

A Method for Determining the Effect of Fasteners on the Stiffness and Strength of Wood Drive-In-Rack Pallets

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ABSTRACT: Wood pallets are increasingly stored in warehouses with drive-in or drive-through racks. A pallet needs adequate stiffness and strength to function safely under conditions where it spans the rack support rails. When the stringers run parallel to the supports, the fasteners reinforce the deckboard load-carrying ability. This report experimentally determines the effect of fasteners on pallet performance. The effect is characterized in terms of the ratio of the joint rotation modulus to a normalized deckboard bending stiffness. This approach enables the joints to be compared with pinned and rigid joints in a pallet stiffness and strength theory.

KEYWORDS: pallet, racks, warehouse, fork truck, material handling, design, wood structure, nails, fasteners, joints

Nomenclature

B_t, B_b	Cumulative deckboard widths
c	Fraction of top deck area covered by load
C_d	Deflection factor calculated from c and J
C_p	Capacity factor calculated from c and J
d_t, d_b	Nail moment arm distance
E	Modulus of elasticity
F	Fastener separation modulus
G	Geometry factor calculated from $B_t, B_b, L,$ and S
h	Deckboard-stringer separation
J	Joint modulus ratio
k_t, k_b	Normalized deckboard bending stiffness
K_t, K_b	Joint rotation modulus
K_p	Pallet stiffness (load-to-deflection ratio)
L	Effective length of top deckboards
M, M'	Outer joint bending moment
N	Regression variable
P	Pallet strength
r	Pallet unnailed/nailed strength
R	Pallet unnailed/nailed stiffness
S	Effective length of bottom deckboards
t	Deckboard thickness

T	Ratio of bending stress in top deckboards to bending stress in bottom deckboards
T_1, T_2	Term for determining location of maximum bending stress
θ	Deckboard-stringer rotation
σ	Design stress

Subscripts

b	Bottom deckboards
t	Top deckboards
3	3.05 by 63.5 mm nail
3.8,2.2	Combined 3.76 by 76.2 mm and 2.18 by 38.1 mm nails

Introduction

Wood pallets function as platforms for moving commodities between various locations with forklift trucks. They encounter service hazards including rough handling, fork truck impacts, outdoor storage, and normal stresses of loading and storage. An increasingly popular warehouse operation is to place loaded pallets in drive-in or drive-through racks where they remain while being supported only along the outside edges. It is reasonable to expect the cumulative effects of various service hazards to reduce a pallet's structural integrity, making it increasingly less suitable for rack storage. The stiffness and strength needed by a pallet to function safely in a rack are, therefore, rational design specifications. The primary purpose of this report is to experimentally determine the effect of fasteners on pallet stiffness and strength under conditions where the deckboards span the rack supports.

This report was written in conjunction with my pallet-bending theory [1] for deriving closed-form engineering formulas that evaluate pallets based on performance in a rack and accommodate a range of fastener and load characteristics. The formulas calculate the short-term, constant environmental condition bending strengths and bending stiffnesses of drive-in-rack pallets. The effects of load duration and creep accompanying long-term loading are beyond the scope of the theory. Because these pallets are often supported along the edges parallel to the outermost stringers, their deckboard and joint bending performance warrant specific attention.

A primary contribution of my earlier theory was to derive a dimensionless joint rigidity, J , as the ratio of the joint rotation modulus to a normalized deckboard bending stiffness. Compromising the effects of upper and lower joints with a single weight-averaged J led

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to approximate, but greatly simplified, pallet bending formulas. The theory assumes beam-like pallet bending with all upper deckboards being equally subjected to a uniformly distributed central load. Under actual loading conditions, the pallet center may deflect more than the midpoints of its unsupported edges. In this report, I overcome the limitations of my theory by determining empirical J 's according to actual loading conditions.

This report characterizes the effect of fasteners in terms of J , thus enabling the joints to be compared with pinned joints ($J = 0$) and rigid joints ($J = \infty$).

Three-stringer and nine-block lumber pallets supported along the edges parallel to the outermost stringers or stringer boards were tested for both stiffness and load-carrying capacity. The tests were performed first on unfastened pallets and then repeated on fastened pallets to obtain a direct measurement of the fasteners' effect.

A secondary purpose of this report is to determine if J is calculable from more fundamental fastener characteristics (i.e., the fastener separation modulus F and nailing pattern, F being the force needed to separate the deckboard from the stringer over a unit distance). This was done using the data on fastener behaviors determined from full-scale pallet bending tests. The suitability of calculating J from F was then evaluated based on calculating F from the measured J 's and comparing the results to an independent investigation [2] of other F 's.

