Glued-Laminated Timber Panels for Bridge Deck Replacement

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Abstract

Research was conducted to evaluate the viability of using Oklahoma timber species in glued-laminated panel designs for bridge deck replacement. Panels were fabricated from southern pine, red oak, and cottonwood. Laboratory tests were conducted to determine the mechanical properties of panels fabricated from the three different species and allowable spans were computed based on test results. Panels were installed on seven in-service bridges ranging in width from 4.82 to 6.89 m (15.8 to 22.6 ft), and in length from 9.5 to 37.2 m (31 to 122 ft). Advantages of timber panels relative to other decking materials include reduction in out-of-service time, easy installation, reduced dead loads, increased resistance to road chemicals, and a wider tolerance to weather conditions during installation.

Keywords: Bridge deck, glued-laminated, wood, timber, southern pine, red oak, cottonwood

Introduction

The condition of the nation's rural bridges is of high concern within the transportation industry and general public (Walzer and Chicoine 1989). Of specific concern are rural bridges located in agriculturally significant counties, because they exhibit more structural and functional inadequacies than those in other locations (Marathon 1989). This is particularly true for the agriculturally-oriented state of Oklahoma, in which 57 % of the 20,682 rural highway bridges are considered structurally deficient or functionally obsolete (Anderson et al. 1994).

The bridge deck, being exposed to both weather and vehicular traffic, is one of the more vulnerable components of the bridge system. An analysis of the Oklahoma Department of Transportation bridge inventory system indicates that there are 5,291 bridges with decks in fair or worse condition (Oberlender and Vonkarey 1993). Low-cost, low-maintenance alternatives are needed by county governments to improve the rural transportation infrastructure.

During the last 20 years, extensive engineering research has led to significant advances in the design and use of glued-laminated timber for bridge construction (Williamson 1990). Although economic analyses of timber versus traditional steel and concrete bridges are few, indications are that timber bridges are cost competitive (Behr et al. 1990). In general, timber bridges built in those areas of the country where timber

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species are produced have a cost advantage over other areas (Leichti 1992).

Research was conducted to evaluate the viability of using Oklahoma timber species in glued-laminated panel designs for bridge deck replacement. Specific objectives were to: (1) determine strength characteristics of panels fabricated from Oklahoma-grown wood species (southern pine, red oak, and cottonwood); and (2) determine the acceptability of these wood species for bridge-deck installations under varying conditions.

Raw Materials

Locating and obtaining raw materials for the test and bridge panels was of concern during the project. Little difficulty was encountered in obtaining No. 2 common or better 2x4 and 2x6 dimension lumber of southern pine. Initially, kiln-dried material of southern pine was obtained from local merchants within two to four weeks of placing an order. Longer delays were encountered towards the end of the project as prices for southern pine lumber had increased almost 60% and No. 1 common lumber was becoming more difficult to obtain.

Adequate raw material of cottonwood and red oak was more difficult to obtain. No local merchants had kiln-dried material readily available. Subcontracts were made with a local sawmill to provide both 2x4 and 2x6 stock of random lengths. Initial orders were for No. 1 common or better cottonwood and No. 2 common or better oak. This material was then transported to a kiln-drying facility where it was dried to a target moisture content between 12% and 15%. Delays were experienced in both the cutting and kiln-drying phases. Excessive variation in board thickness and width resulted in difficulties during fabrication. Height differences between mating boards within a panel were of primary concern. Warping of both cottonwood and red oak boards was also evident following the drying process. Excessive variation in board dimensions combined with warping of boards and the normal defects found in lumber resulted in elimination of a substantial number of boards.

Surfacing of cottonwood and red oak boards was required to reduce dimension variability between boards. This added to the total cost of panel fabrication. To reduce the number of cull boards, orders for raw materials towards the end of the project were specified No. 1 common or better. This did not successfully address the problems with red oak. Future attempts to obtain kiln-dried cottonwood and red oak will require additional administrative efforts to ensure raw material quality.

