LOAD-CARRYING CAPACITY OF DECK BOARDS FOR GENERAL-PURPOSE PALLETS

August 1959

No. 2153

FOREST PRODUCTS LABORATORY
MADISON 5, WISCONSIN

UNITED STATES DEPARTMENT OF AGRICULTURE
FOREST SERVICE

In Cooperation with the University of Wisconsin
LOAD-CARRYING CAPACITY OF DECK BOARDS
FOR GENERAL-PURPOSE PALLETS

By

T. B. HEEBINK, Engineer

Forest Products Laboratory,1 Forest Service
U. S. Department of Agriculture

Introduction

The wood pallet industry has in recent years become an important market for wood of many species and qualities. In 1958, it is estimated, some 40 million pallets were manufactured, utilizing more than a billion board feet of lumber. Good design and serviceability are essential for the maintenance and further expansion of this market for wood.

To aid pallet manufacturers in improving their designs, the Forest Products Laboratory has conducted research on the engineering aspects of pallet construction. This report presents information intended to aid manufacturers in producing improved pallets specifically designed for known weights of commodities on the basis of the physical characteristics of the lumber and the strength properties of the particular species of wood used.

Sizes for general-purpose pallets are usually determined by either the dimensions of the mechanical materials-handling equipment, the physical arrangement and size of the storage area, or both. The lengths and widths are often controlled by the dimensions of carriers such as highway trucks or freight cars, and other times by the spacing of columns in warehouses. The cross-sectional dimensions of stringers are fairly well fixed by considerations other than strength. The stringers must be wide enough to receive the nails or other fasteners, and deep enough to receive the tines of forklift trucks or permit hand trucks to roll in between top and bottom deck boards.

1Maintained at Madison, Wis., in cooperation with the University of Wisconsin.

Rept. No. 2153
The load-carrying capacity of pallets, then, is almost wholly dependent upon the size and strength of the deck boards. The calculation of the load-carrying capacity of top deck boards, therefore, is an important factor in the logical design of pallets.

This report considers the factors involved and includes the development of formulas and constants to make it possible for a pallet producer or user to calculate the load-carrying capacity of top deck boards of general-purpose pallets. The following discussion and calculations are limited to 3-stringer, flush-stringer, and notched-stringer pallets. If single-wing, double-wing, or four-way-entry pallets had been included, the variables would be too numerous to be adaptable to the circular calculator reproduced in this report for use in pallet design.

Factors That Influence Deck-Board Capacity

There are many factors to be considered when discussing the ability of top deck boards to carry loads just as there are when establishing structural grades of lumber. Deck boards make up the faces of pallets, provide racking resistance, and help to distribute the load over a larger area for stacking. The principal function of deck boards in the performance of pallets, however, is to transfer, as a beam, the loads placed upon them to the stringers. The bending strength of the wood is a factor of prime consideration and it, in turn, is influenced by other factors. They are: species, quality, moisture content, and such defects as knots, cross grain, decay, checks, and wane. The character and placement of the load are involved and, therefore, factors such as longtime loading and position of load with reference to stringers must be considered.

Quality and Species of Wood

Almost any species of wood can be fabricated successfully into pallets. Hardwoods are generally stronger, but the softwoods are lighter in weight. High-density hardwoods have the greatest bending strength, shock resistance, and nail-holding capacities, but they present difficulties with respect to drying, machining, nailing, and splitting at the nails. Low-density softwoods (including the softer broad-leaved species) are easy to dry and work, and are relatively free from splitting. Their bending strength, shock resistance, and nail-holding capacities are low, however.

In spite of these advantages and disadvantages for particular species, cheapness and availability are the chief factors that influence the choice of species of wood for pallets, and almost all species are utilized. Usually the lower grades with respect to quality are used, but in any region of the country the choice of grade is determined by economic conditions, which include the transportation facilities available.