Test Material and Procedure

Eight reusable-type pallets, half having a notched stringer and half a nine-block design, were made to compare their performance with and without fasteners. The notched four were three-stringer pallets with a conventional four-way entry, nonreversible, flush-type design, measuring 1.22 by 1.02 m (48 by 40 in.) The other four block-type pallets were full four-way entry units having similar length and width dimensions. Pallet assembly drawings are shown in Figs. 1 and 2.

The pallets were further equally divided into two species, red oak and Douglas fir. Because of the nature of this experiment, all components were fastened in the air-dried condition. The holes in all stringers and blocks were predrilled to prevent splitting.

Three types of nails were used. The stringer pallets were fastened with 3.05 by 63.5 mm (0.120 by 2½ in.) helically threaded, tempered pallet nails. For the block pallets, 2.18 by 38.1 mm (0.086 by 1½ in.) 5d cement-coated nails were first used to fasten the top deckboards to the subdeck boards. Then 3.76 by 76.2 mm (0.148 by 3 in.) nails were used to complete the upper assembly. The nails used in the bottom were the same as those used in the stringer pallets. A more complete description of the nails is given in Table 1.

Two stringer and two nine-block pallets were reserved for the stiffness portion of the experiment, and all eight pallets were in-

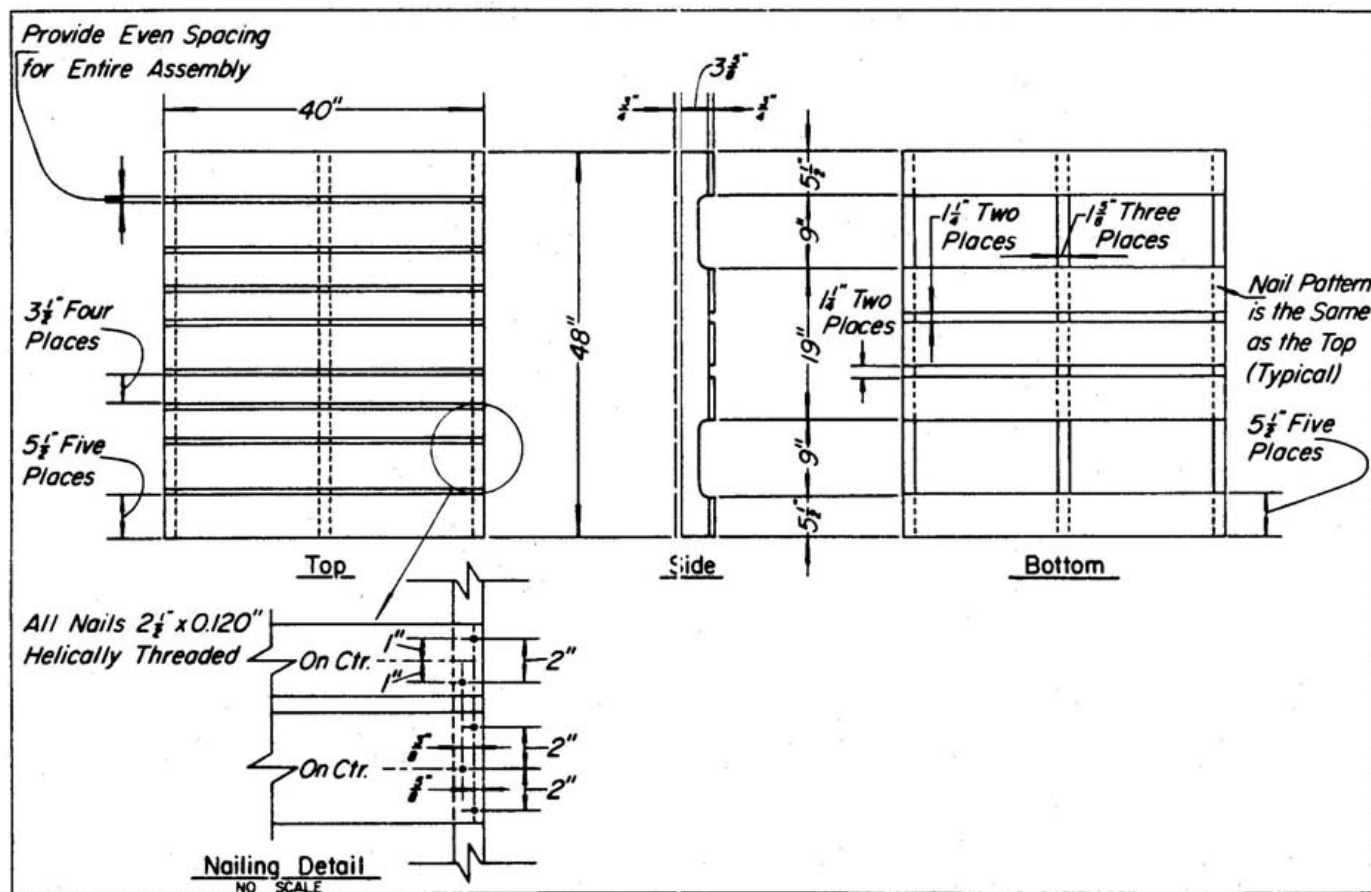


FIG. 1 - Assembly drawing with nominal dimensions of the 1.22 by 1.02 m (48 in.) by 40 in.) three-stringer pallet used in this study (11 in. = 25.4 mm).

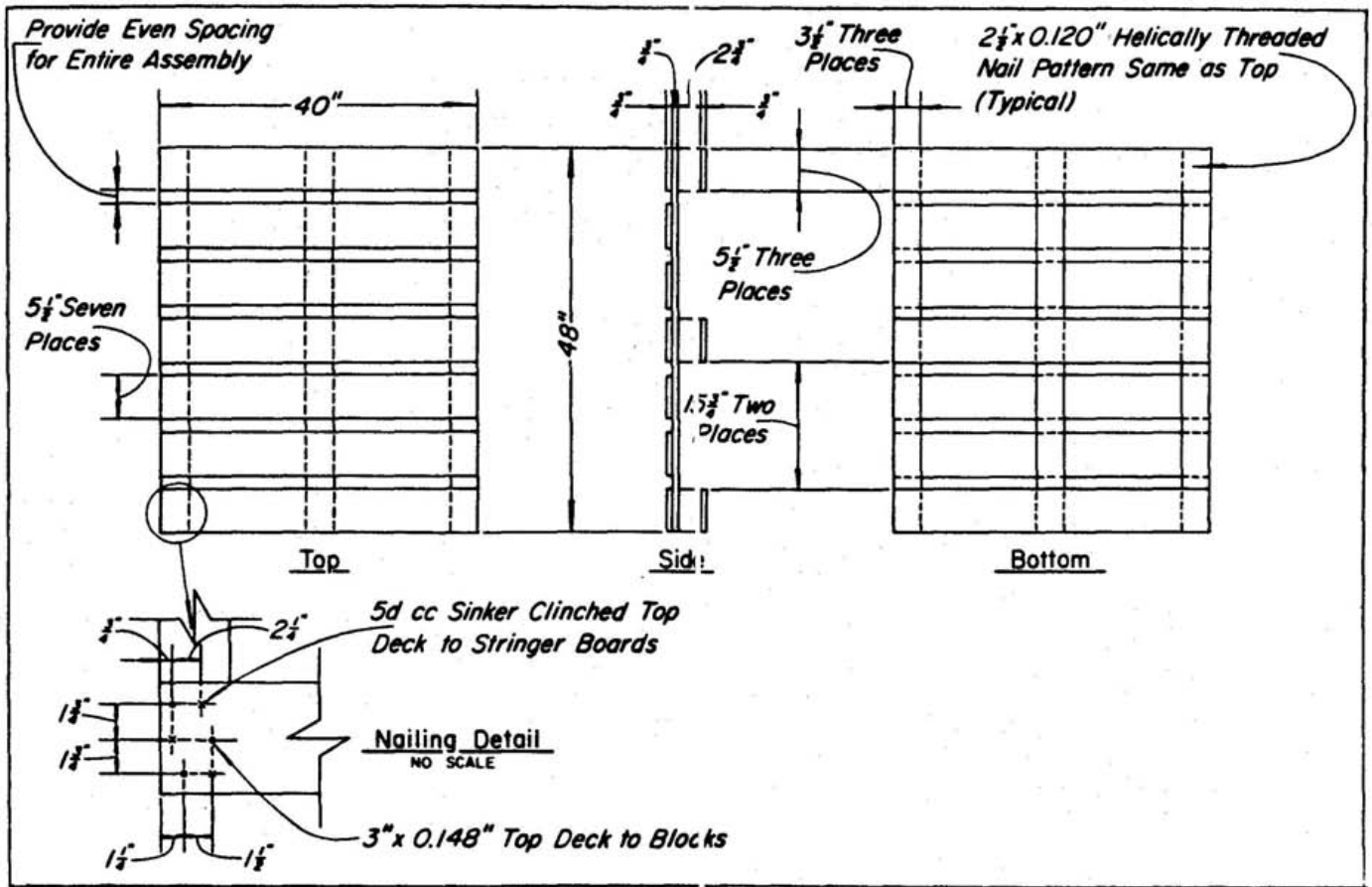


FIG. 2 - Assembly drawing with nominal dimensions of the 1.22 by 1.02 m (48 by 40 in.) nine-block pallet used in this study (1 in. = 25.4 mm).

