Committee Name:
Assembly Committee – Rural Affairs and Forestry (AC–RAF)

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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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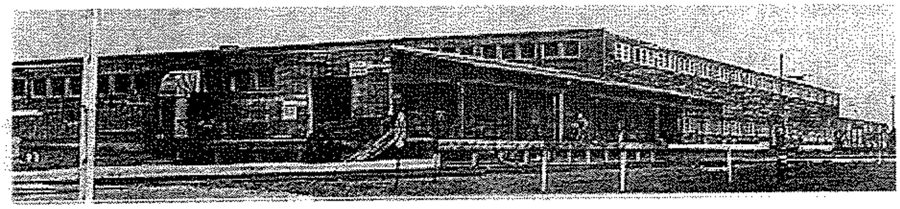

Figure 1. — Building 503 at Twin Cities Army Ammunition Plant, Arden Hills, Minn.

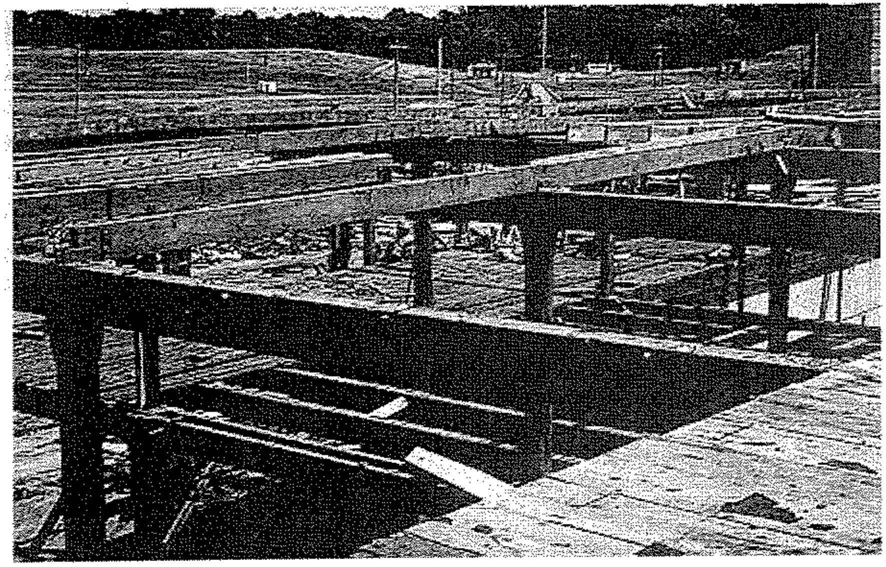

Figure 2. — Building 503; dismantlement in progress.

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 1-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.

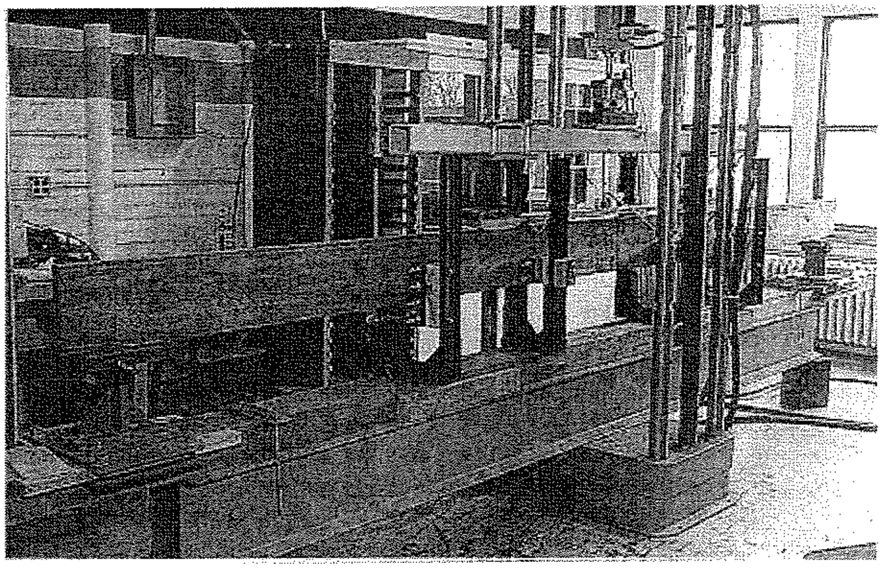

Figure 3. — Bending test of 2 by 10.

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]
		(%)	(× 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
			(× 10^6 psi (MPa))		(× 10^6 psi (MPa))		(× 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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EFFECT OF DAMAGE ON THE GRADE YIELD OF RECYCLED LUMBER

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DALE STANSBURY

ABSTRACT

In the past, building disposal has focused on demolition. However, there is an increased interest in finding a more environmentally acceptable means of disposal that focuses on material recovery and reuse. This paper is a summary of the results of visual grading performed on lumber salvaged from four buildings deconstructed at the U.S. Army's Fort Ord in California. Several sizes of lumber were collected for grading: 184, 2- by 4-inch(38- by 89-mm) wall studs and rafter ties; 275, 2-by6-inch (38-by 140-mm) roof rafters; 504, 2- by 8-inch (38- by 184-mm) floor joists; and 46, 2- by 10-inch (38 by 235-mm) floor joists. Results indicate that damage affected the grade of more than a third of the lumber. Nail holes accounted for the highest occurrence of grade reduction (36%), and edge damage reduced the grade of 26 percent of the lumber. With careful deconstruction practices, the yield of high grades of lumber can be increased, resulting in the maximum value from material resale.

During the past several decades, building disposal has focused on demolition, where the building is demolished and the debris is placed in a landfill. Interest has been growing in finding more environmentally acceptable means of disposal that focus on material recovery and reuse. Recent studies indicate that building deconstruction (or building dismantlement) can be a viable alternative to demolition.[1,2] Deconstruction requires more labor than does demolition, which tends to be machine intensive. The use of labor affects both the cost and required performance period for building disposal. Although deconstruction takes longer than demolition, the cost of deconstructing a building can be offset by the value of the recovered materials. The value of these materials will depend on the establishment of reuse options and resale markets. Lumber is often a large component of the materials recovered from building deconstruction.

There are several potential advantages to reusing recycled lumber. Because much of this lumber was cut from old-growth timber, it may have tighter grain structure. Also, being relatively dry, there is less tendency for the lumber to warp on the job site. From an environmental perspective, this material is attractive because if reused, it carries with it half the embodied energy (total energy costs to produce a material) of new lumber. However, little is known about the quality of lumber extracted from these buildings, the amount of damage inflicted on the lumber from deconstruction, and the effect of damage on grade yield and engineering properties.

The Fort Ord Reuse Authority (FORA) formed a cooperative research agreement with the USDA Forest Service, Forest Products Laboratory (FPL), and the West Coast Lumber Inspection Bureau (WCLIB) to develop information on the quality of lumber reclaimed from deconstructed buildings at Fort Ord. As a first step in determining reuse options for reclaimed lumber, this study was devel-

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[2] Kreitner, P. 1996. Case study: building deconstruction for resuse and recycling the Presidio of San Francisco, buildings 901 and 283, Wood Resource Efficiency Network, Portland, Oreg.

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† Forest Products Society Member.

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TABLE 1. – Lumber size distribution.

Size	Pieces	Percent	Volume		Percent
			(BF)	(m^3)	
2 by 4	184	18.2	780	(1.8)	8.0
2 by 6	275	27.3	2,230	(5.3)	23.0
2 by 8	504	50.0	6,070	(14.3)	62.6
2 by 10	46	4.5	620	(1.5)	6.4
Total	1,009	100.0	9,700	(22.9)	100.0

TABLE 2. – Lumber size distribution by building.

	Lumber size	Pieces	Percent
Building 21	2 by 4	40	4.0
One-story clinic	2 by 6	--	--
	2 by 8	160	15.9
	2 by 10	10	10.0
	Total	210	20.8
Building 1807	2 by 4	27	26.8
One-story classroom	2 by 6	--	--
	2 by 8	90	8.9
	2 by 10	--	--
	Total	117	11.6
Building 2143	2 by 4	--	
Two-story barracks	2 by 6	134	13.3
	2 by 8	210	20.8
	2 by 10	36	3.6
	Total	380	37.7
Building 2252	2 by 4	117	11.6
Shop building	2 by 6	141	14.0
	2 by 8	44	4.4
	2 by 10	--	--
	Total	302	29.9
Total		1,009	100.0

TABLE 3. – Distribution of prior lumber usage (all buildings).

Prior usage	Pieces	Percent	Volume		Percent (by volume)
			(BF)	(m^3)	
Floor/ceiling joists	463	45.9	5,390	(12.7)	55.6
Rafters	275	27.3	2,230	(5.3)	23.0
Rafter ties	27	2.7	220	(0.5)	2.3
Stringers	87	8.6	1,290	(3.0)	13.3
Truss braces	96	2.9	80	(0.2)	0.8
Wall studs	61	12.6	490	(1.2)	5.0
Total	1,009	100.0	9,700	(22.9)	100.0

oped to: 1) assess the quality of lumber salvaged from these buildings through a grade yield evaluation: and 2) investigate the effects of damage on grade yield. An ongoing experimental study is evaluating the engineering properties of the lumber graded in this study.

FORT ORD DECONSTRUCTION PROJECT

The 1994 closure of the Fort Ord U.S. Army Military Reservation in Marina, Calif., left more than 28,000 acres and more than 7,000 buildings to be programmed for civilian reuse. An additional 1,200 buildings at Fort Ord do not meet current building code requirements or contain remnant hazardous materials that require abatement. The cost of demolition and removal of the buildings on site has been estimated to exceed $100 million.

FORA developed a specialized program that would test the feasibility of a more environmentally preferable approach to building disposal than landfilling. This deconstruction project focused on distinct building types and monitored the cost, timing, and job creation involved in building disassembly, material collection, and material reuse. This effort is documented in a FORA report[3]

BUILDING DESCRIPTION

Four buildings that were deconstructed yielded lumber for this study. These buildings are representative of 740 other buildings requiring disposal on site. Building 21 was a 2,300-ft.^{2} (210-m^2), single-story wood-frame building that had served as a dental clinic. Approximately 150 buildings of this type exist at Fort Ord. Building 1807 was an 11,500-ft.^{2} (1070-m^2), single-story wood-frame building that was used as a classroom and is similar to 180 other buildings on site. Building 2143 was a 4,720-ft^2 (440-m^2), two-story wood-frame barracks built in 1940. Approximately 385 buildings of this type remain. Building 2252 was a 22,000-ft.^{2}(2040-m^2), single-story wood-frame shop. Only one bay (about 10%) of this building was deconstructed because other bays were similar. This building was representative of approximately 25 similarly constructed buildings at Fort Ord. The deconstruction process performed by FORA preserved all lumber from the deconstructed buildings. However, only the structural lumber was evaluated in this study (i.e., 2- by 4-in. (38- by 89-mm), 2-by 6-in. (38- by 140-mm), 2- by 8-in. (38- by 184-mm), 2- by 10-in. (38 by 235-mm)(hereafter referred to as 2 by 4, 2 by 6, 2 by 8, and 2 by 10)). The structural lumber represented about 40 percent of the total lumber in the buildings. This percentage was quite consistant regardless of building type.

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[3] Fort Ord Reuse Authority. 1997. Pilot deconstruction project, final report. FORA, Marina, Calif.

[4] West Coast Lumber Inspection Bureau. 1996. Standard No. 17, Grading rules for West Coast lumber, rev. WCLIB, Portland, Oreg.

TABLE 4. – Grade distribution, accounting for damage, 910 pieces.

