EFFECT OF HEART CHECKS ON FLEXURAL PROPERTIES OF RECLAIMED 6 BY 8 DOUGLAS-FIR TIMBERS

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ABSTRACT

A sampling of nominal 6- by 8-inch (standard 140- by 184-mm) Douglas-fir timbers was obtained from an industrial military building in Minnesota. Thirty selected timbers had heart checks (boxed heart splits), which are characteristic of most old timbers installed in dry locations. Sixty selected timbers did not have heart checks. Most of the beams would grade as Select Structural Beams and Stringers by current grading rules. The modulus of elasticity (MOE) of the unchecked beams was greater than the allowable values given in the National Design Specification, but the modulus of rupture (MOR) was low. Analyses of the results suggested that heart checks decrease the mean MOR about 15 percent but have no direct effect on MOE. A good correlation was found between MOE determined by longitudinal stress wave techniques and that determined in static edgewise bending. Results suggest that the feasibility of developing mechanical grading systems for reclaimed timbers might be useful for on-site grading. Additional data are needed on wider beams with heart checks than those used in this study to confirm this hypothesis.

For the first time in its history, the United States does not have a large, unreserved volume of softwood sawtimber. An increasing demand for lumber, coupled with shifts in sawtimber availability between regions of the country, has spurred interest in more efficient utilization and in alternative sources of material (9,15,17). This decreased availability is a problem, especially with larger solid-sawn lumber, called timbers. For many uses, glued laminated beams, wood I-joists, or wood trusses may be substituted for large solid-sawn beams. However, such substitutions are not always possible, or desirable. One alternative is more efficient grading procedures, which can help prevent waste of virgin timbers (8, 10). Reclaiming is another alternative, which can help conserve existing forest resources. Within the last few years, reclaiming old timbers for architectural and structural use has dramatically increased (11,16).

Structural timbers are usually green when installed in buildings. Timbers in covered buildings eventually reach a moisture content (MC) of 6 to 10 percent (6). Whether trying to reevaluate timbers in existing structures or grading timbers removed from a building during demolition, the engineer wanting to recycle old timbers as structural members is often confronted with timbers containing severe drying checks or splits. Heart checks (also called box heart splits) are characteristic of dry timbers containing the pith **(Fig. 1).** Heart checks are a result of stresses set up by the difference in tangential and radial shrinkage of wood around the pith (14). Although there may be more than one heart check in a member, typically an individual check is not a continuous split down both sides of the beam. Rather, heart checks are confined to one side of the member and contain numerous "bridges" of wood fiber across the split.

The primary objective of this study was to evaluate the effect of heart checks on the residual bending properties of nominal 6- by 8-inch (standard 140- by 184-mm) timbers (hereafter called 6 by 8's). Secondary objectives included an evaluation of relationships between modulus of rupture (MOR) and modulus of elasticity (MOE) for potential use in mechanical grading as well as an evaluation of property assignments for visually graded timbers. A previous pa-

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TABLE 1. — Selected limiting characteristics of 6 by 8 Douglas-fir timbers graded as Beams and Stringers (19).[a]

	Grade			
Limiting characteristic	Select Structural	No. 1	No. 2	Utility
Knots				
On narrow face and edge of wide face in middle third of beam length (in.)	1-3/4	2-1/2	4-1/2	3-3/4
At ends and along center-line of wide face (in.)	2	3	4-1/2	3-3/4
Slope of grain				
In middle third of beam length	1 in 15	1 in 10	1 in 6	1 in 6
Balance of beam area	1 in 12	1 in 8	1 in 6	1 in 6
Splits	1/2 the width	Equal to width	Twice the width	1/4 of length
Shake	1/6 the thickness on ends	1/6 the thickness on ends	1/2 the length[b]	1/2 the thickness

[a] 1 in. = 25.4 mm.
[b] If on end, limit as splits.

TABLE 2. — Property relationships for structural timbers.

