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Performance and Rehabilitation of Timber Bridges

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ABSTRACT

Eighteen timber bridges were inspected to assess their long-term performance. In general, they were in excellent structural condition with glued-laminated decks performing better than nail-laminated decks. Extensive moisture content readings indicated that wet-use stresses should be used when designing bridge decks, regardless of deck type or treatment. Dry-use stresses are appropriate for the stringers. A comprehensive program, including new technologies and demonstration projects, must be developed to address the repair and rehabilitation of older nailed-laminated decks.

Many recent developments have increased the interest in timber bridges, such as new materials and manufacturing methods, improvements in preservative treatment, a systems approach to bridge engineering, alarm over needed bridge replacement and rehabilitation, and improved technology (1,2). A number of these developments reflect the advancement in knowledge of the general behavior of wood as a structural material (3). The importance of these developments has been underscored in comprehensive state-of-the-art reports and technical presentations and publications (4-7). A recent workshop helped identify research needs that are pertinent to timber bridge engineering (8).

The Forest Service (U.S. Department of Agriculture) is keenly interested in this engineering area because it maintains over 10,000 road bridges and adds 100-250 bridges to the system annually. Wood is the major construction material in over one-half the existing and new bridges. In the late 1960s and early 1970s, the Forest Service sponsored the construction of timber bridges containing novel features that would be expected to improve performance. These bridges were built in various national forests in seven states across the northern United States. They were primarily constructed with transverse glued-laminated (glulam) panel decks and a variety of interpanel connections. Some bridges had nail-laminated (nail-lam) decks for comparative purposes. Also, different types of members, construction, and materials were used in the remainder of the superstructure and substructure. Some of the new features were, at the time, considered to be experimental.

Although these bridges had received routine inspections over the years, little had been done to specifically monitor the structural performance and condition of the experimental features. The relative performance of glulam decking and traditional nail-lam decks is of particular interest. Although nail-lam construction is still used at some sites and numerous nail-lam decks are still in service in Forest Service timber bridges, the glulam panel deck is now the preferred material.

There are thousands of older, poorly maintained, timber bridges in the United States with nail-lam decks that have deteriorated badly. At some time, a decision must be made in each case to abandon the

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structure, reduce the load limit, or repair the deck. Options for repair of nail-lam decks include total replacement or reinforcement.

This paper reports on research studies aimed at developing criteria to improve the performance of timber bridges. The objectives of the work were to (a) determine the in-place performance of timber bridges, particularly those made with glued-laminated panel decks and dowel connectors, (b) determine patterns of moisture content in the deck and stringer systems to assess the merits of dry-use versus wet-use design stresses, and (c) determine methods of extending the service life of existing timber bridges with nailed-laminated decks.

DOWEL-CONNECTED GLULAM DECKS

Glulam decking systems were developed in the 1970s to ease construction and provide longer life than nail-lam decking. Typical glulam deck panels are 4-ft wide and composed of vertically laminated, dimension lumber that spans continuously across the supporting stringers. McCutcheon and Tuomi investigated several alternative deck interconnection concepts, including steel dowels, tongue-and-groove joints, and splines, to determine the most effective vertical shear transfer mechanism (9). They determined that steel dowels were the most effective for achieving load transfer and continuity between adjacent panels. This work produced design procedures for glulam decks and steel dowel connectors that were incorporated into AASHTO bridge specifications and led to the development of standard plans and details for glulam bridges by the American Institute of Timber Construction (AITC) (10).

Proper erection procedures for dowel-connected glulam decks are detailed by Tuomi (11). However, construction problems such as tightness, misalignment, or binding of dowels have discouraged more widespread use of this system. These problems appear to be related to the inexperience of the erection crew and imprecision in the fabricator's drilling of deck panels. Gutkowski investigated the influence of the size of the dowel lead hole; his results suggested that the usual lead-hole oversize of 1/32 in. might be relaxed to 1/16 in. (12).

DRY- AND WET-USE STRESSES

Until recently, the AITC recommended dry-use stresses for deck panels if heavy oil and creosote preservative treatments were specified; otherwise wet-use stresses should apply (10). Dry-use stresses were and are recommended for stringers, although this practice has been questioned by some bridge engineers, particularly when site conditions and climate suggest high moisture content. Industry standards define the dividing line between wet- and dry-use stresses as 16 percent moisture content for glulam and 19 percent for sawed timbers. In practice, 20-percent moisture content is commonly considered the level at which potential decay is a concern, but this limit includes a considerable margin of safety against damage caused by fungal growth. Serious decay occurs only when the moisture content exceeds the fiber saturation point, which is approximately 30 percent for species commonly used in timber bridge members. Thus, field measurement of the in-service moisture content of bridge stringers was a prerequisite for assessing the merit of dry-use design stresses. As will be seen, AITC changed one of its recommendations as a result of this study.

