DEVELOPMENT OF FLEXURAL DESIGN VALUES FOR PALLET SHOOK

by

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(ABSTRACT)

Rational design of wood pallets requires estimates of average flexural properties of pallet lumber of many species and visual grades. The objective of this study was to develop procedures for estimating these design values for use in a first-order second-moment design format.

Preliminary studies were performed to assess the effects of increased loading rates on in-grade flexural data, size effects between deckboard and stringer properties, and the effectiveness of the ASTM strength ratio concept as applied to pallet shook. An increased load rate (ten times the ASTM rate) resulted in an 8.0% increase in average MOR and a 4.7% increase in average MOE. No definite conclusions could be reached concerning the relative strength of deckboards vs. stringers. Several factors, other than a statistical size effect, may influence their relative strength. Estimated strength ratios (ESR) generally underpredicted the experimentally determined actual strength ratios (ASR). As knot size increased, the ESR increasingly underpredicted the ASR.

Two approaches were used to derive pallet shook design values. The best is full-size in-grade testing of commercial material. However, only yellow-poplar and eastern oak species have currently been evaluated in this manner. For all other species, a modified procedure based largely on the methods of ASTM D 2555 and D 245 was recommended. This procedure yields conservative estimates of strength for grades allowing large knots.

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1.0 INTRODUCTION

The main objective of the four year Cooperative Pallet Research Program (PRP) was to develop a rational design procedure for wooden pallets based on load carrying capacity, stiffness performance, and durability. The design procedure, called PALLET DESIGN SYSTEM (PDS), is a computerized, first-generation, reliability-based design procedure. PDS uses a first-order, second-moment approach and therefore requires estimates of the mean and standard deviation of both the load effects and member resistances.

The member resistances are measured in terms of bending strength and stiffness. Unfortunately, little information is currently available on the flexural properties of cut-to-size pallet shook. Two investigations (20,45) of the flexural properties of yellow-poplar and eastern oak pallet shook were recently made at Virginia Tech. Other species must be researched to build a reasonable data base.

However, it may be many years before these in-grade investigations of various species of pallet shook can be completed. For PDS to be immediately useful, design values for pallet shook of any species or combination of species must be estimated in some manner. Therefore, interim methods of developing estimates of design values from existing data are needed. The main objective of this thesis is to describe these methods.

ASTM D 2555 (5) and ASTM D 245 (4) provide methods of establishing strength and stiffness working stress design values for any grade and species of lumber. However, these standard methods establish near minimum strength values as the basis for design and are not usually employed to establish the variability and mean of strength or stiffness values for relatively short full-size pallet lumber. Modifications to these standard methods are necessary to establish mean strength and stiffness values for pallet shook for use as PDS input. Other methods are required to estimate the variability of the strength and stiffness values.

The ASTM D 245 (4) method of deriving design values for full-size structural lumber is based on the use of certain adjustment factors. One factor, the strength ratio, is defined as the ratio of the strength of the piece of lumber, including knots, cross-grain, splits, checks, and other strength reducing defects, to the hypothetical strength of the piece had it been clear and straight grained. These strength ratios are used to modify the clear wood strength value in order to predict the strength of a piece with defects. This strength ratio approach could easily be incorporated into a method of deriving design values for pallet shook of both hardwood and softwood species. However, the effectiveness of the ASTM D 245 strength ratios in predicting the strength of hardwood pallet shook should first be determined since the strength ratios were developed for softwood structural lumber and have only recently been used with hardwoods.

Extensive research on softwoods has shown that an increased beam depth results in decreased bending strength. Unfortunately, little or no information on similar effects with hardwood beams of sizes commonly used by the pallet industry is available. Results from Holland's (20) and Spurlock's (45) studies of hardwood pallet shook indicate that any depth effect on bending strength for hardwoods may vary by species. Holland tested yellow-poplar, a diffuse-porous species, and found the average MOR of deckboards to be greater than that of stringers. This might be expected due to the greater depth of stringers. However, Spurlock tested oak, which is ring-porous, and found the average MOR of stringers and deckboards to be approximately equal. This would seemingly indicate a lack of depth effect on MOR.

ASTM D 245 uses a size factor to adjust bending stress values for different depths. This size factor, $F = (2/d)^{1/9}$, assumes center point loading and a span-to-depth ratio of 14. This formula is technically only valid for clear, straight-grained Douglas-fir at 12% moisture content (7). Its applicability to pallet shook needs to be investigated before the size factor is used to develop estimated design values and before these estimated values can be compared with experimentally obtained values of full-size shook.

Research has shown that an increased rate of bending deformation used in testing may result in increased flexural strength and stiffness for clear material (19,46). However, research on full-size lumber with defects has shown that increased load rates lead to increased strength and stiffness only for the stronger pieces in a population (13,27).

The two recently completed investigations at Virginia Tech on the bending properties of oak and yellow-poplar pallet shook (20,45) used loading rates approximately 10 times greater than the ASTM loading rate. The data from these two studies may require adjustment for the rapid loading rate used in testing before it can be used in any derivation of design values or before it is compared to data obtained at slower rates of loading. The evaluation of the effect of increased loading rates is also desirable since future testing of other species of full-size pallet shook will likely use increased loading rates.

2.0 OBJECTIVES

The overall objective of the research described in this thesis is to recommend methods of developing design values for pallet shook for use in the PALLET DESIGN SYSTEM.

Three preliminary studies were required. The objective of the first study was to determine if increased loading rates during testing influence the bending strength and stiffness distribution of green hardwood pallet shook. If loading rate has a significant influence, then adjustment factors to account for the increased rates are required.

The objective of the second study was to determine any depth effect on bending strength of green hardwood pallet shook.

The objective of the third study was to evaluate the effectiveness of the strength ratios given in ASTM D 245 in predicting the effect of defects on bending strength of green hardwood pallet shook.

The final objective was to recommend interim methods of developing estimates of design values from existing data for pallet shook of any species or combination of species and any grade or combination of grades for use in PDS.

3.0 RATE OF LOADING STUDY

3.1 INTRODUCTION

Research has shown that increased bending load rates may result in increased flexural strength and stiffness for clear material (19,46). However, research on full-size lumber with defects has shown that increased load rates lead to increased strength and stiffness only for the stronger pieces in a population (13,27).

Two recently completed investigations at Virginia Tech on the bending properties of oak and yellow-poplar pallet shook (20,45) used loading rates approximately 10 times greater than the ASTM loading rate. The data from these two studies may require adjustment for the rapid loading rate used in testing before it can be used in any derivation of design values or before it is compared to data obtained at slower rates of loading. The evaluation of the effect of increased loading rates is also desirable since future testing of other species of full-size pallet shook will likely use increased loading rates.

The objective of this study was to evaluate any effect of an increased bending load rate on the flexural strength and stiffness of full-size pallet shook.

3.2 REVIEW OF LITERATURE

The term "rate of loading" implies a constant increase in the load applied to a specimen, whereas the term "rate of deformation" implies a constant rate of increase in the deformation or deflection. Research on loading rate effects is usually conducted using various rates of deformation measured in terms of unloaded cross-head travel of a testing machine. However, this is typically refered to as "rate of loading" in the literature. Therefore, in this thesis "rate of loading" refers to rate of deformation of the specimen measured in terms of unloaded cross-head travel of a testing machine, unless specifically stated otherwise.

Early research on small, clear specimens showed that bending strength of clear wood is affected by rate of loading. Tiemann (46) reported that the bending strength of clear wood increased with increased rate of loading, as did Wood (55). Liska (26) investigated rate of loading effects on small, clear specimens of sitka spruce, Douglas-fir, birch, and maple at approximately 12% MC. He found that the MOE was approximately the same for all loading rates but that MOR increased with increase in loading rate. Liska reported that if loading time changed by 100%, a change in strength of 2.5% in the opposite direction was observed. Deflection at maximum load was the same for all loading rates in softwoods but increased as loading time decreased in hardwoods. Brokaw and Foster (11) also studied rate of loading effects on small clear specimens of sitka spruce and Douglas-fir at 12% MC. They, too, reported that MOE was not significantly affected but that bending strength increased with increased rate of loading. Deflection at failure was observed to be constant regardless of loading rate.

James (21) investigated rate of loading effects on small, clear, matched specimens of sweetgum, yellow-birch, and red oak at both green and air-dry moisture contents. MOR was seen to increase with increased loading rate, with a greater increase in strength for the green than the air-dry specimens. This is in agreement with Gerhards (19). James reported a small increase in MOE for faster loading rates, with a slightly higher increase in air-dry than green specimens. Stress at proportional limit increased with faster loading rates, again with a slightly higher increase for air-dry than green specimens. In a similar study of ponderosa and loblolly pine, James (22) reported a 7% increase in strength with a tenfold increase in loading rate for air-dry specimens but a 12% increase in strength for the green specimens. Stress at proportional limit increased at faster loading rates with a greater increase seen for the green than for the air-dry specimens. MOE and deflection at maximum load were independent of loading rate.

While early research was limited to small clear specimens, recent studies have dealt specifically with full-size, commercially available lumber. Madsen (27) investigated rate of loading effects for dry lumber in bending using both defect free and No. 2 grade kiln-dried Hem-fir 2 x 6's. In this study, rate of loading refers to a stepwise increase in load, or ramp loading. Madsen found that for No. 2 grade, the average MOE decreased with decreased loading rates, but for the clear material, the average MOE was fairly constant for all loading rates. The rate of loading effect was dependent on material strength; increased rates led to increased bending strength for the strong pieces but did not significantly influence bending strength of the weaker pieces. Spencer (44), in a study of bending of No. 2 and better Douglas-fir 2 x 6's at 12% MC, also found that rate influenced the stronger pieces but not the weaker ones.

Madsen (28) also investigated rate of loading effects on wet lumber in bending using No. 2 grade green Hem-fir 2 x 6's and ramp loading. Results of this study were essentially the same as results of the dry lumber study. There was a slight loading rate effect on MOE and the loading rate effect on bending strength was dependent on material strength. Madsen concluded that moisture does not significantly affect the influence of loading rate on the bending strength and stiffness of wood.

In a report on the In-Grade Testing Program, Madsen (29) states that fast loading rates have not been shown to significantly affect bending strength values for commercial lumber, which are based on the lower fifth percentile. Thus, it is unneccessary to use slow rates of loading as called for by ASTM standards. DeBonis, Woeste, and McLain (13) recently investigated the rate of loading influence on bending tests of No. 2 Dense kiln-dried southern pine 2 x 4's. Rates of loading of 0.2 in./min. and 5.0 in./min. were used. No statistically significant differences in MOE or MOR distributions were seen. While rate of loading did influence the stronger pieces, the weaker pieces were relatively unaffected by loading rate. This indicates that in-grade strength and stiffness data used in deriving allowable design values may not require adjustments for rapid testing rates if design values are based on a lower percentile.

3.3 MATERIALS AND METHODS

Eighty yellow-poplar stringers (2 x 4 x 48 inch nominal size), 80 yellow-poplar deckboards (1 x 6 x 40 inch nominal size), 80 mixed oak stringers, and 80 mixed oak deckboards, all at green moisture content, were obtained for this study. These two species at green moisture content were selected to correspond directly to the two recent investigations at Virginia Tech (20,45). The shook was randomly sampled from inventory at Williamsburg Millwork Corporation in Bowling Green, Virginia. After wrapping in six mil polyethelene, the shook was transported back to the Sardo Laboratory at Virginia Tech.

Once at the laboratory, the shook was randomly stacked and one edge of each stringer and one face of each deckboard were systematically marked to indicate the compression side during subsequent testing. Thus, the compression and tension sides were determined independent of the presence and location of defects. The shook was then re-wrapped and stored in a cold chamber kept at 34 ° F and 85% relative humidity. The shook remained wrapped and in the cold chamber at all times except when being measured, mapped, and tested. Before use, the shook was allowed to reach equilibrium temperature with the laboratory (72 ° F) while remaining wrapped in plastic. After use, the shook was re-wrapped and returned to the cold chamber. The shook was thus kept from drying or biodegradation during the several week span required to complete the study.

All major defects expected to influence strength or stiffness were measured according to ASTM D 245 (4). The location and size of the defects within the piece were computer recorded. Appendix A gives a detailed description of the defect mapping and coding procedure. The cross-sectional dimensions of each piece (width and thickness, each the average of three separate measurements within the middle third of the length) were recorded to the nearest 0.001 inch with dial calipers. The MOE of each piece was determined non-destructively from the average of dead-weight deflection tests of both sides, with both stringers and deckboards tested flatwise (as a plank). Stringers were tested at a 45-inch span and deckboards were tested at a 36-inch span. A dial gauge was used to record deflection at mid-span to the nearest 0.001 inch. A reference weight of 6.87 lbs. and measuring weight of 22.07 lbs. were used to test deckboards. A reference weight of 6.87 lbs. and measuring weight of 56.50 lbs. were used to test stringers. These weights were chosen to cause a significant deflection for accurate MOE computation while remaining well below the proportional limit of the material. The reference weight was placed on the piece at mid-span and allowed to settle the piece on the supports for thirty seconds. The initial deflection reading was taken from the dial gauge. The measuring weight was then placed on top of the reference weight and a final deflection reading was taken immediately. The piece was then flipped over and the procedure repeated. The MOE of each side was calculated using the measuring weight and the difference between final and initial deflections. The MOE of the piece was computed as the average of the two sides.

All shook data was entered and stored on computer disk. A computer program (Appendix D) was written and used to calculate the estimated strength ratio (ESR) for each piece of shook using equations given in ASTM D 245. The strength ratio of a piece of structural lumber is defined as the ratio of the strength of the piece, which may have knots, cross-grain, splits, checks, and other strength reducing defects, to the hypothetical strength of the piece had it been clear and straight grained. All shook within a particular species/size class was then ranked on the basis of MOE to the nearest 1000 psi. Pieces with the same MOE were then ranked according to the ESR. The material within a particular species/size class was segregated into two equivalent groups, based on MOE and ESR, by grouping every other piece in order of rank. The desired end result of this ranking and segregation procedure was the establishment of two populations equivalent in terms of strength and stiffness.

Procedures outlined in ASTM D 198 (3), except for loading rate, were used in testing both groups of a particular species and size. The first group was tested at the ASTM strain rate of 0.001 in./in./min.. This required a crosshead speed of 0.1 in./min. for stringers and 0.3 in./min. for deckboards. The second group was tested at a strain rate of 0.010 in./in./min.. This required a crosshead speed of 1.1 in./min. for stringers and 3.2 in./min. for deckboards. One-third point loading was used, with deckboards tested at a 36-inch span and stringers at a 45-inch span. The testing procedures, including strain rate, span, and third-point loading, were selected to duplicate the procedures used in the recent testing of full-size oak and yellow-poplar shook (20,45). The pieces were tested to failure on a Tinius-Olsen screw-driven testing machine, with load and deflection recorded continuously by a Tinius-Olsen chart recorder. The failure type and location were recorded as a 3-digit failure code (see Appendix B).

The defect which initiated failure was also noted. A specific gravity and moisture content specimen was taken from near the point of failure immediately after the test for every fifth piece. The specimen was weighed to the nearest 0.001 gram, oven-dried at 104 ° C for 48 hours, and re-weighed. The specimen was then coated with hot melted paraffin and its oven-dry volume determined by water immersion.

After testing it was decided that the shook should be graded according to the scheme proposed by Sardo and Wallin (42). This is also the grading procedure used by Spurlock in the oak study (45). Since defects had been mapped and recorded on computer, a computer program (Appendix C) was written to assign a grade to each piece. A complete grade description is given in Appendix I.

3.4 RESULTS AND DISCUSSION

To evaluate the effect of loading rate on the strength and stiffness distribution of pallet shook, two equivalent samples of shook were tested at two different loading rates. By ranking all shook within a particular species and size class in order of non-destructively determined MOE, with ties broken by ESR, and then separating every other piece in order of rank, two presumably equivalent groups in terms of strength and stiffness were formed. Except for loading rate, both groups were tested in exactly the same manner. Therefore, differences between strength and stiffness distributions of the two groups is assumed to be the result of loading rate alone.

The experiment is a balanced factorial design, with three factors (loading rate, species, size) and two levels of each (fast and slow, oak and poplar, deckboards and stringers). The Statistical Analysis System (43) was used to perform a factorial analysis of variance to test for all main effects, as well as interactions, on MOR and MOE. Table 3.1 gives the results which indicate that loading rate had a significant effect on MOR at any reasonable level and a significant effect on MOE at alpha levels greater than

TABLE 3.1 - RESULTS OF FACTORIAL ANALYSIS OF VARIANCE

SOURCE	PR > F (1) DEPENDENT VARIABLE MOR	 MOE
LOADING RATE	0.0016	0.0534
SPECIES	0.0001	0.0024
SIZE	0.3237	0.0001
LOADING RATE * SPECIES	0.9895	0.6711
LOADING RATE * SIZE	0.5996	0.6919
SPECIES * SIZE	0.1644	0.0014
LOADING RATE * SPECIES * SIZE	0.9348	0.4046

(1) THE PR > F COLUMN GIVES THE ALPHA LEVEL CORRESPONDING TO THE F VALUE. THEREFORE, REJECT THE NULL HYPOTHESIS (NO EFFECT) AT ALPHA LEVELS GREATER THAN THE PR > F VALUE.

0.0534. The alpha level indicates the confidence level at which the null hypothesis of no effect can be rejected. Species had a significant effect on MOR and MOE at any reasonable level while size only had a significant effect on MOE. The only significant interaction indicated by the analysis was a species-size effect on MOE.

Table 3.2 lists the average and coefficient of variation (C.V.) for the MOR and MOE of each loading rate/species/size class. The non-parametric lower 5th percentile MOR is also listed but the small sample size makes this value questionable. The average MOR and the average MOE were greater at the fast rate of loading than at the slow rate of loading for all species/size classes. The lower fifth percentile MOR was greater at the fast rate of loading for all species/size classes except oak stringers.

Table 3.3 lists the ratio of values at the fast rate to values at the slow rate for average MOR, average MOE, and lower 5th percentile MOR for each of the species/size classes. The general trend of increased MOR and MOE values due to increased loading rate is apparent. Table 3.3 also lists the average ratios for deckboards and for stringers, the average ratios for oak and for poplar, and an overall average ratio for all the shook.

TABLE 3.2 - MECHANICAL PROPERTIES OF PALLET SHOOK FROM RATE OF LOADING STUDY

			MOR			MOE		
SPECIES	SIZE	LOADING RATE	MEAN (PSI)	C.V. (%)	LOWER FIFTH PERCENTILE (PSI)	MEAN (KSI)	C.V. (%)	N
OAK	DECKBOARD	FAST	7860	17.6	5290	1649	19.9	40
		SLOW	7450	17.3	5110	1530	20.8	40
	STRINGER	FAST	7580	17.7	3320	1267	17.7	40
		SLOW	6990	22.1	3870	1230	19.7	40
POPLAR	DECKBOARD	FAST	5890	24.1	3740	1400	26.7	40
		SLOW	5460	18.0	3690	1364	24.3	40
	STRINGER	FAST	6020	20.7	3520	1286	19.3	40
		SLOW	5460	25.0	2880	1222	21.9	40

* STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

TABLE 3.3 - RATIOS OF MOR AND MOE AT FAST VS. SLOW LOADING RATE

		RATIO (FAST/SLOW)		
		MOR		MOE
SPECIES	SIZE	MEAN	LOWER FIFTH PERCENTILE	MEAN
OAK	DECKBOARD	1.05	1.04	1.08
	STRINGER	1.09	0.86	1.03
POPLAR	DECKBOARD	1.08	1.01	1.03
	STRINGER	1.10	1.22	1.05
AVERAGE RATIO FOR DECKBOARDS		1.066	1.024	1.052
AVERAGE RATIO FOR STRINGERS		1.095	1.040	1.041
AVERAGE RATIO FOR OAK		1.070	0.947	1.054
AVERAGE RATIO FOR POPLAR		1.091	1.118	1.039
AVERAGE RATIO		1.080	1.032	1.047

Figures 3.1 through 3.4 show cumulative distribution functions of the actual MOR data for each species/size class. The general trend of increased MOR at the faster loading rate is clear. This trend is very consistent throughout the range of MOR values for both oak and poplar stringers. For oak deckboards, the MOR values at the fast rate of loading are greater than the values at the slow rate in the higher as well as lower range of strength. However, the MOR values in the middle range of strength are nearly equal for both loading rates. For poplar deckboards, the MOR values in the lower range of strength are nearly equal for the two different loading rates. However, the MOR values at the fast rate of loading are greater in the middle and upper range of strength.

Figures 3.5 through 3.8 show cumulative distribution functions of the actual MOE data for each species/size class. The general trend of increased MOE at the faster loading rate is illustrated. However, the increase in MOE is generally not as great as the similar increase in MOR. The increase in MOE at the fast rate is greatest for oak deckboards and is very consistent throughout the range of stiffness. For oak stringers, the increase in MOE at the fast rate is most consistent in the lower stiffness range with a somewhat less consistent increase in the upper

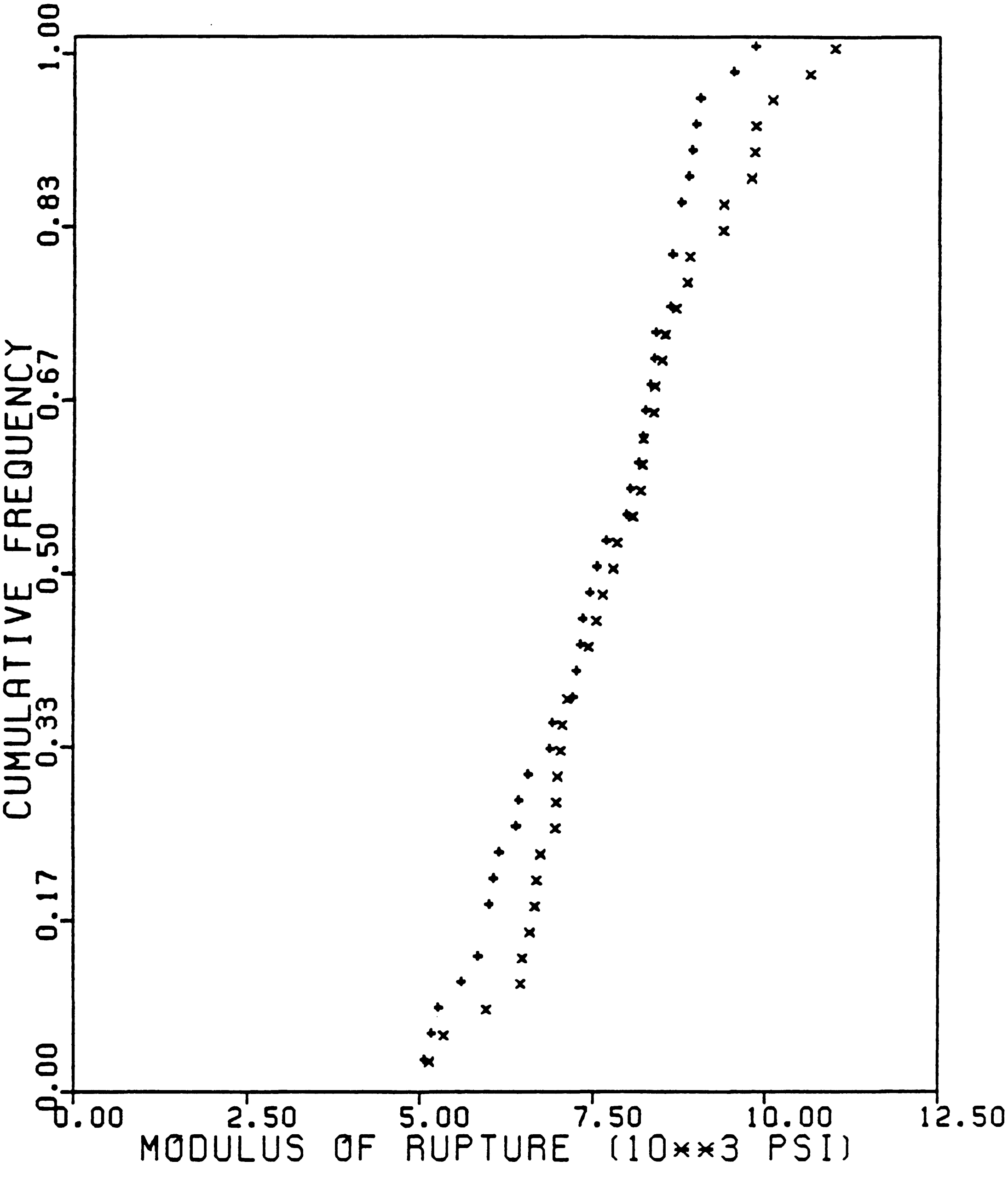

FIGURE 3.1
CDF OF OAK DECKBOARD MOR AT FAST AND SLOW LOADING RATE

x = 3.2 in./min.

+ = 0.3 in./min.

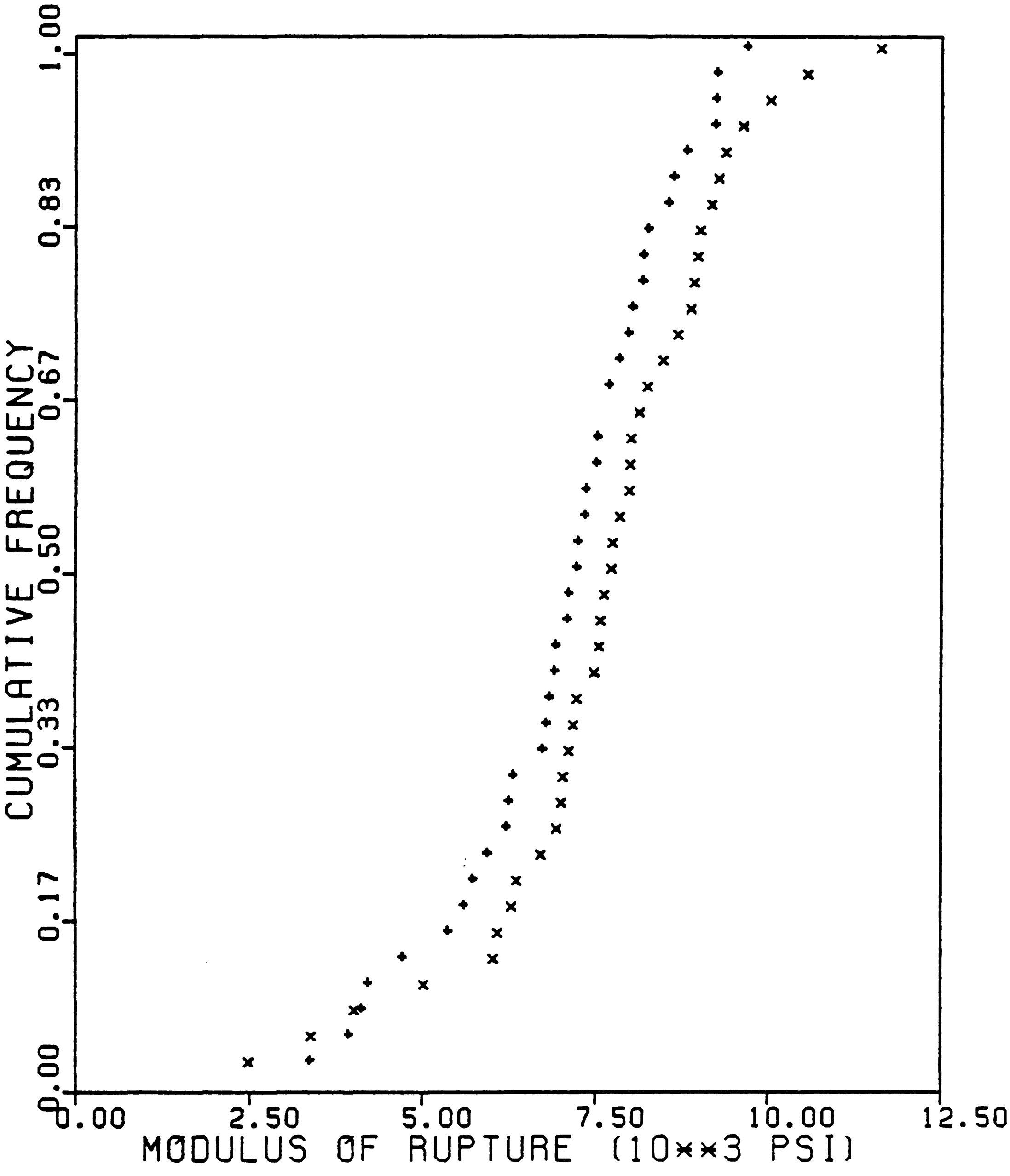

FIGURE 3.2
CDF OF OAK STRINGER MOR AT FAST AND SLOW LOADING RATE

x = 1.1 in./min.

+ = 0.1 in./min.

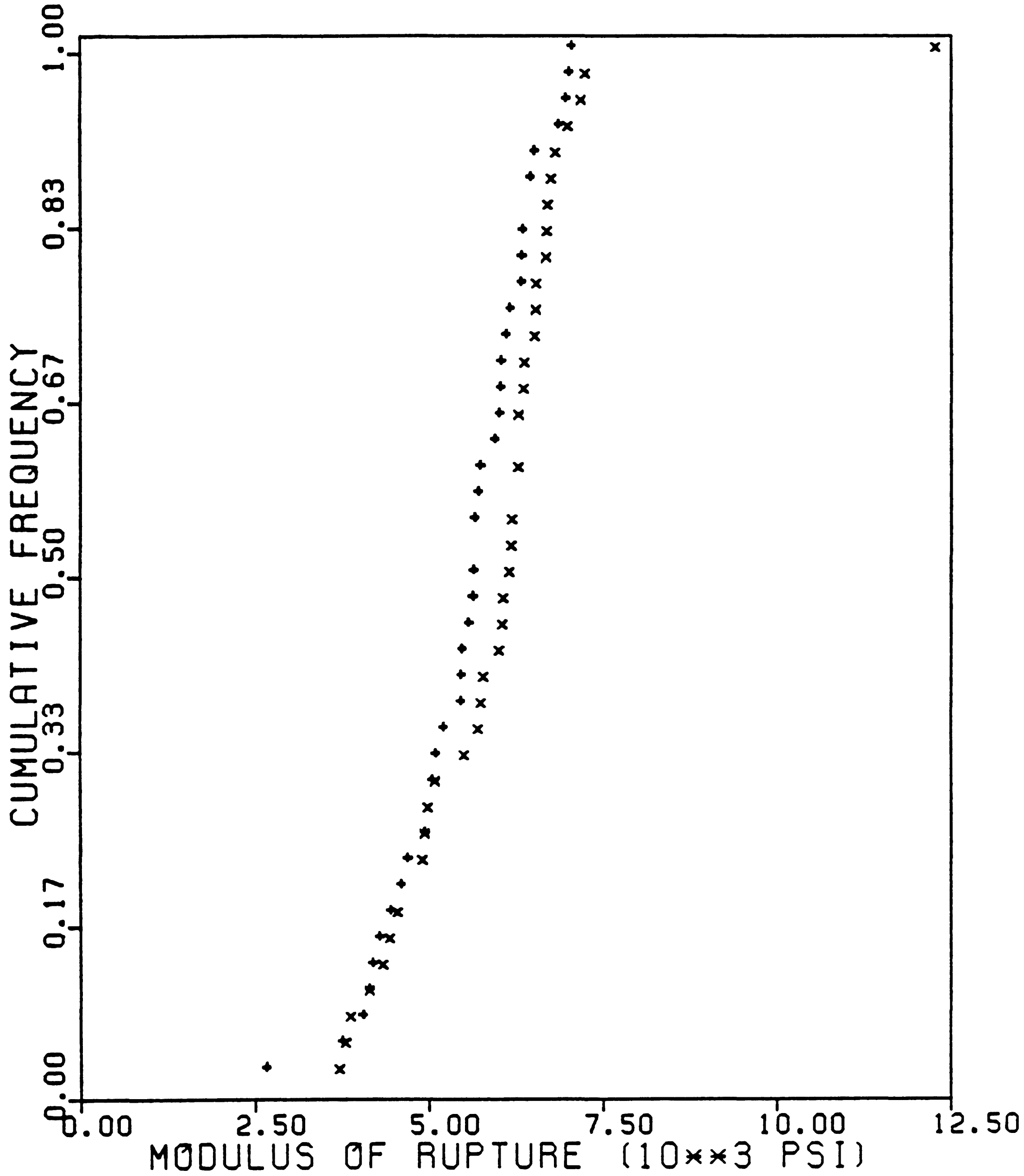

FIGURE 3.3
CDF OF POPLAR DECKBOARD MOR AT FAST AND SLOW LOADING RATE

x = 3.2 in./min.

+ = 0.3 in./min.

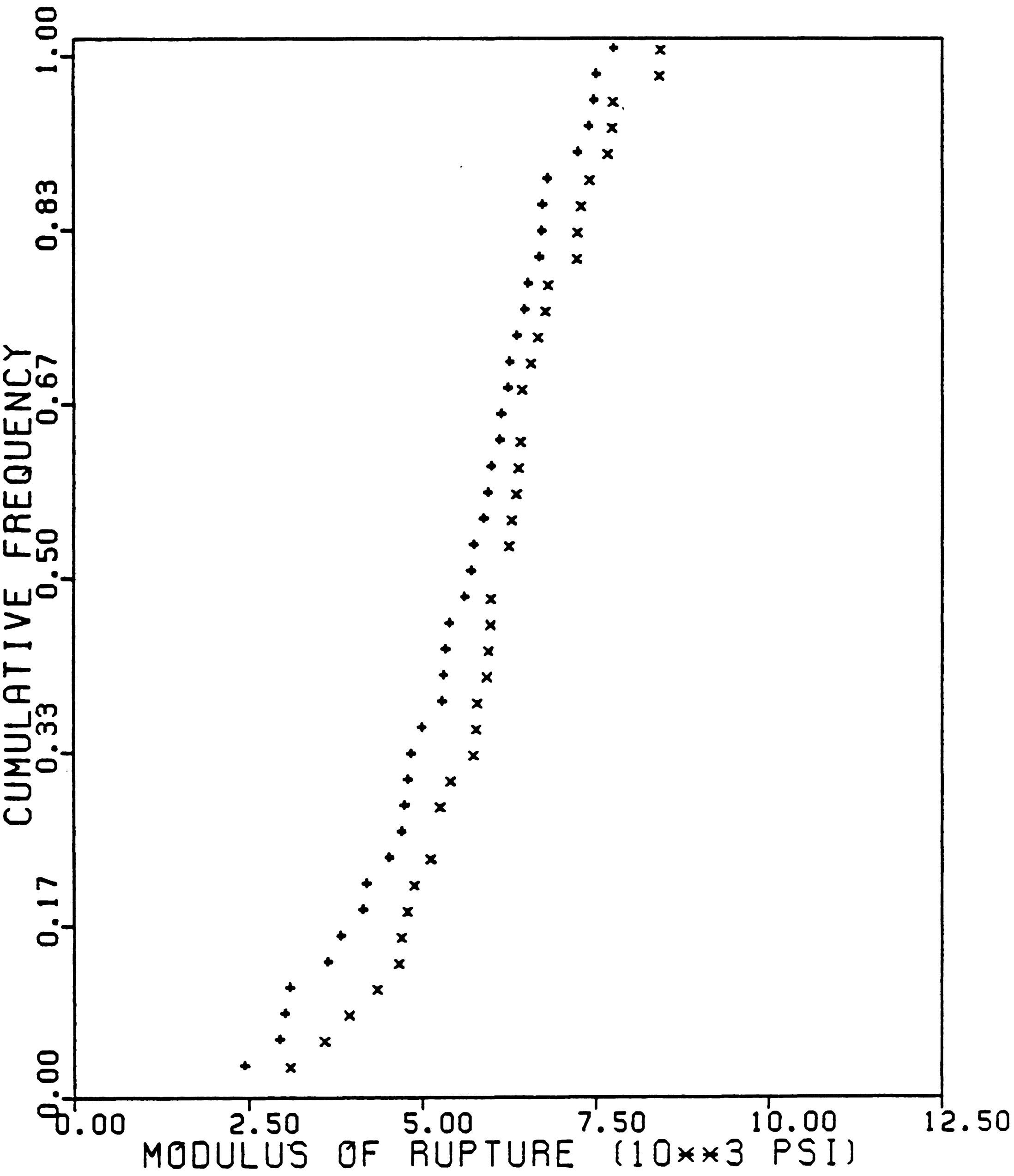

FIGURE 3.4
CDF OF POPLAR STRINGER MOR AT FAST AND SLOW LOADING RATE

x = 1.1 in./min.

+ = 0.1 in./min.

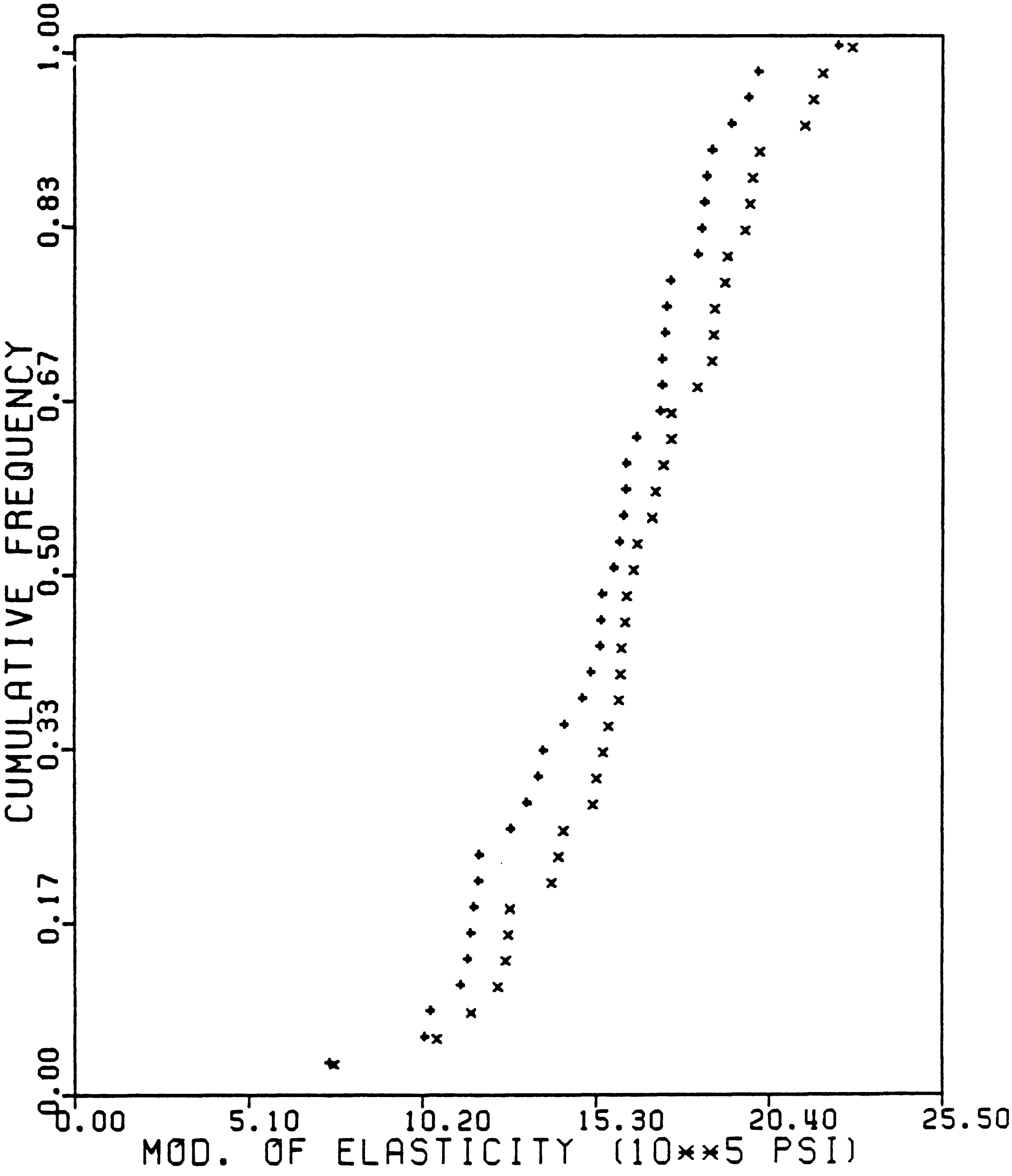

FIGURE 3.5
CDF OF OAK DECKBOARD MOE AT FAST AND SLOW LOADING RATE

x = 3.2 in./min.

+ = 0.3 in./min.

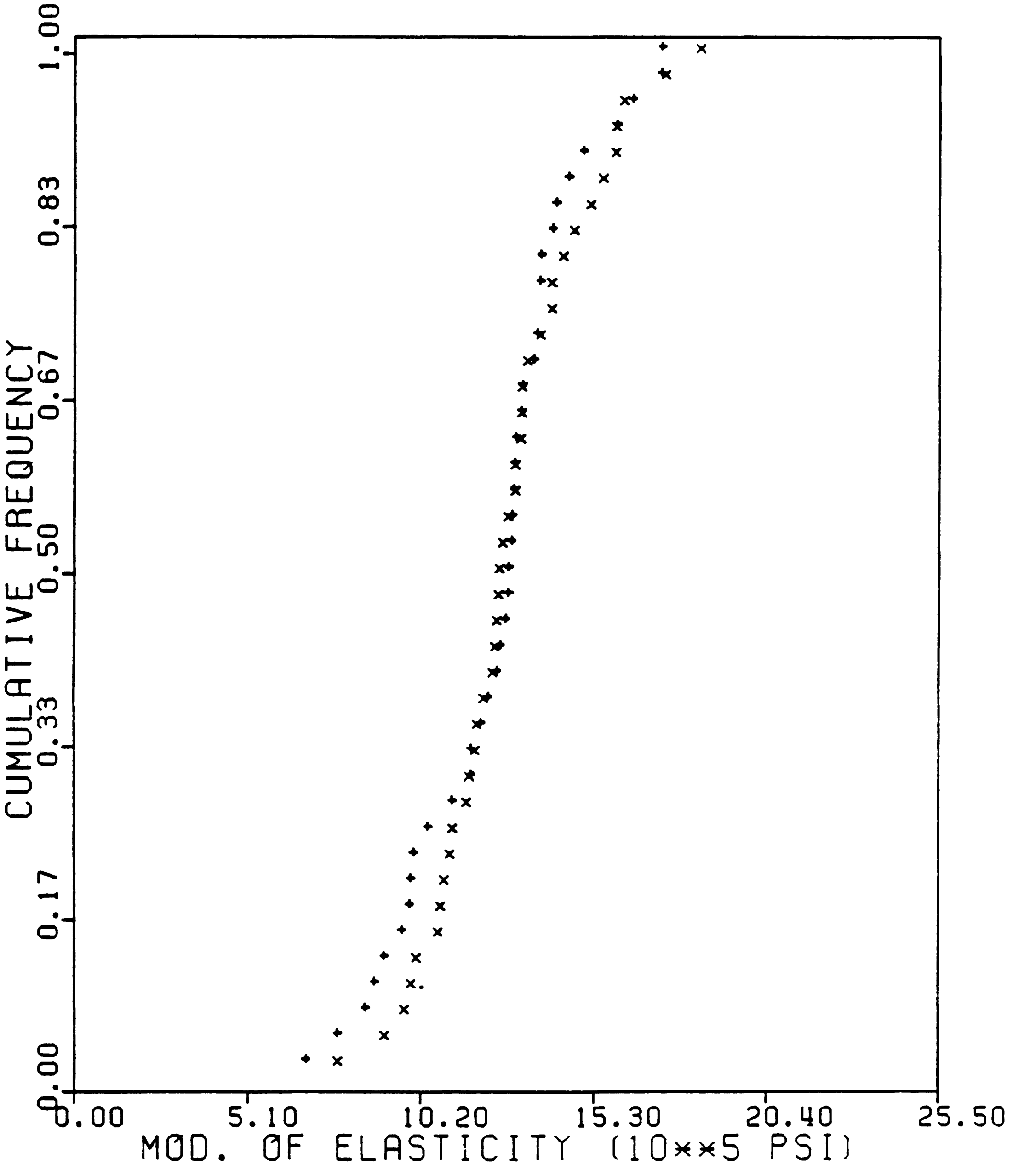

FIGURE 3.6
CDF OF OAK STRINGER MOE AT FAST AND SLOW LOADING RATE

x = 1.1 in./min.

+ = 0.1 in./min.

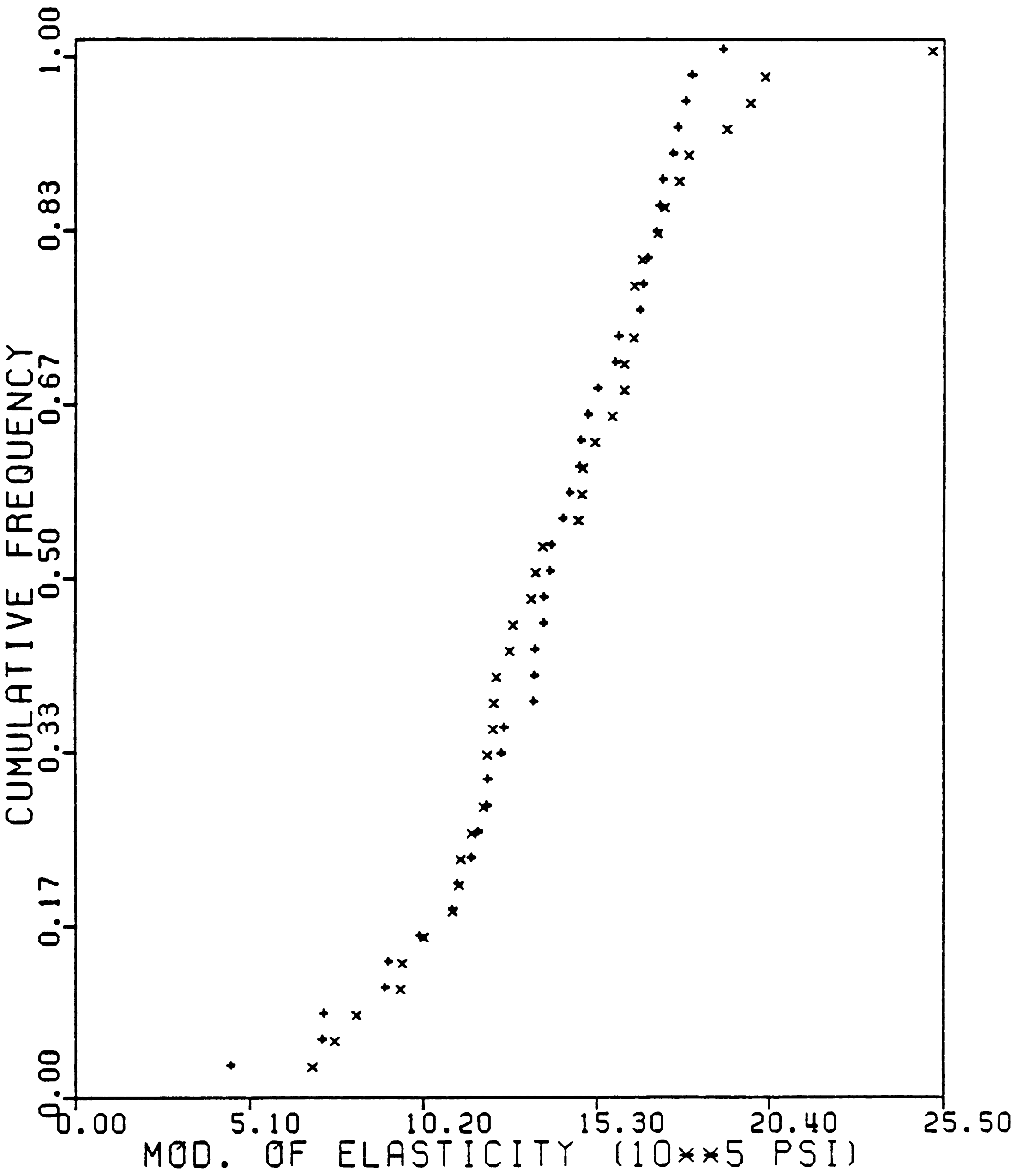

FIGURE 3.7
CDF OF POPLAR DECKBOARD MOE AT FAST AND SLOW LOADING RATE

x = 3.2 in./min.

