FINAL REPORT

THE INTRODUCTION OF MODERN TIMBER BRIDGES IN VIRGINIA: A FINAL REPORT ON THE VIRGINIA TIMBER BRIDGE INITIATIVE

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16. Abstract

In 1990, the Virginia General Assembly established a commission to propose and enhance the economic development of the Southside region of the Commonwealth, the tier of largely rural counties across the southern border. The commission's 1991 report, House Document 42, included a recommendation for a timber bridge initiative to evaluate those structures as replacements for Virginia's structurally deficient bridges. The commission suggested that timber bridges might save highway construction funds and stimulate the forest products industry in Southside Virginia.

Subsequently, the Virginia Department of Transportation developed a three-phase research effort that began with the construction of one bridge in each of the state's nine construction districts. This report, which concludes the formal stage of the initiative, addresses the costs, structural performance, and maintenance requirements to date for these structures. Although the performance of the study bridges has been acceptable, there is no indication that timber has been significantly accepted as a bridge construction material at this time. Timber bridges have not proven economically competitive from a first cost standpoint, and their life cycle cost competitiveness cannot be determined at this time. The economic viability of timber bridges is adversely affected by the lack of an industry presence in Virginia. This lack also casts doubt on the ability of the Virginia timber bridge initiative to enhance economic development in the Southside region of the Commonwealth.

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ABSTRACT

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INTRODUCTION

In 1990, the Virginia General Assembly established a commission to propose recommendations to enhance the economic development of the southside region of the Commonwealth. The southside region, commonly called Southside Virginia, is the tier of counties across the southern border of the state. The region is largely rural and has significant underutilized timber resources. The commission's 1991 report, House Document 42, included a recommendation for a timber bridge initiative in order to replace Virginia's structurally deficient bridges.[1] The commission noted that timber bridges could save highway construction funds and stimulate the forest products industry in Southside Virginia.

After the commission presented its recommendations, the commissioner of the Virginia Department of Transportation (VDOT) appointed a committee to investigate further the feasibility of using timber in the construction of bridges. The committee was composed of representatives of VDOT's Structure & Bridge Division, the Department of Forestry, the Division of Legislative Services, and the Virginia Transportation Research Council. In response to House Document 42, the committee published its report in 1991.[2] This document proposed an initiative that might lead to the realization of the goals of the house document and noted five factors that were considered critical to its success:

1. The immediate and future potential for using timber in the replacement of many of Virginia's bridges,
2. The available timber resources in Southside Virginia,
3. The best suited wood species for use in the first phase of the initiative
4. Factors affecting timber bridge economy and,
5. The need for a supporting structural timber manufacturing industry in Virginia.

Although the committee estimated that 5,612 Virginia bridges might be suitable for timber construction and that 521 of these were in need of immediate repair or replacement, the committee concluded that the development of a structural timber manufacturing industry in the Commonwealth would be essential to the long-term viability of timber bridge construction.

The committee called for a three-phase program to implement the timber bridge initiative. In Phase I, one timber bridge was to be constructed in each of VDOT's nine construction

districts. The bridges were to placed on low-volume secondary roads and would have spans varying in length from 4.9 to 9.1 m (16 to 30 ft). Both stress-laminated (stresslam) and glued-laminated (glulam) bridge designs were to be used. Phase II would expand the use of the short-span bridges, and Phase III would include the construction of longer, more complicated structures. Implementation of the latter phases of the plan would be dependent on several factors, including design and construction considerations; the economic feasibility of timber bridges and their components; and the structural performance of the Phase I bridges; as well as "continued legislative support to advance the initiative; funding; evidence of potential development of a structural timber products industry; and evidence that a timber bridge industry will contribute to developing the economy of Southside Virginia."[2]

Stresslam bridges are composed of timbers placed on edge and tensioned together by high-strength steel rods running normal to the bridge. The rods are post-tensioned to such a degree that the individual timbers act as an integral system to resist the applied loads. In glulam systems, the timbers are bound together by a high-strength adhesive to produce an integral system.[3]

Virginia is one of several states considering an expanded use of timber bridges. West Virginia has taken the lead in the research, development, and construction of timber bridges. The Constructed Facilities Center, located on the campus of West Virginia University, has conducted significant research in this area. Pennsylvania has also constructed a significant number of timber bridges.