Fabrication

Panels were fabricated by the industry cooperator, Rocking Horse Timber Bridges Inc., located in Seminole, Oklahoma. All test panels and demonstration bridge decks were built with raw materials from Oklahoma. Finger joints were glued using Borden "Cascomel" MF-684U adhesive mix on southern pine, and the adhesive mix plus a 5% Perkins GF-10 bonding agent on cottonwood and red oak. All finger joints were cured in a radio-frequency machine at about 93°C (200°F). Face-gluing of the lumber was accomplished with a mix of Borden "Casophen" Lt-5210 resin and "Cascoset" FM-6210 slurry. Both finger-joint and face-joint adhesives conformed to ASTM D 2559-84 standards and met the requirements of ANSI/AITC A 190- 1 - 1983. All AITC requirements were met except for having a certified lumber grader or trained quality control supervisor on staff.

The original clamping system for holding the boards during gluing consisted of hand tightened clamps 0.3 m (1 ft) on center along both long edges of the 1.2-m (4 ft) timber panels. Clamps were tightened to a torque of approximately 237 Nm (175 ft lbs). Rods extended between these clamps. The configuration required two panels in order to provide concentric pressures. All test panels plus five of seven demonstration bridge decks were fabricated using this system. Shortcomings of this clamping system resulted in height differences between mating boards, bowing across the 1.2-m (4 ft) dimension, and face-glued surface failures. These failures were corrected with a hydraulic clamping system designed and constructed by the Biosystems and Agricultural Engineering Department at OSU. The 27 kN (3 ton) movable A-frame is capable of accommodating 1.2-m (4 ft) wide panels up to 9.1 m (30 ft) in length. Eight hydraulic cylinders placed 1.2 m (4 ft) apart apply approximately 8.3 MPa (1200 psi) pressure to the panel. This system was used for fabricating panels for the last two demonstration bridge decks.

Preservative Treatment

Creosote treatment of the test and bridge deck panels was contracted to treatment facilities in Oklahoma. Panels were placed in long containers for pressure treatment at approximately 970 kPa (140 psi). Treatment required approximately eight hours and followed American Wood Preservers Association standards. Treated panels were allowed to drain for several days prior to testing or bridge-deck installation.

Laboratory Tests

Specimens

Test panels were fabricated from lumber graded No. 2 common or better. A total of 36 panels were built for the test program, with one-third from southern pine, one-third from red oak, and one-third from cottonwood. Half of the test panels were built with 2x4 boards and had final nominal dimensions of 10 cm (4 in.) thick, 1.2 m (4 ft) wide, and 3.0 m (10 ft) long. The other half of the panels were built from 2x6 boards and had final nominal dimensions of 15 cm (6 in.) thick, 0.6 m (2 ft) wide, and 3.0 m (10 ft) long. The 1.2-m (4 ft) wide panels typically contained 34 laminations, and the 0.6-m (2 ft) wide panels contained 17 laminations. Laminations contained one fingerjoint along their length, with approximately one-third of the fingerjoints in a panel falling in the maximum moment region. One of the 2x4 red oak panels was severely damaged in shipping and is not included in the reported data.

Static bending tests were conducted according to ASTM D198-84. The first test on each panel was conducted on the full panel, loaded at the third points to produce stress parallel to the laminations. A schematic of the load frame is shown in Figure 1. Longitudinal bending tests were conducted under displacement control to beyond ultimate load. Load and displacement were monitored continuously throughout the test.

After a panel had been tested in longitudinal bending, two 10-in. (25.4 cm) wide strips were cut from one end of the panel. These strips were tested by loading at the third points to produce stress perpendicular to the laminations. In these transverse bending tests, span length between supports was 46 cm (18 in.) and only maximum load was recorded. A total of 32 (20 2x4, 12 2x6) southern pine, 34 (31 2x4, 3 2x6) red oak, and 24 (12 2x4, 12 2x6) cottonwood specimens were tested in transverse bending.