+ = 0.3 in./min.

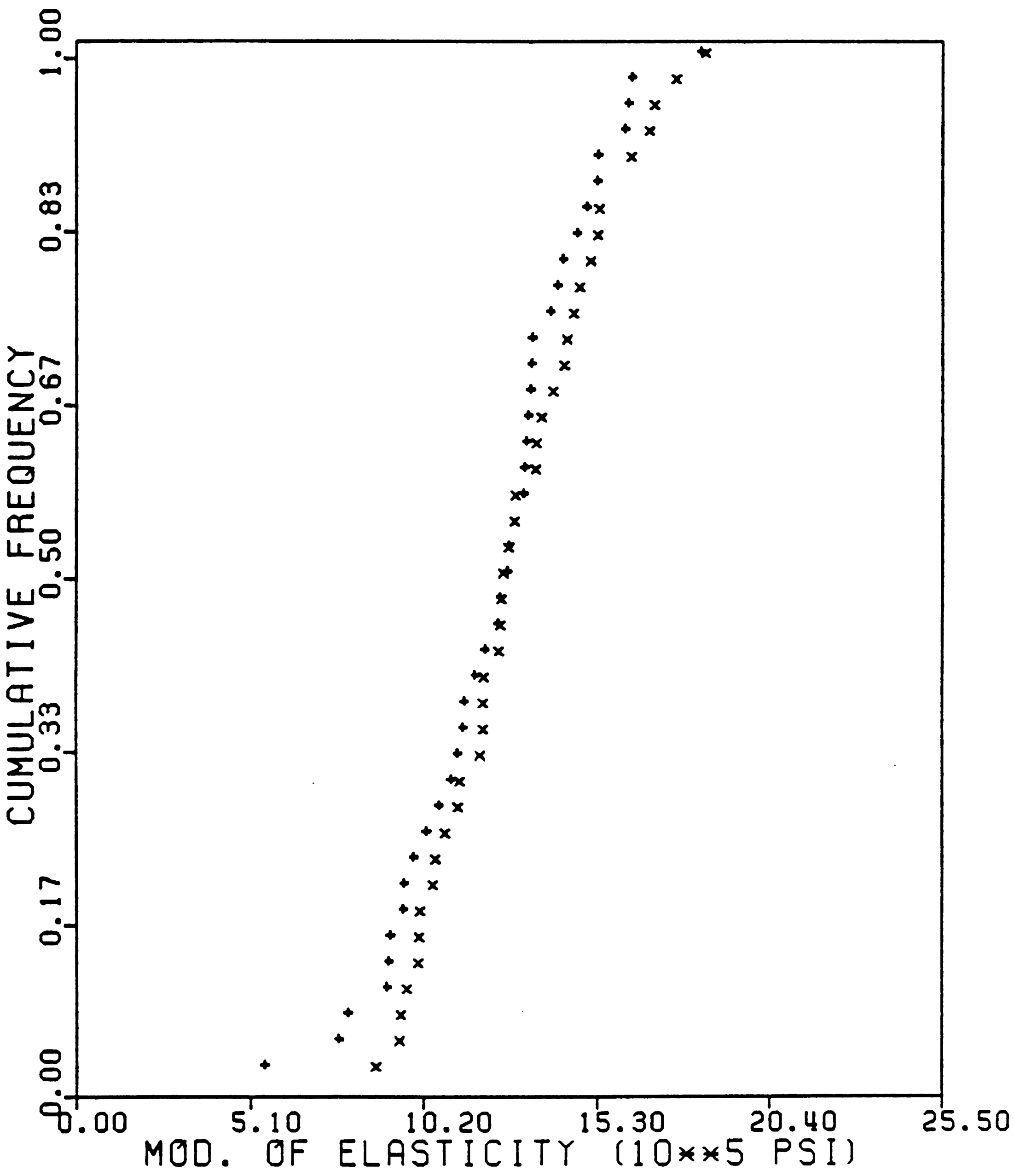

FIGURE 3.8
CDF OF POPLAR STRINGER MOE AT FAST AND SLOW LOADING RATE

x = 1.1 in./min.

+ = 0.1 in./min.

stiffness range. In the middle stiffness range, oak stringer MOE is approximately the same at both loading rates. The increase in MOE at the fast loading rate is evident at both the high and low stiffness range for poplar stringers. However, this increase is evident only in the very highest stiffness range for poplar deckboards, the species/size class exhibiting the lowest overall increase in MOE due to increase in loading rate.

In conflict with the results of this study, which indicate that increased loading rate can affect MOR values throughout the full range of strength, are results reported by Madsen (27,28,29), Spencer (44), and DeBonis, Woeste, and McLain (13), which indicate that increased loading rates affect the MOR only for the stronger pieces of a population. Results reported by the above authors do indicate a slight loading rate effect on MOE for lower strength and stiffness material, but not for clear material. Results from the study reported here indicate that loading rate can affect MOE throughout the range of strength and stiffness, although the effect on MOE is less than that for MOR.

There are several possible explanations for this conflict between results from other studies and the results from this study. The studies cited above were exclusively on softwoods (hem-fir, Douglas-fir, and southern pine) while this study dealt with a ring porous hardwood, oak, and a diffuse-porous hardwood, yellow-poplar. There may be basic differences in the response to varied strain rates between hardwoods and softwoods due to anatomical characteristics. For example, Liska (26) reported that as loading rate increased, stress at proportional limit (SPL) increased more rapidly than MOR for softwoods, while MOR increased more rapidly than SPL for hardwoods. Table 3.4 shows that for this study of oak and poplar shook, the increase in SPL at increased loading rate was indeed less than the corresponding increase in MOR. In fact, the SPL for deckboards actually decreased with increase in loading rate.

Previous studies of full-sized softwood lumber (13,27,87,44) tested only No. 2 or No. 2 and Better 2 x 4 and 2 x 6 inch commercial lumber. This study of oak and poplar pallet shook included all grades and therefore contained a wider range of defects. Pallet shook, especially deckboards, is also considerably different in dimensions than full-size 2 x 4's and 2 x 6's. The wider range of defects, coupled with any basic behavioral differences between softwoods and hardwoods due to anatomy, may be responsible for the observed differences in MOR and MOE response to increased loading rate compared to previous

TABLE 3.4 - STRESS AT PROPORTIONAL LIMIT

SPECIES	SIZE	MEAN FAST RATE (PSI)	MEAN SLOW RATE (PSI)	RATIO (FAST/SLOW)
OAK	DECKBOARDS	3440	3920	0.88
	STRINGERS	2660	2740	0.97
POPLAR	DECKBOARDS	4050	3980	1.02
	STRINGERS	3480	3250	1.07

work with softwoods. The fact that the SPL of deckboards actually decreased with increase in loading rate may indicate the presence of some as yet unexplained size related phenomenon.

All the previous work cited above, except one (28), dealt with dry lumber, while this study of pallet shook used only green material. Although Madsen (28) observed no basic change in the response of No. 2 grade hem-fir 2 x 6's due to moisture content, a hardwood pallet shook population consisting of all grades at a lower moisture content might exhibit different trends in response to loading rate than the green shook used in this study.

Although the total sample size for this study was fairly large at 320 pieces, there were only 40 pieces in each loading rate/species/size class. The ranking and sorting procedure used to establish two equivalent populations may have influenced the results. While it is not known if a larger sample size would have produced different results, more definitive conclusions could certainly have been reached.

Nevertheless, this study does provide a preliminary evaluation of the effect of the increased loading rate used in the recent studies on oak and yellow-poplar shook at

Virginia Tech (20,45). The results of this study indicate that both the MOR and MOE values obtained at the increased rate of loading should be adjusted down in order to compare with values obtained at the ASTM rate or before they are used as design values. This adjustment could readily be made by dividing the strength or stiffness value obtained at the increased loading rate by the appropriate ratio given in Table 3.3. The ratios given in Table 3.3 allow specific adjustment by species/size class, specific adjustment by size class only, specific adjustment by species only, or an overall adjustment factor to be applied to all shook indiscriminate of species or size. Because of the limited sample size used in this study, it may be most reasonable to apply an overall adjustment factor to all shook. This factor, the average ratio given in Table 3.3, would not drastically over-penalize nor under-penalize any particular species/size class in adjustment of the average MOR or average MOE. The extreme range of ratios given for the lower 5th percentile MOR indicates the sensitivity of the distribution tails given the small number of samples (in fact, the lower fifth percentile is represented by the second lowest value.) Thus, these ratios are quite unreliable and not recommended.

3.5 CONCLUSIONS

Bending tests were performed on green oak and yellow-poplar deckboards and stringers at both the ASTM rate of loading and 10 times this rate. Results indicate that both MOR and MOE increase with increased loading rate and that this increase is reasonably constant throughout the range of strength and stiffness values. The average increase was 8.0% for MOR and 4.7% for MOE. Not all species/size groups exhibited the same effects. In general, the stringers showed a slightly higher increase in MOR than deckboards, while the deckboards showed a slightly higher increase in MOE than stringers. The poplar shook had a slightly higher increase in MOR than the oak, but the oak shook had a slightly higher increase in MOE than the poplar. Given the small sample size and the inconsistent trends between the various species/size groups, an overall adjustment of the MOR and MOE for loading rate using the average values reported above may be most reasonable.

This preliminary study has shown that full-size hardwood pallet shook at green moisture content may respond differently than full-size softwood lumber and that strength and stiffness values determined at increased loading rates may indeed require adjustment before being used in deriving design values or comparing to data obtained at ASTM rates.

4.0 DEPTH EFFECT STUDY

4.1 INTRODUCTION

Extensive research on softwoods has shown that an increased beam depth results in decreased bending strength. Unfortunately, little or no information on similar effects with hardwood beams in sizes commonly used by the pallet industry is available. The objective of this preliminary research was to explore a possible depth effect on bending strength of hardwood pallet shook.

Results from Holland's (20) and Spurlock's (45) studies of hardwood pallet shook indicate that any depth effect on bending strength for hardwoods may vary by species. Holland tested yellow-poplar, a diffuse-porous, relatively homogeneous species, and found the average MOR of deckboards to be greater than that of stringers. This might be expected due to the greater depth of stringers. However, Spurlock tested oak, a ring-porous, non-homogeneous species, and found the average MOR of stringers and deckboards to be approximately equal. This would seemingly indicate a lack of depth effect on MOR.

The objective of this study was to determine any depth effect on bending strength of green hardwood pallet shook. This study investigated the depth effect for both a ring-porous and a diffuse-porous species. The applicability of existing depth adjustment factors used in the derivation of design values for structural lumber was also investigated.

4.2 REVIEW OF LITERATURE

It is well established that as the depth of a wood bending member increases, its bending strength, or modulus of rupture (MOR), decreases. However, most research on the effect of depth or size has been limited to clear specimens of softwood species. Any interaction that growth characteristics, such as knots, have with a depth effect is not known. Similar size effects with lumber of hardwood species is not documented. If there is a depth effect on bending strength for hardwoods, it may vary by species given the wide variation in anatomy and homogeneity.

Newlin and Trayer (35) proposed a fiber support theory to explain the effect of depth on bending strength. They observed that a wood member in bending developed a greater compressive stress at the extreme fiber than a wood member subjected to a uniaxial compressive force parallel to the grain. They assumed that the wood fibers in the member under axial compression acted as columns all bound together. Since these fibers were all subject to the same compressive stress, they offered each other little lateral support. However, for a bending member, the stress is non-uniform. The extreme fibers are under more stress than fibers closer to the neutral axis. On the compression side of the beam, the extreme fibers are laterally supported by the lower stressed fibers closer to the neutral axis. Therefore, it was thought that the extreme fibers can sustain a greater compressive stress due to this support.

The fiber support theory is best explained by comparing a shallow and a deep beam with equal extreme fiber stresses. The stress gradient over the cross-section is greater for a shallow beam than for a deep beam. In a shallow beam, fibers close to the extreme compression fibers are under much less stress than the extremes. Therefore, the extreme compression fibers of a shallow beam are laterally supported by adjacent fibers. In a deep beam, fibers close to the extreme compression fibers are under nearly as much stress as the extremes. Therefore, the extreme compression fibers of a deep beam are offered less lateral support by adjacent fibers than in the shallow beam. Consequently, the extreme compression fibers in a shallow beam may be expected to withstand greater stress than the extreme compression fibers in a deep beam. Accordingly, this would lead to greater modulus of rupture values for a shallow beam than a deep beam.

Newlin and Trayer (35) gave the following equation relating the modulus of rupture of a beam of depth, d, to a beam two inches deep:

$$Rd/R2 = 1.07 - 0.07\sqrt{d/2} \qquad (4.1)$$

Freas and Selbo (16) noted that equation (4.1) predicted MOR values for deep beams less than the compressive strength of the material. Furthermore, they found the equation was inconsistent with the data in their study. Based upon the fiber support theory, Freas and Selbo gave the equation:

$$Fh = 0.81\ (d^2 + 143)/(d^2 + 88) \qquad (4.2)$$

For very large values of depth (d), the MOR of a beam as predicted by this equation approaches the compressive strength of the material as a limit.

Weibull (52) developed a statistical approach to the strength of brittle materials. The basis of Weibull's theory is that there is a greater probability of a region of low strength occuring in a large volume of a material than for a small volume of the material. Weibull's theory, often called the "weakest link theory", assumes that a specimen under stress will fail when the stress exceeds the strength of the weakest element in that specimen. This is analogous to a chain being only as strong as its weakest link. The weakest link theory assumes the links (or elements of a material) act in series. Weibull also considered the possibility of the links acting in parallel but concluded that the probability of failure is the same whether the links act in series or parallel.

Bohannan (10) developed a relationship between beam depth and modulus of rupture based upon the statistical theory of strength of materials suggested by Weibull (52). Bohannan concludes, however, that the elements of a cross-section of a wood bending member act not as links in a series but as links in parallel. He recognized that when a link of depth fails, the section modulus of the beam is effectively reduced but must still support the same moment that caused failure of the weakest link. This may lead to failure of the next weakest link and the next, resulting in a cascade-type failure. Tension failure, the typical failure mode for wood beams, is a cascade-type failure. Bohannan's theory is the currently accepted explanation of the effect of depth on bending strength. However, it is still inconsistent with Weibull's theory since it is a function of only depth and span and not volume.

Bohannan related the modulus of rupture of a beam of depth, d, to a beam with a two-inch depth:

$$Rd/R2 = (2/d)^{1/9} \qquad (4.3)$$

Technically this equation is only valid for clear, straight-grained Douglas-fir at 12% moisture content with a span to depth ratio of 14 and center-point loading.

It should be noted that Weibull's statistical strength theory, upon which Bohannan's work is based, is not intended to explain the strength reduction due to obvious defects such as knots and cross-grain. Instead, the theory is intended to explain the reduction in strength due to occurrences of regions of low density or strength which otherwise appear free of defects.

The National Design Specification (34) and the Timber Construction Manual (1) require that a size factor be used to modify the value for extreme fiber stress in bending for structural glued laminated beams or sawn lumber exceeding twelve inches in depth. The size factor is calculated as follows:

$$Cf = (12/d)^{1/9}$$

where d equals depth. This equation is based on the assumption of simple supports, uniformly distributed load, and a span to depth ratio (l/d) of 21. Adjustments for other loading conditions or l/d ratios are given. For stress-grades of lumber and timbers, the effect of depth has been incorporated into the grading process of ASTM D 245 (4). Bohannan's formula, $F = (2/d)^{1/9}$, is used as the size adjustment factor. Although this equation assumes center-point loading and an l/d ratio of 14, no adjustments for other loading conditions or l/d ratios are made.

Fewell and Curry (15) analyzed four depth factor equations to determine the best overall fit to data from tests of various grades of several softwood species at depths of 100 to 300 mm. (3.93 to 11.8 in.) The following equations were analyzed:

a. $K = 0.73\ (h^2 + 92300)/(h^2 + 56800)$

b. $K = (200/h)^{1/9}$

(4.4)

c. $K = (200/h)^{0.403}$

d. $K = 1.631 - 0.00316\ h$

where h = beam depth in millimeters.

These equations are indexed to a factor of 1.0 for a depth of 200 mm. Equation 4.4a is the equation originally given by Freas and Selbo (16) and presented as equation 4.2 earlier in this thesis. Equation 4.4b is the equation originally given by Bohannan (10) and presented as equation 4.3 earlier in this thesis. Equation 4.4c is an equation given by Bury (12), while equation 4.4d is an equation given by Madsen (30).

Equation 4.4c was found to best fit the overall data for the species and grade mixtures contained. The fit was improved by rounding the exponent to 0.4. The authors concluded that for visually stress graded softwood lumber in sections from 100 to 300 mm deep, the effect of depth on bending strength can be defined by the adjustment factor:

$$K = (200/h)^{0.4} \qquad (4.5)$$

Doyle and Markwardt (14), in a study of full-size southern pine dimension lumber, found a reduction in bending strength with increasing depth for all grades. An average reduction in MOR of 2.4% per inch of depth was found with considerable variation between grades. The decrease in strength with depth was found to increase for lower grades. A 0.58% reduction in MOR per inch of depth was found for No. 1 grade while a 6.15% reduction per inch was found for No. 3 grade. The actual strength ratio (MOR of full size piece / MOR of small clear piece) of a given grade was found to decrease as depth increased.

Recent research on hardwood pallet shook at Virginia Tech has generated results seemingly inconsistent with the accepted depth effect. In Holland's (20) study of the flexural properties of yellow-poplar pallet shook, deckboards were found to have an average strength greater than that of stringers. This would be expected due to the greater depth of the stringers. However, in a similar study of oak pallet shook, Spurlock (45) found the mean strength of deckboards and stringers to be approximately equal. The high quality stringers were stronger than the high quality deckboards, which is opposite of what would be predicted due to the depth effect. The reverse was seen for low quality material: low quality deckboards were stronger than low quality stringers. This reversal can at least partially be explained by the relative effect of defects on the deckboards and stringers. A knot would most likely occur on the widest face of the piece and would therefore tend to effectively reduce the width of deckboards and the depth of stringers. Since depth is a squared term in MOR computation and width has an exponent of unity, stringers should be weakened more by knots than deckboards.

The difference in strength of the yellow-poplar and oak shook as related to depth may be attributable to differences in anatomy betweeen the two species. Yellow-poplar is diffuse-porous and therefore more homogeneous than oak, which is ring porous and has large rays. On the basis of homogeneity, yellow-poplar might be expected to exhibit a depth effect similar to softwoods, which are also relatively homogeneous.

Bodig and Jayne (9) give two reasons, other than probability of flaws, for the effect of specimen size on mechanical properties: material inhomogeneity and stress concentrations. Material inhomogeneity, such as large differences in density between earlywood and latewood, results in stress concentrations. As the specimen size decreases, the effect of inhomogeneity increases. This may provide insight into why the high quality oak stringers were stronger than the high quality oak deckboards.

4.3 MATERIALS AND METHODS

To examine the hypothesis that depth effect is anatomically related, two shook populations from each of two species were obtained. The samples were equivalent except for depth. One-hundred four white ash stringers (2 x 4 x 48 inch nominal size) and 104 eastern cottonwood stringers, all at green moisture content, were obtained for this study. These species were selected as representatives of a ring-porous species and a diffuse-porous species, as well as due to their similarities to oak and yellow-poplar, respectively. The shook was randomly sampled from the production line at St. Charles Lumber Company in St. Charles, Michigan. The shook was wrapped in six mil polyethelyene and transported to the Sardo Laboratory at Virginia Tech.

Once at the lab, the shook was randomly stacked by species and one edge was systematically marked to indicate the compression side during subsequent testing. Thus the compression and tension side were determined independent of the presence and location of defects. The shook was then re-wrapped and stored in a cold chamber kept at 34° F and 85% relative humidity. The shook remained wrapped and in the cold chamber at all times except when being measured, mapped and tested. Before testing the shook was allowed to reach equilibrium temperature with the laboratory (72 ° F) while remaining wrapped in plastic. After use, the shook was re-wrapped and returned to the cold chamber to minimize drying or biodegradation during the several week span required to complete the study.

The cross-sectional dimensions of each piece (width and thickness, each the average of three separate measurements within the middle third of the length) were recorded to the nearest 0.001 inch with dial calipers. The MOE of each piece was determined non-destructively from the average of dead-weight deflection tests of both sides. The stringers were tested flatwise (as a plank) at a 45-inch span. A dial gauge was used to record deflection at mid-span to the nearest 0.001 inch. A reference weight of 6.87 lbs. and measuring weight of 56.50 lbs. were used. These weights were selected to cause a significant deflection allowing accurate MOE calculation while remaining well below the proportional limit of the material. The reference weight was placed on the piece at mid-span and allowed to settle the piece on the supports for thirty seconds. The initial deflection reading was taken from the dial gauge. The measuring weight was then placed on top of the reference weight and a final deflection reading was taken immediately. The piece was then flipped over and the procedure repeated. The MOE of each side was calculated using the measuring weight and the difference between final and initial deflections. The MOE of the piece was computed as the average of the two sides.

All pieces within a species class were then ranked according to MOE to the nearest 1000 psi. Every other piece in order of rank was then placed in a separate group. Thus, two groups of equivalent strength distribution (estimated by MOE) were formed, each group containing one-half of the pieces of each species. One-half inch of material was sawn from both edges of all the pieces in one group. One group then had a depth of 3-1/2 inches and the other group had a depth of 2-1/2 inches.

The pieces were tested to failure on a Tinius-Olsen screw driven testing machine, with load and deflection recorded continuously by a Tinius-Olsen chart recorder. Procedures outlined in ASTM D 198 (3), except loading rate, were used in testing. A strain rate of 0.009 in./in./min. was used, which required a crosshead speed of 1.0 in./min. for the 3-1/2 inch pieces and 0.7 in./min. for the 2-1/2 inch pieces. One-third point loading was used, with the

3-1/2 inch pieces tested at a 45-inch span and the 2-1/2 inch pieces tested at a 32-inch span (l/d ratio = 12.8).

The failure type and location were recorded as a 3-digit failure code (see Appendix B). The defect initiating failure was also noted. A specific gravity and moisture content specimen was taken from near the point of failure immediately after the test for every fifth piece. The specimen was weighed to the nearest 0.001 gram, oven-dried at 104 degrees Centigrade for 48 hours, and re-weighed. The specimen was then coated with hot melted paraffin and its oven-dry volume determined by water immersion.

After testing it was decided that the shook should be graded according to the scheme proposed by Sardo and Wallin (42), which is also the grading procedure used by Spurlock in the oak study (45). Since defects had been mapped and recorded on computer, a computer program (Appendix C) was written to assign a grade to each piece. A complete grade description is given in Appendix I.

4.4 RESULTS AND DISCUSSION

The ranking and segregation procedure yielded two equivalent samples in terms of strength and stiffness distributions. Re-sawing one group resulted in a different depth. Exactly what changes were made to the strength and stiffness of the re-sawn group is unknown. However, by removing only 1/2 inch of material from each edge, centerline knots remained centerline knots, and most edge knots were not totally removed. It was thus felt that overall the two groups would still be equivalent with any difference in strength attributable to difference in depth.

This experiment is a balanced factorial design, with two factors (species and depth) and two levels of each (ash and cottonwood, 3-1/2 inch and 2-1/2 inch). The Statistical Analysis System (43) was used to perform a factorial analysis of variance to test all main effects, as well as interactions, on MOR and MOE. Table 4.1 gives the results of this analysis of variance. Species had a significant effect on both MOR and MOE. Depth had an insignificant effect on MOE but a significant effect on MOR at alpha levels greater than 0.0516. The alpha level indicates the confidence level at which the null hypothesis of no effect

TABLE 4.1 - RESULTS OF FACTORIAL ANALYSIS OF VARIANCE

SOURCE	PR > F (1) DEPENDENT VARIABLE MOR	 MOE
SPECIES	0.0001	0.0001
DEPTH	0.0516	0.3691
SPECIES * DEPTH	0.6051	0.6249

(1) THE PR > F COLUMN GIVES THE ALPHA LEVEL CORRESPONDING TO THE F VALUE. THEREFORE, REJECT THE NULL HYPOTHESIS (NO EFFECT) AT ALPHA LEVELS GREATER THAN THE PR > F VALUE.

can be rejected. There was not a significant interaction between species and depth on either MOR or MOE.

Table 4.2 gives the average and coefficient of variation (C.V.) for both the MOR and the MOE of each species/depth class. For both ash and cottonwood, the average MOR was greater at the 2-1/2 inch depth than the 3-1/2 inch depth, while the C.V. was approximately the same at the two depths. Although insignificant, a slight increase in average MOE was seen at the greater depth, a trend opposite that for the MOR. The C.V. of the MOE was greater at the 2-1/2 inch depth.

Table 4.3 shows a comparison between the observed depth ratio on MOR for this study and the predicted depth ratios using equations given by Bohannan (10), Fewell and Curry (15), Newlin and Trayer (35), Freas and Selbo (16), and Madsen (30). The observed depth ratio is calculated simply by dividing the MOR at the 2-1/2 inch depth by the MOR at the 3-1/2 inch depth. The predicted depth ratios are determined by using the equations given to calculate the depth factor for the 2-1/2 inch depth and the 3-1/2 inch depth (using the actual average depth measurements given), and then dividing the factor for the 3.5 inch depth by the factor for the 2.5 inch depth.

TABLE 4.2 - MECHANICAL PROPERTIES OF PALLET SHOOK FROM RATE OF LOADING STUDY

SPECIES	DEPTH (IN.)	N	MOR (PSI) MEAN	MOR (PSI) C.V. (%)	MOE (KSI) MEAN	MOE (KSI) C.V. (%)
ASH	3.5	52	6760	31.8	1365	22.7
	2.5	52	7350	32.1	1349	27.8
COTTONWOOD	3.5	52	5480	17.0	1054	18.5
	2.5	52	5820	17.2	1000	20.9

* MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

TABLE 4.3 - COMPARISON OF OBSERVED AND PREDICTED DEPTH RATIOS

	AVERAGE ACTUAL DEPTH (INCHES)		OBSERVED DEPTH RATIO	DEPTH RATIOS PREDICTED BY THE FOLLOWING EQUATIONS: [2]				
SPECIES	3.5" GROUP	2.5" GROUP	[1]	(4.1)	(4.2)	(4.3)	(4.4D)	(4.5)
ASH	3.554	2.494	0.919	0.985	0.977	0.961	0.941	0.868
COTTONWOOD	3.578	2.502	0.940	0.985	0.977	0.961	0.940	0.867

[1] (MOR 3.5"/MOR 2.5")

[2] EQUATION NUMBERS ARE AS GIVEN IN TEXT

(4.1) - EQUATION GIVEN BY NEWLIN AND TRAYER (35)
(4.2) - EQUATION GIVEN BY FREAS AND SELBO (16)
(4.3) - EQUATION GIVEN BY BOHANNAN (10)
(4.4D) - EQUATION GIVEN BY MADSEN (30)
(4.5) - EQUATION GIVEN BY FEWELL AND CURRY (15)

The observed depth ratios for ash, a ring-porous species, and for cottonwood, a diffuse-porous species, are fairly close. This would lead to the conclusion that there is no obvious difference in the effect of depth on MOR between ring-porous and diffuse-porous species, at least within this size range of stringers. The lack of a significant species-depth interaction in the factorial analysis of variance supports this conclusion.

The depth ratio calculated using Madsen's (30) equation exactly predicts the observed depth ratio for cottonwood and comes nearest to the observed depth ratio for ash. Fewell and Curry's (15) equation underpredicts the observed depth ratio while the equations from Bohannan (10), Newlin and Trayer (35), and Freas and Selbo (16) overpredict the observed depth ratio.

The equations that overpredict the depth ratio were all developed for clear wood beams, while the equations by Madsen (30) and Fewell and Curry (15) were developed from tests of various grades of full-size softwood lumber in depths from 4 to 12 inches. This would seem to indicate that the effect of depth on MOR for full-size lumber with defects is greater than the depth effect for clear wood. The results reported by Doyle and Markwardt (14) are consistent with this idea, where the decrease in strength with depth was found to increase for lower grades of full-size southern pine lumber.

Table 4.4 presents MOR data and observed depth ratio by grade for the ash and cottonwood shook. A decrease in the depth ratio was found for the lower grades in this study. However, the results from the lower grades of cottonwood shook are not reliable due to the small number of pieces in Grades 3 and 4. The smaller observed depth ratio (greater effect of depth) for ash than for cottonwood may be due to the fairly large number of pieces of ash in the lower grades compared to the relatively few pieces of cottonwood in the lower grades. This also accounts for the much higher C.V. for the MOR of the ash compared to cottonwood.

Figures 4.1 and 4.2 are cumulative distribution functions (CDF) of the MOR of the 3.5 inch group compared to the 2.5 inch group of each species. The decrease in MOR with increase in depth is evident. A greater difference in MOR between the two depths might have been expected for the lower strength range due to the greater observed depth ratio for lower grades. However, this trend was not evident from the CDF's. In fact, the CDF's for the ash stringers tend to overlap in the lower strength range.

TABLE 4.4 - MOR DATA BY GRADE

SPECIES	GRADE	3.5 INCH DEPTH		2.5 INCH DEPTH		OBSERVED DEPTH RATIO [1]
		N	MOR (PSI)	N	MOR (PSI)	
ASH	2&BTR	18	7060	18	7100	0.995
	3	10	7540	13	8130	0.927
	4	9	6450	3	7200	0.897
	CULL	15	6060	18	7080	0.856
	3&BTR	28	7230	31	7530	0.960
	4&BTR	37	7040	34	7500	0.939
	ALL SHOOK	52	6760	52	7350	0.920
COTTONWOOD	2&BTR	31	5600	32	5900	0.950
	3	19	5330	14	5600	0.950
	4	0	----	3	5390	-----
	CULL	2	4860	3	6410	0.759
	3&BTR	50	5500	46	5810	0.947
	4&BTR	50	5500	49	5790	0.950
	ALL SHOOK	52	5480	52	5820	0.942

[1] OBSERVED DEPTH RATIO = (3.5" MOR / 2.5" MOR)

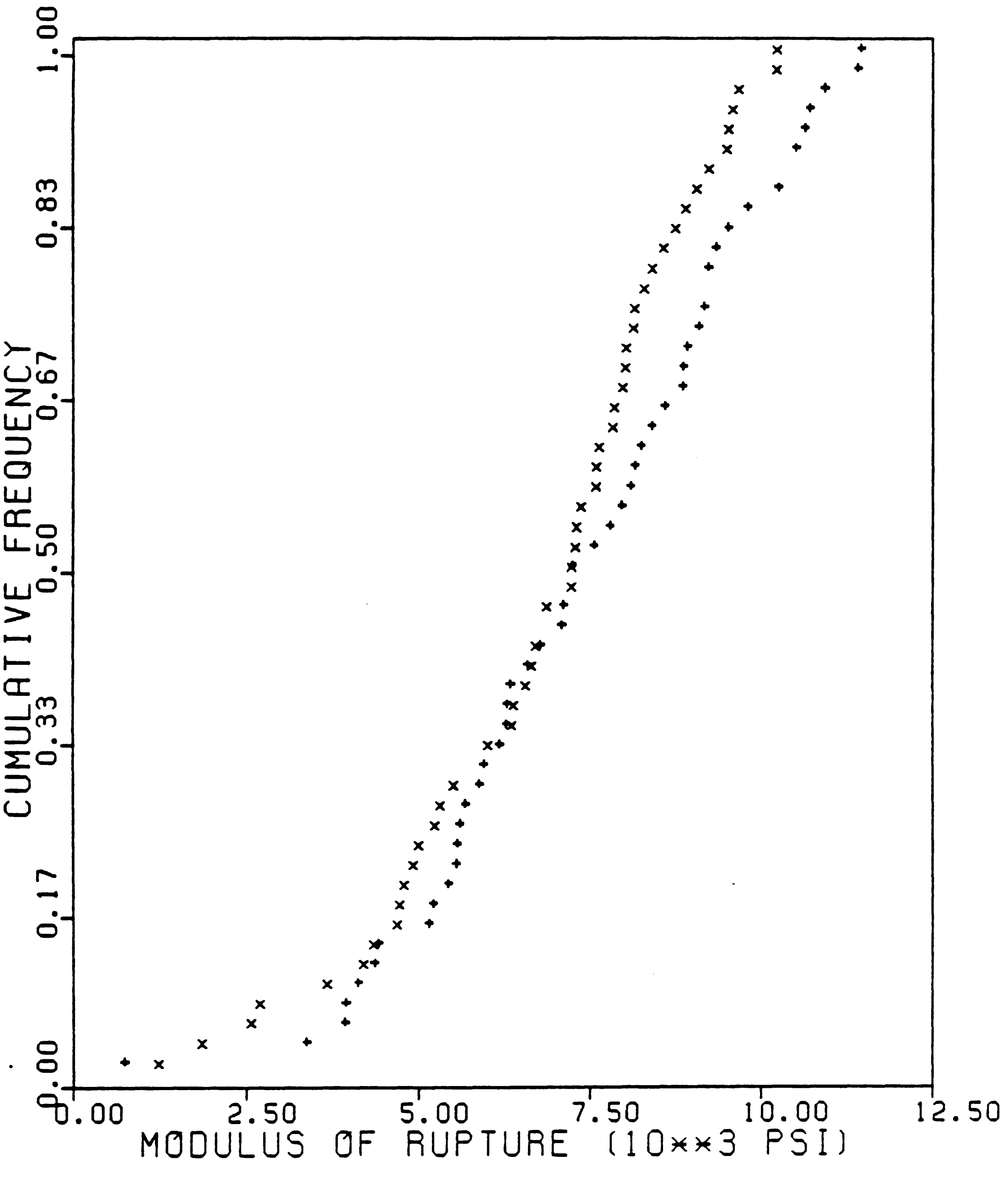

FIGURE 4.1
CDF OF MOR FOR 3.5 INCH AND 2.5 INCH ASH STRINGERS

x = 3.5 inch depth

+ = 2.5 inch depth

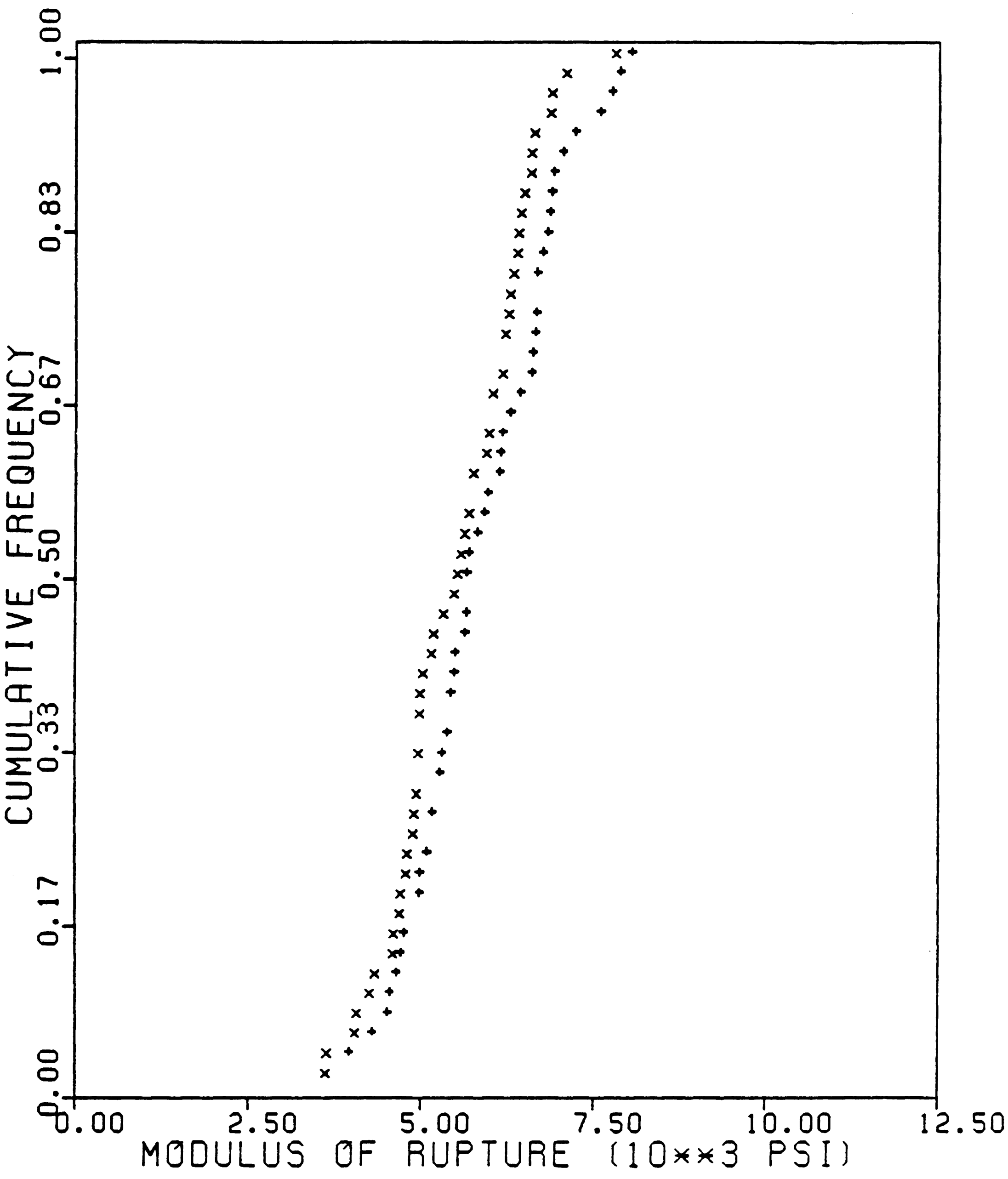

FIGURE 4.2
CDF OF MOR FOR 3.5 INCH AND 2.5 INCH COTTONWOOD STRINGERS

x = 3.5 inch depth

+ = 2.5 inch depth

Although the results of this study indicate a significant effect of depth on MOR for 3.5 versus 2.5 inch hardwood stringers of both a ring-porous and diffuse-porous species, the effect of depth on MOR for stringers versus deckboards remains unsolved. Table 4.5 presents a comparison of the MOR between stringers and deckboards from several data sets. The observed depth ratio is inconsistent between the various data sets. An apparent lack of a depth effect was seen for the poplar shook from the Rate of Loading Study, presented in Section 3 of this thesis, as well as for the oak shook from Spurlock's (45) study. A slight depth effect was seen for the oak shook from the Rate of Loading Study, while a very substantial depth effect was seen for the poplar shook from Holland's (20) study. (The actual raw data for the various data sets can be found in Appendix H.)

A comparison between Spurlock's oak deckboards and stringers and those from the Rate of Loading Study may explain the difference in the observed depth ratio between these two studies. As seen in Appendix H, Spurlock's oak stringers and deckboards had the same average grade, and nearly identical specific gravity as well as MOR. The oak stringers and deckboards from the Rate of Loading Study had nearly identical specific gravity, but the deckboards had a

TABLE 4.5 - DEPTH EFFECT ON MOR: COMPARISON OF DECKBOARDS AND STRINGERS

DATA SET	SPECIES	AVERAGE ACTUAL DIMENSIONS (INCHES) STRINGERS DEPTH	WIDTH	SPAN	DECKBOARDS DEPTH	WIDTH	SPAN	OBSERVED DEPTH RATIO [1]	DEPTH RATIOS PREDICTED BY THE FOLLOWING EQUATIONS: [2] (4.1)	(4.2)	(4.3)	(4.4D)	(4.5)
RATE OF LOADING STUDY (*)	OAK	3.769	1.714	45	0.801	5.753	36	0.950	0.950	0.949	0.842	0.848	0.538
	POPLAR	3.768	1.726	45	0.792	5.740	36	1.011	0.942	0.949	0.841	0.848	0.536
SPURLOCK (**)	OAK	3.740	1.600	45	0.805	3.869	36	1.011	0.950	0.950	0.843	0.850	0.541
					0.825	5.819	36	0.988	0.950	0.950	0.845	0.850	0.546
HOLLAND	POPLAR	3.782	1.654	45	0.815	4.843	36	0.737	0.950	0.950	0.843	0.848	0.541

(*) COMBINED LOADING RATES (UNADJUSTED)
(**) STRINGERS VS. 4" DECKBOARDS AND 6" DECKBOARDS SEPARATELY
[1] (MOR STRINGERS/MOR DECKBOARDS)
[2] EQUATION NUMBERS ARE AS GIVEN IN TEXT

(4.1) - EQUATION GIVEN BY NEWLIN AND TRAYER (35)
(4.2) - EQUATION GIVEN BY FREAS AND SELBO (16)
(4.3) - EQUATION GIVEN BY BOHANNAN (10)
(4.4D) - EQUATION GIVEN BY MADSEN (30)
(4.5) - EQUATION GIVEN BY FEWELL AND CURRY (15)

higher average grade and MOR than the stringers. The higher average grade indicates that the deckboards were of overall higher quality than the stringers. This explains the higher MOR of the deckboards and may also explain the difference in the observed depth ratios between the shook in Spurlock's study and the shook from the Rate of Loading Study.

Unfortunately, the difference in the observed depth ratio between the poplar stringers and deckboards in Holland's study and those from the Rate of Loading Study cannot easily be explained. The stringer MOR for the two studies was very close. However, Holland's deckboard MOR was 34% greater than the deckboard MOR from the Rate of Loading Study. Specific gravity and average grade are of no value in explaining this spectacular difference.

A major problem in determining the MOR of green deckboards is that a large percentage never actually fail during the bending test, instead deflecting to the maximum limit of the testing apparatus. In this case, failure is characterized as excessive deflection and MOR is calculated using the maximum load attained. Spurlock and Holland were able to deflect deckboards a maximum of 5 inches. It was found in the Rate of Loading Study that after 4 to 4.5 inches of deflection, there was little or no increase in load with increasing deflection. Thus, although wood failure had not occurred at 5 inches of deflection, for all practical purposes the deckboard had failed and the maximum load had been reached.

If the bearing plates and loading blocks of the testing apparatus are not free to slide as the deckboard deflects, excessive frictional forces will be developed between the load and support points and the deckboard's surface, and the measured load will be higher than that required only to deflect the deckboard in a bending test. Also, if the bearing plates cannot pivot freely as the deckboard deflects, the actual span will decrease. In either case, the calculated MOR will be erroneously high. If a load-deflection graph is continuously plotted by a chart recorder during the test, the erroneous increases in load caused by either of the above two conditions can be detected by unusual deviations from the load-deflection curve. Since Holland tested most of his shook in the field, he did not have the convenience of such a chart recorder. It was thus hypothesized that his surprisingly high deckboard MOR might be attributable to a problem involving his testing apparatus and the relatively large deflections that occurred in testing the green deckboards.

To test this hypothesis, two groups of ten matched poplar deckboards, which were clear and at green moisture content, were tested in bending to failure or 5 inches of deflection, whichever occurred first. Both groups were tested on a Tinius-Olsen testing machine in third-point loading at a 36-inch span. However, one group was tested using the load and support set-up of the Rate of Loading Study, and the other group was tested using Holland's load and support set-up. Although potential problems existed with Holland's set-up, MOR results obtained with its careful use were the same as MOR results obtained using the Rate of Loading set-up. Therefore, assuming extreme care was taken in the use of Holland's testing set-up, the high deckboard MOR cannot be explained by erroneous results from his tests due to the set-up itself.

The difference in poplar deckboard MOR between the two data sets may be attributable to the fact that the shook in the Rate of Loading Study was sampled from only one mill while Holland's shook was sampled from many mills over a large geographical area.

The large deflections exhibited by the green deckboards during testing result in the violation of a very important assumption in Weibull's statistical strength theory, which is valid only for materials exhibiting brittle failure. Assuming tension failure, which is a brittle failure, this theory can be applied to wood beams in bending. However, for those deckboards failing due to excessive deflection, no brittle failure occurs and Weibull's brittle link theory is violated.

Those deckboards in Holland's study which failed from excessive deflection were eliminated and the MOR for the remaining deckboards was compared to the MOR of the stringers. However, the deckboard MOR was not substantially changed and thus the observed depth ratio was also unchanged. However, even those deckboards that ultimately failed in tension exhibited large deflections, which is uncharacteristic of brittle materials. Due to the violation of the brittle failure characteristic, Weibull's statistical strength theory may not be valid in explaining and estimating differences in strength between green deckboards and stringers.

Spurlock (45) points out that in his study the high quality stringers were stronger than the high quality deckboards, while the reverse was true below the 40th percentile: low quality deckboards were stronger than low quality stringers. Spurlock attributed this reversal to the relative effect of defects (particularly knots) on the moment of inertia of the shook.

Spurlock suggested that ring orientation might explain the differences in clear wood strength between deckboards and stringers, and noted that the large ray volume of oak may in some way influence the relative strength between the two sizes. As stated in the literature review of this section, the inhomogeneity of oak leads to stress concentrations within the member. Since these stress concentrations would be more severe in a smaller member, deckboard strength may be affected more than stringer strength due to stress concentrations at the earlywood-latewood interface. Unfortunately, the lack of research in these areas prevents definite conclusions on the effects of ring orientation, ray volume, and stress concentrations.

An obvious difference between stringers and deckboards, other than the difference in depth, is the much greater width of deckboards, as well as the difference in span during testing. Bohannan (10) concluded that MOR is dependent on depth and length of a beam but independent of width. For simplicity, his equation, $(2/d)^{1/9}$, which is indexed to 1.0 at a standard depth of 2 inches, assumes a constant l/d (span/depth) ratio and the same method of loading. If a constant l/d ratio is not assumed, Bohannan's equation can be re-derived as follows to compare the MOR of stringers to that for deckboards:

$$\frac{R_{\text{stringers}}}{R_{\text{deckboards}}} = \frac{A_{\text{deckboards}}}{A_{\text{stringers}}}^{1/m} = \frac{36 \text{ x } 0.8}{45 \text{ x } 3.75}^{1/18} = 0.906$$

where:

R = Modulus of Rupture

A = Aspect Area (depth x span)

m = constant determined by Bohannan

This ratio (0.906) is closer to the observed depth ratios than the equation assuming equal l/d ratios. Bohannan's equation can also be re-derived assuming a volume effect. A volume effect takes depth and length, as well as width, into account. Assuming MOR is not independent of width, the following equation can be used to compare the MOR of stringers to that for deckboards:

$$\frac{R_{\text{stringers}}}{R_{\text{deckboards}}} = \frac{V_{\text{deckboards}}}{V_{\text{stringers}}}^{1/m} = \frac{36 \text{ x } 0.8 \text{ x } 5.75}{45 \text{ x } 3.75 \text{ x } 1.70}^{1/18} = 0.970$$

where:

R = Modulus of Rupture

V = Volume (depth x width x span)

m = constant determined by Bohannan

This ratio (0.970) comes much closer to the observed depth ratio between deckboards and stringers for the majority of the data sets as presented in Table 4.5.

Bohannan concluded that the MOR of a beam was independent of width not only because his data showed no effect of width, but because his equation based on volume effect (as above) indicated that a beam loaded on edge (as a joist) would have the same strength as the same beam loaded on its wide face (as a plank). Bohannan considered this to be inconsistent with the idea of a size effect on MOR.

If the MOR of a beam is independent of width, then 1 x 4 x 40 inch deckboards would be expected to have the same strength as 1 x 6 x 40 inch deckboards. However, this was not the case for the oak shook in Spurlock's study. Table 4.6 compares the MOR for 4 inch versus 6 inch wide deckboards. The 4 inch wide deckboards were slightly weaker than the 6 inch deckboards for all grades as well as for the clear material. If the actual average dimensions for all 4 and 6 inch deckboards (see Table 4.6) are used in Bohannan's (10) equation, $(2/d)^{1/9}$, then the ratio of the 4 inch MOR to the 6 inch MOR would be expected to be 1.003. If the actual dimensions are used in the volume effect equation given above, then the ratio of the 4 inch MOR to the 6 inch MOR

TABLE 4.6 - MOR OF 4 INCH VERSUS 6 INCH OAK DECKBOARDS [1]

	MOR (PSI)		
GRADE	4 INCH DECKBOARDS	6 INCH DECKBOARDS	RATIO (4"/6")
CLEAR	8040	8420	0.954
ALL SHOOK	7100	7270	0.977
2&BTR	7950	8160	0.974
3	7320	7470	0.980
4	6920	7010	0.986
CULL	6180	6300	0.978

[1] DATA SOURCE: SPURLOCK (45)

would be expected to be 1.024. Thus the 4 inch deckboards would be expected to have the higher MOP when actually the 6 inch deckboards were stronger.

