CONVENTIONAL LUMBER DECKING: EFFECT OF BOARD SIZES.

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ABSTRACT

The introduction of stress laminated lumber decks has helped in the elimination of the problems associated with conventional lumber decks. However, there are thousands of conventional lumber decks that will continue to require maintenance. In some other instances, some of these conventional wood bridges may be kept as historical landmarks. One problem that needs attention on these conventional lumber decks is the one caused by dimensional instability of lumber, when used in a varying environmental condition. Proper material selection and proper board placement may help in minimizing the effect of these dimensional instabilities. However, when we have wetting from one side only, there is a cupping tendency regardless of material selection and placement. In this paper results of a study aimed at the determination of forces developed during the cupping of lumber subjected to uni-directional wetting are presented. The forces developed during cupping depends on the depth and width of the lumber.

Keywords: Lumber cupping, lumber decks, dimensional instability, bridges

INTRODUCTION AND BACKGROUND

Sawn lumber plank decks may be very practical in low-volume roads and special use bridges such as those servicing forest plantations. These decks are constructed of lumber planks, 75 to 150 mm (3 to 6 inches) thick and 250 to 300 mm (10 to 12 inches) wide, that are placed flat-wise and spiked to supporting beams (USDA Forest Service 1992).

Dimensional instability of lumber when used in varying environmental conditions is a major problem in any wood structure. Dimensional changes, especially differential changes, may lead to serious aesthetic and structural problems. These problems may range from damage to finishes in buildings, failure of pavements laid over lumber bridge decks, uneven riding surface on unpaved lumber decks, and withdrawal of nails and spikes due to cupping of flat lumber boards. It may be possible to minimize the problem of board cupping by proper selection of material and orientation of the boards. A primary contributing factor to the cupping of wood, when under uniform moisture change is the higher expansion in the annual ring orientation. Flat sawn boards exhibit greater shrinkage on the "back" side, and thus the common rule of thumb is "back side down" for laying boards. Quarter sawn material shows significantly less cupping than flat sawn. Lumber which falls between these two categories will fall between the two in terms of cupping tendency as well. In addition, the size of the lumber plays an important role. As the thickness increases, we tend to get more vertically oriented annual rings, and thus resulting in rhomboid shapes rather than cupping.

When you have non-uniform moisture change, noticeable cupping will occur, regardless of material selection or board orientation. The fibers on the wet side will expand while the fibers on the dry side remain unchanged. This will occur no matter whether the board is a quarter cut or a flat cut.

For example, in the sketch shown below (Fig. 1), the board is laid with "bark" side down. When the upper side becomes wet, say due to rain, the upper side elongates while the lower side, which remains dry, will remain unchanged. This variation in elongation will lead to a cupping tendency up to when the wetness reaches the lower side. It is only when the wetness reaches the lower side will the minimization of cupping by proper material selection and proper board orientation will be of consequence. Therefore, it can generally be urged that when there is differential wetting of flat boards, as may be in exposed lumber decks, large cupping forces will develop no matter what material or board placement is adopted. For properly selected and placed materials, most of these forces will be dissipated once the moisture reaches the other side of the board. If damage to finishes and other components supported by the boards is to be avoided or minimized, adequate connectors should be provided to restrain the cupping up to when the moisture reaches the other side of the board.

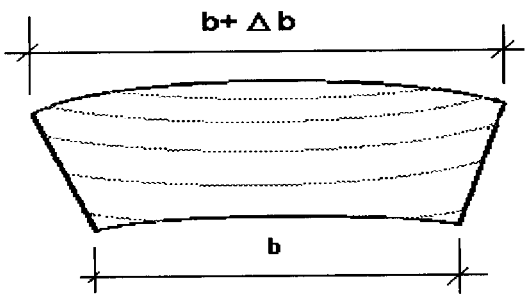

Fig. 1 Behavior of a Lumber Board When Wetted from One Side

To the knowledge of the authors of this proposal, there is very limited literature on stresses developed in lumber due to environmental changes and its effect on the performance of structures. Lang et. al. (1994) report on studies conducted to determine the performance of oak strip flooring systems under changing environmental conditions. In these studies, fastener withdrawal forces greater than 800 N are reported. The wood industry has been conducting studies on lumber deformations during the drying process (Hsu 1975). There are similarities between lumber cupping associated with the wood drying process and the moisture variation expected in lumber exposed to annual weather variations.