Results

For each longitudinal bending test, modulus of elasticity (MOE) was computed in accordance with ASTM D3737-89a and modulus of rupture in accordance with ASTM D198-84. The mean and standard deviation of the test data for each species are shown in Table 1, with data for 2x4 and 2x6 panels combined. A statistical analysis of the data indicated no significant difference in the means for these two groups. Lower five percent exclusion limit (L5%EL) values were computed as suggested in ASTM D2555-88. Lower five percent exclusion limits were used to compute the allowable design values in Table 2, following procedures suggested in ASTM D3737-89a. Allowable design values include a factor of safety and an adjustment to normal duration of loading. Allowable design values computed from experimental data are compared to values from the National Design Specification (NDS) Supplement (National 1988).

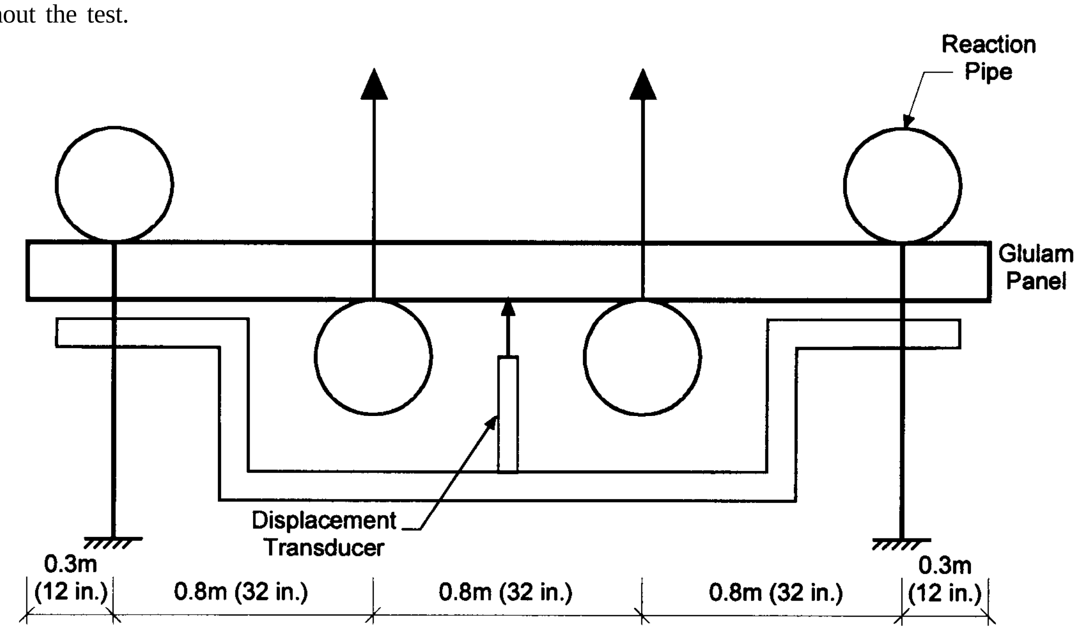

Figure 1 - Schematic of setup for longitudinal bending tests

Table 1 - Results for Longitudinal Bending Tests (1.0 psi = 6.89 kPa)

Property	Southern Pine	Red Oak	Cottonwood
Modulus of rupture (psi)			
Mean	6,570	6,590	6,660
Standard deviation	422	788	511
L5%EL	5,870	5,230	5,820
Modulus of elasticity (x 10^6 psi)			
Mean	1.56	1.40	1.60
Standard deviation	0.098	0.169	0.086

Table 2 - Allowable Design Values for Longitudinal Bending (1.0 psi = 6.89 kPa)

