EVALUATION OF LUMBER RECYCLED FROM AN INDUSTRIAL MILITARY BUILDING

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ABSTRACT

During the past century, millions of structures were built from sawn lumber and timber. When these structures reach the end of their service lives, contemporary practices emphasize landfill disposal. In recent years, the public has expressed a strong interest in developing environmentally acceptable and efficient reuse options for this solid-wood material. As a result of this interest, a test program was developed to evaluate the grades and engineering properties of nominal 2-by 10-inches (standard 38- by 236-mm) lumber collected from the Twin Cities Army Ammunition Plant and compare this material with the performance of lumber produced today. On-site grading of 500 lumber pieces indicated the effect of damage on grade yield. An analysis of test data indicated that the stiffness was similar to lumber produced today; however, bending strength was somewhat less. Mechanical grading yields and potential reuse options are also presented.

Millions of residential homes, commercial and industrial buildings, bridges, and other structures were built from sawn lumber and timber during the past century. Potentially, a vast amount of this dismantled lumber will be available for future reuse. Since the turn of the century, more than 3 trillion board feet (BF) (7.3 billion m^3) of lumber and timber have been sawn in the United States, much of it still residing in existing structures (11,12). When these structures reach the end of their service lives, become obsolete, or change use, contemporary practices emphasize quick, cheap disposal in landfills. In recent years, the public has expressed a strong interest in finding environmentally acceptable and efficient material reuse options that focus on building dismantlement (i.e., deconstruction) and the reuse of these materials in new construction and remodeling.

In the past decade, the use of recycled timbers has moved from a small cottage industry into a mainstream construction market (9). Although the focus has been on the use of larger timbers resawn for architectural and structural uses, the potential does exist to reuse dimension lumber in its present form as primary or secondary members in wood-framed construction (e.g., studs, joists, rafters, siding, flooring). (Dimension lumber is material 2 to 4 in. (50 to 100 mm) thick, and timbers are 5 in. (137 mm) and greater in thickness (13).)

Even though public interest in utilizing this recycled wood resource is increasing, several technical impediments hinder widespread acceptance. (Several terms are currently in use to describe the full-sized solid-wood members salvaged from existing wood structures, including reclaimed, reused, salvaged, antique, and recycled. To avoid confusion, the term recycled will be used throughout this article.) The technical obstacles hinder general acceptance in the marketplace, and more specifically, acceptance by building officials at the job site. Although existing grading rules can be used to grade recycled lumber and the general requirements for sizing, grading, and marking of softwood lumber have been established through the American Softwood Lumber Standard (3) neither rules nor standards specifically address the use of recycled lumber or the characteristics that distinguish it from new lumber. Evaluating recycled lumber with existing grading rules may not result in the most efficient use of this resource. Existing grade limitations for certain charac-

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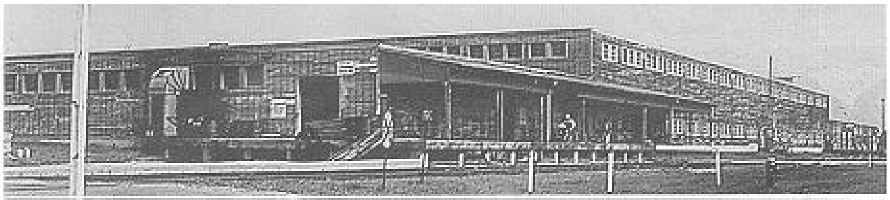

Figure 1. — Building 503 at Twin Cities Army Ammunition Plant, Arden Hills, Minn.

