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Bending tests of bridge deck planks

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Abstract

This paper presents results of timber plank tests, for planks used in highway bridge decks. Tests were carried out to determine the flat-wise use factor, which is represented by the ratio of modulus of rupture (MOR) for flat-wise loading to MOR for edge-wise loading. Four sizes were tested. The tests confirmed that MOR for flat-wise loading is considerably larger than for edge-wise loading for the larger planks tested and that flat-wise use factor increases for larger plank width. The flat-wise use factor in the current bridge design code is overly conservative for typical plank sizes. New flat-wise use factors are recommended for the design of wood plank decks for highway bridges. The recommended values vary from 1.10 to 1.6.

Keywords: Flat-wise use factor; Modulus of rupture; Edge-wise use; Flat-wise use; Timber

1. Introduction

In a recent study by Nowak et al. [1] dealing with the design criteria for plank decks for highway bridges, it was found that there is no in-grade test data available for flat-wise bending. The flat-wise use factor is defined as the ratio of the modulus of rupture (MOR) for flat-wise load application to MOR for edge-wise load application. The need for rational design criteria for plank decks was identified by the AASHTO Subcommittee on Bridges, Committee on Timber Bridges, as a priority item requiring an urgent solution. The current flat-wise use factor in AASHTO [2] seemed to be overly conservative for typical plank sizes. Therefore, tests were carried out at the University of Michigan to verify the flat-wise use factor for bridge design codes [2,3]. The objective of this paper is to present the testing procedure and test results.

A typical plank deck consists of planks laid flat-wise and placed on supporting stringers, as shown in Fig. 1. There are two categories of plank decks depending on the direction of planks vs. direction of traffic: transverse deck and longitudinal deck. A typical transverse plank deck is shown in Fig. 2. The span length of stringers is usually 5–6 m, in older structures it can be up to 11 m. Stringers can be spaced at 300–600 mm (center-to-center), but mostly 300–450 mm. Stringers are made of sawn lumber, typical Southern Pine size is 150×450 mm, or Douglas-Fir (larger size). The planks are typically 100×250 mm or 100×300 mm, and their length can be 3.5–11 m. Planks are nailed to stringers. A longitudinal plank deck is shown in Fig. 3 and is similar to transverse plank decks in terms of plank and stringer size and stringer spacing. The major design

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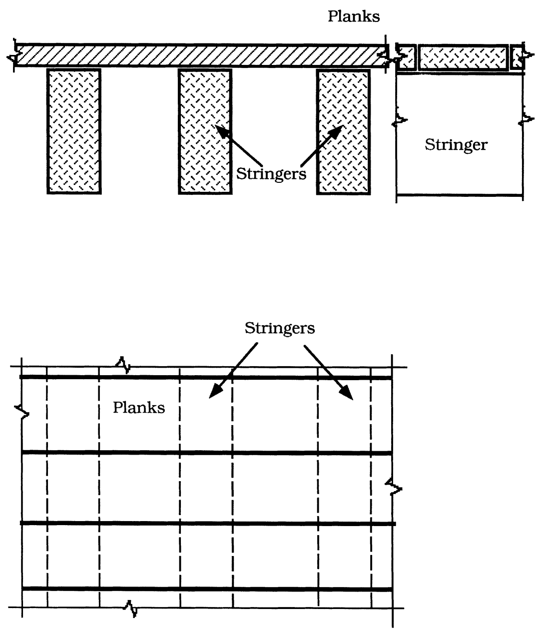

Fig. 1. Typical plank deck.

parameter determined by the designer is the spacing between stringers.

The design provisions for plank decks in AASHTO [2] and AASHTO LRFD Code [3] include specified live load (wheel load), load distribution, and material strength. The latter is specified as allowable stress in [2] and base resistance in [3]. For typical bridge planks, [2] specifies a flat-wise use factor of 1.10. The LRFD Code [3] does not specify any flat-wise use factor.

