Behavior of a Bilayer Reinforced Stressed Timber Bridge Deck Under Static and Dynamic Loads

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Stressed timber bridge decks are constructed by pressure laminating thin wooden members into solid slab, using a simple posttensioning system. Economic studies indicate that finding ways to lower timber costs is important in making this type of structure more cost competitive. Recently, stressed timber decks reinforced with steel sandwich plates have been introduced. They are inherently more stiff, ductile, and resistant to creep than their nonreinforced predecessors. A "bilayer" reinforced stressed timber deck configuration, using two separate layers of relatively small, low-cost deck boards, was investigated. Full-scale laboratory testing was performed to measure stiffness, efficiency, and material stresses of a bilayer prototype deck constructed with combinations of three prestressing pressures and six steel reinforcement plate levels. Both static and dynamic loads were applied to the deck. The bilayer prototype demonstrated predictable, orthotropic behavior for decks containing as low as 1.64 percent steel by volume. In a nondimensional comparison, the bilayer was found to be slightly less efficient than single-layered decks, but comparable. Application of heavy static and dynamic loads did not introduce any measurable interlaminate slip. Whereas an economical bilayer configuration is possible when steel sandwich plates are present, additional testing is needed to further establish comprehensive design criteria for this type of structure.

The practice of friction laminating wood originated in Canada when deteriorating nail-laminated bridge decks were rehabilitated with transverse prestressing (*1*). Prestress pressure was applied perpendicular to laminations by tensioning high-strength steel rods placed transversely on the top and bottom of the deck and anchored on deck sides. This posttensioning system caused high interlaminate friction between adjacent timbers and increased load distribution capabilities of the deck. The stressed timber deck was eventually introduced into new bridge construction and was refined to have a single row of high-strength prestressing rods inserted through fabricated holes running transversely through the middepth of the deck.

These friction-laminated decks were found to be very efficient, possessing orthotropic (slablike) behavior. A major shortcoming of these stressed decks, however, was excessive deflections observed on longer spans. One solution involved increasing deck thicknesses to raise section properties and thus overall deck stiffnesses. The Trout Road Bridge (Table 1), a 1987 demonstration bridge located in Houserville, Pennsylvania, has played an important role in stressed timber bridge development, and several lessons have been learned from its design. Specifying widths more than 305 mm (12 in.) or lengths more than 3.66 m (12 ft) increases timber costs dramatically. Also, bearing plates have crept into facia timbers as much as 25 mm (1 in.), causing loss of prestress force, increasing maintenance costs, and making the bridge appear deficient in the public's eye. Another disturbing feature of this structure is the loss of camber that occurred both during construction and over time due to creep in wood members.

One method of increasing longitudinal and transverse stiffness of stressed timber bridge decks involves the addition of thin steel plates continuous through the length and depth of the deck. A model study conducted at The Pennsylvania State University (Mozingo, unpublished data, 1987) indicated that thin steel strips sandwiched between oak timbers could effectively limit deflections and creep in the model. The effects of using shorter deck timbers were investigated by increasing the number of "butt joints," which weakened the overall stiffness contribution of wood in the deck. A butt joint is a longitudinal gap in timbers present on all stressed decks more than 6.1 m (20 ft) in length, and the arrangement of butt joints in a stressed timber deck is commonly referred to as the butt pattern. Stiffness of the model deck with shorter timbers (more butt joints) was found to converge to stiffness of the original deck as more steel strips were added.

Full-scale testing of a steel-reinforced stressed deck at The Pennsylvania State University was funded by a grant from The Ben Franklin Technology Center. A 12.2-m (40-ft) half-lane prototype was constructed and tested (*2*). The prototype, called Butt Pattern A (Figure 1a, Table 1), consisted of unseasoned, visually graded No. 2 mixed red and white oak timbers along with high-strength, corrosion-resistant (ASTM A588) steel sandwich plates 9.5 mm × 356 mm × 12.2 m (3/8 in. × 14 in. × 40 ft 0 in.). The sandwich plates were not galvanized. It was found that when the prototype deck contained about 5 percent steel by volume, stiffness was doubled, bearing plates did not significantly deform facia timbers of the hardwood deck, and lower-grade lumber was used without introducing structural deficiencies.

The scarcity of wide, long timbers in most states prompted investigation of the use of shorter (and, thus, more economical) deck timbers. Load testing of a modified single-layer deck, or Butt Pattern B, was performed (Yannuzzi, unpublished data, 1990). Construction of the new deck merely required doubling butt joints in the existing deck (Figure 1b). To consider worst-case placement of butt joints, additional joints were added along the same transverse lines as previous joints. Therefore, along any given row of butt joints, 50 percent of timber was absent, double the amount in Butt Pattern A.

