

Experimental characterization of basic connection properties of Hinoki and Sugi

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Abstract: Hinoki (*Chamaecyparis obtusa*) and Sugi (*Cryptomeria japonica*) are two promising softwood species gaining attention beyond their traditional use in Japanese residential construction. Following the establishment of design values through in-grade testing and their inclusion in the American Wood Council (AWC) National Design Specification (NDS) Supplement, further evaluation of their connection performance is essential to increase the information about the two species of wood and support broader adoption, particularly in the U.S. construction market. This study characterized the connection performance of these species through a series of standardized tests: withdrawal resistance, lateral resistance, and dowel bearing strength. The objectives were to characterize the yield behavior, withdrawal capacity, and bearing strength of fasteners embedded in the species, and to evaluate the relevance of the predictive equations provided in the NDS for wood construction within the context of the experimental findings. The experimental results demonstrated species-specific differences in withdrawal and lateral resistance performance, with both species exhibiting consistent failure modes in agreement with NDS yield mode predictions, primarily modes III and IV. Dowel bearing strength showed a similar trend to withdrawal behavior, with the species generally exhibiting higher bearing strength values than those predicted by current design equations. While the results were conservative, they indicate that designers can safely employ the current equations for connections in both Hinoki and Sugi. These findings contribute essential connection performance data to support the structural application of Hinoki and Sugi in mainstream construction.

Keywords: Connection performance; Dowel bearing strength; Withdrawal resistance; National Design Specification.

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Introduction

In the United States, wood has long served as one of the most versatile building materials and the backbone of residential construction, where nearly all new single-family houses and low rise multifamily residential structures are constructed using wood framing and sheathing (McKeever 2009). The structural performance of wood combined with its environmental benefits, such as carbon sequestration, secure its place in modern sustainable building strategies. Timber structures can be prefabricated for on-site assembly or traditionally built in place using conventional framing methods and mechanical fasteners. As in all structural systems, the load-bearing capacity of timber constructions is usually governed by the capacity at the joints (Harte 2009).

Connections are central to the structural integrity of wood-based constructions. The performance of these connections determines the overall performance of the structure. The American Wood Council (AWC) National Design Specification (NDS) for wood construction (AWC 2024) prescribes methods to design dowel-type fasteners, including nails, bolts, and wood screws. A dowel-type fastener commonly undergoes two kinds of loading scenarios: one is dominated by lateral loading of connections and the other leads to withdrawal from the framing member. The NDS (AWC 2024), as well as the Forest Products Laboratory (FPL) Wood Handbook (FPL 2021), provide empirical equations for determining allowable withdrawal strength and fundamental methods for designing and evaluating dowel connections. They include design criteria such as yield mode equations and empirical relationships between dowel bearing strength, specific gravity (G), and the bending yield strength of common dowel-type fasteners. The underlying formulations are based on the European Yield Model (EYM), proposed by Johansen (1949), and were later incorporated into the NDS (AWC 2024). Studies have evaluated the lateral load carrying capacity, withdrawal and dowel bearing strength of common and novel wood-based building material to foster their use in structural applications (Miyamoto et al. 2020; Morris et al. 2018; Sinha and Avila 2014; Sinha and Miyamoto 2014; Zarnani and Quenneville 2014)

Hinoki, or Japanese cypress (*Chamaecyparis obtusa*), and Sugi, or Japanese cedar (*Cryptomeria japonica*), are being considered for construction application beyond Japan. Combined, the two species are the most planted coniferous species in Japan, with their production volume by tree species totaling 73.4% in 2022 (Annual Report on Forests and Forestry in Japan 2023). Both species have been utilized in residential construction,

particularly for wall paneling and structural posts (Huang et al. 2021). Recently, they were approved by the American Lumber Standards Committee to be included in the National Design Specification supplement as per the Pacific Lumber Inspection Bureau (PLIB 2024). To expand their application potential, particularly in the United States construction market, additional evaluation of their structural performance is required. One such evaluation is to characterize connection behavior for these species.

