# PRACTICAL CONSIDERATIONS OF DOWEL BEARING STRENGTH AND ANNULAR RING/FASTENER ORIENTATION

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## ABSTRACT

The orientation of the fastener with respect to annular growth rings can affect the strength of laterally loaded wood connections. Connection properties are dependent on localized dowel bearing strength, which in turn is dependent on the specific gravity of the earlywood and latewood that constitute the annular rings. In the study reported here, dowel bearing strength was determined for matched specimens of three softwood species (southern pine, Douglas-fir/larch, and spruce-pine-fir) using a 0.131-inch- (3.33-mm-) diameter nail. Tests were conducted with the nail oriented radially and tangentially with respect to the annular rings. Specific gravity, percentage of latewood, and number of rings per inch were also determined for each specimen. Results illustrated that although the difference between radially and tangentially loaded dowel bearing strength can be significant, this difference is of no practical consequence. The combination of fastener size (in contact with many growth rings) and the relatively infrequent occurrence of very coarse- and flat-grained lumber resulted in nearly equal values of dowel bearing strength in the radial and tangential directions. Little correlation was found between dowel bearing strength and percentage of latewood or number of rings per inch.

The adoption of yield theory methodology for the design of laterally loaded wood connections has required the determination of dowel bearing strength, also referred to as embedment strength. This methodology, new to the 1991 edition of the *National Design Specification for Wood Construction* (NDS) (l), is based on the interaction of the crushing resistance of the wood around the fastener (dowel bearing strength) and the bending resistance of the fastener. The NDS values of dowel bearing strength were derived from work by Wilkinson (11) that correlated dowel bearing strength to wood specific gravity. Specific gravity, a measure of wood density, is recognized as a good indicator of mechanical properties as long as the wood is clear, straight-grained, and free of defects (4). Furthermore, the density of a particular piece of wood is determined by a number of factors, including the relative proportions of earlywood and latewood and the density of this wood. Earlywood and latewood (often referred to as springwood and summerwood, respectively) are found as annular rings in a tree cross section, the result of differences in growth characteristics between wood cells formed in the early and late stages of the growing season.

Several researchers have identified relative differences in both the physical and mechanical properties of earlywood and latewood in adjacent rings, which will be discussed later in this report. Because dowel bearing strength has been defined relative to specific gravity and many researched have found large differences between the specific gravity of earlywood and latewood, dowel bearing strength could be affected by the characteristics of the annular rings at a connection. Characteristics such as the position of the fastener relative to the annular rings and the relative proportions and density of earlywood and latewood could affect the performance of a fastener in a connection.

This study originated from a research project in which connection tests were conducted to verify the yield model for nailed connections (12). Here we describe the results of dowel-bearing tests that were conducted as part of that project.

## BACKGROUND

The majority of wood used for light-frame construction in the United States is from softwood species, combined into commercial groupings such as southern pine, Douglas-fir/larch, and spruce-pine-fir. Softwoods such as these (as well as ring-porous hardwoods) grown in temperate climates develop distinct annular growth rings. The earlywood of annular rings has relatively large cavities and thin cell walls. Conversely, the latewood has smaller cavities and thicker cell walls.

The difference in composition between earlywood and latewood results in a difference in density, which has been verified by several researchers.