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TABLE 1 Comparison of Various Stressed Timber Bridge Deck Configurations

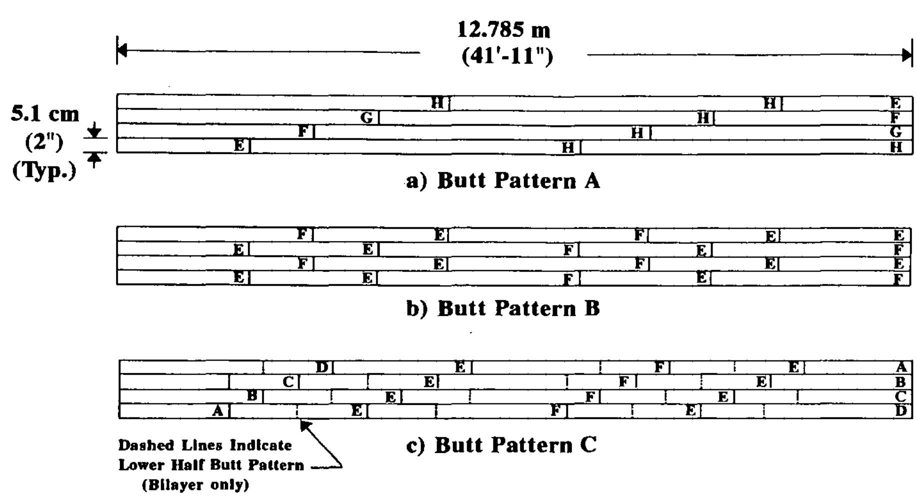
	Trout Rd. Bridge[c]	Butt Pattern A	Butt Pattern B	Butt Pattern C
Layer Configuration	Single, unreinforced	Single, reinforced	Single, reinforced	Bilayer, reinforced
Wood Species	Douglas Fir	Mixed red/white oak	Mixed red/white oak	Mixed red/white oak
Grade of Wood	No. 2	No. 2	No. 2	No. 2
Cross-sectional dimensions	102 mm x 406 mm (4" x 16")	51 mm x 356 mm (2" x 14")	51 mm x 356 mm (2" x 14")	51 mm x 165 mm (2" x 6.5")
Range of timber lengths	up to 5.5 m (up to 18')	2.1 m to 5.3 m (6'-11" to 17'-5")	2.1 m to 3.2 m (6'-11" to 10'-5")	1.8 m to 3.5 m (6'-0" to 11'-4")
Approx. wood MOE[a]	9,715 mPa (1.41 x 10^6 psi)	10,300 mPa (1.49 x 10^6 psi)	10,300 mPa (1.49 x 10^6 psi)	11,100 mPa (1.61 x 10^6 psi)
Approx. wood MOR[b]	51.0 mPa (7,400 psi)	72.6 mPa (10,540 psi)	72.6 mPa (10,540 psi)	69.6 mPa (10,100 psi)

[a] Modulus of Elasticity
[b] Modulus of Rupture
[c] Values of MOE and MOR for Trout Road Bridge were estimated from the Wood Handbook (*9*). Properties for butt patterns A, B, and C were obtained from static bending tests in conformance with ASTM D143.

Without steel, Butt Pattern B stiffness was found to be 77 percent of the original stiffness of Butt Pattern A. With 15 steel plates in the deck, Butt Pattern B exhibited 95 percent of the stiffness of Butt Pattern A. Thus, the problem of shorter timber lengths was solved. But what about shorter timber widths? Could timber from small- and medium-diameter trees be used to form layers of stressed decks?

A new concept in stressed timber bridge design involves the use of a "bilayer" wooden deck with steel sandwich plates. A model study (Mozingo, unpublished data, 1988) conducted at The Pennsylvania State University showed that the bilayer configuration behaved efficiently with modest levels of steel plate reinforcement (as low as 2 percent steel, by volume). The bilayer reinforced stressed timber deck configuration offers a sturdy and economical design, well suited for short and medium spans and ideal for low-volume roads.

Load testing of a 12.2-m (40-ft) bilayer deck (Butt Pattern C, Figure 1c) was conducted (*3*), which is the focus of this paper. Unlike the "ideal" bilayer configuration in which timbers with unequal widths are stacked vertically and alternated,



Timber Lengths							
A	**B**	**C**	**D**	**E**	**F**	**G**	**H**
1.83 m (6'-0")	**2.36 m (7'-9")**	**2.92 m (9'-7")**	**3.46 m (11'-4")**	**2.11 m (6'-11")**	**3.18 m (10'-5")**	**4.24 m (13'-11")**	**5.31 m (17'-5")**

FIGURE 1 Three stressed timber bridge deck prototypes: Butt Patterns A, B, and C (typical four-row patterns).

the bilayer prototype constructed for this study had a gap in the midheight of the cross section (Figure 2) because of the limited resources at the time of the study.