The board cupping effect, as shown in Fig. 1, coupled with the fact that gaps between the lumber boards will vary with respect to changes in environmental conditions, will cause cracking in a pavement laid on a conventional lumber deck. Thus, it is not practical to lay pavement over a conventional lumber deck. During the cupping process the connectors holding the boards to the stringers will be subjected to withdrawal forces. It can be seen from Fig. 1 that the cupping of a tide board will have more significant impact than a narrower board, and thus requiring connectors that can withstand higher withdrawal forces. There is need for quantifying the forces developed during the differential moisture variation induced cupping. These forces will vary with lumber width, thickness, wood species and the environmental conditions of the deck. The AASHTO Standard Specification for Highway Bridges (American.. 1992) specifies the minimum lumber dimensions (Sect. 13.9.4) while remaining silent on maximum width dimensions.

Recently, a $2.5 million, 300 m (1000 ft) fishing pier in south Florida had to have its lumber decking reconstructed before its commissioning. The original deck was made up of a combination of 3 by 10 and 3 by 12 lumber boards, nailed to stringers spaced at 1150 mm (46 in). Before turning the project over to the owners, there was evidence of lumber distortion and evidence of nail withdrawal. This fishing pier deck, which was evaluated by the author of this paper, is a good example of problems that may result from cupping of lumber due to varying environmental conditions.

CUPPING STUDIES

The problem mentioned above motivated the author of this paper to conduct some studies on the behavior of wide lumber boards subjected to differential moisture variation. In the experiment, the lumber specimens were restrained flat-wise with three sets of frames equipped with proofing rings (see Fig. 2 below).