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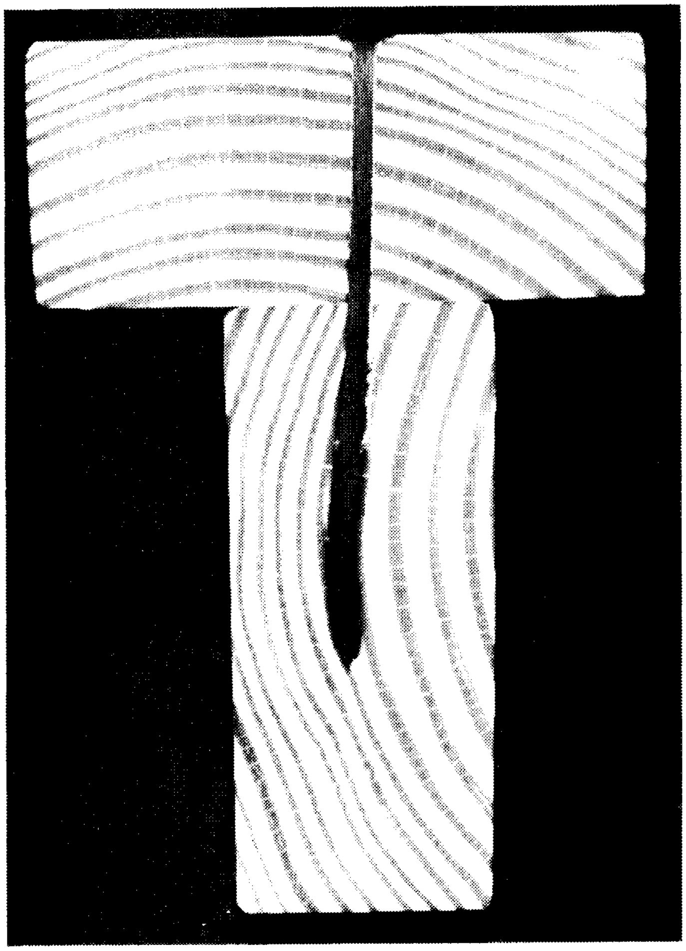

Figure 1. — Nail oriented radially (top member) and tangentially (bottom member) to annular rings in a connection.

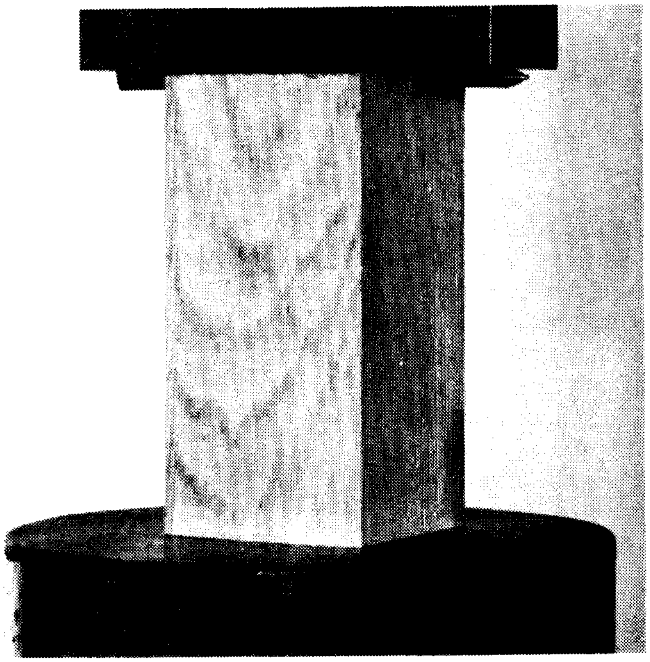

Figure 2. — Test set-up illustrating how nail is loaded over its entire supported length.

Vikhrov (9) found that latewood was 2.5 times denser than earlywood in Siberian larch; he also found that latewood constituted 23 to 28 percent of the width of the annular ring. Ivanov and Panferov (5) found similar differences in density between earlywood and latewood in their investigation of the relative differences in compressive strengths between earlywood and latewood bands in pine. The authors felt that characterizing the relative differences between compressive strength and associated deformations of earlywood and latewood would be relevant to the process of connecting wood joints with metal fasteners. They found that earlywood deformed 65 percent more than latewood up to strengths of 3,500 kg/cm$^2$ (49.8 × 10$^3$ psi). In a related study, Panferov (6) found that the strength of whole wood in radial compression is determined by the strength of the earlywood zone of the weakest annular ring. He came to this conclusion by comparing radial compressive strength of the whole wood (43.7 kg/cm$^2$ (622 psi)) with that of the earlywood (52.3 kg/cm$^2$ (744 psi)) and latewood (157.6 kg/cm$^2$ (2,242 psi)).