Species	Moisture content	Size	Dependent variable	Independent variable	n	r^2
	(%)	(in. [mm])				
Southern pine[a]	14	6 by 6 [152 by 152]	MOR	MOE	99	0.34
			MOE	Stress wave MOE	99	0.71
Mixed oak[b]	Green	7 by 9 [178 by 229]	MOR	MOE	220	0.51
			MOE	Stress wave MOE	220	0.63

[a] Reference (8).
[b] Reference (10).

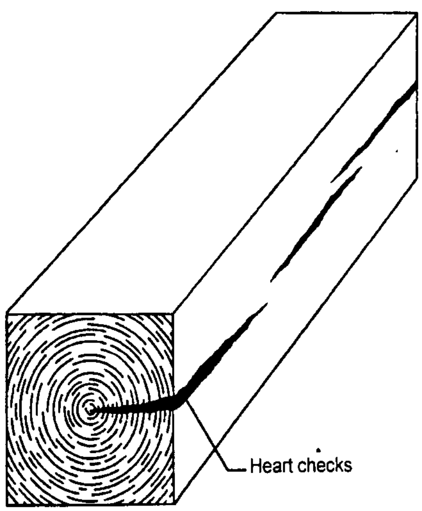

Figure 1. — Typical heart check in pith-centered timbers.

per included an evaluation of the effect of heart checks on column strength (4), and testing is currently underway to quantify the effect of heart checks on beam shear strength

BACKGROUND

Timbers are members 5 inches (114 mm) or more in the least dimension (2). Structural timbers are currently visually graded according to regulations published by rules-writing grading agencies, with allowable properties calculated from test data on small, clear specimens according to procedures given in ASTM D 245 (2).

Lumber 4 inches (102 mm) and less in thickness is called dimension lumber. More than 98 percent of structural dimension lumber is visually graded (20), with properties calculated from tests of full-sized members according to procedures given in ASTM D1990 (2). Since the early 1960s however, more accurate and efficient grading has been available for 2-inch- (51-mm-) thick dimension lumber using mechanical grading (3, 21). Currently, mechanically graded timbers are not commercially available. However, recent studies have demonstrated the technical feasibility of extending the mechanical grading process to timbers cut from virgin wood (8,10).

VISUAL GRADING OF TIMBERS

There are some significant differences between the application of visual grading techniques to structural dimension lumber and the application to timbers. Unlike dimension lumber, grading rules for timbers are not standardized across species. Thus, for example, the allowable knot size for a No. 2 southern pine timber is not the same as that for a No. 2 Douglas-fir timber (18,19). Another difference is that dimension lumber is graded for all intended uses. For all species except southern pine, timbers are graded as either Beams and Stringers or Posts and Timbers. Southern pine timbers are graded without respect to intended use. Beams and Stringers are members 5 inches (114 mm) or more in thickness, with a width more than 2 inches (51 mm) greater than its thickness. Beams and Stringers are primarily used in bending applications, and the grade description of the middle third of the length of the beam is more stringent than that of the outer two-thirds **(Table 1).** Posts and Timbers are members 5 by 5 inches (114 by 114 mm) and larger, where the width is not more than 2 inches (51 mm) greater than the thickness. Posts and Timbers are used primarily in applications involving axial loads, and the grade criteria are applied uniformly along the length of the member.

MECHANICAL GRADING OF TIMBERS

Recent research has established the technical basis for mechanically grading structural timbers (8,10). This process

TABLE 3. — Visually graded lumber properties of reclaimed 6 by 8 Douglas-fir timbers.