TABLE 1 - Descriptions of nails used in this study.

Description	Wire Drilling		MIBANT Test Value ^a		Function	Predrilling Required?		
	Diameter	Nominal Length	Range, %	Average, %				
	mm	in.	mm	in.				
Helicely threaded tempered pallet nails ^b	3.05	0.120	63.5	2 1/2	16 to 19	17	fastening all joints in notched stringer pallets, but only bottom deckboard-block joints in 9-block design	yes
Helicely threaded "hardened" pallet nails ^c	3.76	0.148	76.2	3	5 to 6	7	fastening top deckboard-subdeckboard assembly to blocks	yes
5d cement-coated nails	2.18	0.086	38.1	1 1/2	fastening deckboards of 9-block pallets to subdeckboards	no

^aStern, E. G., "The MIBANT Quality-Control Tool for Nails," Bulletin 100. Virginia Polytechnic Institute and State University, Blacksburg, VA, 1971.

^bShanks threaded with five flutes at a helical angle of about 60° with a plane perpendicular to the axis.

^cFour flutes at about 60°.

involved in the strength determination tests. The first group of pallets, consisting of a Douglas fir stringer (DFS1), red oak stringer (ROS1), Douglas fir block (DFB1), and andredoak block (ROB1), was tested for both stiffness and strength. A second replicate group (DFS2, ROS2, DFB2, and ROB2) was tested only for strength.

Stiffness Test Method

The stiffness portion of the experiment tested Pallets DFS1, ROS1, DFB1, and ROB1 in each of four load and support configurations with the pallet parts placed together without fasteners in the

testing apparatus. For each test the pallet was centered over and supported by two parallel pipes spaced either 914 or 991 mm apart and running parallel to the outermost stringers or stringer boards. A movable frame applied a load at a rate of 10 mm/min through an airbag overlapping the pallet's perimeter. To simulate conditions where the product covers the full deck or a partial area, the force was applied either directly via the airbag or by separation with a 996 by 831 mm polyurethane cushion covering the centermost two-thirds area of the top deck.

Load was measured using an electronic sensing transducer attached to the frame, and deflection was measured with a linear variable differential transformer (LVDT) positioned beneath the centermost point of the pallet. Stiffness equaled the slope of the linear portion of the load-deflection trace recorded up to a force large enough (less than 500 kg) to linearize the curve. Loading and unloading the pallet twice in succession gave an average stiffness.

After testing all unfastened pallets, the pallet parts were nailed together in their original arrangements, and the whole test sequence was repeated.

Strength Test Method

The fastened pallets retained from the stiffness test were tested again for load-carrying capacity along with similar, but unfastened, pallets: DFS2, ROS2, DFB2, and ROB2. The supports, loading rate, and instrumentation were the same as for the stiffness tests. Because the airbag could not transmit high loads, it was replaced by a channel iron and pipe centered between and parallel to the support pipes and connected to the movable frame of the test machine by a ball bearing.

Pallets DFS1, ROS2, DFB2, and ROB1 were supported over 914-mm spans and Pallets DFS2, ROS1, DFB1, and ROB2 over 991-mm spans. The test was halted when, according to the load-deflection trace, the applied load first decreased with increasing deflection. Strength equaled this maximum. Because these were destructive in nature, only one test per pallet was performed.

Joint Behavior Theory

When a pallet is loaded and supports run parallel to the outermost stringers, the deckboards bend and the joints tend to open. As shown in my theory [1], pallet stiffness and strength increase nonlinearly by increasing the dimensionless joint rigidity, derived as a ratio of the joint rotation modulus to a normalized deckboard bending stiffness.