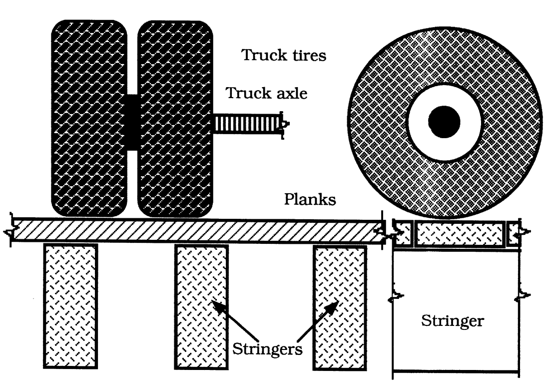

Fig. 2. Transverse plank deck.

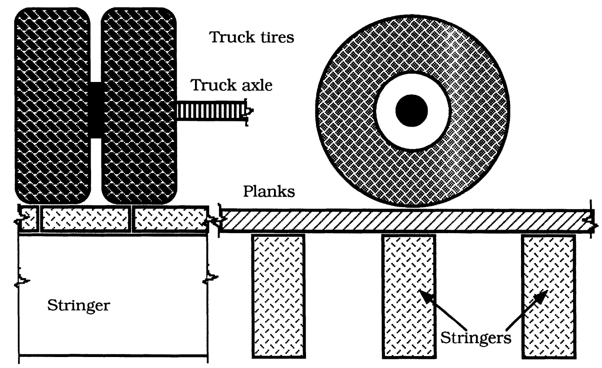

Fig. 3. Longitudinal plank deck.

2. Description of tests

The tests were carried out on the most common species used for plank decks in Michigan, Red Pine. Four sizes were ordered, two of them are typical for bridge planks: 100 × 250 mm and 100 × 300 mm, and the other two sizes have good potential for future applications: 100 × 150 mm and 100 × 200 mm. Material was supplied by Woodstock, Inc., from West Branch, MI, USA. The planks were pressure in-kiln treated to retention of 10 kg/m^3 with CCA Type C (Chromated Copper Arsenate). A special request was made to ensure a random selection of specimens. The number of tested planks was limited by the available budget for this project. The sizes and quantities are given in Table 1. A total of 169 edge-wise and 177 flat-wise specimens were tested.

The tests were performed using the electronically controlled digital Instron Model 8500 testing system with a 445-kN load cell and hydraulic actuator having a ±125-mm stroke. Test set-ups and example specimens for edge-wise and flat-wise bending are shown in Figs. 4 and 5. Monotonically increasing, displacement controlled, linear ramp loading was applied, with the load rates selected depending on specimen depth, as given in Table 2. The load rates assured comparable stress rates for different specimen sizes. Each test took about 10 min.

The edge-wise tests were performed using a third-point loading setup. The span of tested specimens was 2135 mm. The specimens were placed on roller bear-

Table 1
Sizes and quantities of tested planks

Nominal size of specimens [mm (inches)]	Dressed size [mm (inches)]	Tested specimens	
		Edge-wise	Flat-wise
100 × 150 (4 × 6)	89 × 140 (3.5 × 5.5)	43	45
100 × 200 (4 × 8)	89 × 184 (3.5 × 7.25)	9	8
100 × 250 (4 × 10)	89 × 235 (3.5 × 9.25)	74	77
100 × 300 (4 × 12)	89 × 286 (3.5 × 11.25)	43	47