Beam	Grade	*n*	Specific gravity[a]	Moisture content	MOE		MOR psi Mean	MOR psi 5th	MOR MPa Mean	MOR MPa 5th
				(%)	(× 10^6 psi)	(MPa)				
Unchecked	Select Structural	48	0.46	13.8	1.89	13,000	4.87	3.06	33.58	21.10
	No. 1	8	0.45	12.2	1.82	12,547	4.20	- -	28.96	- -
	No. 2	5	0.43	12.1	1.60	11,030	4.18	- -	22.82	- -
	Utility	2	0.51	14.4	- -		- -	- -	- -	- -
Checked	Select Structural	22	0.42	14.9	1.76	12,133	4.14	2.54	28.55	17.51
	No. 1	2	0.43	15.8	1.32	9,100	2.99	- -	20.62	- -
	No. 2	4	0.41	14.9	1.54	10,617	3.49	- -	24.06	- -
Ratio[b]	Select Structural	- -	0.90	- -	0.93	0.93	0.85	0.83	0.85	0.83
	No. 2	- -	0.96	- -	0.96	0.96	0.83	- -	0.83	- -

[a] Based on ovendry weight and volume.
[b] Checked to unchecked.

involved first establishing a relationship between MOE and MOR, then estimating a lower confidence bound on this regression relationship **(Fig. 2).** The 95 percent lower confidence bound provides the equivalent of the 5th percentile used to calculate allowable bending strength (*Fb*) for visually graded lumber (2) and is used to establish grade boundaries for MOR and MOE. Because the timbers in these two studies were too short to vibrate by transverse vibration, a method was also needed to presort the beams by MOE. Sorting of timbers in the field was accomplished using longitudinal stress wave techniques to estimate MOE **(Table** 2). This mechanical grading approach was applied to green, mixed oak 7- by 9-inch (178- by 229-mm) timbers, and good yields were obtained for 1500f-1.5E and 1900f-1.7E mechanically graded timbers (10). However, the application of this technique to recycled timbers, which typically contain a wider assortment of drying defects, has not been evaluated

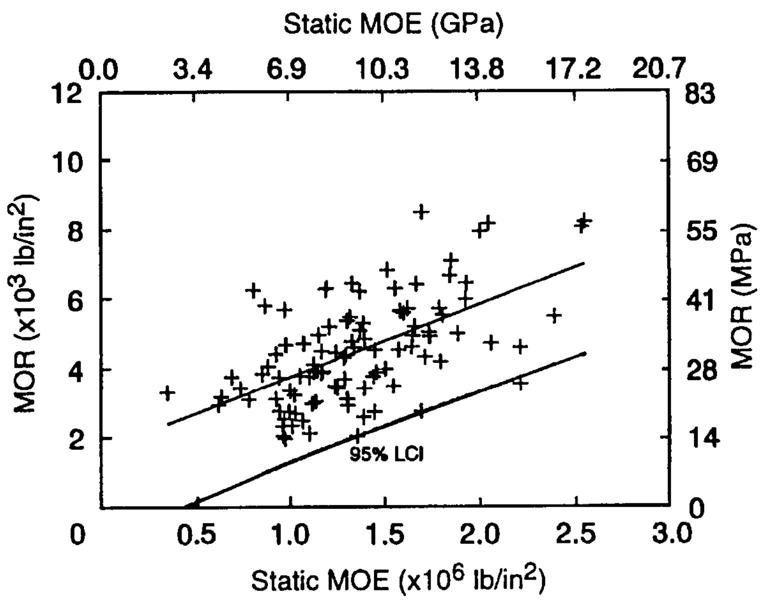

Figure 2. — Relationship of MOR to MOE for dry southern pine 6- by 6-in. (152- by 152-mm) timbers (8).

MATERIALS AND METHODS

TIMBERS

Ninety-one 6- by 8-inch by 16-foot (152- by 203-mm by 4.9-m) Douglas-fir timbers were obtained from building 503 at the Twin Cities Army Ammunition Plant in Arden Hills, Minnesota. Built in 1942, the 548,000-ft.^{2} (50,909-m^2) building had been used as a general manufacturing facility containing metal machining, stamping, and assembly equipment. From building 503, approximately 28 timbers were selected that had large heart checks located down the center of the member. These timbers will be referred to as "checked" timbers. Another 63 timbers were selected that may have had minor surface checking but did not have major heart checks. These timbers will be called "unchecked" timbers. The timbers, selected before the building was dismantled, were chosen to provide a range of quality typical of those in the building and to evaluate the MOR-MOE relationship. The smaller sample size for the checked timbers is a reflection of the difficulty encountered in finding members containing the pith in a building of this vintage.