Grade	All sizes	2 by 4		2 by 6		2 by 8		2 by 10	
	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
Structural Joists and Planks									
Select Structural	5.5	--	--	13	4.7	36	7.2	0	0
No. 1	17.9	--	--	64	23.3	92	18.4	1	2.2
No. 2	46.8	--	--	135	49.1	250	49.9	38	82.6
No. 3	13.0	--	--	47	17.1	70	14.0	4	8.7
Economy (< No. 3)	7.9	--	--	16	5.8	53	10.6	3	6.5
Light Framing									
Construction	2.4	22	25.0	--	--	--	--	--	--
Standard	6.5	59	67.1	--	--	--	--	--	--
Utility	0.7	6	6.8	--	--	--	--	--	--
Economy	0.1	1	1.1	--	--	--	--	--	--
Total	100.0	88	100.0	275	100.0	501	100.0	46	100.0

GRADING METHODOLOGY

The lumber selected at Fort Ord was visually assessed for structural grade by a certified WCLIB Grading Supervisor according to Standard No. 17, Grading Rules for West Coast Lumber.[4] The WCLIB is one of six rules-writing agencies recognized by the American Lumber Standards Committee. The lumber was graded twice in this study:

1. Grade reduction as a result of damage: The full length of each piece of lumber was graded according to the noted grading rules, and notes were taken as to what type of defect or lumber characteristic determined the grade (e.g., knots, slope-of-grain, wane, warp, damage). For those pieces where damage was the grade-determining defect, the grader also made an estimate of grade assuming the damage was not present. This provided an estimate of average grade reduction as a result of damage. For this first grading, the 2 by 4 lumber was graded as Light Framing. The Light Framing designation applies to lumber 2 to 4 inches thick and 2 to 4 inches wide. Four grades exist under this designation (listed from highest to lowest quality): Construction, Standard, Utility, and Economy. The 2 by 6, 2 by 8, and 2 by 10 lumber were graded as Structural Joists and Planks. The Structural Joists and Planks designation applies to lumber 2 to 4 inches thick, 5 inches and wider. Four grades exist under this designation (listed from highest to lowest quality): Select Structural, No. 1, No. 2, and No. 3.

2. Grade yield with end trimming: For each piece with a localized grade-determining defect, an evaluation was made to determine if trimming the lumber would increase grade or if multiple pieces of higher grade could be cut from the graded piece. For this second grading, the 2 by 4 lumber was graded as Structural Light Framing. The Structural Light Framing designation applies to lumber 2 to 4 inches thick, 2 to 4 inches wide. Similar to Structural Joists and

TABLE 5. – Grade-determining factors (910 pieces).

Reason	No.	Percent
Knots	372	40.9
Damage[a]	345	37.9
Shakes	45	5.0
Splits (due to drying)	27	3.0
Wane	3	0.3
Slope-of-grain	13	1.4
Warp	2	0.2
Checks	2	0.2
Meets highest grade[b]	50	5.5
Other[c]	51	5.6
Total	910	100.0

[a] Includes holes caused by nails or bolts, splits caused by factors other than drying, saw cuts, notches, decay and termite damage, and mechanical damage (e.g., gouges, broken ends, missing sections as a result of splits).

[b] No reason recorded because piece met highest grade requirements.

[c] Includes drying defects, skip, grain distortion, dimensional variation, white speck, and twist.

TABLE 6. – Damage in graded lumber.

Damage type	Reason	Percentage of damaged pieces (345 total)
Type I	Nail holes	36.2
	Bolt holes	5.5
	Notching, saw cuts	5.4
Type II	Decay, termites	7.8
Type III	Splits (due to disassembly)	7.5
	Edge damage	26.7
	End damage	10.7
	Total	100.0

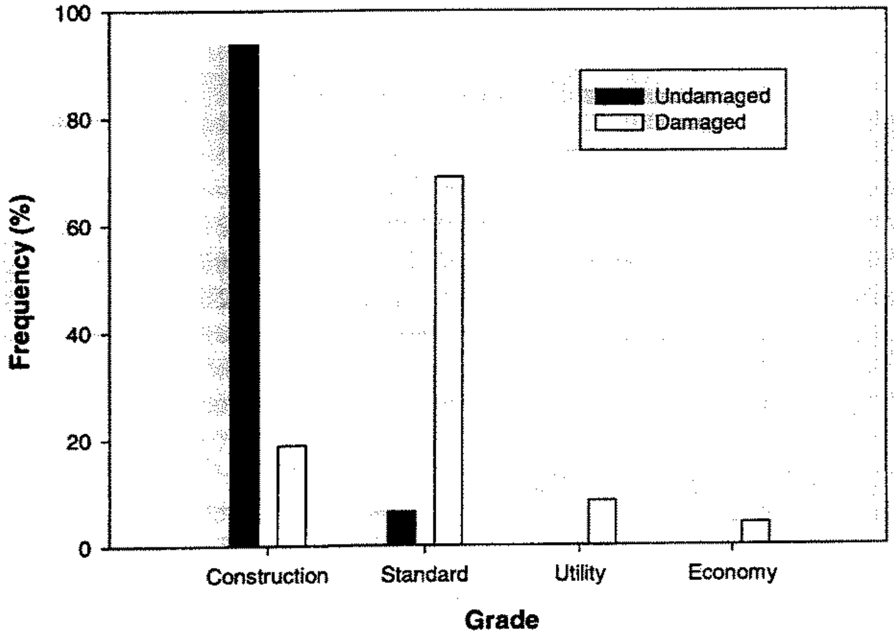

Figure 1. – Grade reduction as a result of damage, 2 by 4's, all forms of damage.

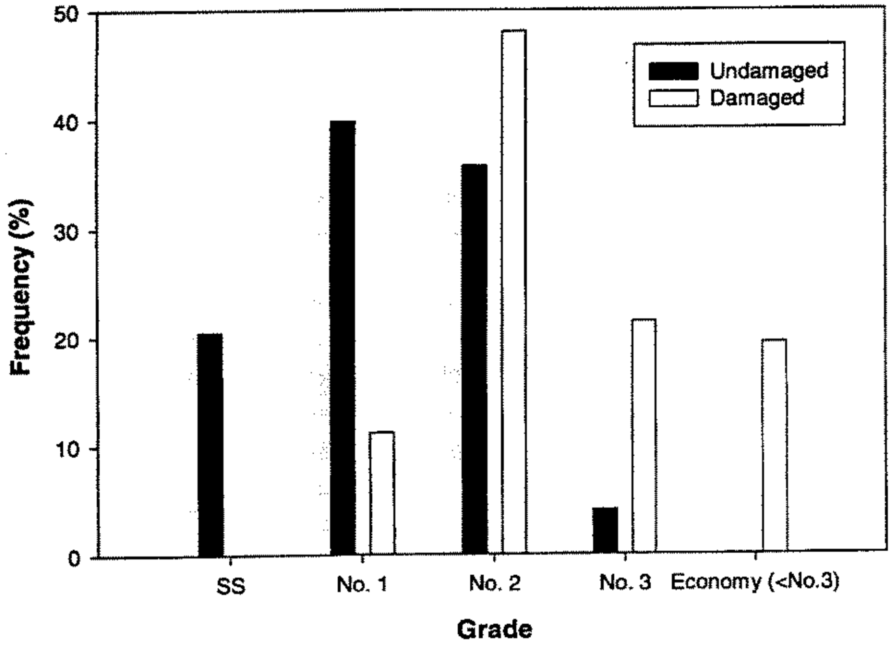

Figure 2. – Grade reduction as a result of damage, 2 by 6's, all forms of damage.

Planks, four main grades exist under this designation (listed from highest to lowest quality): Select Structural, No. 1, No. 2, and No. 3. For this second grading, the 2 by 6, 2 by 8, and 2 by 10 lumber were again graded as Structural Joists and Planks.

For purposes of this study, damage was defined as: holes as a result of nails or bolts, splits caused by factors other than drying, saw cuts, notches, decay, and mechanical damage (gouges, broken ends, missing sections due to splits, etc.). When nail holes were present in the piece, the grader summed up the nail holes and equated this area to an equivalent knot size for grade determination. For bolt holes, the grader allowed holes half the size of an allowable knot for a given grade (a common rule of thumb).

In this paper, reference is given to a designation: Economy (< No. 3). This is not an official WCLIB grade; however, the designation is used for comparative purposes to indicate those pieces that did not meet the lowest No. 3 grade for Structural Joists and Planks or Structural Light Framing.

Also, some pieces were painted and could not be graded (paint can obscure critical defects in lumber, such as slope-of-grain and knots).

LUMBER QUANTITY AND SPECIES

Table 1 indicates that most of the lumber from the buildings were 2 by 6's or 2 by 8's. Of the 1,009 pieces graded, about 30 percent came from Building 2252, 38 percent from Building 2143, 21 percent from Building 21, and 11 percent from Building 1807 (**Table** 2). Because of the West Coast location, it was expected that most lumber would be of the Douglas-fir species. Douglas-fir was found to be the predominate species (92% of total), although some hem-fir (6%) and sugar pine (2%) were also present, probably resulting from repair work.

LUMBER USAGE

Depending on lumber size and building type, the pieces graded had been used as different structural elements. As shown in **Table 3,** most pieces had been used as floor joists or rafters. All the 2 by 10's graded had been used as ceiling or floor joists, and all the 2 by 6's had been used as rafters. The 2 by 8's had been used either as floor joists or as stingers. The 2 by 4's had been used in various applications, including wall studs, rafter ties, or truss braces.

LUMBER GRADES

Ninety-six 2 by 4's were shorter than 7 feet (2.1 m) in length. Although shorter pieces of lumber might be reused as web members in trusses, typically the shortest piece of commodity lumber purchased for platform-framed construction is a trimmed stud with a length of 92-5/8 inches (2.35 m). For this reason, we do not think there is a large market value for material shorter than 7 feet (2.1 m) and decided not to grade these pieces. This left 910 pieces that were graded.

As shown in **Table 4,** most of the 2 by 4's (67.1%) qualified for the Standard grade, and 25.0 percent fell into the Construction grade. For the 2 by 6, 2 by 8, and 2 by 10 lumber, 49.1, 49.9, and 82.6 percent, respectively, fell into the No. 2 grade. **Table 5** indicates that the predominant factors for grade determination were knots and damage. Knot size determined grade in 40.9 percent of the pieces, and damage determined grade in 37.9 percent of the pieces.

EFFECTS OF DAMAGE

From a structural use standpoint, the most distinguishing feature of recycled wood (compared with freshly sawn lumber) is the presence of damage. This damage may be a result of: 1) the original construction process (nail holes, bolt holes, saw cuts, notches) (Type I); 2) building use (drying defects, decay and termite damage) (Type II); and/or 3) the deconstruction process (edge damage, end damage, end splitting, and gouges) (Type III).

It is desirable to minimize damage so that yields of high-grade lumber can be maximized. In an existing building, it is not possible to change the amount of Type I or Type II damage, because it is pre-existing. It may be possible to minimize Type III damage, however. Note that edge damage, end damage, end splitting, and gouges are all listed as Type III damage. In evaluating the lumber in this study, in some cases it could not be determined if the damage resulted from the deconstruction process or if it was pre-existing. For this reason, data presented will serve as an upper bound estimate of the damage as a result of deconstruction. In other words, for the deconstruction process used in these buildings, the damage as a result of deconstruction should not be greater than presented here.