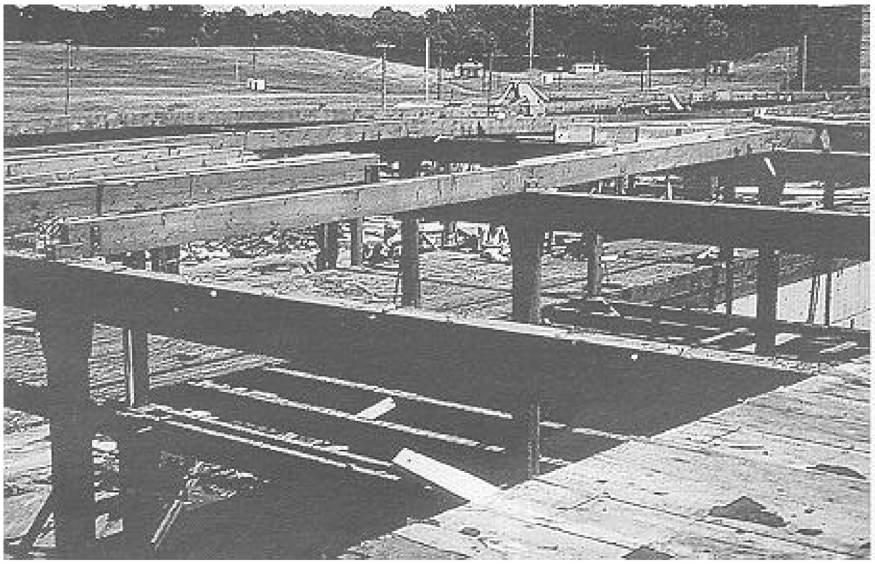

Figure 2. — Building 503; dismantlement in progress.

teristics (e.g., checks and splits) were developed for freshly sawn lumber. It is not clear to what extent these defects affect recycled lumber engineering properties and subsequent reuse options.

In many cases, the lumber found in older structures was cut from large-diameter trees from old-growth forests. Typically, this lumber is thought to be of higher quality (e.g., greater density, fewer growth defects, more rings per inch) than currently available lumber. However, the quality of recycled lumber can be affected by service-related defects, such as drying checks, splits, bolt and nail holes, and exposure to weather and decay. In addition, structural members have experienced an often-unknown load history. Members may have also been exposed to chemicals and extreme temperatures, depending on the building type and use.

BACKGROUND

With the end of the Cold War era in the early 1990s many military facilities have been classified as excess to our Nation's defense requirements. As a result, the U.S. Army made a decision to discontinue military manufacturing operations at their Twin Cities Army Ammunition Plant (TCAAP) in Arden Hills, Minn. Two of their large World War II era wood-framed industrial buildings (501 and 503) that had been used for small-caliber ammunition manufacturing were dismantled and used as a case study to determine if recycling is a feasible alternative to conventional demolition and landfilling (4,8). Building 501 contained a foundry. Building 503 was a general manufacturing building containing metal machining, stamping, and assembly equipment **(Fig. 1).** Both buildings were built in 1942.

In 1995, we had an opportunity to collect a sample of lumber and timber during the dismantlement of building 503 **(Fig. 2).** This 548,000-ft.^{2} (51,900-m^2) heavy timber building contained approximately 1,875,000 BF (4,500 m^3) of softwood timber, primarily Douglas-fir. Research staff at the USDA Forest Service, Forest Products Laboratory (FPL), worked cooperatively with U.S. Army facilities engineers and demolition contractors at the TCAAP to select a limited amount of lumber and timber members for testing. Approximately 35,000 BF (85 m^3) of lumber and timber were collected from building 503, including nominal 2 by 10's, 6 by 8's, 8 by 8's, 6 by 14's, and 10 by 18's.

We developed an experimental test program to evaluate the grades and engineering properties of this collected material and to determine how these properties compare with the performance of lumber and timber produced today. This article focuses on the experimental testing of nominal 2- by 10-inch (standard 38- by 235-mm; hereafter referred to as 2 by 10) lumber. Future articles will focus on the performance of the larger timber members.

MATERIALS AND METHODS

GROUP 1: 500 PIECES GRADED ON SITE

The dismantlement contractor set aside 500 2- by 10- by 18-foot (38-mm by 235-mm by 5.5-m) pieces of lumber that had served as either floor joists or roof rafters in building 503. The lumber pieces were unpainted and had been cleaned of nails and other hardware.