The overarching goal of this study was to evaluate the connection properties of Hinoki and Sugi for use in U.S. wood construction. Although both species are currently recognized in U.S. building codes, existing research has largely focused on their fundamental mechanical properties, with little to no investigation on the performance of structural connections involving these species. This study aimed to address that gap by experimentally characterizing the performance of common wood connections fabricated using these species and evaluate how well the results correlate with predictive methods based on specific gravity, as applied in U.S. specifications and contexts. The specific objectives of this study were as follows:

1. Characterize dowel withdrawal from Hinoki and Sugi at the single-fastener level with common dowel connections.
2. Characterize the dowel bearing behavior of Hinoki and Sugi using a range of dowel sizes up to 25 mm.
3. Characterize the performance of Hinoki and Sugi single-fastener framing connection using a sheathing side member and common framing nails.
4. Determine failure modes and connection strength for both species using standardized methods, including ASTM D5764 Standard Test Method for Evaluating Dowel-Bearing Strength of Wood and Wood-Based Products (ASTM International 2024) and NDS-based methods (AWC 2024), to generate experimentally validated data supporting the reliable use of Hinoki and Sugi in U.S. structural design applications.

Materials and methods

Materials used in this study included Hinoki and Sugi lumber imported from Japan for a separate, larger research project. Specimens were fabricated from defect-free sections of panels previously tested in that project, with knots, splits, and other defects excluded. As per reporting from the Pacific Lumber Inspection Bureau (PLIB), the specific gravities of the two species are 0.45 (Hinoki) and 0.36 (Sugi) for design (PLIB

2024). Identical test procedures, fastener types, side material, and numbers of test repetitions were applied to both species (Table 1)

Withdrawal test

Fasteners used for withdrawal tests consisted of nails and screws: 8d common nail (64 mm × 3.3 mm), 16d box nail (89 mm × 3.4 mm), 20d common nail (101 mm × 5.16 mm), 16d ring-shank nail (89 mm × 4.11 mm), and #6 wood screw (50 mm × 2.7 mm). The withdrawal tests involved nails being pulled individually across the edge face of the specimen.

Withdrawal tests were carried out across a large specimen's edge face measuring 38 mm × 184 mm (2 × 8 inches) with the fastener installed in the 38 mm face of the wood section. As specified in ASTM D1761 Standard Test Methods for Mechanical Fasteners in Wood and Wood-Based Materials (ASTM International 2020), all fasteners were installed to a minimum depth of nine times the diameter. The wood screw was tested at this depth, while the nails, both smooth and ring-shank, were tested such that approximately 25 mm of the fastener was exposed above the wood. Testing was conducted using an Instron Universal Testing Machine (UTM) with a 100 kN capacity by applying a displacement-based loading protocol (Figure 1a). The moving crossarm of the UTM was connected to the nail head and raised at a constant rate of

Table 1. Test matrix for connection tests for Hinoki (*Chamaecyparis obtusa*) and Sugi (*Cryptomeria japonica*).

Test	Fastener	Side Material	Number of Tests
Withdrawal	8d common nail	N/A	36
	16d box nail	N/A	36
	20d common nail	N/A	36
	16d ring-shank nail	N/A	36
	#6 wood screw	N/A	36
Lateral resistance	8d common nail	12.5 mm (1/2") plywood	10
	3.5 mm dowel parallel	N/A	10
Dowel bearing	3.5 mm dowel perpendicular	N/A	10
	6 mm dowel parallel	N/A	10
	6 mm dowel perpendicular	N/A	10
	13 mm dowel parallel	N/A	10
	13 mm dowel perpendicular	N/A	10
	19 mm dowel parallel	N/A	10
	19 mm dowel perpendicular	N/A	10
	25 mm dowel parallel	N/A	10
25 mm dowel perpendicular	N/A	10	

2.54 mm/min, per ASTM D1761 (ASTM International 2020). Testing was stopped after the peak load was attained and the load subsequently declined.