Following along lines of reasoning similar to that given by Bohannan (10), a possible explanation arises for the difference in clear wood strength for 4 inch versus 6 inch deckboards. When an element of width fails, the stress in the remaining elements is increased by n/(n-1), where n equals the number of elements. This may or may not cause failure of the next weakest element; thus cascade failure may not occur. However, the increase in stress for a 4 inch deckboard will be greater than for a 6 inch deckboard after failure of the first element. Statistical theory implies that as the width increases, the probability of occurrence of a region of low strength increases. But as the width increases, the probability of a cascade failure across the width decreases.

At this point in the line of reasoning, Bohannan concludes that the net effect of these counteracting probabilities may be negligible. However, if the decrease in the probability of a cascade failure across the width is greater than the increase in probability of an occurrence of a region of low strength, then this would explain the observed behaviour of clear 6 inch versus 4 inch deckboards.

It may be possible to statistically calculate the decrease in probability of a cascade failure across the width with increasing width, as was possible for the increase in probability of an occurrence of a region of low strength. This may be a fracture mechanics problem, especially considering the anisotropic, heterogeneous nature of wood.

There is another possible explanation for the greater strength of 6 inch versus 4 inch deckboards when defects are considered. It seems reasonable that 6 inch deckboards would have a greater MOR than 4 inch deckboards when defect size, particularly knot size, is considered. The average knot size would not be expected to be much larger for 6 inch deckboards than for 4 inch deckboards due to typical sawing practices for pallet shook, which is often resawn from cants or sawn from small diameter, low quality logs. Indeed, for the 4 inch oak deckboards in Spurlock's (45) study, the average knot diameter was 1.44 inch while the average knot diameter was 1.54 for the 6 inch deckboards - only slightly higher. Therefore, the 4 inch deckboards would have their strength reduced much more by knots, on average, than the 6 inch deckboards. Note, however, that this trend of relative knot sizes between 4 and 6 inch deckboards may only be a random occurrence for this particular data set.

ASTM D 245 uses Bohannan's formula, $(2/d)^{1/9}$, in the derivation of design values for lumber by adjusting clear wood strength values of 2 inch beams to the depth of the full-size piece. Since the 2 inch deep beams were tested using center-point loading and an l/d ratio of 14, the adjustment for depth is technically valid only for these conditions. Full-size lumber typically has l/d ratios larger than 14. It was shown earlier how Bohannan's formula could be re-derived to account for the different l/d ratios between deckboards and stringers. Full-size lumber is also not usually center-point loaded. A more complicated form of Bohannan's equation can be used which accounts for the different l/d ratios as well as loading conditions of full-size lumber.

For example, Bohannan's equation can be re-derived as follows in order to adjust the clear wood strength of center-point loaded 2 inch deep beams at a 28 inch span to 3.5 inch deep stringers assuming a 45 inch span and third-point loading:

$$\frac{R_{\text{stringers}}}{R_{2'' \text{ beam}}} = \frac{[(d \times L)(1 + \frac{a}{L}\ m)]^{1/m}_{2'' \text{ beam}}}{[(d \times L)(1 + \frac{a}{L}\ m)]^{1/m}_{\text{stringers}}}$$

$$= \frac{[(2.0 \times 28)(1 + \frac{0}{28} \times 18)]^{1/18}}{[(3.5 \times 45)(1 + \frac{15}{45} \times 18)]^{1/18}}$$

$$= 0.847$$

where:

R = MOR
d = depth
L = span
a = distance between load points
m = constant determined by Bohannon (10)

This is a larger reduction than obtained using $(2/d)^{1/9}$: 0.847 vs. 0.940. However, the correction for l/d ratio and loading condition has historically been ignored in deriving design values for solid-sawn lumber less than 12 inches in depth.

4.5 CONCLUSIONS

A decrease in strength with increased depth was seen for both ash and cottonwood stringers. No apparent difference was seen for the effect of depth on bending strength between the ring-porous and diffuse-porous species within the size range tested. Of the several depth factor equations analyzed, Madsen's (30) was seen to best predict the observed depth factor. However, Bohannan's (10) equation is currently used in the derivation of design values using the standard methods of ASTM D 245.

No definite conclusions can be reached concerning the relative strength of deckboards versus stringers. From the currently accepted depth effect point of view, deckboards should be stronger than stringers. However, this was not consistently the case for the various data sets analyzed. Several factors, other than depth, which may influence the relative strength of deckboards versus stringers have been discussed. These factors include:

-excessive deflection of green deckboards during testing

-effect of width on bending strength

-effect of ring orientation on bending strength

-effect of stress concentrations due to material inhomogeneity

-relative effect of defects on deckboards versus stringers

In fact, all these factors may influence the relative strength of deckboards and stringers, thus confounding the problem. It appears that the depth factor equation given by Bohannan (10) does not accurately account for differences in strength between deckboards and stringers. This may be due to the violation of the key assumption in the Statistical Strength Theory of a brittle failure. The excessive deflection of green deckboards during testing is uncharacteristic of brittle materials and violates the brittle failure requirement.

Any size effect on the bending strength of lumber is probably composed of the relative effect of defects, the effect of anatomical charateristics, as well as the statistical occurrence of regions of low strength as expressed by the Statistical Strength Theory. Unfortunately, such a size effect is not yet completely understood.

Despite its apparent inconsistencies, it is recommended that Bohannan's formula, $(2/d)^{1/9}$, be used in the derivation of design values for pallet shook, without correction for span or loading condition. This recommendation is based not only on the historically successful use of the formula, but due to the lack of a rational alternative based on the limited available data. Since a depth effect was seen between 2.5 and 3.5 inch stringers, it is recommended that a depth factor be applied to stringers in the derivation of design values from tests of small clear specimens. However, in light of the controversy between strength of deckboards and stringers, a depth factor should not be applied to deckboards. This would be a conservative approach since a depth factor applied to deckboards would actually increase the small clear specimen value, which has a standard depth of two inches.

Sufficient evidence exists to warrant further research on the effect of width on bending strength of wood.

5.0 STRENGTH RATIO STUDY

5.1 INTRODUCTION

The ASTM D 245 (4) method of deriving design values for full-size structural lumber is based on the use of certain adjustment factors, including strength ratios. The strength ratio of a piece of structural lumber is defined as the ratio of the strength of the piece, with knots, cross-grain, splits, checks, and other strength reducing defects, to the hypothetical strength of the piece had it been clear and straight grained. These strength ratios are used to modify the clear wood strength value to predict the strength of a piece with defects. The ratios were developed for softwood structural lumber and have only recently been used with hardwoods. This strength ratio approach could easily be incorporated into a method of deriving design values for pallet shook of both hardwood and softwood species. However, the effectiveness of the ASTM D 245 strength ratios in predicting the strength of hardwood lumber has been questioned (24,41,51). Their effectiveness in predicting the strength of hardwood pallet shook should be determined before using in the derivation of design values.

This study examined the use of ASTM strength ratios for estimating the influence of defects on the strength of several species and sizes of hardwood pallet shook. This was accomplished by comparing the estimated strength ratio from ASTM D 245 for each piece of shook with the actual strength ratio determined through testing. The accuracy of the ASTM strength ratios in predicting the strength of the different species and sizes of shook for various types of defects was thus determined.

5.2 REVIEW OF LITERATURE

Wilson (54) published strength ratio tables in his guide to the grading of structural timbers. The methods of ASTM D 245 (4), including the strength ratio approach, are based upon this guide. The effect of a defect on lumber strength depends on the type of defect and the kind of loading and stress to which the piece is subjected. The strength ratios of bending members with knots were derived as the ratio of moment-carrying capacity of a member with its cross section reduced by the largest knot to the moment carrying capacity of the member of full cross section. For simplicity, all knots are treated as either edge knots or centerline knots. Shakes, splits, and checks are assumed to affect only horizontal shear in bending members. Strength ratios for these defects were derived by assuming that a critical cross section is reduced by the amount of the shake, split, or check (4). The strength ratios of bending members with slope of grain were determined experimentally (53).

Researchers often check the validity of estimated strength ratios (ESR) by testing a full-size piece of lumber to obtain an MOR and then testing a small, clear specimen taken from the undamaged portion of the full-size piece (40). The ratio of the MOR of the full-size piece to the MOR of the small, clear specimen is the actual strength ratio (ASR). The ESR and the ASR can then be compared. Doyle and Markwardt (14) used this procedure to determine the ASR of full-size southern pine dimension lumber. The ESR was determined using strength ratios given in ASTM D 245 (4). A correlation coefficient of 0.678 was found between the ESR and the ASR, indicating a moderately strong relationship.

The methods of ASTM D 245 were developed and are typically used for the grading of softwood structural lumber. Nevertheless, the potential use of the strength ratio approach of ASTM D 245 has been proposed for estimating the strength of hardwood structural lumber. This approach is, in fact, used to derive design values for certain hardwood species including yellow-poplar, cottonwood, and aspen. Knab et.al. (23) used the strength ratios provided in ASTM D 245 for knots, slope of grain, and other strength reducing characteristics in estimating the strength of mixed hardwood trenching lumber. Galligan (17) proposed that yellow-poplar lumber can be stress graded by existing standard procedures regularly used for softwoods.

Walters et.al. (51) compared the ESR and ASR of red oak and cottonwood lumber. The coefficients of determination ranged from .12 to .44. Since the degree of correlation between ESR and ASR was very low, the strength ratios were of little utility in estimating actual strength for red oak and cottonwood. The relationship between ESR and ASR was seen to vary with knot size and location. Orosz (40) suggests that the ESR should be a good predictor of strength for pieces with single large knots but that ESR would not be as good a predictor for pieces with several small knots.

Rousis and Koch (41), in a study of yellow-poplar 2 x 4's, found a higher degree of correlation between ASR and ESR than Walter's but less than that from most softwood studies. Later, Koch (24) again examined the prediction of bending strength of yellow-poplar 2 x 4's using strength ratios. Knot size was determined by the displacement method as well as by the knot diameter on the worst face. The mean displacement ESR was 1.5 times the mean worst face ESR, indicating the high degree of taper of knots in the yellow-poplar specimens. From a regression analysis, the worst face ESR was seen to be a better predictor of ASR than the displacement ESR. The relationship between ESR and ASR was similar to that found for oak and cottonwood (51). The ESR underpredicted the ASR for large knots and overpredicted the ASR for small knots. Koch points out the upward branching pattern in yellow-poplar and other hardwoods, as well as the prevalent bark pockets around knots in yellow-poplar. These features are not usual in softwoods. The grain distortion was found to be greater around yellow-poplar knots than that around softwood knots of comparable size. Koch states that because there may be greater grain disorientation around knots in hardwoods than in softwoods, some modification may be necessary in the technique of measuring knots in hardwood lumber before it can be accurately stress graded using existing strength ratios.

Spurlock (45) briefly examined the potential of using the strength ratio approach of ASTM D 245 in estimating strength of the oak pallet shook used in his study. The clear wood properties were determined from the full size, defect-free pieces of the shook sample. A 5% exclusion value of the clear wood MOR was computed and adjusted for normal load duration and a factor of safety. The clear wood MOE was adjusted for shear deformation only in stringers. Estimated allowable properties for each grade were determined by multiplying the clear wood MOR values by the minimum ASTM strength ratio for each grade. The clear wood MOE values were multiplied by the ASTM quality factor for each grade. Experimentally determined strength values were computed as the 5% exclusion value modified for normal load duration and by a factor of safety. The average experimentally determined MOE values for each grade were adjusted only for shear deformation in the stringers.

The allowable stresses obtained from ASTM D 245 were found to be consistently conservative: the experimental values were higher than predicted values. However, data for all shook with splits and for stringers with narrow face knots were deleted because these defects caused negative ASTM strength ratios. Spurlock concluded that the use of the strength ratio approach of ASTM D 245 for estimating strength of pallet shook warranted further study.

5.3 MATERIALS AND METHODS

The main source of data for this study was Spurlock's (45) oak shook data involving 2811 stringers and deckboards at green moisture content. Other sources of data included the oak and poplar pallet shook tested in the Rate of Loading Study (Section 3 of this thesis) and the ash and cottonwood stringers tested in the Depth Effect Study (Section 4 of this thesis).

For each piece of shook in the above studies, all significant defects were measured according to ASTM D 245 (4) and their location was recorded. Appendix A gives complete details of the defect mapping and coding procedure.

The 14 digit code used to identify and characterize each defect within a piece was entered and stored on computer. A computer program was written to calculate the strength ratio associated with each defect according to the equations and tables in ASTM D 245 for knots, checks, shakes, and slope of grain. A copy of this program is included in Appendix D.

The estimated strength ratio (ESR) of the piece was taken to be the lowest strength ratio associated with any defect within the piece. Pieces having only defects for which strength ratios do not exist (e.g. wane, decay) were not assigned an ESR.

To calculate the actual strength ratio (ASR), the MOR of the full-size piece is typically divided by the strength of a small clear specimen taken from the full-size piece. However, this procedure was not feasible in this study. Instead, the clear wood strength was estimated by the average MOR of the clear, straight-grained pieces within a particular species/size class and data set.

If a regression relationship could have been established between the MOR and specific gravity of the clear wood pieces, then this regression could have been used to predict an individual clear wood MOR for each piece containing defects based on its specific gravity. However, the relationship between the MOR and specific gravity of the clear wood pieces was very poor. The coefficient of determination was .30 for stringers, .05 for four inch deckboards, and .004 for the six inch deckboards. Therefore, the attempt to relate the clear wood MOR to the specific gravity was abandoned.

There were too few clear pieces in the Rate of Loading Study to calculate a reliable clear wood value. Instead, the clear wood MOR was taken from ASTM D 2555 (5). A depth factor (.93), calculated from Bohannan's (10) formula, was used to adjust the clear MOR for stringers. The ASTM clear wood value was left unadjusted for depth in deckboards. A rate of loading adjustment factor (1/1.08) was used to adjust the clear wood MOR for the data tested at the fast rate of loading (see Section 3).

In determining the clear wood strength for the stringers in the Depth Effect Study, a reliable clear wood MOR could only be calculated for the 2.5 inch deep stringers. Therefore, to calculate the clear wood MOR of the 3.5 inch stringers, the 2.5 inch clear wood MOR was adjusted using the observed depth ratio for each species (see Table 4.3). This adjusted value was used as the clear wood strength value of the 3.5 inch stringers. Table 5.1 presents the clear wood strength values used for each species/size class in this study.

The ASR of each piece was then calculated as the ratio of the actual MOR of the piece to the average clear wood MOR determined for the respective species/size class. By comparing the ASR with the ESR, the effectiveness of the strength ratios in predicting MOR could be determined.

TABLE 5.1 - CLEAR WOOD STRENGTH (USED AS BASIS OF ASR VALUES)

DATA SET	SPECIES	LOADING RATE	SIZE	MEAN CLEAR WOOD MOR (PSI)	N
SPURLOCK (41)	OAK	****	3.5" STRINGERS	8930	115
			4" DECKBOARDS	8040	120
			6" DECKBOARDS	8420	47
RATE OF LOADING STUDY	OAK	FAST	3.5" STRINGERS	8260	***
			6" DECKBOARDS	8890	***
		SLOW	3.5" STRINGERS	7650	***
			6" DECKBOARDS	8230	***
	POPLAR	FAST	3.5" STRINGERS	5980	***
			6" DECKBOARDS	6430	***
		SLOW	3.5" STRINGERS	5530	***
			6" DECKBOARDS	5950	***
DEPTH EFFECT STUDY	ASH	****	3.5" STRINGERS	8680	**
		****	2.5" STRINGERS	9440	3
	COTTONWOOD	****	3.5" STRINGERS	6620	**
		****	2.5" STRINGERS	7040	6

**** LOADING RATE COLUMN APPLIES ONLY TO DATA FROM THE RATE OF LOADING STUDY

*** CLEAR WOOD VALUES DERIVED FROM ASTM D 2555 DUE TO INSUFFICIENT NUMBER OF CLEAR WOOD PIECES

** CLEAR WOOD VALUES FOR 3.5" STRINGERS WERE DERIVED FROM CLEAR WOOD VALUES FOR 2.5" STRINGERS BY ADJUSTING FOR DEPTH

5.4 RESULTS AND DISCUSSION

The method of determining clear wood strength used in this study requires much less time and expense than machining and testing a small clear specimen from the full-size piece. The cost of the small clear method was prohibitive for this study, and in many cases a clear, straight-grained specimen could not be cut from destructively-tested pallet shook.

The standard method does have the advantage of producing a clear wood strength value potentially more representative of the particular piece from which it came. The alternative clear wood strength values used in this study are averages and therefore underestimate the true clear wood strength of some pieces while overestimating it for others. This results in wider variation of the ASR, with values well over 100% common. Nevertheless, the average ASR for a particular species/size class should be fairly accurate since the overestimation of clear wood strength for some pieces is balanced by the underestimation for other pieces.

Table 5.2 presents a comparison of the average ESR and average ASR by size and grade for Spurlock's eastern oak

TABLE 5.2 - COMPARISON OF ASR AND ESR FROM SPURLOCK'S OAK SHOOK DATA

SPECIES	SIZE	GRADE	ASR (%)	ESR (%)	RATIO (ASR/ESR)	N
OAK	3.5" STRINGERS	ALL SHOOK	82	66	1.24	1131
		2&BTR	95	85	1.12	332
		3	84	67	1.25	295
		4	77	59	1.31	262
		CULL	68	48	1.42	242
OAK	4" DECKBOARDS	ALL SHOOK	89	73	1.22	695
		2&BTR	99	93	1.06	231
		3	92	73	1.26	176
		4	84	62	1.35	119
		CULL	76	53	1.43	169
OAK	6" DECKBOARDS	ALL SHOOK	86	75	1.15	426
		2&BTR	97	93	1.04	127
		3	86	78	1.10	127
		4	84	63	1.33	76
		CULL	73	55	1.33	90

shook data set. It should be noted that of all the data sets analyzed, Spurlock's provides the most reliable comparison of the ESR and ASR due to the large sample size. Although the average ESR is less than the average ASR in all sizes and grades for Spurlock's data, this conservatism in the estimation of strength does not appear unreasonable. The ratio of the ASR to the ESR is smaller for the higher grades than the lower grades, indicating that the ESR overpredicts the strength reduction for the more severe defects.

Table 5.3 presents a comparison of the average ESR and ASR for the data from the Rate of Loading and the Depth Effect Studies. Due to the limited sample size and the method of determining clear wood values, a comparison of ESR and ASR is most reliable only as an average value for all grades of each species for these data sets. The ASR is generally much higher than the ESR for these data sets, also. Table E-1 in the appendix compares the ASR and ESR for the individual grades of these data sets.

To provide a visual comparison of the accuracy of the ESR in predicting the ASR for different types of defects, line-plots of the ESR versus defect size were superimposed on scatter-plots of the ASR versus defect size. These plots

TABLE 5.3 - COMPARISON OF ASR AND ESR FOR DATA FROM RATE OF LOADING STUDY AND DEPTH EFFECT STUDY

DATA SET	SPECIES	SIZE	ASR (%)	ESR (%)	RATIO (ASR/ESR)	N
RATE OF LOADING STUDY	OAK	3.5" STRINGERS	91	71	1.28	80
		6" DECKBOARDS	89	87	1.02	80
	POPLAR	3.5" STRINGERS	100	70	1.43	80
		6" DECKBOARDS	92	83	1.11	80
DEPTH EFFECT STUDY	ASH	3.5" STRINGERS	77	54	1.43	51
		2.5" STRINGERS	78	54	1.44	46
	COTTONWOOD	3.5" STRINGERS	82	71	1.15	46
		2.5" STRINGERS	83	68	1.22	51

NOTE: SEE TABLE E-1 IN THE APPENDIX FOR BREAKDOWN BY GRADE were made separately for the various types of defects and shook sizes using Spurlock's eastern oak shook data and are presented in Figures 5.1 through 5.24. To be included in a plot for a particular type of defect, a shook piece had that particular defect as its only or its worst defect (i.e. the defect resulted in the lowest ESR for the piece).

Immediately noticeable from these plots is the wide variation in the ASR for a given defect size. This is due in part to the use of an average clear wood strength value in determining the ASR. The general trend of conservatism in the ESR is also obvious. A regression analysis showed the degree of correlation between ASR and ESR to be nearly zero.

Figures 5.1 and 5.2 are strength ratio plots of centerline knots and edge knots, respectively, in oak stringers. While ASTM strength ratios for centerline knots are applicable throughout the length of the piece, the strength ratios for edge knots apply only to those knots within the middle one-third of the length. Therefore, only those edge knots within the middle one-third of the length of the oak stringers are plotted in Figure 5.2. For both centerline and edge knots in oak stringers, the ESR predicts the average ASR fairly well for small knot sizes. As the

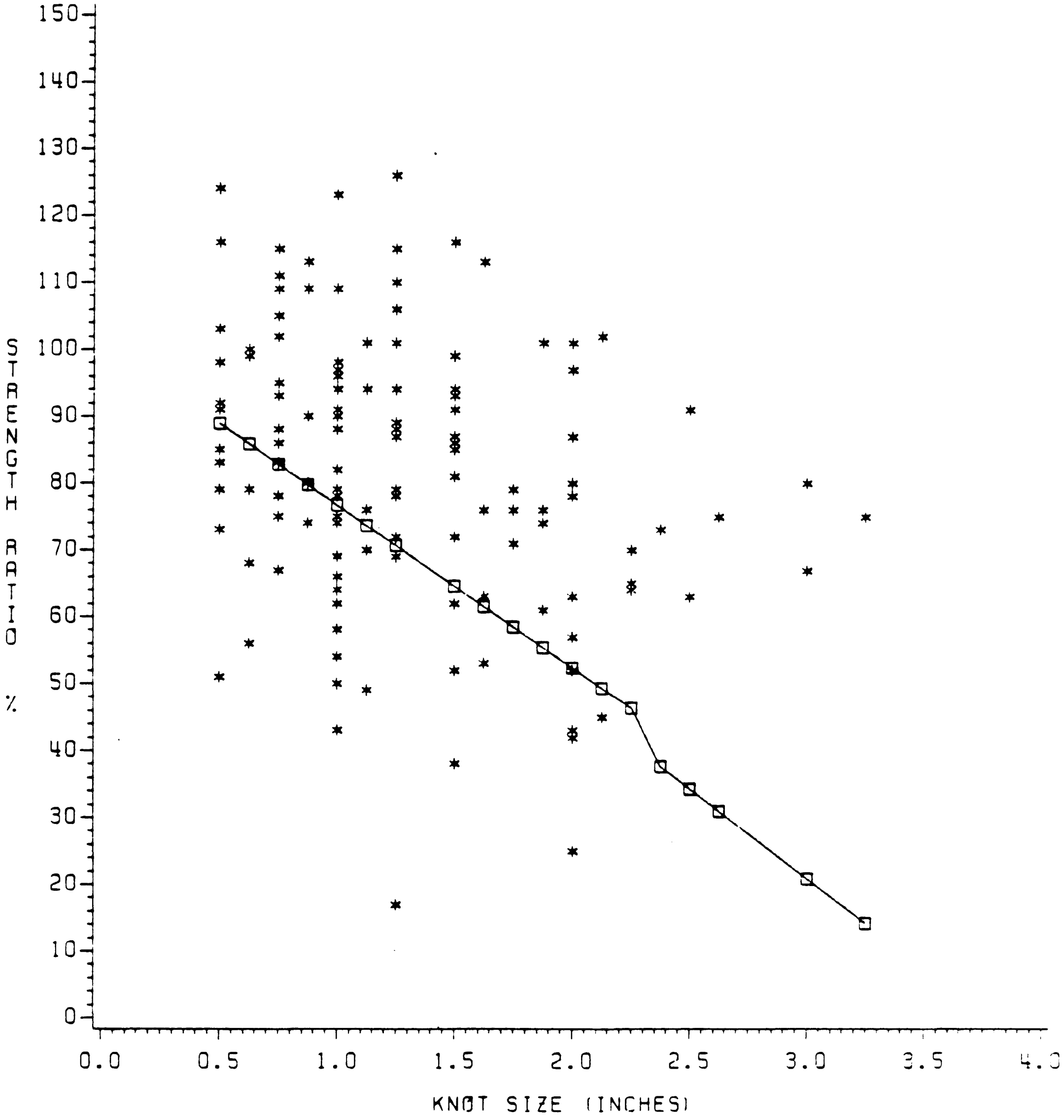

FIGURE 5.1 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR CENTERLINE KNOTS IN OAK STRINGERS

* = ASR
□ = ESR

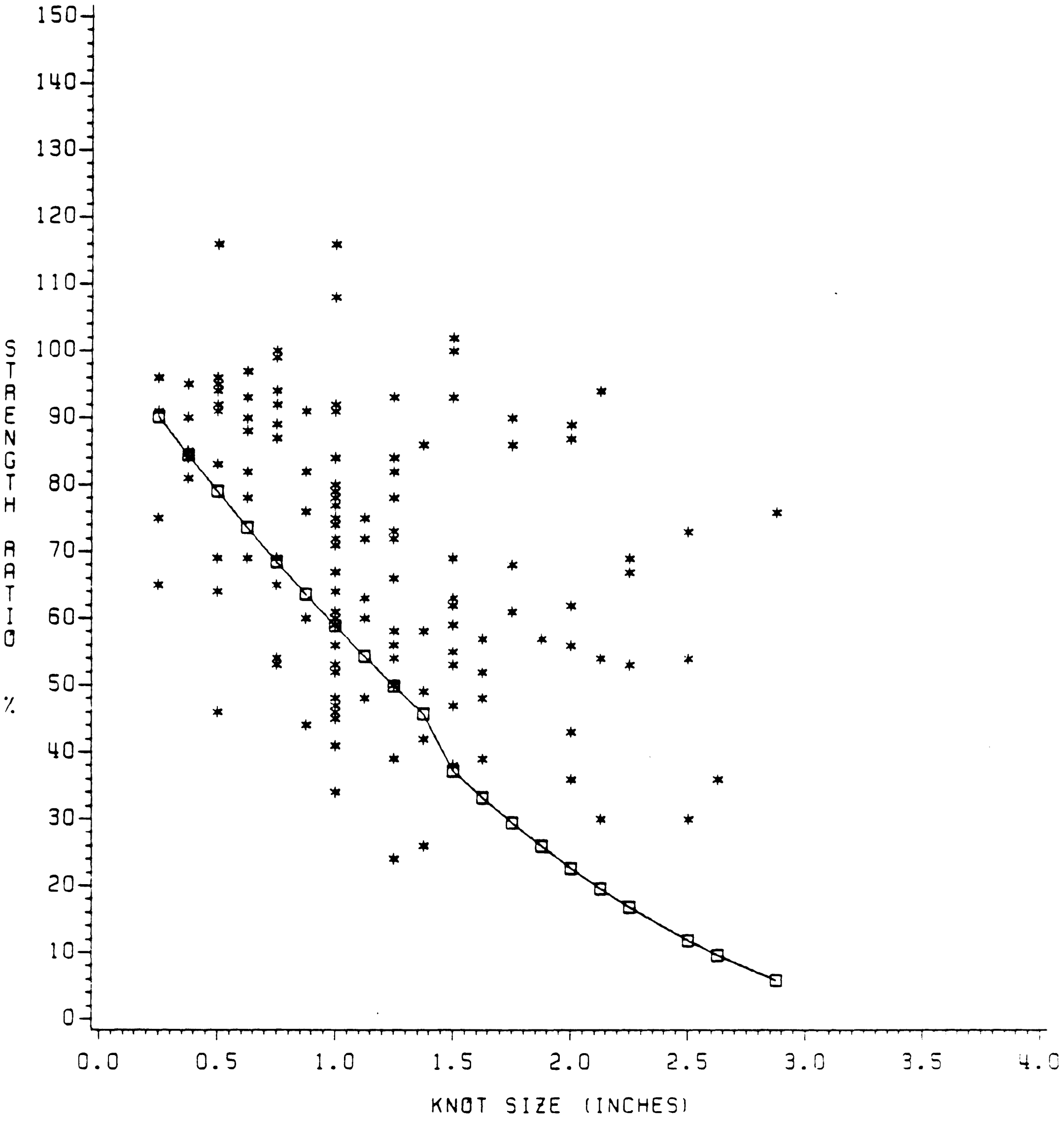

FIGURE 5.2 - STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR EDGE KNOTS IN OAK STRINGERS

(KNOTS WITHIN CENTRAL THIRD OF LENGTH ONLY)

* = ASR
□ = ESR

knot size increases, however, the ESR becomes increasingly conservative. The edge knot ESR is even more conservative than the centerline knot ESR for large knot sizes (greater than 2 inches). The formula for calculating the ESR changes below an ESR of 45% for all sizes of members and all types of knots. This can be seen as a sudden shift of the ESR line at the 45% point in Figures 5.1 and 5.2, as well as the remaining plots comparing ASR and ESR for members containing knots. As seen in Figures 5.1 and 5.2, as well as other figures, this change in the formula below an ESR of 45% does not appear justifiable. However, only limited data are available for large defects.

Figure 5.3 is a strength ratio plot of "elsewhere" knots. ASTM D 245 considers wide-face knots in stringers as either edge knots or centerline knots. However, Spurlock (45) defined a category of knots, which he termed "elsewhere" knots, that neither intersect the edge nor the centerline of a stringer. Some of these knots would have been considered edge knots according to ASTM D 245, while the others would have been considered centerline knots. The ESR line in Figure 5.3 was calculated using the formula for centerline knots and predicts the average ASR fairly well. Had the formula for edge knots been used instead, the ESR line would have been much steeper.

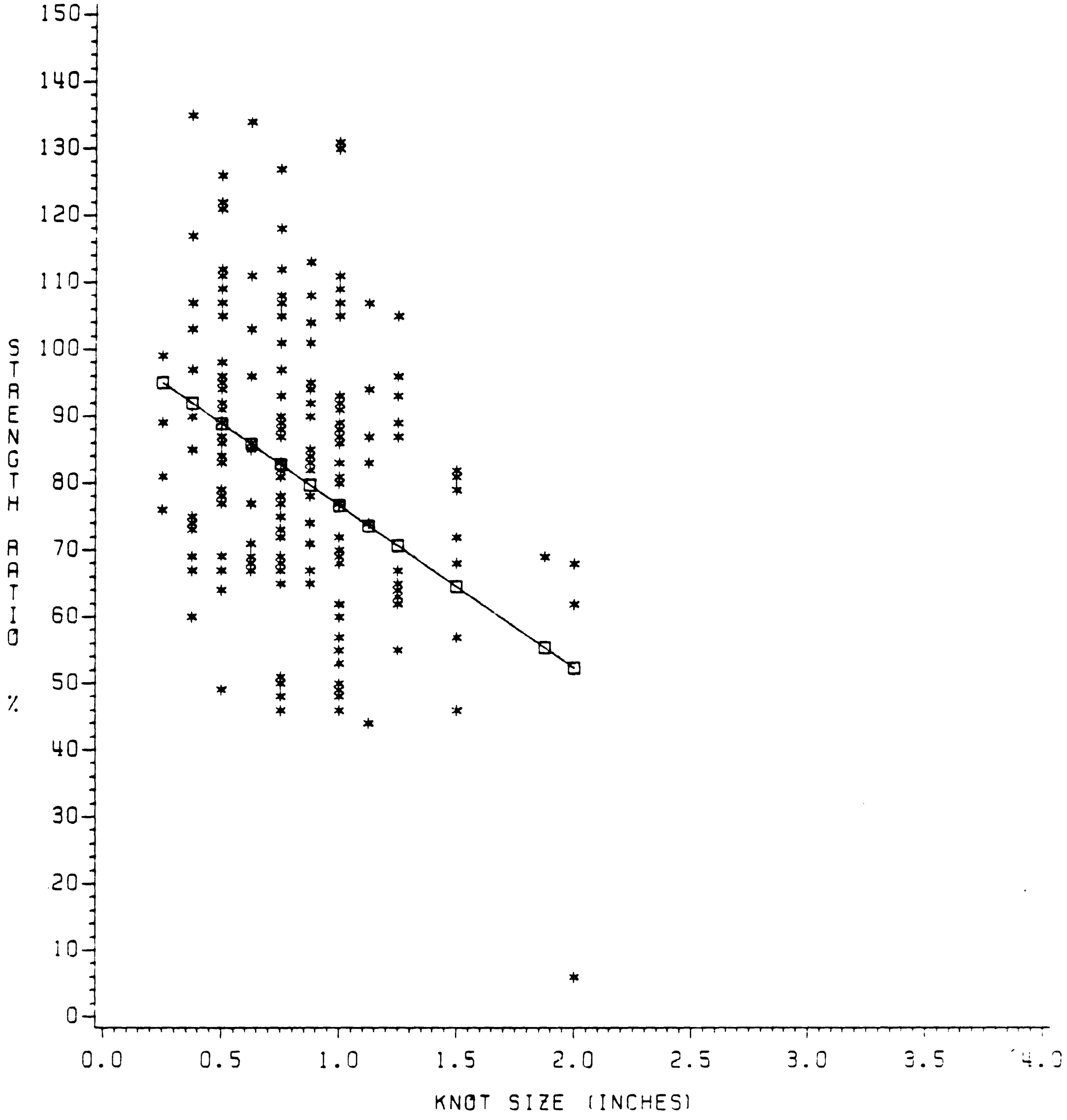

FIGURE 5.3 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR ELSEWHERE KNOTS IN OAK STRINGERS

* = ASR
□ = ESR

Unfortunately, a comparison of ASR and ESR for narrow face knots in stringers could not be made with Spurlock's data. This is because narrow face knots were not measured according to ASTM D 245 and could not be assigned an ESR. This explains why Spurlock erroneously obtained negative strength ratios for narrow face knots.

The strength ratio equations given in ASTM D 245 for edge knots make no differentiation as to which edge (compression or tension) the knot occupies. However tension edge knots would be expected to reduce the strength much more than compression knots due to the more severe effect of grain disorientation on tensile strength. Separate strength ratio plots were made for tension and compression edge knots as shown in Figures 5.4 and 5.5. As expected, the ESR underpredicts the ASR of compression edge knots much more than for the tension edge knots. A few of the stringers had large edge knots that intersected both the tension and compresion edges. Therefore, the ASR was plotted for these pieces in both Figures 5.4 and 5.5.

Figure 5.6 is the strength ratio plot for slope of grain in oak stringers. As for knots, the ESR is fairly conservative in predicting strength. However, the ESR does not appear to become increasingly conservative as the severity of the slope of grain increases.

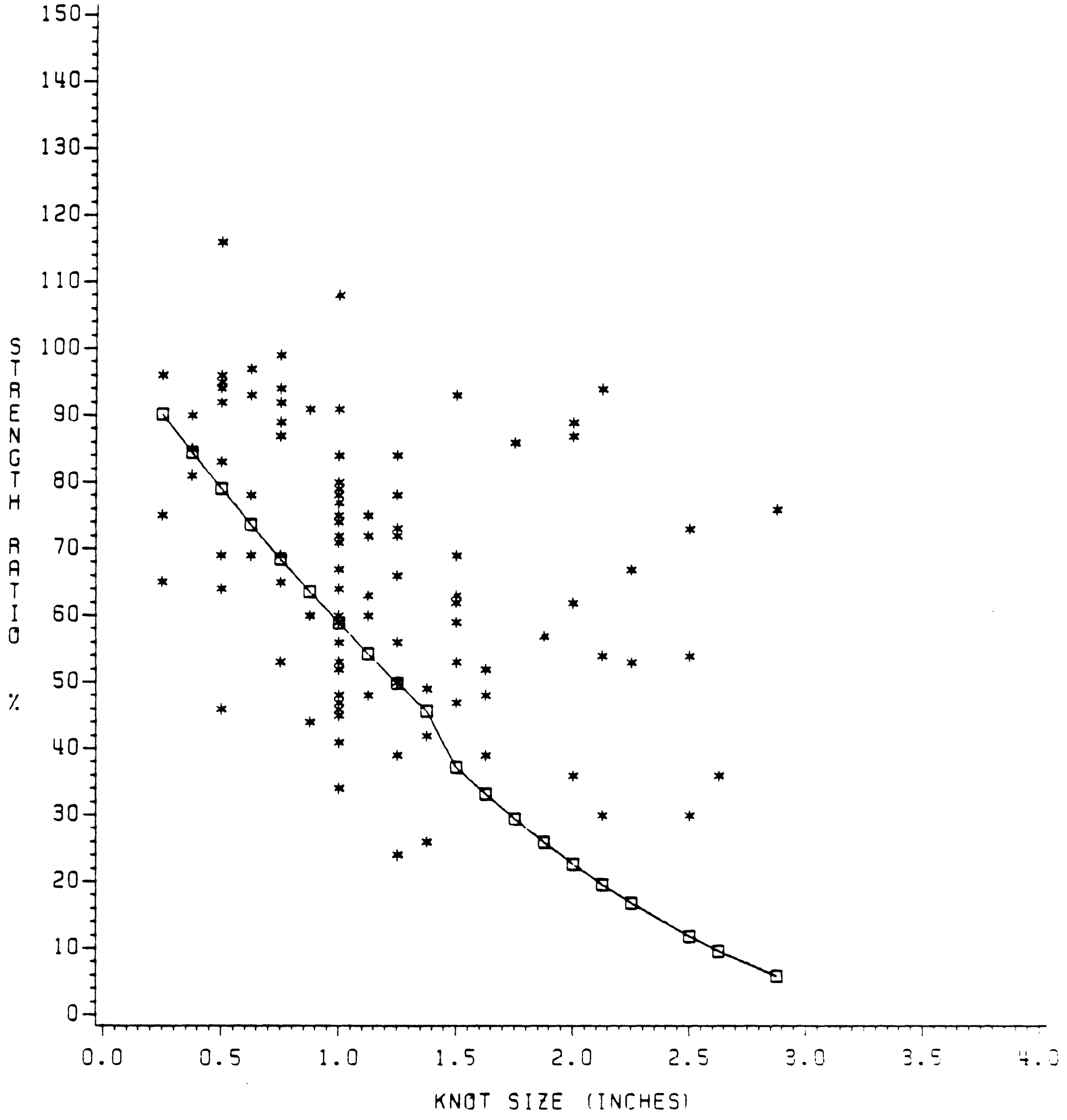

FIGURE 5.4 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR TENSION EDGE KNOTS IN OAK STRINGERS

(KNOTS WITHIN CENTRAL THIRD OF LENGTH ONLY)

* = ASR
□ = ESR

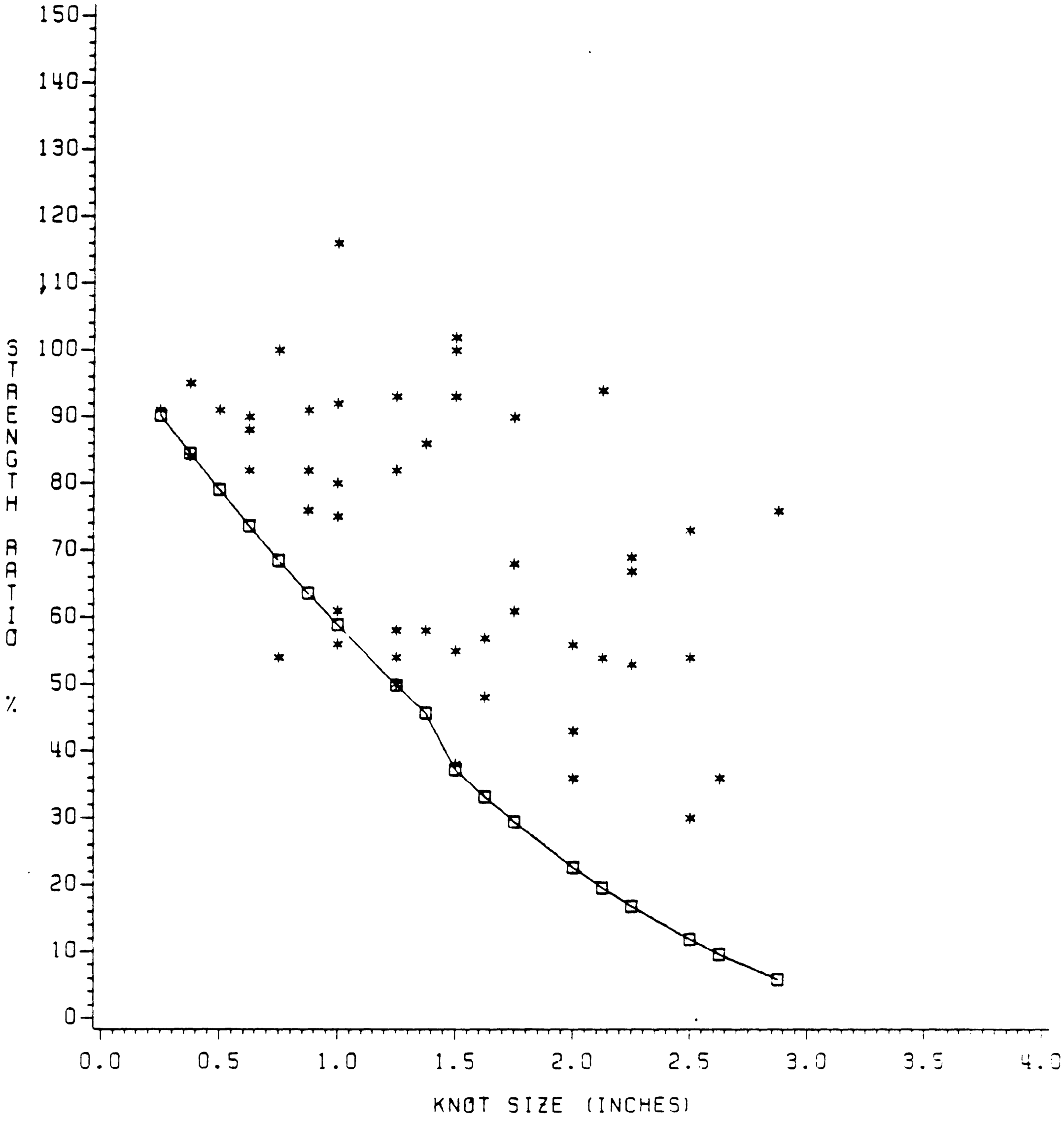

FIGURE 5.5 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR COMPRESSION EDGE KNOTS IN OAK STRINGERS

(KNOTS WITHIN CENTRAL THIRD OF LENGTH ONLY)

* = ASR
□ = ESR

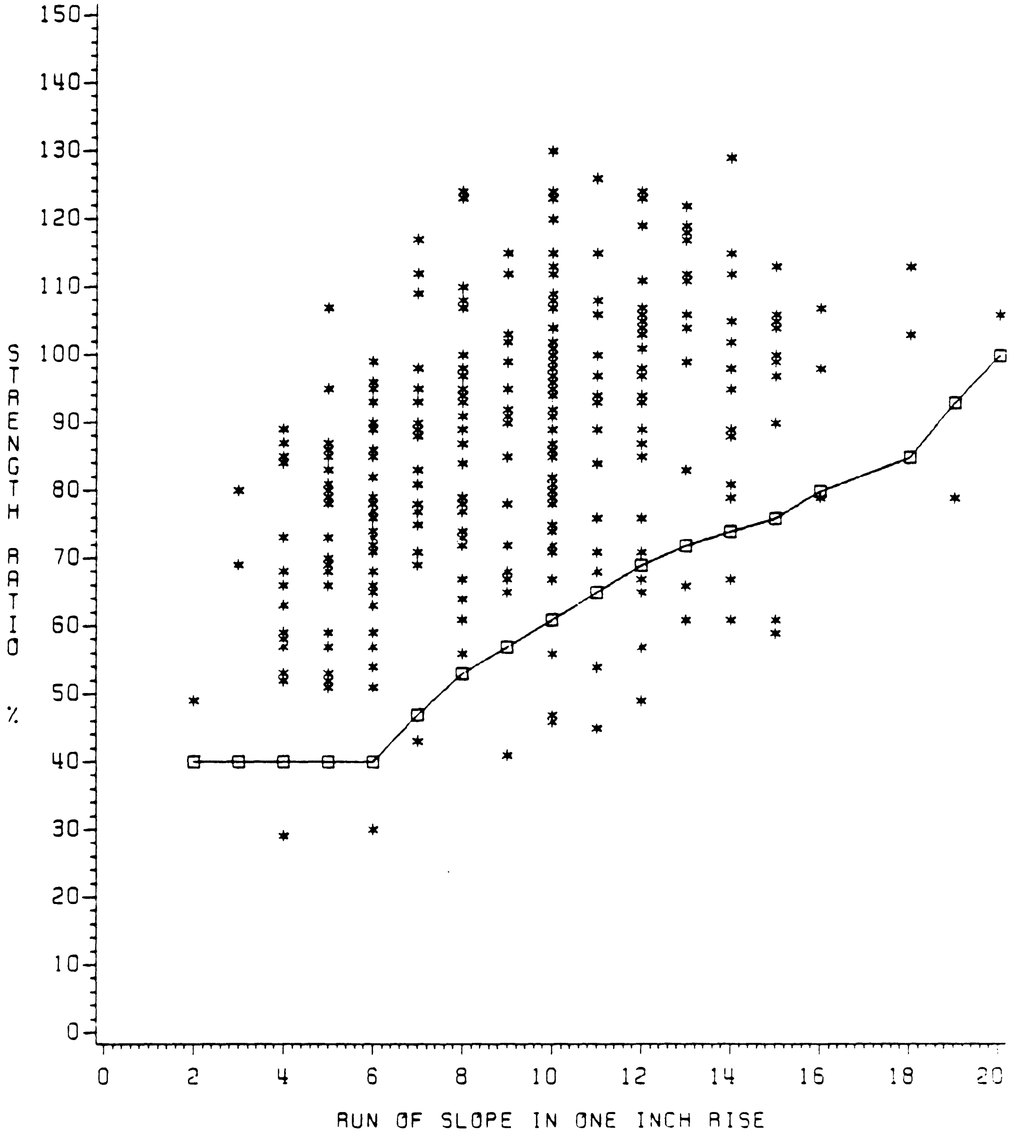

FIGURE 5.6 – STRENGTH RATIO AS A FUNCTION OF DEGREE OF SLOPE FOR SLOPE OF GRAIN IN OAK STRINGERS

* = ASR
□ = ESR

Figure 5.7 is the strength ratio plot for splits in oak stringers. ASTM D 245 strength ratios for splits apply to horizontal shear. For a split of 5.25 inches in length, the ESR for stringers would be 50%. The ESR becomes a negative number after a split length of 10.5 inches. Since the ASR is the actual strength ratio of bending strength and thus is not directly comparable to the ASTM ESR, a lower bound of 50% was set for the ESR for splits. As seen in Figure 5.7, the ASR is well above 50% for all but full-length splits.

Figure 5.8 is the strength ratio plot for knots in four inch deckboards. The ESR calculated from ASTM D 245 is for knots anywhere in the wide face of boards one-inch in nominal thickness. A trend similar to that found for centerline knots in stringers is seen: the ESR predicts the average ASR fairly well for small knot sizes but becomes increasingly conservative as the knot size increases. Although knot location is not considered in calculating the ESR, figures 5.9 and 5.10 are plots of strength ratios of centerline knots and edge knots, respectively, in four-inch oak deckboards. No qualitative difference in the ASR-ESR relationship can be seen between the centerline and edge knots.

