EFFECT OF DAMAGE ON THE GRADE YIELD OF RECYCLED LUMBER

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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-

[1] National Association of Home Builders. 1997. Deconstruction - building disassembly and material salvage: the Riverdale case study. NAHB Research Center, Upper Marlboro, Md.

[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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The use of trade or firm names in this publication is for reader information and does not imply endorsement by the USDA of any product or service. This project would not have been possible without the generous support of the U.S. Army and staff at the Fort Ord Reuse Authority. We also thank Grading Supervisors Tom Bigham and Bob Nelson from WCLIB for their expertise and assistance in lumber grading. This paper was received for publication in January 1999. Reprint No. 8929.
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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.

[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

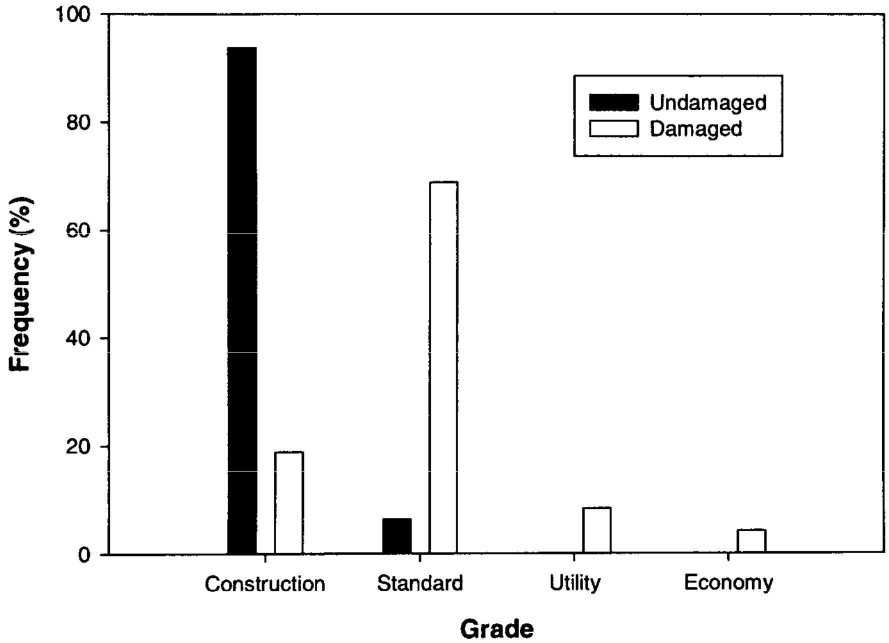

Figure 1. – Grade reduction as a result of damage, 2 by 4's, all forms of damage.

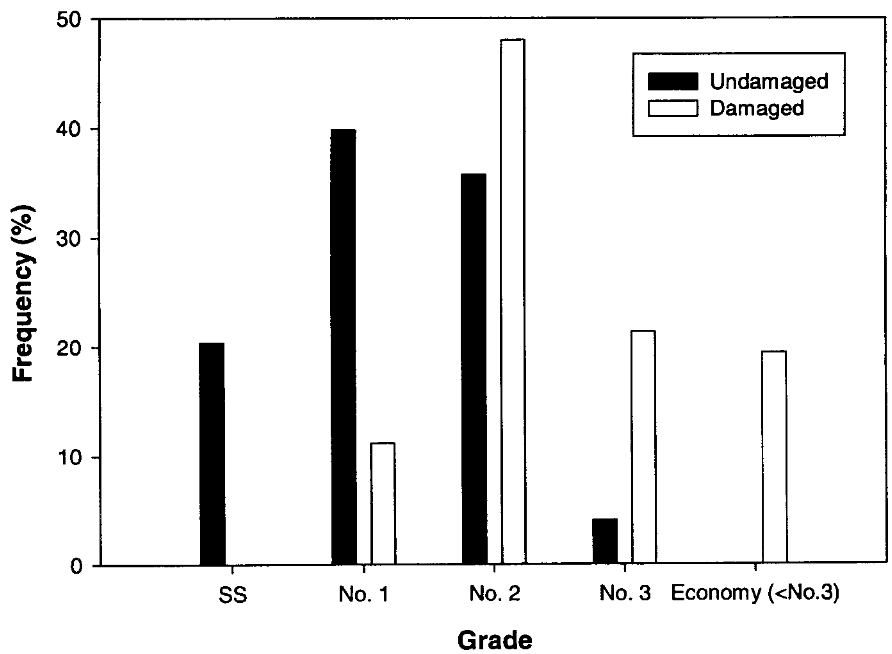

Figure 2. – Grade reduction as a result of damage, 2 by 6's, all forms of damage.

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.