The timbers were graded as Beams and Stringers by a grading supervisor from the West Coast Lumber Inspection Bureau (WCLIB) **(Table** 3). Because it was assumed that all timbers would be trimmed prior to use, damage on the last 1 foot (0.3 m) on either end of all beams was ignored. To provide a comparison of the effect of heart checks on timbers of otherwise equal quality, the grade of the checked timbers ignored the heart check in the middle of the member. For testing, the timbers were transported to the USDA Forest Service, Forest Products Laboratory, in Madison, Wisconsin.

NONDESTRUCTIVE MEASUREMENTS

To obtain the stress wave measurement of MOE, a double-threaded screw was placed in the end of the timber and an accelerometer was attached. If the pith was present in the member, the screw was placed midway between the

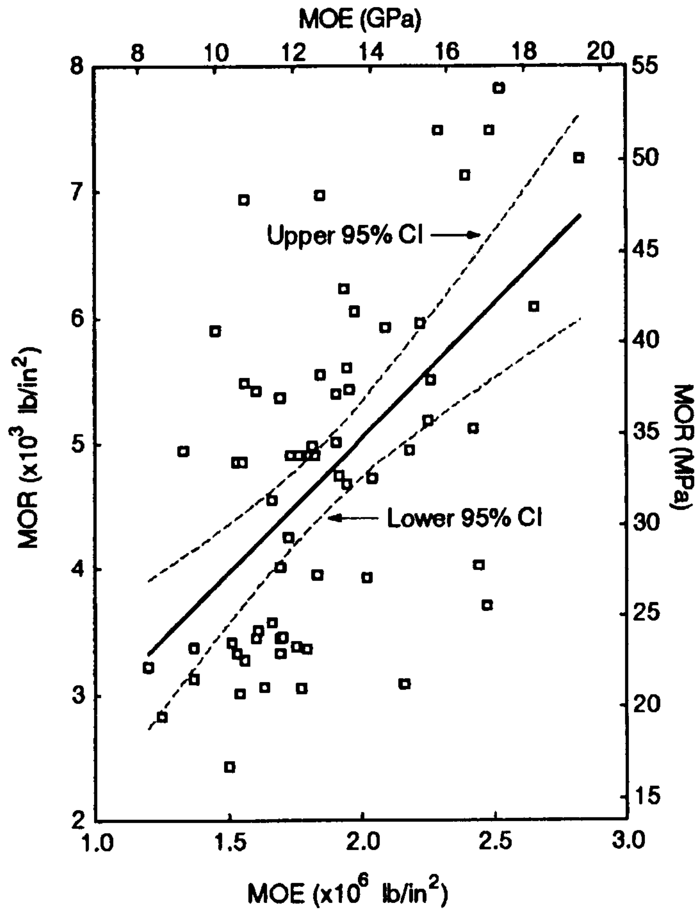

Figure 3. — Regression relationship and 95 percent confidence interval for "unchecked" Douglas-fir 6 by 8 timbers.