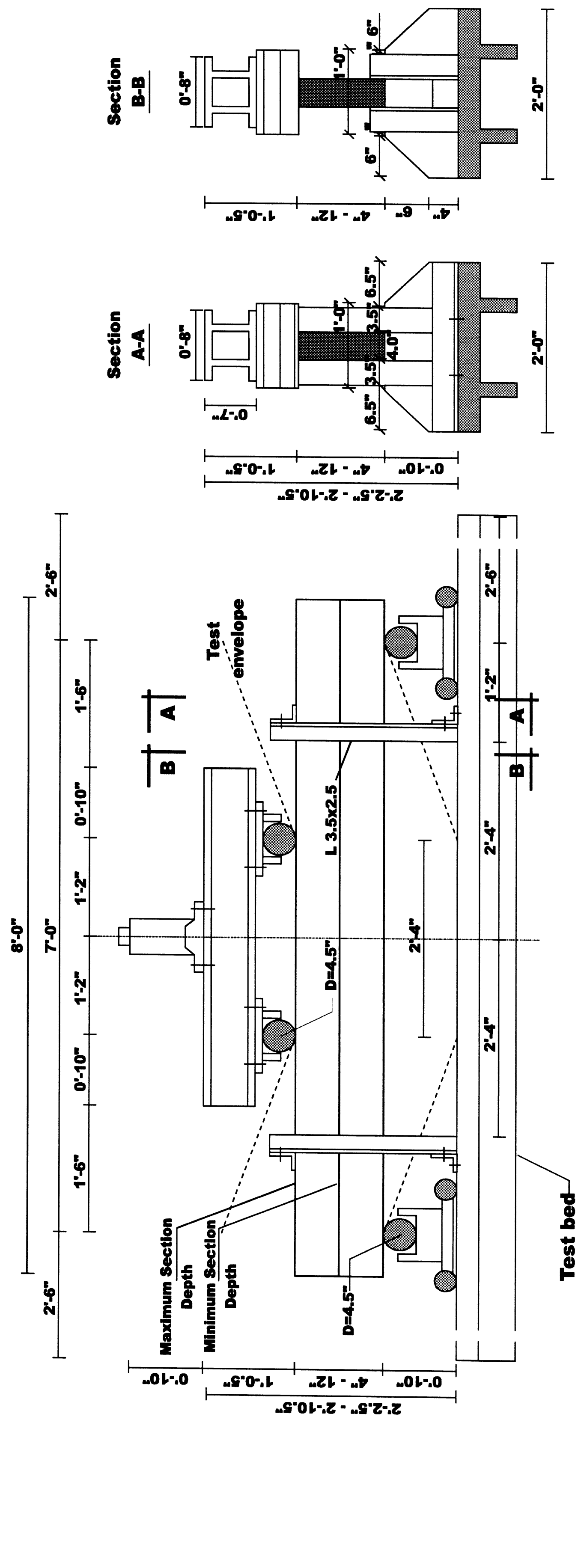

Fig. 4. Edge-wise test set-up.

Table 2
Load rates

Nominal depth of specimen [mm (inches)]	Test rate (deflection) [mm/s (inch/s)]
100 (4) (flat-wise)	0.152 (0.0060)
150 (6)	0.254 (0.0100)
200 (8)	0.190 (0.0075)
250 (10)	0.152 (0.0060)
300 (12)	0.127 (0.0050)

ings. In order to prevent the transverse buckling and deformation of the specimen, special side braces were provided. The load was transferred from the actuator to the specimen using a loading steel beam equipped with load bearings.

The flat-wise tests were performed using a single-point loading set-up. The span of tested specimens was 915 mm. The load was transferred from the actuator to the specimen using a roller. A rubber pad was used between the loading roller and the specimen to reduce the stress concentration and indentation.

Prior to test, each specimen was measured to determine the actual dimensions. Moisture content was measured using the device provided by the Forest Products Lab and it varied from 9 to 15% in most cases.

Examples of tested specimens are shown in Figs. 6 and 7 for edge-wise test and flat-wise test, respectively.

3. Test results

For each specimen, the ultimate force, P, was determined as the force at failure. The statistical parameters of P, in particular the mean and coefficient of variation, are given in Table 3. The corresponding bending moment, M, and modulus of rupture, MOR, were calculated using the following formulas:

$$\mathrm{MOR} = \frac{M}{S} \tag{1}$$

where

$$M = \frac{P}{2}\left(\frac{L}{3}\right) \tag{2}$$

for edge-wise tests,

$$M = P\left(\frac{L}{4}\right) \tag{3}$$

for flat-wise tests,

$$S = \frac{bd^2}{6} \tag{4}$$

L = test span equal to 2134 mm for edge-wise tests, and 914 mm for flat-wise tests;
b, d = dimensions (width and thickness) of the cross-section.