A variability exists in the strength of clear wood within each species, which results from the natural and normal differences in the growth of individual trees. To illustrate the variability of strength-test results at the Forest Products Laboratory, the ultimate bending strength tests of southern yellow pine small clear specimens are used. Figure 1 shows a frequency-distribution curve that illustrates how the strength of individual specimens varies from 4,000 to 13,000 pounds per square inch around an average of 8,100 pounds per square inch. The ordinates represent the percentage of the total number of tests that lie below the corresponding value of strength. One percent of the values are under 5,000 pounds per square inch, 5-1/2 percent are under 6,000 pounds per square inch, 22 percent are under 7,000 pounds per square inch, and so forth. If the average, 8,100 pounds per square inch, were chosen for design, 52 percent of the boards could be expected to fail. If 7,000 pounds per square inch were used, 22 percent might fail. To assure a choice of a strength limit that is logical and reasonable, the intersection with the 5 percent ordinate has been chosen as a stress not likely to be affected by an occasional abnormal value. This means that, in 95 percent of the cases, the design value is on the safe side. In this example, the reduction factor for variability is 74 percent (stress at 5 percent ordinate is 5,930 pounds per square inch, which is 74 percent of the average, 8,100 pounds per square inch). This factor, of course, varies between species.

Moisture Content of Wood

When wood is seasoned, the direct effect of the loss of moisture is the stiffening and strengthening of the wood fibers. When pallets that have been fabricated with green lumber dry out in service, however, the increase in strength due to the drying may be largely offset by the cupping, twisting, and splitting that usually occurs. Also, because load-carrying capacity varies with the square of the thickness, the accompanying shrinkage tends to nullify the increase in the ability of the boards to carry loads due to moisture loss. Therefore, pallets that have been fabricated from green lumber cannot be depended upon to gain strength during the drying that takes place in service.

On the other hand, pallets that have been fabricated from dry lumber have a greater capacity for carrying load than do those made from green lumber. This fact is recognized, and a method of taking advantage of it is presented in "Other Considerations" at the end of the report.

Defects

Lumber typically contains knots, checks, and other defects that reduce its strength, and they must be considered when deck boards are designed.

Knots interrupt the direction of grain and cause localized cross grain with steep slopes. Intergrown or live knots resist some kinds of stress, but encased knots or knotholes are of little or no value. On the other hand, distortion of grain is greater around an intergrown knot than around an encased or dead knot. As a result, overall strength effect is roughly equalized, and no distinction should be made in allowable stress between live knots, dead knots, and knotholes. The strength-reducing effect of a knot depends on the proportion of the width of the remaining clear material to the width of the board. Limits on knot sizes are therefore expressed in terms of the width of the face in which the knot appears.

When areas of cross grain exist, that is, where the direction of the wood fibers is not parallel to the edges of the piece, bending stresses have components that act across the grain. Since this is the direction in which wood is least strong, cross grain becomes a strength-reducing factor.

The extent of decay in wood is difficult to determine, and its effect on strength is greater than visual observations would indicate. Decay in any form, therefore, should usually be prohibited in pallet lumber.

Checks, splits, and shakes are strength-reducing factors when present in structural timbers and when they occur at fastening points, but for flat, load-carrying boards they are not otherwise very significant. Most pallet specifications restrict checks and splits by requirements, so in this discussion they are not considered as a strength factor.

Wane is usually permitted up to only one-fourth the thickness or one-sixth the width of the piece, so it does not seriously affect the load-carrying capacity of deck boards. Because the strength reduction caused by wane, as well as by cross grain, splits, and so forth, is small compared to the maximum permissible knots, it will be considered here that the reduction in load capacity for maximum permissible knots is sufficient to compensate for all permissible defects.
Placement of Load

The load-carrying capacity of deck boards is affected by how the load is applied, that is, by the position of the load with respect to the span of the boards. A beam loaded uniformly along its span is capable of supporting twice as much as a beam with a concentrated load at its center. Some assumptions must therefore be made regarding placement of load.