REHABILITATION OF NAIL-LAM DECKS

Numerous short-span timber bridges are in need of deck rehabilitation. The majority of these were built with preservative-treated lumber that was nail-laminated together to provide a continuous deck. Such decks can be constructed easily and rapidly at low initial cost. After several years, the mechanical fasteners in these decks tend to loosen because of repetitive loadings and moisture cycling and the decks often become unserviceable. Methods are needed to extend the service lives of these bridges.

As previously noted, there are several options for bridges with nail-laminated decks that have deteriorated badly: abandonment, reposting with lower load limits, total deck replacement, or deck reinforcement. Because the bridges are needed, abandonment has seldom been an option. The most common response to poor bridge decks has been to lower the load limit.

Rehabilitation or replacement of nail-lam decks rarely occurs on Forest Service timber bridges. Lack of funds places maintenance at low priority and rehabilitation even lower. Glulam panels are usually used in cases of "deck only" replacement. Complete bridge replacements are typically made of steel or concrete girders with concrete deck. Decayed laminations, excessive maintenance needs, loss of tightness, poor load distribution, and asphalt deterioration are major reasons for replacement, the first two being the most compelling factors.

Reinforcement of timber bridges with steel is also uncommon. Some exploratory attempts were conducted in the Forest Service from 1965 to 1975. Several longitudinal decks were transversely reinforced with ordinary A36 steel rods. This proved unsuccessful primarily because the effective post-tensioning force could not be maintained. Recent field inspection of two sites indicated the physical condition of the reinforcing to be excellent, but the chip seal surfaces had deteriorated badly.

PROCEDURES

To address the first two objectives previously stated (determining structural performance and moisture patterns), eighteen bridges were inspected during the summer of 1983. The bridges, which were distributed across the northern United States (Figure 1), included a variety of types and sizes (Figure 2) and were from 7 to 17 years old. The determination of methods for rehabilitating nail-lam decks, was addressed through a literature survey and extensive discussions with bridge engineers throughout the Forest Service.

Inspection Procedure

Structural performance of the deck and connectors was determined by observing the condition of the wearing surface, especially cracking in the surface and gaps between deck panels. The inspectors also looked for signs of swelling in the deck and checked for tightness and fit of the connections. Drainage conditions on the bridge decks (i.e., whether water can drain freely from the road surface or is trapped by blocked drainage paths, potholes, etc.) were noted. Also, the underside of each bridge was examined for signs of water penetration through the deck. The condition of each bridge was thoroughly documented with photographs.

Moisture Content Readings

Extensive measurement of moisture content was a key feature of the inspections. A trio of readings was taken at each of over 600 locations on the 18

FIGURE 1 Eighteen bridges were inspected across the northern United States.

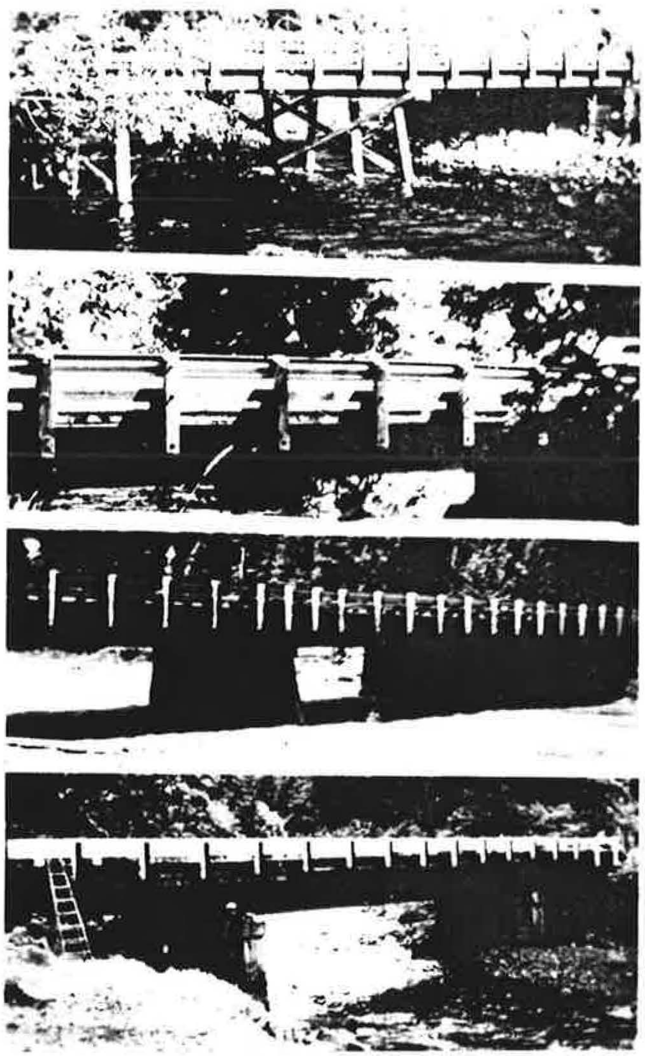

FIGURE 2 Study included a variety of bridge types and spans.

bridges. On average, this represents 100 readings per bridge.