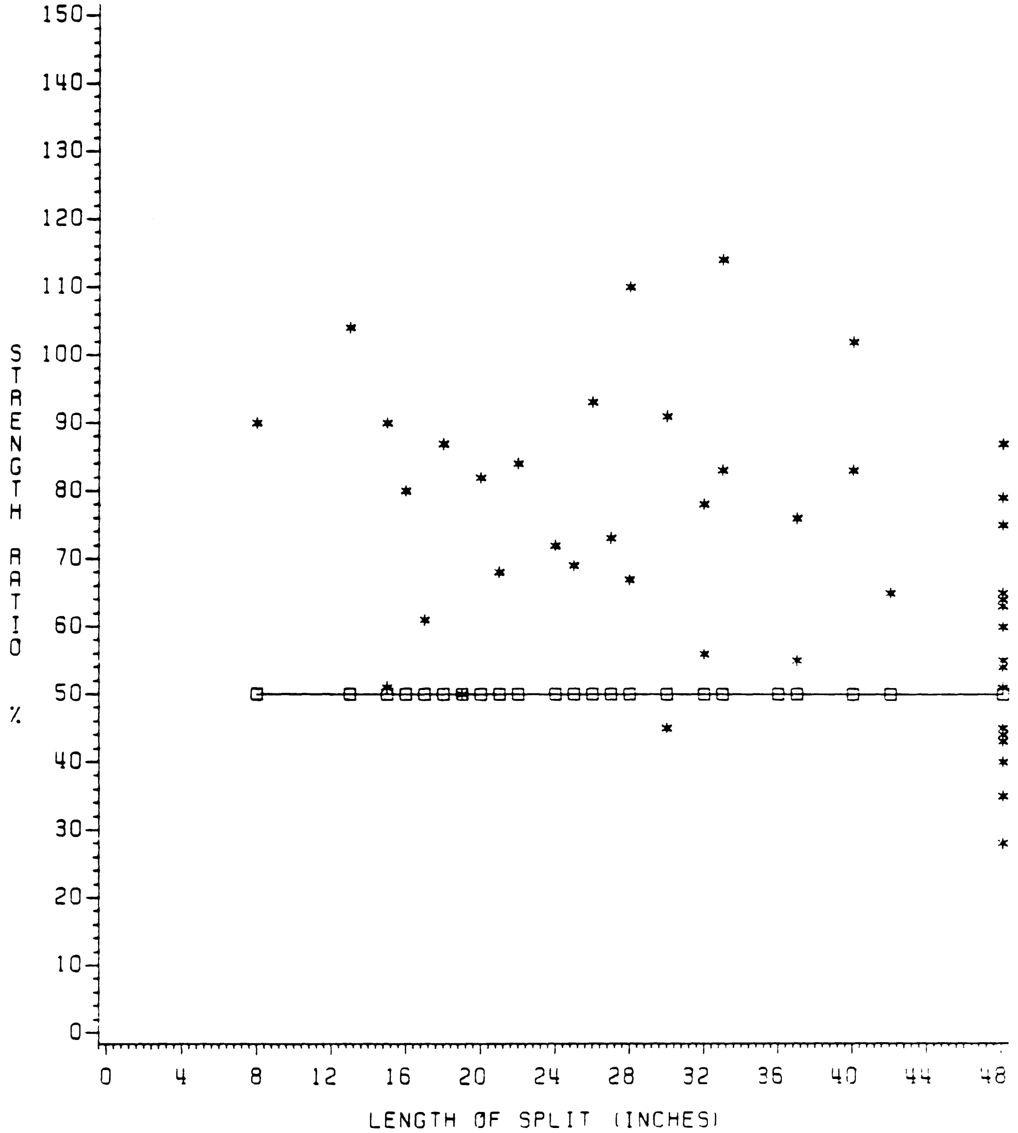

FIGURE 5.7 - STRENGTH RATIO AS A FUNCTION OF SPLIT LENGTH FOR SPLITS IN OAK STRINGERS

(ESR LIMITED TO MINIMUM VALUE OF 50%

* = ASR
□ = ESR

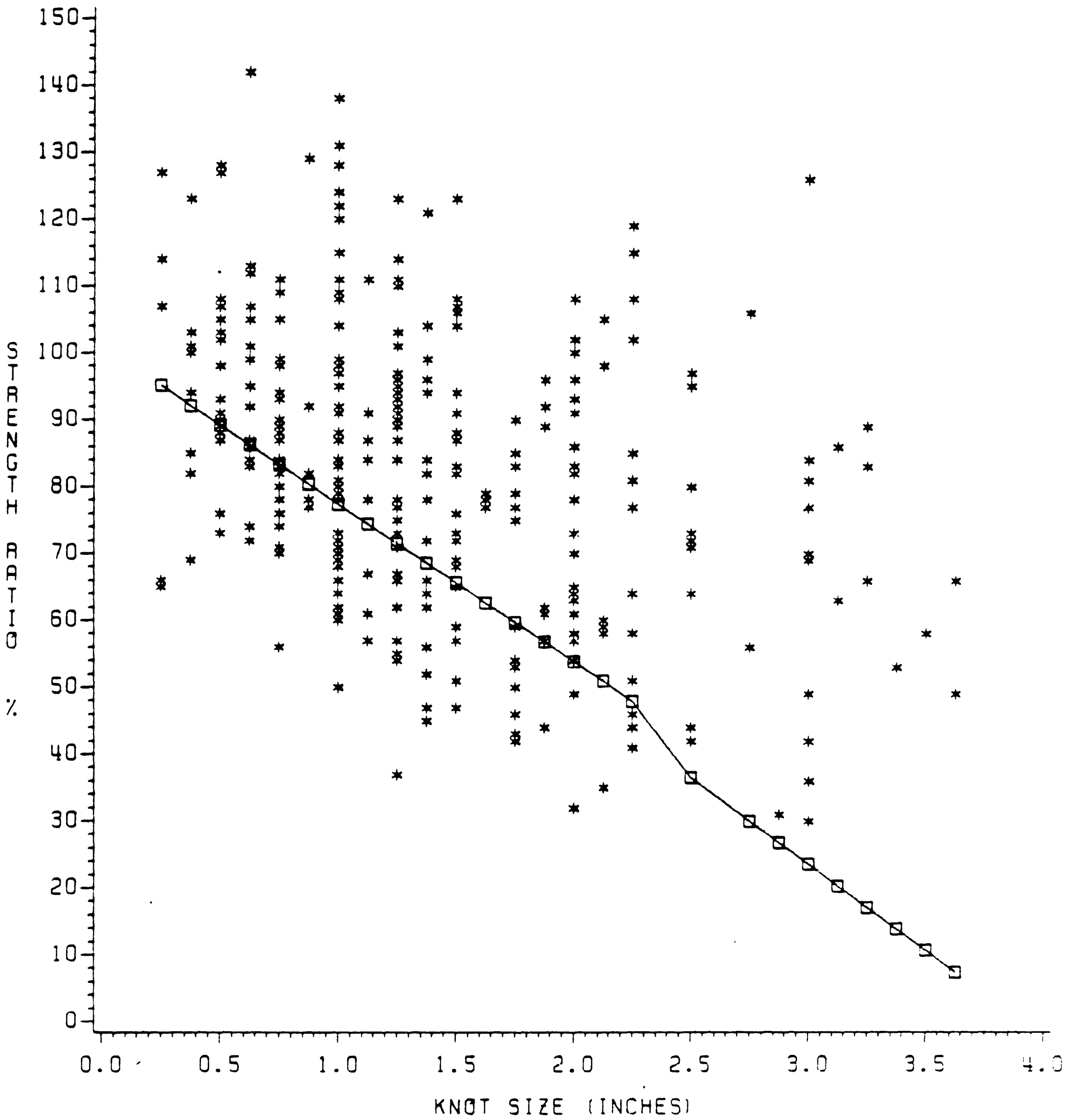

FIGURE 5.8 - STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR KNOTS IN FOUR INCH OAK DECKBOARDS

* = ASR
□ = ESR

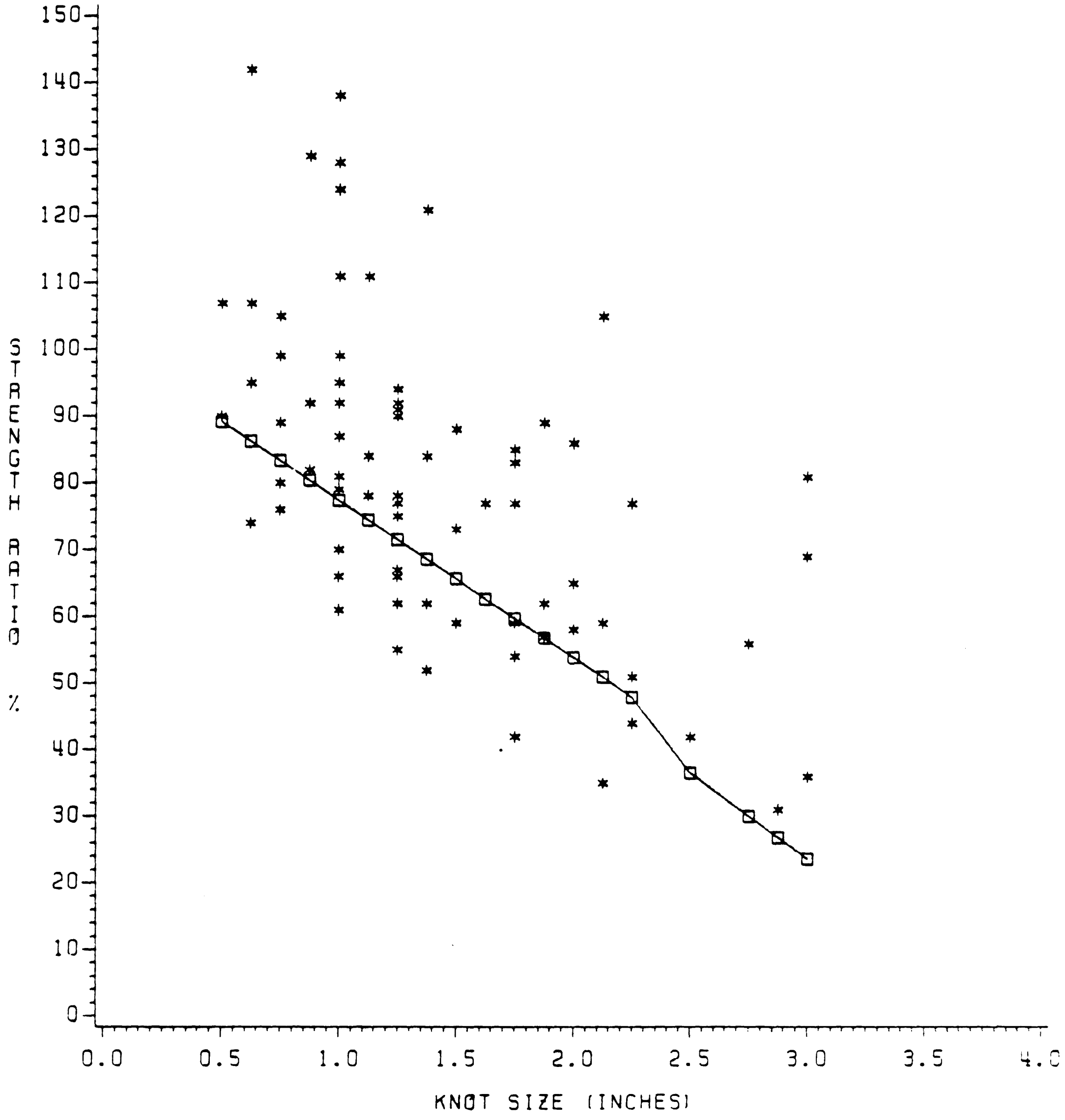

FIGURE 5.9 - STRENGTH RATIO AS A FUNCTION OF KNOT SIZE
FOR CENTERLINE KNOTS IN FOUR INCH OAK DECKBOARDS

* = ASR
□ = ESR

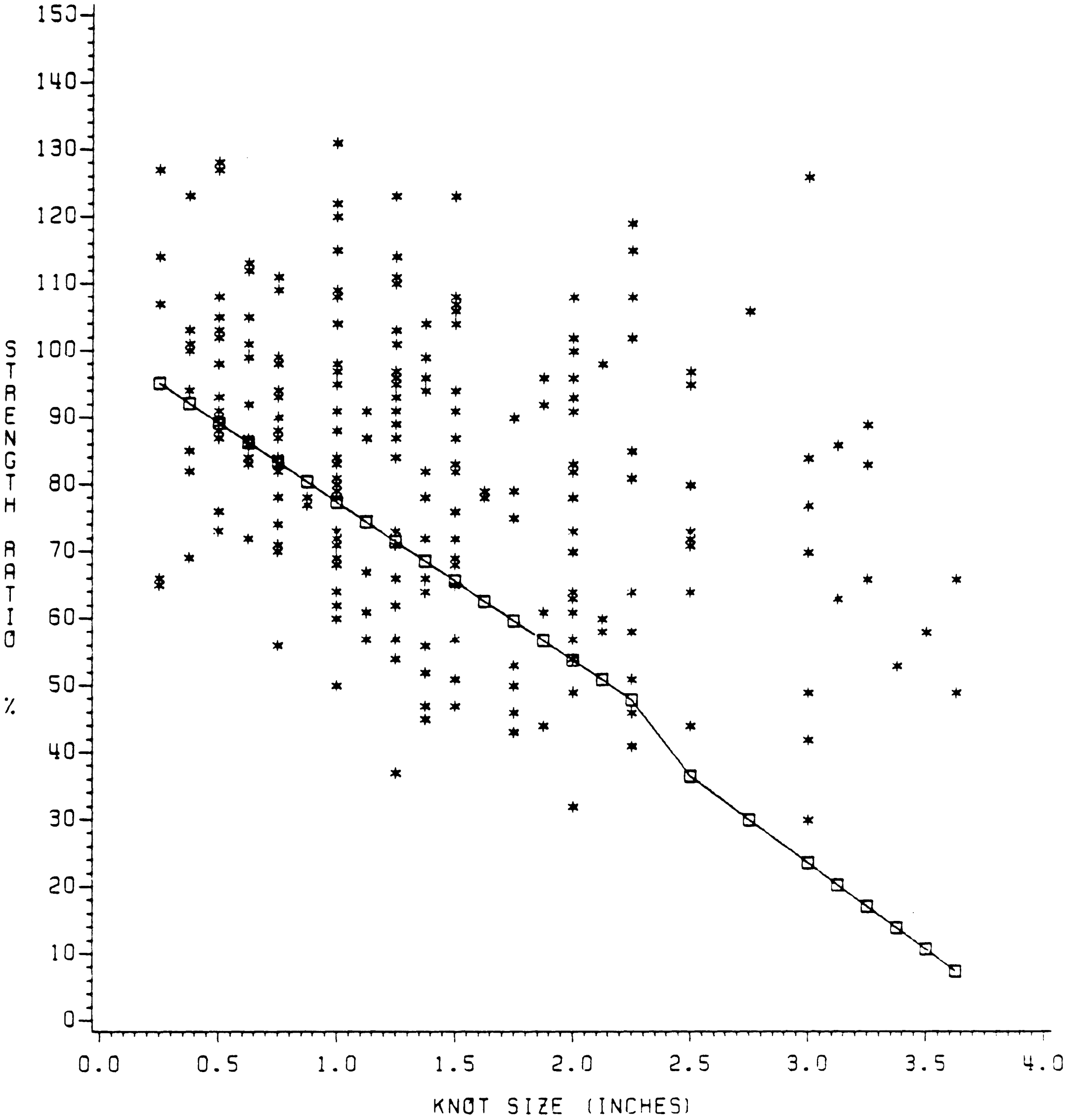

FIGURE 5.10 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR EDGE KNOTS IN FOUR INCH OAK DECKBOARDS

* = ASR
□ = ESR

Figure 5.11 is the strength ratio plot for slope of grain in four inch oak deckboards. The ESR underpredicts the ASR for four inch deckboards with slope of grain even more than for stringers. However, as with stringers, the conservatism of the ESR does not increase as the severity of the slope of grain increases.

Figure 5.12 is the strength ratio plot for knots in six-inch oak deckboards. Just as for four inch deckboards, the ESR predicts the average ASR fairly well for small knot sizes but becomes increasingly conservative as knot size increases. Figures 5.13 and 5.14 are strength ratio plots of centerline and edge knots, respectively, in six inch deckboards. As with four inch deckboards, no basic differences can be seen in the ASR-ESR relationship between centerline and edge knots. Figure 5.15 is the strength ratio plot for slope of grain in six inch deckboards. The ESR again underpredicts the ASR uniformly throughout the range of severity of slope of grain.

The ESR as plotted for centerline knots in oak stringers and all knots in oak deckboards is valid for knots located throughout the length of the piece. However, since the shook was tested in third-point loading, the length of the piece between load points was subjected to the maximum

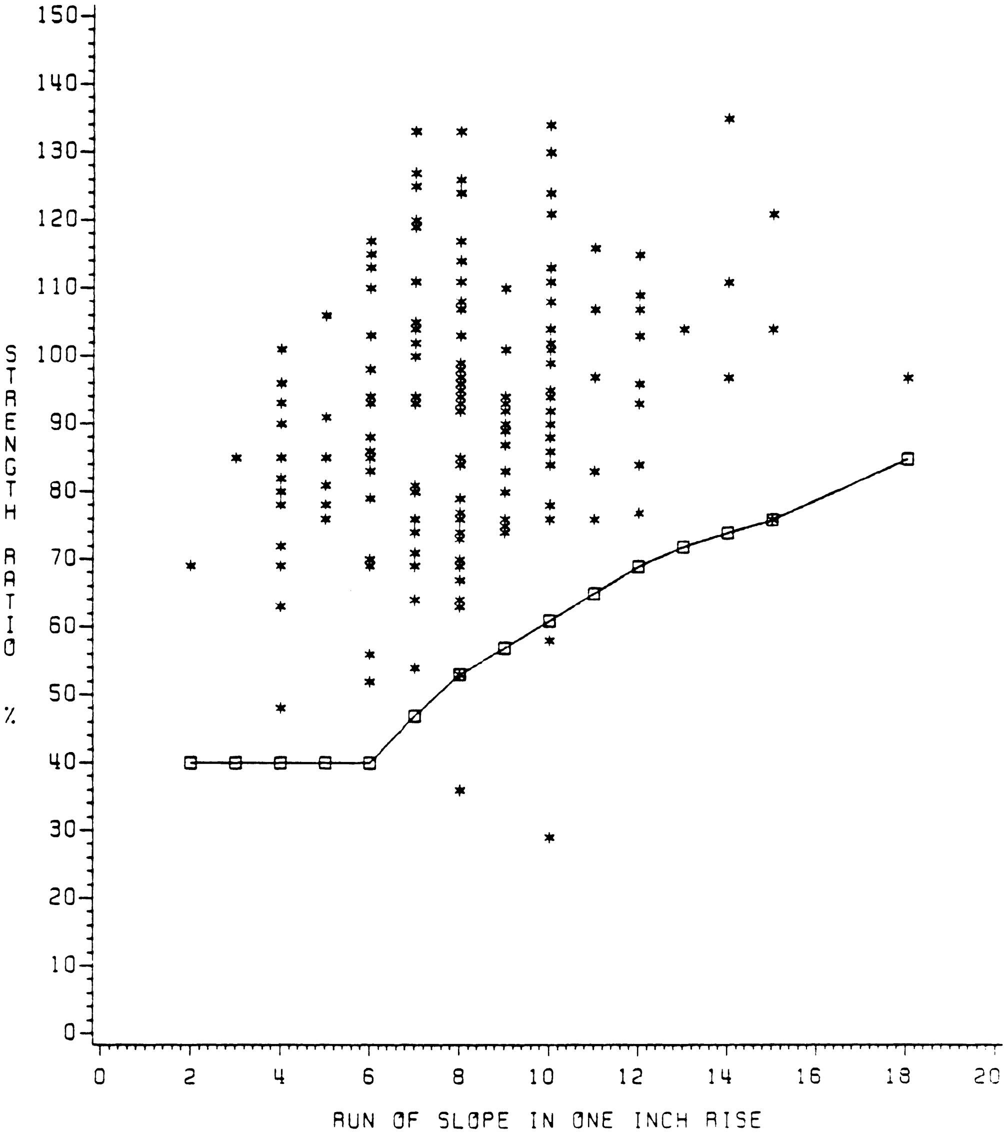

FIGURE 5.11 – STRENGTH RATIO AS A FUNCTION OF DEGREE OF SLOPE FOR SLOPE OF GRAIN IN FOUR INCH OAK DECKBOARDS

* = ASR
□ = ESR

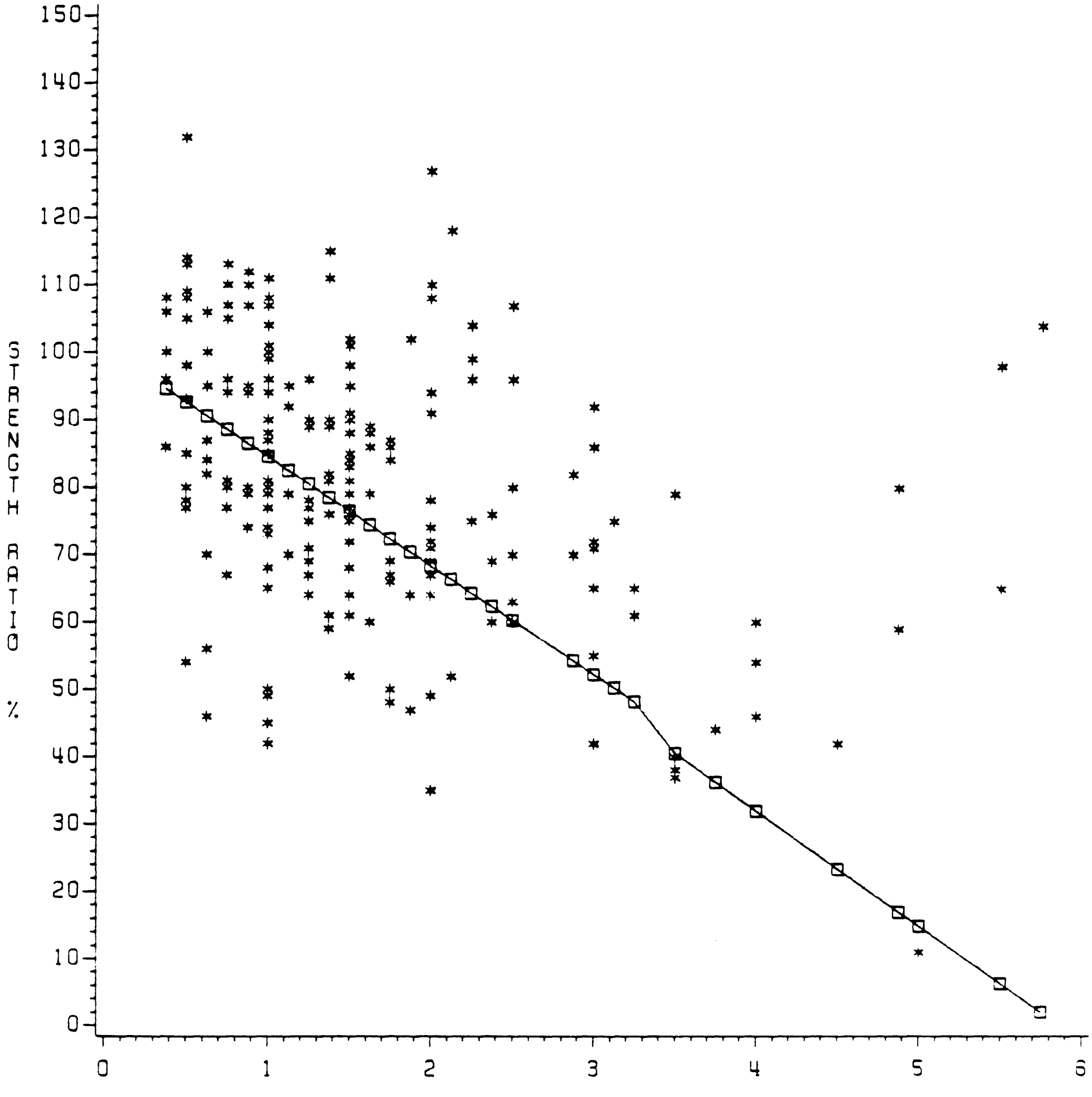

FIGURE 5.12 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR KNOTS IN SIX INCH OAK DECKBOARDS

* = ASR
☐ = ESR

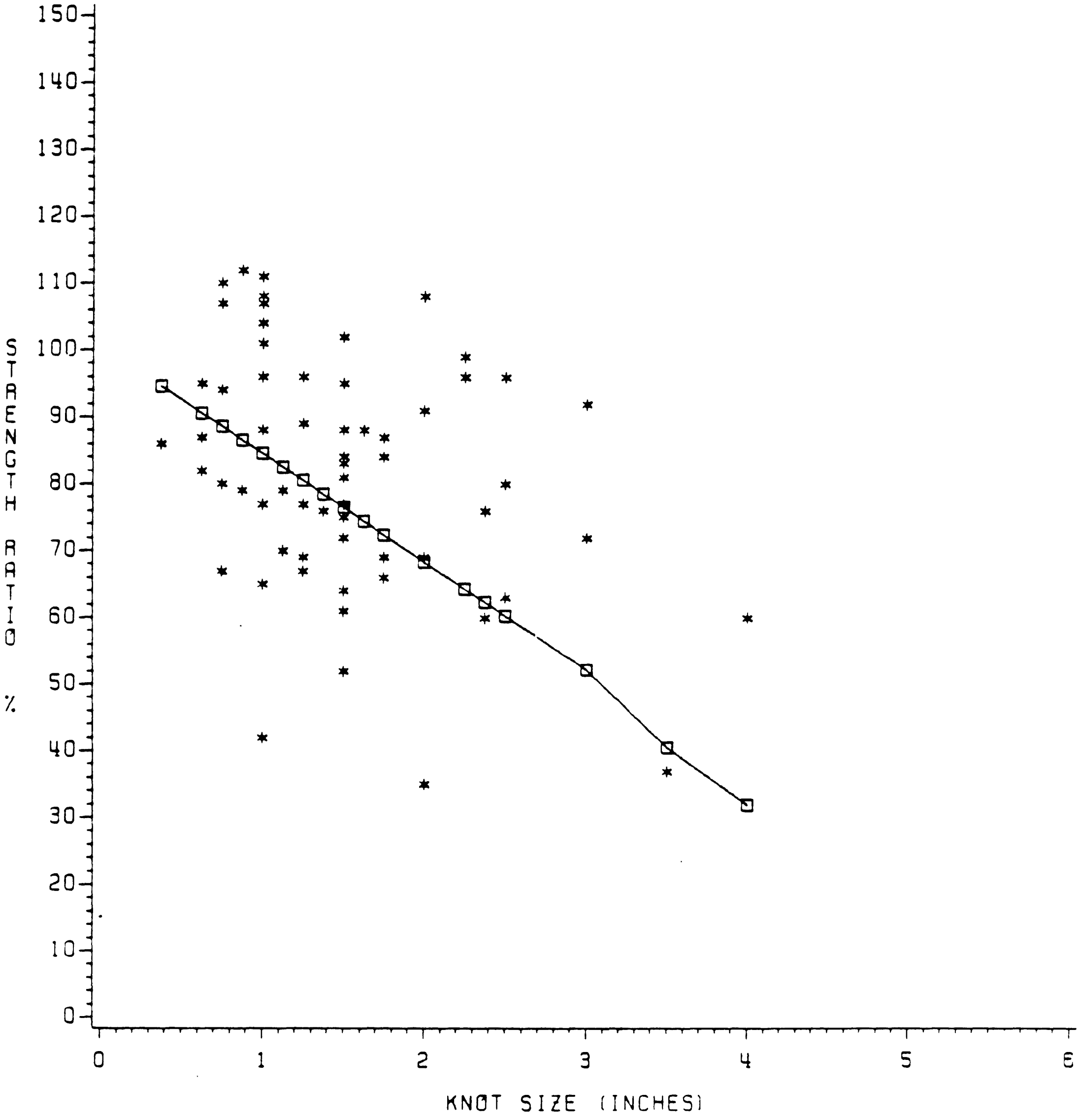

FIGURE 5.13 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR CENTERLINE KNOTS IN SIX INCH OAK DECKBOARDS

* = ASR
□ = ESR

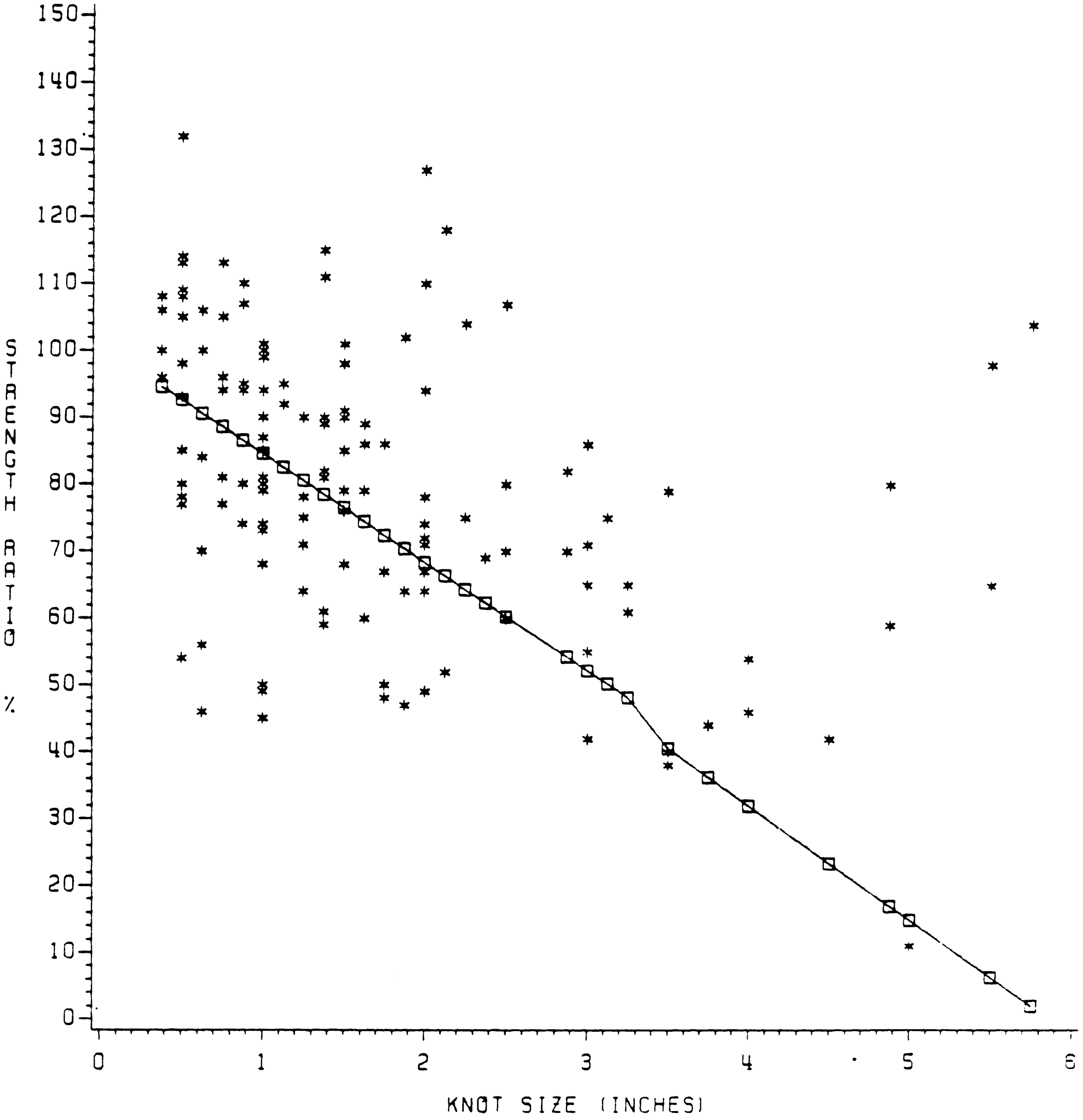

FIGURE 5.14 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR EDGE KNOTS IN SIX INCH OAK DECKBOARDS

* = ASR
□ = ESR

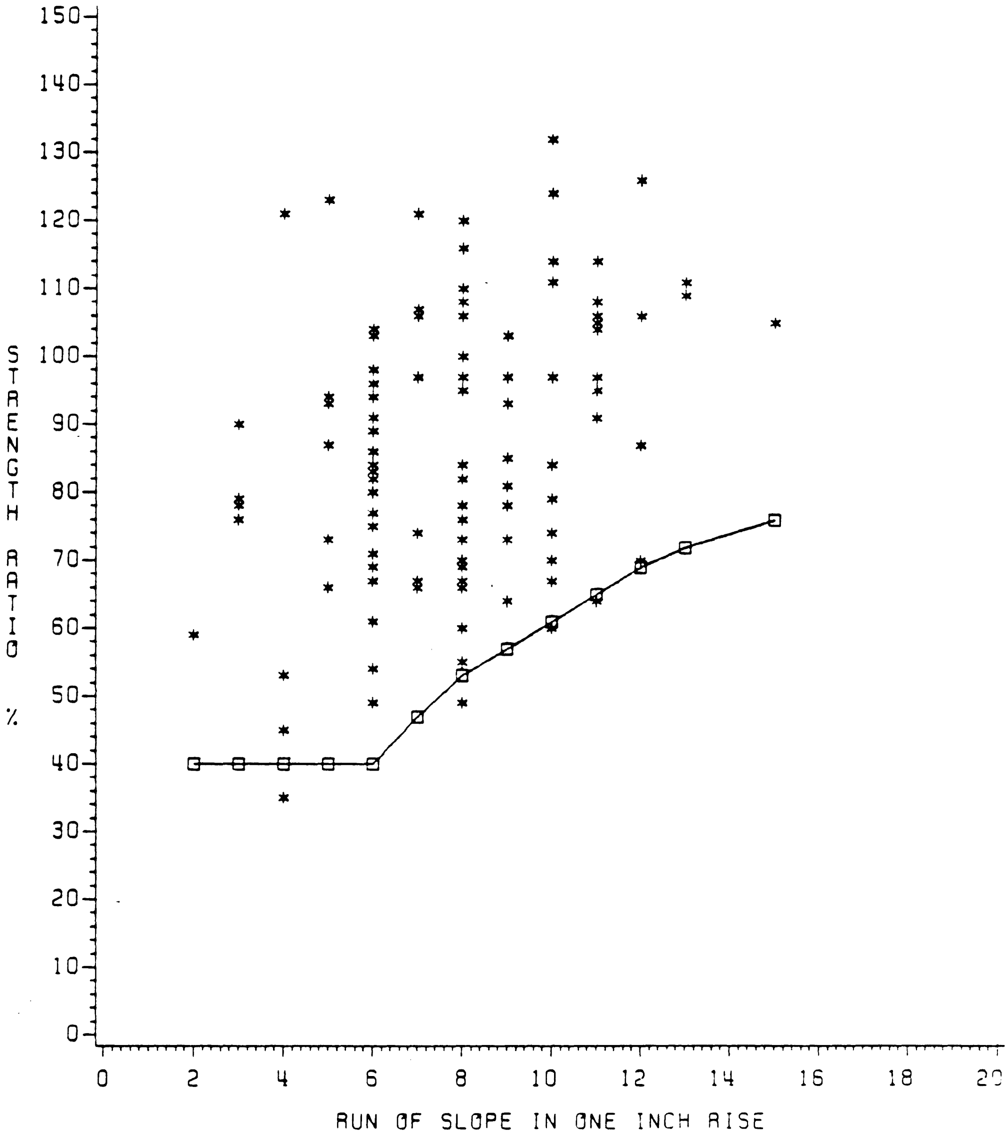

FIGURE 5.15 – STRENGTH RATIO AS A FUNCTION OF DEGREE OF SLOPE FOR SLOPE OF GRAIN IN SIX INCH OAK DECKBOARDS

* = ASR
□ = ESR

moment. To determine how the knots outside the load points affected the strength ratio plots for centerline knots in oak stringers (figure 5.1) and all knots in oak deckboards (figures 5.8 and 5.12), similar strength ratio plots were made including only knots between the load points of the bending test. These plots are presented in Figures 5.16 through 5.18. The variation in ASR is slightly reduced, and some of the outlying points are eliminated. However, there is no shift in position of data relative to the ESR line.

Strength ratio plots were also made for the data from the Rate of Loading and the Depth Effect studies. Unfortunately, the sample sizes of these studies were small, and when data was further sequestered by species, size, and defect type, only a few points were available for any given plot. Therefore, most plots are not presented. However, the plots indicated ESR-ASR trends similar to those for the oak data. The ESR predicted the average ASR fairly well for small knots but became increasingly conservative as knot size increased. The ESR was more conservative with increasing knot size for edge knots than for centerline knots in stringers. The ESR for slope of grain was uniformly conservative throughout the range of severity of the slope. The trends between ESR and ASR were also consistent between the different species and size groups of these data sets.

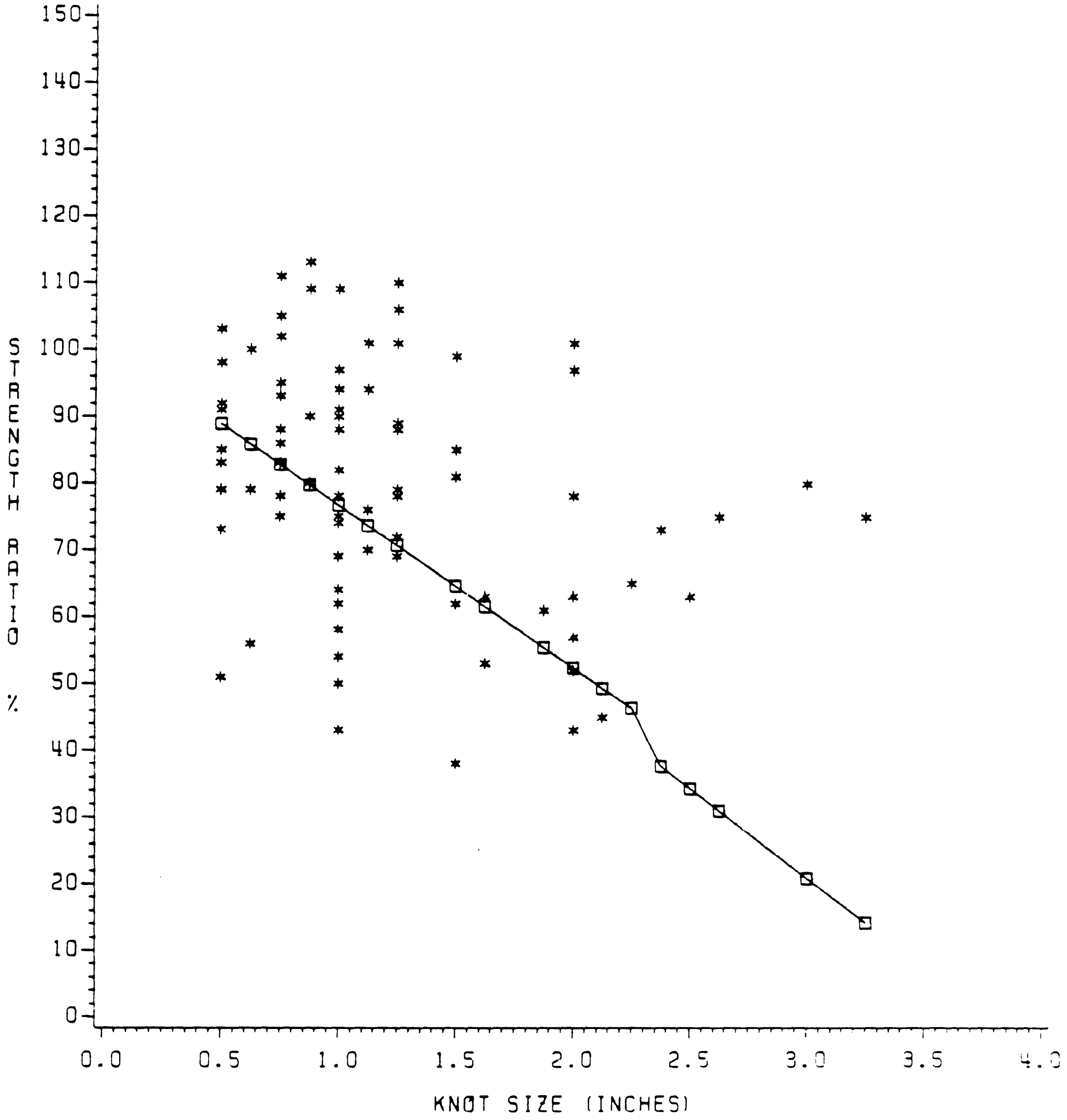

FIGURE 5.16 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR CENTERLINE KNOTS IN OAK STRINGERS

(KNOTS BETWEEN LOAD POINTS ONLY)

* = ASR
□ = ESR

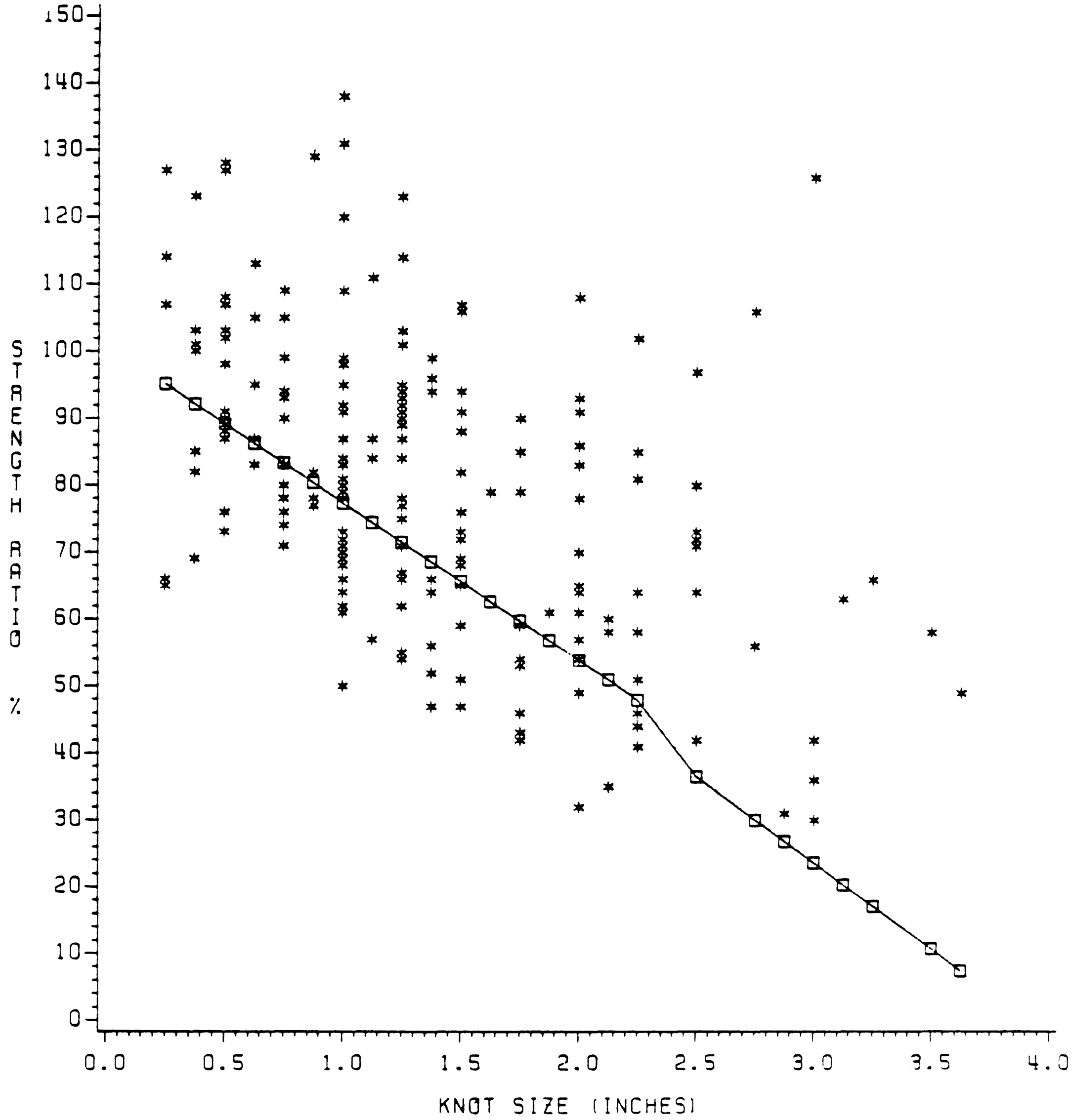

FIGURE 5.17 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR KNOTS BETWEEN LOAD POINTS IN FOUR INCH OAK DECKBOARDS

* = ASR
☐ = ESR

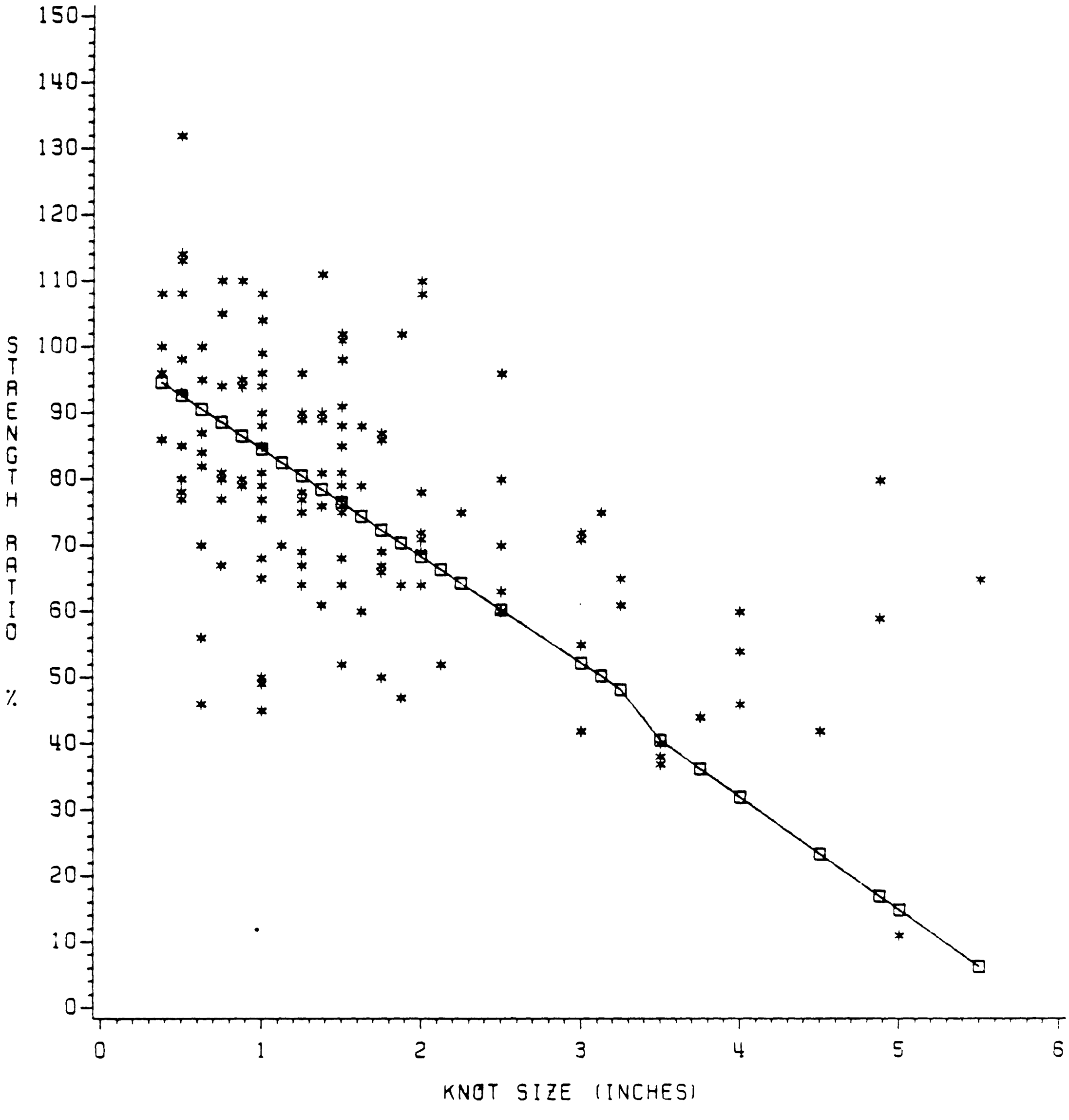

FIGURE 5.18 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR KNOTS BETWEEN LOAD POINTS IN SIX INCH OAK DECKBOARDS

* = ASR
□ = ESR

The strength ratio plots for the Rate of Loading and Depth Effect studies that are presented are for narrow face knots in stringers and are given in Figures 5.19 through 5.24. These are particularly useful despite the relatively few data points since the strength ratio for narrow face knots in Spurlock's data could not be determined. With some variation, the ESR predicts the average ASR fairly well, with no obvious differences between the different species or sizes.