BILAYER DECK CONFIGURATION AND CONSTRUCTION

Butt Pattern Comparison

The bilayer butt pattern, or Butt Pattern C, was designed to minimize timber lengths and disperse butt joints as well as possible (Figures 1c and 2). The four-row pattern was repeated eight times across the width of the bilayer prototype deck for a total of 32 longitudinal rows of wood members. Bilayer deck timbers ranged in length from 1.8 m to 3.4 m (6 ft 0 in. to 11 ft 4 in.) and were 51 × 165 mm (2 × 6½ in.) in cross section.

Whereas Butt Pattern B had 50 percent timber absent at any transverse row of butt joints (Figure 1b) with each butt joint encompassing the entire depth of the deck, Butt Pattern C was designed such that only 25 percent timber was absent at any row of butt joints. In addition, the butt pattern arrangement of the upper half of the deck was shifted relative to the lower half of the deck in Butt Pattern C to ensure that no butt joint continued through the full depth of the deck. Butt Pattern A possessed the most conservative design, having the fewest butt joints and, subsequently, the longest timber lengths (Figure 1a).

Construction of Bilayer Prototype Deck

A mix of unseasoned, rough-cut, No. 2 mixed red and white oak was requested for the bilayer prototype deck (Figure 2) to be consistent with previous studies. Although the authors recommend that timber widths be controlled to within 3.2 mm (⅛ in.) for reinforced stressed decks (*4*), bilayer prototype timbers varied in thickness by as much as 6.4 mm (¼ in.). Given the other inconsistencies present (variation in width, timbers not perfectly straight or true), it is reasonable to conclude that timber used in the prototype deck was fairly representative of rough-cut timber used in practice. Because testing was performed indoors, timbers were not treated with creosote. The 9.5-mm × 356-mm × 12.2-m (⅜-in. × 14-in. × 40-ft), high-strength, corrosion-resistant (ASTM A588) steel sandwich plates used in Butt Patterns A and B were used for Butt Pattern C.

Because the bilayer prototype was constructed and tested as part of an unfunded master of science project, several concessions were made in the deck design. The most notable is the use of a middepth material gap (Figure 3) to eliminate costs associated with fabrication of holes in timbers. With the absence of holes, the gap allowed stressing rods [Dywidag 25 mm (1 in.), high-strength steel threadbars, F_u = 1.03 MPa (150 ksi)] to pass transversely through the deck. As a result, spacers were needed to support the upper deck approximately 32 mm (1¼ in.) above the lower deck. Although butting bilayer deck halves together will certainly be the chosen standard in practice, the chosen configuration (Figure 3) represents a "worst case" design for a bilayer deck, and measures of deck efficiency are somewhat conservative.

With bilayer deck timbers and stressing rods in place, bearing plates, anchor plates, and conical nuts were placed on each end of the rods (Figure 3). A hollow-core jack was used to slowly pull the loose deck timbers and steel plates together. Care was taken not to apply any prestress force until all gaps between laminates were removed. The stressing sequence found to minimize distortion of deck shape agrees with the suggested procedure in the *Quality Assurance and Inspection Manual for Timber Bridges* (*5*), which involves stressing midspan rods first and working toward outer rods.

TESTING PROCEDURE

The 12.8-m (41-ft 11-in.) bilayer deck rested on timber sills 305 × 305 mm (12 × 12 in.), having a span length of 12.2 m (40 ft 0 in.) from center to center of bearing areas. A military loading arrangement was used with jacks (servohy-

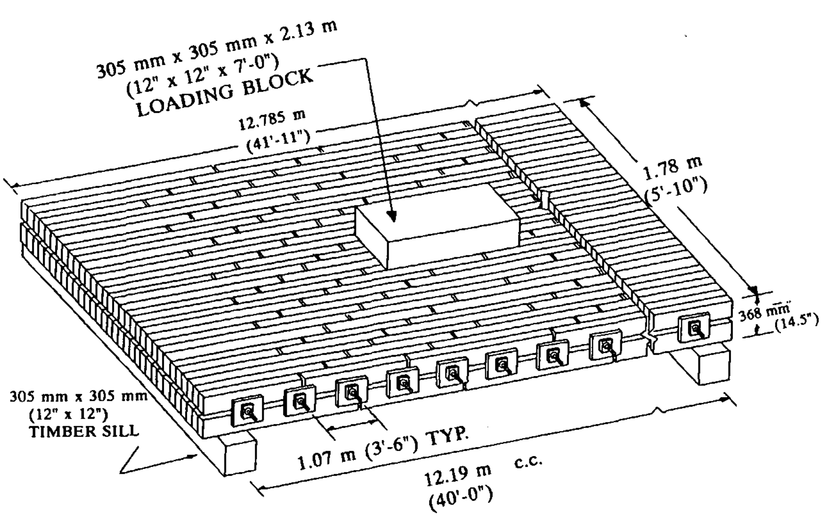


FIGURE 2 Isometric representation of bilayer prototype deck (Butt Pattern C).