The joint rotation modulus K_t or K_b for, respectively, the top or bottom decks is the cumulative nailed joint rigidities equaling the bending moment M per unit deckboard rotation θ away from the stringer. For example, the assumed bending condition indicated in Fig. 3 gives

$$K_t = M/\theta \quad (1)$$

The normalized deckboard bending stiffness k_t or k_b is the cumulative deckboard bending stiffness per effective length. Using subscripts t or b to indicate either top or bottom deckboards, the k 's are calculated from the wood elastic modulus E ; the cumulative deckboard widths B_t and B_b ; the deckboard thickness t ; and the effective deckboard lengths L , for the top, equaling the distance between the inside edges of the outermost stringers, and S , for the bottom, equaling the distance (span) between the supports.

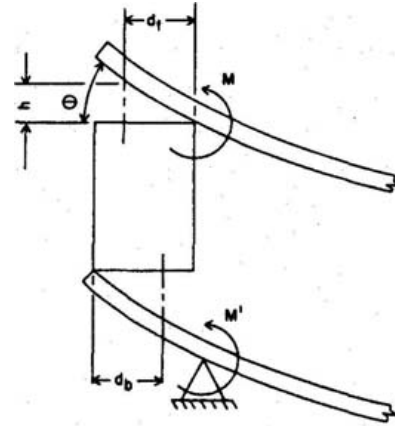


FIG. 3—Section of pallet around an outside stringer showing the theoretical deckboard-stringer separations due to a load on the pallet in a rack. Bending moments M and M' act at the ends of the deckboards and are caused by the nailed joints.

$$k_t = \frac{EB_t t^3}{12L} \quad (2a)$$

$$k_b = \frac{EB_b t^3}{12S} \quad (2b)$$

The joint modulus ratio J is the dimensionless joint rigidity derived assuming that K_t/k_t and K_b/k_b are nearly equal. Stiffness and strength formulas then followed from the approximate formulas:

$$K_t = Jk_t \quad (3a)$$

$$K_b = Jk_b \quad (3b)$$

As will be shown, an average J fitting Eqs 3a and 3b can be empirically determined without knowing E , B_t , B_b , t , L , and S . Pinned end conditions yield $J = 0$ and fixed end conditions, $J = \infty$.

Experimental Evaluation of Joint Modulus Ratio

From Stiffness Tests

The joint modulus ratio is determined empirically from bending tests performed on pallets first without and then with fasteners. As was derived in Ref 1, pallet stiffness K_p for the loading condition under discussion is given by

$$K_p = \frac{16Et^3G}{C_d} \quad (4)$$

The geometry factor G is calculated from

$$G = \frac{B_t}{L^3} + \frac{B_b}{S^3} \quad (5)$$

and the deflection factor C_d , being a function of J and c (where c as defined here is the fractional area of the top deck covered by the centrally applied load), is given by

$$C_d(J, c) = \frac{8 + J}{2 + J} \left[1 + \frac{c^2}{2} \left(\frac{c(2 + J) - (8 + 2J)}{8 + J} \right) \right] \quad (6)$$

For a pallet without fasteners, $J = 0$ in calculating C_d . For a pallet tested first without and then with fasteners under equal load coverages, all the parameters used in Eq 4 remain constant except J . Therefore, for any given c , J can be calculated from the stiffness ratio R determined from two tests where

$$R = \frac{K_p(\text{without fasteners})}{K_p(\text{with fasteners})} = \frac{C_d(J, c)}{C_d(0, c)} \quad (7)$$

Upon entering Eq 6 into Eq 7 and then evaluating J in terms of R , one obtains for $c = 1$:

$$J = \frac{2(1 - R)}{R - 0.2} \quad (8a)$$

and for $c = 2/3$:

$$J = \frac{2(1 - R)}{R - 0.2159} \quad (8b)$$

From Strength Tests

Having data for destructive load-carrying capacity tests on pallet replicates tested both without and with fasteners, the joint modulus ratio can be determined as is similarly done from stiffness data. As was derived in Ref 1, pallet load-carrying capacity P for the loading condition of this study is given by

$$P = \frac{\sigma S^2 t^2 G}{C_p T} \quad (9)$$

where σ is the wood design stress. The capacity factor C_p , also a function of J and c , is given by

$$C_p(J, c) = \frac{3}{4} \frac{4 + J}{8 + J} C_d \quad (10)$$

T , a correction factor, is given by $T = 1$ when the maximum bending stress occurs in the bottom deckboards. When the maximum occurs in the top deckboards:

$$T = \frac{1}{4C_p} \left[(c^3 - 3) \frac{J}{2 + J} + 3(2 - c) \right] \left[\frac{S^2}{L^2} + \frac{B_b L}{B_t S} \right] - \frac{B_b L}{B_t S} \quad (11)$$