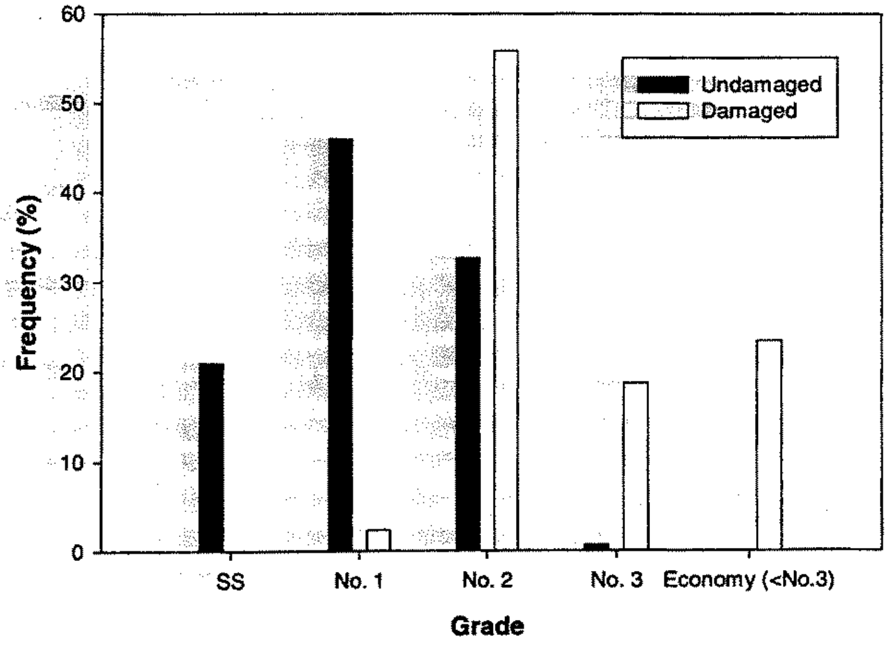

Figure 3. – Grade reduction as a result of damage, 2 by 8's, all forms of damage.

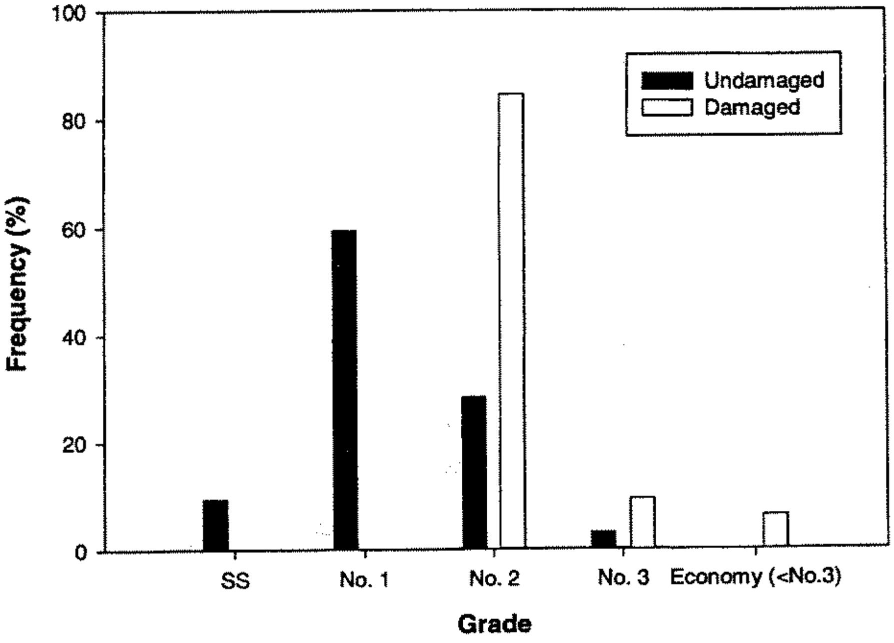

Figure 4. – Grade reduction as a result of damage, 2 by 10's, all forms of damage.

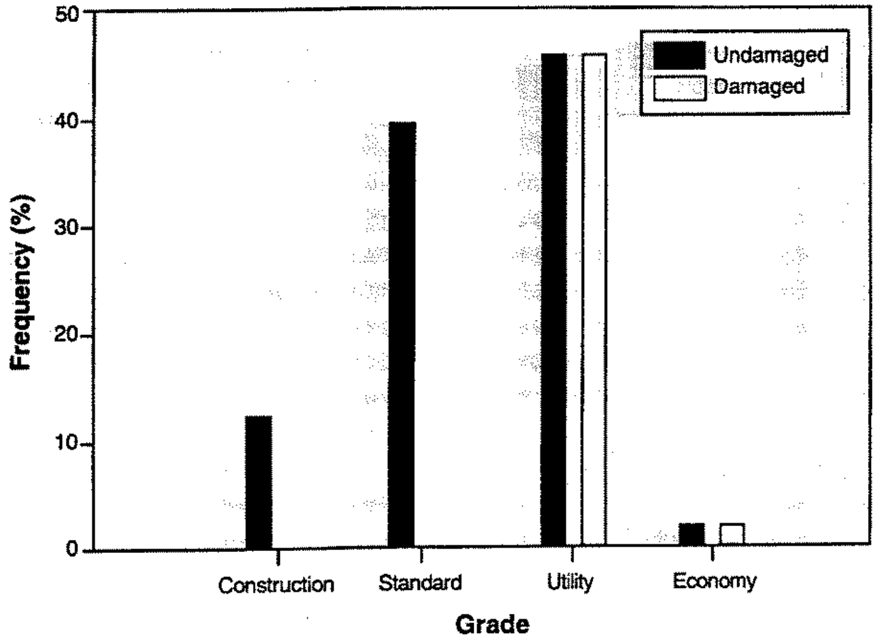

Figure 5. – Grade reduction as a result of damage, 2 by 4's, deconstruction damage only.

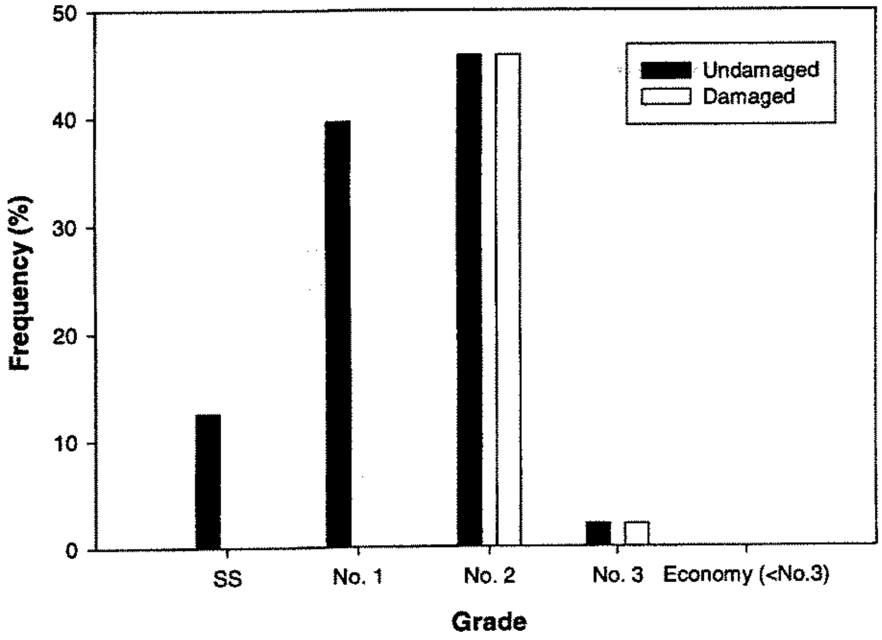

Figure 6. – Grade reduction as a result of damage, 2 by 6's, deconstruction damage only.

As indicated in **Table 5,** damage affected the grade of more than a third of the lumber evaluated in this study. **Table 6** indicates that for the 345 pieces in which damage determined grade, the presence of nail holes was the predominate reason (36.2%). Edge damage accounted for 26.7 percent of the damaged pieces.

Edge damage (similar to wane) was the most common form of deconstruction damage (Type III) to the lumber. It is likely that this damage resulted while removing floorboards from the joists and roof sheathing from roof rafters.

Figures 1 through **4** show the reduction in grade as a result of damage in 2 by 4's, 2 by 6's, 2 by 8's, and 2 by 10's, respectively. For all forms of damage (Types I, II, III), the figures indicate 1) the grades of lumber (as graded, including damage) and 2) the grades of lumber if no damage existed (undamaged). As expected, for all sizes of lumber, when damage exists, the grade was reduced.

Figures 5 through **8** indicate the effect of only deconstruction damage (Type III) on the grades of lumber evaluated.

DAMAGE BY USAGE

The data collected allowed an evaluation of the amount of damage based upon usage. As shown in **Table 7,** for nearly all sizes and usages, nail holes and edge damage predominated. An exception was the joists, especially the 2 by 10's, where notches, holes, and/or sawcuts appeared more frequently than did edge damage. This is not surprising, as joists are more likely to be modified during construction (to accomodate utilities and plumbing) than other member types.

In general, decay was found to occur more frequently in joists than in other members. This was expected because first-floor joists are closer to the ground than are other members. In addition, some joists in bathroom areas were decayed due to water leakage.

TRIMMING DEFECTS TO INCREASE GRADE

The second grading indicated the yield of lumber based upon trimming each piece to eliminate grade-determining defects. In some cases, it may be worthwhile to trim a defect from a piece to increase grade yield. However, this will result in shorter pieces. If the market prices of various grades of used lumber are known, the information in **Table 8** can be used to determine if a longer/

lower grade piece is more valuable than a shorter/higher grade piece.

Note that the 2 by 4's were graded as Structural Light Framing. Overall, the results indicated that the grade of about 18 percent of the lumber is affected by trimming. Specifically, 8.7 percent of the 2 by 10's, 21.2 percent of the 2 by 8's, 15.6 percent of the 2 by 6's, and 15.9 percent of the 2 by 4's were affected by trimming. On average, trimming increased the grade of the pieces by one grade, except for the 2 by 4's, which increased an average of two grades. To obtain this grade increase, some loss of length was required. On average, the 2 by 4's required a 2.4-foot (0.7-m) trim, and the other sizes required approximately a 3.0-foot (0.9-m) trim.

For some of the longer lumber, it was feasible to trim such that two pieces of higher grade could be obtained. Although only about 1 percent of the members yielded two lengths of lumber after trimming, an average increase of one grade was possible, with a required length reduction between 1.0 and 3.0 feet (0.3 to 0.9 m) **(Table 8).** The effect of trimming on grade yield is summarized in **Table 9.** A comparison of trimmed compared with untrimmed grade yield for the 2 by 8's **(Fig. 9)** indicates that the yield of the higher grades can be increased with trimming.

CONCLUSIONS

The following general conclusions can be drawn from the lumber grading study conducted at Fort Ord:

- The predominate grade of the 2 by 6, 2 by 8, and 2 by 10 lumber was No. 2. The predominate grade of the 2 by 4 lumber was Standard.

- The prevailing grade-determining defects were knots and damage. The most frequent forms of damage were nail holes and damage to the edge of the members. Damage affected the grade of about a third of the lumber.

- Damage reduced the lumber quality one grade, on average.