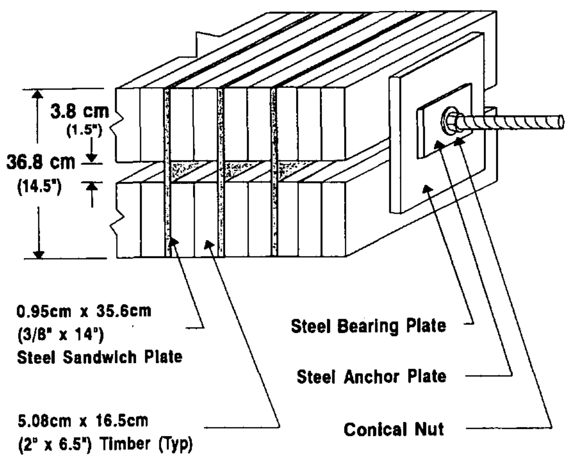


FIGURE 3 Cross section of bilayer prototype deck.

draulic) placed symmetrically about the centerline at 1.2-m (4-ft 0-in.) center-to-center spacing. A timber loading block (Figure 2) was used to transfer the load to the deck. Bridge deflections were read to the nearest 1.5 mm (0.005 ft, or about 1/16 in.) using a rotating laser (EGL Beam Machine) with an automatic leveling base and a level rod. Deflections were taken on each timber and steel laminate across the width of the bridge at midspan.

The bilayer deck was tested with 15, 11, 7, 5, 3, and 2 steel sandwich plates, and strain gauges were mounted on the top and bottom of 5 steel sandwich plates as indicated (Figure 4). Tests were performed at three prestress levels for each steel plate reinforcement level. The chosen prestress levels were 356, 222, and 89 kN (80, 50, and 20 kips) per rod, corresponding to prestress pressures of 1011, 632, and 253 kPa (146.8, 91.8, and 36.7 psi).

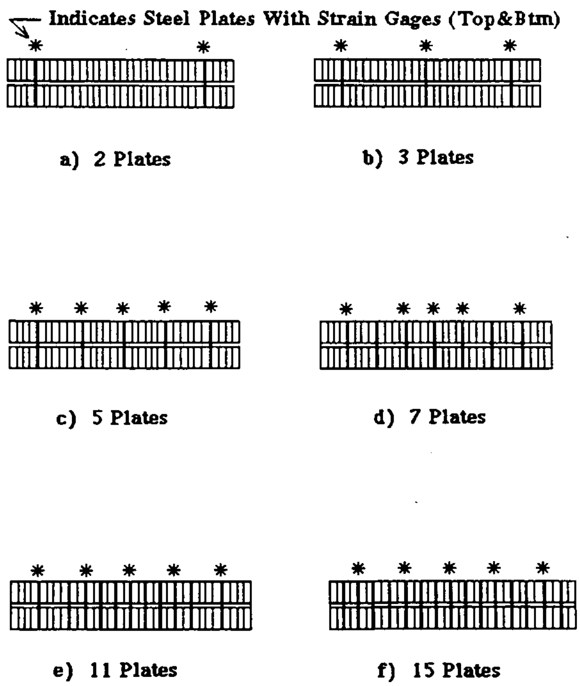


FIGURE 4 Steel plate locations in bilayer prototype deck.

Before each test, the deck was stressed to the required prestress pressure and a static shakedown was applied. The typical load sequence was 26.7, 53.4, 80.1, and 106.8 kN (6.0, 12.0, 18.0, and 24.0 kips) per jack; however, for stiffer decks, a load sequence of 33.4, 66.8, 100.1, and 133.5 kN (7.5, 15.0, 22.5, and 30.0 kips) was often used. Conversely, for less heavily reinforced decks, the load sequence was often modified or cut short to keep materials in the elastic range. Loads were applied quickly (about 5 sec between load levels) and deflections measured on all laminates in about 2 min. Because of the presence of steel reinforcement plates, time-dependent deflections due to creep in timber were found to be minimal. In addition to the load deflection tests, a dynamic shake was performed to measure interlaminate slip due to impact loads.