By measuring the strength ratio r between replicate pallets, J can thus be determined from the equation

$$r = \frac{P(\text{without fasteners})}{P(\text{with fasteners})} \quad (12)$$

For loads applied with a channel iron and pipe, $c = 0$, and one obtains the following evaluation of J in terms of r after entering Eqs 9 to 11 into Eq 12:

$$J = \frac{2(1 - r)}{r - 0.5} \quad (13)$$

Experimental Results for Joint Modulus Ratio

Stiffness Data

The pallet bending test stiffness data arranged in a 2^4 full factorial are given in Table 2. The usual factorial analysis methods tested the effects of the four pallet variables—species, design, covered area, and span—and their interactions on the observed R 's. The results appear in a frequency diagram (Fig. 4). A linear equation formulated for R in terms of only the main effects and interactions found significant at the 95% confidence level smoothed the R data. All main pallet variables, the two-way species-design interaction, and the three-way species-design-covered area interaction affected R .

Smoothed R values based only on the most significant effects and entered into Eqs 8a and 8b gave J values for the full top deck and centermost two-thirds area loading conditions. The calculation results are given in Table 2. The joint modulus ratio ranged between 0.837 and 8.02, characterizing the dimensionless joint rigidity in terms of the pallet variables. The average J determined for all the stringer pallets was 1.78. The average J for all the block pallets was 4.89. These values are compared in the next section with those obtained from strength data.

Strength Data

The data for pallet load-carrying capacity tests are given in Table 3 arranged according to a 2^{4+1} fractional factorial. The effects of the four pallet variables—species, design, span, and fasteners—and their interactions on the observed strengths were again obtained by conventional factorial analysis methods. A frequency diagram of the results appears in Fig. 5. Only the effects of design and fasteners were found to significantly affect strength at the 95% confidence level. Even though species and span obviously affect the strength of wood beams, their effects on the pallets used here were indeterminate from these tests.

A linear equation formulated for P in terms of the effects of design and fasteners smoothed the data and yield predicted P 's to use in Eq 12. Values for r were then calculated from the predicted P 's for each pallet with and without fasteners. The results gave predicted strength ratios of $r = 0.756$ for all stringer pallets and $r = 0.659$ for all block pallets. These r predictions entered into Eq 13 yielded calculated J values. The results are given in Table 3. All stringer pallets are characterized by $J = 1.90$ and all block pallets by $J = 4.29$. These values compare very well with the values 1.78 and 4.89 previously determined from stiffness data. This close agreement suggests that J remains constant up to pallet failure and that nondestructive stiffness tests are adequate for determining J .

Analytical Method for Determining Joint Modulus Ratio

Simultaneously loading all pallet deckboards and fasteners eliminates the problems of their variation. The J value so obtained char-

TABLE 2 —Pallet stiffness data.

Pallet No.	Experimental Design Variable				Stiffness				Joint Modulus Ratio (J) ^a
	Species	Design	Covered Area, %	Span, mm	Without Fasteners,	With Fasteners,	Stiffness Ratio (R)		
					MN/m	MN/m	Observed	Smoothed	
DFS1	Douglas fir	stringer	100	914	1.46	1.89	0.761	0.764	0.837
ROS1	red oak	stringer	100	914	1.29	1.99	0.646	0.630	1.72
DFB1	Douglas fir	block	100	914	1.18	2.06	0.572	0.569	2.34
ROB1	red oak	block	100	914	.956	2.12	0.452	0.438	4.71
DFS1	Douglas fir	stringer	66.7	914	1.03	1.34	0.764	0.767	0.845
ROS1	red oak	stringer	66.7	914	0.839	1.56	0.539	0.571	2.42
DFB1	Douglas fir	block	66.7	914	0.652	1.26	0.518	0.510	3.33
ROB1	red oak	block	66.7	914	0.609	1.40	0.434	0.442	4.95
DFS1	Douglas fir	stringer	100	991	1.07	1.54	0.696	0.695	1.23
ROS1	red oak	stringer	100	991	1.04	1.81	0.567	0.561	2.44
DFB1	Douglas fir	block	100	991	0.859	1.81	0.474	0.500	3.34
ROB1	red oak	block	100	991	0.691	1.93	0.358	0.369	7.45
DFS1	Douglas fir	stringer	66.7	991	0.788	1.13	0.698	0.698	1.25
ROS1	red oak	stringer	66.7	991	0.713	1.40	0.511	0.512	3.48
DFB1	Douglas fir	block	66.7	991	0.529	1.16	0.456	0.441	4.97
ROB1	red oak	block	66.7	991	0.480	1.27	0.378	0.373	8.02

^a Calculations based on smoothed R's.