These 500 joists were visually graded by a grading supervisor from the West Coast Lumber Inspection Bureau (WCLIB) according to Standard Rule 17 (13), both for visual stress grade and the visual requirements of mechanically graded lumber. Normal grading characteristics applicable to freshly sawn lumber were considered when visually grading the recycled material, including checks, knots, splits, shake, wane, slope-of-grain, and warp. **Table 1** indicates the grade limitations for these characteristics for nominal 2 by 10 lumber. Unlike freshly sawn lumber, recycled lumber often exhibits defects as a result of in-service use or the dismantlement process. This can include mechanical damage (broken ends and edges of members, splits due to disassembly), damage from fasteners and hardware (bolt holes, clusters of nail holes), and notches from other framing members or utilities. Although holes can be treated as an equivalent-sized knot, other defects are not specifically defined in the grading rules; therefore, the grader must equate these defects to those found in the grading rules.

TABLE 1. —Limiting characteristics for nominal 2 by 10 dimension lumber graded as "structural joists and planks" (13).

Characteristic	Grade			
	Select Structural	No. 1	No. 2	No. 3
Surface seasoning checks	Not limited[a]	Not limited[a]	Not limited[a]	Not limited[a]
Knot: centerline-wide face	2-5/8 in.	3-1/4 in.	4-1/4 in.	5-1/2 in.
Knot: edge-wide face	1-7/8 in.	2-1/2 in.	3-1/4 in.	4-1/2 in.
Holes	1-1/4 in[b]	1-1/2 in.[c]	2-1/2 in.[d]	3 in.[e]
Splits	10 in.	10 in.	15 in.	1/6 length of piece
Wane	1/4 thickness 1/4 width (full length)	1/4 thickness 1/4 width (full length)	1/3 thickness 1/3 width (full length)	1/2 thickness 1/2 width (full length)
Slope-of-grain	1:12	1:10	1:8	1:4
Warp[f]	1/2 of medium	1/2 of medium	Light	Medium

[a] Through checks at ends limited as splits.
[b] One hole or equivalent smaller holes per 4 lineal feet.
[c] One hole or equivalent smaller holes per 3 lineal feet.
[d] One hole or equivalent smaller holes per 2 lineal feet.
[e] One hole or equivalent smaller holes per 1 lineal feet,
[f] Refer to par. 752 from source (13) for definition

In grading the recycled lumber, it was assumed that 1 foot (300 mm) would be trimmed from each end of each piece. Any defect in the l-foot end zones was ignored. In addition, dynamic modulus of elasticity (MOE) was measured for each piece using a portable DynaMOE transverse vibration test device (10).

GROUP 2: 100 PIECES SHIPPED TO FPL

A possible alternative to the visual stress grading of nominal 2- inch- (standard SO-mm-) thick lumber is mechanical grading. Mechanical grading combines visual assessment of growth features with direct measurement of MOE to sort individual pieces of lumber into grades (5). A batch of recycled lumber may contain more than one species; therefore, mechanical grading may be an efficient way to sort this material into grades. To investigate the potential for mechanical grading of recycled lumber, 100 pieces that met the visual requirements of Machine Stress Rated (MSR) lumber were randomly selected from the population of 500 pieces. These 100 pieces were shipped to FPL for additional testing.

The 100 2 by 10 joists shipped to FPL were conditioned at 65 percent relative humidity and 74°F (9°C) (12% equilibrium moisture content) for 2 months prior to testing. The joists were tested in a third-point bending test loaded on edge over a 16- foot (4.9-m) span that resulted in a span-to-depth ratio of approximately 21 **(Fig. 3)** (2). A constant rate of loading of 0.2 inch (5 mm) per minute resulted in failure in about 10 minutes. After testing, small specimens were cut from the members for moisture content (5) measurement, specific gravity determination (5), and annual ring count.

