ALLOWABLE BENDING STRESSES OF WOOD FOR USE IN PORTABLE WOOD LADDERS

USDA FOREST SERVICE
GENERAL TECHNICAL REPORT
FPL-5
1975

U.S. DEPARTMENT OF AGRICULTURE FOREST SERVICE
FOREST PRODUCTS LABORATORY MADISON, WISCONSIN

ABSTRACT

A standard for portable wood ladders has been in effect since 1923, and has been revised several times since then. The most recent publication is "American National Standard Safety Standard for Portable Wood Ladders," A14.1-1975, from American National Standards Institute, Inc. Methods of arriving at allowable stresses for wood ladder parts have never been clearly documented. This report outlines what was done in the latest revision of the standard to calculate allowable fiber stresses for establishing species groupings.

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INTRODUCTION

This report describes a procedure that was used by American National Standards Institute (ANSI) Subcommittee A14.1 to establish working stresses for various species of wood used for ladder parts. Such parts are made from high quality, essentially clear wood for a product that requires a high level of safety. The procedures outlined here might suggest ways to arrive at working stresses for other structural members made from high quality wood.

History

Wood ladders have a long history of good performance when constructed according to recognized codes or standards and properly stored and used. The first code developed was the "Tentative American Standard Safety Code for Construction, Care, and Use of Ladders," which was approved in 1923. Experience gained in the manufacture and use of ladders in accordance with the original code led to a revision and the approval of the "American Standard Safety Code for Construction, Care, and Use of Ladders" in 1935. Work started on a further revision in 1939 was suspended during World War II. Subsequently, the code was discussed and revised, and revisions were published by the American Standards Association in 1948, 1952, and 1959. In 1968, the code was again revised; it was published by the United States of America Standards Institute (now American National Standards Institute, Inc.), and was entitled "USA Standard Safety Code for Portable Wood Ladders," A14.1-1968.

The code has traditionally listed various species of wood acceptable for ladder construction, and has classified the species into

1/ The author gratefully acknowledges the contributions of Andrew J. Kass, Research Technologist at the Forest Products Laboratory, for his interest and work in searching out and updating information needed for preparing ANSI Standard A14.1-1975.

2/ Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

different groups depending primarily on their strength properties. These groupings have changed slightly over the years as new strength data have been developed. Additionally, the number of groups has been changed to reflect availability of material and improved practices: The 1948 code had five groups, and subsequent codes through 1968 had four groups.

Revision of the 1968 code required reconsideration of species groupings. New techniques and data had to be recognized, particularly the species properties as reported in standards of the American Society for Testing and Materials (ASTM).[3/] It also became apparent that some of the species were in groupings not justified by strict analysis of strength data available when the groupings were made. These "judgment" factors, applied in addition to what strength data showed, were carried forward in periodic revisions. Unfortunately, these judgment factors were not recorded, and members of the current ANSI subcommittee were unable to find out exactly what had been done.

Objective

It is the purpose of this report to describe the procedures that were used by the subcommittee in developing allowable bending stresses for various species of wood during the revision of the A14.1-1968 code.[4/]

PROCEDURES

To develop allowable working stresses for wood species for use in ladders, there must be reliable and accepted data on the strength properties of clear wood. Such data are developed by recognized procedures through ASTM. Values published in ASTM D 2555, "Standard Methods for Establishing Clear Wood Strength Values," for wood grown in the United States and Canada, are appropriate as a basis for determining allowable stresses and groupings of wood for ladders.

The average strength values in D 2555 are for green, clear, straight-grain wood. They must be modified to arrive at an allowable stress for any structural use. Bending strength is the primary consideration for use in ladders, so further discussion will relate to that property. Factors affecting bending strength include species average and variability, moisture content, duration of load, size effect, slope of grain, knots, etc.

The basic principles for visually grading structural lumber and establishing related unit stresses are covered in ASTM D 245, "Standard Methods for Establishing Structural Grades and Related Allowable Properties for Visually Graded Lumber." It is intended primarily for grading of structural lumber, such as is used in construction, rather than for highly

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3/ Standards of ASTM are available in many technical libraries or may be purchased from the American Society for Testing and Materials, 1916 Race Street, Philadelphia, Pa. 19103, for $1.50 per standard.

4/ American National Standard Safety Standard for Portable Wood Ladders, A14.1-1975," approved November 25, 1974. American National Standards Institute, Inc., 1430 Broadway, New York, N.Y. 10018. $5.00 per single copy.

selective uses such as ladder rails and rungs. These principles, however, may be used as a guide to establish allowable stresses for the individual species and for grouping species of wood for ladders.