The Intermodal Surface Transportation Efficiency Act (ISTEA) provides for funds for research in the development of new timber bridges and design criteria.[4] Further, ISTEA funding is available for construction of timber bridges on all public roads.

PURPOSE AND SCOPE

The purpose of this study was to evaluate the long-term performance and economic viability of timber bridges constructed under Phase I of Virginia's initiative and to assess the potential benefits to the timber industry in the Commonwealth. The results of this study will be used to assess the benefits to be gained from and guide the implementation of Phases II and III of Virginia's timber bridge initiative.

METHODOLOGY

An ongoing, though limited, literature survey was conducted throughout the initial phase of the initiative to provide a broader view of developments in the design and construction of timber bridges. This effort supplemented the evaluation effort, which concentrated on the bridges, generally one per construction district, built under the auspices of the initiative.

Evaluations of the study bridges concentrated on the actual bid costs of the structures and comparisons with the costs for alternative structures developed by the district bridge offices. Bridge safety inspection results for the bridges were reviewed, and any maintenance problems encountered by district personnel were noted. Research personnel inspected each of the bridges at intervals during the study and evaluated the structural performance by taking level readings at selected points on the decks to reveal any changes in elevations indicative of a loss of integrity.

RESULTS

Literature Review

A limited literature review was performed to provide information on technical developments emanating from research by other agencies during the course of the subject study. Much research has been conducted since 1991 under the auspices of the U.S. Department of Agriculture's Forest Service and the Federal Highway Administration. A comprehensive listing of publications by year available on the U.S. Forest Service's website was most helpful in providing an overview of developing technology.[5]

Also helpful in defining the research effort was a summary paper presented at the Transportation Research Board's Fifth International Bridge Engineering Conference in April 2000.[6] Federally sponsored research, at the time of this writing, included 44 studies that supported timber bridge technology in six areas: system development and design, lumber design properties, preservatives, alternative transportation system timber structures, inspection and rehabilitation, and technology and information transfer. In addition to refining the design process, the research investigated the use of fiber-reinforced composites to strengthen timber structural members and develop components such as timber bridge rails. The basic technology needed to support a continued timber bridge initiative and its expansion to include the underutilized timber species in Virginia exists.

Among the studies that addressed particular concerns that arose in the current study were those involving hardwoods, notably yellow poplar, which is relatively abundant in the Commonwealth. Although additional work was recommended and economics were not addressed, a study of the use of thin strips of glass fiber reinforced plastic applied to the bottoms of yellow poplar glulam beams showed increases in both strength and stiffness, allowing a decrease in the depth of the members.[7] Member depth is an important consideration in bridge design, and it is more critical in the case of poplar, which has a relatively low allowable bending strength. Promise is shown in the preliminary results of studies investigating effective preservative treatments for yellow poplar and other underutilized hardwoods.[8,9]

A study team was formed to examine and report on the possibility of establishing a timber bridge construction industry in Virginia.[10] Representatives of the Division of Forestry, the Department of Economic Development, and the Virginia Department of Agriculture and Consumer Affairs met to consider several issues. The team concluded that timber resources in

Virginia were adequate to meet the demands of the timber industry and that the existing infrastructure could produce and treat the necessary material. Figures for sawtimber in millions of board feet were appended to the report. There was interest in expanding fabrication operation in the state if there was a commitment to the continuing building of timber bridges. Although the advantages of rapid construction of timber structures to localities were noted, no commitment to timber structures was obtained. In fact, "[e]arly discussions with DOT personnel indicate[d] that the number of timber bridges built per year would probably be no more than 10. Timber needs for these bridges would probably be 100,000 board feet or less."[10] Discussions with representatives of the state's one small glulam plant indicated that the annual fabrication of timber bridge components was only 5 percent of production and was unlikely to exceed 10 percent.