LOAD-DEFLECTION RESULTS FOR BILAYER DECK

Deflection often controls the design of stressed timber bridges, so accurate prediction of deck stiffness is important. The most significant variables that affect stiffness of stressed timber bridges are longitudinal and transverse MOE of deck timbers, quantity of steel sandwich plate reinforcement, degree of transverse prestressing, frequency and location of butt joints, and moisture content of deck timbers. Because of obvious limitations in studying some of these effects, only the most influential factors were examined. Thus, for testing of Butt Patterns A, B, and C, the two chosen variables were quantity of steel sandwich plate reinforcement and degree of transverse prestressing pressure.

The master stiffness curves for the bilayer prototype deck (for the six reinforcement and three prestress levels) are based on average centerline deflections (Figure 5). Comparisons between average and maximum centerline deflections are presented later in this section. Because the prestress pressure induced from 222 kN (50 kips) force per rod is closest to a typical prestress level maintained in the field, best-fit straight

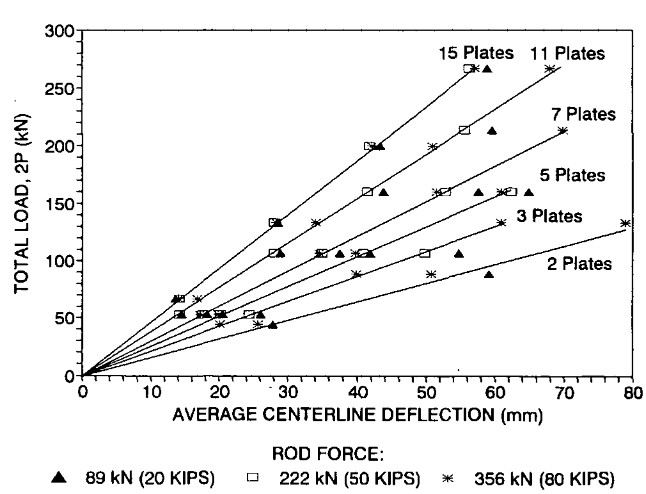


FIGURE 5 Load-deflection results for all reinforcement and prestress arrangements (Butt Pattern C).

lines were drawn through data points corresponding to that prestress level (Figure 5). Deck stiffness is defined as the slope of load-deflection curves in the elastic range and has units of force per length. The obvious trends seen are that stiffness is very dependent on steel plate reinforcement level and is somewhat dependent on prestress level. A quantitative measure of this difference is presented hereafter.

To study the effects of prestress pressure on deck stiffness, stiffnesses were computed for all three prestress pressures (Table 2) using linear regression of load deflection data. The linear model fit data well, with r^2 values ranging between 0.992 and 0.999, a finding consistent with other studies of stressed timber decks with steel sandwich plates. This result suggests that materials were kept within the elastic range. Another regression was made and stiffnesses calculated for the collection of load-deflection data of all three prestress levels within each reinforcement level. These values, displayed in rows labeled "all" (Table 2), represent an approximate mean stiffness value for a particular reinforcement level and were used to study the effect of prestress level on stiffness.

Stiffnesses for decks tested with 356 kN (80 kips) prestress force per rod were between 0.9 and 3.2 percent higher than the respective averages for "all" reinforcement levels (excluding two plate results). Stiffnesses for decks tested with

TABLE 2 Comparison of Bilayer Prototype Stiffness Based on Average Centerline Deflections for Various Prestress and Reinforcement Levels

NUMBER OF STEEL PLATES	PRESTRESS FORCE PER ROD (kN)	K (kN/m) BASED ON AVERAGE CENTERLINE DEFLECTIONS	PERCENT DIFFERENCE BETWEEN PRESTRESS LEVELS[a]	PERCENT DIFFERENCE BETWEEN REINFORCEMENT LEVELS[b]
15	89	20.8	-4.0	+53.4
	222	22.4	+3.1	
	356	21.9	+1.2	
	ALL[c]	21.7	0	
11	89	16.7	-7.6	+27.7
	222	18.2	+0.7	
	356	18.4	+1.8	
	ALL	18.1	0	
7	89	12.7	-9.9	0.0
	222	14.2	+0.5	
	356	14.4	+1.5	
	ALL	14.1	0	
5	89	11.3	-5.7	-15.3
	222	11.9	-0.7	
	356	12.1	+0.9	
	ALL	12	0	
3	89	8.7	-12.2	-29.9
	222	9.8	-0.7	
	356	10.2	+3.18	
	ALL	9.9	0	
2[d]	89	6.7	-15.5	-44.1
	222	---	---	
	356	7.8	-1.04	
	ALL	7.9	0	

[a] Percent difference of stiffness, K, in each plate category from the average (see note 'c' below) of that category.