Property	Southern Pine	Red Oak	Cottonwood
Bending stress F_{byy} (psi)			
Test result	2,080	1,690	1,880
NDS	1,750	2,240	1,240
Modulus of elasticity (x 10^6 psi)			
Test result	1.6	1.4	1.6
NDS	1.4	1.6	1.2

Table 3 - Results for Transverse Bending Tests (1.0 psi = 6.89 kPa)

	Southern Pine		Red Oak		Cottonwood	
Statistical property	2x4	2x6	2x4	2x6	2x4	2x6
Mean (psi)	190	103	223	63	409	368
Standard deviation (psi)	74	48	118	34	137	126
L5%EL (psi)	68	24	29	7	184	161

Results for transverse bending tests are shown in Table 3, with values for 2x4 and 2x6 panels reported separately. The 2x4 and 2x6 data were not combined because of substantial differences in the means.

Observations

Examination of the data presented in Table 1 reveals that the mean bending strengths of panels made from the three different species are not substantially different. However, the standard deviation for the red oak panels is higher than for the other two species. Also, stiffness of the red oak panels, as measured by apparent MOE, is less than stiffness of panels made with southern pine and cottonwood. This may be due to the fact that several of the red oak panels were noticeably cupped when they were delivered for testing. In this cupped condition, the full width of the panel did not contact the supports in the loading frame. As load was applied, panels were gradually forced into full contact with supports, sometimes by longitudinally splitting the panel along a lamination. Once the panel was in contact across its full width, stiffness increased, but the net result was a more flexible panel.

In Table 2, it can be seen that the strength and stiffness of the southern pine panels tested in the Structural Engineering Laboratory at OSU are respectively, 19% and 14% higher than NDS values; tested strength and stiffness of red oak are 25% and 13% less than NDS values; and tested strength and stiffness of cottonwood are 52% and 33% higher than NDS values. Also note that the allowable design bending strength based on test results for red oak is lower than for southern pine and cottonwood, even though the mean strengths in Table 1 are approximately the same. The computation of allowable design values includes a consideration of variability in the data. The higher standard deviation for the red oak pulls the allowable design strength for this species to below that for the other two species.

The underlying cause of the lower than expected allowable design values for red oak and the higher values for cottonwood may, in part, be explained by the transverse-bending strengths reported in Table 3. The cottonwood transverse bending strength is much higher than the transverse-bending strengths of southern pine and red oak. The mean transverse bending strength of the red oak panels is similar to the southern pine panels, but there is more variability in the data. It may be that the soft, porous cottonwood absorbs a portion of the glue applied to its surface, and produces a very strong connection between laminations. The much harder red oak did not appear to absorb the glue, and produced very poor connections between laminations. In support of this hypothesis, it was observed during testing that the red oak panels regularly failed in transverse bending by breaking between laminations, and cottonwood typically failed by breaking within laminations. Both the density and performance of the southern pine panels fall between red oak and cottonwood.

Allowable Spans

The design procedure presented by Ritter (1990) is used to determine allowable spans. Calculations are based on bending strengths and stiffnesses reported here, and on allowable horizontal shear strengths published by NDS. Allowable horizontal shear strength from NDS for southern pine is 1.21 MPa (175 psi), for red oak is 1.59 MPa (230 psi), and for cottonwood is 0.758 MPa (110 psi). Design live load is an HS20-44 truck, live load displacement is limited to 2.5 mm (0.1 in.), and wet-use conditions are assumed. It is also assumed that supporting stringers are at least 15 cm (6 in.) wide.

Allowable spans are given here only for southern pine and cottonwood panels. The fabrication quality and performance under load of the red oak panels was so erratic that recommending a general-purpose allowable span is not appropriate. The allowable clear span between stringers for a 2x4 southern pine panel is 79 cm (31 in.), for a 2x6 southern pine panel is 130 cm (52 in.), for a 2x4-in. cottonwood panel is 45 cm (17.5 in.), and for a 2x6 cottonwood panel is 110 cm (43 in.) (Wang 1992). Allowable spans for the 2x4 southern pine panel and both cottonwood panels are governed by horizontal shear. The allowable span for the 2x6 southern pine panel is governed by live load deflection. Computed allowable spans are sufficient to permit both thicknesses of both species to be used on county bridges.