In earlier work involving Canadian softwood species, Vintila (10) found specific gravity ratios of latewood to earlywood between 2.1 and 3.0. More recently, Smith (8) identified a linear relationship between specific gravity and percentage of summerwood in Douglas-fir. She found that latewood constituted 33 percent of the width of the annular ring and was 2.75 times more dense than earlywood.

The relative mechanical and physical properties of earlywood and latewood are fairly well defined, and limited work has been conducted to determine the influence of their relative differences on the strength of mechanical connections. Siimes and others (7) found no significant difference in the embedding strength of Finnish pine *(Pinus silvestris)* when nails were driven in tangential, diagonal, and radial directions.

Given the new attention to dowel bearing strength with NDS adoption of yield theory for lateral connections, the objective of this project was to determine if the results found for Finnish pine by Siimes and others in 1954 can be applied to species currently in use in the United States. The aim was to determine whether the orientation of the annular rings, given the difference in earlywood and latewood properties, has a practical effect on the strength of lateral connections, which might affect associated design values. An example of a joint that might be affected is shown in **Figure 1,** where a nail connecting a roof purlin to a truss top chord is oriented radially to the annular rings in the purlin and tangentially to the rings in the top chord.

## RESEARCH METHODS

Dowel bearing strength was originally determined for three matched sections of each of 56 joints (12). In these 168 tests, the load was applied parallel to the grain and the fastener length was oriented radially relative to the annular rings. Three species groups were tested (southern pine, Douglas-fir/larch, and spruce-pine-fir) at two moisture contents (6% and 19%). Specimens were 1.5 inches thick, 3.5 inches wide, and 3 inches long (38.1 mm thick, 88.9 mm wide, and 76.2 mm long). A 0.131-inch- (3.33-mm-) diameter, smooth-shank nail was placed in a routed half-hole, creating an effective bearing length of 1.5 inches (38.1 mm). Uniform pressure was applied across the entire length of the nail **(Fig. 2)** in accordance with proposed methods (3). Continuous load-deformation data were recorded with a microcomputer.

The 168 dowel-bearing specimens from the radial tests were each cut to yield a 1.5-inch- (38.1-mm-) square specimen, 3 inches (76.2 mm) long. Dowel-bearing tests were conducted as described in the previous paragraph except that the nail was oriented tangentially to the annular rings **(Fig. 3).** Specific gravity and moisture content of each specimen were previously determined using standard test methods (2). The number of rings per inch (1 in. = 25.4 mm) and estimated percentage of latewood were determined using a magnifying scale with 0.005-inch (0.13-mm) graduations.

The 5 percent diameter offset yield load was determined for each specimen. In several cases, the load-deformation curve yielded abruptly and the offset intersected the load-deformation curve after maximum load was reached. In these cases, maximum load was used as the 5 percent offset yield load.

Approximately 40 percent of the matched specimens were judged to be unrepresentative of a nearly radial-tangential comparison (i.e., the specimens were neither flat-grained nor vertical-grained but somewhere in between) and were not considered for analyses.

## RESULTS AND DISCUSSION

The main objective of this study was to determine the relative difference in dowel bearing strength of a nail positioned in a radial or tangential direction with respect to annular growth rings.

Statistical analyses of matched specimens showed no significant difference in the dowel bearing strength of nails oriented radially or tangentially to annular rings. **Table 1** lists the dowel bearing strength and coefficient of variation, as well as specific gravity, number of rings per inch, and percentage of latewood for each species and moisture content group. Regression analyses showed a high correlation between radial and tangential dowel bearing strength ($r^2 = 0.76$), good correlation between dowel bearing strength and specific gravity ($r^2 = 0.54$), and little correlation between dowel bearing