The Virginia timber bridge initiative also served as the impetus for an important study by faculty in Forest Products Marketing at Virginia Tech.[11] These researchers performed a separate and complementary analysis exploring the factors in the decision-making processes of bridge engineers in Wisconsin, who make relatively extensive use of timber structures, and those in Virginia, who do not. Despite advances in timber bridge research, the number of timber bridges in the United States has declined by nearly 50 percent since 1980. Timber as a bridge material has largely been replaced by concrete or steel. The decline was attributed to various factors affecting the choice of a bridge material and the costs of timber bridges as opposed to those of competing materials.

Factors for and against timber as a bridge construction material were presented during the decision practice. Some of the factors were prone to local bias, with contrasting views supported by the literature. Examining durability as the most notable example, a reference was cited noting that wood has good shock resistance and is immune to the deleterious effects of deicing chemicals. On the other hand, a second citation used an "extensive analysis of the National Bridge Inventory" to conclude that timber was the worst performer of all bridge materials. "Numerous studies" were cited that found timber decks lasting 30 to 50 years with minimal maintenance requirements. Concrete decks were found to require maintenance after 20 years and were estimated to last 30 to 35 years. Estimated costs varied greatly among agencies and their favored options.[11]

Not unexpectedly, there is local bias apparent in the feeling of bridge engineers. The results of a questionnaire widely distributed by the Virginia Tech research team to engineers in government and private practice across the nation were reported as follows:

> Highway officials across the United States perceive timber to be the poorest performing bridge material. It was rated lowest of all materials by state DOT engineers, private consultants, and local highway officials. . . . Virginia officials rated timber similar to the national average, while Wisconsin highway officials rated timber significantly higher than those in Virginia on perceived performance.[11]

An earlier publication by two of the authors agreed, noting that "Virginia respondents rated timber lowest on low maintenance and high strength" whereas Wisconsin respondents rated "low maintenance and high strength" "significantly higher" than those in Virginia.[12] Aesthetics

of timber bridges rated well throughout. Evidently, the attitudes of the bridge engineers in the two selected states tended to buy into the "supporting" literature that confirms the local preferences.

Timber bridges were found to cost more than competing materials in both Virginia and Wisconsin, although the authors noted that only a minimal number of timber bridges had been built in either state. In fact, "[t]imber represented less than 3 percent of the bridges built in both states since 1992."[12]

Costs

Table 1 summarizes Phase I of VDOT's timber bridge initiative. All costs are for bridge superstructure only. The costs for the bridges in the Bristol, Salem, Suffolk, Fredericksburg, and Culpeper districts were derived from actual bid tabulations provided by the successful bidder. The costs for the bridge in the Staunton District are for materials and state force labor and equipment. All of the bridges were fabricated with Southern pine, with the exception of the Bristol District bridge, which was fabricated with red oak. All of the structures were treated with creosote and were designed for HS-20 loading.

Four districts did cost estimates of bridge superstructures constructed of conventional materials for comparison purposes. These costs were normalized with respect to square meters of deck to enable a direct comparison with the timber data as they were reported. In the Lynchburg District, an equivalent prestressed concrete slab span was estimated to cost $392 per square meter whereas that of a steel beam and concrete slab superstructure cost $424 per square meter. In the Richmond District, an equivalent prestressed concrete slab span was estimated to cost $315 per square meter. In the Culpeper District, an equivalent precast concrete slab structure was estimated to cost $380 per square meter. In the Bristol District, a reinforced concrete rigid frame bridge structure was estimated to cost $544 per square meter. These estimates are summarized in Table 1, which also shows the cost differential as a percentage of the cost of the timber superstructure. In contrast, the average cost statewide for short-span bridges consisting of steel beams and concrete decking was $326 per square meter. There were 22 bridges constructed in Virginia under the Federal-Aid Highways Program in 1995, and, although the cost of these bridges cannot be directly compared with the cost of the study bridges because both superstructure and substructure costs were included, the average total cost per square meter for the 22 bridges was $674.77.