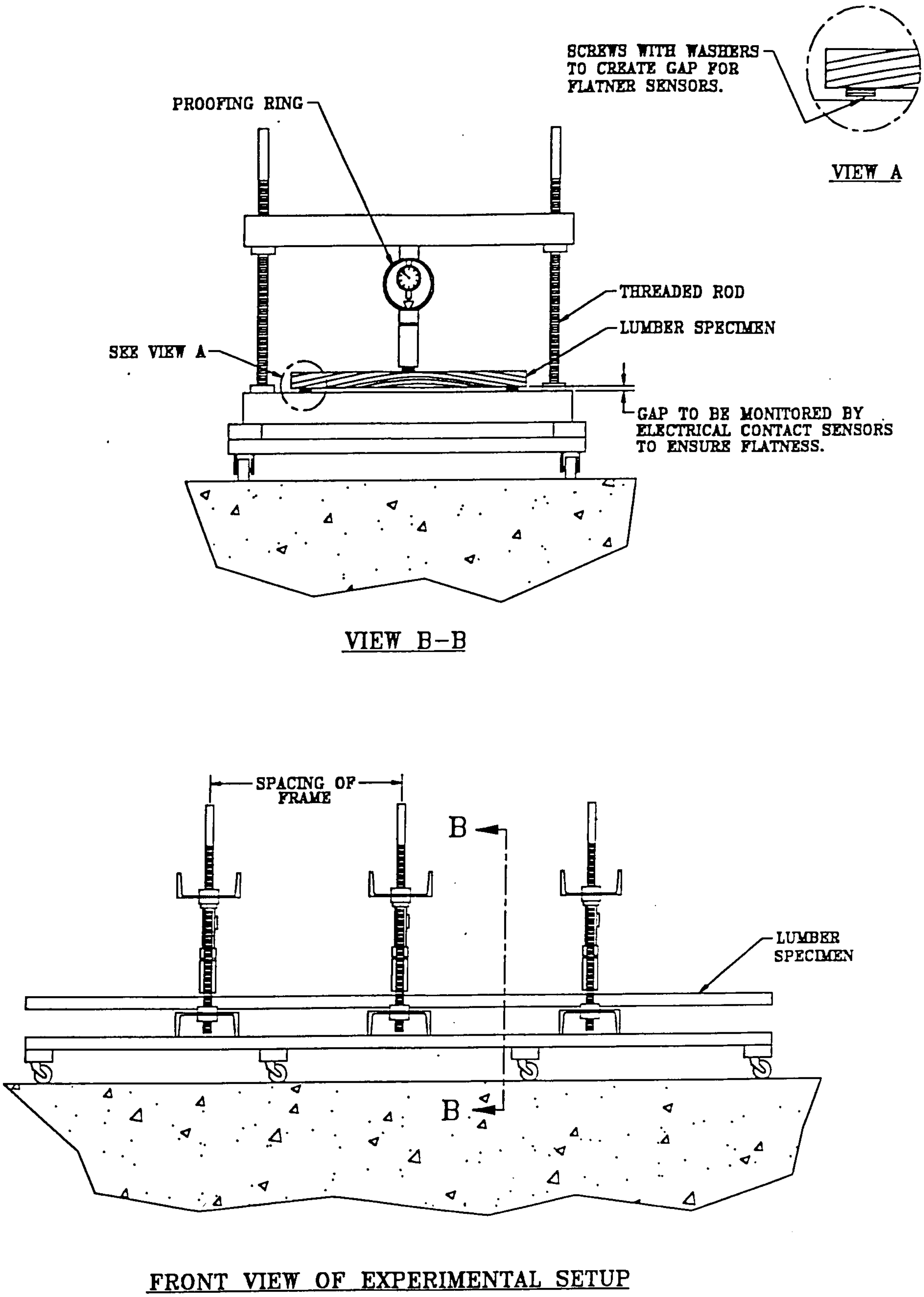

Fig. 2. A Schematic Diagram of Test Setup for this Study

Two wood screws with large washers were attached to the lower side of the lumber specimen at each frame location. The plunger of the proofing ring rest on a wood screw with a set of washers as shown in Fig 2. The spacing employed on the frames varied as a function of the thickness of the lumber boards.

Simulated rain, in the form of shower sprinklers, was allowed to fall on the upper sides of these specimens. The readings of the various dial gauges were then monitored during the testing of each specimen. The fifteen minute interval monitoring was continued until a stable reading was achieved. At this stage the rain was terminated. Shortly after, the cupped lumber was compressed to its original flat position. This was achieved by inducing a jacking force to the frames. Flatness of the specimen was judged by a beeper like device made to check return contact of the flat posture. The force required to attain this flat posture was then recorded by the proofing ring. Data pertaining to three types of outdoor deck specimens were collected. Their denominations being 1 x 6, 1 x 8 and 1 x 12 specimens. The other specimen examined was that of the 2 x 12 which is sometimes used in the construction of bridge decks.

RESULTS AND DISCUSSIONS

Presented in Fig. 3 are the variation of the forces required to bring the lumber specimens to original position after the cupping process. The values plotted are the average of three data samples. Due to the limited nature of these preliminary results no much statistical analysis can be performed. However, the preliminary trend of the results presented in Fig. 3, suggest a linear variation as the board width is increased. The change of lumber thickness from a nominal dimension of 25 mm to 50 mm (for the 300 mm wide boards) approximately doubles the magnitude of the cupping forces. We can therefore say, as expected, the magnitude of the forces increases with respect to lumber width and lumber depth.

PRACTICAL APPLICATIONS

According to National Design Specifications (NDS) (NFPA, 1991) the allowable nail withdrawal design values are a function of nail type, nail size, specific gravity of the lumber and the condition that the wood has to remain wet. NDS specifies a modification factor of 0.25, to be applied to the tabulated allowable values, for situations where the lumber is subjected to wetting and drying, as may be the case in exposed lumber decks.

Assuming all other factors, such as temperature factors, size factor, et., will not apply, the required connector (nail or lag screw) penetration in the holding (point) end can be computed as follows:

$$L_p = \frac{4F}{P} \qquad (1)$$

where F = cupping force

Lp = required minimum connector penetration in the point side

P = NDS tabulated allowable values

The required minimum penetration length computed according to Eq. 1, for the cupping forces observed in this study, are presented in Table 1 for the different lumber sizes studied. As shown in Fig. 1, only connectors in the middle of the board will resist significant cupping forces. Thus the computed minimum penetration length has to be provided by one or two connectors only. This fact has significant impact on the nature and size of connectors to be specified.

CONCLUSIONS AND RECOMMENDATIONS

From the preliminary results of the presented on going studies, the following conclusions can be drawn:

1) There are significant cupping forces developed when a lumber board is exposed to wetness from one side.
2) The magnitude of the cupping force increase with increases in both lumber width and lumber depth.
3) Lumber boards used in cyclic wetting and drying conditions require large point end penetration lengths, if the board is to be prevented from cupping.

The following recommendations can be put forward:

1) Nails, especially common wire nails, should be avoided as connectors for lumber boards exposed to cyclic wet/dry conditions.
2) There is need to continue studying the cupping behavior of lumber boards and determine “muscle” techniques of holding down the lumber during the short periods when the moisture is not uniform.