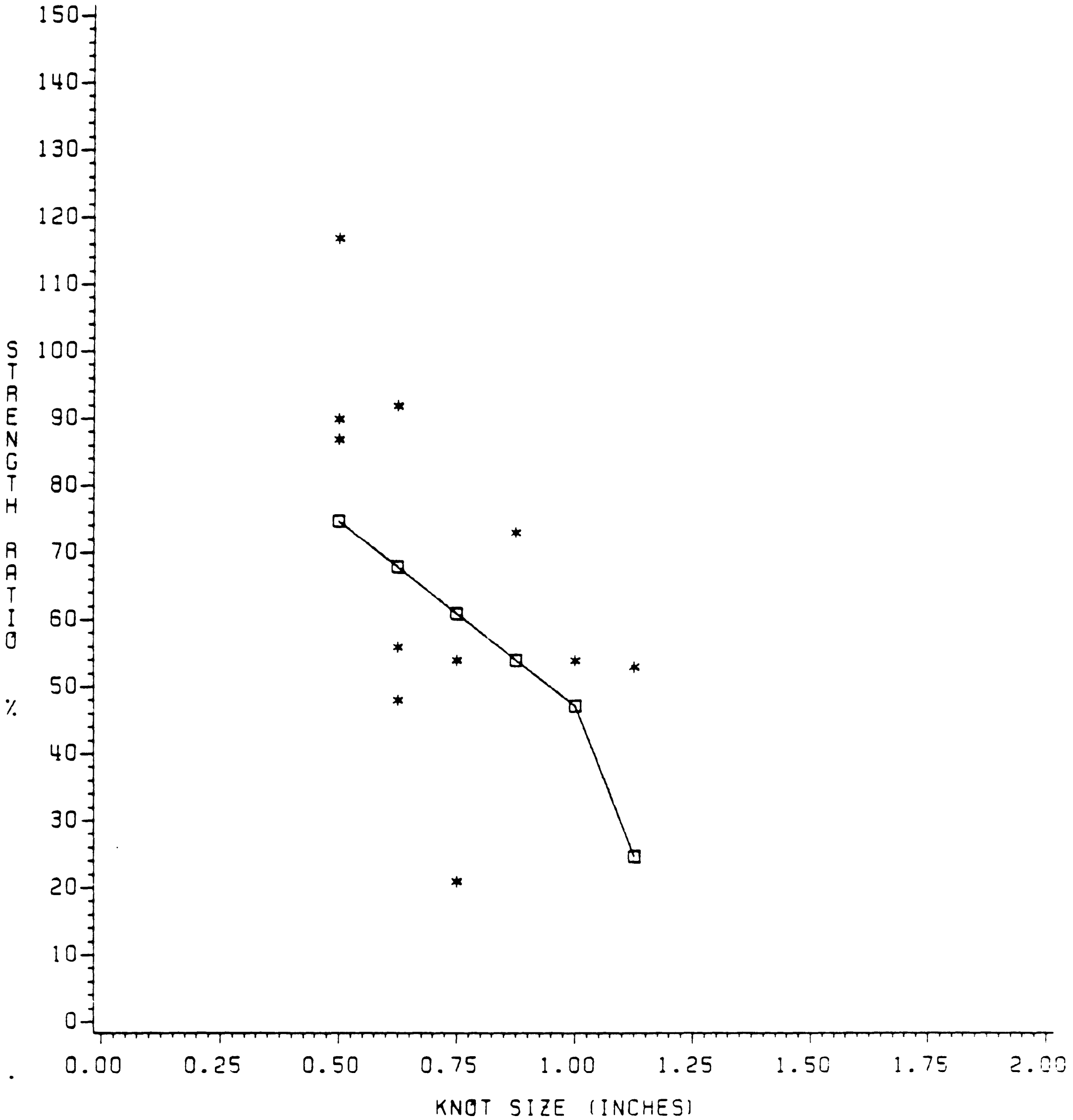

FIGURE 5.19 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN 3.5 INCH ASH STRINGERS

* = ASR
□ = ESR

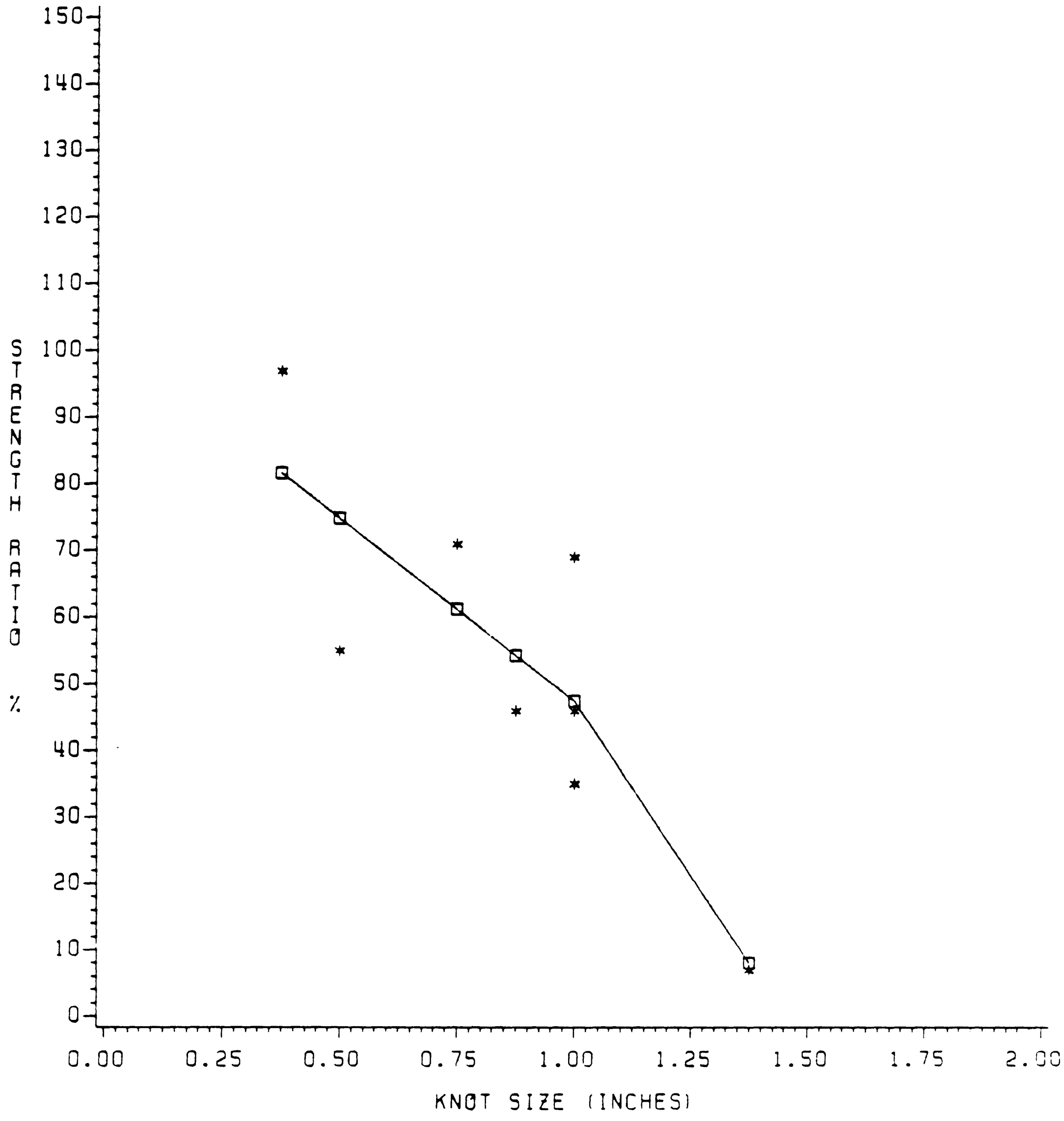

FIGURE 5.20 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN 2.5 INCH ASH STRINGERS

* = ASR
□ = ESR

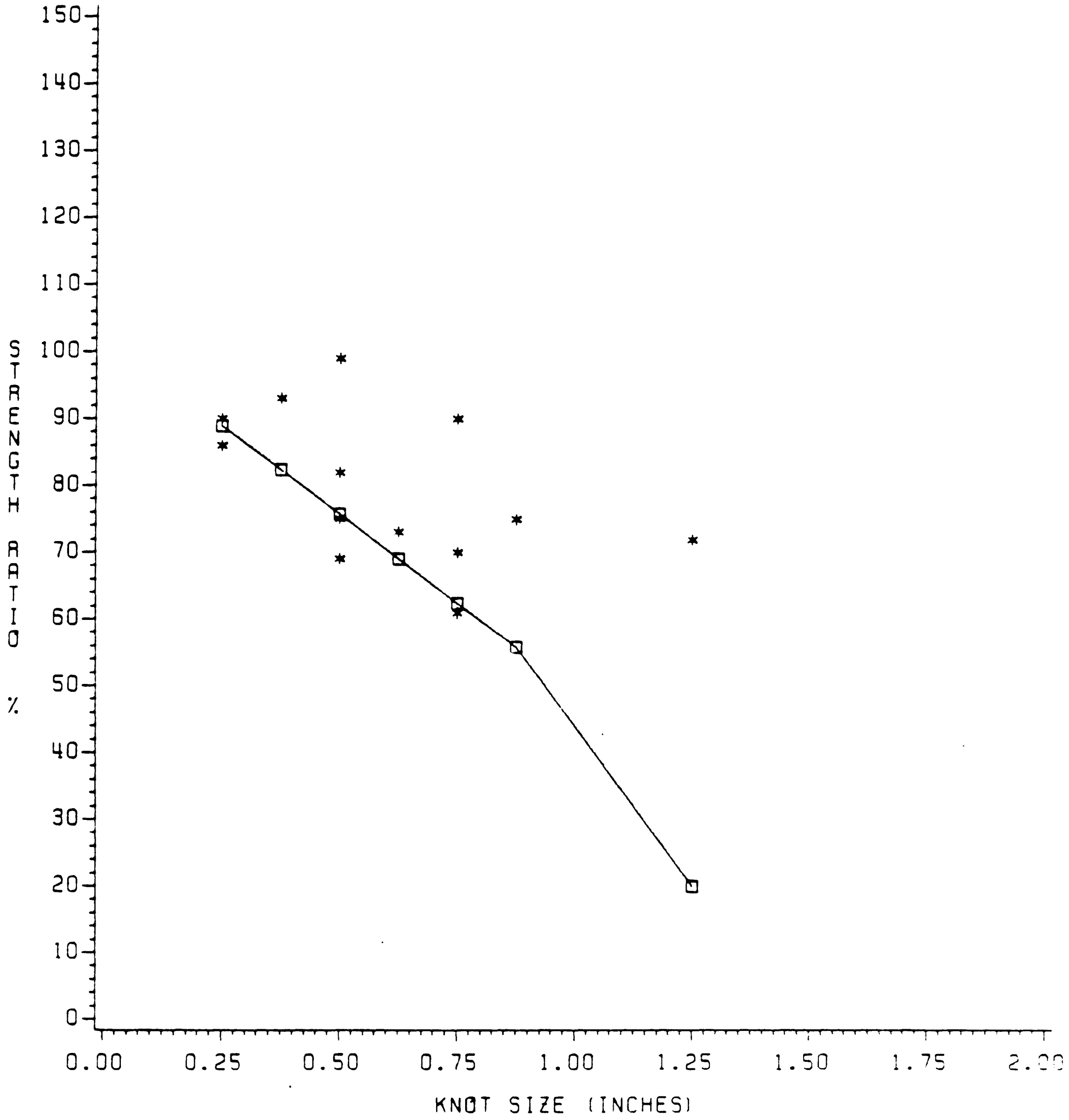

FIGURE 5.21 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN 3.5 INCH COTTONWOOD STRINGERS

* = ASR
□ = ESR

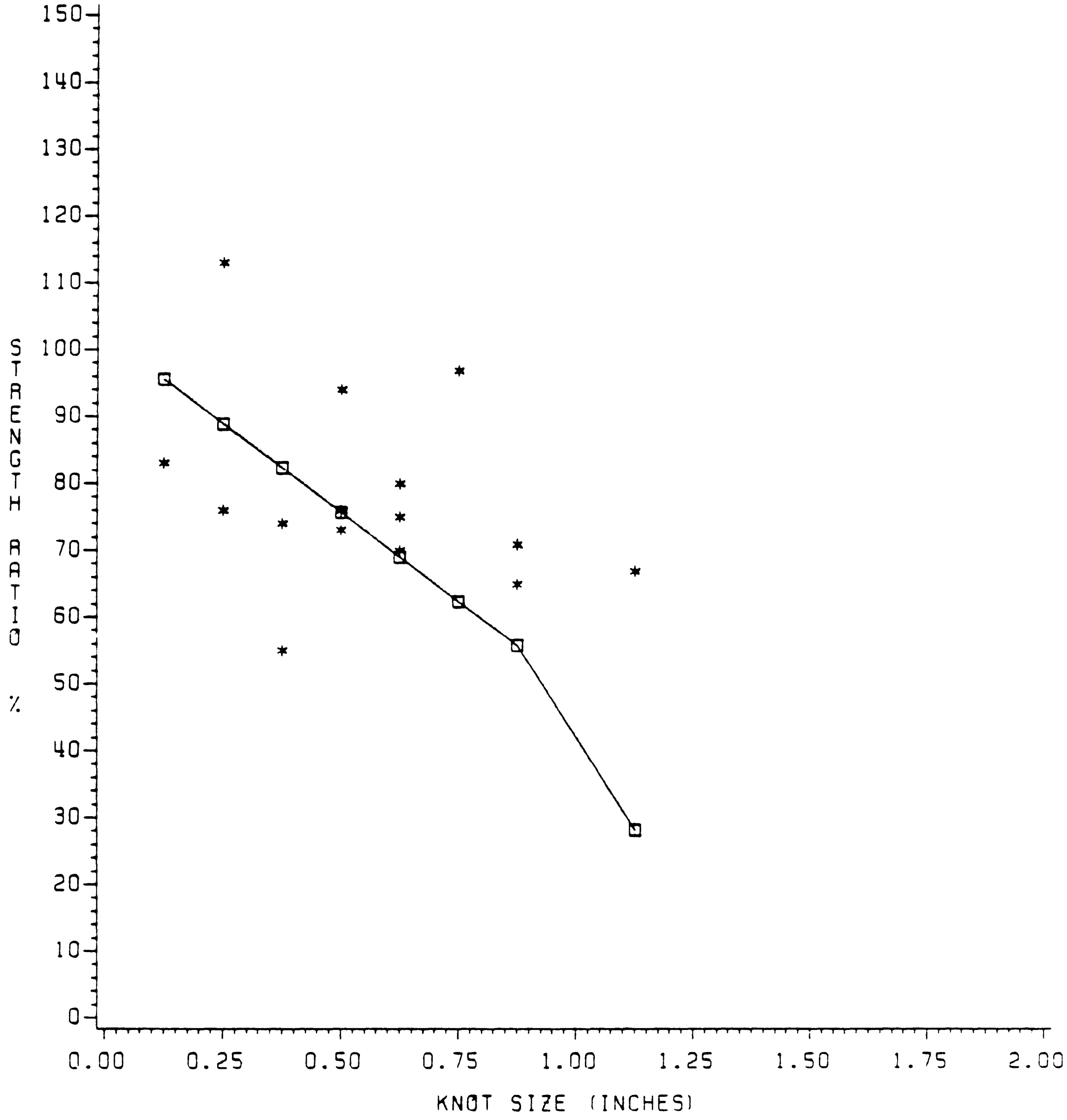

FIGURE 5.22 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN 2.5 INCH COTTONWOOD STRINGERS

* = ASR
□ = ESR

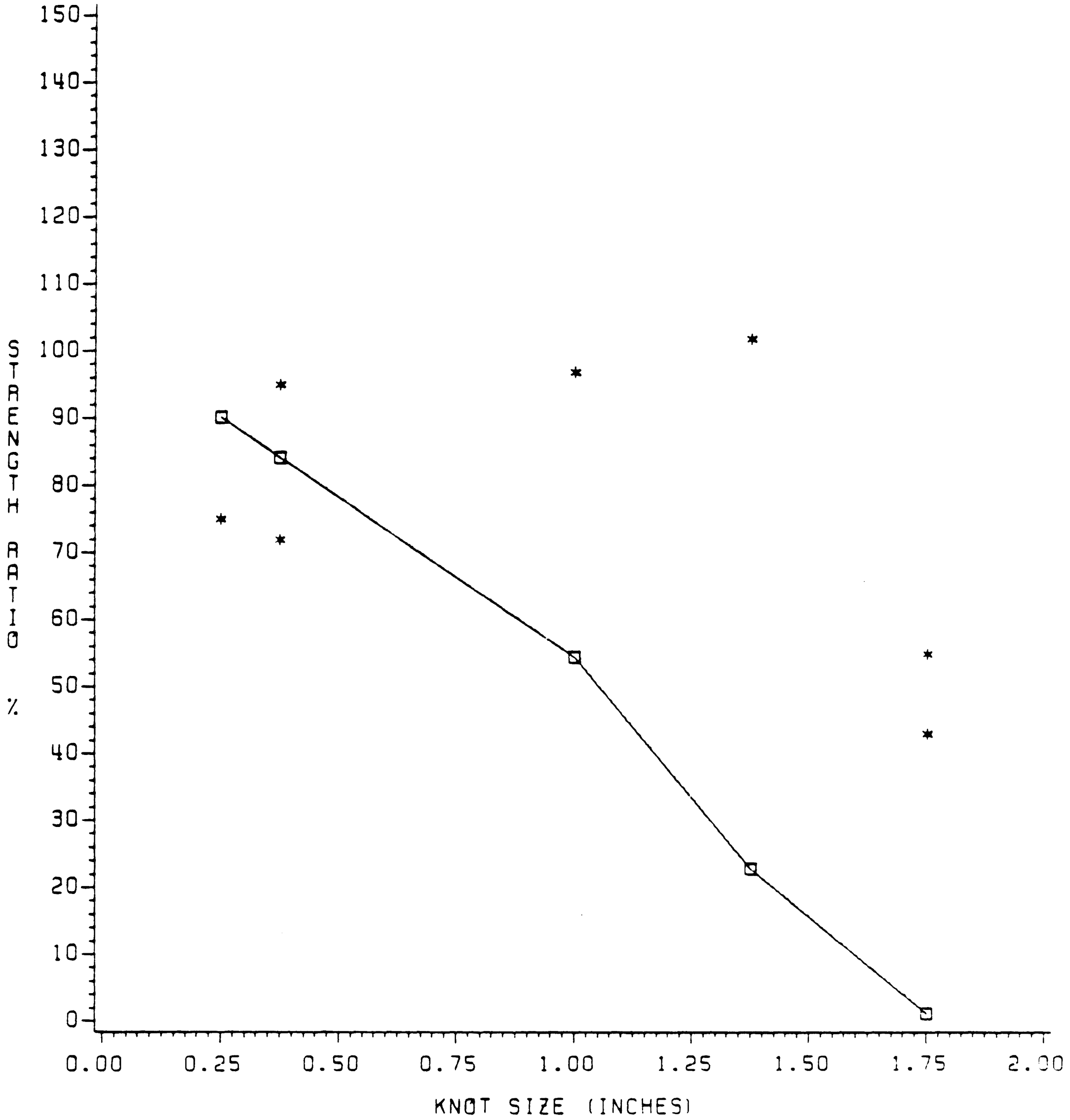

FIGURE 5.23 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN POPLAR STRINGERS

* = ASR
□ = ESR

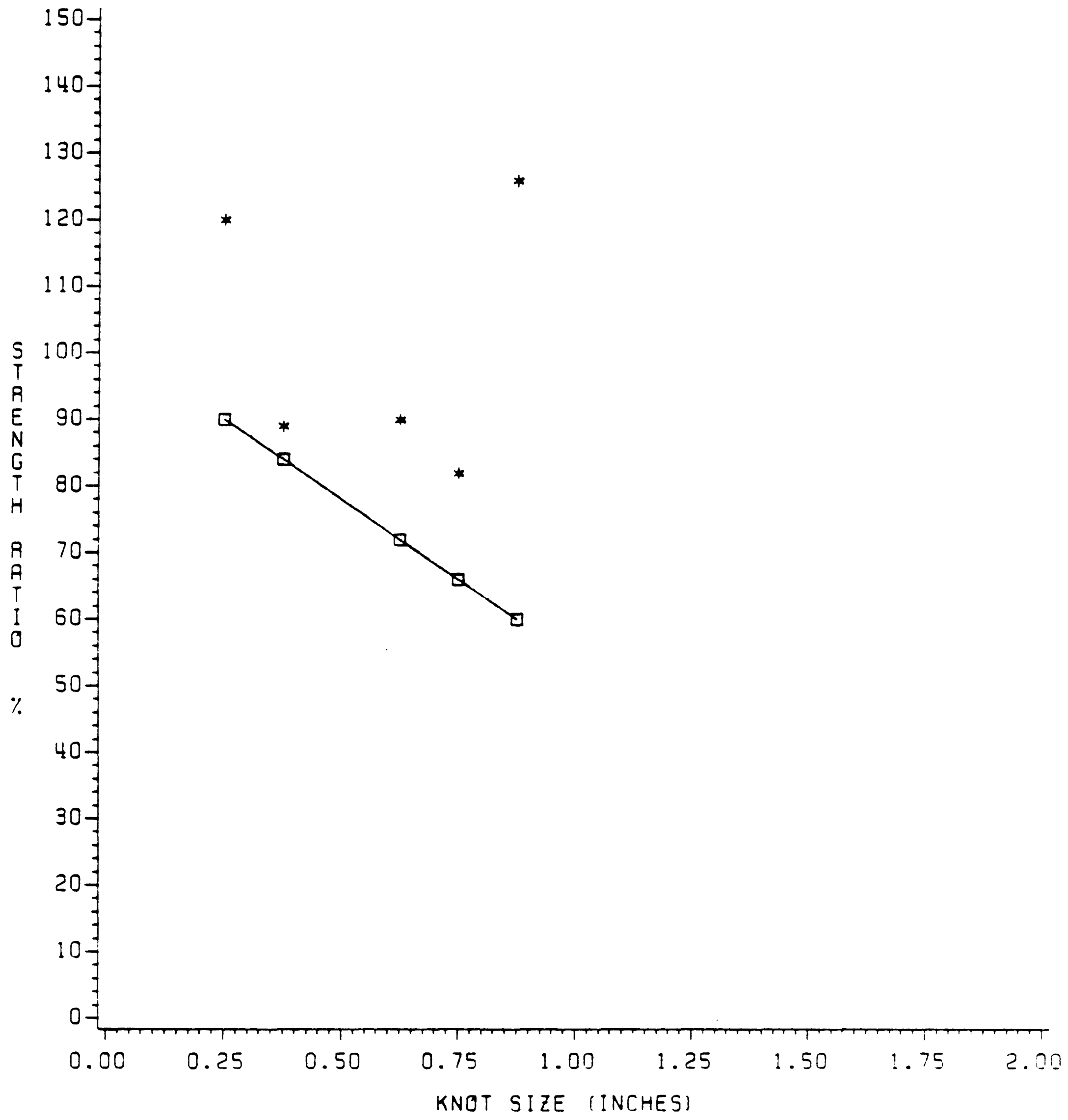

FIGURE 5.24 – STRENGTH RATIO AS A FUNCTION OF KNOT SIZE FOR NARROW FACE KNOTS IN OAK STRINGERS

* = ASR
□ = ESR

5.5 CONCLUSIONS

The estimated strength ratios of green hardwood pallet shook, determined according to ASTM D 245, generally underestimated the actual strength ratios, determined experimentally. The following specific conclusions can be made:

- The ESR predicts the average ASR fairly well for small centerline knots and small edge knots in stringers but increasingly underestimates the ASR as the knot size increases.
- The underestimation of the ASR with increasing knot size is greater for edge knots than for centerline knots.
- The ESR underestimates the average ASR for compression edge knots more than for tension edge knots in stringers.
- The ESR predicts the average ASR fairly well for small knots in deckboards but increasingly underestimates the ASR as the knot size increases.

- There is no apparent difference in the ESR-ASR relationship between centerline and edge knots in deckboards.

- From limited data, the ESR predicted the average ASR fairly well for stringers with narrow-face knots.

- The ESR consistently underestimates the ASR for slope of grain in stringers and deckboards throughout the range of severity of the slope of grain. The ESR underestimates the ASR more for deckboards with slope of grain than for stringers.

- The average ASR for stringers with splits, checks, and shakes is well above 50% for all but full-length splits.

- The change in the formula for calculating the ESR for stringers and deckboards with knots below an ESR of 45% does not appear justifiable.

If the strength ratio concept of ASTM D 245 is used in deriving design values for green pallet shook, conservative estimates of strength should be anticipated, particularly for pieces having or grades allowing large knots.

6.0 ESTABLISHING DESIGN VALUES FOR PALLET SHOOK

6.1 INTRODUCTION

The PALLET DESIGN SYSTEM (PDS) requires estimates of the mean and standard deviation of the bending strength and stiffness of the shook used to produce a pallet. Two investigations (20,45) of the flexural properties of yellow-poplar and eastern oak pallet shook were recently made at Virginia Tech. Other species must be researched to build a reasonable data base.

However, it may be many years in the future before these in-grade investigations of various species of pallet shook can be completed. For PDS to be immediately useful, design values for pallet shook of any species or combination of species must be estimated in some manner. Therefore, interim methods of developing estimates of design values for pallet shook from existing data are needed. The objective of this chapter is to describe these methods.

ASTM D 2555 (5) and ASTM D 245 (4) provide methods of establishing strength and stiffness design values for any grade and species of lumber. However, these standard methods establish near minimum strength values as the basis for design and are not usually employed to establish the variability and mean of strength or stiffness values for relatively short full-size pallet lumber. Modifications to these standard methods were necessary to establish mean strength and stiffness values for pallet shook for use as input to PDS. Other methods were required to estimate the variability of the strength and stiffness values.

In the following sections of this thesis, the ASTM standard methods of establishing design values for visual grades of lumber are reviewed. The grading of pallet shook is discussed, and the procedures for developing pallet shook design values for PDS are presented. Finally, an evaluation of the pallet shook design values is presented.

6.2 REVIEW OF ASTM STANDARD METHODS OF ESTABLISHING DESIGN VALUES

6.2.1 Introduction

The traditional method of establishing design values for structural lumber is outlined in ASTM D 245 (4). This process begins with strength and stiffness values from tests of small, clear, green specimens. These properties are then modified by a series of adjustment factors to account for the end-use characteristics of full-size structural pieces.

The following is a review of the current standard method of establishing design values for structural lumber. Since only bending strength and stiffness design values are required for pallet shook, this review is restricted to those properties.

6.2.2 Clear Wood Strength and Stiffness Values

ASTM D 2555 (5) provides tables of clear wood strength and stiffness values for individual species. These values are based on tests of small, clear, green specimens. Procedures are given for establishing clear wood values for a single species or any combination of species.

There are two different methods for establishing clear wood properties. Method A involves the use of wood density surveys in combination with the clear wood strength and stiffness data. However, wood density surveys are only available for a limited number of species; Method B is used for all other species. The Method B data come from a wide variety of tests on limited numbers of samples conducted at the U. S. Forest Products Lab.

Average clear wood MOE is used as the basis for determining design MOE values. If values for a single species are desired, then the average MOE for the particular species can be taken directly from the tables in D 2555. However, if design values for a combination of species are desired, then a volume-weighted average value is determined. The volume-weighted average is the sum of the average MOE listed for each species in the combination weighted by the ratio of standing timber volume for the species to the standing timber volume for the combination. Standing timber volume estimates are given for many species in D 2555.

The MOE value assigned to a combination for Method A species is to be no more than 16% greater than the average MOE divided by the variability index for any included species. The variability index is a measure of the variability of the property for a particular species. The volume-weighted average assigned to a combination of Method B species can be no more than 10% greater than the average MOE of any included species.

For either Method A or B, a species for which there is no standing timber volume estimate may be included in the species combination if its average MOE is greater than or equal to the volume-weighted average MOE for the combination.

The lower fifth percentile clear wood MOR is typically used as the basis for determining bending strength design values. The lower fifth percentile is determined from the mean and standard deviation given in the tables of ASTM D 2555 for a single species by:

$$\text{MOR (5\% E.L.)} = \overline{\text{MOR}} - 1.645 \text{ s.d.}$$

where:

$\overline{\text{MOR}}$ = average MOR value

s.d. = standard deviation of MOR

A normal or Gaussian distribution is assumed. For a combination of species, the 5% exclusion limit is determined by adding the areas under the standing timber volume-weighted frequency distributions of each species at successively higher levels of strength until a value is obtained below which 5% of the area under the combined frequency distribution will fall (5).

Restraints on the 5% exclusion limit for both Method A and B species are given in ASTM D 2555. For Method A species, a composite dispersion factor (CDF) shall not be less than 1.18 for any included species. The CDF is calculated as follows:

$$\text{CDF} = ((\text{Y/V.I.}) - \text{A})/\text{s.d.}$$

where:

Y = average MOR value for the species

V.I. = variability index for the species

s.d. = standard deviation

A = the computed 5% E.L. MOR for the combination

For Method B species, the composite dispersion factor (CDF) shall not be less than 1.48 for any included species. The CDF is calculated as follows:

CDF = (Y - A)/s.d.

A species for which no timber volume data is available may be included in a combination if the 5% exclusion MOR value of the species equals or exceeds the 5% exclusion limit MOR value assigned to the combination.

6.2.3 Adjustment Factors For Clear Wood Values

ASTM D 245 (4) provides adjustment factors to be applied to the clear wood strength and stiffness values. These adjustment factors account for the end-use characteristics of full-size structural pieces.

The clear wood 5% exclusion MOR is adjusted for the effect of defects such as knots, splits, and slope-of grain. This is done by the use of strength ratios given in D 245.

The strength ratio of a piece of structural lumber is defined as the ratio of the strength of the piece with knots, cross-grain, splits, checks, and other strength reducing defects, to the hypothetical strength of the piece had it been clear and straight grained. The strength ratios used for knots depend on the property, the type of structural member, the knot location, and the relative size of the knot. The strength ratios for slope of grain are dependent only on the severity of the slope. The strength ratio to be applied to clear wood strength for a particular grade and type of structural member is the lowest strength ratio associated with any defect allowable in that grade. Therefore, the near minimum clear wood bending strength is further reduced by the strength ratio for the worst defect that could occur within the grade, resulting in a conservative strength value for the grade. This near minimum estimate is fundamental to the development of "working stress" design values.

The modulus of elasticity of a piece is not affected by defects to the same degree as strength. The clear wood MOE is modified by a quality factor that is keyed to the bending strength ratio assigned to the grade. These quality factors were experimentally determined and are tabulated in D 245.

The clear wood bending strength values of ASTM D 2555 were obtained from tests of 2 inch deep specimens. To adjust the values to other depths of structural members, the following formula is used:

$$F = (2/d)^{1/9}$$

where:

F = factor to be applied to clear wood MOR

d = net surfaced depth of the structural bending member

This formula is based on an assumed center-point load and a span-to-depth ratio of 14 .

The strength value is further modified by a load duration factor. A "normal" load duration factor of 0.625 is typically used. This assumes the application of the maximum design load for 10 years either continuously or cummulatively, or the application of 90% of this maximum load continuously throughout the life of the structure, or both. If other load durations are applicable, then other factors are applied.

A factor of safety, also called a "manufacturing and end-use factor", is applied to the bending strength value. This factor varies by property and is generally greater for hardwoods than softwoods. ASTM D 245 combines a 10-year duration of load factor and the factor of safety into one value, which is given separately for softwoods and hardwoods and for the various properties. For bending strength, a combined factor of 2.1 results for softwoods and 2.3 for hardwoods. This translates into a factor of safety of approximately 1.3 for softwoods and 1.4 for hardwoods. Presumably the higher factor for hardwoods reflects greater uncertainty in property values or higher variability.

ASTM D 245 provides a correction factor for MOE to account for the effect of shear deformation in testing. This factor (1/0.94) adjusts the ASTM D 2555 MOE from a span-to-depth ratio of 14 to a span-to-depth ratio of 21 and assumed uniform loading. The adjusted MOE is free of shear effects and more nearly represents the true MOE of the material.

ASTM D 245 provides for increases in allowable stresses and MOE for maximum moisture contents of 19% and 15%. The adjustment factors depend on the maximum moisture content, the property, and the size of the structural member. ASTM D 245 also provides for an increase in allowable stresses and MOE for dense material of any species.

Below is a formula summarizing the adjustment factors used to modify the clear wood values in the derivation of MOR and MOE design values via the methods of ASTM D 245.

$$\mathrm{MOR}_{\text{(clear wood 5\% E.L.)}} \times F_{\text{strength ratio}} \times F_{\text{depth}} \times F_{\text{load duration}} \times F_{\text{MC\%}} \times F_{\text{density}} \times F_{\text{safety}} = \text{Allowable MOR}$$

$$\mathrm{MOE}_{\text{(clear wood average)}} \times F_{\text{quality}} \times F_{\text{shear}} \times F_{\text{MC\%}} \times F_{\text{density}} = \text{Allowable MOE}$$

After adjusting the clear wood properties, the resulting design values are termed "Allowable Properties". The allowable MOE is intended to be an average value for the grade. The allowable MOR is intended to be less than the stress permissible for 95% of the pieces in the grade.

The rationale for the use of these allowable properties is as follows. If the allowable MOE overestimates the MOE of the full-size structural piece, then a serviceability failure may occur. A serviceability failure would include a possible excessive deflection . Serviceability failures due to the overestimation of the MOE are relatively inconsequential. However, overestimation of the MOR could result in a catastrophic failure involving complete failure of a structural member. This could result in loss of life and property and thus very severe consequences. Therefore, the very conservative allowable MOR is used.

6.3 VISUAL GRADING OF PALLET SHOOK

6.3.1 Purpose of Grading

Pallet shook and other structural lumber, even of a single species, has a wide range of strength and stiffness largely due to the presence of highly variable strength reducing defects such as knots and slope of grain. Structural grades can be developed which limit the size and severity of the defects within a grade. Grades with strict limitations on defects will generally have higher average strength and stiffness values than grades with less restrictive defect limitations. The use of graded lumber is more efficient because the full potential of the lumber within a grade can be more nearly realized since the variability of the strength and stiffness is reduced. The use of higher grades of pallet shook allows the production of pallets with greater load carrying capacity compared to pallets produced from ungraded shook. The use of lower grades of pallet shook allows the production of pallets with known lower load carrying capacity but without underutilizing the higher quality material. The use of appropriate grades of pallet shook allows the production of pallets which economically and efficiently meet the requirements of the user.

Currently there are no universally accepted grades or grading criteria for pallet shook in use in the United States. While the establishment of visual grades of pallet shook with limitations on strength reducing defects is not required to derive design values, this makes establishing design values a difficult task unless some lower quality limit is established or can be identified on a de facto basis. There are some quality criteria that are used by a sizeable portion of the pallet industry. These criteria can be used as a starting point for the purposes of this thesis. It is not the purpose of this thesis to recommend any particular grades or grading schemes for pallet shook. Rather, it is intended to show how design values have been derived using existing quality criteria.

6.3.2 Pallet Specifications

The National Wooden Pallet and Container Association has three current Pallet Grade Specifications. While these specify the grade of the pallet, they do include quality requirements for the pallet shook allowable in a particular pallet grade. These grade specifications include the NWPCA Hardwood Pallet Standards (38), the NWPCA Southern Pine Pallet Specifications (39), and the NWPCA West Coast Softwoods (36) and NWPCA White Woods (37) Pallet Standards. (The NWPCA West Coast Softwoods grades and the NWPCA White Woods grades are identical.)

There are also two other grading schemes specifically for pallet shook that have some historical basis. The first, consisting of four visual grades, was proposed by Wallin and Frost (50) at the onset of a large Pallet Exchange Program study. The second and more recent, describes three visual grades and was proposed by Sardo and Wallin in the concluding report of the PEP study (42). The second criteria were designed to replace the scheme proposed by Wallin and Frost and were the result of much discussion with industry representatives at the end of the PEP study.

The restrictions on defects specified by these various grade descriptions are based on perceived differences in quality. These differences are in terms of durability, joint integrity, assembly ease, cosmetic factors relating to pallet marketability, as well as strength and stiffness.

In keeping with the ultimate goal of obtaining flexural design values, it is useful to compare the specifications of the various grading schemes in terms of their segregation by bending strength and stiffness. Complete grade descriptions for each of the schemes are included in Appendix I. Table 6.1 shows the minimum bending strength ratio, as determined from ASTM D 245, associated with a particular defect allowed within a grade for the various grades and grading schemes of pallet shook.

By grouping the two highest grades (1 and 2) in the grading scheme from Wallin and Frost, the three resulting grades can be compared to the three grades from Sardo and Wallin. The main difference between these two grading schemes is the greater restrictions on slope of grain in the scheme from Wallin and Frost.

The NWPCA Hardwood Pallet Grade specification consists of four grades: Precision, Premium, AA, and A. However, Premium and AA are identical in terms of bending strength

TABLE 6.1 - COMPARISON OF MINIMUM STRENGTH RATIO OF EACH GRADE FOR ALL GRADING SCHEMES

GRADING SCHEME	GRADE	MINIMUM STRENGTH RATIO (%)		DEFECT ASSOCIATED WITH MINIMUM STRENGTH RATIO	
		DECKBOARDS	STRINGERS	DECKBOARDS	STRINGERS
SARDO AND WALLIN	2&BTR	61	61	SLOPE OF GRAIN	SLOPE OF GRAIN
	3	53	50	SLOPE OF GRAIN	EDGE KNOT
	4	40	26	SLOPE OF GRAIN	EDGE KNOT
WALLIN AND FROST	1	89	81	KNOT	EDGE KNOT
	2	76	62	SLOPE OF GRAIN	EDGE KNOT
	3	61	45	SLOPE OF GRAIN	EDGE KNOT
	4	40	26	SLOPE OF GRAIN	EDGE KNOT
NWPCA HARDWOOD PALLET SPECIFICATIONS	PRECISION	61	61	SLOPE OF GRAIN	SLOPE OF GRAIN
	PREMIUM	53	50	SLOPE OF GRAIN	EDGE KNOT
	AA	53	50	SLOPE OF GRAIN	EDGE KNOT
	A	40	26	SLOPE OF GRAIN	EDGE KNOT
NWPCA SOUTHERN PINE PALLET SPECIFICATIONS	SELECT	69	69	SLOPE OF GRAIN	SLOPE OF GRAIN
	SP-1	61	61	SLOPE OF GRAIN	SLOPE OF GRAIN
	SP-2	53	50	SLOPE OF GRAIN	EDGE KNOT
	SP-3	34	26	KNOT	EDGE KNOT
NWPCA WEST COAST SOFTWOODS AND NWPCA WHITE WOODS PALLET STANDARDS	PREMIUM	53	50	SLOPE OF GRAIN	EDGE KNOT
	STANDARD	40	34	SLOPE OF GRAIN	EDGE KNOT
	SHIPPING	26	7	KNOT	EDGE KNOT

and stiffness of the shook since they differ only in the restriction of knots in the edge of deckboards. If these two grades are combined, the three resulting grades (Precision, Premium/AA, and A) are comparable to Grades 2&BTR, 3, and 4, respectively, of the grading scheme from Sardo and Wallin. In terms of bending strength and stiffness of the shook, these compared grades are equivalent.

The NWPCA Southern Pine Pallet Specifications define four grades: SP-Select, SP-1, SP-2, and SP-3. SP-Select is a very high quality grade and is particularly restrictive on knots. SP-1 defect limitations are comparable to those of Grade 2&BTR of the PEP Study scheme, with the exception of knots in deckboards. SP-2 and SP-3 are comparable to Grades 3 and 4, respectively, of the PEP Study scheme, again with the exception of knots in deckboards. The Southern Pine grades are less restrictive on knots in deckboards than the PEP Study grades. SP-3 is also less restrictive on slope of grain.

The NWPCA West Coast Softwoods Pallet Standards and the NWPCA White Woods Pallet Standards define three grades: Premium, Standard, and Shipping. Premium is comparable to Grade 3&BTR in terms of defect restrictions. Standard is equivalent to Grade 4 for slope of grain, but is more restrictive for knots. Shipping is a low quality grade which would be considered Cull in the PEP Study grading scheme.

The end result of these comparisons is that despite the different sources, there is reasonable uniformity in the criteria for segregating shook on a visual basis. It seems reasonable to exploit this commonality in developing design values based on strength and stiffness for the various quality groups or grades.

6.3.3 Grade Mix of Pallet Shook

The grade mix of pallet shook is defined here as the relative proportion of the total population of shook that falls within each grade. The grade mix, which indicates the grade distribution of the shook, is essential to the procedure for developing design values presented later in this section. By using the grade mix, this procedure seeks to equitably account for the shook quality distribution in the derivation of design values.

Table 6.2 compares the grade mix of all available data sets of graded pallet shook. From this data, an Average Grade Mix can be determined. The Average Grade Mix is the best available estimate of the grade mix of a shook population and is calculated as the weighted average (based on number of shook pieces) of the grade mixes of all available data sets. Three of the data sets in Table 6.2 were graded according to the scheme proposed by Wallin and Frost (50), but most were graded according to the scheme proposed by Sardo and Wallin in the PEP Study Report (42). As seen in Table 6.1 and the grade specifications in Appendix I, there are slight differences between the two schemes in the defect restrictions for the various grades. However, the effect of the differences between the two grading schemes on the grade mix was considered relatively minor and no differentation between the grading schemes was made in the calculation of the Average Grade Mix. Note that Grades 1 and 2 were combined in those data sets graded according to the scheme proposed by Wallin and Frost. The Average Grade Mix is based on the grade mix of both stringers and deckboards and both hardwood and softwood species. Therefore the Average Grade Mix is assumed valid for all shook sizes and species.

TABLE 6.2 - GRADE MIX OF ALL AVAILABLE DATA SETS OF GRADED SHOOK

			GRADE MIX				
DATA SOURCE	SPECIES	SIZE	%2&BTR	%3	%4	%CULL	N
EASTERN OAK SHOOK STUDY (45)	OAK	STRINGERS	25	25	25	25	1354
		DECKBOARDS	26	30	18	26	1430
RATE OF LOADING STUDY	OAK	STRINGERS	34	40	11	15	80
		DECKBOARDS	58	33	8	3	80
	POPLAR	STRINGERS	54	34	6	6	80
		DECKBOARDS	48	39	9	5	80
DEPTH EFFECT STUDY	ASH	STRINGERS	35	22	12	32	104
	COTTONWOOD	STRINGERS	61	32	3	5	104
FOREST SERVICE (25)	EASTERN HARDWOODS [1]	DECKBOARDS	48	31	13	8	17817
	S. PINE	DECKBOARDS	48	28	17	7	5372
	D. FIR	DECKBOARDS	53	26	11	10	2749
	TANOAK	STRINGERS	67	20	9	4	150
		DECKBOARDS	55	24	15	6	225

(DATA SETS THIS PAGE GRADED ACCORDING TO SARDO AND WALLIN'S GRADING SCHEME)

[1] - SPECIES INCLUDE MAPLE, BEECH, BIRCH, OAK, AND GUM

TABLE 6.2 (CONTINUED) - GRADE MIX OF ALL AVAILABLE DATA SETS OF GRADED SHOOK

			GRADE MIX				
DATA SOURCE	SPECIES	SIZE	%2&BTR	%3	%4	%CULL	N
YELLOW POPLAR SHOOK STUDY (20)	POPLAR	STRINGERS	44	30	15	11	448
		DECKBOARDS	47	25	15	12	482
WASHINGTON STATE UNIVERSITY (48)	S. PINE	DECKBOARDS	41	26	26	8	90
	D. FIR	DECKBOARDS	44	18	24	13	90
	HEMLOCK	DECKBOARDS	47	17	27	10	30
	MAPLE	DECKBOARDS	48	19	22	11	90
	ASPEN	DECKBOARDS	56	24	11	9	90
	OAK	DECKBOARDS	48	23	20	9	90
PEP STUDY (50)	MIXED [2]	MIXED [3]	50	35	10	5	12478

(DATA SETS THIS PAGE GRADED ACCORDING TO WALLIN AND FROST'S GRADING SCHEME)

[2] - SPECIES INCLUDE MIXED HARDWOODS, SOUTHERN PINE, DOUGLAS-FIR, WESTERN LARCH, WESTERN HEMLOCK, AND CALIFORNIA BLACK OAK

[3] - 10197 DECKBOARDS AND 2281 STRINGERS

Table 6.3 gives the Average Grade Mix for all available data calculated using the information of Table 6.2. According to the Average Grade Mix, in a population of shook, 48% would be expected to be Grade 2&BTR, 31% would be expected to be Grade 3, 13% would be expected to be Grade 4, and 8% would be expected to be Cull. These are the expected percentages for the single grades. The expected percentages of the total shook population for composite grades are also given. Composite grades are grades containing more than one single grade. Therefore, 3&BTR, 4&BTR, and All Shook are composite grades. Note that 2&BTR is considered as a single grade.

Composite grades are very important in the derivation of design values for pallet shook since they are more likely to be used in the production of pallets than are single grades. As shown later, deriving design values for single grades is a relatively simple procedure independent of the grade mix of shook. However, in deriving design values for composite grades, it is desirable to know the distribution of the single grades within the composite grade.

While the Average Grade Mix gives the expected percentages of the single and composite grades within the total shook population, the Composite Grade Mix is defined

TABLE 6.3 - AVERAGE GRADE MIX

GRADE	EXPECTED % OF TOTAL SHOOK POPULATION
2&BTR	48
3	31
4	13
CULL	8
3&BTR	79
4&BTR	92
ALL SHOOK	100

as the relative proportions of each of the single grades contained in the composite grade. The Average Grade Mix can be used to determine the Composite Grade Mix, which is given in Table 6.4.

To calculate the percentages of the single grades contained in a composite grade, the expected percentages of the single grades in the total population of shook (Table 6.3) are indexed to the expected percentage of the composite grade in the total population of shook.

$$\begin{array}{c}\text{\% SINGLE GRADE IN}\\ \text{COMPOSITE GRADE}\end{array} = \frac{\begin{array}{c}\text{\% SINGLE GRADE}\\ \text{IN TOTAL SHOOK POPULATION}\end{array}}{\begin{array}{c}\text{\% COMPOSITE GRADE}\\ \text{IN TOTAL SHOOK POPULATION}\end{array}} \text{ X } (100\%)$$

For example:

$$\begin{array}{c}\text{\% GRADE 3 IN}\\ \text{GRADE 4\&BTR}\end{array} = \frac{\begin{array}{c}\text{\% GRADE 3}\\ \text{IN TOTAL SHOOK POPULATION}\end{array}}{\begin{array}{c}\text{\% GRADE 4\&BTR}\\ \text{IN TOTAL SHOOK POPULATION}\end{array}} \text{ X } (100\%)$$

$$= \frac{31\%}{92\%} \text{ X } (100\%)$$

$$= 34\%$$

The Average Grade Mix was determined from all available shook data. This data was graded according to the schemes

TABLE 6.4 - COMPOSITE GRADE MIX

	% OF EACH SINGLE GRADE IN COMPOSITE GRADE			
COMPOSITE GRADE	2&BTR	3	4	CULL
3&BTR	61	39	0	0
4&BTR	52	34	14	0
ALL SHOOK	48	31	13	8

from Wallin and Frost (50) and Sardo and Wallin (42). The parallel grading restrictions of the NWPCA Hardwood and NWPCA Southern Pine Standards makes the Average Grade Mix applicable to these grading schemes, also. However, the NWPCA West Coast Softwoods and White Woods grades do not parallel Sardo and Wallin's grades. Thus, the grade mix under this grading scheme is not the same. However, it was possible to estimate the grade mix for West Coast Softwoods and White Woods grades from the Average Grade Mix by comparing the specifications of each grade of the West Coast grading scheme with the specifications of each grade from Sardo and Wallin's scheme. Based on the similarities of the strength ratio ranges for the various grades from the two schemes, Premium was assigned the combined proportions of 2&BTR and 3, Standard was assigned the proportion of Grade 4, and Shipping was assigned the proportion of Cull. The Average Grade Mix for shook graded under the West Coast Softwoods Standard or White Woods Standard is therefore 79%/13%/8% for Premium/Standard/Shipping. Table 6.5 lists the Average Grade Mix of pallet shook for each grading scheme. Table 6.6 lists the Composite Grade Mix for the composite grades of each grading scheme.