The calculations were carried out using the actual dimensions, as measured prior to the test. For comparison, MORs were also calculated for dressed dimen-

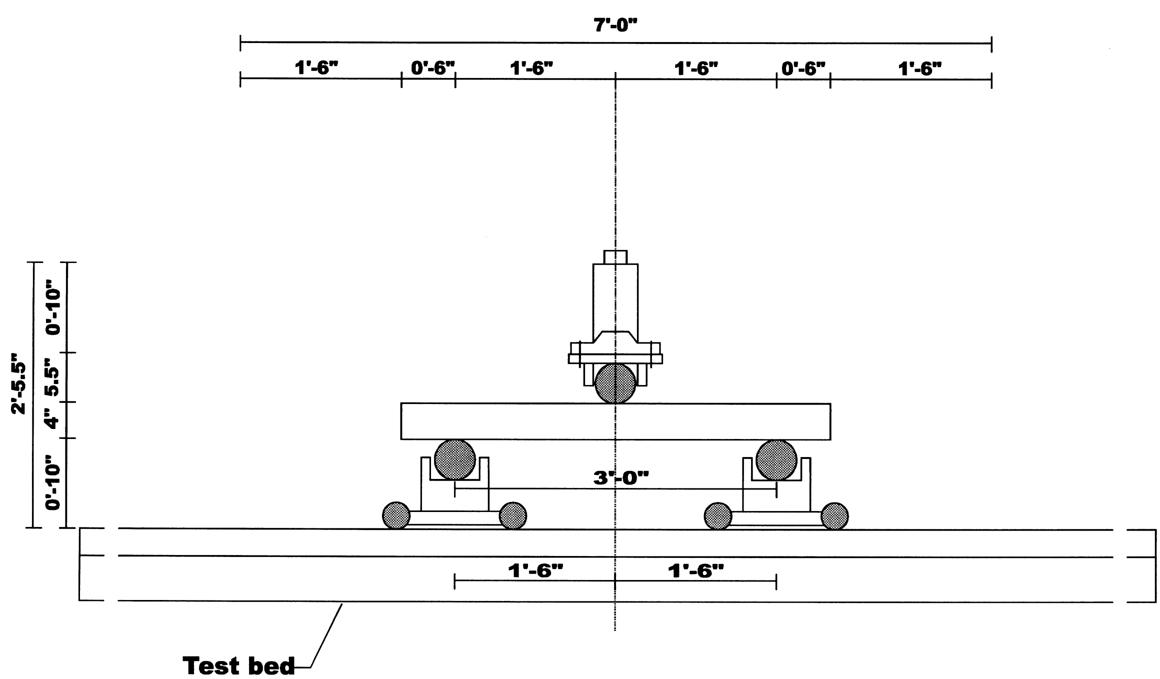

Fig. 5. Flat-wise test set-up.

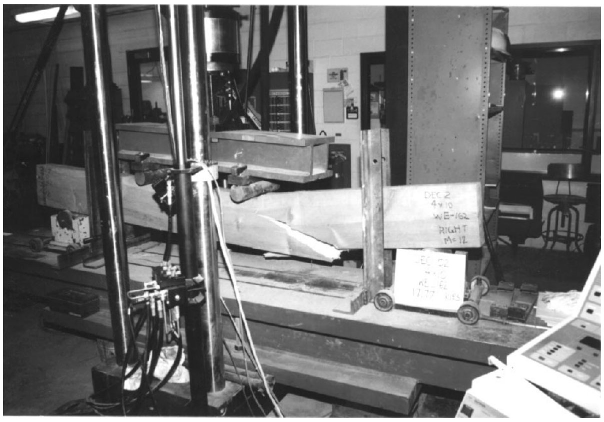

Fig. 6. Example of edge-wise loaded specimen.