- Lumber degrade, as a result of damage in the deconstruction process, could be lessened by reducing the edge damage to joists and rafters. Careful removal of the floor underlayment and roof sheathing could help minimize this form of damage. Also, careful removal of the end nails from joists and rafters (i.e., not prying the joists and rafters free, where pos-

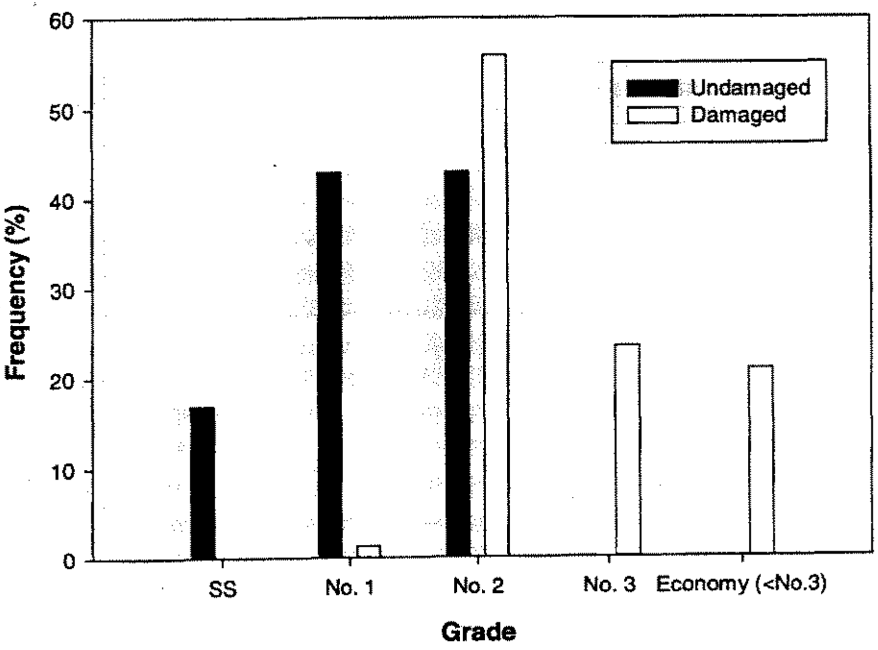

Figure 7. – Grade reduction as a result of damage, 2 by 8's, deconstruction damage only.

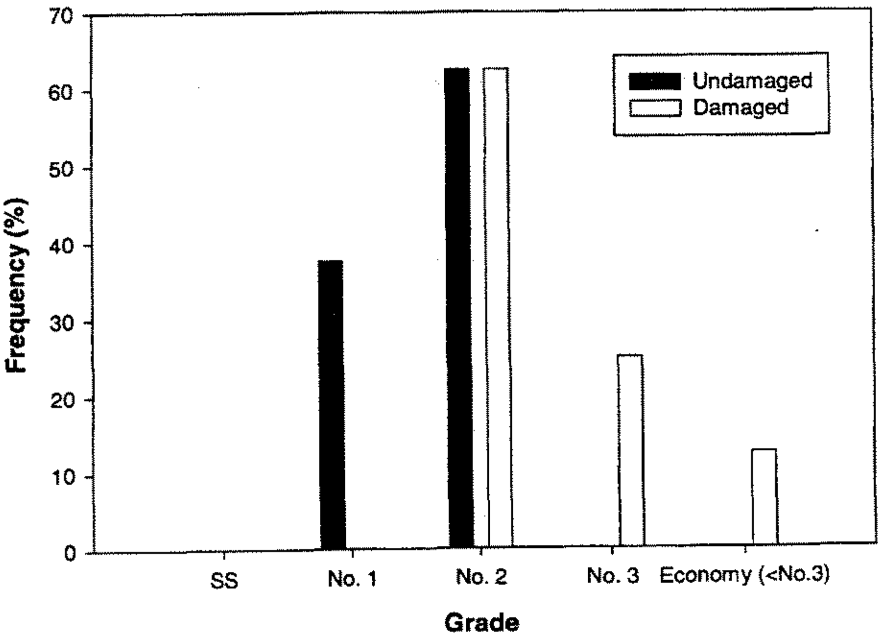

Figure 8. – Grade reduction as a result of damage, 2 by 10's, deconstruction damage only.

TABLE 7. – Amount of damage by usage.

	Size and usage											
	2 by 4				2 by 6		2 by 8				2 by 10	
Damage type	Wall studs		Rafter ties		Rafters		Joists		Stringers		Joists	
	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
Decay	2	6.1	--	--	5	5.1	17	13.3	2	4.1	1	3.1
Edge damage	5	15.1	1	25.0	30	30.2	27	21.1	23	46.9	6	18.8
End damage	2	6.1	--	--	5	5.1	7	5.5	5	10.2	1	3.1
Edge/end damage	--	--	--	--	6	6.1	10	7.8	--	--	1	3.1
Notch/holes/sawcut	3	9.1	--	--	7	7.1	15	11.7	3	6.1	10	31.3
Nail holes	21	63.6	3	75.0	35	35.3	40	31.3	13	26.5	13	40.6
Splits	--	--	--	--	11	11.1	12	9.4	3	6.1	--	--
Total	33	100.0	4	100.0	99	100.0	128	100.0	49	100.0	32	100.0

TABLE 8. – Effect of trimming defects.

	Trim to yield one piece					Trim to yield two pieces		
Size	No.	Percent of total	Avg. grade increase (no. of grades)	Avg. length reduction		No.	Avg. grade increase (no. of grades for both pieces)	Avg. length reduction
				(ft.)	(m)			(ft.)
2 by 10	4	8.7	1	3.0	(0.9)	--	--	--
2 by 8	107	21.2	1	3.0	(0.9)	4	1	1.0
2 by 6	43	15.6	1	2.9	(0.88)	1	1	3.0
2 by 4	14	15.9	2	2.4	(0.7)	4	2	2.0

TABLE 9. – Grade distribution if trimmed.

Grade	All sizes	2 by 4		2 by 6		2 by 8		2 by 10	
	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)	(no.)	(%)
Select Structural	8.1	6	6.8	14	5.1	54	10.8	0	--
No. 1	20.1	9	10.2	66	24.0	108	21.6	1	2.2
No. 2	53.9	52	59.1	146	53.1	254	50.7	40	87.0
No. 3	14.1	15	17.1	40	14.5	66	13.2	4	8.7
Economy (< No. 3)	3.8	6	6.8	9	3.3	19	3.8	1	2.2
Total	100.0	88	100.0	275	100.0	501	100.0	46	100.0

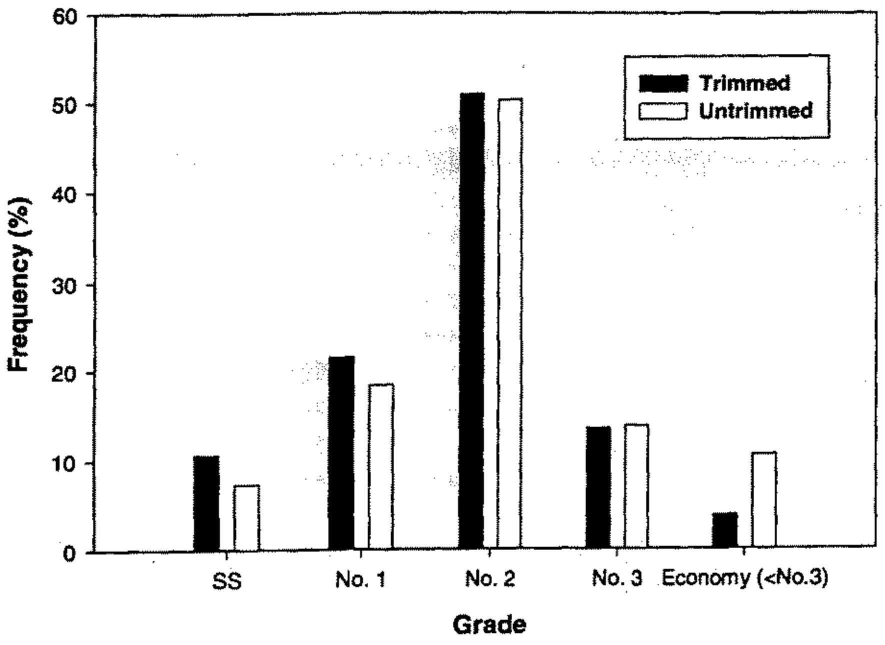

Figure 9. – Grade distribution: trimmed compared with untrimmed 2 by 8's.

sible) could help minimize this form of damage.

- Trimming increased the grade of about 18 percent of the lumber. On average, trimming increased the grade of the pieces by one grade; however, some loss of length resulted. On average, the 2 by 4's required a 2.4-foot (0.7-m) trim, and the other sizes required a 3.0-foot (0.9-m) trim.

END

END

ENGINEERING EVALUATION OF 55-YEAR-OLD TIMBER COLUMNS RECYCLED FROM AN INDUSTRIAL MILITARY BUILDING

ROBERT H. FALK†
DAVID GREEN†
DOUGLAS RAMMER
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ABSTRACT

A large sample of timber was collected from a 548,000-ft.^{2} (50,900-m^2) World War II era industrial military building containing approximately 1,875,000 board feet (4,400 m^3) of lumber and timber. Sixty 12-foot- (3.6-m-) long, nominal 8- by 8-inches (190- by 190-mm) Douglas-fir columns were tested at the USDA Forest Service, Forest Products Laboratory, and the results were compared with the National Design Specification allowable design capacity. The effects of seasoning checks and splits on residual column strength are presented. Results indicate that about one-third of the columns were downgraded due to in-service defects, such as checks, splits, and mechanical damage. Both the modulus of elasticity and compressive strength were found to be greater than today's design values.

In the early 1990s, the U.S. Army made a decision to shut down military manufacturing operations at its Twin Cities Army Ammunition Plant near St. Paul, Minn. Two large buildings, representing more than 900,000 ft.^{2} (83,600 m^2) of manufacturing space, were successfully dismantled, and a substantial volume of the wood materials was recycled. As a part of this deconstruction effort, a sample of lumber and timber was collected from one industrial building, a 548,000-ft.^{2} (50,900-m^2) structure that had been used for small-caliber ammunition manufacturing (building 503). Approximately 35,000 board feet (BF) (82 m^3) were obtained, including 2- by 10-inch (38- by 235-mm), 6- by 8-inch (140- by 191-mm), 8- by 8-inch (190- by 190-mm), 6- by 14-inch (140- by 340-mm), and 10- by 18-inch (240- by 445-mm) lumber and timber (hereafter called 2 by 10's, 6 by 8's, 8 by 8's, 6 by 14's, and 10 by 18's). According to lumber grading rules, "lumber" (or "dimensional lumber") is material 2 to 4 inches (51 to 102 mm) in thickness, whereas "timbers" are typically 5 inches (127 mm) and greater in thickness. A previous article describes the results of testing 2 by 10's collected from this building (5). This article describes the results of testing the collected 8 by 8's.

During the evaluation of old wood buildings, engineers are confronted with members containing severe drying checks or splits. The question is often asked if these checks and splits affect the residual strength of the members. Because the timbers were installed green in building 503, some members exhibited severe drying checks and splits. The objectives of this study were to determine the effects of these checks and splits on residual column capacity and to determine how the engineering properties of this 55-year-old timber compared with today's design values.

BACKGROUND

As our country's building infrastructure ages, there are increasing opportunities to reclaim building materials from

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demolition. Many older (1800 to 1960s) industrial structures, including warehouses, sawmills, and industrial buildings, were built from solid timber. The wood from these structures is increasingly being salvaged for use in new construction; larger-sized timbers are in demand for reuse as structural framing in new timber-frame construction. According to Davis-O'Connell and Smith (4), 24 percent of the wood used by the timber frame industry is recycled. Many customers value not only the recycled nature of this material, but also its unique character, especially the aged patina. Timber framers appreciate that the material is dry and stable when erected into a frame. Depending on the original use of the timber, splits, checks, bolt holes, and other defects may also affect the aesthetics, and possibly the structural capacity, when timber is reused.