The wood properties and those factors that affect the allowable bending stress for ladder parts can be classified into two general categories: (1) variables dependent on species, and (2) factors independent of species. The variables dependent on species include the average green modulus of rupture for the species and the corresponding standard deviation and the dry/green strength ratio. Such values are published in ASTM D 2555. From these, it is possible to calculate a near-minimum strength value for a species of wood at 12 percent or the moisture content it is likely to have in use. Factors independent of species, on the other hand, are considered to apply to all species except that an additional reduction factor is applied for hardwoods. They include consideration of load duration, size effect, slope of grain, knots, and factor of safety. Thus, a single value may represent one combination of these various factors for softwoods and another for hardwoods.

The following procedure was used in the derivation of allowable stresses for the 1975 issue of the A14.1 standard because it can be applied to any species when recognized ASTM values are available. Allowable stresses were calculated for woods grown in the United States as based on values presented in ASTM D 2555-73.

Variables Dependent on Species

Species average.--Average values for modulus of rupture are from tables 1 and 2 of D 2555-73.

Species variability.--The lower 5 percent exclusion limit is typically used as a starting point for determining allowable stresses for wood structural members. This is to account for the inherent variability in wood strength and thus establish a near-minimum value for clear, straight-grain material. The same procedure was used for ladder parts and the near-minimum modulus of rupture (bending strength) was obtained as follows:

$$MOR_{\text{near minimum}} = MOR_{\text{average}} - 1.645\sigma$$

where MOR = modulus of rupture for clear, straight-grain wood and
σ = standard deviation (tables 1 and 2 of D 2555-73).

As an example, calculate the 5 percent exclusion limit for green Coast Douglas-fir, based on values in table 1 of D 2555-73:

$$MOR_{\text{near minimum}} = 7.665 - 1.645(1{,}317)$$
$$= 5{,}499 \text{ p.s.i.}$$

Note that the near-minimum value is about 72 percent of the average.

In earlier editions of A14.1, an effort was also made to account for species variability. As far as is known, a three-fourths factor (0.75) was applied to the average to account for this. But we now have standard deviations for various properties of different species and it is desirable to work from the newest and most reliable data.

Dry/green ratio.-- Dry wood will have greater bending strength and stiffness than green wood. The dry/green ratios for modulus of rupture, presented in table A1 of ASTM D 2555-73, show the average increase in strength that can be expected on small, clear specimens that dry from the green condition to 12 percent moisture content. Ladder stock is essentially clear material and of relatively small size. It seems reasonable, therefore, that the full increase (or nearly so) achieved by proper drying can be utilized. The moisture content of most ladders in service will probably be 12 percent or less, although some will have a higher moisture content. It was the judgment of the subcommittee that a maximum moisture content of 15 percent is reasonable for ladder parts so the full increase achieved by drying to 12 percent should not be taken.

Assuming that, for all practical purposes, the total increase for drying (the dry/green ratio) occurs between the fiber-saturation point (at about 30 pct moisture content) and 12 percent moisture content, then only five-sixths of the increase should be applied for drying green wood to 15 percent moisture content. This is what was done in the revision of A14.1.

As an example, consider modulus of rupture for Coast Douglas-fir. The dry/green ratio at 12 percent moisture content is 1.62 from table A1 of ASTM D 2555-73. For 15 percent moisture content, the dry/green ratio is $5/6(1.62-1) + 1 \simeq 1.52$.

Sample calculation.--Compute the near-minimum modulus of rupture for clear, straight-grain Coast Douglas-fir at 15 percent moisture content:

$$MOR_{\text{near minumum}} = [7{,}665 - 1.645(1{,}317)] \times [5/6(1.62-1) + 1] = 8{,}340 \text{ p.s.i.}$$

where 7,665 is the average green modulus of rupture,
1.645 is the factor for 5 percent exclusion,
1,317 is the standard deviation, and
1.62 is the dry/green ratio for modulus of rupture at 12 percent moisture content.

Factors Independent of Species

Load duration.--Load duration can have a significant effect on the strength of wood structural members, as is described in ASTM D 2555. Allowable stresses are usually reduced to provide for what is called normal loading (10 yr duration at maximum load), such as may occur in certain parts of buildings. For ladders, however, duration of load is far less than the so-called normal loading and, therefore, adjustments are much less than those normally applied.

Size effect.--Modulus of rupture values from ASTM D 2555 are almost always based on tests of 2-inch-deep specimens center-loaded over a 28-inch span. Modifications are made for size factors in structural lumber to adjust for other size and loading conditions.[5/] As depth and

5/ U.S. Department of Agriculture. 1974. Wood Handbook--Wood as an Engineering Material. U.S. Dep. Agric., Agric. Handbook No. 72, p. 8-5 to 8-6.

span-depth ratio increase, the reduction for size effect becomes greater. Compared with structural lumber and timbers, ladder rails are of small size so the size effect is relatively small.