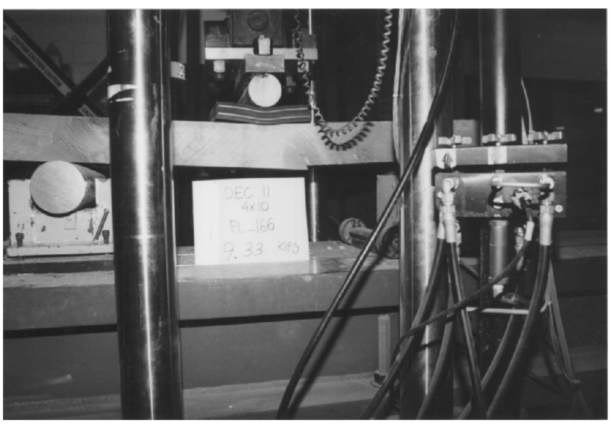

Fig. 7. Example of flat-wise loaded specimen.

sions (shown in Table 1), because these dimensions are used in the design.

The resulting values of MOR are presented in the form of cumulative distribution functions (CDF), plotted on normal probability paper. The construction and use of probability paper is given in the theory of probability textbooks [4]. Probability paper utilizes a special scale that has two important properties: (1) the CDF of a normal distribution is represented by a straight line; and (2) conversely, a straight line represents a normal distribution. The horizontal scale is in terms of the considered parameter, e.g. MOR. The vertical scale represents the probability of being exceeded, p. In order to conveniently plot CDFs by computer, the probability of being exceeded (vertical scale) is replaced with the inverse standard normal distribution function, $\Phi^{-1}(p)$. For example, $\Phi^{-1}(p) = 0$ corresponds to the probability of being exceeded, $p = 0.5$; $\Phi^{-1}(p) = 1$ corresponds to $p = 0.841$; and $\Phi^{-1}(p) = -1$ corresponds to $p = 0.159$; and so on.

The CDFs representing test results are shown in Figs. 7–11. The actual and dressed cross-section dimensions are considered. The curves in Figs. 7–10 are almost straight lines, which is an indication that the

Table 3
Statistics of ultimate force values

Nominal size of specimens mm (inches)	Ultimate force			
	Edge-wise test		Flat-wise tests	
	Mean [kN (kips)]	Coefficient of variation	Mean [kN (kips)]	Coefficient of variation
100 × 150	28.75	0.32	32.66	0.28
(4 × 6)	(6.46)		(7.34)	
100 × 200	47.48	0.42	43.39	0.46
(4 × 8)	(10.67)		(9.75)	
100 × 250	82.10	0.20	64.48	0.21
(4 × 10)	(18.45)		(14.49)	
100 × 300	100.1		74.98	0.30
(4 × 12)	(22.50)	0.27	(16.85)	

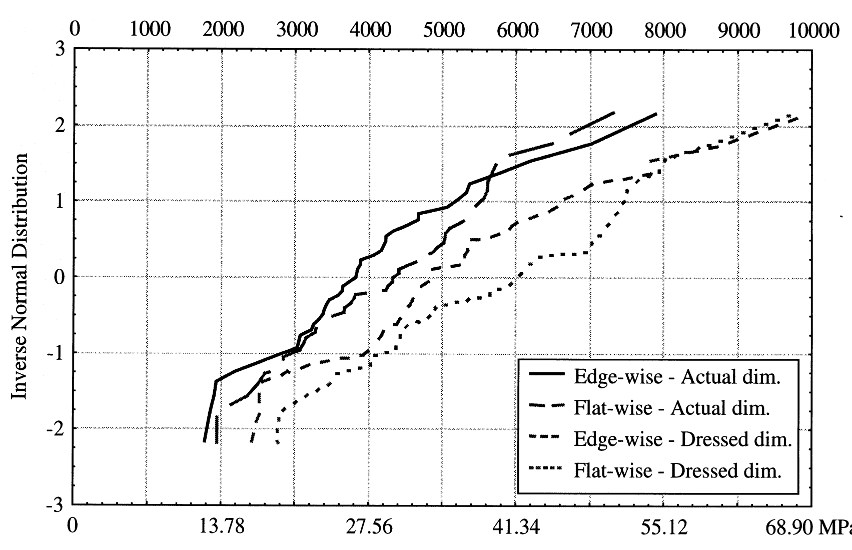

Fig. 8. CDF of MOR on the normal probability paper. Size 100 × 150 mm (4 × 6 inches).

