Evaluation of Nail Dowel Bearing Strength Expression

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Abstract

An experimental study was conducted to improve the dowel bearing specific gravity relationship for nails. Dowel-bearing strength tests were performed on Maple, Southern Pine, Spruce–Pine–Fir, and Yellow Cedar specimens using 4.11-mm nails. New derived expressions are compared to current design equations.

Introduction

In the United States, structural connections utilizing wood under lateral loading are currently designed by the yield theory (National 1997, "Standard" 1996), which relates the connection load to geometry and dowel bearing and bending strength. European communities developed the yield model and have generated much information on joint strength and dowel yielding and bearing strength. Using a method that loads the dowel at the ends, Whale and Smith (1986) determined that nail bearing strength, defined by maximum load or deformation of 2 mm, is a function of both specific gravity and nail diameter. They noted a difference between parallel and perpendicular to grain orientation, but since the difference was small they combined data for regression analysis.

Since an ASTM standard ("Standard" 1998) for evaluating dowel bearing strength has been developed and accepted only recently, dowel bearing strength data generated according to this new standard are limited. Wilkinson (1991) determined the nail bearing strength of 4.11-mm nails for wood species with specific gravity ranging between 0.37 and 0.50. For nails driven into slide grain, he developed the following expression relating specific gravity and dowel bearing strength:

$$F_e = 126.8 G_{12}^{1.84} \tag{1}$$

where F_e is expressed in N/mm and G_{12} is specific gravity using volume at 12% moisture content. After converting expression (1) to a specific gravity based on oven-dry volume, this expression was accepted into the current U.S. wood construction standards for wood dowel bearing strength (*National* 1997, "Standard" 1996). Expression (1) is based on a limited data set that contained Douglas Fir

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material with a specific gravity value lower than published norms and two species groupings with moisture content values below 6%.

In comparing the current nail dowel bearing design expression with two Guatemalan hardwoods with high specific gravity (0.70 and 0.76), Rammer (submitted for publication) showed that the Wilkinson (1991) dowel bearing specific gravity relationship, based on 0.37 to 0.50 specific gravity range, overpredicts the experimental values. The difference between the relationship and experimental data was greater for the wood with higher specific gravity. Several researchers have investigated the effect of moisture content on bolt dowel bearing strength (Fahlbusch 1949; Koponen 1991, Winistorfer, in press). Expressions developed by these researchers predict an 8% to 30% increase in bearing strength for a 6% decrease in moisture content.

My objective was to improve the empirical relationship between specific gravity and dowel bearing strength for nails used for connection design (*National* 1997, "Standard" 1996). This objective is part of a larger study on the effects of specific gravity, nail diameter, and moisture content on nail dowel hearing strength

Research Methods

The methods described here address only the 4.11-mm nail size and 12% moisture content condition. Dowel bearing strength of four species groupings– Southern Pine, Yellow Cedar, Spruce–Pine–Fir, and Maple–was investigated both parallel and perpendicular to the grain Specimens were conditioned in a 21°C–65% relative humidity environment to achieve 12% moisture content. Pilot holes approximately 75% the diameter of the shank were drilled prior to nailing in accordance with ASTM D5764 ("Standard" 1998) and specimens were tested between 24 and 32 h after nailing. During the 24-h waiting period, specimens remained in the 21°C-65% relative humidity environment.

Results

Table 1 shows total number of tests, average specific gravity and moisture content, average and coefficient of variation (COV) values for stiffhess (calculated between 20% and 40% of maximum load), and dowel bearing strength parallel and perpendicular to grain (calculated using 5%-diameter offset load ("Standard" 1998)).

Data Analysis

T-tests indicated that grain orientation has a significant (p = 0.05) effect on 5%-diameter dowel bearing strength for all species except Maple. Comparison of mean parallel- and perpendicular-to-grain values revealed the greatest difference for the lower specific gravity woods (Spruce–Pine–Fir and Yellow Cedar).

In this study, the specific gravity range (0.4 to 0.7) was greater and the moisture content variation (10.8% to 14.4%) was less than that in Wilkinson's dowel bearing study. Therefore, a regression analysis of the combined parallel and perpendicular to grain results led to a better relationship between specific gravity and dowel bearing strength.