During the last decade, many U.S. military facilities have been classified as excess to our nation's defense needs. Two World War II era wood-framed industrial buildings at the U.S. Army's Twin Cities Army Ammunition Plant were two such structures. These large buildings were dismantled as a case study to determine if recycling is a feasible alternative to conventional demolition and landfilling (6,7).

A large sample of timber was collected from building 503, a 548,000-ft.^{2} (50,900-m^2) building containing approximately 1,875,000 BF (4,400 m^3) of lumber and timber. Building 503 had been used for the manufacture of small-caliber ammunition. Although the building contained an extensive amount of machinery for the forming and assembly of ammunition cartridges, there was no evidence that excessive heat or moisture had been generated in the portion of the building where the columns were removed.

Sixty 12-feet- (3.6-m-) long 8 by 8 Douglas-fir columns were collected and shipped to the Forest Products Laboratory (FPL) for testing. These columns had been used to support the mezzanine floor of building 503 (**Fig. 1**). Before dismantlement, we marked specific timbers to be saved for testing. An inspection of the building indicated that the timber had been installed green, and many members had developed significant drying checks and/or splits. To investigate the effect of these defects on column strength, we selected 30 members that were considered "checked" and 30 members considered "unchecked." Although the selection criteria were rather qualitative, a member typical of what we considered to be checked is shown in **Figure 2**.

Figure 1. — The 8- by 8-columns supporting the mezzanine floor of building 503.

TABLE 1. — Selected limiting characteristics for 8 by 8 Douglas-fir timbers graded as posts and timbers (10).

Grade characteristic	Grade			
	Select Structural	No. 1	No. 2	Utility[a]
Surface seasoning checks[b]	4 in. (102 mm)	4 in. (102 mm)	Unlimited	Unlimited
Knots	1-5/8 in. (41 mm)	2-1/2 in. (64 mm)	3-3/4 in. (95 mm)	Large, unsound or not firmly fixed, not larger than about 3/4 of the width of the face
Holes	Limited pin holes	Limited pin holes	3-3/4 in.	3/4 width of the face
Splits	6 in. (152 mm)	Short splits or equivalent end checks	Medium splits or equivalent end checks	1/4 the length
Wane	1/8 of any face or equivalent	1/4 of any face or equivalent	1/3 of any face or equivalent	1/3 of any face
Slope-of-grain	1:12	1:10	1:6	Unlimited
Shake	1/3 thickness on end	1/3 thickness on end	1/2 length, 1/2 thickness; if through at ends, limited as splits	Full length, if not continuous

[a] WCLIB does not publish assigned design values for this grade.

[b] Seasoning checks in areas at ends, single, or opposite each other are limited to a sum total of value shown.

Detailed load history information did not exist for building 503; however, U.S. Army records did not indicate loading greater than assumed in the original design. Though engineering design information was scarce, the original design drawings for this building called for timber members with 1,200-psi (8.3-MPa) and 1,400-psi (9.7-MPa) bending design stresses. However, as a result of material shortages during the World War II construction period, some of this material did not meet grade because of excessive knots and slope of grain (8).

GRADING

After shipping the 8 by 8's to the FPL in Madison, Wis., the members were visually graded by a grading supervisor from the West Coast Lumber Inspection Bureau (WCLIB) according to Grading Rule No. 17 (10). **Table 1** indicates the grade limitations for these characteristics for nominal 8-inch (203-mm) timber graded as "post and timber." Because of the recycled nature of this material, damage caused by in-service use or from the dismantlement process was encountered. This included mechanical damage (e.g., broken edges of members, damage from fasteners and hardware (e.g., bolt holes, clusters of nail holes), and notches from other framing members or utilities).

EXPERIMENTAL TESTING

The 8 by 8's were covered outdoors for 2 months prior to testing. Because of damage to the ends of many of the members, 12 inches (300 mm) was trimmed from each end, resulting in a 10-foot (3.0-m) column length for testing (*l/d* = 16.3). We did not directly measure a static modulus of elasticity (MOE) for the columns; however, a stress-wave timer was used to measure a dynamic MOE. Using a previously established correlation between static and dynamic MOE for recycled timbers (5), the measured dynamic MOE was converted to a static bending MOE.

The columns were tested, as shown in **Figure 3**, in direct compression with no intermediate lateral support (2). The ends were laterally supported to prevent slippage, although no attempt was made to provide end fixity. Lateral displacement was monitored at mid-span for safety reasons (to monitor buckling), and an ultimate compressive stress was calculated from the maximum load achieved for each column. A constant rate of loading resulted in compression failure in 5 to 10 minutes. After strength testing, small specimens were cut from the members for moisture content measurement, specific gravity determination, and annual ring count.

RESULTS

GRADING

As shown in **Table 2**, 40 percent of the columns qualified for Select Struc-

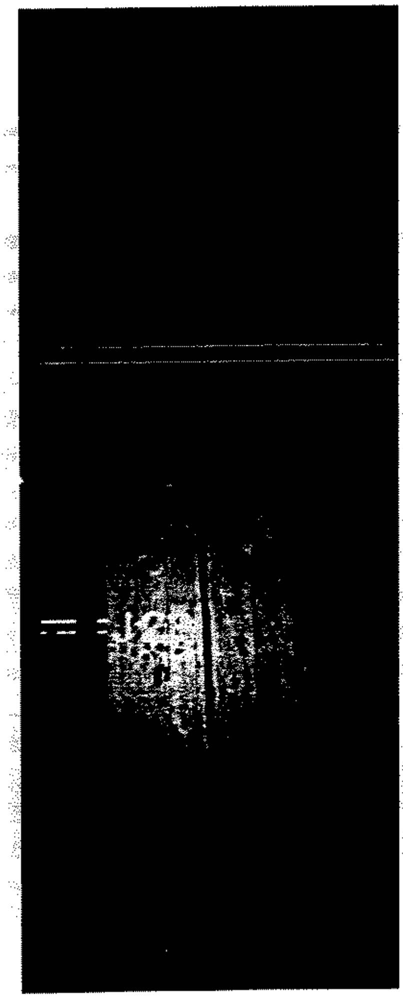

Figure 2.—Typical checked column.

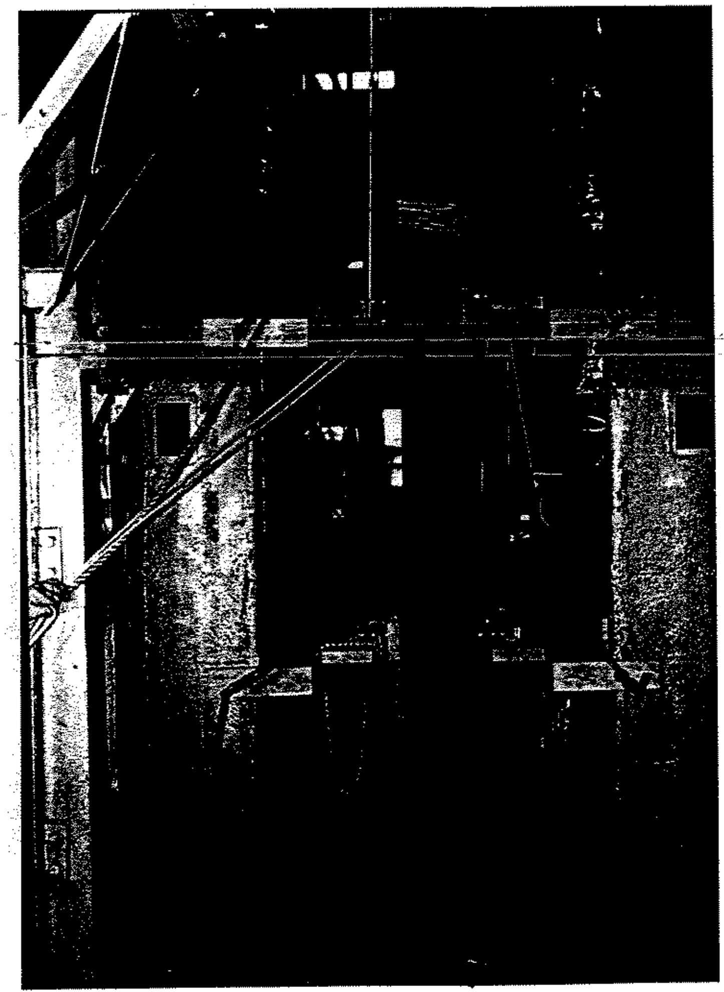

Figure 3. — Testing of column.

tural, 18 percent for No. 1, and 17 percent for No. 2. The balance, 25 percent, was either graded as Utility or was rejected. As indicated in **Table 3**, the most common reason for the timber to be downgraded was the presence of knots, followed by checks and splits, then damage. Roughly a third of the timbers was downgraded because of checks, splits, or damage, those factors we attribute to the recycled nature of the material. The following lists some of the average property values measured for these columns.

n	Avg. MC	COV	Specific gravity	Rings per inch
	----- (%) -----			
58	14.0	18.2	0.44	10.7

Although an attempt was made to select 30 checked and 30 unchecked timbers after the building was disassembled and the columns returned to FPL, it was discovered that some of members that had been marked as unchecked were, in fact, checked. This was not too surprising because utilities and other existing building contents prevented a complete visual inspection of some columns.

Two columns were rejected; that is, they did not meet the Utility grade. The splits in these members were so severe that they nearly fell apart during handling. In spite of this damage, these rejected members were tested and, as explained later, carried a surprising amount of load.

COLUMN CAPACITY

The 60 columns were tested to failure in the 1-million-pound (4.45×10^6 N) test machine in the Engineering Mechanics Laboratory at the FPL. Ultimate loads ranged from about 22,000 to 295,000 pounds (98 to 1312 kN). **Figure 3** shows failure of one column. In spite of the fact that they were nearly split in two pieces, the rejected columns carried 21,800 and 25,900 pounds (97 and 115 kN), respectively. As shown in **Table 4**, the estimated bending MOE for the columns ranged from 1,680,000 psi (11,600 MPa) to 1,910,000 psi (13,200 MPa). Mean compressive strength ranged from 2,810 psi (19.4 MPa) for the Utility grade columns to 3,830 psi (26.4 MPa) for the Select Structural columns.

TABLE 2. — Visual grades of 8 by 8 columns.

Grade[a]	No. in grade	Percentage in grade
Select Structural	24	40.0
No. 1	11	18.3
No. 2	10	16.7
Utility	13	21.8
Reject	2	3.3
Total	60	100.0

[a] Visual grades according to WCLIB grading rule 17.

TABLE 3. — Reasons for visual grade of tested 8 by 8 columns.

Reason	Select Structural	No. 1	No. 2	Utility	Reject	Total	
						(no.)	(%)
Met highest grade	24	--	--	--	--	24	40
Checks, splits	--	--	5	5	2	12	20
Knots	--	11	4	--	--	15	25
Damage	--	--	--	8	--	8	13
Wane	--	--	1	--	--	1	2
Total	24	11	10	13	2	60	100

TABLE 4. — Results for tested columns mean values.

	n	MOE[a]		COV	Mean compressive strength	
		($\times 10^6$ psi)	(MPa)	(%)	(psi)	(Pa)
All columns	58	1.84	12,700	13.1	3,340	23.0
Select Structural	24	1.91	13,180	12.3	3,830	26.4
No. 1	11	1.90	13,110	11.2	3,320	22.9
No. 2	10	1.68	11,590	8.0	2,890	19.9
Utility	13	1.78	12,280	15.9	2,810	19.4

[a] Static bending MOE predicted from stress wave MOE.