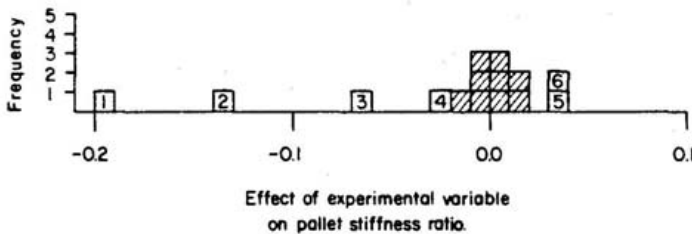


FIG. 4 —Frequency diagram of the effects of species, design, covered area, span, and all interactions on the pallet unnailed/nailed stiffness ratio. All effects are plotted; only significant effects that deviate at the 95% confidence level from a normal distribution are numbered. Legend: (1) Design. (2) Species. (3) Span. (4) Coverage. (5) Species X design. (6) Species X design X coverage.

acterizes an average pallet joint. The method offers the advantage of sensing fastener behavior subject to the actual loading condition: within a pallet. Tests of individual joints may yield more specific fastener characteristics but raise uncertainties about duplicating loading conditions in a combined pallet. Useful fastener data are nevertheless available and thus warrant that we offer a means to compare our results with previous research.

Mack obtained by direct measurement a separation modulus in the fastener direction for individual deckboard stringer joints [2]. He used the results in engineering calculations to compare the predicted bending stiffnesses of pallet sections with experimental data. Using the separation modulus was found to accurately describe the joint behavior for green red oak and dry southern pine.

Based on Mack's results, K_t and K_b are calculable from the fastener separation modulus F and the number and position of fasteners. The relation of K_t (and also K_b) to F depends on the number of fasteners and their distances from the deckboard and outermost stringer edge contact points.

In deriving K_t , M is the cumulative moment due to summing the nail withdrawal forces times their level arms (Fig. 3). Given F for each individual nail, its distance from the inside stringer edge d_t , and the separation h (Fig. 3):

$$M = \sum F h d_t \tag{14}$$

For a small angle θ :

$$h = d_t \sin \theta = d_t \theta \tag{15}$$

TABLE 3 —Pallet load-carrying capacity data.

Pallet No.	Experimental Design Variable			Maximum Load			
	Species	Design	Span, mm	Without Fasteners,	With Fasteners,	Predicted Strength Ratio (r)	Joint Modulus Ratio (J)
				Mg	Mg		
DFS1	Douglas fir	stringer	914	...	3.48	0.756	1.90
ROS2	red oak	stringer	914	2.98	...	0.756	1.90
DFB2	Douglas fir	block	914	1.71	...	0.659	4.29
ROB1	red oak	block	914	...	3.10	0.659	4.29
DFS2	Douglas fir	stringer	991	3.06	...	0.756	1.90
ROS1	red oak	stringer	991	...	4.18	0.756	1.90
DFB1	Douglas fir	block	991	...	2.62	0.659	4.29
ROB2	red oak	block	991	1.82	...	0.659	4.29

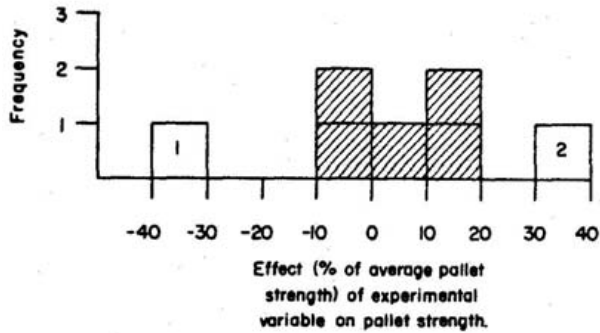


FIG. 5—Frequency diagram of the effects of species, design, span, fasteners, and all interactions, based on a fractional factorial, on pallet strength. All effects are plotted; only the significant effects that deviate at the 95% confidence level from a normal distribution are numbered. Legend: (1) Design, (2) Fasteners.