District and Location	Type and Length	Date Completed	Fabricator	Cost per Sq. Meter of Superstructure and Total Superstructure Cost	Alternative Conventional Structure (If Designed)	Cost per Sq. Meter of Alternative Superstructure Design	Percent Difference
Northern VA., Rte. 662, Loudon County	Glulam, 1- 4.9 m span	Fall 1992	Laminated Concepts, Elmira, New York	$652/$23,040			
Staunton, Rte. 708, Shenandoah County	Stresslam, 1- 6.1 m span	Summer, 1993	Burke, Parsons, Bowlby Corporation, Ripley, West Virginia	$598/$26,500			
Bristol, Rte. 622, Smyth County	Stresslam, 2- 5.2 m continuous spans	Fall, 1993	Burke, Parsons, Bowlby Corporation	$630/$53,500	Reinforced Concrete Rigid Frame Bridge	$544	(14%)
Culpeper, Rte. 708, Faquier County	Stresslam, 1- 7.9 m span	Fall, 1993	Laminated Concepts	$935/$43,000	Precast Concrete Slab Span	$380	(59%)
Salem, Rte. 635, Roanoke County	Glulam, 1-6.1m span	Winter 1993/94	Unit Structures' Specialty Products Group, Inc., Morrisville, North Carolina	$837/$31,080			
Fredericksburg, Rte. 622, Richmond County	Glulam, 3- 6.1 m spans	Spring 1994	Unit Structures' Specialty Products Group, Inc.	$413/$68,770			
Suffolk, Rte. T-1303, Accomack County	Stresslam, 9- 4.9 m spans	Summer 1994	Atlantic Wood Industries, Hainesville, New Jersey	$413/$76,044			
Lynchburg, Rte. 725, Buckingham County	Stresslam, 1- 7.3 m span	Winter 94/95	Burke, Parsons, Bowlby Corporation	$652/$37,244	Prestressed Concrete Slab Steel Beam/Concrete Slab	$392 $424	(40%) (35%)
Richmond, Rte. 610, Nottoway County	Glulam, 2- 9.1 m spans	Winter 94/95	Laminated Concepts	$587/$88,680	Prestressed Concrete Slab Span	$315	(46%)

Table 1. Descriptions of Study Bridges With Fabrication and Cost Data and With Contrasting Cost Data for Comparable Conventional Structures When Available

Performance to Date

Inspection reports on each of the bridges in each of the construction districts were collected and analyzed and are summarized in Table 2.

Table 2. Inspection Results and Maintenance Requirements for Study Bridges

District and Location	Last Inspection	NBI Rating*	Maintenance Performed?
Northern VA, Rte. 662, Loudoun County	11/98	Deck 8 Superstructure 8	No
Staunton, Rte. 708, Shenandoah County	10/99	Deck 8 Superstructure 8	No
Bristol, Rte. 622, Smyth County	11/99	Deck 7 Superstructure 7	No
Culpeper, Rte. 708, Faquier County	11/99	Deck 8 Superstructure 8	No
Salem, Rte. 635, Roanoke County	3/00	Deck 8 Superstructure 8	No
Fredericksburg, Rte. 622, Richmond County	6/98	Deck 8 Superstructure 8	Yes
Suffolk, Rte. T-1303, Accomack County	6/98	Deck 7 Superstructure 8	Yes
Lynchburg, Rte. 725, Buckingham County	11/99	Deck 8 Superstructure 8	No
Richmond, Rte. 610, Nottoway County	11/99	Deck 8 Superstructure 8	No

*An NBI rating of 8 indicates "Very Good Condition – no problems noted." An NBI rating of 7 indicates "Good Condition – some minor problems."