An electrical resistance-type moisture meter was used to take readings at penetrations of 1/2 in., 1 in., and 2 in. With few exceptions, the moisture reading at the 2-in. penetration was the highest of the three readings. Therefore, readings are reported only at that penetration.

All readings were taken during the summer months. Although some variation in moisture content exists during the year, large treated timbers change little from season to season.

Deck Rehabilitation

The feasibility of rehabilitating nail-lam decks was investigated by interviewing Forest Service bridge engineers and reviewing technical literature. The conversations with Forest Service engineers revealed the extent of the rehabilitation needs together with current practices and constraints. The literature survey included an evaluation of technology that may be applicable to rehabilitating transverse nail-lam decks.

RESULTS OF VISUAL INSPECTIONS

Structural Integrity

The inspection of the 18 bridges revealed few instances of significant structural problems. The bridge superstructures were commonly found to be in excellent condition. In most cases, the glulam stringers and bottom sides of deck panels appeared like new. Occasionally, some leaching had discolored the stringers at the abutment ends. Glulam deck panels were tightly butted. Nail-lam decks were providing a smooth road surface (except at abutments) even when moisture content was high and decayed boards were present. Although future physical deterioration of the nail-lam decks appeared inevitable, major deck replacements would likely not be warranted for many years. Glulam decks generally appeared drier and in better physical condition with essentially no evidence of imminent deterioration. Typically, backing planks in abutment walls were tightly mated. At three sites, gaps up to 3/4-in. wide existed but all walls were structurally sound.

Asphaltic Wearing Surfaces

Twelve of the eighteen bridges had asphaltic or chip seal wearing surfaces. Five of these exhibited some degree of transverse cracking in their wearing surfaces. In all cases, the cracks had neither propagated laterally nor seriously affected roadway smoothness. Potholes, as distinguished from cracks, were noted on only two bridges.

Drainage and Appearance

With a few exceptions, drainage at the curbs and abutment corners was unhindered regardless of deck surfacing method. Two bridges had major blockage at the curbing caused by heavy accumulation of gravel resulting from blading the roadway surface and a third had similar blockage on one side of the bridge because of collected roadway debris and gravel. Two others had ponding at the abutments and one of these had scoured embankments at all four bridge corners. Gravel roadways and approaches were generally well graded and maintained. However, buildup of moisture and mud at the abutments for nail-lam decks was a general concern. Such buildup greatly contributes to moisture penetration through the deck. Bleeding of creosote was evident at five bridge sites. Although this was of no structural consequence to the members, it detracted from their otherwise good appearance.

RESULTS OF MOISTURE INVESTIGATION

Decks

Moisture content varied greatly among individual laminations of nail-lam deck, with many boards above the fiber saturation level. The moisture content and deterioration in nail-lam decks were consistently greatest adjacent to the abutment. Wear caused by the impact of entering vehicles and subsequent ponding of water appear to be the primary causes. Where running planks are present, water is often channeled to the abutment zone. Adjacent to abutments, nail-lam decks averaged 26 percent moisture content with 30 percent of the readings above 30 percent and away from abutments they averaged 18 percent with 7 percent of the readings above 30 percent.

Passage of moisture through nail-lam decks was greater than through glulam decks. Both the moisture data (stringer top versus bottom laminations) and visual observations attest to this. There was virtually no evidence of saturated boards in the glulam decks, and tight mating of deck panels generally prevented moisture from penetrating to the stringers at the deck joints.

In the abutment area, above exterior stringers and in the overhanging portions, nail-lam decks typically had higher moisture content than glulam decks. Between interior stringers, nail-lam decks were drier than glulam. The overall moisture content for nail-lam decks was 21 percent with 15 percent of the readings above 30 percent and for glulam decks, the average was 20 percent with only 3 percent of the readings over 30 percent. Visually, the nail-lam decks consistently appeared much wetter in comparison with the glulam decks than was indicated by the measured data. Indeed, the bottom surface of glulam deck often looked dry and new, while the nail-lam looked moist and aged.