TABLE 4. — Reasons for assignment of visual grade.[a]

	No. of timbers graded				
Reason	Select Structural	No. 1	No. 2	Economy	Total
Met highest grade	70	--	--	--	70
Shake	--	--	3	--	3
Knots, slope of grain	--	10	3	1	14
Damage	--	--	2	1	3
Wane	--	--	1	--	1
Total	70	10	9	2	91

[a] Heart checks were not included in the grading of 28 pieces.

pith and the edge of the cross section. Pulse energy was introduced to the specimens through a hammer impact on the opposite end. Echo waves were recorded on an oscilloscope to obtain time between peaks. The stress wave MOE was calculated using the speed of the sound wave c and density p of each timber using the following:

$$\text{Stress wave MOE} = c^2 \times p$$

LUMBER MOR AND STATIC MOE MEASUREMENT

Bending tests were conducted according to ASTM D 198 (2). The beams were loaded on edge with loads applied at one-third points of the span **(Fig. 1). The** span-to-depth ratio was 17:1. A constant rate of crosshead movement of about 0.02 in./min. (0.5 mm/min.) resulted in beam failure in about 10 minutes. After testing, samples were cut from each timber to determine ovendry MC and specific gravity (SG) (2).

CLEAR WOOD PROPERTIES

Following testing of the timbers, 1- by 1- by 16-inch (25.4- by 25.4- by 406-mm) clear wood bending specimens were cut from the undamaged ends of each beam. One specimen was cut from near the surface of the beam and one from the interior. The specimens were cut so that the growth rings were oriented parallel to the edges of the specimen, thus allowing the specimens to be tested with the load applied tangentially to the growth rings. The specimens were conditioned at 73°F (23°C) and 70 percent relative humidity and tested according to ASTM D 143 (2).

RESULTS AND DISCUSSION

VISUALLY GRADED LUMBER

Visually graded lumber properties of the 6 by 8's are summarized in **Table 3.** By current rules, 77 percent of the lumber was graded as Select Structural. Knots and slope of grain were the biggest grade-limiting factors for the timbers sampled **(Table 4).** The MC of the

TABLE 5. — Comparison of properties for green unchecked 6 by 8 timbers.

	Mean MOE						5th percentile MOR					
Grade	Study reported herein[a]		Madsen & Stinson (12)		NDS (1)		Study reported herein		Madsen & Stinson (12)		NDS (1)	
	($\times 10^6$ psi)	(MPa)	($\times 10^6$ psi)	(MPa)	($\times 10^6$ psi)	(MPa)	($\times 10^3$ psi)	(kPa)	($\times 10^3$ psi)	(kPa)	($\times 10^3$ psi)	(kPa)
Select Structural	1.85	12,754	1.85	12,754	1.60	11,030	2.54	17,500	4.36	30,000	3.36	23,200
No. 1	1.78	12,271	1.70	12,271	1.60	11,030	--		4.28	29,500	2.84	19,600
No. 2	1.57	10,824	--		1.30	8,962	--		--		1.84	12,700

[a] MOE for timbers decreased 2 percent for green estimate.

unchecked beams was about 13 percent, and that of the checked beams was about 15 percent. This slight difference probably occurred because the beams had been stored outside underneath a tarp prior to testing and the unchecked beams were tested before the beams with checks. SG, based on ovendry weight and volume, was about 0.46 for the unchecked timbers and 0.42 for the checked timbers. The generally lower SG values for the beams with checks were probably a reflection of the presence of pith in the checked beams.

Estimation of properties by visual grade was not the primary objective of this study. Therefore, it was not surprising that sample sizes were generally insufficient for that purpose. However, an attempt was made to compare the results of our tests on unchecked beams with results from available literature. Because the heart checks were not used in the grade assignment, checked beams were not used in this comparison. Madsen and Stinson (12) tested 150 Douglas-fir beams in the green condition. The average MC of the beams was 32 percent. The beams had been graded as Beams and Stringers by the Canadian National Lumber Grades Authority (NLGA) (13). The NLGA rules appear to be substantially equivalent to those of WCLIB (19). The mean MOE values of our dry Douglas-fir beams were greater than those obtained by Madsen and Stinson **(Table 5).** If we decreased our dry MOE results by 2 percent to adjust for the MC difference (2), our results would be the same as Madsen and Stinson for Select Structural grade and slightly greater than their No. 1.