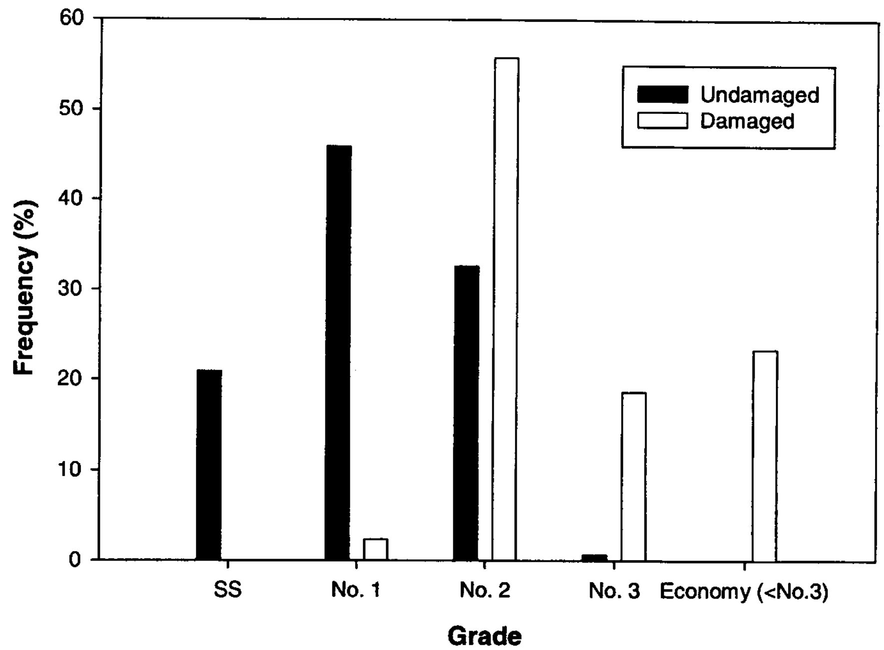

Figure 3. – Grade reduction as a result of damage, 2 by 8's, all forms of damage.

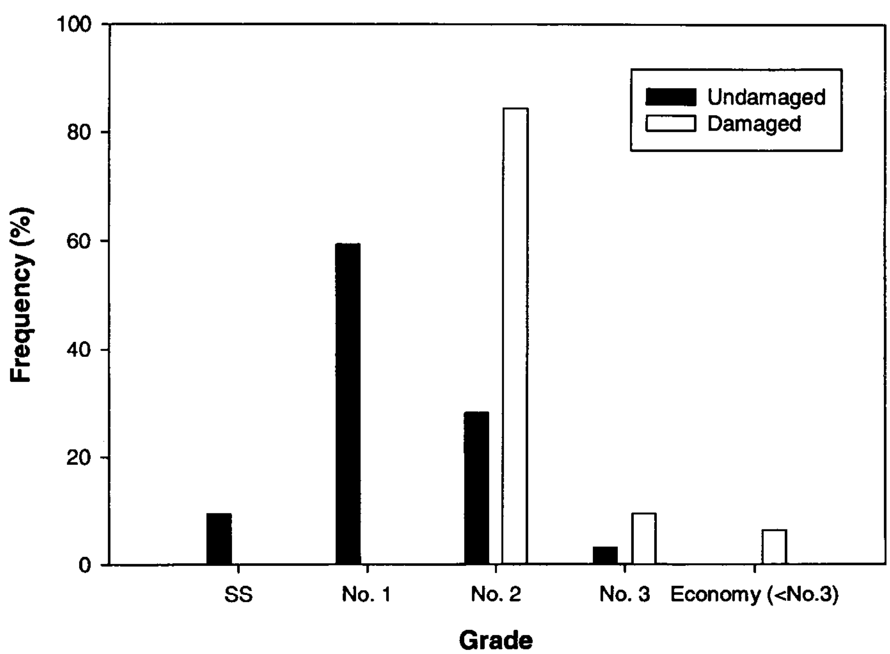

Figure 4. – Grade reduction as a result of damage, 2 by 10's, all forms of damage.

