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

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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-by8-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-

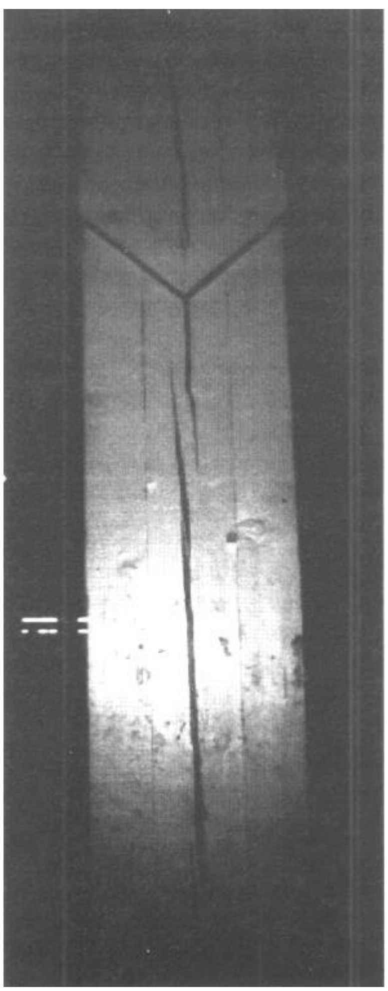

Figure 2.—Typical checked column.

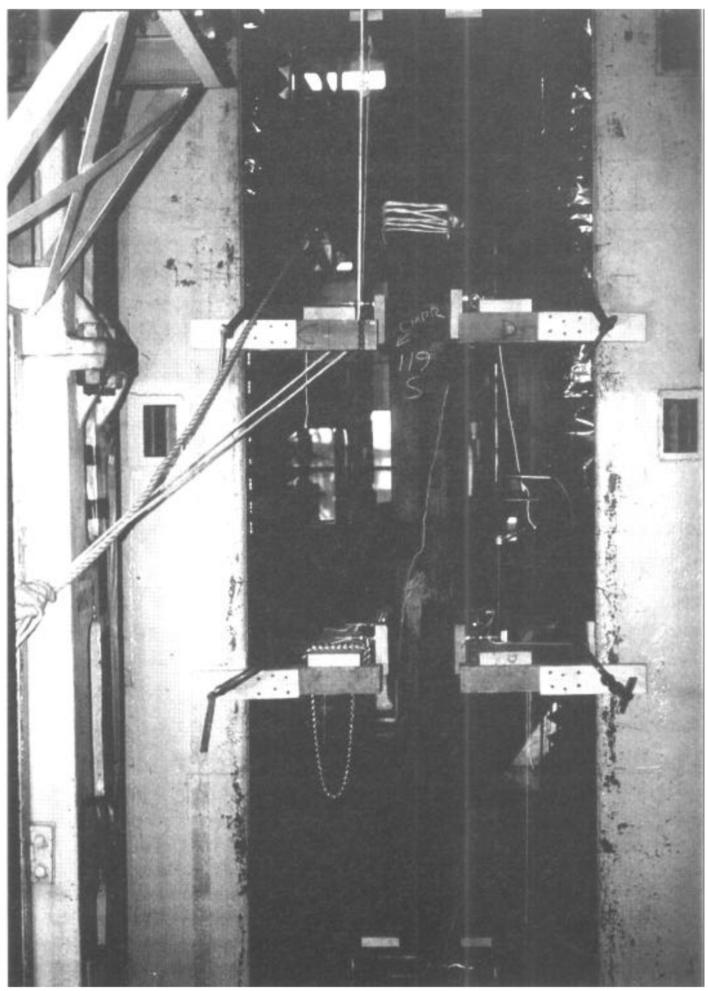

Figure 3.—Testing of column.

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 l-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.

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:

$$F_c^* = C_p F_c$$

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.