Our MOE values were greater than those given in the *National Design Specification for Wood Construction* (NDS), even if our values were reduced 2 percent to adjust for MC (1). After a review of the historical literature, it appears that the 2 percent increase for drying may be conservative (7). A more reasonable increase in MOE for members that have dried inside a building might be 12 percent. If the Twin Cities MOE values of Select Structural and No. 2 of 1.89 × 10^6 psi and 1.60 × 10^6 psi (13,000 and 11,030 MPa), respectively, **(Table 3)** were reduced by dividing by 1.12, the resulting values of 1.67 × 10^6 psi and 1.42 × 10^6 psi (11,513 and 9,789 MPa) would still be greater than those in the NDS.

TABLE 6. — Mean flexural properties of clear Douglas-fir 1 - by 1 -inch specimens cut from 6 by 8 timbers.[a]

Results from	Specific gravity[b]	MOR		MOE	
		(× 10^3 psi)	(MPa)	(× 10^6 psi)	(MPa)
Study reported herein	0.47	11.80	81.40	1.88	12,963
Wood Handbook (6)					
Coast Douglas-fir	0.48	12.40	85.50	1.95	13,443
Interior West Douglas-fir	0.50	12.60	86.90	1.83	12,616
Interior North Douglas-fir	0.48	13.10	90.30	1.79	12,340

[a] 86 specimens; 12 percent moisture content.
[b] Based on ovendry weight and volume at time of test.

TABLE 7. — Property relationships for dry Douglas-fir 6 by 8 timbers.[a]

Variable: Dependent (D)	Variable: Independent (I)	Timber condition	$D = A + B(I)$: A	B	r^2	Root mean square error
MOE (× 10^6 psi)	Stress wave MOE (× 10^6 psi)	Unchecked	0.034	0.956	0.78	0.170
		Checked	0.189	0.926	0.79	0.148
MOR (× 10^3 psi)	MOE (× 10^6 psi)	Unchecked	0.758	2.144	0.31	1.110
		Checked	0.263	2.176	0.23	1.200
MOR (× 10^3 psi)	Stress wave MOE (× 10^6 psi)	Unchecked	0.290	2.334	0.32	1.111
		Checked	-0.431	2.923	0.35	1.106

For MOR, there is no adjustment in ASTM D 245 (2) for MC between green and dry. The 5th percentile MOR of the tested Select Structural timbers was only about 60 percent of that obtained by Madsen and Stinson (12) and only about 75 percent of that given in the NDS (1). These results are similar to those we obtained for nominal 2- by 10-inch (standard 38- by 235-mm) lumber from the Twin Cities facility in that the MOE values of the 2 by 10's were about what was expected, and the MOR values were low (5). It is not known if the lower than expected MOR values are typical of reclaimed Douglas-fir timbers or are a result of some type of chemical exposure from the industrial climate in building 503.

As might be expected, the mean MOE and MOR values of the checked beams were less than those of the unchecked beams **(Table 3).** For Select Structural beams, the ratio of checked to unchecked was 0.93 for mean MOE and 0.85 for mean MOR. For Select Structural timbers, the ratio for 5th percentile MOR was 0.83. Limited data for No. 2 timbers suggest a ratio of checked to unchecked for mean properties that was similar to that of Select Structural. With only two pieces of No. 1 timbers with checks, no conclusion could be drawn.

CLEAR WOOD PROPERTIES

Some 1- by 1-inch (25.4- by 25.4-mm) specimens contained small knots or excessive slope of grain. Test results on these specimens were not considered. For individual timbers, a significant difference was not found between small specimens cut near the surfaces of the timber and the specimen cut from the interior. Test results for all remaining specimens are given in **Table 6.** The average SG of the clear specimens cut from the timbers was only slightly less than that given in the *Wood Handbook* (6) for Coast, Interior West, or Interior North Douglas-fir at 12 percent MC. In a similar manner, the average MOR value was slightly less than the *Wood Handbook* values. The average MOE of the Twin Cities material was slightly less than that of Coast Douglas-fir, but was slightly greater than the average values for Interior West and Interior North. Overall, the results on the clear specimens seem typical for the species and do not indicate a reduction as a result of chemical exposure. Thus, we are left to speculate possible causes of the reduced MOR values for the full-sized timbers. One possibility is that the clear wood procedures of ASTM D 245 are not accurately predicting the strength of Douglas-fir timbers. Potential effects of long-term loading are a less likely possibility.