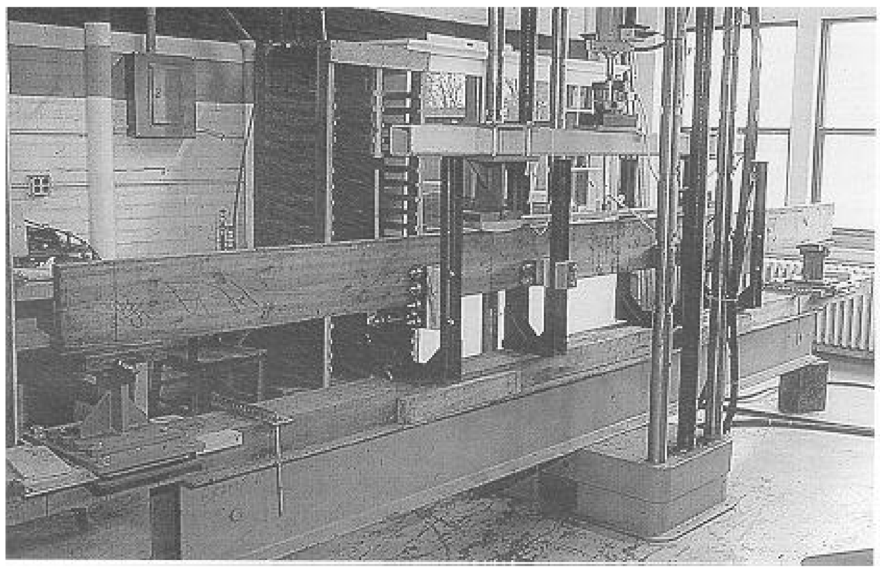

Figure 3. — Bending test of 2 by 10.

RESULTS

GROUP 1: 50 PIECES GRADED ON SITE

Yield of the 500 pieces of lumber graded on site is shown in **Table 2.** Twenty-eight percent of the pieces were graded as Select Structural. Fifty-six percent were graded as No. 2 or better. However, about the same number of pieces failed to make No. 3 grade as qualified for Select Structural. Knots, damage (primarily gouges that occurred during demolition), and end splits were the major reasons that the lumber was downgraded **(Table 3).** As noted previously, defects in the first 1 foot (300 mm) on either end of the piece were not considered because it was assumed that the pieces would be end trimmed. From visual observation during grading, it appeared that about half the grade-limiting splits were due to prying the lumber loose from the structure. Therefore, it is estimated that as much as 30 percent of the lumber was downgraded as a result of the deconstruction process (i.e., damage, plus half the splits) **(Table 3).**

GROUP 2: 100 PIECES SHIPPED TO FPL

Samples from all 100 lumber pieces shipped to FPL for testing were given to a wood anatomist for species identification. We originally thought that the entire building was constructed of Douglas-fir;

53 were Douglas-fir, 25 were Hem-Fir,
Table 4
shows the mean properties as a result of

commercial practice, the 53 pieces of Douglas-fir are referred to as Douglas Fir-Larch in the remainder of this paper.

COMPARISON WITH IN-GRADE DATA

One objective of this study was to determine how test data for the recycled lumber compare with existing data on currently available lumber. For this comparison, we turned to the results of an in-grade study (7), where test data forms the basis of lumber design values for common construction species. Under normal circumstances, we would consider the in-grade data as "true" values and test if our data supported the hypothesis that recycled lumber has the same property values. Because the 100 pieces shipped to FPL for destructive testing were not of one species and resulted in small sample sizes per species, comparison with the in-grade values was somewhat problematic. Small sample sizes can produce wide confidence intervals, and species with widely differing sample sizes can have different width confidence limits, even when the variability of the species is similar. For MOE, we calculated confidence intervals for our estimated mean value to see if the in-grade value was within the confidence interval. **Table 5** shows median MOE values for both the tested lumber and in-grade data (7) for Select Structural and No. 2 grades. Because of the small sample sizes, median rather than mean values were evaluated. For the same reason, the more restrictive 75 percent confidence interval of the median value was used, rather than the broader 95 percent confidence interval. Both sets of data were adjusted to 12 percent moisture content (7).

For Douglas Fir-Larch, the median MOE for the test data was greater than that of the in-grade data. For the other species, the ratio was close to one except for No. 2 Southern Pine. However, in all instances except one, the in-grade median values were within the confidence interval of the test data. For No. 2 Douglas Fir-Larch, the lower 75 percent confidence interval of the test data was above the in-grade data. Thus, we concluded that there is no reason to expect that the MOE of the recycled lumber test data is less than that of the in-grade data.