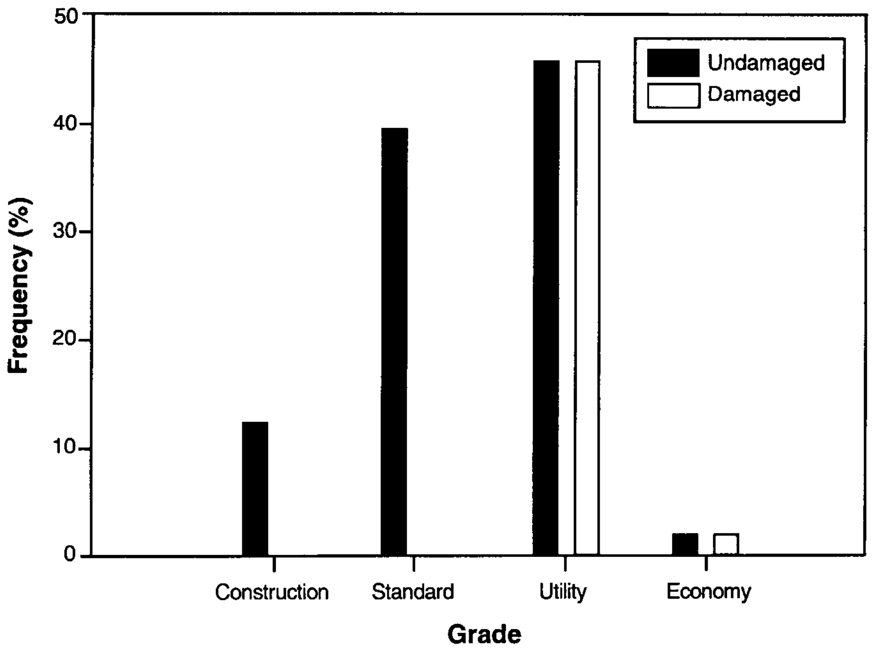

Figure 5. – Grade reduction as a result of damage, 2 by 4's, deconstruction damage only.

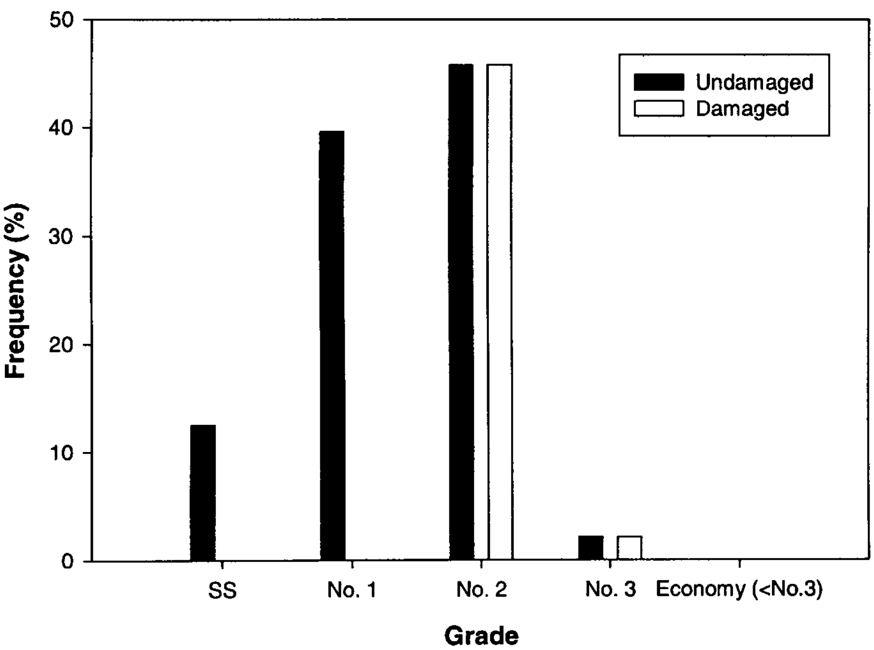

Figure 6. – Grade reduction as a result of damage, 2 by 6's, deconstruction damage only.

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-

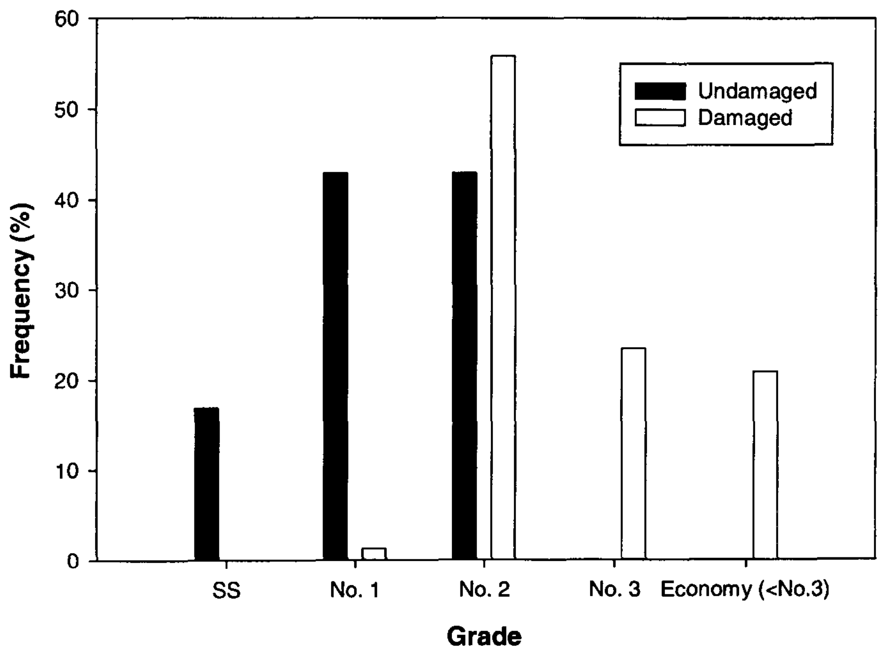

Figure 7. – Grade reduction as a result of damage, 2 by 8's, deconstruction damage only.