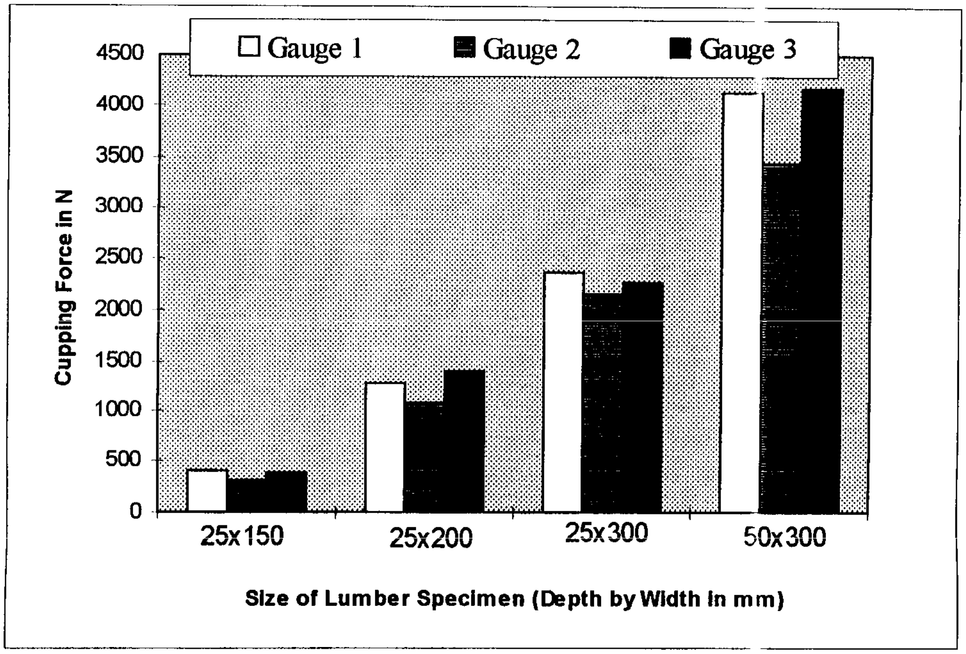

Fig. 3 Variation of Forces Produced by Lumber Cupping

Table 1. Required Minimum Penetration Depth Based on NDS Design Approach and Observed Cupping Forces

Connector Type	Connector Size mm(in)	NDS-Tabulated Allow. Values N (lb)	Required Min. Penetration in Holding End for:			
			25 x 150 mm (in)	25 x 200 mm (in)	25 x 300 mm (in)	50 x 300 mm (in)
Threaded Nails	3.0 (0.120)	182 (41)	139 (5.5)	367 (14.4)	681 (26.8)	1294 (50.9)
	3.4 (0.135)	205 (46)	124 (4.9)	327 (12.9)	607 (23.9)	1153 (45.4)
	3.8 (0.148)	223 (50)	114 (4.5)	301 (11.8)	559 (22.0)	1061 (41.8)
	4.5 (0.177)	263 (59)	96 (3.8)	255 (10.0)	474 (18.6)	899 (35.4)
	5.3 (0.207)	312 (70)	81 (3.2)	215 (8.5)	399 (15.7)	758 (29.8)
Lag Screws	6.4 (1/4)	1157 (260)	22 (0.9)	58 (2.3)	107 (4.2)	204 (8.0)
	7.9 (5/16)	1366 (307)	19 (0.7)	49 (1.9)	91 (3.6)	173 (6.8)
	9.5 (3/8)	1566 (352)	16 (0.6)	43 (1.7)	79 (3.1)	151 (5.9)
	11.1 (7/16)	1758 (395)	14 (0.6)	38 (1.5)	71 (2.8)	134 (5.3)
	12.7 (1/2)	1945 (437)	13 (0.5)	34 (1.4)	64 (2.5)	121 (4.8)
	15.9 (5/8)	2296 (516)	11 (0.4)	29 (1.1)	54 (2.1)	103 (4.0)
	19.1 (3/4)	2634 (592)	10 (0.4)	25 (1.0)	47 (1.9)	90 (3.5)
	22.2 (7/8)	2955 (664)	9 (0.3)	23 (0.9)	42 (1.7)	80 (3.1)
	25.4 (1)	3266 (734)	8 (0.3)	20 (0.8)	38 (1.5)	72 (2.8)

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