For MOR, our small sample sizes presented even more problems. Nonparametric fifth percentile estimates were not possible for our smaller data sets. We could have assumed a distributional form for our data; however, the in-grade numbers were based on nonparametric methods. Thus, we had no good way of using our data to test the hypothesis that it had the same MOR property values as resulted from the in-grade program. At best, we could use the variability found in the in-grade program to see if our data were generally within the range of values that subsets of the in-grade data exhibited. To this end, we sampled the in-grade data in lots, with 10 pieces of lumber per lot (6). Each 10-piece lot had a mean value; therefore, it was possible to calculate the mean and standard deviation of these lot-means. With this information, it was possible to establish a 95 percent confidence interval on the distribution of lot-means from the in-grade data using the following relationship:

$$\text{C.I.} = \text{mean} + t \times \text{standard deviation}$$

where:

C.I. = confidence interval

t = Student's t test

If we assume that the test data for a given species and grade are also a "lot," we can determine if the mean of the MOR test data was within the confidence interval of the in-grade data **(Table 6).**

TABLE 2. — Visual grades of 500 2 by 10'S (13).

Grade[a]	Number in grade	Percentage in grade
Select Structural	142	28.4
No. 1	42	8.4
No. 2	97	19.4
No. 3	78	15.6
Economy (< No. 3)[b]	141	28.2

[a] Visual grades according to WCLIB Grading Rule 17 (13).
[b] Not an official WCLIB grade; however, the designation is used for comparative purposes to indicate those pieces that did not meet the No. 3 grade for structural joists and planks.

TABLE 3. —Number of pieces in each grade for 500 visually graded 2 by 10's and the reasons for grade assignment.

Reason in grade	Select Structural	No. 1	No. 2	No. 3	Economy (< 3)	Total	Percent of grand total
	(no. of pieces)						(%)
Met highest grade	142	--	--	--	--	142	28
Splits	--	--	22	35	32	89	18
Knots	--	35	41	24	2	102	20
Holes	--	4	14	2	9	29	6
Damage	--	--	1	--	93	94	19
Shake	--	--	13	12	4	29	6
Wane	--	--	3	1	1	5	1
Slope of grain	--	--	1	1	--	2	< 1
Warp	--	--	--	2	--	2	< 1
Unknown[a]	--	3	2	1	--	6	1
Grand total	142	42	97	78	142	500	100

[a] Reason not recorded.

For all three species, the mean MORs of the test data for the Select Structural grade were less than the lower confidence limit from the in-grade data. The mean value for the test data was also less than the in-grade confidence interval for No. 2 Southern Pine, but was within the confidence interval for No. 2 Douglas Fir-Larch and Hem-Fir. In addition, the mean MOR for the test data was always less than the mean value of the lot-means from the in-grade program. Thus, we concluded that the MOR of these recycled 2 by 10's is less than that of currently produced lumber. However, because of the limited sample size by species group and grade, this is not a strong conclusion.

It is also logical to establish confidence limits for the in-grade data and determine if the test data are within these bounds. However, when comparing the two sets of data in this way, we obtained some rather illogical results. For example, the ratio between median MOE values for Select Structural Southern Pine was 0.98 **(Table 5).** However, the median MOE for the test data was found to be less than the lower 95 percent confidence interval of the in-grade data. This occurred because the confidence intervals of median

TABLE 4. —Average property results for 100 2 by 10's by species.

Species group	n	Moisture content	MOE	MOR	Rings/ in.	Specific gravity[a]
		(%)	($\times 10^6$ psi (MPa))	(psi (MPa))		
Douglas Fir-Larch	53	11.2	1.97 (13,590)	4,630 (32.0)	16.9	0.47
Hem-Fir	25	12.1	1.37 (9,450)	3,820 (26.4)	22.5	0.39
Southern Pine	22	12.0	1.55 (10,690)	3,540 (24.4)	6.0	0.45

[a] Based on ovendry weight.

TABLE 5. —MOE comparison of test data with in-grade data.