Duration of Load

The ultimate strength of wood is higher under short-time loading than under long-time loading. This fact is important in strength uses because it directly affects allowable stresses. A substantial reduction factor is applied to stress values from laboratory tests, in which the load duration is a few minutes, to convert them to allowable stresses suitable for long-time loading.

Figure 2 illustrates the relation of allowable stress to duration of load. At about 10 minutes, 100 percent represents the duration of a standard strength test. As the duration increases, the allowable stress decreases. At 1 year, the allowable stress is about 67.5 percent.

Development of Design Formulas

Because most pallets are fabricated from relatively green lumber, it is logical to use design stresses based on tests of green lumber. A few fabricators dry their lumber for pallet deck boards, however, and allowance is therefore made on page 8 to adjust upward the load-carrying capacity of deck boards that were at time of fabrication and will remain during use at a moisture content of 18 percent or less.

The Forest Products Laboratory, over a period of many years, has conducted thousands of static bending tests on small, clear specimens to establish strength values for all species. These have been published in the Wood Handbook and Technical Bulletin No. 479, "Strength and Related Properties of Woods Grown in the United States." In table 1 of the present report, column 3, are listed the average values of modulus of rupture for green lumber for the important pallet species. Where the species represents several types, the value is listed for the weaker type. In column 4, the specific gravity of each species is shown, and it is easy to recognize that generally strength increases as specific gravity increases. In table 1, the species are arranged approximately in order of increasing strength.


Rept. No. 2153
Toughness values are presented for some species in column 5. These figures are in inch-pounds and represent the ability of the wood to absorb shock or impact loads. Since this property is essential in pallet deck boards, toughness should be considered when evaluating a species for use in pallet manufacture.

Basic stresses are presented in column 6. Basic stresses by definition are generalized working strength values for clear wood of a species. They are reduced from the average laboratory value in order to conform more closely to the conditions of use of lumber. Derivation of basic stresses involves consideration of a number of factors. Some are well understood or can be evaluated from available data; others are definable only in the light of engineering judgment and experience. It is not possible, therefore, to arrive at exact basic stresses by any mathematical analysis alone. Generally, the values listed in column 6 were computed by reducing the stresses in column 3 by several factors: for variability of test results within species (approximately 3/4—we have seen where this factor was 74 percent for southern yellow pine); for long-time loading—9/16; and for a factor of safety (approximately 3/5). The factor 9/16 for long-time loading was originally based on a loading time of about 70 years. This is considerably longer than any ordinary pallet is expected to sustain maximum load. Therefore, if 1 year is chosen as a reasonable maximum period for pallets, then basic stresses can be raised by 20 percent (a factor of 6/5). The net product of all of these factors is approximately 3/10.

The species in table 1 have been divided into three groups, which will be called bending strength classes A, B, and C. The first 11 species are in class A, the next 16 in class B, and the last 8 in class C. The wood groups in this table refer to the container wood groups that are referenced in nearly all pallet specifications. This division into bending strength classes has been made primarily on the basis of modulus of rupture. With a few exceptions, class A includes species with moduli of rupture from 3,800 to 5,100 pounds per square inch and specific gravities of 0.32 to 0.38. Class B includes species with moduli of rupture from 5,600 to 6,800 pounds per square inch, and specific gravities from 0.40 to 0.51, and class C includes species with moduli of rupture from 6,900 to 10,500 pounds per square inch, and specific gravities of 0.52 to 0.64. Hemlock and redwood were placed in class A because their toughness and specific gravity were considered too low for class B. Southern yellow pine, Douglas-fir (coast type) and western larch were placed in class B because their toughnesses and specific gravity were considered too low for class C. Tupelo, sweetgum, tamarack, and soft elm were placed in class B because their basic stress and specific gravity were considered too low for class C. Birch and oak were placed in class C because their toughness and specific gravity justified it. The net result is that the three classes are somewhat arbitrary, but on the other hand, logical arguments justify the position of each species.
On the basis of these three classes, it is possible to assign a single basic stress to each class. These basic stresses, which correspond to the lowest in each class, are: Class A, 1,320 pounds per square inch; class B, 1,740 pounds per square inch; and class C, 2,460 pounds per square inch. These, then, are the basic stresses for clear lumber that are applicable to pallet deck boards.

