria for the system of which it is an integral part (FHWA 2011). In general, FO means that the bridge was built to standards that are not used today.

GeoTRAQS: Web-based data application that contains information from a variety of Georgia Department of Transportation program areas, and allows staff, consultants and the public to use the information analyzed for transportation decision making. Based upon the Department's existing Geographic Information System (GIS), the GeoTRAQS application can be used to locate and synthesize data from key areas to improve visualization and spatial analysis. Features of the program, especially the improved online mapping, enhance communication efforts with stakeholders.

GHBS: The Georgia Historic Bridge Survey, a database of all historic bridges in the State of Georgia greater than or equal to 50 years of age.

General Condition Rating: According to the National Bridge Inspection Standards (NBIS), the general condition rating describes the current condition of a bridge or culvert. The general condition rating is an overall assessment of the physical condition of the deck (riding surface), the superstructure (load carrying members such as beams or trusses that support the driving surface), substructures (abutments and piers) or the culvert. The general condition rating codes range from 0 (failed condition) to 9 (excellent) as follows (FHWA 2011):

Code	Description
N	NOT APPLICABLE
9	EXCELLENT CONDITION
8	VERY GOOD CONDITION - no problems noted.
7	GOOD CONDITION - some minor problems.
6	SATISFACTORY CONDITION - structural elements show some minor deterioration.
5	FAIR CONDITION - all primary structural elements are sound but may have minor section loss, cracking, spalling or scour.
4	POOR CONDITION - advanced section loss, deterioration, spalling or scour.
3	SERIOUS CONDITION - loss of section, deterioration, spalling or scour have seriously affected primary structural components. Local failures are possible. Fatigue cracks in steel or shear cracks in concrete may be present.
2	CRITICAL CONDITION - advanced deterioration of primary structural elements. Fatigue cracks in steel or shear cracks in concrete may be present or scour may have removed substructure support. Unless closely monitored it may be necessary to close the bridge until corrective action is taken.
1	"IMMINENT" FAILURE CONDITION - major deterioration or section loss present in critical structural components or obvious vertical or horizontal movement affecting structure stability. Bridge is closed to traffic but corrective action may put back in light service.
0	FAILED CONDITION - out of service - beyond corrective action.

Historic bridge: A bridge that is listed in, or eligible for listing in, the National Register. The National Register is the official federal list of districts, sites, buildings, structures, and objects significant in American History, architecture, archaeology, engineering, and culture.

Historic integrity: The authenticity of a bridge's historic identity, evidenced by the survival and/or restoration of physical characteristics that existed during the bridge's historic period. A bridge may have integrity of location, design, setting, materials, workmanship, feeling, and association.

Inventory rating: The load level a bridge can safely carry for an indefinite amount of time expressed in metric tons or by the rating factor described in design load. Inventory rating values typically correspond to the original design load for a bridge without deterioration.

Inspections: Periodic field assessments and subsequent consideration of the fitness of a structure and the ability of associated approaches and amenities to continue to function safely.

Load Rating: The determination of the safe load carrying capacity.

Maintenance: Work of a routine nature to prevent or control the process of deterioration of a bridge.

National Bridge Inventory (NBI): A database compiled by the Federal Highway Administration with information on all bridges in the United States that have roads passing above or below. This data is often used for bridge condition assessment.

National Bridge Inspection Standards (NBIS): Federal requirements for procedures and frequency of inspections, qualifications of personnel, inspection reports, and preparation and maintenance of state bridge inventories. NBIS applies to bridges located on public roads.

National Register of Historic Places: The official inventory of districts, sites, buildings, structures, and objects significant in American history, architecture, archaeology, and culture, which is maintained by the Secretary of the Interior under the authority of the National Historic Preservation Act of 1966 (as amended)

Preservation: According to the Secretary of the Interior's Standards, preservation is defined as "the act or process of applying measures necessary to sustain the existing form, integrity, and materials" of the bridge (NPS 1995). In general, preservation mostly entails basic maintenance and repair of historic materials rather than replacement and new construction. The Standard's guidance for preservation recommends first identifying the important features of the bridge so that its historic characters can be retained. Secondly, protection and maintaining are recommended. Protection and maintaining include cleaning, limited paint removal, applying protective coatings, and installing barriers to minimize access to the bridge. Thirdly, repair by consolidating and conversing is recommended.

Rating Factor: For load rating, results are expressed in terms of a rating factor for a particular live load model. Rating factors more than one means that the bridge is safe for the loads.

Rehabilitation: According to the Secretary of the Interior's Standards, rehabilitation is defined as "the act or process of making possible use for a property through repair, alterations, and additions, while preserving those portions or features which convey its historical, cultural, or architectural values (NPS 1995). Rehabilitation differs from preservation in the sense that it focuses more than repair and replacement of deteriorated features rather than basic maintenance.

Reconstruction: According to the Secretary of the Interior's Standards, reconstruction is defined as "the act or process of depicting, by means of new construction" so that the bridge would replicate "its appearance at a specific period of time and in its historic location" (NPS 1995).

Within the scope of this Manual, reconstruction is the least applicable since the bridge is to be stored and reconstructed at a different location.