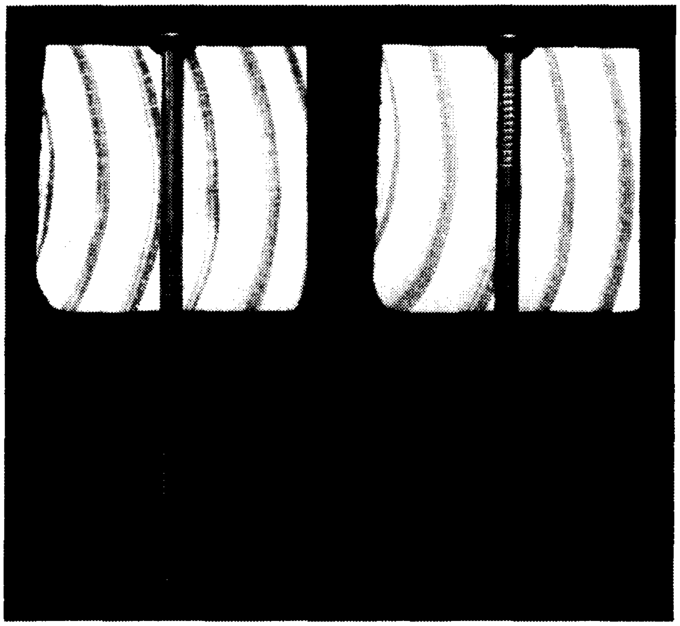

Figure 3. — Nail oriented tangentially to annular rings is positioned principally in earlywood (left) and latewood (right) zones.

*TABLE 1. — Average dowel bearing strength values and related properties.*[a]

| Moisture content level and species | No. of specimens | SG | Rings/inch | Latewood | Dowel bearing strength[b] | | | |
|---|---|---|---|---|---|---|---|---|
| | | | | | Radial | COV | Tangential | COV |
| | | | | (%) | (× $10^3$ psi) | (%) | (× $10^3$ psi) | (%) |
| 6% moisture content | | | | | | | | |
| Spruce-pine-fir | 15 | 0.52 | 40 | 30 | 8.07 | 0.13 | 8.00 | 0.10 |
| Douglas-fir/larch | 16 | 0.54 | 38 | 28 | 8.18 | 0.15 | 8.13 | 0.04 |
| Southern pine | 15 | 0.50 | 5 | 29 | 7.87 | 0.10 | 8.19 | 0.12 |
| 19% moisture content | | | | | | | | |
| Spruce-pine-fir | 27 | 0.45 | 33 | 21 | 4.40 | 0.12 | 4.63 | 0.15 |
| Douglas-fir/larch | 18 | 0.49 | 37 | 28 | 4.93 | 0.06 | 5.07 | 0.04 |
| Southern pine | 8 | 0.48 | 10 | 26 | 4.95 | 0.10 | 4.98 | 0.09 |

[a] SG = specific gravity; COV = coefficient of variation.

[b] 1psi = 0.689 N/m$^2$.

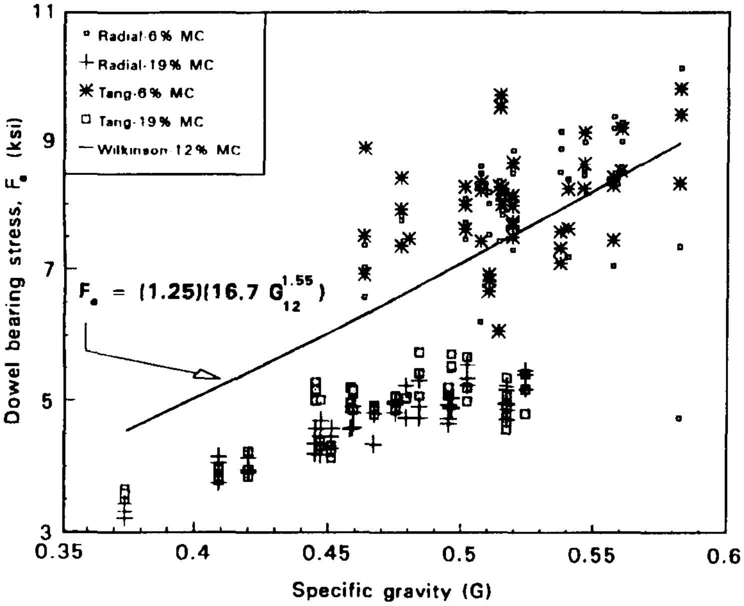

**Figure 4. — Specific gravity compared to dowel bearing strength for radial and tangential orientations and different levels of moisture content. Wilkinson's data taken from reference 11.**

strength and percentage of latewood ($r^2$ = 0.28) or number of rings per inch ($r^2$ = 0.01). These values verify the results found for Finnish pine (7) and confirm the standard design practice that does not distinguish the relative position of the fastener with respect to the annular growth rings.