Field Installations

Deck panels were fabricated from No. 2 or better lumber. Substructure-stringer spacing dictated whether 2x4 or 2x6 lumber was used in fabricating the 4-ft (1.22 m) wide replacement panels for each bridge deck. A total of seven demonstration bridge decks were installed between April 1992 and September 1993. Panel lengths (bridge widths) ranged from 4.82 to 6.89 m (15.8 to 22.6 ft), and bridge lengths ranged from 9.5 to 37.2 m (31 to 122 ft).

Bridge Deck 1

The first demonstration deck was fabricated from No. 2 or better 2x4 southern pine lumber. No modifications were made to the bridge’s super- or substructure prior to deck replacement. Installation began by removing about 1.8 m (6 ft) of bridge planking from one end of the bridge using a back hoe. The first 1.2 x 6.1 m (4 x 20 ft) deck panel was placed in position using a forklift and “locked” into place using a total of eight offset steel clips [Figure (2b)]. Three offset clips were placed on the outer two girders and two clips were used on the girder closest to panel midlength. Offset clips were placed on alternate sides of girders to prevent horizontal movement.

Because of difficulties in gaining access underneath the panels to install offset clips and the time required for clip installation, it was decided to discontinue offset clip installations on subsequent panels and use standard bridge clips along each edge of the panel [Figure 2(a)]. To clip the edge of the panel being installed (panel X) adjacent to an installed panel (panel Y), enough planking was removed to place panel X approximately 46 cm (18 in.) away from panel Y. Panel X was squared and aligned with respect to panel Y. Six to eight bridge clips were then installed along panel X’s edge closest to panel Y using 60d ring-shank nails. After bridge-clip installation, panel X was then pushed toward and against panel Y using the bucket of the back hoe. Panel X’s exposed edge (toward the old planking) was then secured using six to eight bridge clips. Clips were placed on alternate sides of girders to prevent horizontal movement. Clips from panel X were located to avoid contacting clips from panel Y. This process continued for the remaining panels. The last three panels at the end of the bridge were also secured from the bottom using offset clips to minimize panel movement resulting from vehicles coming onto the deck.

Approximately half of the panels were installed the first day. The decision was made to reopen the bridge that evening by removing just enough planking to place an unsecured panel into the 1.2-m (4 ft) wide