RELATIONSHIPS BETWEEN TIMBER PROPERTIES

Property relationships for the unchecked and checked beams are given in **Table 7.** With a coefficient of determination (r^2) of almost 0.8, the correlation between MOE and stress wave measurement of MOE was excellent for both the checked and unchecked members. The correlation was low between MOR and MOE. This was probably because most of the timbers were of high quality. As noted in previous studies, the low correlation may be a result of the relatively small sample size **(Table 2).** However, the MOR-MOE relationship was still highly significant. The good correlation between stress wave and static MOE, and a significant correlation between MOE and MOR, suggests a basis for mechanical grading for both checked and unchecked Douglas-fir beams that might parallel the grading developed for unchecked oak timbers (10).

Figure 3 shows the MOE-MOR relationship for the unchecked Douglas-fir timbers, and **Figure 4** shows the relationship for the checked timbers. An upper and lower 95 percent confidence interval is also shown for both data sets. These are the traditional (nonlinear) confidence intervals and indicate the region you could expect to find the regression line with 95 percent confidence if the study were repeated many times. The more limited range in MOE values for the checked beams is evident in **Figure 4.** The slope of the MOE-MOR regression is identical for both data sets **(Table 7),** with the primary difference being the intercept. This suggests that there was no real effect of the heart check on MOE, and that the only real effect was on MOR. Additional data, especially for wider beams, would be helpful to confirm the effect of heart checks on the MOE-MOR relationship.

The parallelism of the regression lines in **Figures 3** and **4** also suggests that even if only MOR and MOE data were available for unchecked beams, it might be possible to mechanically grade beams

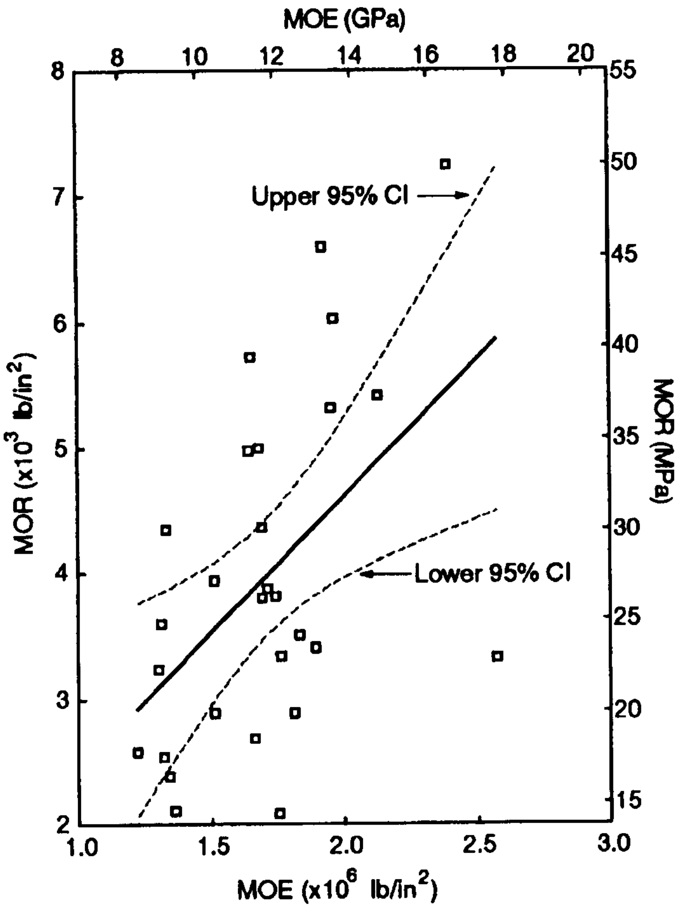

Figure 4. — Regression relationship and 95 percent confidence interval for "checked" Douglas-fir 6 by 8 timbers.