Restoration: According to the Secretary of the Interior's Standards, restoration is defined as "the act or process of accurately depicting the form, features, and character" of the bridge "as it appeared at a particular period of time" (NPS 1995). While preservation and rehabilitation attempt to maintain and repair the bridge, restoration's goal is to make the bridge appear as one particular point in the past. Restoration could remove features from other periods and repaint the bridge so that its paint appearance matches the restored period's paint. Absent features from the restored period can be substituted based on historical research.

Secretary of the Interior's Standards for the Treatment of Historic Properties: Standards for treatments for historic properties developed by the Secretary of Interior in 1995. The standards apply to all properties listed in the National Register of Historic Places including bridges. The standards are created to promote responsible preservation practices that help protect the nation's cultural resources (NPS 1995). The standards list four treatment approaches Preservation, Rehabilitation, Restoration, and Reconstruction in hierarchical order.

Stabilization: Stabilization is the first and immediate work conducted to prevent and avoid any further damage to the bridge to ensure safety. Stabilization could include structural reinforcement and temporary shoring. Stabilization work should be conducted in a way that minimizes impact to the bridge's structural components and its appearance.

Structural Evaluation: According to NBI, structural evaluation is an indicator of the condition of a bridge designed to carry vehicular loads, expressed as a numeric value and based on the condition of the superstructure and substructure, the inventory load rating, and the average daily traffic.

Structurally deficient: The Federal Highway Administration (FHWA) classification of a bridge indicating an NBI condition rating of 4 or less for any of the following: deck condition, superstructure condition, substructure condition, or culvert condition. A structurally deficient bridge is restricted to lightweight vehicles; requires immediate rehabilitation to remain open to traffic; or requires maintenance, rehabilitation, or replacement.

Sufficiency rating: The sufficiency rating formula provides a method of evaluating high-way bridge data by calculating four separate factors to obtain a numeric value which is indicative of bridge sufficiency to remain in service (FHWA 2011). The result of this method is a percentage in which 100 percent would represent an entirely sufficiency bridge and zero percent would represent an entirely insufficient or deficient bridge. The formula considers the structural adequacy; functional obsolescence and level of service; and essentiality for public use.

11.2 Prototype Website

Figures 57 and 58 show prototype web pages for marketing of historic metal truss bridges created by the project team.

Figure 56. Home page.

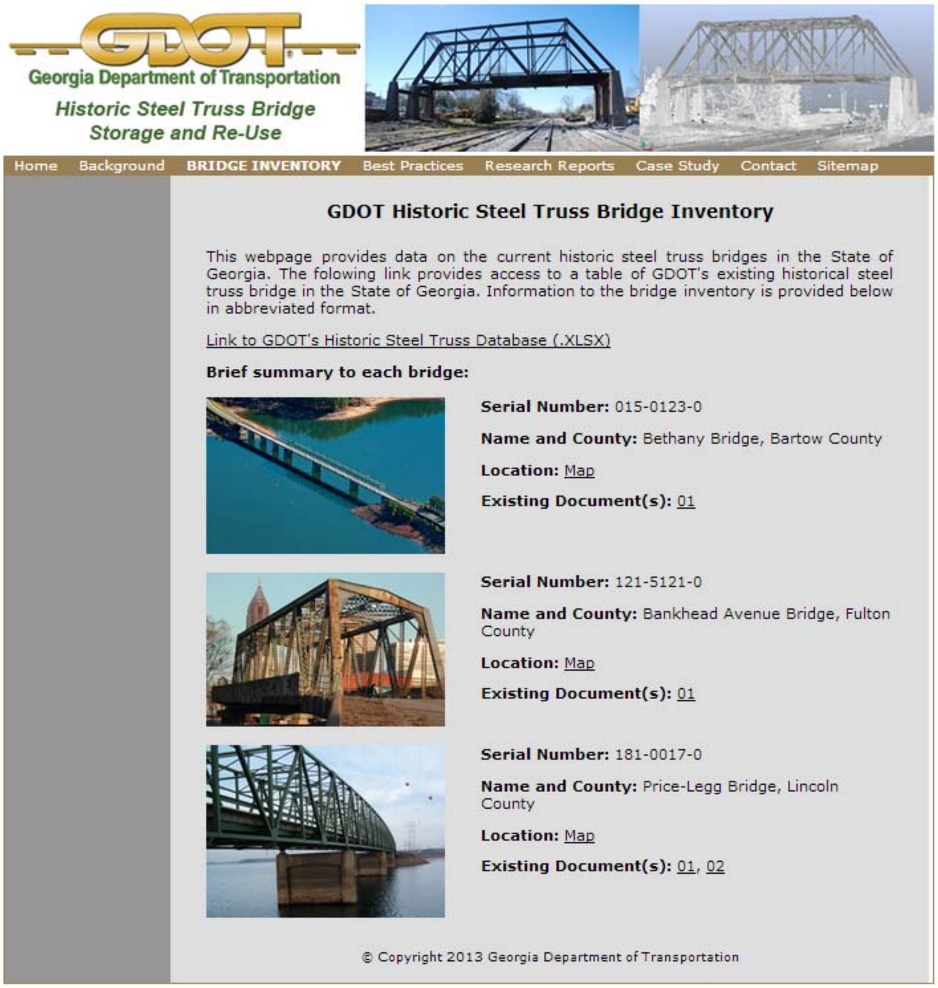

Figure 57. Bridge inventory page.