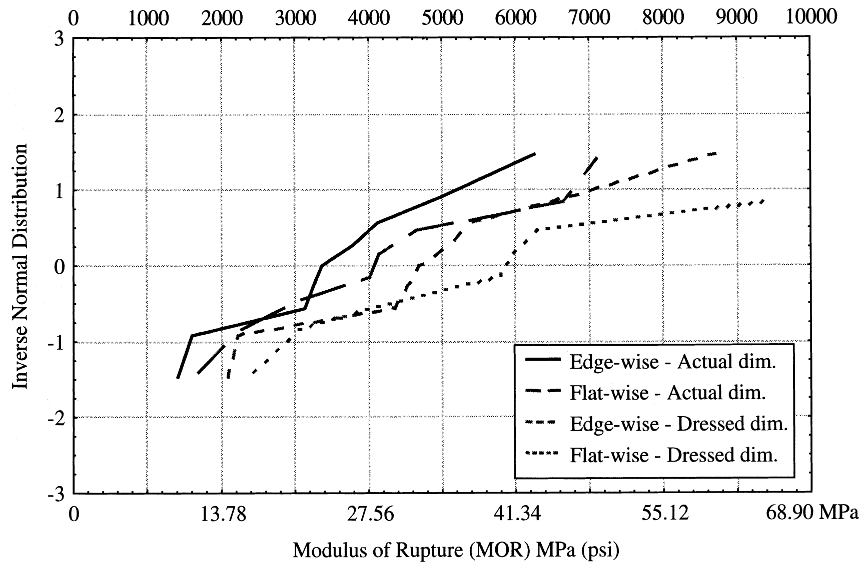

Fig. 9. CDF of MOR on the normal probability paper. Size 100 × 200 mm (4 × 8 inches).

corresponding CDFs represent normal distributions for the test results. However, it can be expected that for a larger sample size, the distributions will be closer to log-normal because strength is always positive. In particular, this applies to a lower tail of the CDF.

It can be seen that the difference between flat-wise and edge-wise CDFs increases for larger dimensions of the cross-section. For 100 × 150-mm specimens, the difference between flat-wise MOR and edge-wise MOR is not visible, because the thickness to depth ratio is not very large. However, for 100 × 250-mm and 100 × 300-mm, flat-wise MOR is clearly larger than edge-wise MOR. This observation can be justified by consideration of a beam as a system of parallel fibers in the longitudinal direction. The capacity of a wood beam is practically determined by presence and size of defects (knots, splits). For example, a knot at the bottom of an edge-wise loaded beam can drastically reduce the load carrying capacity, because there are fewer remaining strong fibers compared to a wide side of flat-wise loaded beam.