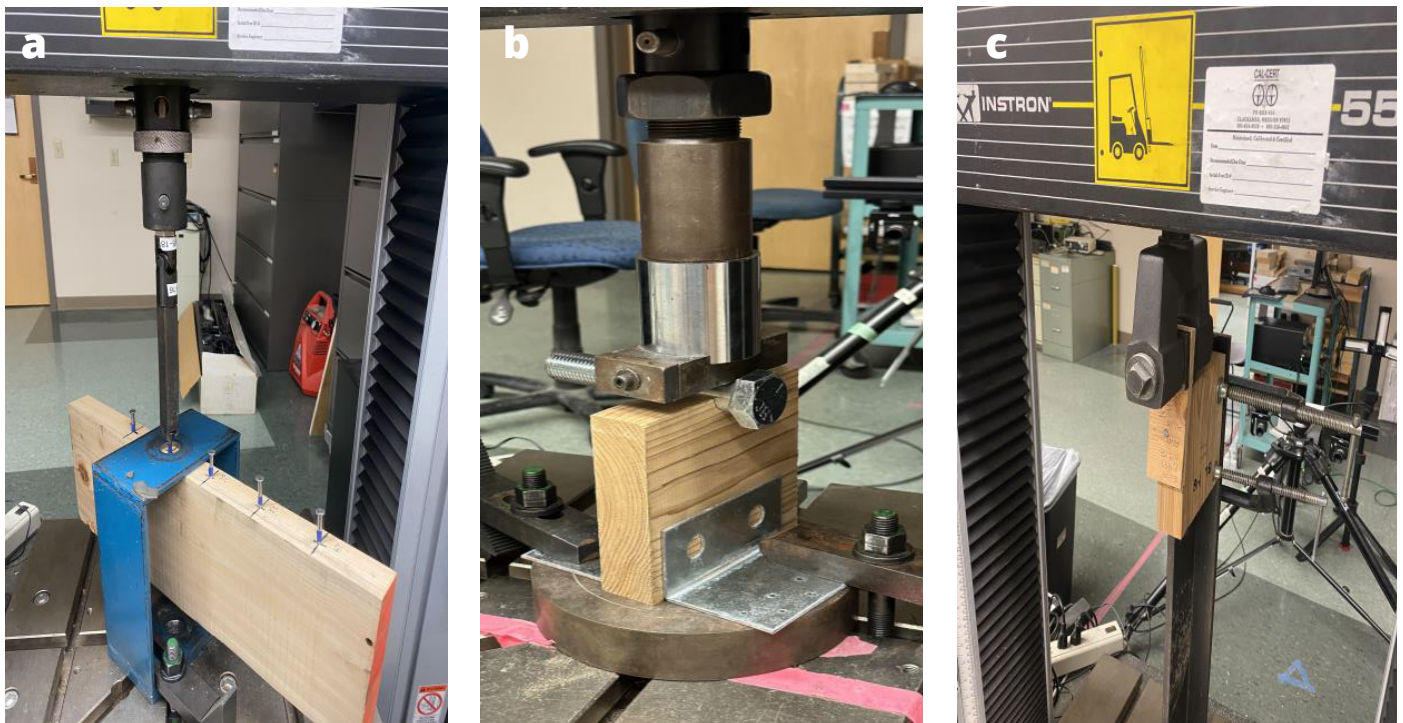


Figure 1. Connection tests set up (a) withdrawal; (b) dowel bearing; (c) lateral resistance.

The withdrawal strength (WS) was calculated using the expression per ASTM D5764 (ASTM International 2024).

$$WS = \frac{P_{peak}}{L} \quad [1]$$

where P_{peak} = max force observed in withdrawal test; and L = length of the nail that was embedded into the wood specimen.

Lateral resistance test

Lateral resistance tests were conducted by securing the lumber to the fixture and applying a transverse load to the fastener or member until failure. Sheathing used for lateral testing was derived from 12.5 mm plywood 2440 mm × 1220 mm sheets. The lateral resistance test specimens consisted of the defect-free sections of both Hinoki and Sugi species of 38 × 140 mm (2 × 6 inches) and a side member of 13 mm (1/2 inch) plywood. An 8d common nail was driven through the plywood side member into the narrow 38-mm wide face of the lumber. The nail was installed fully into both members, with care to avoid any overdriving into the plywood. This study closely follows ASTM D1761 (ASTM International 2020) to ensure comparability with existing data for North American wood species (Figure 2).