COLUMN DESIGN

To compare the strength performance of the recycled timber columns with current allowable design values, the National Design Specification for Wood Construction (NDS) is referenced (1). Wood column design uses a nonlinear interaction between crushing strength and buckling strength to derive allowable design values. For crushing, design values are derived using a coefficient of variation (COV) of strength that varies between 15 and 20 percent for solid-sawn lumber, accompanied by a 1.9 adjustment factor applied to the 5th percentile strength. For buckling, the design equations assume a 25 percent COV for the solid lumber elastic modulus and a 1.66 factor of safety applied to the 5th percentile strength. These adjustments are applied through the K_{cE} variable (see Appendix). Therefore, variability and the safety factor vary with column slenderness.

Although 5th percentile strength values are used as a basis for allowable design values, the limited number of columns available for testing did not allow for a confident calculation of 5th percentile strength for the several grades represented. Therefore, mean column capacities were used for comparisons. We were able to calculate a mean column compression strength (F_c*) with the NDS column interaction by removing the adjustment factors on the compression strength (F_c) and elastic buckling (F_E) values. This is acceptable because column interaction is the same in the design and failure space. For failure space, column interaction is expressed by the following expression:

$$F_c^* = C_p F_c$$

$$C_p = \frac{F_c + F_E}{2c} - \sqrt{\left[\frac{F_c + F_E}{2c}\right]^2 - \frac{F_E F_c}{c}}$$

where:

F_c^* = column compression strength at a specific l/d

$F_E = \frac{\pi^2 E}{12(l/d)^2}$ at the l/d of tested columns

E = shear-free flexural MOE

F_c = compression strength

c = 0.8 for solid-sawn lumber

To calculate F_E, published flexural elasticity values must be adjusted to a shear-free MOE. Also, because we could not use the 8 by 8 columns to determine both compression strength (F_c) and column capacity (f), F_c was not experimentally determined. Therefore, mean compression strength, F_c, was determined using ASTM D 245 procedures (3) for this Douglas-fir-Larch species grouping. This compression strength F_c was calculated for each of the following grades: Select Structural, No. 1, and No. 2. MOE and compression strength values used in the previous interaction expression are listed in **Table 5**.

A comparison of the calculated column strength F_c^* and the column capacity f indicates that the tested columns are a minimum of 40 percent greater in strength than would be calculated by current design methods. This result is consistent with results obtained for dimension lumber in the In-Grade Testing program, where the compression test results were found to be considerably higher than those calculated by ASTM D 245 clear wood (9). A comparison of the tested column strength with design equations graphed over a range of l/d ratios is shown in **Figure 4**.

Zahn and Rammer (11) found a column capacity for Douglas-fir glued-laminated columns (L3 grade) at an l/d ratio of 16 was 3,470 psi (23.9 MPa), a value slightly greater than the tested select structural timbers. (Unpublished data of 4 by 8 columns also indicate similar values.)

EFFECT OF CHECKS AND SPLITS

As explained previously, columns were selected from the building to determine if the checks and splits evident in many of the members affected residual compressive strength. A check is a separation of the wood normally occurring across or through the growth rings (10). Large checks are more than 0.79 mm (1/32 in.) wide or longer than 0.25 m (10 in.), or both. A through check extends from one surface of a piece to the opposite or adjoining surface. A split is a separation of the wood through the piece to the opposite surface of an adjoining surface as a result of tearing the wood cells.

Overall, the mean compression strengths of checked and unchecked columns were the same (**Table 6**). The small sample size for each grade makes definitive conclusions about differences in grade questionable. However, we note that except for Utility grade, the strength of checked columns is at least as high as that of unchecked columns. A plot of compression strengths versus MOE indicates similar results for

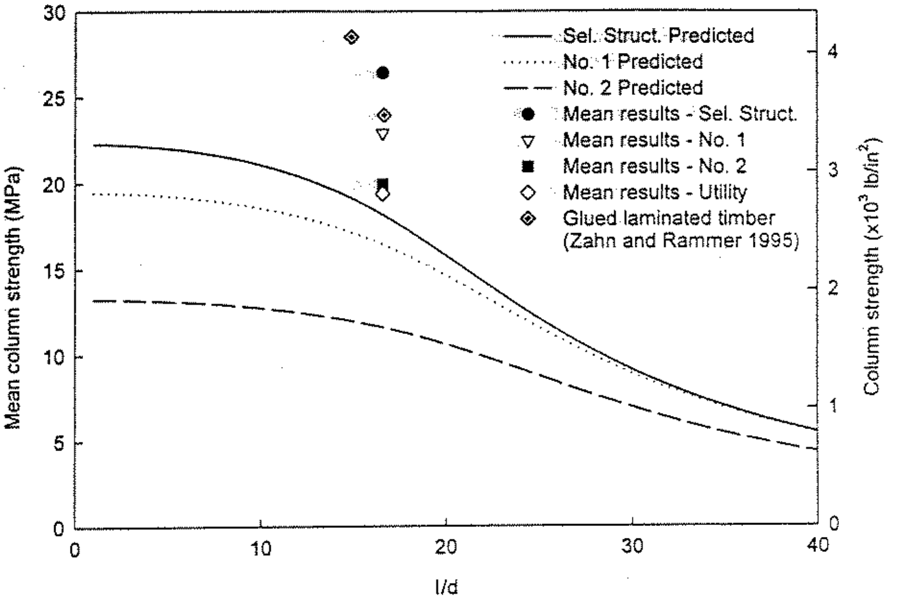

Figure 4. — Comparison of NDS design equations and test results.

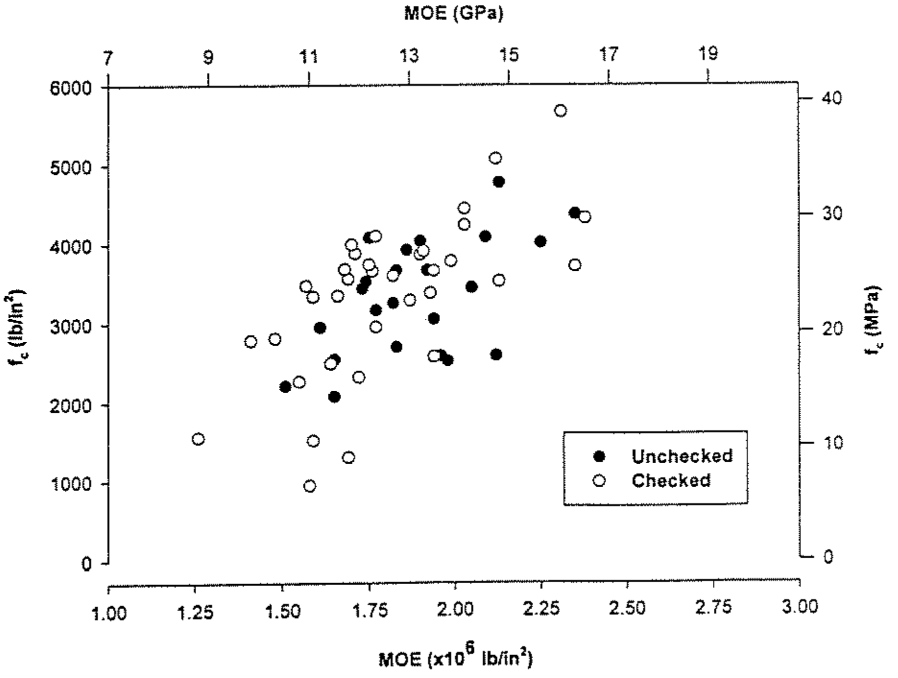

Figure 5. — Checked compared with unchecked column data.

TABLE 5. — Comparison of NDS derived design values with test results.

Grade	NDS derived values						Measured column capacity (f) (2)		Ratio (2)/(1)
	Elastic modulus (E)		Compression strength (F_c)		Calculated column strength (F_c^*) (1)				
	($\times 10^6$ psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	(psi)	(MPa)	
Select Structural	1.65	11,370	3,240	22.3	2,640	18.2	3,830	26.4	1.45
No. 1	1.65	11,370	2,830	19.5	2,380	16.4	3,320	22.9	1.40
No. 2	1.34	9,240	1,930	13.3	1,680	11.6	2,890	19.9	1.72

TABLE 6. — Comparison of column capacity (f) of checked and unchecked columns.

Grade	n	Checked columns (1)		n	Unchecked columns (2)		Ratio (2)/(1)
		(psi)	(MPa)		(psi)	(MPa)	
All grades	35	3,340	23.0	23	3,340	23.0	1.00
Select Structural	12	3,950	27.2	12	3,700	25.5	0.94
No. 1	5	3,340	23.0	6	3,310	22.8	0.99
No. 2	6	3,240	22.3	4	2,360	16.3	0.73
Utility	12	2,790	19.3	1	3,060	21.1	1.10

checked and unchecked columns (**Fig. 5**). Thus we conclude that there is little reason to assume that checking reduces the load capacity of these timbers in axial compression.

CONCLUSIONS

Several conclusions can be drawn from the data collected in this study:

- In spite of being in service for 55 years and containing numerous in-service defects, 75 percent of the columns were graded as No. 2 & Better and 40 percent of the columns were graded as Select Structural.
- Roughly a third of the columns was downgraded due to in-service defects, i.e., checks, splits, and mechanical damage.
- Quantifying the actual size and severity of checks and splits in existing wood members is very difficult, if not impossible.
- The MOE of the Select Structural, No. 1, and No. 2 columns was greater than the NDS derived values. The mean compressive strength of the tested columns was a minimum of 40 percent greater than the mean compressive stress derived from the design equations.
- There was no consistent difference between the compressive strength of columns selected as checked and unchecked.

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APPENDIX

DERIVATION OF K_{cE} VALUES

This appendix shows how the elastic modulus variability and a factor of safety are included in elastic buckling calculation through the K_{cE} parameter.

Euler buckling stress equals

$$F_{\bar{\mu}} = \frac{\pi^2 E}{12(l/d)^2}$$

where:

E = shear-free elastic modulus

The NDS and LRFD (Load Resistance Factor Design) lumber supplement flexural elastic values (E_{pub}) represent mean values on a standardized loading configuration. When design for strength capacity adjustment factors are applied to the 5th percentile levels (E^{5th}), NDS and LRFD flexural elastic modulus values are adjusted to shear-free 5th (E^{5th}_{Free}) percentile levels by the following expressions:

$$E^{5th} = E_{pub}\,(1 - 1.645COV_E)$$

$$E^{5th}_{Free} = 1.03E^{5th}$$

where:

COV_E = coefficient of variation of the flexural elastic modulus

The 1.03 value adjusts the elastic modulus determined from a standardized loading configuration to a shear-free value. Substituting these two expressions in the Euler buckling stress expression becomes

$$F'_{cE} = \frac{1.03\pi^2 E_{pub}(1 - 1.645COV_E)}{12 \times 1.66(l/d)^2} = \frac{K_{cE}\,E_{pub}}{(l/d)^2}$$

$$K_{cE} = 0.510 - 0.839COV_E$$

For lumber and timber, the NDS assumes a 25 percent COV for the elastic modulus, resulting in K_{cE} = 0.3. Therefore, both the material variables and a factor of safety for elastic buckling are addressed by K_{cE}.

END

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WOOD RECYCLING

Opportunities for the Woodwaste Resource

By Bob Falk

For most of us, the word *recycling* conjures up visions of curbside programs focused on collecting glass bottles, aluminum cans, plastic jugs, and old newspapers. Considerable attention has been paid to these "post consumer" waste materials, while until recently, the recycling of solid woodwaste has received relatively little attention. For many decades, waste from the wood industry's sawmills was burned in teepee burners. Today, much of this woodwaste is utilized for new product manufacture (composite products, etc.) But what about other sources of woodwaste in this country? Demolition projects, land clearing, new construction, and other sources generate millions of tons of woodwaste every year. These wastes are typically viewed as a burdensome disposal problem; however, this material has potential to become a usable resource.