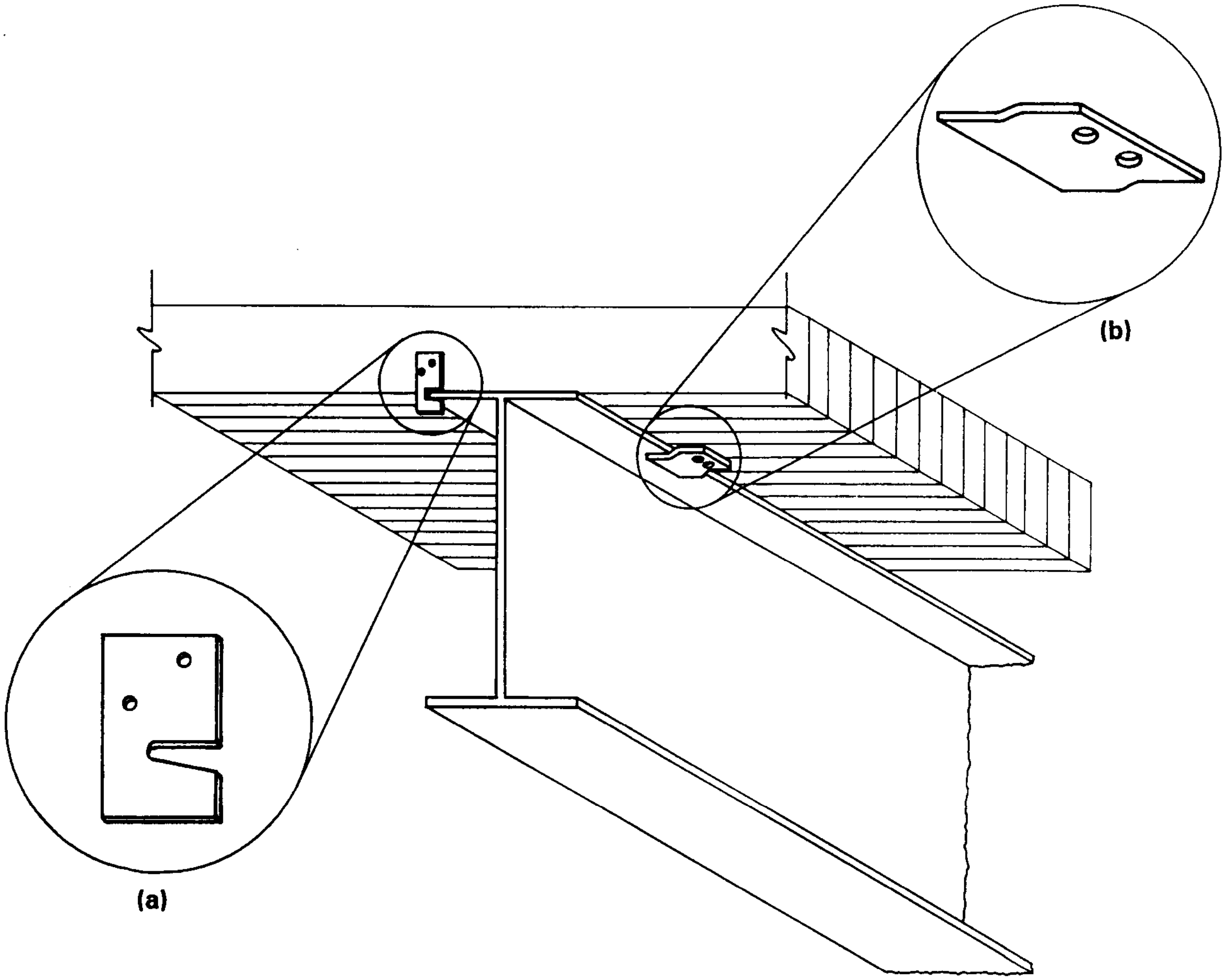

Figure 2 - Bridge with deck-connection clips: (a) 2.375 in. x 4.0 in. by 11 gauge steel clip attached to deck using 60d ring-shank nails; (b) 4.0 x 4.0 x 0.25 steel clip attached to deck using 0.375-in. diameter lag bolts (1.0 in. = 2.54 cm)

opening. Deck installation was completed by mid-afternoon of the second day.

Several minor problems were encountered during installation. First, the panel surfaces were unexpectedly slick from the creosote treatment. To correct this situation, a thin layer of sand was spread onto the panel surface. Second, several panels partially split in the glue joints during handling and placement. The fabricator was made aware of these defects. It was determined that these splits would not affect the strength, stability or service of the bridge. (An inspection 19 months after installation provided verification.) Third, because the bridge had an above-deck truss, minor difficulties were experienced in maneuvering the panels between the trusses and bracing. This was corrected on subsequent bridges by specifying panel lengths approximately 2 in. (5.08 cm) shorter than the full bridge width.