As seen in Table 6.2, there is reasonable uniformity in the grade mixes for the various data sets. In particular,

TABLE 6.5 - AVERAGE GRADE MIX FOR EACH GRADING SCHEME

GRADING SCHEME	GRADE	EXPECTED % OF TOTAL SHOOK POPULATION
SARDO AND WALLIN	2&BTR	48
	3	31
	4	13
	CULL	8
	3&BTR	79
	4&BTR	92
	ALL SHOOK	100
NWPCA HARDWOOD PALLET SPECIFICATIONS	PRECISION	48
	PREMIUM/AA	31
	A	13
	PREMIUM/AA&BTR	79
	A&BTR	92
NWPCA SOUTHERN PINE PALLET SPECIFICATIONS	SP-1&BTR	48
	SP-2	31
	SP-3	13
	SP-2&BTR	79
	SP-3&BTR	92
NWPCA WEST COAST SOFTWOODS / NWPCA WHITE WOODS PALLET STANDARDS	PREMIUM	79
	STANDARD	13
	SHIPPING	8
	STANDARD&BTR	92
	SHIPPING&BTR	100

TABLE 6.6 - COMPOSITE GRADE MIX FOR EACH GRADING SCHEME

GRADING SCHEME	COMPOSITE GRADE	% OF EACH SINGLE GRADE IN COMPOSITE GRADE			
		2&BTR	3	4	CULL
SARDO AND WALLIN	3&BTR	61	39	0	0
	4&BTR	52	34	14	0
	ALL SHOOK	48	31	13	8
		PRECISION	PREMIUM/AA		A
NWPCA HARDWOOD PALLET SPECIFICATIONS	PREMIUM/AA&BTR	61	39		0
	A&BTR	52	34		14
		SP-1&BTR	SP-2		SP-3
NWPCA SOUTHERN PINE PALLET SPECIFICATIONS	SP-2&BTR	61	39		0
	SP-3&BTR	52	34		14
		PREMIUM	STANDARD		SHIPPING
NWPCA WEST COAST SOFTWOODS / NWPCA WHITE WOODS PALLET STANDARDS	STANDARD&BTR	86	14		0
	SHIPPING&BTR	79	13		8

there is a larger percentage of high quality than low quality grades. An exception is the eastern oak shook data set, which had approximately equal percentages of each grade. This may be explained by the furniture industry's demand for high quality oak at the time of sampling for this data set. The result is a greater percentage of low quality grades obtained from the oak used to produce pallet shook. Depending on the market demand at any given time, similar trends might exist for other species. The grade mix of shook may also fluctuate with time as a function of the overall quality of trees available for harvest.

However, the Average Grade Mix and Composite Grade Mix are the best available estimates of the grade mix of a shook population. The significance and use of the Average Grade Mix, other than providing an indication of the grade and quality distribution of a typical shook population, is in calculating the Composite Grade Mix. The significance and use of the Composite Grade Mix will become apparent in the derivation of design values for composite grades of pallet shook as presented next in this thesis.

6.4 DEVELOPMENT OF PALLET SHOOK DESIGN VALUES

6.4.1 Introduction

The PALLET DESIGN SYSTEM (PDS) is a first-order second-moment reliability-based design procedure which utilizes the mean and standard deviation of the load effect and resistance quantities. The resistance quantities are measured in terms of the MOR and MOE of the pallet shook. Thus, the resistance design values required by PDS are the mean and standard deviation of the MOR and MOE of the pallet shook.

Two different approaches to the development of pallet shook design values are detailed here. The best approach is that of testing full-size in-grade lumber sampled from commercial material. However, to date only yellow-poplar and eastern oak shook have been evaluated through such a testing program, and thus design values can be derived from actual data for only these two species classes.

The other approach is similar to the traditional method of establishing design values reviewed in Section 5.2 of this thesis. This approach uses strength and stiffness of small, clear, green specimens modified by a series of adjustment factors to account for the end-use characteristics of the full-size shook. The major difference between the traditional method and the method described here for pallet shook is that the latter seeks estimates of the average strength and stiffness and the variability for a grade. The traditional method establishes near-minimum strength values and average stiffness values as allowable properties for a grade.

6.4.2 Modified Clear Wood Value Approach

Species Classes

Average clear wood values are required as a starting point for bending strength (MOR) and bending stiffness (MOE). In the development of pallet shook design values, average clear wood values for both MOR and MOE for either a single species or a combination of species are calculated using the procedure given in ASTM D 2555 (5) for calculating the average MOE. This procedure was explained in Section 6.2.2 of this thesis.

For the PALLET DESIGN SYSTEM, several species classes, each containing from one to several species, were created. These species classes are largely based on those proposed by Wallin (49), but are separate for hardwoods and softwoods. The species included in a particular class have similar ranges of bending strength, stiffness, and specific gravity. Species commonly marketed together were included in the same species class. Table 6.7 lists the species contained in each species class. For some of the species listed, small clear values were unavailable from ASTM D 2555 but were available from the Wood Handbook (47). In this case, the values listed in the Wood Handbook were used. If unavailable in either D 2555 or the Wood Handbook, then small clear values were taken from USDA Technical Bulletin No. 479 (31). Standing timber volume estimates for several hardwood species were taken from the Forest Products Lab General Technical Report FPL 20 (8) when estimates for these species were unavailable in ASTM D 2555. Table 6.8 lists the clear wood MOR and MOE values calculated as above and assigned to each species class. Appendix G includes the specific calculations for each species class.

TABLE 6.7 - PDS SPECIES CLASSES

1	2	3	4	5
HICKORY: PECAN WATER MOCKERNUT PIGNUT SHAGBARK SHELLBARK BITTERNUT NUTMEG BIRCH: YELLOW SWEET MAPLE: SUGAR BLACK RED ASH: GREEN WHITE ELM: ROCK SLIPPERY AMERICAN BEECH BLACK LOCUST BLACK CHERRY RED AND WHITE OAKS TANOAK DOGWOOD PERSIMMON EUCALYPTUS	BIGLEAF MAPLE OREGON ASH	SWEETGUM TUPELO: BLACK WATER MAGNOLIA: CUCUMBERTREE SOUTHERN PAPER BIRCH	OREGON WHITE OAK CALIFORNIA BLACK OAK CASCARA CHINQUAPIN MYRTLE MADRONE	ASH: BLACK PUMPKIN HACKBERRY SYCAMORE MAPLE: SILVER STRIPED BOXELDER SASSAFRAS SUGARBERRY

6	7	8
RED ALDER	YELLOW POPLAR EASTERN COTTONWOOD ASPEN: BIGTOOTH QUAKING CATALPA BUCKEYE BUTTERNUT AMERICAN BASSWOOD	COTTONWOOD: BLACK BALSAM POPLAR

TABLE 6.7 (CONTINUED) - PDS SPECIES CLASSES

11	12	13	14
DOUGLAS-FIR:	HEMLOCK:	SPRUCE:	
COAST	WESTERN	WHITE	CEDAR:
INTERIOR WEST	MOUNTAIN	BLACK	ALASKA
INTERIOR NORTH	FIR:	RED	INCENSE
INTERIOR SOUTH	CALIFORNIA RED	ENGELMANN	PORT ORFORD
WESTERN LARCH	GRAND	SITKA	ATLANTIC WHITE
SOUTHERN PINE:	NOBLE	PINE:	NORTHERN WHITE
LOBLOLLY	PACIFIC SILVER	SUGAR	EASTERN RED
LONGLEAF	WHITE	WESTERN WHITE	
SHORTLEAF		LODGEPOLE	
SLASH		PONDEROSA	
		MONTEREY	
		JACK	
		NORWAY	
		EASTERN WHITE	
		SOUTHERN PINE:	
		PITCH	
		POND	
		SPRUCE	
		VIRGINIA	
		FIR:	
		SUBALPINE	
		BALSAM	
		BALDCYPRESS	
		EATERN HEMLOCK	
		WESTERN RED CEDAR	

TABLE 6.8 - SMALL CLEAR VALUES (USED AS BASIS OF DESIGN VALUES)

PDS SPECIES CLASS [*]	AVERAGE MOR (PSI)	AVERAGE MOE (KSI)
1	8450	1430
2	7500	1220
3	7000	1230
4	6800	760
5	5950	980
6	6550	1280
7	5300	1020
8	4300	910
11	7450	1250
12	6250	1250
13	5150	1130
14	4650	780

[*] THE SPECIES CLASS NUMBER DISTINGUISHES THE VARIOUS CLASSES AND IS INPUT TO THE COMPUTERIZED PROCEDURE BY THE PDS USER. TABLE 6.7 LISTS THE SPECIES IN EACH CLASS.

Grade Factors

Grade factors are used to adjust the clear wood MOR for the effect of defects in the full-size pallet shook. The grade factors are based on the bending strength ratios given in ASTM D 245. While D 245 specifies that the minimum bending strength ratio be used for a grade, the grade factor for single grades of pallet shook is the average bending strength ratio for that grade. The average bending strength ratio is calculated as one-half the sum of the maximum and the minimum strength ratio associated with any defect allowable within a grade. For example, using the grading scheme from the PEP Study Report (42), the maximum bending strength ratio for Grade 2&BTR stringers is 100% (i.e. no defect) and the minimum strength ratio is 61%. Therefore, the grade factor for 2&BTR stringers is (100 + 61)/2 = 80.5 or 81%.

The minimum bending strength ratio for Grade 3 stringers is 50%. The maximum bending strength ratio is taken as the minimum bending strength ratio of the next higher grade. Thus the grade factor for Grade 3 stringers is (61 + 50)/2 = 55.5 or 56%.

This procedure was followed to establish grade factors for all single grades. The single grade factors were then used in conjunction with the Composite Grade Mix (Table 6.6) to establish composite grade factors.

To calculate the composite grade factors, the single grade factors were weighted by the proportions of the single grades contained in the composite grade and then summed.

$$\text{COMPOSITE GRADE FACTOR} = \sum \left(\text{SINGLE GRADE FACTORS} \quad X \quad \frac{\text{\% SINGLE GRADE IN COMPOSITE GRADE}}{100} \right)$$

For example:

$$\begin{aligned} \text{GRADE FACTOR (4\&BTR/STRINGERS)} &= \left(\text{GRADE FACTOR (2\&BTR/STRINGERS)} \quad X \quad \frac{\text{\% 2\&BTR IN 4\&BTR}}{100} \right) \\ &+ \left(\text{GRADE FACTOR (3/STRINGERS)} \quad X \quad \frac{\text{\% 3 IN 4\&BTR}}{100} \right) \\ &+ \left(\text{GRADE FACTOR (4/STRINGERS)} \quad X \quad \frac{\text{\% 4 IN 4\&BTR}}{100} \right) \\ &= (.81 \text{ X } 52/100) + (.56 \text{ X } 34/100) + (.38 \text{ X } 14/100) \\ &= 0.66 \end{aligned}$$

Table 6.9 gives the grade factors for all single and composite grades of each grading scheme for pallet shook.

TABLE 6.9 - GRADE AND QUALITY FACTORS FOR EACH GRADING SCHEME

GRADING SCHEME	GRADE	GRADE FACTOR		QUALITY FACTOR
		DECKBOARDS	STRINGERS	
SARDO AND WALLIN	2&BTR	.81	.81	1.0
	3	.57	.56	.90
	4	.47	.38	.85
	CULL	.20	.13	.80
	3&BTR	.72	.71	.96
	4&BTR	.68	.66	.95
	ALL SHOOK	.64	.62	.93
NWPCA HARDWOOD PALLET SPECIFICATIONS	PRECISION	.81	.81	1.0
	PREMIUM/AA	.57	.56	.90
	A	.47	.38	.85
	PREMIUM/AA&BTR	.72	.71	.96
	A&BTR	.68	.66	.95
NWPCA SOUTHERN PINE PALLET SPECIFICATIONS	SP-1&BTR	.81	.81	1.0
	SP-2	.57	.56	.90
	SP-3	.47	.38	.85
	SP-2&BTR	.72	.71	.96
	SP-3&BTR	.68	.66	.95
NWPCA WEST COAST SOFTWOODS / NWPCA WHITE WOODS PALLET STANDARDS	PREMIUM	.77	.75	.96
	STANDARD	.47	.42	.85
	SHIPPING	.33	.21	.80
	STANDARD&BTR	.73	.70	.95
	SHIPPING&BTR	.70	.66	.93

The composite grade mix was used to establish composite grade factors in order to equitably account for the relative presence of both high and low quality single grades in the composite grade. The resulting composite grade factors are valid only for composite grades with a grade mix similar to that reported in Table 6.6. If the PDS user requires design values for composite grades with a radically different grade mix, then he can use his grade mix in conjunction with the grade factors for single grades to determine a composite grade factor.

Quality Factors

Quality factors are used to adjust the clear wood MOE values for the effect of defects in the full-size pallet shook. ASTM D 245 provides only three quality factors to be applied to the clear wood MOE values. These factors are related to the minimum bending strength ratio of a grade. It was felt that these quality factors would not adequately account for differences in the MOE between the various grades of pallet shook since only three factors are provided.

The quality factors recommended for use in PDS were derived from the eastern oak shook data set (45). The quality factors were based on this data set because it is the most complete data set available for graded pallet shook. There is also a fairly even distribution of shook between the grades in this data set and a consistent expected trend of decreasing MOE with decreasing grade.

To calculate the quality factor for single grades, the average MOE for the shook (deckboards and stringers combined) of each single grade (2&BTR,3,4,and Cull) was divided by the average MOE for Grade 2&BTR. Table 6.10 lists the MOE for each single grade of the eastern oak shook data set as well as the quality factor calculated for each grade.

Since the eastern oak data set (45) was graded according to the Sardo and Wallin grading scheme, the quality factors are directly applicable to single grades of this grading scheme. Due to the parallel grading restrictions, the quality factors are also directly applicable to the single grades under the NWPCA Hardwood and the NWPCA Southern Pine specifications. The recommended quality factors were assigned to the NWPCA West Coast Softwoods and the NWPCA White Woods single grades according

TABLE 6.10 - DERIVATION OF QUALITY FACTORS FROM EASTERN OAK SHOOK DATA SET

GRADE [*]	MOE (KSI)	RATIO (MOE/MOE-2&BTR)	RECOMMENDED QUALITY FACTOR
2&BTR	1406	1.0	1.0
3	1295	.92	.90
4	1194	.85	.85
CULL	1098	.78	.80

[*] STRINGERS AND DECKBOARDS COMBINED

to the similarity between the grade factors (and thus the grade specifications) for these schemes compared to Sardo and Wallin's scheme. Premium was assigned the quality factor for Grade 3&BTR, Standard the quality factor for Grade 4, and Shipping the factor for Cull.

The composite grade quality factors were determined using the quality factors for single grades in conjunction with the Composite Grade Mix of Table 6.6. To calculate the quality factors for composite grades, the quality factors for the single grades were weighted by the proportions of the single grades contained in the composite grade and then summed.

$$\begin{array}{c}\text{COMPOSITE GRADE}\\ \text{QUALITY FACTORS}\end{array} = \sum \left(\begin{array}{c}\text{SINGLE GRADE}\\ \text{QUALITY FACTORS}\end{array} \times \frac{\begin{array}{c}\text{\% SINGLE GRADE IN}\\ \text{COMPOSITE GRADE}\end{array}}{100} \right)$$

For example:

$$\underset{(4\&BTR)}{\text{QUALITY FACTOR}} = \left(\underset{(2\&BTR)}{\text{QUALITY FACTOR}} \times \frac{\%\ 2\&BTR\ IN\ 4\&BTR}{100} \right)$$

$$+ \left(\underset{(3)}{\text{QUALITY FACTOR}} \times \frac{\%\ 3\ IN\ 4\&BTR}{100} \right)$$

$$+ \left(\underset{(4)}{\text{QUALITY FACTOR}} \times \frac{\%\ 4\ IN\ 4\&BTR}{100} \right)$$

$$= (1.0 \times 52/100) + (.90 \times 34/100) + (.85 \times 14/100)$$

$$= 0.95$$

The quality factors for single and composite grades of each grading scheme for pallet shook are given in Table 6.9. Note that while the grade factors for a particular grade of shook usually differ between stringers and deckboards, the quality factors for a particular grade of shook are applicable to both stringers and deckboards.

The composite grade mix was used to establish composite grade quality factors in order to equitably account for the relative presence of both high and low quality single grades in the composite grade. The resulting composite grade quality factors are valid only for composite grades with a grade mix similar to that reported in Table 6.6. If the PDS user requires design values for composite grades with a radically different grade mix, then he can use his grade mix in conjunction with the quality factors for single grades to determine a composite grade quality factor.

Correction for Shear Deformation

The small clear MOE values given in ASTM D 2555 are unadjusted for the effect of shear deflection during the testing procedure. The MOE values as given are therefore only apparent values. To obtain the true MOE values, an adjustment factor must be applied to the MOE values as given in order to correct for the effect of shear.

For the ASTM test method used to determine the MOE values given in ASTM D 2555, and assuming the ratio of longitudinal MOE to the Modulus of Rigidity (G) is equal to 16, the ratio of the apparent MOE to the true MOE can be shown to be 0.911 (9).

$$\text{MOE (apparent)}/\text{MOE(true)} = 0.911$$

Therefore, an adjustment factor of 1.10 is applied to the small clear MOE values calculated for each species class.

The MOE values listed in Table 6.8 have been adjusted by this factor.

Depth Factor

The clear wood MOR values obtained from ASTM D 2555 and used as the basis of design values were obtained from tests of two-inch deep specimens. Research has shown that as the depth of a beam increases, the MOR decreases (10). To adjust the small clear MOR values to the actual depths of pallet shook, a depth adjustment factor is used.

ASTM D 245 (4) gives the following equation to calculate the depth adjustment factor:

$$F = (2/d)^{1/9}$$

where:

F = factor to be applied to small clear MOR values

d = actual depth of design member

This formula is based on an assumed center-point load and a span-to-depth ratio of 14. It is also based on tests of clear Douglas-fir beams.

Section 4 of this thesis describes a Depth Effect Study performed to investigate the effect of depth on hardwood pallet shook, including the applicability of the adjustment factor given above. The results of this study indicated that although there was a depth effect on the MOR of full-size hardwood pallet shook, the formula ($F = (2/d)^{1/9}$) did not predict the effect as well as other possible formulas. Further, the depth effect equation did not account for the differences in MOR between deckboards and stringers. Since the depth adjustment factor would actually increase the small clear MOR base value for deckboards, it was noted that a conservative approach would be to use the factor only to adjust stringers.

Although the Depth Effect Study indicated that ($F = (2/d)^{1/9}$) did not work as well as other equations, it was decided to use this formula nevertheless. This decision was based on the current and historical use of this formula and because a rational alternative is not available based on the limited available data. However, it was decided not to apply the formula to deckboards based on the recommendations from the Depth Effect Study.

For a typical depth of 3.5 inches, the depth adjustment factor applied to the clear wood MOR values assigned to stringers is 0.94.

Load Duration Factor

Research has shown that the strength of wood under short term loading is greater than under long-term loading (55). The clear wood MOR values given in ASTM D 2555 were obtained from a standard 5-minute duration test. ASTM D 245 defines a "normal" load duration, which assumes the application of the maximum design stress either continuously or cumulatively for 10 years, or the application of 90% of the maximum design stress continuously throughout the life of the structure, or both. An adjustment factor of 0.625 is used to account for this normal load duration.

Pallets, however, are not subjected to a 10-year duration of load. A duration of load of two months is more appropriate. From Figure 5 in ASTM D 245, the ratio of strength for a 2-month load duration to the strength obtained from a standard 5-minute test is 0.72. Therefore, a duration of load adjustment factor of 0.72 is applied to the MOR values to obtain design values for pallet shook.

The load duration factor is based on engineering judgement. It is unknown whether the factor should be applied to all properties for all situations. Until the forest products industry develops a more rational means of assessing the load duration effect, this admittedly arbitrary factor should stand.

Summary of Adjustment Factors

The formulas which include the series of adjustment factors used to modify the clear wood strength and stiffness values to design values are as follows:

$$\overline{\text{MOR}}_{\text{(clear wood)}} \times \text{Grade Factor} \times F_{\text{depth}} \times F_{\text{load duration}} = \overline{\text{MOR}}_{\text{(design)}}$$

$$\overline{\text{MOE}}_{\text{(clear wood)}} \times \text{Quality Factor} \times F_{\text{shear}} = \overline{\text{MOE}}_{\text{(design)}}$$

Adjustment factors prescribed by ASTM D 245 but not used for pallet shook are a moisture content factor, a density factor, and a factor of safety. A moisture content factor was not used because of the lack of information on the effects of seasoning on the MOR and MOE of pallet shook. Research on full-size lumber indicates that the effect of moisture content on strength is dependent on lumber size and quality while the effect on stiffness is independent of size and quality (32). Therefore, a conservative approach is taken by not applying a moisture content adjustment factor until more information on the effect of seasoning is available. A density factor was also not used due to lack of information on the relationship between the strength and stiffness and the specific gravity of the various species of pallet shook. A density factor would not be practical at this stage of the development of design values for pallet shook since some sophistication in grading practice and experience is necessary. Finally, since PDS is a reliability-based design procedure, a working stress factor of safety is not used.

Following is an example of the process PDS uses to compute design values. The user specifies the species class and grade of shook which he is using for a particular pallet. Let's assume he is using a mixture of dense hardwoods, such as hickory, ash, elm, and oak. He will input #1 as his species class. Assume also that he inputs Grade 4&BTR. PDS then calculates MOR and MOE design values for both stringers and deckboards as follows:

$$\begin{array}{ccccccc}
\text{DESIGN} & & \text{CLEAR WOOD} & & \text{GRADE} & & \text{LOAD} \\
\text{MOR} & = & \text{VALUE} & \text{X} & \text{FACTOR} & \text{X} & \text{DURATION} \\
\text{(deckboards)} & & \text{(species} & & \text{(4\&BTR} & & \text{FACTOR} \\
 & & \text{class \#1)} & & \text{deckboards)} & & \\
 & & & & & & \\
 & = & 8450 \text{ psi} & \text{X} & 0.68 & \text{X} & 0.72 \\
 & & & & & & \\
 & = & 4140 \text{ psi} & & & &
\end{array}$$

$$\begin{array}{ccccccccc}
\text{DESIGN} & & \text{CLEAR WOOD} & & \text{GRADE} & & \text{DEPTH} & & \text{LOAD} \\
\text{MOR} & = & \text{VALUE} & \text{X} & \text{FACTOR} & \text{X} & & \text{X} & \text{DURATION} \\
\text{(stringers)} & & \text{(species} & & \text{(4\&BTR} & & \text{FACTOR} & & \text{FACTOR} \\
 & & \text{class \#1)} & & \text{stringers)} & & & & \\
 & & & & & & & & \\
 & = & 8450 \text{ psi} & \text{X} & 0.66 & \text{X} & 0.94 & \text{X} & 0.72 \\
 & & & & & & & & \\
 & = & 3775 \text{ psi} & & & & & &
\end{array}$$

$$\begin{array}{ccccc}
\text{DESIGN MOE} & & \text{CLEAR WOOD} & & \text{QUALITY} \\
\text{(deckboards} & = & \text{VALUE} & \text{X} & \text{FACTOR} \\
\text{and} & & \text{(species} & & \text{(4\&BTR)} \\
\text{stringers)} & & \text{class \#1)} & & \\
 & & & & \\
 & = & 1430 \text{ ksi} & \text{X} & 0.95 \\
 & & & & \\
 & = & 1359 \text{ ksi} & &
\end{array}$$

(NOTE: CLEAR WOOD MOE HAS BEEN CORRECTED FOR SHEAR)

Estimating Variance

An estimate of the mean and coefficient of variation (C.V.) of the MOR and MOE for a particular grade and species class is required for design purposes. The standard deviation of the clear wood MOR and MOE values for each species is given in ASTM D 2555. However, the variance of the MOR and MOE of full-size pallet shook is greater than the clear wood variance (45). The only way to determine the C.V. of a particular grade and species mix of pallet shook is to actually test samples from a shook population and calculate the C.V.. The limited data available on the strength and stiffness of graded pallet shook does not allow the calculation of the C.V. for all species classes or grading schemes. However, a reasonable estimate of the C.V. can be made.

Table 6.11 lists the coefficient of variation of the MOR and MOE of each grade of eastern oak deckboards and stringers from Spurlock's study. The general trend of increasing variation with decreasing shook quality (grade) is evident. Since these numbers represent the best available information on the variation of MOR and MOE values for pallet shook by grade, they were used to estimate the C.V. of the MOR and MOE by grade for any species class of pallet shook.

TABLE 6.11 - COEFFICIENT OF VARIATION FOR EASTERN OAK SHOOK DATA

	COEFFICIENT OF VARIATION (%)			
	MOR		MOE	
GRADE	DECKBOARDS	STRINGERS	DECKBOARDS	STRINGERS
2&BTR	18.9	20.1	25.1	25.0
3	20.0	22.8	23.6	22.2
4	23.5	25.1	27.2	25.2
CULL	29.3	33.5	29.7	29.2
3&BTR	19.9	22.2	25.6	25.2
4&BTR	21.2	24.2	24.7	24.3
ALL SHOOK	24.3	28.2	27.4	27.2

Table 6.12 lists the appropriate coefficient of variation of the MOR and MOE for each grade of deckboards and stringers from each of the four grading schemes.

TABLE 6.12 - COEFFICIENT OF VARIATION FOR EACH GRADE OF ALL GRADING SCHEMES

		COEFFICIENT OF VARIATION (%)			
		MOR		MOE	
GRADING SCHEME	GRADE	DECKBOARDS	STRINGERS	DECKBOARDS	STRINGERS
SARDO AND WALLIN	2&BTR	19	20	25	25
	3	20	23	24	22
	4	24	25	27	25
	CULL	29	34	30	29
	3&BTR	20	22	26	25
	4&BTR	21	24	25	24
	ALL SHOOK	24	28	27	27
NWPCA HARDWOOD PALLET SPECIFICATIONS	PRECISION	19	20	25	25
	PREMIUM/AA	20	23	24	22
	A	24	25	27	25
	PREMIUM/AA&BTR	20	22	26	25
	A&BTR	21	24	25	24
NWPCA SOUTHERN PINE PALLET SPECIFICATIONS	SP-1&BTR	19	20	25	25
	SP-2	20	23	24	22
	SP-3	24	25	27	25
	SP-2&BTR	20	22	26	25
	SP-3&BTR	21	24	25	24
NWPCA WEST COAST SOFTWOODS / NWPCA WHITE WOODS PALLET STANDARDS	PREMIUM	20	22	26	25
	STANDARD	24	25	27	25
	SHIPPING	29	34	30	29
	STANDARD&BTR	21	24	25	24
	SHIPPING&BTR	24	28	27	27

6.4.3 Full-Size In-Grade Testing Approach

The best approach to the development of pallet shook design values is that of testing full-size in-grade lumber sampled from commercial material. Due to the constraints of time and money, only yellow-poplar and eastern oak shook have been evaluated through such a testing program. Therefore, design values can be derived from actual data for only these two species classes.

The means and coefficient of variation of the MOR and MOE for the various grades from these two data sets can be input to PDS with relatively little adjustment. It is necessary to adjust the MOR and MOE values for loading rate during testing, to adjust the MOE of stringers for shear deflection, and to adjust the MOR for duration of load.

Both the eastern oak and the yellow-poplar were tested at loading rates approximately 10 times greater than the ASTM loading rate. An investigation of the effects of this increased loading rate on the MOR and MOE is discussed in Section 3 of this thesis. The results indicated that the MOR was 8.0% greater at the increased loading rate compared to the ASTM loading rate, while a 4.7% increase was seen for the MOE. Therefore the MOR values obtained at the increased loading rate were divided by 1.080 and the MOE values by 1.047 to adjust to the standard ASTM loading rate.

A duration of load factor is also applied to the experimentally determined MOR values. This factor adjusts the MOR from an approximate 5-minute test duration to a two-month load duration. This factor, taken from Figure 5 of ASTM D 245 (4), is equal to 0.72. The load duration factor is used in addition to the rate of loading adjustment factor.

Finally, the test MOE of stringers, with an span-to-depth ratio of 12.9, requires adjustment for the effects of shear deformation. However, the MOE of deckboards requires no adjustment due to the large span-to-depth ratio, 48, and a minimal effect of shear. Bodig and Jayne (9) give the following equation relating the test MOE to the true MOE:

$$\frac{\mathrm{MOE}_{\mathrm{test}}}{\mathrm{MOE}_{\mathrm{true}}} = \frac{(\ell/d)^2}{(\ell/d)^2 + 15.05}$$

This equation is for rectangular beams subjected to third-point loading and assumes the ratio of the longitudinal Modulus of Elasticity to the Modulus of Rigidity to be 16.

Since the stringers were tested at a span of 45 inches, and assuming a 3.5 inch average depth, the ratio of the test MOE to the true MOE can be shown to be 0.92. Therefore, the test MOE for stringers should be divided by 0.92 to account for the effect of shear deformation.

Table 6.13 gives a summary of the adjustment factors applied to the MOR and MOE values determined experimentally for each grade. Table 6.14 presents the design values used by PDS for each grade of yellow-poplar and eastern oak pallet shook.

TABLE 6.13 - ADJUSTMENT FACTORS FOR IN-GRADE TEST VALUES

PROPERTY	SIZE	LOADING RATE FACTOR	LOAD DURATION FACTOR	SHEAR FACTOR
MOR	DECKBOARDS	1/1.08	0.72	***
	STRINGERS	1/1.08	0.72	***
MOE	DECKBOARDS	1/1.047	***	***
	STRINGERS	1/1.047	***	1/0.92

*** NOT APPLICABLE

TABLE 6.14 - PDS DESIGN VALUES (IN-GRADE TESTING APPROACH)

PDS SPECIES CLASS	SIZE	GRADE	MOR (PSI)	C.V. (%)	MOE (10**3 PSI)	C.V. (%)
# 21 (EASTERN OAKS)	DECKBOARDS	2&BTR	5350	19.0	1400	25.1
		3	4930	20.0	1300	23.6
		4	4640	23.5	1220	27.2
		CULL	4150	29.3	1120	29.7
		3&BTR	5120	19.9	1340	24.7
		4&BTR	5000	21.2	1310	25.6
		ALL SHOOK	4780	24.3	1260	27.4
	STRINGERS	2&BTR	5670	20.1	1400	25.0
		3	5010	22.8	1270	22.2
		4	4560	25.1	1180	25.2
		CULL	3900	33.5	1060	29.2
		3&BTR	5340	22.2	1340	24.3
		4&BTR	5080	24.2	1290	25.2
		ALL SHOOK	4790	28.2	1230	27.2
# 29 (YELLOW-POPLAR)	DECKBOARDS	2&BTR	5020	24.8	1460	29.5
		3	5090	26.3	1340	26.4
		4	5100	24.0	1270	24.3
		CULL	4980	26.8	1340	24.4
		3&BTR	5040	25.3	1420	28.9
		4&BTR	5050	25.0	1390	28.5
		ALL SHOOK	5040	25.2	1390	28.1
	STRINGERS	2&BTR	4030	17.6	1370	36.1
		3	3720	21.7	1270	37.0
		4	3390	25.2	1020	26.6
		CULL	2960	33.2	950	36.5
		3&BTR	3910	19.6	1330	36.6
		4&BTR	3820	21.0	1280	36.9
		ALL SHOOK	3730	23.1	1250	37.8

6.4.4 Evaluation of Design Values

The pallet shook design values can be compared with data from tests of full-size pallet shook to evaluate their accuracy and applicability. ASTM D 2915 (6) provides standard methods for evaluating allowable properties assigned to grades of structural lumber.

Since the PDS design values are averages, they can be compared with a confidence interval for the mean of the actual data. ASTM D 2915 provides the following formula for calculation of the confidence interval:

$$CI = x \pm (ts/\sqrt{n})$$

where:

CI = confidence interval

x = mean from data

t = t statistic (dependent on n and confidence level)

s = standard deviation from data

n = number of data points

Assuming that the population is normally distributed, a given percentage of all such intervals constructed in this manner should contain the true mean. If the design value falls within this confidence interval, then it is considered verified with the associated confidence. Confidence intervals for any single or composite grade can be found in this manner and compared with the corresponding design value.

Evaluation Data

Several data sets from bending tests of graded pallet shook were used to evaluate the respective design values. Spurlock's (45) eastern oak shook data and Holland's (20) yellow-poplar shook data provide the two largest data sets of graded pallet shook available. The eastern oak and yellow-poplar shook from the Rate of Loading Study (Section 3) and the ash and eastern cottonwood shook from the Depth Effect Study (Section 4) provide two more data sets. Also available are results of tests conducted at Washington State University (48) on 90 deckboards of each of the following species: mixed oak, red and sugar maple, aspen, southern pine, and Douglas-fir. Thirty deckboards of western hemlock were also tested. Results from bending tests conducted at Oregon State University (7) on red alder and bigleaf maple pallet shook are also available, although the shook in this study was not graded. All material was green except the deckboards tested at Washington State University, which were air-dry.

To allow comparison, the design values and actual test data were reduced to the same level. This required adjusting the actual test MOR and MOE to the ASTM standard loading rate, as well as omitting the duration of load adjustment to the MOR design values. (Alternatively, the duration of load adjustment factor could have been applied to the MOR design values as well as the actual MOR data). The MOE for stringers from actual tests was also corrected for shear deformation before comparing to the design values.

The tests conducted at Washington State University were on air-dry deckboards. Therefore, the design values compared to this data set were adjusted to a 19% maximum moisture content using the adjustment factors of 1.25 for MOR and 1.14 for MOE as given in ASTM D 245 for material 4 inches and less in thickness. Due to the lack of information on the effects of seasoning for pallet shook, these adjustment factors are questionable. No adjustment for moisture content is made to PDS design values in actual use. The adjustment was made here to hopefully make the comparison of design values and actual data more realistic.

The design values to be compared to the actual shook data were based on small clear values for only the species represented by the test data and not necessarily the clear wood values for a particular PDS species class. For example, the test data for eastern cottonwood was compared with design values based on eastern cottonwood clear wood values and not clear wood values for PDS Species Class 7, which includes eastern cottonwood.

Verification

Figures 6.1 through 6.4 present a visual comparison of design values and confidence intervals for Spurlock's eastern oak shook data. Necessary adjustments to the design values and data are indicated in the figure footnotes. Table F-1 in the appendix presents a numerical comparison of design values and confidence intervals for data from each of the previously mentioned data sets, including Spurlock's data. Any necessary adjustments to the design values or data are indicated in the table footnotes.

A general trend evident from Figure 6.1 and 6.2 and Table F-1 is the increasing conservitism in the MOR design values for single grades as the shook quality decreases. Grade 2&BTR MOR design values are close to or within the actual data confidence interval, while Grade 4 and Cull design values are far below the confidence interval. These differences are explained by the general trends seen in the estimated and actual strength ratios shown in Section 5 of this thesis. The ASTM strength ratios were fairly close to the actual strength ratios for small defects but became increasingly conservative as the magnitude of the defect increased. Since the MOR design values are derived using ASTM strength ratios, the design values for higher grades of shook would more closely reflect the actual data than those for lower grades of shook.

As indicated by the Average and Composite Grade Mix, the higher quality grades account for the largest percentage of pallet shook. The grade factors for the high quality single grades are therefore heavily weighted in the calculation of the composite grade factors. Therefore, MOR design values for composite grades containing lower quality single grades are much less conservative than the design values for the lower quality single grades themselves.

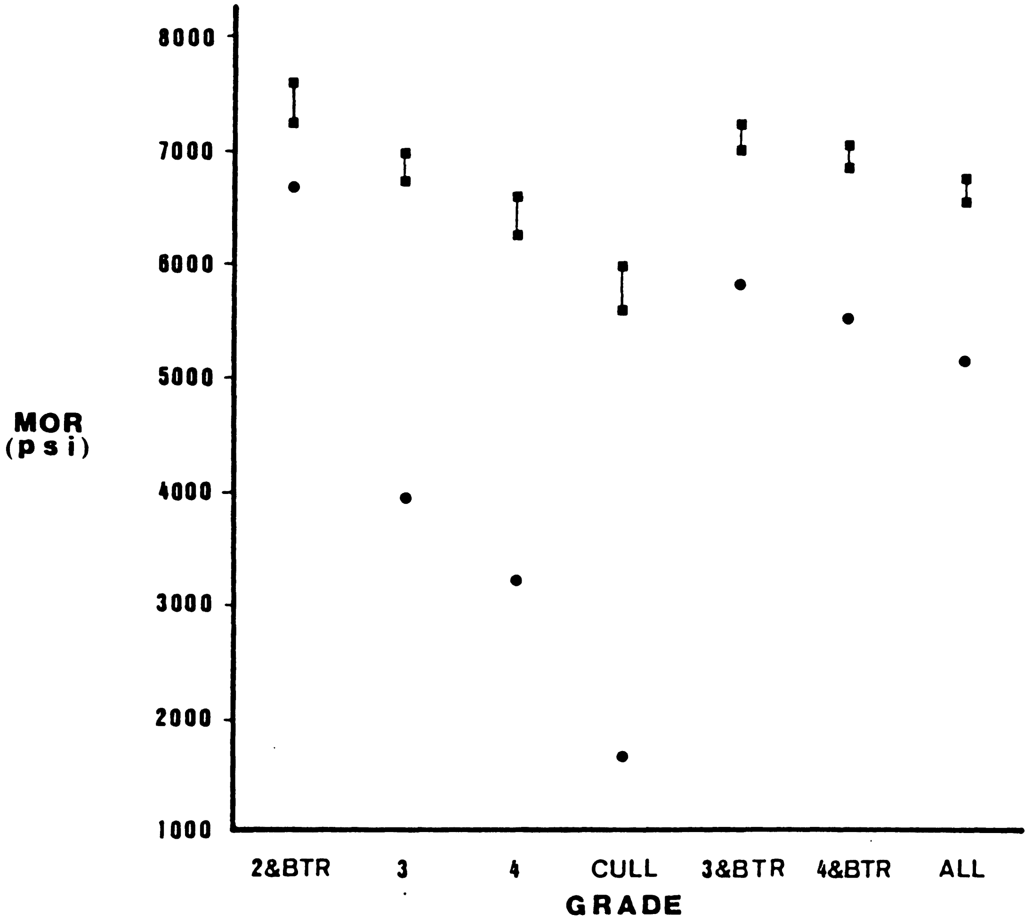

FIGURE 6.1 - COMPARISON OF DESIGN VALUES AND CONFIDENCE INTERVALS FOR DECKBOARDS FROM OAK SHOOK STUDY (45)

● DESIGN VALUE (UNADJUSTED FOR DURATION OF LOAD)

■ 95% CONFIDENCE INTERVAL LIMITS FOR DATA
(ADJUSTED TO ASTM LOADING RATE)

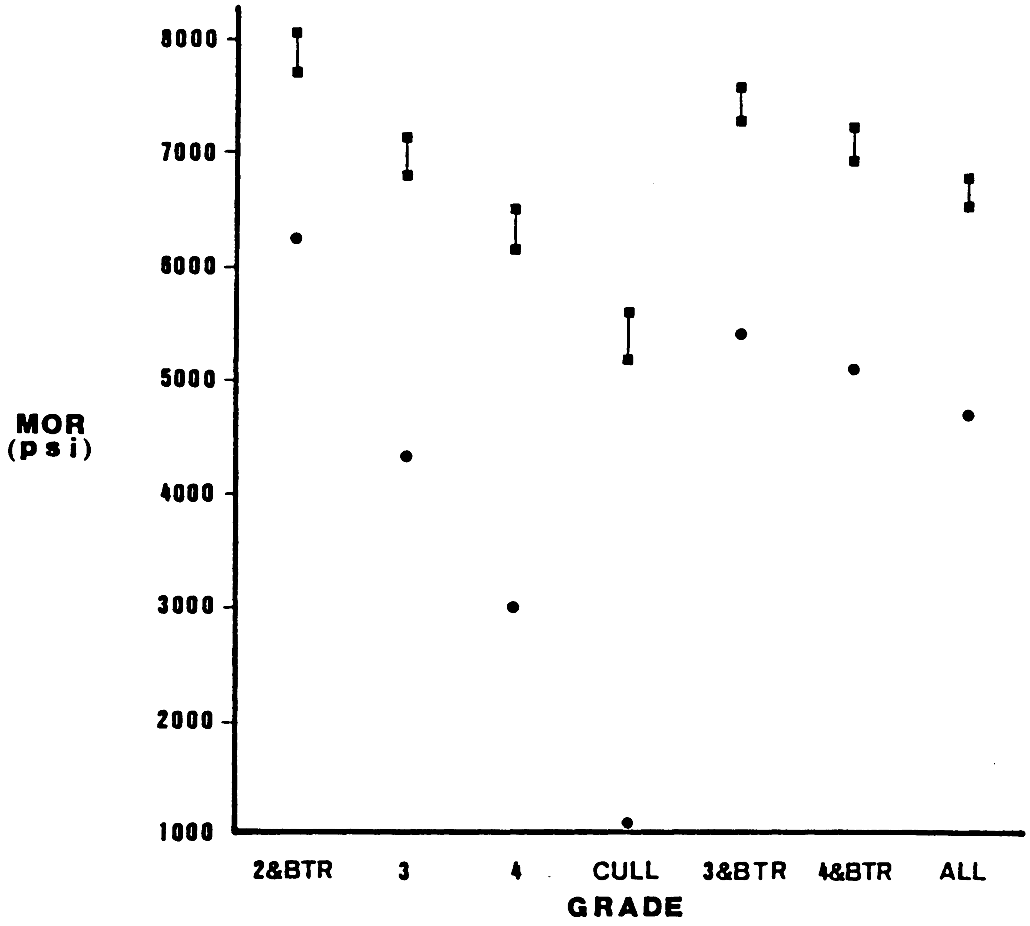

FIGURE 6.2 - COMPARISON OF DESIGN VALUES AND CONFIDENCE INTERVALS FOR STRINGERS FROM OAK SHOOK STUDY (45)

● DESIGN VALUE (UNADJUSTED FOR DURATION OF LOAD)

■ 95% CONFIDENCE INTERVAL LIMITS FOR DATA
(ADJUSTED TO ASTM LOADING RATE)

As can be seen from Figures 6.3 and 6.4 and Table F-1, the MOE design values are generally within or are closer to the actual data confidence intervals than are the MOR design values. While the MOR design values never exceed the upper limit of the actual data confidence interval, the MOE design values occassionally do. The overestimation of the actual MOE is slight, however, and since even a gross overestimation of the MOE would only result in a possible serviceability failure, the MOE design values appear reasonable.

Although the MOR design values are generally conservative, and are increasingly so with decreasing shook quality, this is certainly more desirable than overestimation of the MOR, which could lead to unacceptable failure. Given the known limitations of the strength ratio concept and the modified clear wood value approach in general, the MOR design values are judged acceptable until in-grade test data becomes available. Since design values for the lowest quality single grades will seldom be needed by most PDS users, the very conservative trend seen for the lower grade MOR design values should not pose a serious problem. A possible exception is the case of the West Coast manufacturer producing pallets from Shipping grade shook under the West Coast Softwoods or White Woods grading

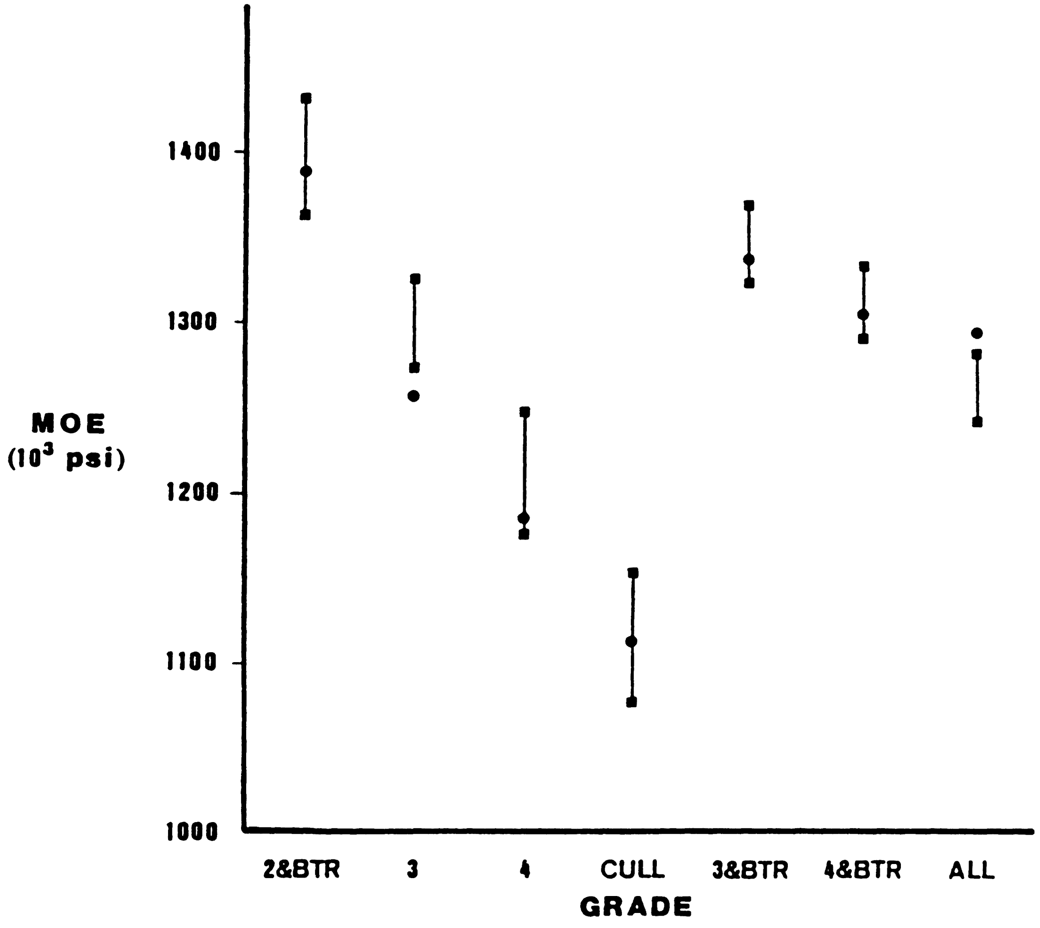

FIGURE 6.3 - COMPARISON OF DESIGN VALUES AND CONFIDENCE INTERVALS FOR DECKBOARDS FROM OAK SHOOK STUDY (45)

- ● DESIGN VALUE
- ■ 95% CONFIDENCE INTERVAL LIMITS FOR DATA (ADJUSTED TO ASTM LOADING RATE)

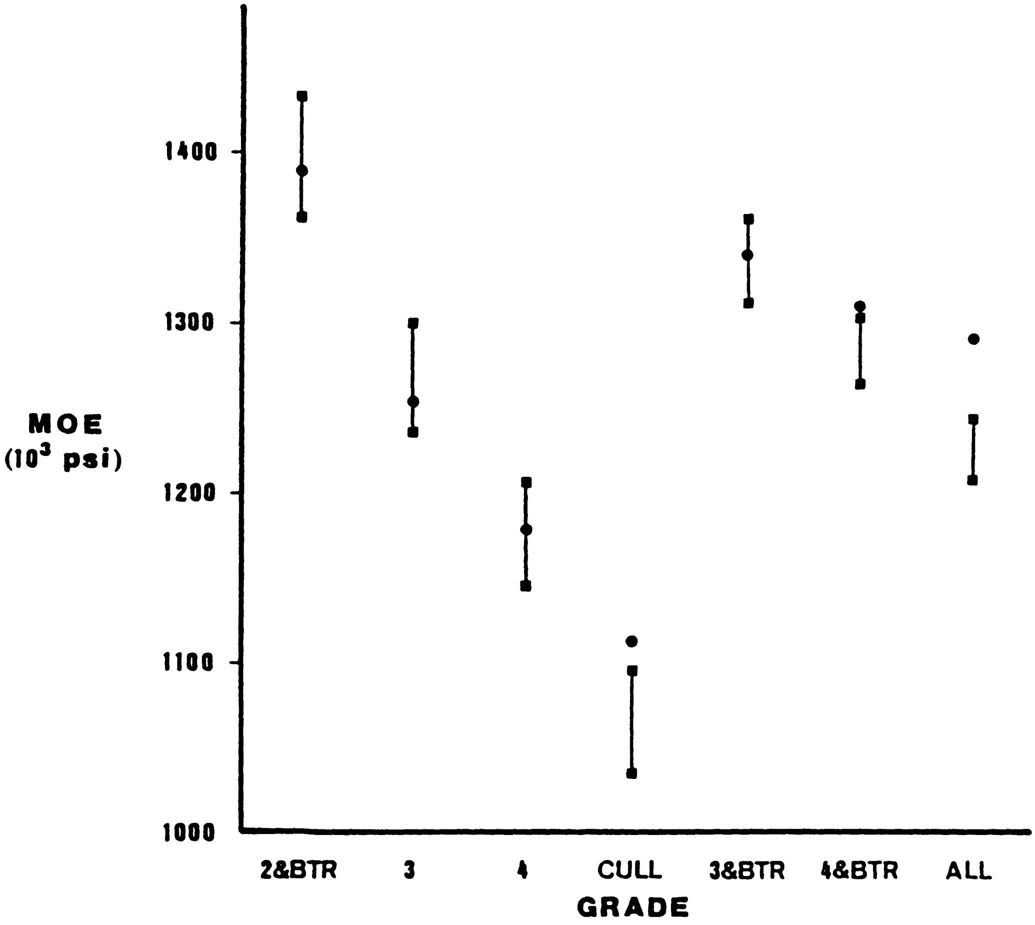

FIGURE 6.4 - COMPARISON OF DESIGN VALUES AND CONFIDENCE INTERVALS FOR STRINGERS FROM OAK SHOOK STUDY (45)

● DESIGN VALUE

■ 95% CONFIDENCE INTERVAL LIMITS FOR DATA
(ADJUSTED TO ASTM LOADING RATE,
CORRECTED FOR SHEAR DEFORMATION)

scheme. Unfortunately, the lack of test data prevents an evaluation of the design values for these species and grading schemes. Until such data is obtained, the design values, as derived, remain the best available.