The Waste Wood Resource

Our nation is blessed with a vast wood resource. Currently, about one-third of our land mass is forested, approximately 737 million acres (2.98 million km^2). From this land, we yearly harvest about 280 million metric tonnes of wood. **Figure 1** illustrates our dependency on this wood resource. Roughly one-half of all industrial materials used in this country are wood-based, far exceeding the use of all metals, cement, and plastic (on a weight basis).

A portion of these industrial resources ends up being discarded, either through manufacturing waste or product disposal. Because so much of our industrial raw material base is wood fiber, and many of the products produced are short-lived, such as newspapers, paperboard, and packaging, a rather large percentage of our waste stream contains fiber. The majority of the woodwaste generated ends up in three different waste streams: 1) municipal solid waste (MSW); 2) construction and demolition (C&D) debris; and 3) wood and paper residues from primary timber and paper processing.

Municipal Solid Waste

In 1994, about 190 million metric tonnes of MSW were generated in the United States. MSW is defined by the Environmental Protection Agency (EPA) as waste from residential, commercial, institutional, and industrial sources, and includes durable goods, non-durable goods, containers and packaging, food scrap, yard trimmings, and miscellaneous organic waste. MSW does not include: C&D waste, automobile bodies, municipal sludges, combustion ash, and industrial process waste that may or may not be disposed of in municipal waste landfills or incinerators. By EPA definition, three categories of MSW contain wood fiber: paper and paperboard, yard trimmings, and wood (**Fig. 2**).

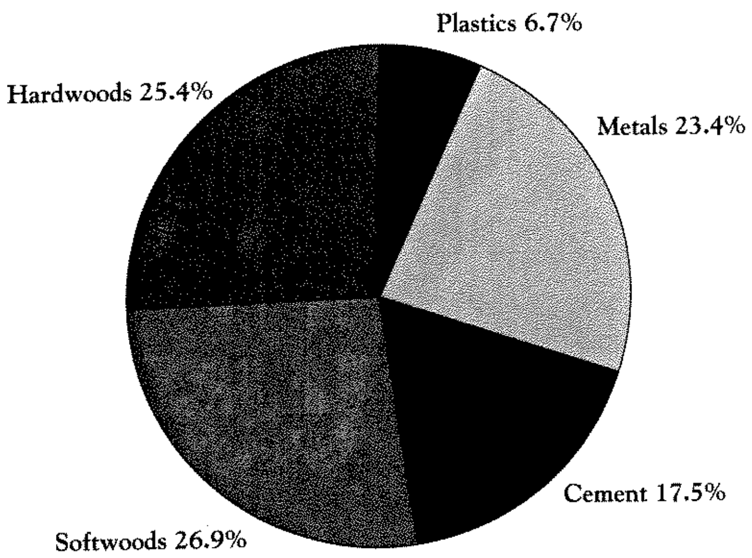

Figure 1. — Consumption of industrial raw materials, U.S. totals, percent by weight, 1995. Fuelwood is included in the total wood usage. Softwoods are assumed to have an average specific gravity of 0.45 and a dry basis moisture content of 15 percent. Hardwoods are assumed to have an average specific gravity of 0.55 and a dry basis moisture content of 10 percent.Source: J.L. Bowyer, University of Minnesota.

Paper Waste from the MSW

Although the focus of this paper is solid woodwaste, it is worth noting the progress being made in paper fiber recycling. The recovery and reuse of paper from the MSW is a recycling success story. For many years in the United States, paper and paperboard have been the most heavily recycled component of the MSW, accounting for more than two-thirds of the materials recovered. The availability of paper for recycling is in large measure a result of community-based curbside collection and the U.S. paper industry is approaching an overall 50 percent recovery level. For some grades, such as old newspapers (ONP) and old corrugated containers (OCC), that level has already been exceeded. In 1993, when the recycling rate was about 30 percent, over 38 million metric tonnes of paper and paperboard were recovered for recycling.

Solid Woodwaste from the MSW

Two EPA-defined categories of the MSW contain solid wood: wood and yard trimmings. The wood category contains such items as wood furniture and cabinets, pallets and containers, scrap lumber and panels that are not considered C&D debris, and waste wood from manufacturing facilities. Yard trimmings include leaves and grass clippings, brush, and tree trimmings and removals. Estimates made from regional and national studies suggest that about 10 percent of the wood in the MSW is currently recycled and an additional 54 percent is potentially recoverable. Currently, it is estimated that about 23 percent of the yard trimmings are recovered, and 46 percent are potentially recoverable for reuse. These sources from the MSW account for about 20 million metric tonnes of potentially recoverable solid wood material (Table 1).

C&D Debris

The waste generated from new construction and from building demolition is in a category by itself. Both these activities generate a significant amount of woodwaste. New construction wastes include all forms of wood used in wood frame construction (both residential and commercial), including solid wood, panels, engineered wood products, and packaging.

Nationally, the construction of residential homes alone consumes about 30 million metric tonnes of wood products. As shown in Table 2, almost 40 percent of the waste generated on a new home site is woodwaste, about 3,000 pounds (1360 kg). It is estimated that nationally about 6 million metric tonnes of new construction waste is considered feasible for reuse (Table 1).

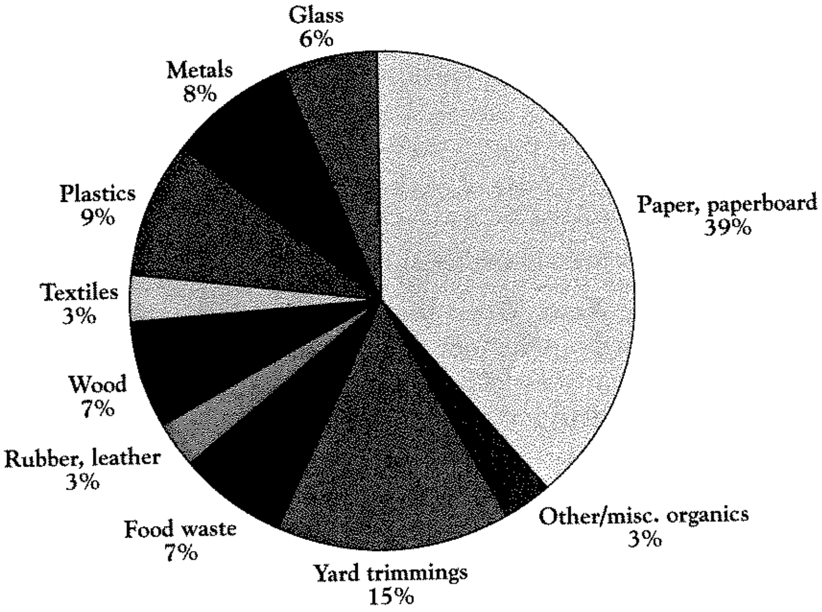

Figure 2—Percentage of municipal solid waste generated in the United States, 1994. Source: U.S. Environmental Protection Agency, Washington, D.C.

Table 1. Waste wood generated and available for recovery.

Source	Currently generated (10^6 metric tonnes)	Potentially available for recovery (10^6 metric tonnes)
Municipal solid waste[a]		
Waste wood	13.2	7.2
Woody yard trimmings	26.4	12.2
C & D debris[a]		
Construction	6.9	5.7
Demolition	22.7	6.8
Primary timber processing[a]		
Bark residues	26.7	1.4
Wood residues	80.1	4.8
Treated woodwaste[b]	4.7	Uncertain

[a] Source: McKeever, D. 1997, Resource Potential of Solid Waste Wood in the United States, The Use of Recycled Wood and Paper in Building Applications, Forest Prod. Soc., Madison, Wis.

[b] Source: Felton, C.C. and R.C. DeGroot. 1996. The recycling potential of preservative-treated wood. Forest Prod. J. 46(7/8):37-46.

Demolition waste is a much more heterogeneous mix of materials and typically contains woodwaste from framing, panels, flooring, etc., as well as aggregate, concrete, paper, metal, insulation, glass, and other building materials. About 44 million metric tonnes of demolition waste was generated in 1994. It is estimated that about 23 million metric tonnes of wood is contained in this mix. Due to the commingled nature of this waste, it is difficult to estimate the potential recovery of wood; however, if a yield of 30 percent is assumed, about 7 million tonnes of demolition woodwaste is available for recovery.[1]

Primary Timber Processing

The reuse of waste wood fiber that is a by-product of primary timber processing operations is not new. By and large, the wood industry has done a commendable job in reusing large amounts of residues (bark, sawmill slabs, sawdust, and peeler log cores) for a variety of applications. Nearly all of these residues are currently used to produce other products, primarily fiber for paper, building panels, landscape mulch, and/or fuel.

Treated Woodwaste

At this time, the recycling potential for treated woodwaste is unknown. A significant volume of treated wood is produced every year and questions regarding its disposal are being raised. Chromated copper arsenate (CCA) is the primary wood preservative used for the treatment of softwood lumber in the United States. Every year, over 8 million metric tonnes of CCA-treated lumber is produced and it is estimated that over 85 million metric tonnes of this product is in service. The feasibility of recycling treated wood is only now being investigated.

There are two major problems associated with recycling treated wood. First, the exposure of workers to preservative chemicals during the recycling process is of concern and must be investigated. Second, products made from recycled treated wood may not have the same resistance to decay and insects as the original treated wood product. This residual durability must be determined so that the recycled product can be used appropriately.

Nearly 5 million metric tonnes of preservative-treated wood is disposed of annually into landfills. If recycling methods can be developed such that health concerns are mitigated, much of this material can potentially be reused.


Waste generated at a building demolition project.

Table 2. Typical construction waste for a 2,000-ft^2 (189-m^2) home.[a]

Waste material	Amount - lb.
Metals	150 (68.2)[b]
Drywall (gypsum)	2,000 (909.1)
Solid sawn wood	1,600 (727.3)
Vinyl (PVC)	150 (68.2)
Engineered wood products	1,400 (636.4)
Masonry (siding material assumes three sides vinyl siding and brick veneer on home's front facade)	1,000 (454.5)
Old corrugated containers	600 (272.7)
Other	1,050 (477.3)
Containers (paints, caulks, etc.)	50 (22.7)
Total	8,000 (3636.4)

[a] Source: National Association of Home Builders Research Center.

[b] Values in parentheses are kg.

Conventional Uses for Woodwaste

Markets for residues from primary wood processing are well established. The pulp and paper industry is by far the biggest user of this material, at about 30 million metric tonnes per year. The production of particleboard, medium density fiberboard (MDF), hardboard, and insulation board consumes another 10 million metric tonnes. Other uses, such as mulch, animal bedding, and fuel are also common.

Woodwaste generated from the MSW and from C&D debris is also marketed, but material variability and contamination often limit the use of these wastes to lower value commodity products, such as fuel and mulch. **Figure** 3 illustrates the materials input/output stream at Recovery 1, a C&D waste processing plant in the state of Washington. At this plant, waste wood is obtained from land clearing/stumpage, pallets, new construction, and demolition. The land clearing/stumpage and pallet portion of this waste stream produces clean pulp chips usable for the pulp and paper industry. The remaining material produces primarily hog fuel. There is also a small percentage of fines, which can be used as a soil amendment. Scrap metal can be recycled, but other residues have no use and must be landfilled.

Other Uses for Woodwaste

Recently there has been considerable interest in increasing the use of woodwaste for higher value products. A conference focusing on this topic was held in Madison, Wis., in September of 1996.[2] Several potential material and product types were discussed.