[b] Percent difference of stiffness, K, for 222 kN force per rod for all plate categories compared to a reference stiffness at 7 plates (14.1 kN/m).

[c] Linear regression through data from all three prestress levels to obtain an approximate average.

[d] Values for deck configuration with 2 plates may be representative of prototype only. Bilayers with similar reinforcement but without mid-height material gap may experience higher stiffness values.

222 kN (50 kips) force per rod were found to be within 0.7 percent of the average when containing between 3 and 11 plates. For decks tested with 89 kN (20 kips) force per rod, stiffnesses were found to be between 4.0 and 12.2 percent less than the average values when containing between 3 and 15 plates. Thus, prestress level has a small but significant effect on stiffness values, especially for lower prestress levels. The increase in average centerline deflections as prestress level is decreased indicates that a reduction of transverse stiffness has occurred in the structure, as described in the following section.

Average Versus Maximum Centerline Deflection

In the preceding sections, all stiffness values used in comparisons were based on linear regression through data points representing load versus average centerline deflection. Although this is a legitimate way to represent average stiffness values for the prototype, averaging of centerline deflections can mask the transverse deflection patterns of the platelike deck system. An accurate measure of stiffness based on maximum centerline deflections is important because load tests performed in the field on recently built structures presently involve placing resultant loads (triaxle trucks) at the centerline of decks and measuring deflections at many points along their widths to obtain the maximum deflection.

For the typical transverse centerline deflection pattern shown (Figure 6), note that the deflection profile is "choppy" because of the resolution of the measuring system used [1.5 mm (1⁄16 in.)]. Also, recall that a loading block 305 mm (12 in.) wide was used to deliver loads to the test deck 1.78 m (70 in.) wide. The linear deformation pattern seen in the middle of each plot is an effect of measuring on the front and back of the loading block 305 mm (12 in.) wide and interpolating to obtain deflections between these points. To help visualize the overall transverse deflection trends, a polynomial of the second degree was fit through data.

It is obvious that transverse stiffness of the deck is very dependent on prestress level. In no case was interlaminate slip detected, however, even at the lowest prestress level, under static and dynamic loading. In general, maximum centerline deflections are only about 5 percent larger than average centerline deflections for the half-lane prototype deck.

Calculated and Measured Stresses in Wood and Steel

Because timber stresses were not physically measured, they were estimated using simple beam theory for the various deck arrangements and plotted versus percent steel (Figure 7). In Ritter's treatment of longitudinal stressed-laminated deck design (*6*), allowable bending stress (F_b) is calculated by adjusting tabulated single-member allowable bending stress for moisture, C_M, and load sharing, C_{LS}, and not for size factor, C_F. Taking the base value for allowable bending stress in the supplement to the 1991 National Design Specification for Wood Construction (NDS) tables (*7*) and making the proper adjustments gives

$$F'_b = F_b C_M C_{LS} = (5.51 \text{ MPa})(1.0)(1.5)$$
$$= 8.27 \text{ MPa } (1{,}200 \text{ psi})$$

Note that the 1991 NDS specifies that when (F_b) $(C_F) \leq 7.9$ MPa (1,150 psi), $C_M = 1.0$ is used. Even if $C_F = 1.3$ was applied, $(5.51)(1.3) = 7.2$ MPa (1,040 psi) ≤ 7.9 MPa (1,150 psi), thus $C_M = 1.0$ was used. By comparing this allowable bending stress value with plotted data (Figure 7), it appears that bending stresses in wood are critical for the loads considered. However, optimum design studies (*4*) indicate that the optimum deck thickness for a multilayered deck having a 12.2-m (40-ft) span length is 457 mm (18 in.), considerably deeper than the 368-mm (14.5-in.) bilayer deck. In fact, it was found that when generating optimum design curves, live load deflections were almost always the controlling design criteria, not timber stresses.

Consider the plot of calculated and average measured steel stresses versus percent steel in the deck (Figure 8). The al-

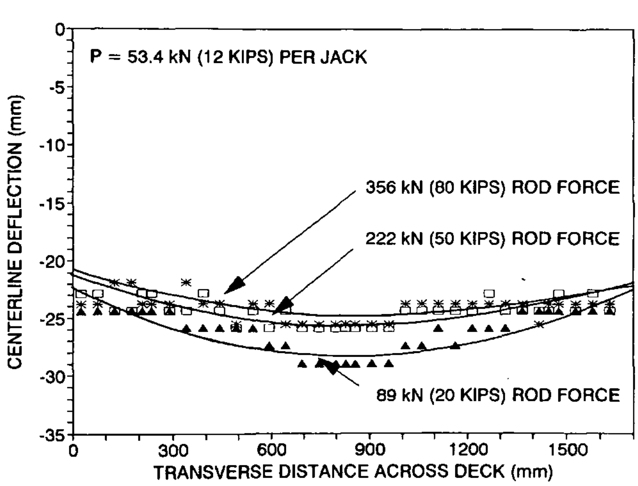


FIGURE 6 Transverse centerline deflection pattern for bilayer deck arrangement with three steel plates (Butt Pattern C).