Wearing Surfaces

The average moisture contents in nail-lam decks and in the top laminations of stringers were lower below asphaltic wearing surfaces than below running planks (with gravel). This is consistent with the frequent occurrence of saturated running planks and the field observation that the space between planks is often a reservoir for water and the buildup of wet gravel.

Stringers

Whether solid-sawed or glulam, stringers typically appeared sound and dry. There was little difference in appearance between the two types. The moisture readings support this finding. Combining all data, glulam stringers averaged 17 and 14 percent moisture content in the top and bottom surfaces, respectively. Only 1 of 64 data points exceeded 30 percent. Treated solid-sawed stringers averaged 14 and 15.5 percent in the top and bottom zones, respectively; the highest reading was 20 percent. Thus, preservative-treated solid-sawed and glulam stringers performed about the same with regard to moisture.

Substructure

Posts typically appeared solid and sound. In contrast, the piles often looked saturated. However, above the stream level, piles and posts were usually not saturated. Only 4 percent of the moisture readings exceeded 30 percent. None of the abutment walls showed visual evidence of deterioration, and although backing planks exhibited high moisture content on the exterior face, they were usually not saturated. Creosote-treated glulam pile caps were markedly drier than creosote-treated solid-sawed pile caps.

Preservative Treatments

When two bridges having identical component materials but different preservative treatments were compared for moisture, creosote-treated deck and stringers exhibited lower average moisture contents but greater frequency of readings above the fiber saturation level than those components treated with waterborne salts. No distinction could be made between the moisture contents of decks and stringers treated with creosote versus those treated with pentachlorophenol in oil. Average moisture readings and ranges were nearly identical for the two.

Miscellaneous

Some components other than the decks and stringers were expected to be saturated. However, only 8 of 285 moisture readings in these other components exceeded 30 percent. Although some high moisture readings were obtained, posts, wheel guards, and bridging were typically the driest components in any given bridge. Seasoning checks in the heartwood of solid timber wheel guards were frequent. Curbing blocks were typically the components with the highest moisture content. A pile-up of wet soil resulting from blocked drainage was a contributing factor. Rails were measurably wetter than the supporting posts. Seasoning checks and broken end pieces were common and are likely to have left these components particularly susceptible to moisture penetration. Rusted metal parts were uncommon. Moisture readings adjacent to metal fastenings were not unusually high compared to other locations.

RESULTS OF REHABILITATION INVESTIGATION

The rehabilitation investigation revealed a promising technology and developed recommendations for carrying out a comprehensive program.

An effective method for post-tensioning old nail-lam decks and prestressing new decks has been developed, tested, and embodied in design code criteria in Ontario, Canada (13). The method has been implemented on several longitudinal nail-lam deck bridges (for which it was specifically developed) but has recently also been applied to a transverse deck. The fundamental concept is promising; however, there are concerns about loss of pretension, need for periodic retightening, effects of humidity, and initial costs.

A long-term solution to problems of bridge maintenance, repair, and rehabilitation for the Forest Service, or any organization with a large inventory, will require the following steps:

1. The computerization of the bridge inventory to put statistics on bridge condition in a common format and identify and clarify needs.
2. The organization of workshops to disseminate information to administrators, engineers, and maintenance personnel.
3. The demonstration of new methods and technologies, such as the Ontario prestressing procedure, for display and evaluation purposes (note that the Forest Service is planning several such projects).
4. The development of a long-term program modeled after the Ontario Ministry of Transportation's successful efforts to upgrade timber bridges (14). The

Forest Service is proceeding with such a program that will include field surveys of current conditions, economic studies, experimental and theoretical development of new rehabilitation concepts, and dissemination of the new methods to the appropriate audience.

SUMMARY

Overall, the 18 bridges investigated in the northern United States were in excellent structural condition. Typically, roadway conditions were excellent, providing for smooth passage regardless of surfacing. There was extensive asphalt cracking only where the surface was unusually thin. Evidence of deterioration either from propagation of cracks or presence of potholes was rare. Dowel-connected deck panels were tightly mated and the dowels provided continuity between the individual panels.

Glulam decks generally provided a more effective roof over stringers than nail-lam decks, but both types of deck had high moisture contents (over 20 percent). In contrast, the stringers were relatively dry, with few readings in excess of 20 percent. Because of this finding, AITC now recommends wet-use stresses for all glulam decks, regardless of treatment type, and dry-use stresses for stringers (15).

A long-term solution to the problems of repair and rehabilitation of nail-lam decks will require a coordinated program involving the development of new technologies, the dissemination of information, and the showcasing of new techniques through demonstration projects.

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