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

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

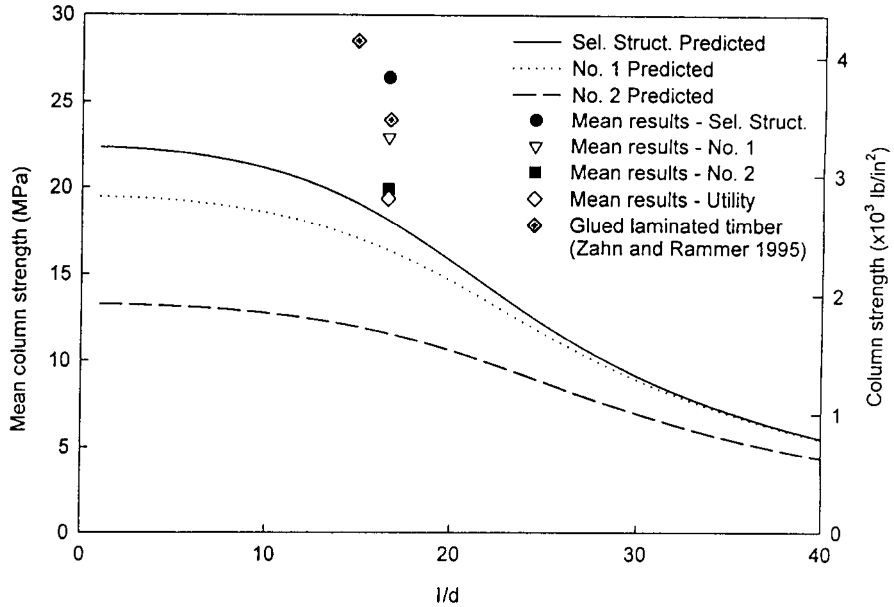

Figure 4.—Comparison of NDS design equations and test results.

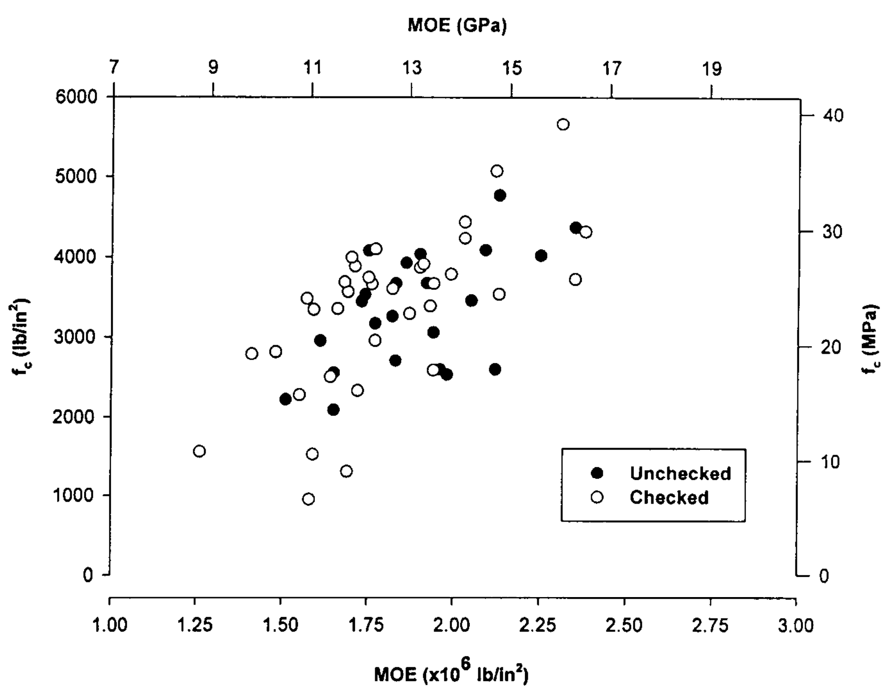

Figure 5.—Checked compared with unchecked column data.

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

Grade	NDS derived values: Elastic modulus (E)		Compression strength (F_c)		Calculated column strength (F_c^*) (1)		Measured column capacity (f) (2)		Ratio (2)/(1)
	(× 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}.