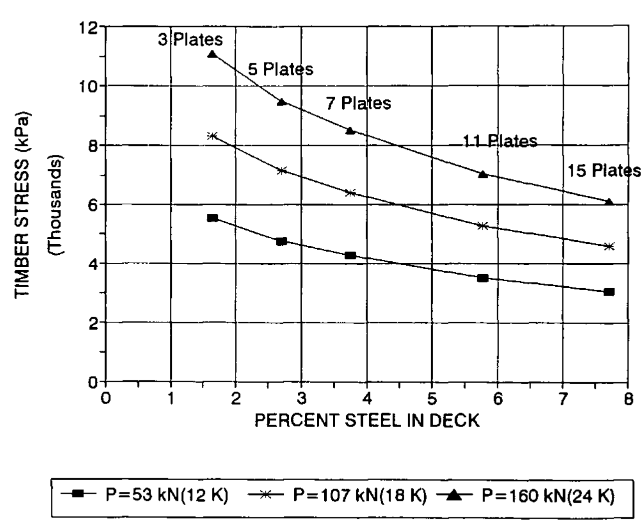


FIGURE 7 Calculated timber stresses versus percent steel in bilayer prototype deck (Butt Pattern C).

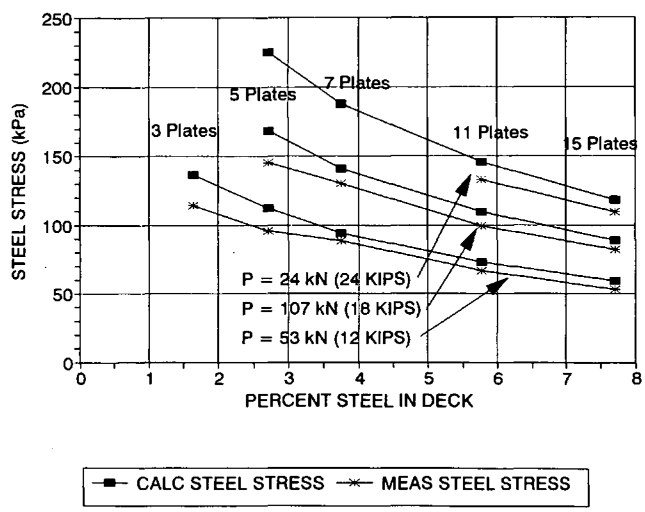


FIGURE 8 Calculated and measured steel stresses versus percent steel in bilayer prototype deck (Butt Pattern C).

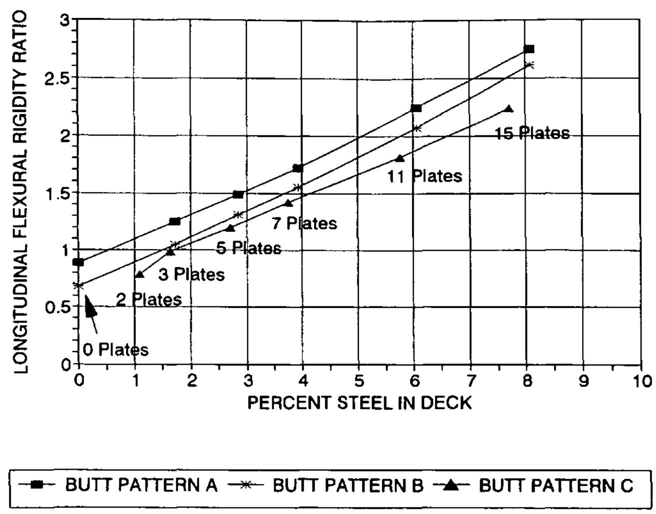


FIGURE 9 LFRR versus percent steel in deck for Butt Patterns A, B, and C.

lowable design stress in ASTM A588 steel [F_y = 345 MPa (50 ksi)] according to AASHTO's *Standard Specifications for Highway Bridges* (*8*) is

$$F_{all} = 0.55\ (345\ \text{MPa}) = 189\ \text{MPa}\ (27.5\ \text{ksi})$$

For the bilayer prototype, steel stresses approach this limit with seven reinforcement plates in the deck (3.75 percent steel) and P = 107 kN (24 kips). In all cases, measured steel stresses are lower than calculated steel stresses. One possible explanation for this consistent difference might be that the modular ratio used in determining calculated steel stresses is based on $E_{APP(WOOD)}$, which assumes that timber properties are constant throughout the entire deck. In reality, the deck has lower stiffness at butt joint locations and higher stiffness where strain gauges were located [at midspan, where wood contained no butt joints for several feet in either direction (Figure 1c)]. Again, note that when considering optimum deck thickness of 457 mm (18 in.), stresses would be considerably lower and that live load deflections almost always govern design thickness.