The relatively equal dowel bearing strength values of radially and tangentially loaded wood can be explained by two factors. First, by definition, a fastener oriented radially to the annular rings is supported by many rings, consisting of both earlywood and latewood. Consequently, radial dowel bearing strength values are dependent on the specific gravity of the whole wood rather than that of either earlywood or latewood. Therefore, any difference between the dowel bearing strength of a fastener oriented radially to the annular rings and that of a fastener oriented tangentially depends on the tangential position of the fastener with respect to the earlywood and latewood bands. Given that many softwood species used for construction framing have tight to medium grain, in most cases fasteners will be supported by many annular rings. Only small fasteners (small-diameter nails and staples) used in coarse-grained lumber would be in contact with only a single earlywood or latewood band.

Second, relatively equal dowel bearing strength in radially and tangentially loaded wood would be noticeable only when flat-grained lumber was used in specific connection types. Much of the commercial lumber being produced today is fast-grown plantation stock in which even smaller dimension lumber, like 2 by 4 lumber (standard 38 by 89 mm lumber), is neither flat nor vertically grained but somewhere in between. This was evident in our study in that 40 percent of available specimens were removed from analysis because no clear radial/tangential comparison was available.

As **Figure 3** illustrates, dowel bearing strength can be affected by the position of the fastener relative to the annular growth rings, although this effect does not influence connection design. Both specimens in **Figure 3** were from adjacent sections of the same piece of coarse-grained southern pine lumber. The dowel bearing strength of the tangentially loaded specimen with the nail positioned over earlywood alone (left) was significantly lower than that of the specimen with the nail positioned over latewood alone (right) (average of three matched specimens = 1,200 lb. (5,340 N) compared to 1,915 lb. (8,520 N), respectively). As expected, the average dowel bearing strength of this matched specimen loaded radially fell between the tangential earlywood and latewood dowel bearing strength values, at 1,570 pounds (6,485 N).

Secondary results are illustrated in **Figure 4,** which shows dowel bearing strength compared to specific gravity of each specimen. Two points warrant discussion. First, data are clustered in two main groups related to moisture content. This phenomenon has been identified previously and is discussed in detail in a report in preparation by the author. Second, the results verify the relationship between dowel bearing strength and specific gravity found by Wilkinson (11). Results of Wilkinson's work with lumber at 12 percent moisture content are shown by the line in **Figure 4.** Wilkinson's data were increased by 25 percent to account for the difference that Wilkinson found between the dowel bearing strength values of driven and undriven fasteners. (Note: Wilkinson's equation was developed for driven nails whereas the nails used for the study reported in reference 12 were placed in undriven holes (i.e., routed half-holes).)

## CONCLUSION

Dowel bearing strength has been defined relative to the specific gravity of lumber. Specific gravity of a whole wood section is a composite of the relative proportions and specific gravities of the earlywood and latewood bands of the annular rings. Because fasteners in laterally loaded connections can be oriented tangentially to the annular rings, it is possible for the dowel bearing strength of either earlywood or latewood to govern the strength of the connections.

For the three softwood species in this study, considering fastener size and the relative infrequent occurrence of very coarse-grained, flat-grained lumber, the data suggest the following:

- There is no practical difference between radial and tangential dowel bearing strength values.
- Radial and tangential dowel bearing strength values are highly correlated for matched specimens.
- Wilkinson's 1991 formula adequately describes the relationship between dowel bearing strength and specific gravity.
- There is little correlation between dowel bearing strength and number of rings per inch or percentage of latewood.

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