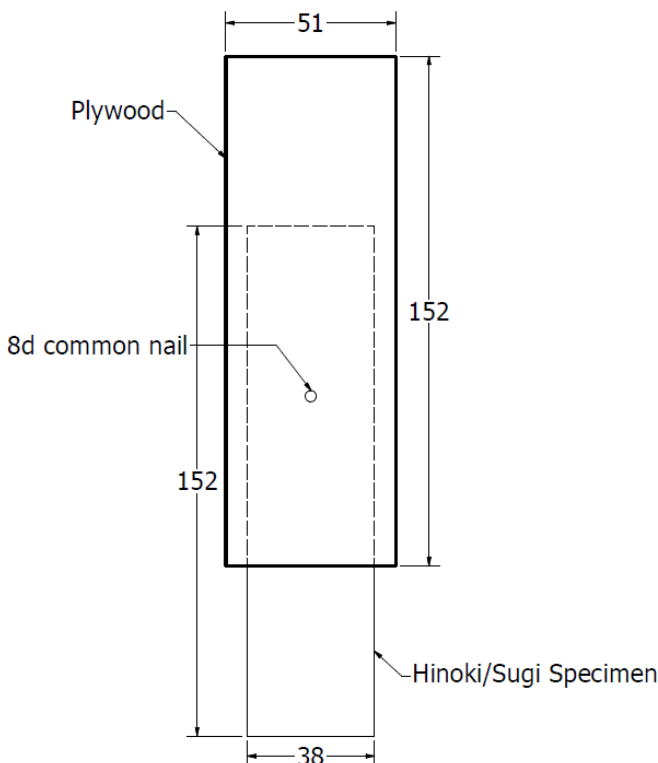


Figure 2. Schematic of lateral connection (dimensions in mm).

The tests were conducted using an Instron UTM with a 100 kN capacity by applying a displacement-based loading protocol (Figure 1b). The moving crossarm of the UTM was attached to the plywood side member and was raised at a constant rate of 2.54 mm/min, per ASTM D1761 (ASTM International 2020) until force resistance in lateral testing reached 80% of peak load. At this stage, testing was halted and the corresponding failure modes were documented.

The yield load is determined using the 5% offset method prescribed in the NDS (AWC 2024) as shown in Figure 3. In the 5% offset method, first the initial stiffness is determined as the slope of the linear portion of the load deflection profile. That slope is offset by 5% of the dowel diameter on the x-axis. The yield point is then defined as the intersection between the offset line and the test data.

Dowel bearing test

Dowel bearing strength was determined following ASTM D5764 using the half-hole method (ASTM International 2024). Due to the orthotropic nature of wood, the dowel strength can differ with respect to the grain direction. As such, tests were conducted with the dowel bearing both parallel and perpendicular to the grain direction for dowel diameters of 3.5 mm, 6 mm, 13 mm, 19 mm, and 25 mm. All specimens were prepared in accordance with geometric guidelines outlined in ASTM D5764.

Dowel bearing tests were conducted using the previously mentioned UTM (Figure 1c). Each specimen was prepared from clear lumber sections with a half-hole routed into the edge that was of equal diameter to the dowel for that test series. The crossarm of the UTM compressed the dowel into the half-hole at a rate of 1 mm/min, per ASTM D5764 (ASTM International 2024). Testing was concluded when the dowel became fully

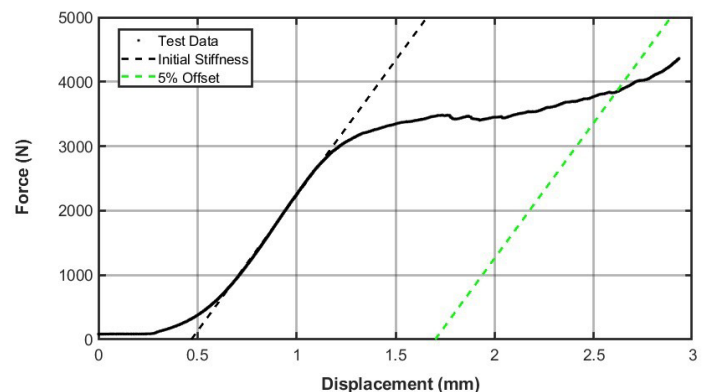


Figure 3. Graphical depiction of 5% offset method used for both lateral resistance and dowel bearing.

embedded within the wood specimen. This stage was identified by the onset of a second region of approximately constant stiffness in the force–displacement response, as illustrated in Figure 3. Dowel bearing (DB) strength was calculated using the 5% offset method, following ASTM D5764 (ASTM International 2024).

$$DB = \frac{F_{yield}}{DL} \quad [2]$$

where DB is the dowel-bearing strength (MPa); F_{yield} = yield load (N) determined at the point at which the 5% offset line intersects with the experimental data; D = diameter (mm) of the dowel; and L = length (mm) of the specimen (ASTM International 2024).