Species group	Grade	Test data (T) n	Test data (T) MOE[a]	In-grade data (I) n	In-grade data (I) MOE[a]	Ratio (T/I)	75% C.I.[b] on test data
			($\times 10^6$ psi (MPa))		($\times 10^6$ psi (MPa))		($\times 10^6$ psi (MPa))
Douglas Fir-Larch	Select Structural	36	2.00 (13,830)	414	1.90 (13,100)	1.06	1.88 to 2.09 (12,970 to 14,420)
	No. 2	13	1.95 (13,450)	388	1.56 (10,770)	1.25	1.62 to 2.26 (11,180 to 15,590)
Southern Pine	Select Structural	10	1.82 (12,520)	413	1.86 (12,830)	0.98	1.68 to 2.22 (11,590 to 15,320)
	No. 2	9	1.06 (7,310)	412	1.57 (10,840)	0.67	1.02 to 1.59 (7,040 to 10,970)
Hem-Fir	Select Structural	13	1.49 (10,280)	368	1.56 (10,750)	0.96	1.22 to 1.70 (8,420 to 11,730)
	No. 2	6	1.33 (9,180)	366	1.34 (9,210)	1.00	0.90 to 1.40 (6,210 to 9,660)

[a] Median values at 12 percent moisture content
[b] C.I. = confidence interval.

TABLE 6. — MOR comparison of test data and in-grade data using lot properties.

Species group	Grade	Test data n	Test data MOR[b]	In-grade data[a] n	In-grade data[a] MOR[b]	Standard deviation	95% C.I.
			(psi (MPa))		(psi (MPa))		(psi (MPa))
Douglas-Fir-Larch	Select Structural	1	5,070 (35.0)	37	7,710 (53.2)	1,180 (8.1)	5,320 to 10,100 (36.7 to 69.7)
	No. 2	1	4,300 (29.7)	37	5,490 (37.9)	1,350 (11.0)	2,740 to 8,230 (18.9 to 56.8)
Southern Pine	Select Structural	1	4,510 (31.1)	33	7,610 (52.5)	770 (5.3)	6,110 to 9,350 (42.1 to 64.8)
	No. 2	1	2,550 (17.6)	36	6,050 (41.7)	750 (5.2)	4,520 to 7,580 (31.2 to 52.3)
Hem-Fir	Select Structural	1	4,010 (27.6)	33	6,130 (42.3)	910 (6.3)	4,260 to 7,990 (29.4 to 55.1)
	No. 2	1	3,730 (25.8)	34	4,550 (3 1.4)	840 (5.8)	2,850-6,250 (19.7-43.1)

[a] n = number of lots; mean = mean value of lots; standard deviation of lots; C.I. = confidence interval.
[b] Mean values at 12 percent moisture content.

values for samples with a large number of specimens can be very narrow. Thus, we chose not to compare data on this basis.

REUSE OPTIONS

The practicality of recycling lumber depends on establishing viable reuse options. Ideally, reuse options would include using the lumber in the same application from which it was taken (i.e., joist used again as a joist). However, the options for reuse may be restricted by the amount of damage to the piece.

As an example of how the investigated lumber might be reused, an analysis was performed to determine its potential reuse as joist material. Because too few data were available to determine 5th percentile bending strength values, the three species were mixed and mechanical grading was investigated as a means to sort this material. Recall that the 100 pieces were selected to meet the visual requirements of mechanically graded lumber. In general, the allowable characteristics for mechanically graded lumber (e.g., checks, splits, shake, wane, and warp) must meet the same visual grading requirements as those permitted in No. 2 visually graded lumber. Curiously, the split limitation for mechanically graded lumber is 1.5 times the width of the piece, and the limit for visually graded Select Structural and No.1 grades is equal to the width of the piece. No rationale or documentation for these differences could be found. Therefore, pieces limited by splits in the visual grading system might not be limited in the mechanical grading system.

To investigate the efficiency of using mechanical grading, a computer simulation was used to sort the 100 pieces of lumber into selected mechanical grades **(Table 7).** All pieces, regardless of species, were graded into four visual quality levels (VQL) according to visual requirements for western lumber (13). In these groupings, knots, holes, burls, distorted grain, or decay partially or wholly at the edges of the wide face cannot occupy more of the cross section than shown in **Table 8.**

The MSR process is composed of grading and quality-control testing (5). Grading involves the assessment of visual characteristics and the measurement of MOE (13). Quality-control testing verifies the measured MOE and the predicted strength. Our computer simulation first checked the visual characteristics for a given grade, then MOE, finally the measured MOR.