Recycled Lumber and Timber

Millions of board feet of lumber and timber exist in old wood structures slated for disposal (especially industrial and military buildings). The U.S. Army has many wood buildings that were constructed for World War II and are now slated for demolition. It is estimated that these buildings contain over 250 million board feet of lumber and timber that could be reused. More and more, the feasibility of deconstructing buildings rather than demolishing them is being explored. Traditional demolition results in a pile of debris that is a mixture of wood, stone, carpeting, metals, and other materials. Deconstruction is the selective dismantling or removal of materials from buildings before, or instead of, demolition. It's been said that demolition is "clearing the table" and deconstruction is "saving the dishes."

In 1993, a study that evaluated the deconstruction of a two-story house in Portland, Oreg., indicated that the manual labor required to dismantle the building for salvage was competitive with the cost of conventional demolition. When the salvage value of materials from the building and the reduced disposal costs were considered, deconstruction cost several thousand dollars less than demolition. Because there are high tipping fees and well-established end-use markets for recyclables in Portland, this may be an optimistic example. It remains to be seen if deconstruction can be an economically attractive strategy nationwide.

Examples of uses of deconstructed wood materials include: 1) large timbers, which are valuable, can be removed from old structures and reused intact as structural members; and 2) wood flooring, siding, doors, and other trim, if not too damaged, can be reused in a new structure. It makes sense to strive for a "highest value use" of recycled materials where possible and reserve solid lumber and timber for uses that maintain their original form. However, the reuse of lumber and timber is hampered by the fact that guidelines on reuse do not exist and that grading rules and engineering design values currently focus on the use of virgin timber. Clarification, and to a certain extent, redevelopment of grading rules and design information specific to old lumber and timber would help its marketability. Only recently has research begun to address these problems. Considering the fact that over 3 trillion board feet of sawn lumber has been produced in this country since 1900 and much of it resides in buildings that will one day be disposed of, these reuse issues are important.

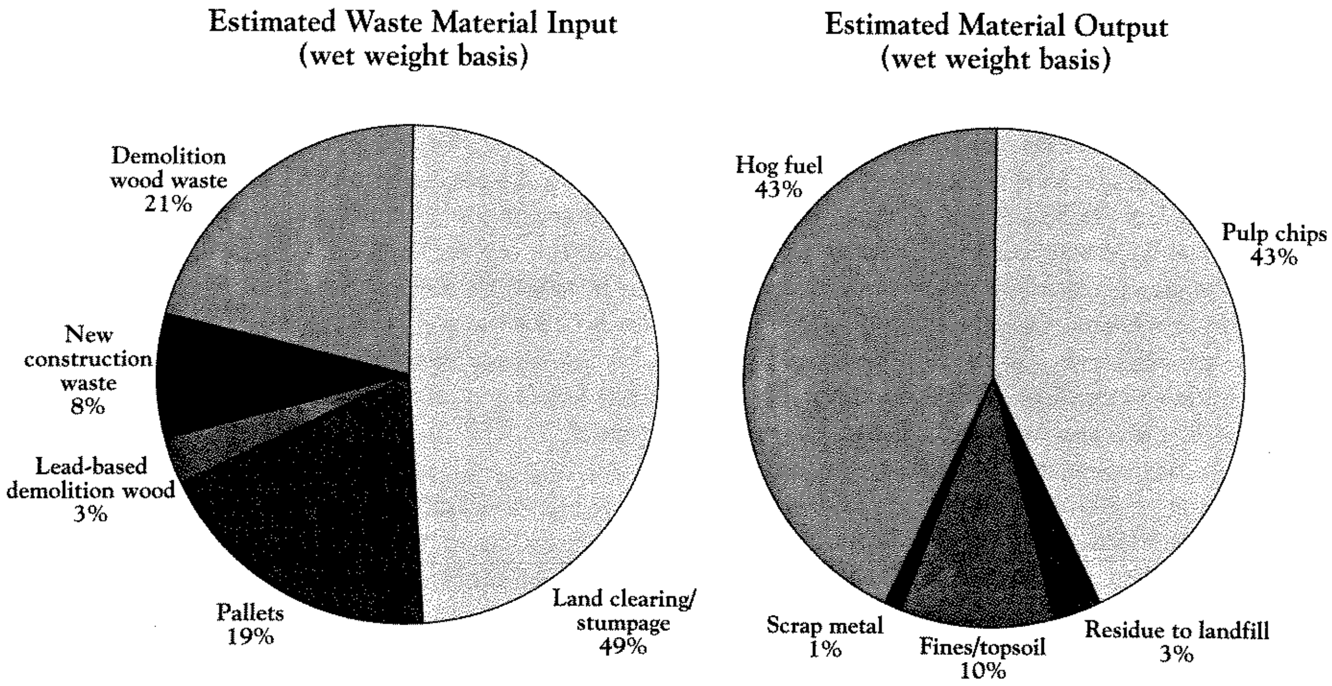

Figure 3.—Estimated material input and output for Recovery 1. Source: *Resource Recycling* magazine, November 1996.

Woodfiber-Plastic Composites

Over the past decade or so, there has been a sharp increase in the use of wood-filled polymeric composites for a variety of applications. The automotive industry manufactures interior parts (e.g., door liners) from these composites and the construction industry uses these materials for exterior applications with members made to standard lumber profiles. Most recently, window and door manufacturers are using these composites as an alternative to clear solid wood in clad components. For more details regarding these products, refer to the feature article by John Youngquist in the October 1995 issue of the *Forest Products Journal*.

Wood/Inorganic-Bonded Products

Recycled particles or fibers of wood held together with an inorganic matrix, such as Portland cement or gypsum, form a composite that can be used in a variety of building applications. These composites offer the potential to be very fire resistant and are highly resistant to attack by decay fungi and insects. These products have been used for decades as construction materials in Europe, Australia, and Japan, but acceptance and growth in the U.S. building products market is only now being realized. Traditionally, virgin fiber was used for these composites, but at least one U.S. manufacturer (Midwest Faswall, Inc., Ottumwa, Iowa) is using a combination of waste wood particles from pallets plus cement to produce a permanent wall form for building construction. James Hardie, Inc., a large Australian manufacturer, is making extensive capital investments in U.S. manufacturing plants in order to produce high density woodfiber/cement panel and roofing products for the U.S. construction market. There is certainly potential for the use of recycled material in these products.

Factors Affecting the Feasibility of Recycling Woodwaste

While it appears that there is a substantial amount of wood available for reuse, as well as a variety of products that might be produced from this wood fiber, several factors affect the feasibility of recycling this material.

Contamination

A major reason that so much of the woodwaste from primary timber processing is utilized (~95%) is that this material is clean and uniform. The primary difficulty in using other forms of woodwaste from MSW and C&D waste streams is that it is often commingled with other materials. Demolition waste is particularly dirty. A demolition waste recycling facility in Massachusetts reports that only about 15 percent of the woodwaste by weight (38% by volume) is usable for their mulch products.

For almost all products produced from woodwaste, cleanliness is an issue. Tolerance of contaminants in high value products, such as MDF and particleboard, is very limited. It's been said that a single Styrofoam coffee cup in a truckload of wood chips destined for an MDF plant is enough to degrade all the boards produced from that truckload. Lower value products, such as boiler fuel, mulch, and animal bedding have tolerance levels for contaminants as well. Most paints (lead!), preservative chemicals, metal, or other foreign materials are not tolerated.

Economics and Market Volatility

How economical it is to recycle woodwaste depends on several factors, including the type of product to be produced from the waste, availability of a nearby resource, and costs of sorting and cleaning. Most importantly, the recycled resource must compete favorably in cost with alternative raw materials.

A good example of the effect of market forces is illustrated by the experience of Willamette Industries.[3] Willamette has been a pioneer in the use of recycled woodwaste from urban sources. After purchasing a Eugene, Oreg., particleboard plant in 1991, Willamette was faced with a shortage of raw materials. With escalating prices and shrinking supplies of traditional particleboard materials, a new source of raw material was needed if the mill was to be kept operational. Between 1993 and 1995, Willamette used over 100,000 bone dry tons of urban woodwaste in its particleboard plant. Although the market demand for fiber was extremely high in 1995, by 1996 demand had softened, prices for all types of wood fiber dropped dramatically, and there was no longer an economic incentive to use urban woodwaste. In 1996, the price of woodwaste from primary processing (sawdust, planer shavings, etc.) had dropped to as little as 50 percent of the price of the urban woodwaste. As a result, Willamette discontinued business with 10 of its 12 suppliers of urban woodwaste. Although the price paid to the remaining two suppliers for their urban woodwaste is higher than the price of available primary processing woodwaste, Willamette has chosen to maintain purchasing contracts with them.

Variability of the Resource

Because waste wood is generated from a variety of sources, the quality, size, species, dryness, and contamination level can vary tremendously. This variability may necessitate more complex processing systems and can affect final product properties. The amount of sorting that is required is also an economic factor. More sorting means higher costs.

Alternative procedures that might result in the delivery of cleaner woodwaste and the ability to produce higher value products from this recycled material are needed. For example, better segregation of waste at new construction sites, i.e., putting the wood in one container and the packaging materials, etc., in other containers is one way to minimize contamination. To facilitate this procedure, the National Association of Home Builders Research Center has just published a field guide for residential construction waste management.[4] Better separation of MSW and C&D debris would certainly help produce a cleaner waste wood resource.

Dispersion of the Resource

Woodwaste exists almost everywhere. But because transportation costs are high relative to the value of this waste material, it is currently only feasible for woodwaste processing facilities to locate where there is a high volume of waste, i.e., urban areas. Obviously, waste wood processors also prefer locations where high volume users are nearby, such as solid-fuel boiler operations, and where high local landfill tipping fees encourage recycling.

Addressing the Difficulties

There are many technical and economic obstacles to overcome, but the indications are that recycled woodwaste can play an increasing role in the production of a variety of wood-based products. Two difficulties that deserve special attention are: 1) developing an infrastructure that can deliver a clean, consistent waste wood resource; and 2) developing definitions and material standards that will help manufacturers and suppliers more uniformly and consistently trade and use this resource. When progress is made in these areas, the potential of woodwaste to become a viable alternative raw material will be realized.

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Accessible information is needed to encourage the use of recycled woodwaste and the following two publications are especially useful.

In cooperation with the USDA Forest Service, the American Forest & Paper Association has developed a directory that lists wood residue receivers nationwide. This document will help those who have recycled woodwaste to find a market for their residue.

The Clean Washington Center, a division of Washington State's Dept. of Community, Trade and Economic Development, has developed a "best practices" manual for woodwaste usage in cooperation with the National Institute of Standards and Technology and the Environmental Protection Agency. This manual contains about 60 best-known uses of wood and concise technical descriptions for the sourcing, handling, and processing of recovered woodwaste, as well as end-use applications, marketing, and safety issues.

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[1] McKeever, D. 1997. Resource Potential of Solid Waste Wood in the United States. *In*: Proc. The Use of Recycled Wood and Paper in Building Applications. Forest Prod. Soc., Madison, Wis.

[2] The Use of Recycled Wood and Paper in Building Applications. 1997. Proc. 7286. Forest Prod. Soc., Madison, Wis.

[3] Smith, D. 1997. Utilization of Urban Wood in the Manufacture of Particleboard and MDF. *In*: Proc. The Use of Recycled Wood and Paper in Building Applications. Forest Prod. Soc., Madison, Wis.

[4] Yost, P. and E. Lund. 1997. Residential Construction Waste Management: A Builder's Field Guide. National Association of Home Builders Research Center, Upper Marlboro, Md.