with heart checks by placing a wider confidence interval on the data. For the timbers tested in our study, a 99 percent confidence interval on the MOE-MOR relationship in the beams without heart checks, instead of the traditional 95 percent confidence interval, would provide a conservative lower estimate than for the beams with heart checks **(Fig. 5).** Again, additional data are needed to confirm this hypothesis.

CONCLUSIONS

From the results of this study, we conclude the following:

• High quality timbers can be recovered from salvaged structures. By current rules, about 75 percent of the timbers sampled from building 503 were visually graded as Select Structural Beams and Stringers.

• The average MOE of the unchecked timbers was greater than that currently given in the NDS.

• Bending strength of the unchecked timber was found to be about 75 percent of that expected from the NDS values. The bending strength of clear wood was only slightly less than expected.

• Heart checks decrease the MOR of timber beams but have no direct effect on MOE. The 5 percent reduction in the MOE of checked beams tested in this study, compared with that of unchecked beams, appears to be a result of lower SG.

• The correlation between static MOE and MOR is less than expected, but a large sample size with a wider range in beam quality would probably yield a better correlation.

• There was a good correlation between static and stress wave MOE for both checked and unchecked Douglas-fir timbers. Thus, it would appear feasible to establish a mechanical grading system for reclaimed timbers. Additional data are needed for wider beams with heart checks to verify this conclusion.

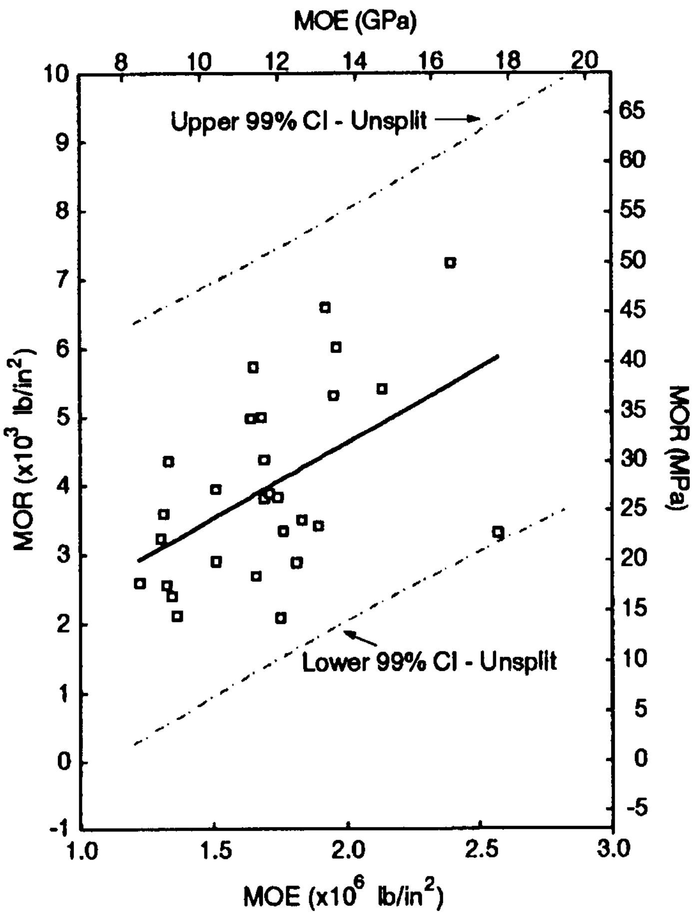

Figure 5. — Data and mean regression line for "checked" beams showing 99 percent confidence intervals on the regression equation determined from the data for "unchecked" beams.

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