For a given grade, the minimum acceptable MOE is 0.82 times the average grade MOE. Finally, the MOR must be as least 2.1 times the allowable bending strength for the grade.

As shown in **Table 7,** grade yield is low if a higher mechanical grade (2250f-1.9E) is targeted. Based only on VQL and MOE, about 53 percent of the lumber would meet this grade; however, only 11 percent of the graded material would qualify based upon MOE, VQL, and MOR. For a lower mechanical grade (1350f-1.3E), the yields were significantly greater. About 97 percent of the pieces would qualify for this grade based on VQL and MOE, and 39 percent would qualify based upon MOE, VQL, and MOR.

Properties of the lumber grades generated from the computer simulation were compared with the requirements for both ceiling and floor joists currently used in residential construction. The grade of the lumber assumed was 1350f-1.3E **(Table 7).**

CEILING JOISTS

Design criteria for ceiling joists typically include a 20-psi live load, 10-psi dead load, and an L/240 deflection limitation. After consulting an allowable span table (1) for joists and rafters, we determined that the allowable span could be up to 22 feet 1 inch if the joists were spaced at 16 inches. This is not an efficient use for these joists because with end trim they are only 16 feet long.

FLOOR JOISTS

A more efficient use of these recycled members would be as floorjoists. Design criteria for floor joists typically assume a 40-psi live load, 10-psi dead load, and an L/360 deflection limitation. Again after consulting the joist and rafter tables, we determined that the recycled 2 by 10's could be used to span 15 feet 3 inches if spaced at 16 inches or 13 feet 0 inch if spaced at 24 inches. Allowing for 1-foot end trim and the need for bearing length over supports, the 16-foot recycled joists would be adequate for this application.

CONCLUSIONS AND RECOMMENDATIONS

Although the sample sizes that were available in this study were rather small, the testing and analysis indicate that lumber recycled from military industrial buildings has potential for reuse in construction applications. Although all the lumber was expected to be Douglas Fir-Larch, the mixture of three species is probably not unusual for such a large building. Stiffness of the lumber was found to be approximately equal to that of current production; however, the strength was less than expected. Because of the historical use as a facility to produce magazines for explosives, it is possible that some form of chemical contamination may have weakened the members in this building. A detailed chemical analysis of wood from the

TABLE 7. —Simulated yield of mechanically graded lumber for 100 2 by 10'S tested at FPL.

	Mechanical grade	
	2250f-1.9E	1350f-1.3E
Maximum visual quality level	1	3
MOE limit = 0.82E	1.56×10^6 psi (10,750 MPa)	1.07×10^6 psi (7,360 MPa)
MOR limit = $2.1F_b$	32.6 psi (4,720 MPa)	19.6 psi (2,830 MPa)
Yield by VQL and MOE	53%	97%
Yield by VQL, MOE, and MOR	11%	39%

TABLE 8. —Visual quality levels.

Visual quality level	Cross section occupied	Allowable bending strength $(F_b)^a$
		(Psi)
4	1/2	0 to 900
3	1/3	950 to 1450
2	1/4	1500 to 2050
1	1/6	2100 and greater

[a] Allowable properties are legally defined values and are not available in metric units. Appropriate conversions may be obtained by multiplying the F_b values by 0.006895 to convert psi to MPa.

tested members could not prove or disprove this possibility.

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

· The use of recycled lumber offers an opportunity for supplementing the U.S. supply of structural lumber.

· For visually graded lumber, the MOE of the lumber from building 503 at the TCAAP was found to be similar to that which would be expected from lumber produced today. Thus, the lumber would be suitable for applications where resistance to excessive deflections are of primary importance.

l Bending strength of the lumber from building 503 was somewhat less than the bending strength of lumber produced today. However, the small sample size, coupled with the possibility of strength degradation resulting from chemical contamination prevents general adoption of this conclusion.

· Follow-up studies should be conducted using dimension lumber from buildings where chemical, or thermal, degradation is known not to be a problem. Larger sample sizes should be used for testing.

l Reuse options for the lumber investigated in this study include ceiling or floor joists; however, the mechanical grading scheme used to sort this material produced a very low yield of material suitable for these end uses.

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