Slope of grain.--As a general criterion, the ANSI A14.1 standard requires a slope of grain of 1:12 or flatter for side rails and back legs. Strength decreases as slope of grain becomes steeper. For ladder rails, the limitation on slope of grain of 1:12 or flatter results in a reduction of bending strength estimated to be up to 15 percent[6/] as compared with clear, straight-grain wood. This reduction is less than for structural lumber having similar slope of grain limitations because ladder stock is of high quality and receives preferential treatment in handling and drying.

Knots.--The ANSI A14.1 standard rather severely restricts knots in ladder parts. The ladder manufacturer, therefore, must obtain and use material essentially free of knots in order to meet requirements. As a result, ladder parts are typically made of knot-free material. Thus, knots rarely are a factor in the strength of portable wood ladders.

Factor of safety.--The factor of safety for wood structural members is difficult to describe and assess because of the variability of wood and the factors affecting strength.[7/] The factor of safety is included in the combined divisors that reduce the near-minimum strength values to allowable unit stresses for ladder parts.

Other factors.--Numerous other factors could be mentioned that have some effect on bending strength of ladder rails such as misgrading, improper size, and moisture content other than specified. These factors, however, are not considered significant because they are a part of the specifications and quality control necessary to produce safe ladders according to the A14.1 standard.

Hardwood-Softwood Factor

In general, less is documented about the structural performance of hardwoods than of softwoods. As a result, it is common practice to apply a "judgment factor" that effectively reduces the working stress for hardwoods about 10 percent. This is done in ASTM D 245 for structural lumber. It was also applied by the ANSI subcommittee in revising the A14.1 standard, although this correction may not be necessary for the high quality wood used for ladder parts. Application of this factor can be reconsidered at the time of the next revision of the A14.1 standard.

Summary of Procedures

Average modulus of rupture, variability, and moisture content were considered and used to calculate a near-minimum modulus of rupture for clear, straight-grain wood of each species at 15 percent moisture content. These values were then divided by a combined divisor to correct for factors independent of species and arrive at the allowable fiber stress. The divisors selected by the subcommittee were 4.1 and 4.5

6/ U.S. Department of Agriculture. 1974. Wood Handbook--Wood as an Engineering Material. U.S. Dep. Agric., Agric. Handbook No. 72, Table 4-10.

7/ Wood, Lyman W. 1960. Factor of Safety in Design of Timber Structures. Paper No. 3051. American Society of Civil Engineers Transactions, Vol. 125, Part I, p. 1033.

for softwoods and hardwoods, respectively.

For the near-minimum modulus of rupture calculated earlier for Coast Douglas-fir, the allowable fiber stress in bending is:

$$\frac{8,340}{4.1} = 2,034 \text{ p.s.i.}$$

Thus, Coast Douglas-fir was classified as a Group B wood in the A14.1 standard, having an allowable fiber stress in bending of 2,000 p.s.i.

APPLICATION OF RESULTS

Allowable unit fiber stresses in bending were calculated for each species and incorporated in table 1 of the ANSI A14.1-1975 standard. This table was completely revised from the 1968 standard. The four wood species groupings were increased to five by inserting a new group, Group C, having an allowable fiber stress in bending of 1,875 p.s.i. A similar grouping had been included in earlier versions of the A14.1 standard, but was removed in the 1952 standard. With the current lumber supply situation, however, the subcommittee deemed it advisable to reinstate a fifth grouping.

Documenting the procedures used for the calculation of allowable fiber stresses for ladders will clarify questions occasionally raised concerning their establishment and application. The procedures incorporated established methods promulgated by a recognized standards group, ASTM. They do not, however, increase the allowable fiber stresses for the major species; in fact, some species now have a lower allowable stress than before. Therefore, it is believed that this reanalysis will help insure uniformity of procedures and greater safety in wood ladders.

DENSITY

For convenience in estimating ladder weights, the average densities of the species listed in table 1 of A14.1-1975 are presented for a moisture content of 15 percent. Also listed is the near-minimum density for each species; this value reflects the 2-1/2 percent exclusion limit calculated as

$$\text{Density}_{\text{near minimum}} = \text{Density}_{\text{average}} - 1.96\sigma$$

where σ = density standard deviation.

Density values are based on specific gravity data in ASTM D 2555-72.

SUMMARY

The "American National Standard Safety Standard for Portable Wood Ladders," A14.1-1975, was recently revised and approved. Procedures for establishing allowable fiber stresses in bending were developed and used in revising the standard. This report describes the procedures used by the subcommittee. They are similar to and based on American Society for Testing and Materials Standards used for developing working stresses for structural lumber.

☆U.S. GOVERNMENT PRINTING OFFICE: 1975-650-254/28

3.5-7-2-75