Bridge Deck 2

Installation of this bridge deck was similar to the system used on deck 1. No modifications were made to the bridge's super- or substructure prior to deck replacement. The 1.2 x 4.9 m (4 x 16 ft) panels were made of No. 2 or better 2x4 red oak lumber. All panels were secured along the edges using standard bridge clips. In addition, the first three panels at each end of the bridge were secured using offset clips to further reduce movement as vehicles enter and exit the bridge. The wood's hardness made fastening the bridge clips especially difficult. Workers were not able to drive 60d ringshank and common nails into the red oak lumber. As a result, 60d common nails were cut to approximately 7.6 cm (3 in.) long and used to fasten the bridge clips.

There are several other concerns with this demonstration deck. Because of wood quality (straightness) and fabrication process, some individual 2x4 laminated members were offset as much as 1.9 cm (0.75 in.) compared to adjacent members. In addition, some panels did not lay flat, i.e. cupping across the width. Another concern was splitting at several glue joints. The fabricator indicated problems in getting the proper glue formulation and heat-treatment process. This was evident in the number of glue-joint splits during installation. The cupping problem also contributed to the splitting. Still, the strength, stability and service of the bridge was not compromised. (An inspection 13 months later confirmed this observation.)

Bridge Decks 3-7

Five additional bridge decks were installed: two consisting of No. 2 or better 2x4 southern pine, one consisting of No. 2 or better 2x6 southern pine, one consisting of No. 1 or better 2x6 southern pine, and one consisting of No. 1 or better 2x6 cottonwood. While cottonwood proved to be a satisfactory lumber for decking, only one deck was installed because of limited lumber availability and cost. The longest demonstration deck installed was approximately 37.2 m (122 ft) in length with the complete replacement taking less than five working hours.

The only significant problem encountered during the installation of these five decks involved the first demonstration bridge deck using 2x6 lumber. It became apparent during installation that many of the deck panels were cupped across the panel width. This resulted in several panels giving an audible “cracking” sound when they were initially loaded. No visible splits in the panels were observed. However, in a few days it was apparent that some panels were not secured to the beams, mainly because of the excessive cupping of these panels. Because of the additional stiffness of the 2x6 lumber, offset clips did not bring the panels into contact with the beams as they did with panels on other bridges made from 2x4 lumber. Upon inspection, it was determined that the existing panels could be clamped to the flanges of the supporting steel beam. This procedure removed the noise and visual movement that was evident just after installation. The deck was then coated with an asphalt layer approximately 7.6 cm (3 in.) thick. After 11 months in service, there is no indication of significant panel movement.

In another installation, the only difficulty not experienced previously was the height difference in newly-installed girders. After installation was complete, wooden shims were placed in the gaps between steel girders and the wooden deck to minimize panel movement and to ensure uniform load bearing.

During installation of the bridge decks, county commissioners identified a number of advantages of timber panels when compared to other decking materials. These advantages include that (1) there is a significant reduction in time the bridge is out of service; (2) there are lower dead loads with timber deck, possibly allowing a higher load rating; (3) the weather is not a factor during installation; (4) inexperienced county road workers can efficiently handle timber panels and can easily learn installation techniques; and (5) wood is more resistant to road chemicals.

Summary And Recommendations

Test panels were fabricated using southern pine, red oak, and cottonwood. Static-bending and transverse-bending tests were performed on test panels at the OSU Structural Engineering Laboratory. Results show that both pine and cottonwood prove satisfactory but red oak panels regularly fail at the face-glued joint, thus producing erratic results. Bending strengths and stiffnesses based on OSU laboratory tests indicate that allowable spans for 2x4 and 2x6 panels are sufficient to allow the use of southern pine or cottonwood on county bridges.

Seven replacement bridge decks were successfully installed using southern pine, cottonwood, and red oak lumber. Southern pine is the preferred species at this time because of the availability of consistent lumber quality and ease of acquiring kiln-dried materials. Cottonwood is acceptable for decking, but is more difficult to obtain than southern pine. Red oak is currently unacceptable for decking due to questions regarding availability of raw material, panel fabrication, and the difficulty in fastening panels to the superstructure.

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