To apply basic stresses and engineering formulas to pallet deck boards, several assumptions must be made. They are:

1. Only 3-stringer pallets will be considered. This means that the deck boards are across two spans. The clear distance between stringers will be used as the span of a beam, and the load-carrying capacity of a pallet will be double that of one beam.

2. The equation for load will be:

\[ W = \frac{2bd^2}{s} f \]  

where \( W \) = load-carrying capacity of deck boards in pounds (this load is double what a beam with span \( s \) will carry)

\( b \) = width of beam, in inches (this will have to be expressed later in terms of length of pallet)

\( d \) = thickness of deck boards, in inches

\( s \) = clear span between stringers, in inches

\( f \) = basic stress for clear lumber, in pounds per square inch

This equation is a compromise between load applications where the beam is loaded with a concentrated load at its center and where the beam is loaded uniformly along its span. The equation is on the safe side for uniform loading, but might be considered critical for a concentrated load. Pallets are seldom loaded with a concentrated load, however, and since a factor of safety of 1-2/3 was used in developing the basic stress, pallets with concentrated loads will undoubtedly be safe.

3. The width of the beam, \( b \), is equal to the width of clear wood along the stringer or the length of the pallet. This means that the length must be reduced for the spaces between boards and for the knots that may be present. Knots are allowed up to one-third the width, so this factor is two-thirds. Spaces between boards are usually about one-fourth, so this factor is three-fourths. The products of these two factors is one-half, so \( b = \) one-half the
length. Equation (1) then becomes

\[ W = \frac{Ld^2}{s}f \]  

(2)

where \( L \) = length of pallet in inches.

Equation (2) can be used to calculate the load-carrying capacity of a pallet when its dimensions and the basic stress of the species are known.

**Other Considerations**

It is not possible to include in a simple equation all of the factors that affect load-carrying capacities of pallet deck boards. It can be seen that several assumptions and approximations have been made in the foregoing development of the design criteria. The formula for computing loads that has been presented is not meant to replace accurate engineering calculations by competent designers. A more precise design can be made when all the factors of pallet materials and use are known and properly applied to engineering formulas. The enclosed formula and calculator are intended for use by the pallet industry as a quick and handy method of computing approximate loads and deck-board thicknesses of wood pallets when all the criteria are not known.

It would be well for a designer of pallets to consider not only all the variables that have been discussed in this report, but also the following conditions of use: (1) Frequency of use--pallets that have prolonged periods of idleness can be lighter than those in continual use; (2) mode of use--when pallets are intended for multiple shipment in trucks or freight cars, for instance, they must be heavier than ordinary warehouse pallets; (3) kind of handling equipment--there are so many variables in the types of forklift trucks and other handling equipment that it is difficult to predict the severity of the rough handling expected; and (4) load variance--if the type of load application is known, such as concentrated or uniformly applied, then the calculations can be made with increased accuracy.

Design stresses in the foregoing formula development were based on green lumber conditions. The formula then penalizes the fabricator who uses relatively dry deck boards and expects the pallets to remain dry during use. To compensate for this condition, a bonus can be taken that will result in higher load capacities for dry pallets. It is recommended that, for deck boards that are at 18 percent moisture content or less, and that will remain that way in use, the load-carrying capacity be increased by 30 percent. Conversely, this means that if the calculator is being used to compute thickness, then the calculated thickness can be reduced by one-eighth if the dry conditions expressed above prevail.
Development of a Circular Calculator

To expedite computations by means of the foregoing equation, a circular calculator has been developed (fig. 3). It can be a useful tool for computing thickness of deck boards when the load is known, as well as for computing the load-carrying capacity of pallets when the thickness of deck boards is known. The following paragraph explains how to assemble a calculator, and the operation of a calculator is explained by the solution of two hypothetical examples.