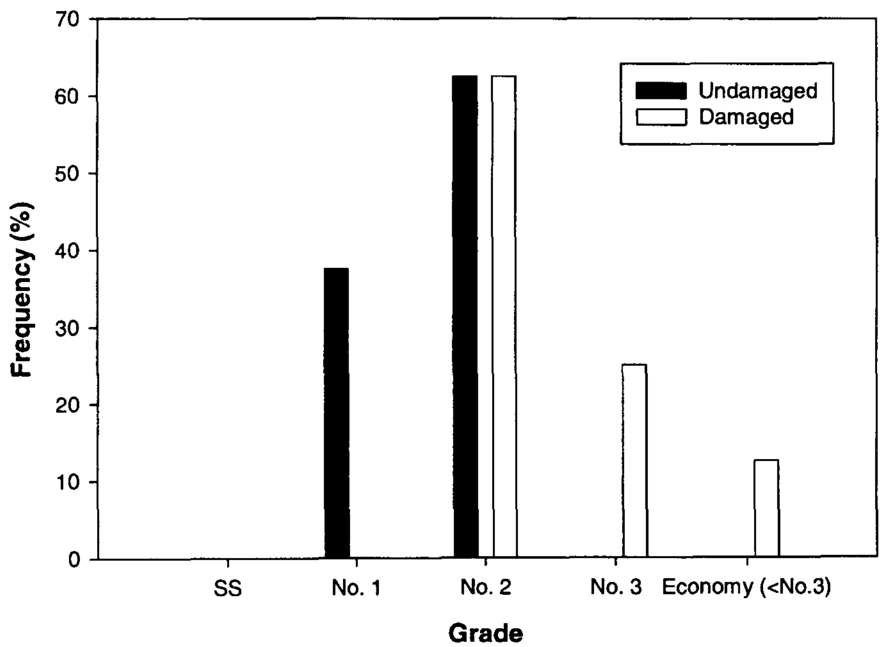

Figure 8. – Grade reduction as a result of damage, 2 by 10's, deconstruction damage only.

TABLE 7. – Amount of damage by usage.

Damage type	Size and usage											
	2 by 4				2 by 6		2 by 8				2 by 10	
	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.

Size	Trim to yield one piece					Trim to yield two pieces		
	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

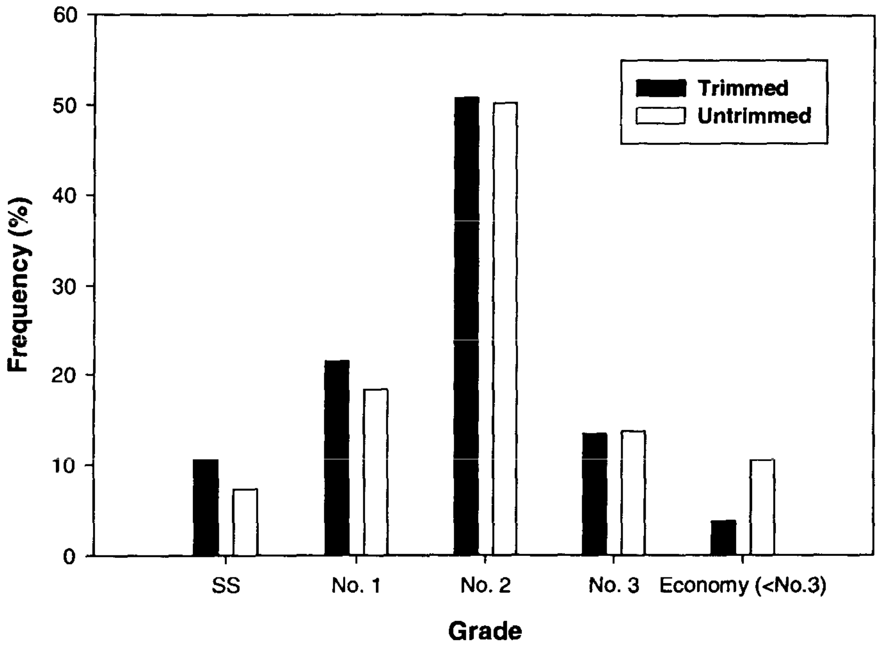

Figure 9. – Grade distribution: trimmed compared with untrimmed 2 by 8's.

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.