If identical nails are used throughout the pallet and assuming all upper outer joints rotate equally, entering Eq 15 into Eq 14, and Eq 14 into Eq 1, equates Eq 1 to Eq 3a giving

$$K_t = F \sum d_t^2 = Jk_t \quad (16)$$

Then, entering Eq 2a into Eq 16 and reformulating Eq 16 in terms of J gives

$$J = \left(\frac{12L \sum d_t^2}{EB_t t^3} \right) F \quad (17a)$$

A similar expression likewise formulated for the bottom deck is

$$J = \left(\frac{12S \sum d_b^2}{EB_b t^3} \right) F \quad (17b)$$

where d_b is an individual nail's distance from the outside stringer edge (Fig. 3). Having L , S , B_t , B_b , E , t , F , $\sum d_t^2$, and $\sum d_b^2$ data, J can thus be calculated from Eqs 17a and 17b as some weighted average of the two predictions.

Comparison Between Analytical and Experimental Methods for Determining J

The J 's from Eq 17, calculated from measured F 's, should theoretically equal the predictions of Eq 8. An indirect test of the match is made by comparing least squares F calculations, derived from a

regression analysis of the J data, to measured values. While measuring F was beyond the scope of this report, Mack's data provide a reasonable check.

Measured values of L , S , B_t , B_b , E , and t and calculated values of $\sum d_t^2$ and $\sum d_b^2$ were first determined and are recorded in Table 4. The elastic moduli were obtained directly from bending tests on deckboard wood samples cut after completing all pallet bending tests.

Next, regression variables N_3 and $N_{3.8.2.2}$ were calculated for the pallet nails from the parenthetical expression of Eqs 17a and 17b. N_3 is identified with the 3-mm nail and $N_{3.8.2.2}$ with the combined 3.8 and 2.2 mm nails, since the nailing pattern precluded deriving separate variables. Finally, treating the stiffness test J data as dependent variables and the calculated N 's as independent variables gave entries to 32 equations (one matching the N 's of the top deck and another the bottom deck, with each of 16 J 's) of the form

$$J = N_3 \times F_3 + N_{3.8.2.2} \times F_{3.8.2.2} \quad (18)$$

The regression constants F_3 and $F_{3.8.2.2}$ thus predict F values associated with the corresponding nail conditions.

The Douglas fir and red oak pallets behaved differently as indicated by significant F differences at the 95% confidence level.

For Douglas fir $F_3 = 509$ kN/m; $F_{3.8.2.2} = 386$ kN/m

For red oak $F_3 = 663$ kN/m; $F_{3.8.2.2} = 487$ kN/m

Based on Mack's results for other nails and woods, F depends on the deckboard-stringer separation. F being initially very large then rapidly decreasing to a minimum (final) value. His final F measurements ranged from 700 to 1790 kN/m, depending on the nail and wood. The F values obtained here are of the same magnitude as values given by Mack. This suggests the feasibility of calculating J values directly from F values. More tests are needed, however, to verify the procedure.

Summary and Conclusions

In previous research, I developed a pallet bending theory for short-term constant environment conditions. Based on that theory, this present study characterizes the effect of fasteners on the stiffness and strength of drive-in-rack pallets. Two popular pallet designs, a nine-block and a three-stringer, were tested with and without nails under conditions simulating rack storage. The unnailed/I ailed stiffness and strength ratios predict a dimensionless joint rigidity. The effect of pallet design was compared with the effects of species and loading conditions. In terms of a joint-modulus ratio,

TABLE 4 - Data for analysis nail withdrawal modulus.

Pallet No.	Parameters to Deckboard End Rotation Modulus						Summation of Nail Moment Arms Squared				
	Modulus of Elasticity (E), GPa	Cumulative Deckboard Width, mm		Deckboard Effective Length, mm			Deckboard Thickness (t), mm	Top Deck ($\sum d_t^2$), cm ²			Bottom Deck ($\sum d_b^2$), cm ²
		Top (B_t)	Bottom (B_b)	Top (L)	Bottom (S)	991		3.05 by 63.5 mm Nail	3.76 by 76.2 mm Nail	2.18 by 38.1 mm Nail	
DFS1, DFS2	12.2	1050	693	935	914	991	15.1	103	0	0	67.1
ROS1, ROS1	11.1	986	653	935	914	991	17.9	103	0	0	67.1
DFB1, DFB2	12.2	970	417	838	914	991	19.1	0	221	517	221
ROB1, ROS2	11.1	912	391	838	914	991	17.9	0	221	517	221

the block pallets had joints averaging 2.7 times stiffer than the stringer pallet joints. Under the same conditions, red oak pallets had joints averaging 1.9 times stiffer than did Douglas fir pallets. Smaller, but still significant, effects were observed as the support span and the load area were changed to provide different loading conditions.

A weight averaging analysis is proposed for calculating the joint-deckboard modulus ratio from the fastener separation modulus. Some limited comparisons with data support the analysis.

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