Assembly of Calculator

The disks of the calculator have been printed on heavy paper and are included in this report as figures 4, 5, and 6. From these disks and a hairline indicator, a calculator can be assembled for use. Cut out the individual disks on the heavy black circle lines. Punch a hole of a size appropriate for a pivot through the center of each disk, which is marked with a cross. Assemble the disks in order of decreasing size with the largest disk on the bottom and the smallest on top as follows: Figure 6 (largest disk), load-carrying capacity and clear span scales; figure 5, length of stringer scale; and figure 4 (smallest disk), deck-board thickness scale. Put the transparent hairline indicator on top and fasten all together with a pivot pin.

Solution of Two Problems

With the Calculator

Suppose a pallet user wants to buy wood pallets to store 3,000 pounds per pallet of goods in his warehouse. The spacing of posts in the warehouse dictates a 48- by 48-inch dimension. The user is in the part of the country where class C lumber is available and economical. He knows that he needs 3-3/4-inch-deep stringers to permit entry of some hand trucks he uses and that 1-3/4-inch widths are needed to get good nailing. The problem, then, is to compute the thickness of the deck boards to carry the 3,000-pound net loads safely. This computation can be made simply in a matter of seconds with the circulator calculator, figures 4, 5, and 6.

1. Turn the brown disk, figure 5, so that the arrow is opposite 21-3/8 inches, clear span \( \frac{48 - 3 \times 1-3/4}{2} \).

2. With the brown and blue disks fixed in position, turn the yellow disk so that the arrow is opposite 48 inches, length of stringer.
3. With the three disks fixed in position, move the hairline of the transparent pointer to 3,000 pounds for strength class C.

4. Read on the inner yellow disk that three-fourths inch is adequate for class C deck boards.

To illustrate the use of the calculator to compute the load-carrying capacity of a pallet, the following example is presented. A manufacturer has a supply of 32- by 40-inch pallets with 25/32-inch-thick Douglas-fir deck boards. He wants to ship his products, which are items that lend themselves to strapping onto these pallets. The stringers are 1-5/8 inches wide, 3-5/8 inches deep, and 32 inches long. The problem, therefore, is to compute how large a load of his products can be shipped safely on these pallets.

1. Turn the brown disk so that the arrow is opposite 17-9/16 inches, clear span $(\frac{40 - 3 \times 1-5/8}{2})$.

2. With the brown and blue disks fixed in position, turn the yellow disk so that the arrow is opposite 32 inches, length of stringer.

3. With the three disks fixed in position, move the hairline of the transparent pointer to 25/32 inch, deck-board thickness, on the yellow disk.

4. Read on the outer blue disk that, for bending strength class B species, the load-carrying capacity is 1,900 pounds.
Table 1.—Division of common species of wood into three strength classes