4. Proposed flat-wise use factors

The flat-wise use factors were calculated as the ratio

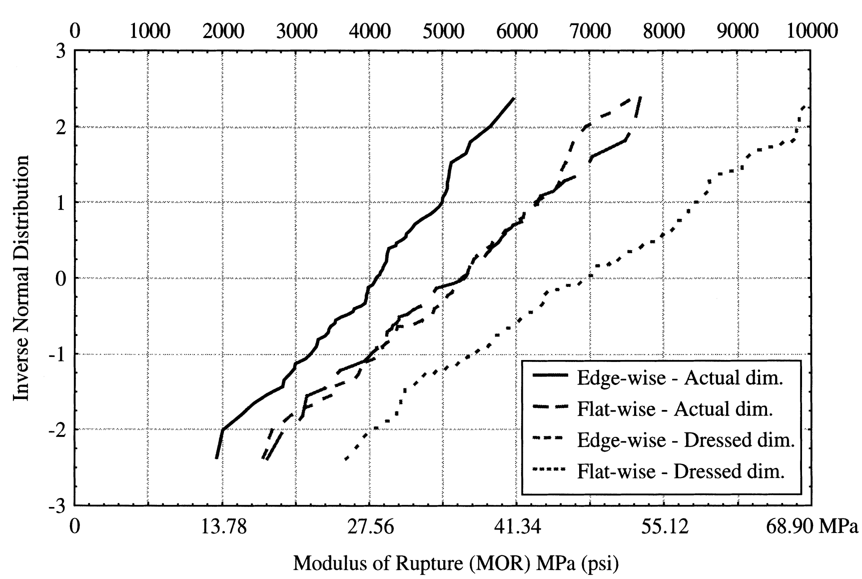

Fig. 10. CDF of MOR on the normal probability paper. Size 100 × 250 mm (4 × 10 inches).

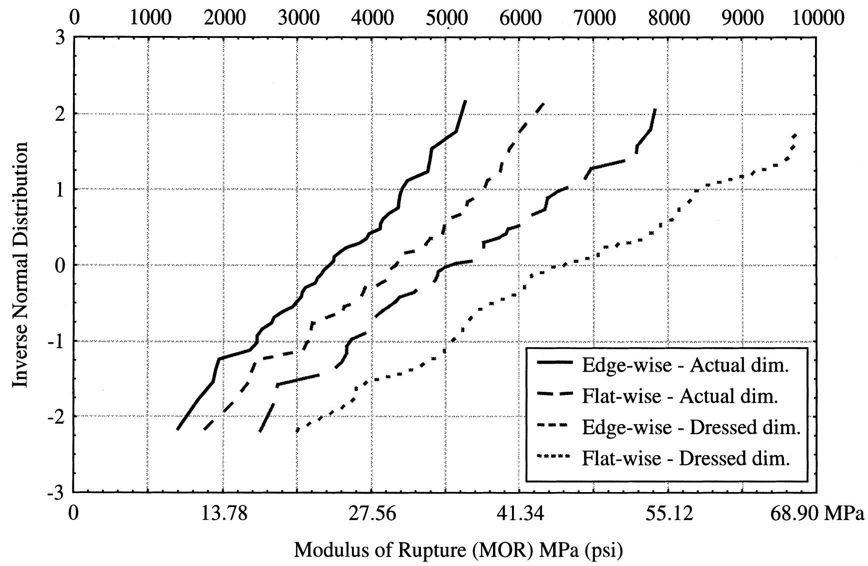

Fig. 11. CDF of MOR on the normal probability paper. Size 100 × 300 mm (4 × 12 inches).

of MOR for flat-wise load to MOR for edge-wise load. The calculations were carried out for MOR corresponding to the lower 15th, 10th and 5th percentile. Actual dimensions and dressed sizes are considered, with results listed in Table 4. The recommended values of flat-wise use factors are also presented in Table 4. The recommended flat-wise use factor is noted to increase with plank width.

5. Conclusions

The wood plank tests performed at the University of Michigan confirmed that the modulus of rupture (MOR) for flat-wise loading is considerably larger than for edge-wise loading for the larger plank sizes tested. Flat-wise use factor increases for larger plank width. The flat-wise use factor in the current bridge design codes is overly conservative, for typical bridge plank sizes.

New flat-wise use factors are recommended for the design of wood plank decks for highway bridges. The recommended values vary from 1.10 for 100 × 150-mm to 1.6 for 100 × 300-mm.

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Table 4
Flat-wise use factors

Nominal size [mm (inches)]	Calculated flat-wise use factors						Recommended flat-wise use factors
	Actual dimensions			Dressed dimensions			
	15%	10%	5%	15%	10%	5%	
100 × 150 (4 × 6)	1.11	1.10	1.14	1.14	1.11	1.12	1.10
100 × 200 (4 × 8)	1.19	1.19	1.15	1.18	1.23	1.16	1.15
100 × 250 (4 × 10)	1.31	1.29	1.32	1.34	1.35	1.36	1.30
100 × 300 (4 × 12)	1.61	1.65	1.67	1.67	1.73	1.74	1.60

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