When the timber bridge in the Fredericksburg District was last inspected in June 1998, the deck panels had expanded in each of the three simple spans. The out-to-out dimension of the first span was determined to have increased by 140 mm, the second span by 98 mm, and the third span by 137 mm. This lateral expansion of the deck resulted in the shearing off of 32 19-mm-diameter bolts used to connect the deck panels to the glulam beams. The district repaired this condition by attaching galvanized steel brackets to the deck and superstructure. The center timber pile of bents 1 and 2 were split 22 mm and 25 mm in width and 914 mm and 711 mm in length, respectively, because of the deck expansion. Galvanized steel collars were placed around the top of each of these piles.

The 1996 inspection of the timber bridge in the Suffolk District revealed a loss in the asphalt wearing surface placed in 1994 by more than 50 percent. The entire bridge was resurfaced with an asphalt overlay in August 1998. A crack 3 mm wide and 457 mm long was detected in one of the timber piles in the east abutment during the 1994 inspection. The crack has been monitored since then, but no other action has been taken to date.

The Bristol District timber bridge has not received any maintenance, but in December 1999, the inspection team noticed that one of the threaded post-tensioning bars had failed and

was protruding from the side of the superstructure. The threaded bars are coupled at mid-width of the bridge for full continuity of post-tensioning force. One of the threaded bars had failed at the coupling that connects two bars. It was felt that the failed bar was damaged prior to construction and should not have been placed in the structure. The bar was replaced, and the bridge will be inspected annually for the next 2 years.

The bridges in the Staunton, Northern Virginia, Salem, and Lynchburg districts were periodically surveyed by personnel from the Virginia Transportation Research Council. Differential leveling was conducted each time to determine any change in dead load deflection. It was felt that any change in dead load deflection would be an indication of structural distress. No change in deflection has been detected in any of the bridges surveyed.

DISCUSSION OF RESULTS

Technology

Research reported during the past 10 years has led to the development of sufficient technology to support the timber bridge initiative. Most of the bridges constructed under the auspices of the initiative have performed well structurally, and only in the case of the Fredericksburg bridge has any serious distress, possibly related to the treatment process rather than design, occurred. Nevertheless, structure and bridge engineers in Virginia do not regard timber as the equal of concrete as a construction material at this time.[11]

Costs

Based on the initial costs of the nine study bridges, timber bridges are not yet competitive with conventional bridge structures. There is no discernible relationship among the timber bridges between span length and cost per square meter or between types (stresslam versus glulam). A comparison of the costs of the structures in the Salem and Fredericksburg districts, which have spans of identical length produced by a single fabricator, may indicate a trend in cost reduction when multiple spans are used. The trend can be seen when comparing the costs in the Northern Virginia and Suffolk districts as well, although those bridges are of different fabrication. Savings attributable to economy of scale would be expected, but the cost data from the limited population of study bridges are too variable to be conclusive.

Discussions with key personnel in each district indicated that the initial costs were inflated because of the contractors' lack of experience with this material. It was felt that the initial costs would be reduced with more usage.

The high initial costs may have been the result of all of the structures being manufactured out of state. Thus, shipping costs alone would contribute to the high initial costs. For the stresslam structure in the Culpeper District, the wood was shipped from a supplier in Minnesota

to the fabricator, Laminated Concepts in Elmira, New York. The structure was then shipped to Indiana for creosote treatment before arriving in Virginia.

Regardless of the causative factors, timber has not yet proven economically advantageous on a first cost basis, and data on the performance of timber bridges are insufficient to support a life cycle approach to the selection of timber over concrete.