<table>
<thead>
<tr>
<th>Wood group</th>
<th>Species and class</th>
<th>Green modulus of rupture (3)</th>
<th>Specific gravity (4)</th>
<th>Toughness stress for basic pallets (5)</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Willow</td>
<td>3,800</td>
<td>.36</td>
<td>110</td>
</tr>
<tr>
<td></td>
<td>Cedar</td>
<td>4,200</td>
<td>.37</td>
<td>140</td>
</tr>
<tr>
<td></td>
<td>Spruce</td>
<td>4,500</td>
<td>.36</td>
<td>160</td>
</tr>
<tr>
<td></td>
<td>Buckeye</td>
<td>4,800</td>
<td>.37</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Cottonwood</td>
<td>4,800</td>
<td>.33</td>
<td>1,320</td>
</tr>
<tr>
<td></td>
<td>Fir (true fir)</td>
<td>4,900</td>
<td>.36</td>
<td>1,320</td>
</tr>
<tr>
<td></td>
<td>Pine (except southern yellow)</td>
<td>4,900</td>
<td>.38</td>
<td>1,560</td>
</tr>
<tr>
<td></td>
<td>Basswood</td>
<td>5,000</td>
<td>.32</td>
<td>1,560</td>
</tr>
<tr>
<td></td>
<td>Aspen</td>
<td>5,100</td>
<td>.35</td>
<td>1,560</td>
</tr>
<tr>
<td></td>
<td>Hemlock</td>
<td>6,100</td>
<td>.38</td>
<td>2,100</td>
</tr>
<tr>
<td></td>
<td>Redwood</td>
<td>7,500</td>
<td>.38</td>
<td>2,100</td>
</tr>
<tr>
<td></td>
<td>Chestnut</td>
<td>5,600</td>
<td>.40</td>
<td>1,920</td>
</tr>
<tr>
<td></td>
<td>Soft maple</td>
<td>5,800</td>
<td>.44</td>
<td>1,920</td>
</tr>
<tr>
<td></td>
<td>Yellow-poplar</td>
<td>6,000</td>
<td>.40</td>
<td>1,920</td>
</tr>
<tr>
<td></td>
<td>Ash (except white)</td>
<td>6,000</td>
<td>.49</td>
<td>2,100</td>
</tr>
<tr>
<td></td>
<td>Douglas-fir (except: coast type)</td>
<td>6,400</td>
<td>.42</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Cypress</td>
<td>6,600</td>
<td>.46</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Magnolia</td>
<td>6,800</td>
<td>.46</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Tupelo</td>
<td>7,000</td>
<td>.46</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Sweetgum</td>
<td>7,100</td>
<td>.46</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Tamarack</td>
<td>7,200</td>
<td>.49</td>
<td>2,280</td>
</tr>
<tr>
<td></td>
<td>Soft elm</td>
<td>7,200</td>
<td>.49</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Southern yellow pine</td>
<td>7,300</td>
<td>.51</td>
<td>2,640</td>
</tr>
<tr>
<td></td>
<td>Douglas-fir (coast type)</td>
<td>7,600</td>
<td>.45</td>
<td>2,640</td>
</tr>
<tr>
<td></td>
<td>Western larch</td>
<td>8,200</td>
<td>.51</td>
<td>2,640</td>
</tr>
<tr>
<td></td>
<td>Birch</td>
<td>6,400</td>
<td>.55</td>
<td>180</td>
</tr>
<tr>
<td></td>
<td>Oak</td>
<td>6,900</td>
<td>.58</td>
<td>220</td>
</tr>
<tr>
<td></td>
<td>Hard maple</td>
<td>7,700</td>
<td>.52</td>
<td>190</td>
</tr>
<tr>
<td></td>
<td>Beech</td>
<td>8,600</td>
<td>.56</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Pecan</td>
<td>9,100</td>
<td>.59</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Rock elm</td>
<td>9,500</td>
<td>.57</td>
<td>250</td>
</tr>
<tr>
<td></td>
<td>White ash</td>
<td>9,600</td>
<td>.55</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Hickory</td>
<td>10,500</td>
<td>.64</td>
<td></td>
</tr>
</tbody>
</table>

Rept. No. 2153
Figure 1.--Frequency-distribution curve of bending-strength values for small, clear specimens of southern yellow pine.

Rept. No. 2153
Figure 2. --Relation between allowable stress and duration of load.

Rept. No. 2153
Figure 3. --Assembled circular calculator.
Figure 4--Deck-board thickness scale.
Figure 5. --Length of stringer scale.
Figure 6.--Load-carrying capacity and clear span scales.
Strength Class A

Aspen
Basswood
Buckeye
Cedar
Cottonwood
Fir (true fir)
Hemlock
Pine (except southern yellow)
Redwood
Spruce
Willow

Strength Class B

Ash (except white)
Chestnut
Cypress
Douglas-fir
Hackberry
Magnolia
Soft elm
Soft maple
Southern yellow pine
Sweetgum
Sycamore
Tamarack
Tupelo
Western larch
Yellow-poplar

Strength Class C

Beech
Birch
Hard maple
Hickory
Oak
Pecan
Rock elm
White ash

Rept. No. 2153