6.5 CONCLUSION

Estimates of the mean and standard deviation of bending strength and stiffness for any species of pallet shook are required as PDS input. Two different approaches were used to develop design values. The best approach is testing full-size in-grade lumber sampled from commercial material. Yellow-poplar and eastern oak shook have been evaluated through such a testing program, and thus design values based on actual data are available for these two species classes.

The other approach uses strength and stiffness values of small, clear, green specimens modified by a series of adjustment factors to account for the end-use characteristics of the full-size piece. This approach is not as desirable as the in-grade testing approach due to the inherent uncertainty in the extrapolation of small, clear properties to those of full-size material with defects. However, for those species for which only small, clear specimen data is available, this is the only rational method of developing design values.

Although there are no universally accepted grades or grading schemes for pallet shook in the United States, there are some quality criteria used by a sizeable portion of the pallet industry. Therefore, these existing criteria were used in the development of design values for pallet shook.

To simplify the modified clear wood value approach, several species classes were created, each of which includes one to several species. Small, clear, green strength and stiffness values were then developed for each species class. Grade Factors and Quality Factors are used to adjust the clear wood MOR and MOE, respectively, for the effect of defects in the full-size shook. While the Quality Factors were experimentally determined based on the oak shook data, the Grade Factors are based on the ASTM D 245 strength ratios. Grade and Quality Factors were developed for both single and composite grades (grades composed of two or more single grades). The composite factors are based on the factors for single grades as well as the grade mix of shook as determined from all available data. Other adjustment factors include a load duration factor for MOR, a depth factor for stringer MOR, and a shear factor for MOE.

The design values developed via the modified clear wood value approach were evaluated by comparing to existing data from tests of full-size shook. The MOE design values were reasonably close to values from actual data, as were the MOR design values for high quality grades. The MOR design values for lower quality grades were very conservative, however. This was attributed to the conservatism in the ASTM strength ratios (upon which Grade Factors are based) in predicting strength for pieces with large knots (see Section 5). The MOR design values for composite grades , which are largely composed of the higher quality single grades, were much less conservative. Since design values for lower quality single grades will seldom be required by most PDS users, their conservatism should not pose a serious problem. A possible exception is the case of the West Coast manufacturer producing pallets from Shipping grade shook under the West Coast Softwoods or White Woods grading scheme. However, until test data for these species and grading schemes is obtained, the design values, as derived, remain the best available.

Given the inherent uncertainties in the modified clear wood value approach, some degree of conservatism is desirable. Therefore, until in-grade test data becomes available, design values developed via the modified clear wood value approach are judged acceptable.

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APPENDIX A

Defect Code

DEFECT CODE

(FOURTEEN DIGIT NUMERICAL CODE
USED TO RECORD TYPE, SIZE, AND LOCATION
OF DEFECTS IN PALLET SHOOK)

FIRST TWO DIGITS - RELATION TO LOAD POINTS AND SUPPORTS

00 - TENSION SIDE BETWEEN LOAD POINTS
01 - COMPRESSION SIDE BETWEEN LOAD POINTS
02 - TENSION SIDE BETWEEN SUPPORT AND LOAD POINT
03 - COMPRESSION SIDE BETWEEN SUPPORT AND LOAD POINT
06 - COMPRESSION SIDE AT LOAD POINT
07 - TENSION SIDE AT LOAD POINT
08 - TENSION AND COMPRESSION SIDES BETWEEN LOAD POINTS
09 - TENSION AND COMPRESSION SIDES BETWEEN SUPPORT AND LOAD POINT
10 - TENSION AND COMPRESSION SIDES AT LOAD POINT

THIRD AND FOURTH DIGITS DEFECT TYPE	FIFTH AND SIXTH DIGITS DEFECT SIZE
10 - CLEAR WOOD	00
11 - NARROW FACE KNOT INTERGROWN	DIAMETER (FIFTH DIGIT = INCHES SIXTH DIGIT = ONE-EIGHTS OF AN INCH)
12 - NARROW FACE KNOT ENCASED	
13 - NARROW FACE KNOT UNSOUND	
14 - WIDE FACE KNOT, CENTER LINE INTERGROWN	
15 - WIDE FACE KNOT, CENTER LINE ENCASED	
16 - WIDE FACE KNOT, CENTER LINE UNSOUND	
17 - WIDE FACE KNOT, EDGE INTERGROWN	
18 - WIDE FACE KNOT, EDGE ENCASED	
19 - WIDE FACE KNOT, EDGE UNSOUND	
20 - KNOT HOLE, CENTER LINE	
21 - KNOT HOLE, EDGE	
22 - KNOT HOLE, NARROW FACE	
23 - GRUB OR TERIDO HOLES	
24 - PIN HOLE	

33 - UNSOUND WOOD	% CROSS SECTION
34 - DISTORTED GRAIN OR BURL	DIAMETER
41 - BARK POCKETS	MAXIMUM THICKNESS
42 - SHAKE	01 FOR LIGHT, NOT THROUGH 02 FOR MEDIUM, NOT THROUGH 03 FOR HEAVY, NOT THROUGH 11 FOR LIGHT, THROUGH 12 FOR MEDIUM, THROUGH 13 FOR HEAVY, THROUGH
43 - SEASONING OR ROLLER CHECK	01 FOR SURFACE 02 FOR SMALL, THROUGH 03 FOR MEDIUM, THROUGH 04 FOR LARGE, THROUGH
44 - SPLITS	LENGTH IN INCHES
45 - SKIP	01 FOR LIGHT 02 FOR MEDIUM 03 FOR HEAVY
47 - MANUFACTURING (MACHINED EDGE)	00
49 - CROSSBREAK	% CROSS SECTION
50 - SAW CUT	01 SAW CUT THROUGH EDGE 02 ALL OTHER SAW CUTS
51 - SLOPE OF GRAIN	RUN OF SLOPE
52 - WANE	FIFTH DIGIT = FOURTHS WIDTH SIXTH DIGIT = FOURTHS THICK
60 - LOCAL GRAIN DEVIATION	RUN OF SLOPE (00 IF LESS THAN 1 IN 1)
61 - THICKNESS MISMANUFACTURE	00
62 - PITH	01 FACE 02 BOXED
63 - SOUND EDGE KNOT CLUSTER	DIAMETER
64 - SOUND CENTER KNOT CLUSTER	
66 - UNSOUND EDGE KNOT CLUSTER	
67 - UNSOUND CENTER KNOT CLUSTER	
90 - MULTIPLE SMALL KNOTS	NUMBER OF KNOTS
91 - INSUFFICIENT SPACING BETWEEN KNOTS	SPACING (INCHES)

SEVENTH DIGIT - RELATIONSHIP BETWEEN DEFECT, FACES, AND EDGES

1 - DEFECT INTERSECTS 1 EDGE, 0 FACES
2 - DEFECT INTERSECTS 2 EDGES, 0 FACES
3 - DEFECT INTERSECTS 0 EDGES, 1 FACE
4 - DEFECT INTERSECTS 1 EDGE, 1 FACE
5 - DEFECT INTERSECTS 2 EDGES, 1 FACE
6 - DEFECT INTERSECTS 0 EDGES, 2 FACES
7 - DEFECT INTERSECTS 1 EDGE, 2 FACES
8 - DEFECT INTERSECTS 2 EDGES, 2 FACES

EIGHTH THROUGH TENTH DIGITS - X-AXIS COORDINATES OF DEFECT

EIGHTH AND NINTH DIGITS - X-AXIS COORDINATE (INCHES)
TENTH DIGIT - X-AXIS COORDINATE (ONE-EIGHTHS OF AN INCH)

ELEVENTH AND TWELVETH DIGITS - Y-AXIS COORDINATE OF DEFECT

ELEVENTH DIGIT - Y-AXIS COORDINATE (INCHES)
TENTH DIGIT - Y-AXIS COORDINATE (ONE-EIGHTHS OF AN INCH)

THIRTEENTH AND FOURTEENTH DIGITS - Z-AXIS COORDINATE OF DEFECT

THIRTEENTH DIGIT - Z-AXIS COORDINATE (INCHES)
FOURTEENTH DIGIT - Z-AXIS COORDINATE (ONE-EIGHTS OF AN INCH)

APPENDIX B

Failure Code

FAILURE CODE

(THREE DIGIT NUMERICAL CODE USED TO RECORD TYPE, LOCATION, AND INITIATOR OF FAILURE)

FIRST DIGIT - LOCATION OF FAILURE

0 = NO FAILURE
1 = BETWEEN LOAD POINTS
2 = BETWEEN SUPPORT AND LOAD POINT
3 = AT LOAD POINT

SECOND DIGIT - TYPE OF FAILURE

0 = EXCESS DEFLECTION
1 = TENSION
2 = COMPRESSION
3 = SHEAR
4 = BRASH TENSION

THIRD DIGIT - INITIATOR OF FAILURE

0 = EXCESS DEFLECTION
1 = FIRST DEFECT RECORDED
2 = SECOND DEFECT RECORDED
3 = THIRD DEFECT RECORDED
4 = FOURTH DEFECT RECORDED
5 = CLEAR WOOD

APPENDIX C

Pallet Shook Grading Computer Program

```
*******************************************************************
*                   PROGRAM SHOOK GRADER                          *
*                                                                 *
*               WRITTEN BY JOHN A. MCLEOD III                     *
*                      DECEMBER 1983                              *
*                                                                 *
*                                                                 *
*  THIS PROGRAM DETERMINES THE GRADE OF PALLET SHOOK              *
*    BASED ON THE GRADING SCHEME PROPOSED BY SARDO AND WALLIN     *
*    IN THE PEP STUDY REPORT (42).  IT IS SET-UP TO WORK WITH     *
*    THE STATISTICAL ANALYSIS SYSTEM (SAS).                       *
*    REQUIRED INPUT DATA INCLUDES THE FOLLOWING:                  *
*      SIZE (DECKBOARD VS. STRINGER)                              *
*      CROSS-SECTIONAL DIMENSIONS OF PIECE                        *
*      NUMERICAL DEFECT CODE  (SEE APPENDIX A)                    *
*******************************************************************


DATA IN;
INPUT SIZE $ 3 NUMBER 4-5 WIDTH 7-11  THICK 13-17
  #2 POSF 2-3
  TYPEF 4-5 SIZEF 6-7 EXTENTF 8 XF 10-12 YF 14-15 ZF 17-18 POSA 20-21
  TYPEA 22-23 SIZEA 24-25 EXTENTA 26 XA 28-30 YA 32-33 ZA 35-36
  POSB 38-39 TYPEB 40-41 SIZEB 42-43 EXTENTB 44 XB 46-48 YB 50-51
  ZB 53-54 POSC 56-57 TYPEC 58-59 SIZEC 60-61 EXTENTC 62 XC 64-66
  YC 68-69 ZC 71-72;
GRADE = 1;
IF TYPEF=10 THEN GO TO CLEAR;
IF SIZE = 'S' THEN GO TO STRING;
ELSE GO TO DECKBD;
STRING: IF TYPEF GE 11 AND TYPEF LE 22 AND SIZEF GT 4 THEN GO TO SKNOT;
IF TYPEF GE 63 AND TYPEF LE 67 AND SIZEF GT 4 THEN GO TO SKNOT;
IF TYPEF = 34 THEN GO TO SKNOT;
IF TYPEA GE 11 AND TYPEA LE 22 AND SIZEA GT 4 THEN GO TO SKNOT;
IF TYPEA GE 63 AND TYPEA LE 67 AND SIZEA GT 4 THEN GO TO SKNOT;
IF TYPEA = 34 THEN GO TO SKNOT;
IF TYPEB GE 11 AND TYPEB LE 22 AND SIZEB GT 4 THEN GO TO SKNOT;
IF TYPEB GE 63 AND TYPEB LE 67 AND SIZEB GT 4 THEN GO TO SKNOT;
IF TYPEB = 34 THEN GO TO SKNOT;
IF TYPEC GE 11 AND TYPEC LE 22 AND SIZEC GT 4 THEN GO TO SKNOT;
IF TYPEC GE 63 AND TYPEC LE 67 AND SIZEC GT 4 THEN GO TO SKNOT;
IF TYPEC = 34 THEN GO TO SKNOT;
GO TO SSLOPE;
SKNOT:  X1=0;   X2=0;   X3=0;   X4=0;
IF TYPEF GE 11 AND TYPEF LE 24 AND SIZEF GT 4 THEN X1=XF;
IF TYPEF GE 63 AND TYPEF LE 67 AND SIZEF GT 4 THEN X1=XF;
IF TYPEA GE 11 AND TYPEA LE 24 AND SIZEA GT 4 THEN X2=XA;
IF TYPEA GE 63 AND TYPEA LE 67 AND SIZEA GT 4 THEN X2=XA;
IF TYPEB GE 11 AND TYPEB LE 24 AND SIZEB GT 4 THEN X3=XB;
IF TYPEB GE 63 AND TYPEB LE 67 AND SIZEB GT 4 THEN X3=XB;
```

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IF TYPEC GE 11 AND TYPEC LE 24 AND SIZEC GT 4 THEN X4=XC;
IF TYPEC GE 63 AND TYPEC LE 67 AND SIZEC GT 4 THEN X4=XC;
GHAND:  IF SIZE = 'S' THEN XX=14;
IF SIZE = 'D' THEN XX=30;
IF X1 GT 0 AND X2 GT 0 AND ABS(X1 - X2) LT XX THEN GO TO FLAG;
IF X1 GT 0 AND X3 GT 0 AND ABS(X1 - X3) LT XX THEN GO TO FLAG;
IF X1 GT 0 AND X4 GT 0 AND ABS(X1 - X4) LT XX THEN GO TO FLAG;
IF X2 GT 0 AND X3 GT 0 AND ABS(X2 - X3) LT XX THEN GO TO FLAG;
IF X2 GT 0 AND X4 GT 0 AND ABS(X2 - X4) LT XX THEN GO TO FLAG;
IF X3 GT 0 AND X4 GT 0 AND ABS(X3 - X4) LT XX THEN GO TO FLAG;
IF TYPEF = 34 THEN X1 = XF;
IF TYPEA = 34 THEN X2 = XA;
IF TYPEB = 34 THEN X3 = XB;
IF TYPEC = 34 THEN X4 = XC;
IF SIZE = 'D' THEN GO TO DPATH1;
XSECT = WIDTH*THICK;  GO TO SPATH1;
SPATH1:  IF X1 GT 0 THEN GO TO SRF;
SPATH2:  IF X2 GT 0 THEN GO TO SRA;
SPATH3:  IF X3 GT 0 THEN GO TO SRB;
SPATH4:  IF X4 GT 0 THEN GO TO SRC;
GO TO SSLOPE;
SRF: NUM=1; TYPE=TYPEF; EXTENT=EXTENTF; SZZE=SIZEF; X=X1; GO TO SRSIZE;
SRA: NUM=2; TYPE=TYPEA; EXTENT=EXTENTA; SZZE=SIZEA; X=X2; GO TO SRSIZE;
SRB: NUM=3; TYPE=TYPEB; EXTENT=EXTENTB; SZZE=SIZEB; X=X3; GO TO SRSIZE;
SRC: NUM=4; TYPE=TYPEC; EXTENT=EXTENTC; SZZE=SIZEC; X=X4; GO TO SRSIZE;
SRSIZE: SS = INT(SZZE/10);
SZE = SS + (SZZE/10 - SS) *10/8;
IF TYPE=11 OR TYPE=12 OR TYPE=13 OR TYPE=22 THEN ASZE=WIDTH*SZE/4;
IF TYPE GE 14 AND TYPE LE 21 AND EXTENT LE 5 THEN ASZE=THICK*SZE/2;
IF TYPE GE 63 AND TYPE LE 67 AND EXTENT LE 5 THEN ASZE=THICK*SZE/2;
IF TYPE GE 14 AND TYPE LE 21 AND EXTENT GE 6 THEN ASZE=THICK*SZE/1.3;
IF TYPE GE 63 AND TYPE LE 67 AND EXTENT GE 6 THEN ASZE=THICK*SZE/1.3;
IF TYPE=34 THEN ASZE=THICK*SZE/2;
IF TYPE=20 OR TYPE=21 OR TYPE=22 THEN ASZE=ASZE*2;
IF (ASZE/XSECT) GT .25 AND (ASZE/XSECT) LE .33 AND GRADE LT 2
    THEN LINK GRADE2;
IF (ASZE/XSECT) GT .33 AND (ASZE/XSECT) LE .5 AND GRADE LT 3
    THEN LINK GRADE3;
IF (ASZE/XSECT) GT .5 THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
IF TYPE NE 34 AND X GT 0 AND X LE 150  AND GRADE LT 2
    THEN LINK GRADE2;
IF TYPE NE 34 AND X GE 330 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPE NE 34 AND X GT 0 AND X LE 150 AND (ASZE/XSECT) GT .25
   AND (ASZE/XSECT) LE .33 AND GRADE LT 3 THEN LINK GRADE3;
IF TYPE NE 34 AND X GE 330 AND (ASZE/XSECT) GT .25
   AND (ASZE/XSECT) LE .33 AND GRADE LT 3 THEN LINK GRADE3;
IF TYPE NE 34 AND X GT 0 AND X LE 150 AND (ASZE/XSECT) GT .33
    THEN LINK GRADE4;
IF TYPE NE 34 AND X GE 330 AND (ASZE/XSECT) GT .33
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    THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
IF NUM=1 THEN GO TO SPATH2;
IF NUM=2 THEN GO TO SPATH3;
IF NUM=3 THEN GO TO SPATH4;
IF NUM=4 THEN GO TO SSLOPE;
SSLOPE: NUM=0;
IF TYPEF=51 THEN NUM=1;
IF TYPEA=51 THEN NUM=2;
IF TYPEB=51 THEN NUM=3;
IF TYPEC=51 THEN NUM=4;
IF NUM=0 THEN GO TO SDIST;
IF NUM=1 THEN SZZE=SIZEF;
IF NUM=2 THEN SZZE=SIZEA;
IF NUM=3 THEN SZZE=SIZEB;
IF NUM=4 THEN SZZE=SIZEC;
IF SZZE LT 10 AND SZZE GE 8 AND GRADE LT 2 THEN LINK GRADE2;
IF SZZE LT 8 AND SZZE GE 6 AND GRADE LT 3 THEN LINK GRADE3;
IF SZZE LT 6 THEN LINK GRADE4;
IF GRADE = 4 THEN RETURN;
SDIST:  IF TYPEF=60 THEN NUM=1;
IF TYPEA=60 THEN NUM=2;
IF TYPEB=60 THEN NUM=3;
IF TYPEC=60 THEN NUM=4;
IF TYPEF=60 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEA=60 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEB=60 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEC=60 AND GRADE LT 2 THEN LINK GRADE2;
IF SIZE = 'D' THEN GO TO DSPLIT;
SSPLIT: NUM = 0;
IF TYPEF=42 THEN NUM=1;
IF TYPEA=42 THEN NUM=2;
IF TYPEB=42 THEN NUM=3;
IF TYPEC=42 THEN NUM=4;
IF NUM = 0 THEN GO TO SSPLIT2;
IF NUM=1 THEN SZZE = SIZEF;
IF NUM=2 THEN SZZE = SIZEA;
IF NUM=3 THEN SZZE = SIZEB;
IF NUM=4 THEN SZZE = SIZEC;
IF SZZE NE 1 AND SZZE NE 11 AND GRADE LT 2 THEN LINK GRADE2;
SSPLIT2:  NUM = 0;
IF TYPEF=43 THEN NUM=1;
IF TYPEA=43 THEN NUM=2;
IF TYPEB=43 THEN NUM=3;
IF TYPEC=43 THEN NUM=4;
IF NUM = 0 THEN GO TO SSPLIT3;
IF NUM=1 THEN SZZE = SIZEF;
IF NUM=2 THEN SZZE = SIZEA;
IF NUM=3 THEN SZZE = SIZEB;
IF NUM=4 THEN SZZE = SIZEC;
```

```
IF SZZE GT 3 AND GRADE LT 2 THEN LINK GRADE2;
SSPLIT3:  NUM = 0;
IF TYPEF=44 THEN NUM=1;
IF TYPEA=44 THEN NUM=2;
IF TYPEB=44 THEN NUM=3;
IF TYPEC=44 THEN NUM=4;
IF NUM=1 THEN SZZE = SIZEF;
IF NUM=2 THEN SZZE = SIZEA;
IF NUM=3 THEN SZZE = SIZEB;
IF NUM=4 THEN SZZE = SIZEC;
IF SIZE='D' THEN GO TO DSPLITE;
IF NUM = 0 THEN GO TO SWANE;
IF SZZE GT 12 AND SZZE LE 24 AND GRADE LT 2 THEN LINK GRADE2;
IF SZZE GT 24 AND SZZE LE 36 AND GRADE LT 3 THEN LINK GRADE3;
IF SZZE GT 36 THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
SWANE:  IF TYPEF=52 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEA=52 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEB=52 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEC=52 AND GRADE LT 2 THEN LINK GRADE2;
SDECAY:  NUM=0;
IF TYPEF=33 THEN SZZE=SIZEF AND NUM=1;
IF TYPEA=33 THEN SZZE=SIZEA AND NUM=2;
IF TYPEB=33 THEN SZZE=SIZEB AND NUM=3;
IF TYPEC=33 THEN SZZE=SIZEC AND NUM=4;
IF NUM = 0 THEN GO TO SPITH;
IF SZZE LE 12 AND GRADE LT 2 THEN LINK GRADE2;
IF SZZE GT 12 AND SZZE LE 25 AND GRADE LT 3 THEN LINK GRADE3;
IF SZZE GT 25 THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
SPITH:  IF TYPEF=62 THEN NUM=1;
IF TYPEA=62 THEN NUM=2;
IF TYPEB=62 THEN NUM=3;
IF TYPEC=62 THEN NUM=4;
IF TYPEF=62 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEA=62 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEB=62 AND GRADE LT 2 THEN LINK GRADE2;
IF TYPEC=62 AND GRADE LT 2 THEN LINK GRADE2;
RETURN;
DECKBD: IF TYPEF GE 14 AND TYPEF LE 21 AND SIZEF GT 4 THEN GO TO DKNOT;
IF TYPEF GE 63 AND TYPEF LE 67 AND SIZEF GT 4 THEN GO TO DKNOT;
IF TYPEF = 34 THEN GO TO DKNOT;
IF TYPEA GE 14 AND TYPEA LE 21 AND SIZEA GT 4 THEN GO TO DKNOT;
IF TYPEA GE 63 AND TYPEA LE 67 AND SIZEA GT 4 THEN GO TO DKNOT;
IF TYPEA = 34 THEN GO TO DKNOT;
IF TYPEB GE 14 AND TYPEB LE 21 AND SIZEB GT 4 THEN GO TO DKNOT;
IF TYPEB GE 63 AND TYPEB LE 67 AND SIZEB GT 4 THEN GO TO DKNOT;
IF TYPEB = 34 THEN GO TO DKNOT;
IF TYPEC GE 14 AND TYPEC LE 21 AND SIZEC GT 4 THEN GO TO DKNOT;
IF TYPEC GE 63 AND TYPEC LE 67 AND SIZEC GT 4 THEN GO TO DKNOT;
```

```
IF TYPEC = 34 THEN GO TO DKNOT;
GO TO DSLOPE;
DKNOT:  X1=0; X2=0; X3=0; X4=0;
IF TYPEF GE 14 AND TYPEF LE 21 AND SIZEF GT 4 THEN X1=XF;
IF TYPEF GE 63 AND TYPEF LE 67 AND SIZEF GT 4 THEN X1=XF;
IF TYPEA GE 14 AND TYPEA LE 21 AND SIZEA GT 4 THEN X2=XA;
IF TYPEA GE 63 AND TYPEA LE 67 AND SIZEA GT 4 THEN X2=XA;
IF TYPEB GE 14 AND TYPEB LE 21 AND SIZEB GT 4 THEN X3=XB;
IF TYPEB GE 63 AND TYPEB LE 67 AND SIZEB GT 4 THEN X3=XB;
IF TYPEC GE 14 AND TYPEC LE 21 AND SIZEC GT 4 THEN X4=XC;
IF TYPEC GE 63 AND TYPEC LE 67 AND SIZEC GT 4 THEN X4=XC;
GO TO GHAND;
DPATH1:  IF X1 GT 0 THEN GO TO DRF;
DPATH2:  IF X2 GT 0 THEN GO TO DRA;
DPATH3:  IF X3 GT 0 THEN GO TO DRB;
DPATH4:  IF X4 GT 0 THEN GO TO DRC;
GO TO DSLOPE;
DRF: NUM=1; TYPE=TYPEF; SZZE=SIZEF; EXTENT=EXTENTF; X=X1; GO TO DRSIZE;
DRA: NUM=2; TYPE=TYPEA; SZZE=SIZEA; EXTENT=EXTENTA; X=X2; GO TO DRSIZE;
DRB: NUM=3; TYPE=TYPEB; SZZE=SIZEB; EXTENT=EXTENTB; X=X3; GO TO DRSIZE;
DRC: NUM=4; TYPE=TYPEC; SZZE=SIZEC; EXTENT=EXTENTC; X=X4; GO TO DRSIZE;
DRSIZE: SS = INT(SZZE/10);
SZE = SS + (SZZE/10 - SS) *10/8;
ASZE=SZE/WIDTH;
IF TYPE=20 OR TYPE=21 THEN ASZE = ASZE*2;
IF ASZE GT .25 AND ASZE LE .33 AND GRADE LT 2 THEN LINK GRADE2;
IF ASZE GT .33 AND ASZE LE .50 AND GRADE LT 3 THEN LINK GRADE3;
IF ASZE GT .5 THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
IF X LE 30 OR X GE 390
   OR TYPE=17 OR TYPE=18 OR TYPE=19 OR TYPE=21 OR TYPE=63
   OR TYPE=66 THEN LINK IG;
IF X LE 30 OR X GE 390 OR TYPE=17 OR TYPE=18 OR TYPE=19 OR TYPE=21
   OR TYPE=63 OR TYPE=66 THEN LINK IG;
IF X LE 30 OR X GE 390 OR TYPE=17 OR TYPE=18 OR TYPE=19 OR TYPE=21
   OR TYPE=63 OR TYPE=66 THEN LINK IG;
IF GRADE=4 THEN RETURN;
IF NUM=1 THEN GO TO DPATH2;
IF NUM=2 THEN GO TO DPATH3;
IF NUM=3 THEN GO TO DPATH4;
IF NUM=4 THEN GO TO DSLOPE;
DSLOPE:  GO TO SSLOPE;
DSPLIT:  GO TO SSPLIT;
DSPLITE:  IF NUM=0 THEN GO TO DDECAY;
IF SZZE GT 11 AND SZZE LE 21 AND GRADE LT 2 THEN LINK GRADE2;
IF SZZE GT 21 AND SZZE LE 32 AND GRADE LT 3 THEN LINK GRADE3;
IF SZZE GT 32 THEN LINK GRADE4;
IF GRADE=4 THEN RETURN;
DDECAY: GO TO SDECAY;
IG:  IF GRADE LT 2 THEN LINK GRADE2;
```

```
IF ASZE GT .25 AND ASZE LE .33 AND GRADE LT 3 THEN LINK GRADE3;
IF ASZE GT .33 THEN LINK GRADE4;
RETURN;
GRADE2:   GRADE=2;  DEF=NUM;  RETURN;
GRADE3:   GRADE=3;  DEF=NUM;  RETURN;
GRADE4:   GRADE=4;  DEF=NUM;  RETURN;
* IF MORE THAN ONE KNOT IS WITHIN A CRITICAL SPACING, THEN THE SUM
*    OF THE KNOT SIZES ARE USED TO CALCULATE THE APPROPRIATE GRADE.
*    IN THIS CASE, THE GRADE IS REPORTED AS "5".  THE ACTUAL GRADE
*    (1 - 4) MUST BE DETERMINED BY HAND.
FLAG:   GRADE=5;
RETURN;
CLEAR:   GRADE=1;  DEF=0;
CARDS;
DATA _NULL_;
SET IN;
FILE PUNCH NOTITLE;
PUT @3 SIZE $1. @4 NUMBER Z2. @7 WIDTH 5.3
  @13 THICK 5.3
  #2 @ 30 GRADE 1.
  #3 @2 POSF Z2. @4 TYPEF Z2. @6 SIZEF Z2. @8 EXTENTF 1.
  @10 XF Z3. @14 YF Z2. @17 ZF Z2. @20 POSA Z2. @22 TYPEA Z2.
  @ 24 SIZEA Z2.
  @26 EXTENTA 1. @28 XA Z3. @32 YA Z2. @35 ZA Z2. @38 POSB Z2.
  @40 TYPEB Z2. @42 SIZEB Z2. @44 EXTENTB 1. @46 XB Z3. @50 YB Z2.
  @53 ZB Z2. @56 POSC Z2. @58 TYPEC Z2. @60 SIZEC Z2. @62 EXTENTC 1.
  @64 XC Z3. @68 YC Z2. @71 ZC Z2.;
/*
//
```

APPENDIX D

Pallet Shook Strength Ratio Computer Program

```
***********************************************************************
*                          PROGRAM SHOOK ESR                          *
*                                                                     *
*                  WRITTEN BY JOHN A. MCLEOD III                      *
*                         SEPTEMBER 1983                              *
*                                                                     *
*      THIS PROGRAM CALCULATES THE ESTIMATED STRENGTH RATIO           *
*          OF PALLET STRINGERS AND DECKBOARDS                         *
*          ACCORDING TO THE EQUATIONS GIVEN IN                        *
*          ASTM D 245 (4).   IT IS SET-UP TO WORK                     *
*          WITH THE STATISTICAL ANALYSIS SYSTEM (SAS).                *
*                                                                     *
*      REQUIRED INPUT INCLUDES THE FOLLOWING:                         *
*          SIZE (DECKBOARD VS. STRINGER)                              *
*          CROSS-SECTIONAL DIMENSIONS                                 *
*          NUMERICAL DEFECT CODE (SEE APPENDIX A)                     *
*                                                                     *
*                                                                     *
***********************************************************************
```

```
DATA IN;
INPUT  SIZE $ 3 NUMBER 4-5 WIDTH 7-11
  THICK 13-17
  #2 POSF 2-3
  TYPEF 4-5 SIZEF 6-7 EXTENTF 8 XF 10-12 YF 14-15 ZF 17-18 POSA 20-21
  TYPEA 22-23 SIZEA 24-25 EXTENTA 26 XA 28-30 YA 32-33 ZA 35-36
  POSB 38-39 TYPEB 40-41 SIZEB 42-43 EXTENTB 44 XB 46-48 YB 50-51
  ZB 53-54 POSC 56-57 TYPEC 58-59 SIZEC 60-61 EXTENTC 62 XC 64-66
  YC 68-69 ZC 71-72;
GO TO RENAMEF;
RENAMEF:  TYPE1=TYPEF;  SIZE1=SIZEF;  X1=XF;  COUNT=1;
GO TO START;
RENAMEA:  TYPE1=TYPEA;  SIZE1=SIZEA;  X1=XA;  COUNT=2;
GO TO START;
RENAMEB:  TYPE1=TYPEB;  SIZE1=SIZEB;  X1=XB;  COUNT=3;
GO TO START;
RENAMEC:  TYPE1=TYPEC;  SIZE1=SIZEC;  X1=XC;  COUNT=4;
GO TO START;
START:  IF TYPE1= . THEN GO TO MISS;
IF TYPE1=10 THEN GO TO CLEAR;
IF TYPE1=51 OR TYPE1=44 THEN GO TO FIRST;
SZE=SIZE1/10;
SSZE=INT(SZE);
SZE1=SSZE+(SZE-SSZE)*10/8;
FIRST:  IF SIZE='D' THEN GO TO DECKBD;
IF TYPE1=11 OR TYPE1=12 OR TYPE1=13 OR TYPE1=22 THEN GO TO NFACE;
IF TYPE1=14 OR TYPE1=15 OR TYPE1=16 OR TYPE1=20 THEN GO TO CENLINE;
```

```
IF TYPE1=64 OR TYPE1=67 THEN GO TO CENLINE;
IF TYPE1=17 OR TYPE1=18 OR TYPE1=19 OR TYPE1=21 THEN GO TO EDGE;
IF TYPE1=63 OR TYPE1=66 THEN GO TO EDGE;
IF TYPE1=51 THEN GO TO SLOPE;
IF TYPE1=44 THEN GO TO SPLIT;
ELSE ESR=100;
GO TO LAST;
CLEAR:  ESR=100;
GO TO LAST;
NFACE: IF X1 GT 157 AND X1 LT 321 THEN GO TO NFACE2;
X=X1/10;
XX=INT(X);
XXX=XX+(X-XX)*10/8;
IF X1 LT 160 THEN GO TO NFACE1;
IF X1 GT 320 THEN GO TO NFACE3;
NFACE2: ESR=100*(1-(SZE1-(1/24))/(THICK+(3/8)));
IF ESR LT 45 THEN ESR=100*(1-(SZE1-(1/24))/THICK);
GO TO LAST;
NFACE1: ESR=100*(1-((XXX/32*SZE1+SZE1/2)-(1/24))/(THICK+(3/8)));
IF ESR LT 45 THEN ESR=100*(1-((XXX/32*SZE1+SZE1/2)-(1/24))/THICK);
GO TO LAST;
NFACE3: ESR=100*(1-((SZE1-(XXX-32)/32*SZE1)-(1/24))/(THICK+(3/8)));
IF ESR LT 45 THEN  ESR=100*(1-((SZE1-(XXX-32)/32*SZE1)-(1/24))/THICK);
GO TO LAST;
CENLINE:  ESR=100*(1-(SZE1-(1/24))/(WIDTH+(3/8)));
IF ESR LT 45 THEN ESR=100*(1-(SZE1-(1/24))/WIDTH);
GO TO LAST;
EDGE: IF X1 GT 157 AND X1 LT 321 THEN GO TO EDGE2;
X=X1/10;
XX=INT(X);
XXX=XX+(X-XX)*10/8;
IF X1 LT 160 THEN GO TO EDGE1;
IF X1 GT 320 THEN GO TO EDGE3;
EDGE2: ESR=100*(1-(SZE1-(1/24))/(WIDTH+(3/8)))**2;
IF ESR LT 45 THEN ESR=100*(1-(SZE1-(1/24))/WIDTH)**2;
GO TO LAST;
EDGE1: ESR=100*(1-((XXX/32*SZE1+SZE1/2)-(1/24))/(WIDTH+(3/8)))**2;
IF ESR LT 45 THEN ESR=100*(1-((XXX/32*SZE1+SZE1/2)-(1/24))/WIDTH)**2;
GO TO LAST;
EDGE3: ESR=100*(1-((SZE1-(XXX-32)/32*SZE1)-(1/24))/(WIDTH+(3/8)))**2;
IF ESR LT 45 THEN GO TO EDGE3S;
ELSE GO TO LAST;
EDGE3S:  ESR=100*(1-((SZE1-(XXX-32)/32*SZE1)-(1/24))/WIDTH)**2;
GO TO LAST;
DECKBD:  IF TYPE1 GE 14 AND TYPE1 LE 19 THEN GO TO ONEINCH;
IF TYPE1 GE 63 AND TYPE1 LE 67 THEN GO TO ONEINCH;
IF TYPE1=51 THEN GO TO SLOPE;
ELSE ESR = 100;
GO TO LAST;
ONEINCH:  ESR=100*(1-(SZE1-(1/24))/(WIDTH+(3/8)));
```

```
IF ESR LT 45 THEN ESR=100*(1-(SZE1-(1/24))/WIDTH);
GO TO LAST;
SLOPE:  IF SIZE1 LE 6 THEN ESR=40;
IF SIZE1=7 THEN ESR=46.5;
IF SIZE1=8 THEN ESR=53;
IF SIZE1=9 THEN ESR=57;
IF SIZE1=10 THEN ESR=61;
IF SIZE1=11 THEN ESR=65;
IF SIZE1=12 THEN ESR=69;
IF SIZE1=13 THEN ESR=71.5;
IF SIZE1=14 THEN ESR=74;
IF SIZE1=15 THEN ESR=76;
IF SIZE1=16 THEN ESR=80;
IF SIZE1=17 THEN ESR=82.5;
IF SIZE1=18 THEN ESR=85;
IF SIZE1=19 THEN ESR=92.5;
IF SIZE1 GE 20 THEN ESR=100;
GO TO LAST;
SPLIT:  ESR = 100*(1-SIZE1/(3*WIDTH));
IF ESR LT 50 THEN ESR=50;
LAST:  ESR=ESR+0.5;
ESR=INT(ESR);
GO TO PATH;
MISS:  ESR = . ;
PATH:  IF COUNT=1 THEN GO TO C1;
IF COUNT = 2 THEN GO TO C2;
IF COUNT = 3 THEN GO TO C3;
IF COUNT = 4 THEN GO TO C4;
C1:  ESRF = ESR;
GO TO RENAMEA;
C2:  ESRA = ESR;
GO TO RENAMEB;
C3:  ESRB = ESR;
GO TO RENAMEC;
C4:  ESRC = ESR;
GO TO ESTIMATE;
ESTIMATE:  ESR = ESRF; CASE=1;
IF ESR GT ESRA AND ESRA NE . THEN DO;
ESR=ESRA; CASE=2;
END;
IF ESR GT ESRB AND ESRB NE . THEN DO;
ESR=ESRB; CASE=3;
END;
IF ESR GT ESRC AND ESRC NE . THEN DO;
ESR=ESRC;  CASE=4;
END;
FINAL: CONTINUE;
CARDS;
DATA _NULL_;
SET IN;
```