Table 1. Dowel bearing strength test results[a]

Species	Grain[b]	Tests (no.)	Dry SG	MC (%)	Stiffness Mean (kN/mm)	Stiffness COV (%)	Bearing strength Mean (MPa)	Bearing strength COV (%)
SPF	P	49	0.42	11.2	7.75	40.9	27.68	26.0
	R	49	0.42	11.4	2.68	42.4	20.45	26.8
Yellow Cedar	P	34	0.51	12.4	16.00	26.5	42.38	15.4
	R	26	0.50	12.7	4.28	39.7	27.62	23.2
Southern Pine	P	43	0.60	11.0	16.62	34.9	46.59	19.4
	R	42	0.60	10.8	7.43	19.6	40.08	17.0
Maple	P	30	0.69	14.3	13.36	32.8	48.09	16.4
	R	30	0.70	14.4	10.13	35.0	46.99	20.4

[a]MC is moisture content; SG, specific gravity; SPF, Spruce–Pine–Fir.
[b]P is loading parallel to grain: R, loading perpendicular to grain.

A least-square fit of a power function resulted in the following expression:

$$F_e = 91.15 G_{12}^{1.39} \tag{2}$$

where F_e is expressed in N/mm and G_{12} is specific gravity based on volume before drying. Figure 1 shows experimental results of the relationship of dowel bearing strength, both parallel and perpendicular to grain, to specific gravity along with Equations (1) and (2). Over the entire specific gravity range, parallel-to-grain strength values were higher than perpendicular-to-grain values, as confirmed by statistical comparison for each species. The fitted expression predicts the middle response of the data, with a range of percent deviation (PD) between the fitted expression and experimental values of 57.7% to -48.5% and an average PD of -0.52. For Wilkinson's expression, the PD range was 88.8% to -51.1% with an average of -2.00. Based on PD and analysis of the actual residuals, Equation (1) over-predicts dowel bearing strength for higher specific gravity values and slightly underpredicts at the lower extreme. These results were not compared to Whale and Smith's expression because of the difference in the definition of failure load between the two test procedures.

Equations (1) and (2) are equivalent when specific gravity is 0.48, but for values lower than 0.39 and higher than 0.6, the expressions differ by more than 10% (Fig. 1). For typical wood species for construction, the difference between best fit and current practice is less than 10%.

Conclusions

The results indicate that grain orientation significantly affects dowel bearing strength in wood with specific gravity of less than 0.7. The current nail dowel bearing design expression is 10% different from the best-fit power function for specific gravity less than 0.4 and greater than 0.6. This design expression overpredicts experimental values by 10% or greater for specific gravity greater than 0.6.

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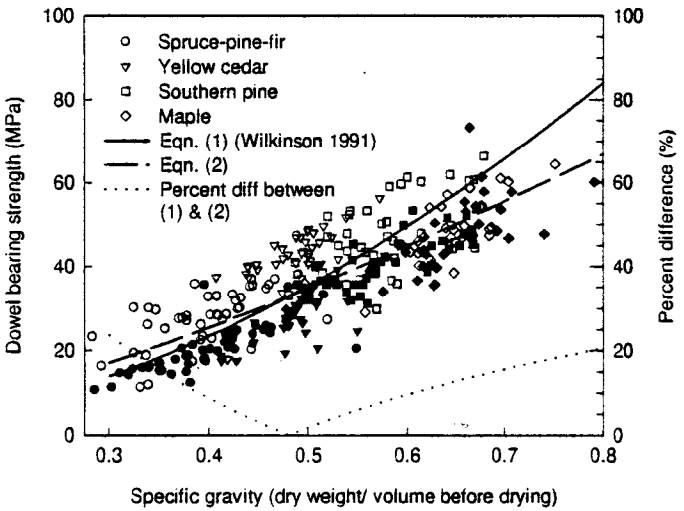

Figure 1. Dowel bearing strength versus specific gravity for 4.11-mm nails (Open symbols = parallel-to-grain strength, filled symbols = perpendicular-to-grain strength.)

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