Acceptance of Timber Bridges

There has been a degree of acceptance of timber bridges in the Northern Virginia District, particularly in Loudoun County. Several have been constructed since the first one on Route 662. Loudoun County, a wealthy jurisdiction that borders the Washington, D.C., metropolitan area, strives to retain a rural and rustic ambiance over much of its area. There are many unpaved secondary roads throughout the county, and a number of timber bridges constructed there have been well received by the community because of their aesthetic appeal. A glulam timber bridge was requested for replacement of a deteriorated structure in the town of Waterford, Virginia (officially the "Waterford National Historic District, VA") because the timber structure was believed to be more in keeping with adjacent historic buildings. A study focusing on perceptions of timber bridges reported that the bridges rated very high in terms of aesthetics.[12]

Timber bridges offer a logistical advantage in locations where the delivery of ready-mix concrete is difficult. Examples in this study are the three Hampton Roads bridges, all located on Tangier Island in the Chesapeake Bay. There are no concrete plants on the island, but the timber components could be easily barged to the sites and erected with light equipment. Similar advantages exist for the replacement of other secondary road bridges in remote locations, many of which use timber decks supported on light steel beams.

Development of a Virginia Timber Manufacturing Industry

The report by the Forestry Department noted a "chicken and egg" effect with regard to the development of a timber treatment and fabrication industry in Virginia sufficient to add viability to the timber bridge initiative and provide the desired economic benefits to the Commonwealth.[10] It seems that VDOT must produce the "first egg;" that is, the development of industrial facilities is unlikely without a demonstrated commitment to timber structures on VDOT's part. A management directive to build a limited number of additional bridges in each construction district, as a second phase of the initiative, would be unlikely to suffice.

The study on the decision process for selecting timber bridges reported that their use has declined by more than 33 percent in the last 10 years.[11] This decline was determined to be the result of the perception that timber is too expensive and a poor performer over the long term, thus requiring higher maintenance costs. VDOT bridge designers echo these perceptions. Timber bridges will likely remain a niche market in Virginia until initial costs are reduced and improvement in long-term performance, supporting a life cycle cost analysis, is demonstrated.

THE FUTURE OF THE TIMBER BRIDGE INITIATIVE

Expansion of the Virginia initiative to its second phase should proceed cautiously. Timber as a structural material has proven adequate for wider use on the secondary system, but greater acceptance is yet to be apparent. At this writing, timber bridges remain more costly then those of alternative materials on a first cost basis, and estimates of needs in the transportation area alone do not support the development of a timber bridge construction industry in Virginia.

Yet the needed technology for the new generation of timber exists in large part, and developmental research continues at other agencies. Certainly, the findings of Phase I of the initiative encourage the continued use of modern timber bridges, although the issuance of a second-phase directive to build another few such bridges would be unlikely to achieve the goal of stimulating the forest products industry. Instead, some latitude in the costing of additional timber bridges, warranted by local preference, aesthetic considerations, or ease of construction, might expand the usage of timber as a structural material, providing opportunities for greater familiarity with the material and the development of data to support life cycle costing. Greater acceptance by the engineering community might follow.

The implementation of the proposed third phase, the use of timber in the construction of larger structures, would likely be accomplished on a case-by-case approach in any event. Recent reports of larger bridges indicate that the selection of timber as the material of choice was heavily influenced by the historic or park-like nature of the bridge site.[13,14]

CONCLUSIONS

- At this time, timber bridges in Virginia have not proven economically competitive from a first cost standpoint.
- The long-term structural performance and maintenance requirements, and thus the life cycle cost competitiveness of timber bridges, cannot be determined at this time.
- The economic viability of timber bridges is adversely affected by the lack of an industry presence in Virginia. Considerable shipping of the timber components for the study bridges, with the attendant costs, was required.
- Lack of an industry presence also casts doubt on the ability of the Virginia timber bridge initiative to enhance economic development in the Southside region of the Commonwealth.
- To date, only one structure has required any significant maintenance resulting from failure of the timber

RECOMMENDATIONS

At this time, it is recommended that Phase II of the Virginia timber bridge initiative, which calls for the expanded use of these short span bridges, proceed cautiously. Continued construction of modern timber bridges where strong local preference warrants them and where site conditions make timber construction appealing should be encouraged. It is anticipated that with more use, contractors will gain confidence in the structures and the Virginia timber industry may move to fabricate these bridges, a vital step in their long-term economic viability. The future of timber bridges will ultimately depend on their cost competitiveness and overall acceptance by bridge engineers and contractors.

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