```
FILE PUNCH NOTITLE;
PUT  SIZE $1. @4 NUMBER Z2. @7 WIDTH 5.3
  @13 THICK 5.3
  #2 @2 ESR 3. @6 CASE 1. @8 ESRF 3. @ 12 ESRA 3. @16 ESRB 3.
  @20 ESRC 3. #3 @2 POSF Z2. @4 TYPEF Z2. @6 SIZEF Z2. @8 EXTENTF 1.
  @10 XF Z3. @14 YF Z2. @17 ZF Z2. @20 POSA Z2. @22 TYPEA Z2.
  @ 24 SIZEA Z2.
  @26 EXTENTA 1. @28 XA Z3. @32 YA Z2. @35 ZA Z2. @38 POSB Z2.
  @40 TYPEB Z2. @42 SIZEB Z2. @44 EXTENTB 1. @46 XB Z3. @50 YB Z2.
  @53 ZB Z2. @56 POSC Z2. @58 TYPEC Z2. @60 SIZEC Z2. @62 EXTENTC 1.
  @64 XC Z3. @68 YC Z2. @71 ZC Z2.;
/*
//
```

APPENDIX E

ASR vs. ESR by Grade for Data from Rate of Loading Study and Depth Effect Study

TABLE E-1 - COMPARISON OF ASR AND ESR BY INDIVIDUAL GRADES FOR DATA FROM RATE OF LOADING STUDY AND DEPTH EFFECT STUDY

SPECIES	SIZE	GRADE	ASR (%)	ESR (%)	RATIO (ASR/ESR)	N
OAK	3.5" STRINGERS	2&BTR	98	85	1.15	27
		3	91	73	1.25	32
		4	96	61	1.57	9
		CULL	76	45	1.69	12
	6" DECKBOARDS	2&BTR	93	91	1.02	46
		3	84	86	0.98	26
		4	87	64	1.36	6
		CULL	85	72	1.18	2
POPLAR	3.5" STRINGERS	2&BTR	107	83	1.29	43
		3	94	61	1.54	27
		4	81	38	2.13	5
		CULL	83	31	2.68	5
	6" DECKBOARDS	2&BTR	94	94	1.00	38
		3	92	81	1.14	31
		4	84	46	1.83	7
		CULL	82	69	1.19	4
ASH	3.5" STRINGERS	2&BTR	81	70	1.16	18
		3	86	64	1.34	9
		4	74	43	1.72	9
		CULL	70	37	1.89	15
	2.5" STRINGERS	2&BTR	74	69	1.07	16
		3	86	62	1.39	10
		4	88	68	1.29	2
		CULL	75	35	2.14	18
COTTONWOOD	3.5" STRINGERS	2&BTR	84	78	1.08	30
		3	79	63	1.25	14
		4	--	--	----	0
		CULL	73	22	3.32	2
	2.5" STRINGERS	2&BTR	84	78	1.08	31
		3	80	61	1.31	14
		4	77	37	2.08	3
		CULL	91	26	3.50	3

APPENDIX F

Evaluation of Pallet Shook Design Values

TABLE F-1 - EVALUATION OF PALLET SHOOK DESIGN VALUES

DATA SOURCE	SPECIES	SIZE	GRADE	DESIGN MOR [1] (PSI)	ACTUAL DATA 95 % C.I. [2] (PSI)	N	DESIGN MOE (KSI)	ACTUAL DATA 95 % C.I. [2] (KSI)	N
YELLOW POPLAR SHOOK STUDY [3,9]	POPLAR	DECKBOARDS	2&BTR	5400	6740-7190	227	1342	1407-1519	225
			3&BTR	4800	6820-7190	349	1288	1376-1462	347
			4&BTR	4540	6850-7180	423	1274	1355-1431	421
			ALL SHOOK	4270	6850-7160	483	1248	1352-1422	480
			3	3800	6740-7400	122	1208	1275-1400	122
			4	3130	6680-7470	74	1141	1200-1343	74
			CULL	1330	6450-7400	60	1074	1257-1427	59
		STRINGERS	2&BTR	4530	5470-5740	198	1342	1304-1444	196
			3&BTR	3980	5310-5540	333	1288	1280-1386	327
			4&BTR	3690	5200-5410	402	1274	1233-1327	396
			ALL SHOOK	3470	5070-5290	448	1248	1202-1290	442
			3	3130	4980-5360	135	1208	1191-1353	131
			4	2130	4430-5000	69	1141	959-1089	69
			CULL	730	3710-4520	46	1074	850-1057	46
EASTERN OAK SHOOK STUDY [3,9]	OAK	DECKBOARDS	2&BTR	7460	7280-7570	369	1392	1361-1433	365
			3&BTR	6630	7010-7210	794	1336	1320-1366	785
			4&BTR	6260	6860-7030	1057	1322	1291-1331	1048
			ALL SHOOK	5900	6550-6720	1430	1295	1242-1278	1414
			3	4410	6710-6970	425	1253	1267-1325	420
			4	4330	6260-6620	263	1183	1175-1255	263
			CULL	1840	5590-5940	373	1114	1081-1149	366
		STRINGERS	2&BTR	6270	7710-8050	340	1392	1361-1433	338
			3&BTR	5490	7290-7540	686	1336	1312-1360	681
			4&BTR	5110	6960-7170	1017	1322	1265-1305	1006
			ALL SHOOK	4800	6550-6750	1354	1295	1212-1248	1340
			3	4330	6790-7120	346	1253	1240-1300	343
			4	2940	6160-6500	331	1183	1146-1210	325
			CULL	1010	5210-5600	337	1114	1031-1097	334

[1] UNADJUSTED FOR DURATION OF LOAD

[2] X +/- t (s.d.)/$\sqrt{n}$

[3] ACTUAL DATA MOR AND MOE ADJUSTED TO ASTM LOADING RATE

[9] ACTUAL DATA MOE CORRECTED FOR SHEAR ONLY IN STRINGERS

TABLE F-1 (CONTINUED) - EVALUATION OF PALLET SHOOK DESIGN VALUES

DATA SOURCE	SPECIES	SIZE	GRADE	DESIGN MOR [1] (PSI)	ACTUAL DATA 95 % C.I. [2] (PSI)	N	DESIGN MOE (KSI)	ACTUAL DATA 95 % C.I. [2] (KSI)	N
RATE OF LOADING STUDY [4,9]	OAK	DECKBOARDS	2&BTR	7460	7310-8050	46	1392	1541-1716	46
			3&BTR	6630	7090-7690	72	1336	1490-1634	72
			4&BTR	6260	7090-7670	78	1322	1484-1628	78
			ALL SHOOK	5900	7080-7650	80	1295	1483-1623	80
		STRINGERS	2&BTR	6270	6950-7980	27	1392	1184-1345	27
			3&BTR	5490	6810-7580	59	1336	1198-1314	59
			4&BTR	5110	6870-7560	68	1322	1194-1298	68
			ALL SHOOK	4800	6650-7360	80	1295	1169-1271	80
	POPLAR	DECKBOARDS	2&BTR	5400	5300-5850	38	1342	1305-1509	38
			3&BTR	4800	5270-5810	69	1288	1291-1453	69
			4&BTR	4540	5230-5750	76	1274	1276-1434	76
			ALL SHOOK	4270	5200-5720	80	1248	1274-1426	80
		STRINGERS	2&BTR	4530	5620-6260	43	1342	1220-1364	43
			3&BTR	3980	5370-5940	70	1288	1189-1307	70
			4&BTR	3690	5290-5860	75	1274	1174-1290	75
			ALL SHOOK	3470	5240-5800	80	1248	1169-1281	80
DEPTH EFFECT STUDY [3,5,9]	ASH	STRINGERS	2&BTR	7220	5570-7500	18	1549	1178-1485	18
			3&BTR	6330	5960-7430	28	1487	1240-1466	28
			4&BTR	5880	5900-7140	37	1470	1239-1433	37
			ALL SHOOK	5530	5700-6810	52	1441	1221-1387	52
	COTTONWOOD	STRINGERS	2&BTR	4010	4870-5510	31	1112	925-1061	31
			3&BTR	3510	4850-5340	50	1067	950-1058	50
			4&BTR	3260	4850-5340	50	1056	950-1058	50
			ALL SHOOK	3070	4830-5310	52	1034	955-1059	52

[1] UNADJUSTED FOR DURATION OF LOAD

[2] X +/- t (s.d.)/$\sqrt{n}$

[3] ACTUAL DATA MOR AND MOE ADJUSTED TO ASTM LOADING RATE

[4] ACTUAL DATA FROM COMBINED LOADING RATES AFTER ADJUSTING TO ASTM RATE

[5] 3.5 INCH STRINGERS ONLY

[9] ACTUAL DATA MOE CORRECTED FOR SHEAR ONLY IN STRINGERS

TABLE F-1 (CONTINUED) - EVALUATION OF PALLET SHOOK DESIGN VALUES

DATA SOURCE	SPECIES	SIZE	GRADE	DESIGN MOR [1] (PSI)	ACTUAL DATA 95 % C.I. [2] (PSI)	N	DESIGN MOE (KSI)	ACTUAL DATA 95 % C.I. [2] (KSI)	N
WASHINGTON STATE UNIVERSITY [6,7,8]	SOUTHERN PINE	DECKBOARDS	2&BTR	8570	7120-8820	37	1653	1205-1482	37
			3&BTR	7620	6670-7920	60	1587	1192-1400	60
			4&BTR	7200	6130-7350	83	1570	1143-1319	83
			ALL SHOOK	6780	6050-7220	90	1537	1141-1321	90
	DOUGLAS-FIR	DECKBOARDS	2&BTR	8620	7200-8670	40	1653	1407-1620	40
			3&BTR	7670	6920-8400	56	1587	1385-1573	56
			4&BTR	7240	6120-7390	78	1570	1312-1470	78
			ALL SHOOK	6820	5840-7030	90	1537	1264-1416	90
	HEMLOCK	DECKBOARDS	2&BTR	7450	5980-8380	14	1461	1210-1405	14
			3&BTR	6620	5820-7860	19	1403	1171-1373	19
			4&BTR	6250	5120-7000	27	1389	1081-1285	27
			ALL SHOOK	5880	5420-6640	30	1359	1119-1255	30
	MAPLE	DECKBOARDS	2&BTR	10390	9490-11220	43	1719	1537-1729	43
			3&BTR	9230	9240-10680	60	1650	1504-1622	60
			4&BTR	8720	8870-10110	80	1633	1451-1591	80
			ALL SHOOK	8210	8410-9670	90	1599	1393-1539	90
	ASPEN	DECKBOARDS	2&BTR	5880	7160-8060	50	1043	1335-1453	50
			3&BTR	5230	6950-7740	72	1001	1312-1408	72
			4&BTR	4940	6880-7640	82	991	1313-1407	82
			ALL SHOOK	4650	6670-7430	90	970	1285-1381	90
	OAK	DECKBOARDS	2&BTR	9330	11530-13403	43	1587	1669-1907	43
			3&BTR	8300	11080-12550	64	1523	1606-1792	64
			4&BTR	7840	10330-11770	82	1507	1537-1705	82
			ALL SHOOK	7380	9780-11290	90	1476	1489-1657	90

[1] UNADJUSTED FOR DURATION OF LOAD

[2] X +/- t (s.d.)/$\sqrt{n}$

[6] DESIGN MOR HAS BEEN ADJUSTED TO 19% M.C. (25% INCREASE)

[7] DESIGN MOE HAS BEEN ADJUSTED TO 19% M.C. (14% INCREASE)

[8] ACTUAL DATA FROM TESTS AT AIR-DRY M.C.%

TABLE F-1 (CONTINUED) - EVALUATION OF PALLET SHOOK DESIGN VALUES

DATA SOURCE	SPECIES	SIZE	GRADE	DESIGN MOR [1] (PSI)	ACTUAL DATA 95 % C.I. [2] (PSI)	N	DESIGN MOE (KSI)	ACTUAL DATA 95 % C.I. [2] (KSI)	N
OREGON STATE UNIVERSITY [9]	RED ALDER	DECKBOARDS	ALL SHOOK	4690	5120-5610	40	1191	1282-1394	40
		STRINGERS	ALL SHOOK	3810	3890-4840	20	1191	994-1126	20
	BIGLEAF MAPLE	DECKBOARDS	ALL SHOOK	4300	5230-6190	22	1118	1116-1294	22

[1] UNADJUSTED FOR DURATION OF LOAD

[2] X +/- t (s.d.)/$\sqrt{n}$

[9] ACTUAL DATA MOE CORRECTED FOR SHEAR ONLY IN STRINGERS

APPENDIX G

Small Clear Value Calculations for PDS Species Classes

SMALL CLEAR VALUE CALCULATIONS FOR PDS SPECIES CLASSES

Following is a listing of the species included in each PDS Species Class. The average small, clear MOR and MOE and the standing timber volume estimate for each species are given. These values are taken from ASTM D 2555 unless noted otherwise. The volume-weighted average MOR and MOE are given, as are the average MOR and MOE values determined according to limitations specified by ASTM D 2555 for Method A and Method B species. Finally, the clear wood values used by PDS for the Species Class are presented.

SPECIES CLASS 1

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
HICKORY (AVE. OF 8 SPECIES)	10528.	1469.	11076.
YELLOW BIRCH	8260.	1504.	4854.
SWEET BIRCH	9390.	1650.	688.
SUGAR MAPLE	9420.	1546.	8566.
BLACK MAPLE	7920.	1328.	1801.
RED MAPLE	7690.	1386.	6037.
GREEN ASH	9460.	1400.	1282. (1)
WHITE ASH	9500.	1436.	575. (1)
BEECH	8570.	1381.	6531.
ROCK ELM	9490.	1194.	4.
SLIPPERY ELM	8010.	1232.	161.
BLACK LOCUST	13800. (2)	1850. (2)	931. (1)
BLACK CHERRY	8000. (2)	1310. (2)	2853. (1)
OAK (AVE. FROM CLASS 21)	8228.	1268.	39736.
DOGWOOD	8800. (3)	1180. (3)	
PERSIMMON	10000. (3)	1370. (3)	
TANOAK			
EUCALYPTUS			

VOLUME WEIGHTED AVERAGE -	8720	1368
METHOD B LIMITATION (4) -	8459	1298
PDS CLEAR WOOD VALUE (5) -	8450	1430

(1) SOURCE: FOREST PRODUCTS LAB GENERAL TECHNICAL REPORT FPL 20 (8)

(2) SOURCE: WOOD HANDBOOK (47)

(3) SOURCE: USDA TECHNICAL BULLETIN NO. 479 (31)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 2

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
BIGLEAF MAPLE	7390.	1095.	----
OREGON ASH	8260. (2)	1504.	----
AVERAGE -	7495	1113	
METHOD B LIMITATION (4) -	8129	1205	
PDS CLEAR WOOD VALUE (5) -	7500	1220	

(2) SOURCE: WOOD HANDBOOK (47)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 3

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
SWEETGUM	7110.	1201.	10024.
TUPELO: BLACK	7040.	1031.	8653. (1)
WATER	7300.	1052.	1864.
PAPER BIRCH	6380.	1170.	3773. (1)
MAGNOLIA: SOUTHERN MAGNOLIA	6780.	1106.	234. (1)
CUCUMBERTREE	7420.	1565.	

	MOR	MOE
VOLUME WEIGHTED AVERAGE -	6984	1124
METHOD B LIMITATION (4) -	7018	1134
PDS CLEAR WOOD VALUE (5) -	7000	1230

(1) SOURCE: FOREST PRODUCTS LAB GENERAL TECHNICAL REPORT FPL 20 (8)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI (ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 4

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
OREGON WHITE OAK	7700. (3)	790. (3)	----
CALIFORNIA BLACK OAK	6200. (3)	740. (3)	----
CASCARA	6300. (3)	630. (3)	----
CHINQUAPIN	7000. (3)	1020. (3)	----
MADRONE	7600. (3)	880. (3)	----
MYRTLE			

AVERAGE -	6960	812
METHOD B LIMITATION (4) -	6820	693
PDS CLEAR WOOD VALUE (5) -	6800	760

(3) SOURCE: USDA TECHNICAL BULLETIN NO. 479 (31)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 5

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
HACKBERRY	6480.	954.	560.
SYCAMORE	6470.	1065.	643.
SILVER MAPLE	5820.	943.	5507.
SASSAFRAS	6000. (2)	910. (2)	192.
PUMPKIN ASH	7600. (3)	1040. (3)	
BLACK ASH	6000.	1043.	
STRIPED MAPLE	7200. (3)	1080. (3)	
BOX ELDER			238.
SUGARBERRY	6600. (3)	810. (3)	

VOLUME WEIGHTED AVERAGE -	5939	954
METHOD B LIMITATION (4) -	6402	891
PDS CLEAR WOOD VALUE (5) -	5950	980

(2) SOURCE: WOOD HANDBOOK (47)

(3) SOURCE: USDA TECHNICAL BULLETIN NO. 479 (31)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 6

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
RED ALDER	6540.	1167.	5389
PDS CLEAR WOOD VALUE (5) -	6550	1280	

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 7

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
YELLOW POPLAR	5950.	1222.	6753.
EASTERN COTTONWOOD	5260.	1013.	1020. (1)
ASPEN: BIGTOOTH	5400.	1120.	2970.
QUAKING	5130.	860.	11093.
BASSWOOD, AMERICAN	4960.	1038.	2771.
CATALPA	5200. (3)	840. (3)	
BUCKEYE	4800. (3)	980. (3)	
BUTTERNUT	5400. (2)	970. (2)	

	MOR	MOE
VOLUME WEIGHTED AVERAGE -	5374	1017
METHOD B LIMITATION (4) -	5456	924
PDS CLEAR WOOD VALUE (5) -	5350	1020

(1) SOURCE: FOREST PRODUCTS LAB GENERAL TECHNICAL REPORT FPL 20 (8)

(2) SOURCE: WOOD HANDBOOK (47)

(3) SOURCE: USDA TECHNICAL BULLETIN NO. 479 (31)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 8

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
COTTONWOOD: BLACK	4900. (2)	1080. (2)	394.
BALSAM POPLAR	3900. (2)	750. (2)	637. (1)

VOLUME WEIGHTED AVERAGE -	4282	876
METHOD B LIMITATION (4) -	4290	825
PDS CLEAR WOOD VALUE (5) -	4300	910

(1) SOURCE: FOREST PRODUCTS LAB GENERAL TECHNICAL REPORT FPL 20 (8)

(2) SOURCE: WOOD HANDBOOK (47)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI (ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 11

SPECIES	MOR (psi)	V.I. (1)	MOE (ksi)	V.I. (1)	STANDING TIMBER VOLUME (MMCF)
DOUGLAS-FIR: COAST	7665.	1.05	1560.	1.05	58878.
INTERIOR WEST	7713.	1.03	1513.	1.04	26602.
INTERIOR NORTH	7438.	1.04	1409.	1.04	20408.
INTERIOR SOUTH	6784.	1.01	1162.	1.00	3987.
WESTERN LARCH	7652.	1.04	1458.	1.02	6914.
SOUTHERN PINE: LOBLOLLY	7300.	1.08	1402.	1.08	27610.
LONGLEAF	8538.	1.07	1586.	1.07	5534.
SHORTLEAF	7435.	1.04	1388.	1.04	16328.
SLASH	8692.	1.09	1532.	1.08	5017.

VOLUME WEIGHTED AVERAGE -	7602	1479
METHOD A LIMITATION (4) -	7462	1278
PDS CLEAR WOOD VALUE (5) -	7450	1250

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(1) VARIABILITY INDEX

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ADJUSTED DOWNWARD BASED ON DATA AND EXPERIENCE WITH SHOOK OF THIS SPECIES CLASS

SPECIES CLASS 12

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
HEMLOCK: WESTERN	6600. (2)	1310. (2)	25596.
MOUNTAIN	6270. (2)	1038. (2)	2930.
FIR: CALIFORNIA RED	5800. (2)	1170. (2)	6355.
GRAND	5800. (2)	1250. (2)	8317.
NOBLE	6200. (2)	1380. (2)	1999.
PACIFIC SILVER	6400. (2)	1420. (2)	9397.
WHITE	5900.	1160.	13199.

VOLUME WEIGHTED AVERAGE -	6237	1266
METHOD B LIMITATION (4) -	6380	1142
PDS CLEAR WOOD VALUE (5) -	6250	1250

(2) SOURCE: WOOD HANDBOOK (47)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 13

SPECIES	MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
SPRUCE: WHITE	4995.	1141.	2518.
BLACK	6118.	1382.	1557.
RED	6003.	1328.	4495.
ENGELMANN	4705.	1029.	16437.
SITKA	5660.	1230.	2018.
PINE: SUGAR	4893.	1032.	5295.
WESTERN WHITE	4688.	1193.	4598.
LODGEPOLE	5490.	1076.	23040.
PONDEROSA	5130.	997.	43056.
MONTEREY	6625.	1420.	
JACK	6030.	1068.	1417.
LODGEPOLE	5650.	1274.	23040.
EASTERN WHITE	4930.	994.	6259.
SOUTHERN PINE: PITCH	6830.	1200.	999.
POND	7450.	1281.	1260.
SPRUCE	6004.	1002.	405.
VIRGINIA	7330.	1218.	2173.
FIR: SUBALPINE	4900. (2)	1050. (2)	8463.
BALSAM	5517.	1251.	6761.
WESTERN REDCEDAR	5184.	939.	6358.
BALDCYPRESS	6640.	1184.	3961.
EASTERN HEMLOCK	6420.	1073.	4813.

	MOR	MOE
VOLUME WEIGHTED AVERAGE -	5362	1096
METHOD B LIMITATION (4) -	5157	1033
PDS CLEAR WOOD VALUE (5) -	5150	1130

(2) SOURCE: WOOD HANDBOOK (47)

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

SPECIES CLASS 14

SPECIES		MOR (psi)	MOE (ksi)	STANDING TIMBER VOLUME (MMCF)
CEDAR:	ALASKA	6450.	1135.	200.
	INCENSE	6220.	840.	2916.
	PORT ORFORD	6598.	1297.	250.
	ATLANTIC WHITE	4740.	752.	104.
	NORTHERN WHITE	4250.	643.	3165.
	EASTERN RED	7030.	649.	249.

	MOR	MOE
VOLUME WEIGHTED AVERAGE -	5342	766
METHOD B LIMITATION (4) -	4675	707
PDS CLEAR WOOD VALUE (5) -	4650	780

(4) SEE SECTIONS 6.2.2 AND 6.4.2 OF THIS THESIS

(5) MOR VALUE ROUNDED TO NEAREST 50 PSI

MOE VALUE ROUNDED TO NEAREST 10 KSI
(ADJUSTED FOR SHEAR - SEE SECTION 6.4.2)

APPENDIX H

Shook Data from:
Rate of Loading Study
Depth Effect Study
Yellow-poplar Shook Study
Eastern Oak Shook Study

TABLE H-1 - RATE OF LOADING STUDY DATA

SPECIES	SIZE	LOADING RATE	GRADE	N	MOR (psi)	C.V. (%)	MOE (ksi) [1]	C.V. (%)	S.G. [2,3]	M.C. (%) [3]	AVERAGE GRADE
OAK	DECKBOARD	FAST	2&BTR	26	8090	17.1	1692	20.0	----	--	**
			3	11	7170	17.0	1526	18.5	----	--	**
			4	2	8520	25.2	1890	22.2	----	--	**
			CULL	1	8150	----	1408	----	----	--	**
			ALL SHOOK	40	7860	17.6	1649	19.9	0.62	81	1.45
		SLOW	2&BTR	20	7920	15.3	1645	16.0	----	--	**
			3	15	7070	17.3	1434	21.7	----	--	**
			4	4	6840	21.4	1330	36.9	----	--	**
			CULL	1	6330	----	1478	----	----	--	**
			ALL SHOOK	40	7450	17.3	1530	20.8	0.65	83	1.65
	STRINGER	FAST	2&BTR	14	8070	16.8	1355	18.6	----	--	**
			3	13	7830	19.7	1270	16.2	----	--	**
			4	6	8320	10.9	1264	6.6	----	--	**
			CULL	7	5510	43.4	1089	19.4	----	--	**
			ALL SHOOK	40	7580	23.9	1267	17.7	0.68	73	2.15
		SLOW	2&BTR	13	7450	18.7	1233	12.9	----	--	**
			3	19	6770	25.9	1272	21.5	----	--	**
			4	3	6690	7.1	1139	16.3	----	--	**
			CULL	5	6760	23.2	1115	30.0	----	--	**
			ALL SHOOK	40	6990	22.2	1230	19.7	0.65	73	2.00

** NOT APPLICABLE

[1] STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

[2] O.D. WEIGHT/O.D.VOLUME

[3] BASED ON 8 SAMPLES

TABLE H-1 - RATE OF LOADING STUDY DATA
(continued)

SPECIES	SIZE	LOADING RATE	GRADE	N	MOR (psi)	C.V. (%)	MOE (ksi) [1]	C.V. (%)	S.G. [2,3]	M.C. (%) [3]	AVERAGE GRADE
POPLAR	DECKBOARD	FAST	2&BTR	16	6020	14.1	1489	22.0	----	--	**
			3	21	5960	29.8	1373	30.2	----	--	**
			4	2	4850	0.0	1064	7.2	----	--	**
			CULL	1	4370	----	1197	----	----	--	**
			ALL SHOOK	40	5890	24.1	1400	26.7	0.51	88	1.70
		SLOW	2&BTR	22	5580	16.0	1396	22.8	----	--	**
			3	10	5430	16.1	1365	23.4	----	--	**
			4	5	5210	30.6	1256	38.6	----	--	**
			CULL	3	5120	23.0	1304	24.4	----	--	**
			ALL SHOOK	40	5460	18.0	1364	24.3	0.59	101	1.73
	STRINGER	FAST	2&BTR	21	6370	16.5	1333	17.7	----	--	**
			3	15	5860	22.1	1279	19.5	----	--	**
			4	2	5960	18.0	1206	25.1	----	--	**
			CULL	2	3700	6.9	931	9.8	----	--	**
			ALL SHOOK	40	6020	20.7	1282	19.3	0.46	68	1.63
		SLOW	2&BTR	22	5580	16.0	1396	22.8	----	--	**
			3	12	4940	30.3	1125	25.7	----	--	**
			4	3	3790	24.4	917	13.0	----	--	**
			CULL	3	5360	21.8	1267	5.3	----	--	**
			ALL SHOOK	40	5460	25.0	1221	22.0	0.50	73	1.68

** NOT APPLICABLE

[1] STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

[2] O.D. WEIGHT/O.D.VOLUME

[3] BASED ON 8 SAMPLES

TABLE H-2 - DEPTH EFFECT STUDY DATA

SPECIES	SIZE	GRADE	N	MOR (psi)	C.V. (%)	MOE (ksi) [1]	C.V. (%)	S.G. [2,3]	M.C. (%) [3]	AVERAGE GRADE
ASH	3.5" STRINGER	2&BTR	18	7060	29.8	1394	23.3	----	--	**
		3	10	7540	26.8	1456	18.9	----	--	**
		4	9	6450	28.0	1344	23.6	----	--	**
		CULL	15	6060	39.9	1283	24.9	----	--	**
		ALL SHOOK	52	6760	31.8	1365	22.8	0.64	44	2.40
	2.5" STRINGER	2&BTR	18	7100	37.0	1313	31.9	----	--	**
		3	13	8130	25.9	1466	25.9	----	--	**
		4	3	7200	44.5	1300	36.4	----	--	**
		CULL	18	7080	31.2	1309	24.7	----	--	**
		ALL SHOOK	52	7350	32.1	1349	27.8	0.67	42	2.40
COTTONWOOD	3.5" STRINGER	2&BTR	31	5610	17.0	1040	18.9	----	--	**
		3	19	5330	16.9	1071	19.2	----	--	**
		4	0	----	----	----	----	----	--	**
		CULL	2	4860	19.2	1115	9.7	----	--	**
		ALL SHOOK	52	5480	17.0	1054	18.5	0.42	104	1.48
	2.5" STRINGER	2&BTR	32	5900	16.9	1019	21.2	----	--	**
		3	14	5610	19.6	951	21.3	----	--	**
		4	3	5390	15.1	938	22.7	----	--	**
		CULL	3	6410	11.1	1073	18.8	----	--	**
		ALL SHOOK	52	5820	17.2	1000	20.9	0.41	124	1.56

** NOT APPLICABLE

[1] STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

[2] O.D. WEIGHT/O.D.VOLUME

[3] BASED ON 11 SAMPLES

TABLE H-3 - YELLOW-POPLAR SHOOK DATA

SPECIES	SIZE	GRADE	N [1]	MOR (psi)	C.V. (%)	MOE (ksi) [2]	C.V. (%)	S.G. [3]	M.C. (%)	AVERAGE GRADE
POPLAR	DECKBOARD	2&BTR	227	7520	24.8	1532	29.5	0.48	61	**
		3	122	7640	26.3	1400	26.4	0.48	57	**
		4	74	7640	24.0	1331	24.3	0.48	53	**
		CULL	60	7480	26.8	1405	24.3	0.50	60	**
		ALL SHOOK	483	7570	25.2	1452	28.1	0.48	59	1.93
	STRINGER	2&BTR	198	6050	17.6	1439	36.1	0.48	61	**
		3	135	5580	21.7	1332	36.9	0.48	61	**
		4	69	5090	25.2	1072	26.6	0.48	64	**
		CULL	46	4440	33.2	998	36.5	0.50	60	**
		ALL SHOOK	448	5600	23.1	1304	37.9	0.48	61	1.92

** NOT APPLICABLE

[1] SAMPLE SIZE MAY VARY SLIGHTLY BETWEEN PROPERTIES

[2] STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

[3] O.D. WEIGHT/O.D. VOLUME

TABLE H-4 - EASTERN OAK SHOOK DATA

SPECIES	SIZE	GRADE	N [1]	MOR (psi)	C.V. (%)	MOE (ksi) [2]	C.V. (%)	S.G. [3]	M.C. (%)	AVERAGE GRADE
OAK	STRINGER	2&BTR	340	8510	20.1	1346	25.0	0.59	61	**
		3	346	7510	22.8	1219	22.2	0.58	62	**
		4	331	6830	25.1	1130	25.2	0.59	61	**
		CULL	337	5840	33.5	1021	29.2	0.59	59	**
		ALL SHOOK	1354	7180	28.2	1180	27.2	0.59	61	2.49
	4" DECKBOARD	2&BTR	238	7950	27.2	1441	27.1	0.58	59	**
		3	232	7320	20.3	1321	24.7	0.58	60	**
		4	160	6920	22.7	1239	26.8	0.58	61	**
		CULL	239	6180	29.4	1146	31.7	0.58	59	**
		ALL SHOOK	869	7100	24.7	1291	28.9	0.58	59	2.47
	6" DECKBOARD	2&BTR	131	8160	17.0	1500	21.2	0.57	62	**
		3	193	7470	19.7	1400	22.0	0.58	62	**
		4	103	7010	24.7	1325	27.3	0.58	65	**
		CULL	134	6310	29.0	1205	26.1	0.58	63	**
		ALL SHOOK	561	7270	23.7	1364	24.8	0.58	63	2.42

** NOT APPLICABLE

[1] SAMPLE SIZE MAY VARY SLIGHTLY BETWEEN PROPERTIES

[2] STRINGER MOE CORRECTED FOR SHEAR ASSUMING E/G = 16

[3] O.D. WEIGHT/O.D. VOLUME

APPENDIX I

Grading Specifications for Pallet Shook

GRADING SPECIFICATIONS PROPOSED BY SARDO AND WALLIN

Grading criteria employed for deckboards

Defect	Description	Grades of Parts: 2 & Better	3	4
Size of Knot	Maximum dimension across width of the board	1/4 of board width	1/3 of board width	1/2 of board width
Location of Knots	Knots in the edges and end 3" of the boards	1/2" diameter	1/4 of board width	1/3 of board width
Clusters of Knots	Knots over 1/2" in diameter spaced 3" or less apart are measured as 1 defect	1/4 of board width	1/3 of board width	1/2 of board width
Type of Knots	Knot holes, unsound knots, loose knots, and holes	1/8 of board width	1/6 of board width	1/4 of board width
Cross Grain	Slope of general cross grain	1" in 10"	1" in 8"	1" in 6"
	Maximum dimension of local cross grain	1/4 of bd. width	1/3 of bd. width	1/2 of bd. width
Split, Check, and Shake	Maximum length singly or in combination Defects 3" or less are ignored	1/4 of board length	1/2 of board length	3/4 of board length
Wane	Maximum portion of the cross section affected at point of deepest penetration	16 units 1/16 of cross section	32 units 1/8 of cross section	48 units 3/16 of cross section
Decay	Cross section deepest penetration	None allowed	32 units	64 units
Pith	In face of board	None	Full length	Full length
	Boxed	None	1/3 length	Full length
Mismanufacture	Maximum 10" length; and maximum cross section	16 units 1/16 of cross section	32 units 1/8 of cross section	128 units 1/2 of cross section

EXCERPTION FROM (42). USED WITH PERMISSION.

GRADING SPECIFICATIONS PROPOSED BY SARDO AND WALLIN (CONTINUED)

Grading criteria employed for stringers

Defect	Description	Grades of Parts 2 & Better	3	4
Size of Knot	Maximum portion of cross section affected	1/4 of cross section	1/3 of cross section	1/2 of cross section
Location of Knots	Over notch or in end 6" of the stringer	1/2" max. diameter	1/4 of cross section	1/3 of cross section
Clusters of Knots	Knots over 1/2" in diameter spaced 3" or less apart are measured as 1 defect	None	1/3 of cross section	1/2 of cross section
Type of Knots	Knot holes, unsound or loose knots, and holes	1/8 of cross section	1/6 of cross section	1/4 of cross section
Cross Grain	Slope of general cross grain	1" in 10"	1" in 8"	1" in 6"
	Max. dimension of local cross grain	1/4 cross section	1/3 cross section	1/2 cross section
Splits, Check, and Shake	Max. length singly or in combination Defects 3" or less are ignored	1/4 of length of part	1/2 of length of part	3/4 of length of part
Wane	Max. portion of cross section	16 units	32 units	48 units
	Portion of nail face width	3/16 of of face	1/4 of of face	5/16 or of face
Decay	Maximum portion of cross section	None	1/8 of section	1/4 of section
Pith	Length in face	None	Full length	Full length
	Length boxed	None	1/3 length	Full length
Mismanufacture	Maximum portion of cross section, and maximum of 10" long	16 units	32 units	48 units

EXCERPTION FROM (42). USED WITH PERMISSION.

GRADING SPECIFICATIONS PROPOSED BY WALLIN AND FROST

Hardwood deckboard grading restrictions
(Green material — std. dim.: 3/4-in. thickness, 3-5/8, 5-5/8, 7-5/8 in. wide)

	Grade 1	Grade 2	Grade 3	Grade 4
KNOTS & HOLES:				
Size:				
Ends and Edges:	1/2 in.	1/8 actual width	1/4 actual width	3/8 actual width
Other	1/2 in.	1/4 actual width	3/8 actual width	1/2 actual width
Quantity:	No limit	No restriction	No restriction	No restriction
Spacing:	3 in. minimum	3 in. minimum	3 in. minimum	3 in. minimum
SLOPE OF GRAIN:	1 in 20 max.	1 in 15 max.	1 in 10 max.	1 in 6 max.
DISTORTED GRAIN:	None	1/8 actual width	1/4 actual width	3/8 actual width
CHECK, SHAKE, SPLIT:				
Check:	2 in. long, any number	4 in. long, any number	No restriction	No restriction
Shake & Split:	None	None	Length=1/2 width	Length=full width
PITH:	None	None	No restriction	No restriction
WANE:	1/2 in. on width 1/2 thickness	1/6 width, 1/2 thickness, none in nail areas	1/4 width No full thickness, none in nail areas	1/2 width Not full thickness, none in nail areas
DECAY:	None	None	Max. 1/4 of cross section	Max. 3/8 of cross section
STAIN:	No restriction	No restriction	No restriction	No restriction
WARP:				
Cup:	1/32 in. in 4-in. face 1/16 in. in 6-in. face	1/16 in. in 4-in. face 1/8 in. in 6-in. face	No restriction	No restriction
Bow & Crook:	1/4 in.	1/4 in.	1/2 in.	3/4 in.
MISMANUFACTURE:	None	None	Equal to knot defect	Equal to knot defect
COMBINED DEFECT:	Reduction in strength equivalent to that caused by a knot defect.			

Hardwood pallet stringer grading restrictions
(Green material — std. dim.: 1-3/4 in. wide, 3-1/2 to 3-3/4 in. deep)

	Grade 1	Grade 2	Grade 3	Grade 4
KNOTS & HOLES:				
Size:				
Notch Area:	None	None	1/2 in. max. any face	1/4 cross section area
Narrow Face:	Pin	1/4 of face width	3/8 of face width	1/2 of face width
Wide Face:	1/8th of face width	1/4 of face width	3/8 of face width	1/2 of face width
Quantity:				
Notch area:	None	None	One notch only	One each notch
End area:	One, each end	One, each end	One, each end	One, each end
Center:	None	Two, spaced 6 in.	Two, spaced 6 in.	No restriction
SLOPE OF GRAIN:	1 in 20 maximum	1 in 15 maximum	1 in 10 maximum	1 in 6 maximum
DISTORTED GRAIN:	None	None in notch area 1/8 of face width elsewhere	None in notch area 1/4 of face width elsewhere	None in notch area 3/8 of face width elsewhere
CHECK, SHAKE, SPLIT:				
Check:	None	One, small, surface	One, medium, surface	No restriction
Shake:	None	None	None	Light
Split:	None	None	None	One, short
PITH:	None	None	Face	Boxed
WANE:	1/8 width 1/8 thickness	1/8 width 1/8 thickness	1/6 width, 1/4 of thickness, 1/2 length	1/3 width, 1/3 of thickness, full length
DECAY:	None	None	None	1/4 cross section max.
STAIN:	Medium	Medium	No restriction	No restriction
WARP:	Very light crook	Light crook	Medium crook	No restriction
PITCH:	Light, very small streak or pocket None in nail face	Medium, very small streak or pocket None in nail face	Heavy, medium streak or pocket None in nail face	Heavy, large streak or pocket
MISMANUFACTURE:	None	None	None	No restriction
COMBINED DEFECT:	Reduction in strength equivalent to a knot defect.			

EXCERPTION FROM (33). USED WITH PERMISSION.

NWPCA HARDWOOD PALLET SPECIFICATIONS

Limitations of Permissible Defects	PRECISION GRADE	PREMIUM GRADE	"AA" GRADE	"A" GRADE
I LUMBER				
A Grade				
1. KNOTS				
(a) Size	The average diameter no greater than one-quarter the nominal width of the piece.	The average diameter no greater than one-third the nominal width of the piece.	The average diameter no greater than one-third the nominal width of the piece.	The average diameter no greater than one-half the nominal width of the piece.
(b) Location	No knot to be on outer edge of any endboard, top or bottom deck. No nail is to be driven through knots in any deckboards. Nails can be driven into sound knots in stringers or stringer boards under inside deckboards only. No nail is to be driven into or through knots in blocks.	No knot to be on outer edge of any endboard, top or bottom deck. No nail is to be driven through knots on end deckboards. Nails can be driven into sound knots in stringers or stringer boards or blocks.	Sound knots are permissible in nailing area but no nail is to be driven through such knots on endboards top or bottom deck at outside stringers or blocks unless compensated for by an additional nail. Nails can be driven into or through sound knots on inside deckboards and all stringer boards without a compensating nail. Nails can be driven into sound knots or sound knot areas in any part of any stringer or block	Sound knots are permissible in nailing area. Nails can be driven into or through sound knots on all deckboards, stringer boards, stringers or blocks without a compensating nail.
(c) Quantity	No more than two maximum size knots or their equivalent in any twelve inch length. Additional such knots must be separated by at least six inches.	No more than two maximum size knots or their equivalent in any eight inch length. Additional such knots must be separated by at least four inches.	No more than two maximum size knots, or their equivalent, in any six inch length. Additional such knots must be separated by at least four inches.	No more than two maximum size knots or their equivalent in any six inch length. Additional such knots must be separated by at least four inches.
2. SPLITS AND SHAKES				
(a) Size	Length of crack or grain separation must be no longer than one-half the width of the piece in all deckboards, stringer boards, and blocks, and no longer than the width of the piece in stringers.	Length of crack or grain separation must be no longer than one-half the width of the piece in all deckboards, stringer boards and blocks, and no longer than the width of the piece in stringers.	Length of crack or grain separation must be no longer than one-half the width of the piece in end deckboards and all blocks, and no longer than the width of the piece in stringers, stringer boards and inside boards.	Length of crack or grain separation must be no longer than two-thirds the width of the piece in end deckboards and blocks and no longer than twice the width of the piece in stringers, stringer boards and inside boards.
(b) Location and Quantity	Splits running through full thickness of the piece (not to be confused with nail splits) are not permitted in endboards, outside stringer boards, outside stringers or blocks. Inside boards may contain splits if straddled by nails.	Splits running through full thickness of the piece (not to be confused with nail splits) are not permitted in endboards, outside stringer boards, outside stringers or blocks. Inside boards may contain splits if straddled by nails.	Splits running through full thickness of piece (not to be confused with nail splits) in endboards and inside boards must be straddled by nails. Splits in ends of outside stringers or blocks are not permitted unless compensated for by a corrugated fastener driven at right angles across split.	Splits running through full thickness of the piece (not to be confused with nail splits) are permitted in any number, but when appearing in endboards must be straddled by nails.
	Shakes are not permitted in endboards, stringer boards, outside stringers and outside blocks, but are permitted in no more than one inside board if contained by nailing.	Shakes are not permitted in endboards, stringer boards, outside stringers and outside blocks, but are permitted in no more than two inside boards if contained by nailing.	Shakes are not permitted in endboards, stringer boards, outside stringers, and outside blocks, but are permitted in no more than three inside boards if contained by nailing	Shakes are permitted in any piece if contained by nailing.
3. CHECKS	No limitation in quantity or length of checks providing they are not in direct line with nails which would cause weakening of fasteners resulting in defect equivalent to nail splits.	No limitation in quantity or length of checks in deckboards, stringer boards, and stringers, providing on end deckboards they are not in direct line with nails which would cause weakening of fasteners resulting in defect equivalent to nail splits, unless compensated for by additional nails (covered under nail splits). Checks in blocks that expose a nail shank to view are not permitted.	No limitation in quantity or length of checks in deckboards, stringer boards, and stringers, providing on end deckboards they are not in direct line with nails which would cause weakening of fasteners resulting in defect equivalent to nail splits, unless compensated for by additional nails (covered under nail splits). Checks in blocks that expose a nail shank to view are not permitted.	No limitation in quantity, length or location.
4. WANE				
(a) Size	Deckboards and stringer boards: 1/6 width—1/4 thickness—unlimited in length. Stringers or blocks: 1/6 width of nailing faces—1/4 width of other faces—unlimited in length.	Deckboards and stringer boards: 1/6 width—1/4 thickness—unlimited in length. Stringers or blocks: 1/6 width of nailing faces—1/4 width of other faces—unlimited in length.	Deckboards and stringer boards: 1/6 width—1/2 thickness—unlimited in length. Stringers or blocks: 1/4 width of nailing faces—1/3 width of other faces—unlimited in length.	Deckboards and stringer boards: 1/4 width—2/3 thickness—unlimited in length. Stringers or blocks: 1/3 width of nailing faces—1/2 width of other faces—unlimited in length.
(b) Location and Quantity	No wane on end deckboards, top or bottom decks, and outside stringers, stringer boards or blocks. Wane is permitted within specified limits on one-fourth of remaining pieces providing it does not appear on exposed surface and no nail is driven into it or through it.	Wane within limits is permitted on any piece provided it is not on exposed surface or exposed edge (as opposed to ends) and provided no nail is driven into it or through it. No more than one-quarter of pieces of an individual pallet may contain wane.	Wane within limits is permitted on any piece provided it is not on exposed surface or exposed edge (as opposed to ends), and provided no nail is driven into it or through it. No more than one-third of pieces of an individual pallet may contain wane.	Wane within limits is permitted on any piece provided it is not on exposed edge of end deckboards. Wane may appear on surface or edge of other pieces but in no cases are nails to be driven into or through wane. No more than one-half of the pieces in an individual pallet may contain wane.

EXCERPTION FROM (38). USED WITH PERMISSION.

NWPCA HARDWOOD PALLET SPECIFICATIONS (CONTINUED)

	PRECISION GRADE	PREMIUM GRADE	"AA" GRADE	"A" GRADE
5. WARP				
(a) Size	No individual piece on any one pallet is to have deviation due to warp which is greater than X% of its measured dimension. Bow —0.5% Crook—0.5% Cup —2%	No individual piece on any one pallet is to have deviation due to warp which is greater than X% of its measured dimension. Bow — 1.5% Crook — 1.5% Cup — 2.5%	No individual piece on any one pallet is to have deviation due to warp which is greater than X% of its measured dimension. Bow — 1.5% Crook — 1.5% Cup — 2.5%	No individual piece on any one pallet is to have deviation due to warp which is greater than X% of its measured dimension. Bow — 2% Crook — 2% Cup — 3%
6. DECAY	No decay permitted.	No decay permitted.	No decay permitted.	No decay permitted in endboards or outside stringers. Decay on inside boards limited to one-third the width of piece and on no more than three boards and must not be in nailing area.
7. STAIN	Permitted.	Permitted	Permitted.	Permitted
8. CROSSGRAIN	Slope of grain must not exceed 1" in 10" of length in endboards, stringer boards, outside stringers, and blocks. 1" in 6" in center stringers and inside boards.	Slope of grain must not exceed 1" in 8" of length in endboards, stringer boards, outside stringers and blocks. Unlimited on center stringers and inside boards.	Slope of grain must not exceed 1" in 8" of length in endboards, stringer boards, outside stringers, and blocks. Unlimited in center stringers and inside boards	Slope of grain must not exceed 1" in 5" of length in endboards, stringer boards, outside stringers, and blocks. Unlimited in center stringers and inside boards.
9. COMBINED DEFECTS	Combinations of defects at or near their limits must not exceed one combination of any two of these defects per piece.	Combinations of defects at or near their limits must not exceed one combination of any three of these defects per piece.	Combination of knots, wane and crossgrain at or near their limits must not exceed one combination of any two of these defects per piece. Splits, shakes, checks and warp are permitted in any number of combinations, or in combination with the above defects as limited.	Combination of knots, wane and crossgrain at or near their limits must not exceed one combination of any two of these defects per piece. Splits, shakes, checks and warp are permitted in any number of combinations, or in combination with the above defects as limited.
B—Moisture Content	Individual pieces in Precision pallets should be at Equilibrium Moisture Content for the destined use. If not specified on the order all pieces at 12% plus or minus 4%, provided the total range does not exceed 4% when adhesives are used as fastenings.	22% to be considered as average for all pieces at time of fabrication and inspection providing no piece exceeds 25%.	To be considered as maximum at time of fabrication and inspection: (a) Deckboards and stringer boards—25% (b) Stringers or Blocks—Unlimited.	Unlimited Moisture Content for all pieces.

EXCERPTION FROM (38). USED WITH PERMISSION.

NWPCA SOUTHERN PINE PALLET SPECIFICATIONS

SP-SELECT	SP-1	SP-2	SP-3
KNOTS—			
Deckboards and Stringers:			
In pallet parts the size of a knot is measured by its greatest dimension across the width of the piece, and limited by cross sectional displacement.			
Knots are to be sound, firm, encased, if tight and well spaced; knots are not to exceed the following or equivalent displacement:	Knots are to be sound, firm, encased, and pith knots, if tight and well spaced in size not to exceed the following or equivalent displacement:	Well spaced knots of any quality are permitted in sizes not to exceed the following or equivalent displacement:	Well spaced knots of any quality are permitted in sizes not to exceed the following or equivalent displacement:
1/5 nominal cross section.	¼ nominal cross section: Knots on edge of wide face of stringers. Unsound or loose knots and holes.	¼ nominal cross section: Holes in 6" nominal width and wider.	⅓ nominal cross section: Holes in 6" nominal width and wider.
	⅜ nominal cross section: Knots along center line of wide face of stringers. Deckboards.	⅓ nominal cross section: Knots on edge of wide face of stringers. Holes in 4" nominal width and less.	½ nominal cross section: Knots on edge of wide face of stringers. Holes in 4" nominal width and less.
		½ nominal cross section: Knots along center line of wide face of stringers. Deckboards.	⅔ nominal cross section: Knots along center line of wide face of stringers. Deckboards.
a) Quantity: The sum of the sizes of knots in any given 6" length not to exceed twice the diameter of maximum single knot allowed, but two knots of maximum permissible size are not allowed in the same 6" length.	The sum of the sizes of knots in any given 6" length not to exceed twice the diameter of maximum single knot allowed, but two knots of maximum permissible size are not allowed in the same 6" of length.	The sum of the sizes of knots in any given 6" of length not to exceed twice the diameter of maximum single knot allowed but two knots of maximum permissible size are not allowed in the same 6" of length.	The sum of the sizes of knots in any given 6" length not to exceed twice the diameter of maximum single knot allowed, but two knots of maximum permissible size are not allowed in the same 6" of length.
b) Location: No knots shall be allowed that interfere with the nailing or exposed edges of any deckboards.	No knots shall be allowed that interfere with the nailing or exposed edges of any deckboards.	No knots shall be allowed that interfere with the nailing or exposed edges of any deckboards.	Sound knots are permitted in the nailing area.
SPLITS, SHAKES & SEASONING CHECKS—			
Deckboards and Stringers:			
(a) Size: Surface checks not over 1/16" wide x ⅕ thickness. Surface shakes not over 1/32" wide x ⅕ thickness. No through splits.	Through splits, through checks, through heart shakes, length equal to width of piece.	Through checks, splits and heart shakes, length equal to 1½ times the width of piece.	Unlimited, provided it does not divide member into two or more pieces.
(b) Location: Confined to center half of width of piece.	Confined to center half of width of piece.	Confined to center half of width of piece.	No restriction provided it does not run out of the width of the piece.
PITCH—			
Deckboards and Stringers:			
Medium pitch is permitted. Pitch streaks ¼ width or equivalent in heavy pitch.	Unlimited.	Unlimited.	Unlimited.
SURFACING—SMOOTH SAWN SKIPS—			
Deckboards and Stringers:			
Occasional light skip (1/32" deep.)	Medium occasional hit and miss (1/16" deep).	Hit and miss (1/16" deep); in addition 5% of pieces may be hit or miss (1/16 by length of piece), or heavy skip (⅛" deep x ¼ length).	Hit or miss (1/16" by length of piece), and in addition 10% of pieces may have heavy skip.

EXCERPTION FROM (39). USED WITH PERMISSION.

NWPCA SOUTHERN PINE PALLET SPECIFICATIONS (CONTINUED)

SP-SELECT	SP-1	SP-2	SP-3
TORN GRAIN— *Deckboards and Stringers:* Permitted, no more than 1/8" deep.	Not limited.	Not limited.	Not limited.
WARP— *Deckboards & Stringers:* (a) Cup . . . 1/8" in 6" of width.	1/8" in 6" of width.	1/8" in 6" of width.	1/8" in 6" of width.
(b) Crook . . . 1/8" in 24" of length.	1/8" in 24" of length.	1/8" in 24" of length.	3/16" in 24" of length.
PIN WORM HOLES— *Deckboards & Stringers:* Scattered 12 per surface foot.	Scattered 12 per surface foot.	Scattered 16 per surface foot.	Scattered 22 per surface foot.
STAIN— *Deckboards & Stringers:* Light stain medium on 25% of face.	Unlimited.	Unlimited.	Unlimited.
DENSITY— *Deckboards & Stringers:* Medium grain—four rings per inch.	Medium grain—four rings per inch.	No restriction.	No restriction.
GRAIN DEVIATION— *Deckboards & Stringers:* Deviation of grain must not exceed 1" deviation in each 12" of length except for short local deviations.	Deviation of grain must not exceed 1" deviation in each 10" of length except for short local deviations.	Deviation of grain must not exceed 1" deviation in each 8" of length except for short local deviations.	Deviation of grain must not exceed 1" deviation in each 4" of length except for short local deviations.
WANE— *Deckboards & Stringers:* 1/4" wide x 1/4" deep.	1/4 thickness, 1/4 width. 5% of the pieces may have wane up to 1/2 thickness and 1/3 width.	1/3 thickness x 1/3 width. 5% of pieces may have wane up to 2/3 thickness, 1/2 width.	1/2 thickness x 1/2 width. 5% of pieces may have wane up to 7/8 thickness, 3/4 width.
UNSOUND WOOD— *Deckboards & Stringers:* None permitted.	None permitted.	Not permitted in thickness over 2", but in 2" thickness and under, heart center streaks not over 1/3 width or thickness.	In spots or streaks. Limited to 1/3 cross section at end of piece and along the length. Must not destroy edge and must be suitable for nailing throughout.

EXCERPTION FROM (39). USED WITH PERMISSION.

NWPCA WEST COAST SOFTWOODS
AND
NWPCA WHITE WOODS PALLET STANDARDS

Shipping	Standard Warehouse	Premium Warehouse
B. Knots and Holes **Sound knots**—no greater than ¾ the nominal width of piece. **Unsound knots and holes**—¾ width of sound knots. **Spike knots**—permitted if visible on only one face of piece.	**B. Knots and Holes** **Sound knots**—average diameter no greater than 2½" for nominal 6" board and 1½" for nominal 4" board. **Unsound knots and holes**—no greater than ½ size of sound knots.	**B. Knots and Holes** **Sound knots**—average diameter no greater than ⅓ the nominal width of piece. **Unsound knots and holes**—½ size of sound knots. No knots in nailing area or exposed edges of end deckboards. No more than two maximum size knots per 8" length and separated by 4" of sound wood.
C. Splits, Shakes and Checks **Deckboards**—permitted provided does not divide piece into more than 2 pieces. **Stringers, deckboards, and blocks**—permitted provided it does not divide the piece.	**C. Splits, Shakes and Checks** **Deckboards**—fine, straight through ½ the length of the piece permitted but must be confined to center half of width of piece. **Stringers, stringerboards, and blocks**—maximum permitted not to exceed in length the nominal width of the piece.	**C. Splits, Shakes and Checks** **Deckboards**—fine, straight through ½ the length of the piece permitted but must be confined to center half of width of piece. **Stringers, stringerboards, and blocks**—none permitted.
D. White Speck **All pieces**—unlimited except honeycomb shall not exceed 25% of surface.	**D. White Speck** **All pieces**—in sound wood limited to 5% of surface area but no honeycomb permitted.	**D. White Speck** **All pieces**—in sound wood limited to 5% of surface area but no honeycomb permitted.
E. Wane **Deckboards** — ⅓ nominal width and full depth of piece permitted provided the average width of piece not less than 75% of nominal width. **Stringers, stringerboards, and blocks**—½ nominal width, ⅔ the thickness and full length of piece permitted.	**E. Wane** **Deckboards** — ¼ nominal width ½ the thickness, and full length of piece permitted. **Stringers, stringerboards, and blocks**—¼ nominal width, ¼ the thickness, and full length of piece permitted.	**E. Wane** **Deckboards**—¼ width, ½ the thickness, and full length of piece permitted. **Stringers, stringerboards, and blocks**— ⅛ width, ¼ the thickness and no more than ½ the length permitted.
F. Slope of Grain N/A	**F. Slope of Grain** Must not exceed 1" deviation in each 6" of length except for local deviation.	**F. Slope of Grain** Must not exceed 1" deviation in 8" of length except for local deviation.
G. Unsound Wood N/A	**G. Unsound Wood** Treat as unsound knot.	**G. Unsound Wood** **Deckboards**—treat as unsound knot. **Stringers, stringerboards, and blocks**—not permitted
H. Pitch N/A	**H. Pitch** **Deckboards**—small pockets or streaks not over 6" in length. **Stringers, stringerboards, and blocks**—small pockets or streaks not over 3" in length.	**H. Pitch** **Deckboards**—small pockets or streaks not over 6" in length **Stringers, stringerboards, and blocks**—small pockets or streaks not over 3" long on width of piece but not permissible on thickness.

EXCERPTION FROM (37). USED WITH PERMISSION.