COMPARISON OF BUTT PATTERNS A, B, AND C

Relative efficiencies of reinforced stressed timber decks were compared using longitudinal flexural rigidity ratio (LFRR). The LFRR is the ratio of apparent EI, or internal stiffness of wood and steel for a given deck arrangement, over the base EI, or the internal stiffness of a solid wood deck made up of clear wood only. This dimensionless quantity is not biased toward section properties and wood MOE, making it an ideal choice for comparing efficiencies of Butt Patterns A, B, and C.

A plot of LFRR versus percent steel (Figure 9) for the single-layered decks (Butt Patterns A and B) and the bilayer deck (Butt Pattern C) shows the following:

1. Butt Pattern A is most efficient, followed by Butt Patterns B and C, respectively. This was expected because Pattern B had twice as many butt joints as A, and Butt Pattern C had a large number of butt joints combined with a midheight material gap.

2. LFRR curves bend slightly upward as the percentage of steel is increased. Although increasing steel content leads toward linearly increasing stiffness, the wood contributes more to overall stiffness of the deck as the amount of steel is increased (even though the quantity of wood in the deck is always constant). The wood contribution increases with steel content because of the increased splicing action provided by the addition of steel plates. Such splicing action plays a major role in the utilization of small lengths and narrow widths of timbers.

The nonlinear drop in stiffness between three and two plates for Butt Pattern C indicates that a breakdown has occurred in the ability of the bilayer to act as an efficient composite deck at this very low steel content level. Because of the midheight gap in material of the bilayer prototype cross section (Figure 3), the upper half of the two-layered configuration was free to deflect more than the lower half in the two-plate (Figure 4a) configuration (1.10 percent steel content). Because no measurements were taken to prove that the phenomenon previously described actually occurred (for instance, deflection measurements taken on the top and bottom of the deck), only limited inferences can be made concerning the presence of the nonlinear drop in stiffness. However, it is likely that a typical bilayer configuration would perform better at this low reinforcement level.

CONCLUSIONS

Prestress level was found to be an important factor in bilayer deck stiffness. Despite the increasing loss of longitudinal and transverse stiffness detected in examining transverse centerline deflection patterns for the three prestress levels, there was no evidence of slippage between adjacent laminates for even the lowest prestress level. This result suggests that although keeping prestress levels near the target level is important in maintaining design stiffness characteristics, prestress loss is, in general, a forgiving and detectable phenomenon rather than a catastrophic one.

The bilayer prototype deck possessed a 38-mm (1½-in.) midheight gap between upper and lower layers of wood. Despite this undesirable design detail, the bilayer deck showed considerable stiffness and efficiency at all but the lowest reinforcement level, which involved using only two steel plates in the half-lane deck. To allow lower reinforcement levels such as these, use of a variety of timber thicknesses to make up the bilayer cross section would be helpful.

The relative efficiencies of Butt Patterns A, B, and C were compared by examining the LFRR versus percentage of steel in deck. For LFRR values of 1.0, Patterns A, B, and C need approximately 0.5, 1.5, and 1.8 percent steel content, respectively. To have LFRR values of 2.0, Patterns A, B, and C need 5.0, 5.5, and 6.5 percent steel content, respectively.

This study clearly shows that the bilayer configuration is not only possible but necessary in making longer stressed timber spans economically feasible. However, further study in this area is needed to investigate

1. Behavior of multilane decks and decks of varied thickness,
2. Effects of preservative treatment on interlaminate friction and deck behavior,
3. Behavior of decks constructed with other hardwood species,
4. Ultimate capacity of reinforced decks, and
5. Effects of moisture content, steel channels on deck sides, and so forth.

Steel sandwich plates in stressed timber bridge decks reduce camber loss due to creep in timbers and enable longer spans. The presence of reinforcement plates also permits the use of both shorter and lower-grade timber, thus significantly lowering timber costs. Additional timber savings are possible with bilayer or multilayer decks, which use timber from smaller trees.

Timber bridges have always been admired for their simple and natural beauty and for using a renewable, widely available resource. Now, with modern designs such as the bilayer reinforced stressed deck, timber bridges are becoming a viable alternative for short- and medium-span bridges.

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