Predictions based on NDS equations

The equations and parameters used to calculate yield performance for each mode are presented in the National Design Specification developed by AWC’s Wood Design Standard Committee (AWC 2024), based on the EYM. The yield performance of both Hinoki and Sugi connections were estimated using the six yield modes presented in Table 12.3.1A of the NDS (AWC 2024), with each mode corresponding to specific components of the connection undergoing deformation. To calculate yield strength and identify yield modes, several input parameters are required. These include the geometry of the main (framing) and side (sheathing members), the geometry and material properties of the dowel, the dowel bearing strengths of both main and side members, and the geometry of the connection. All six yield modes are analyzed, and failure is anticipated to occur following whichever yield mode is calculated with the lowest value. This critical mode and associated load are the predicted yield mode and strength.

Results and discussion

Withdrawal

Hinoki

Fastener withdrawal resistance of Hinoki was determined using the peak force from testing (Table 2). These values were determined on a per embedment length basis and were compared to equations using the geometry and type of dowel fastener and the proposed specific gravity of Hinoki (0.44). Experimentally determined withdrawal resistance of Hinoki was compared with the NDS withdrawal design values given on Table 12.2D of the NDS (AWC 2024). For 8d and 16d box nails, the average withdrawal capacities for Hinoki were 34.7 N/mm and (coefficient of variation [COV] = 21.8%) and 24.3

N/mm (coefficient of variation [COV] = 17.8%), respectively. Corresponding values predicted by the NDS equation were 23.3 N/mm and 23.8 N/mm, respectively. For 20d common nails and 16d ring-shank nails, the average withdrawal resistance was 29.2 N/mm (coefficient of variation [COV] = 21.8%) and 69.8 N/mm (coefficient of variation [COV] = 10.6%), respectively, while the NDS equation predicted 33.3 N/mm and 54.7 N/mm, respectively. In comparison, studies have reported average nail withdrawal capacities of 26.78 N/mm for juniper wood (Morris et al. 2018) and 28.75 N/mm for Douglas-fir (Wang et al. 2011). For wood screws, the average withdrawal resistance was 92.7 N/mm (coefficient of variation [COV] = 8.2%), whereas the NDS equation predicted a withdrawal capacity of 73.3 N/mm (AWC 2024). As shown in Table 2, the predicted values for both nails and wood screws were in close agreement with the observed values.

Sugi

Fastener withdrawal resistance of Sugi was determined using the peak force from testing and is presented in Table 3. These values were determined on a per embedment length basis and were compared to equations using the geometry and type of dowel fastener and the specific gravity of 0.36. The withdrawal strength comparison between experiment results and predictions derived from NDS equation can be seen in Table 3. The experimentally determined withdrawal resistance of fasteners in Sugi was compared with the NDS withdrawal design values presented in Table 12.2D of the NDS (AWC 2024). For 8d and 16d box nails, average withdrawal capacities of 13.6 N/mm (COV = 33%) and 11.6 N/mm (COV = 20.4%) were measured, respectively, while the corresponding NDS predictions were

Table 2. Hinoki withdrawal summary.

Fastener Type	Avg. withdrawal resistance (N/mm)	COV (%)	NDS predicted values (N/mm)
8d box nail	34.7	21.8	23.3
16d box nail	24.3	17.8	23.8
20d common nail	29.2	21.8	33.3
16d ring-shank nail	69.8	10.6	54.7
#6 wood screws	92.7	8.2	73.3

Table 3. Sugi withdrawal summary.

Fastener Type	Avg. withdrawal resistance (N/mm)	COV (%)	NDS predicted values (N/mm)
8d box nail	13.6	33	13.8
16d box nail	11.6	20.4	13.6
20d common nail	14.4	20.6	16.8
16d ring-shank nail	40.0	10.3	26.5
#6 wood screw	54.3	8.1	45.9

13.8 N/mm and 13.6 N/mm, respectively (AWC 2024). Average withdrawal resistances for 20d common nails and 16d ring-shank nails were 14.4N/mm (COV = 16.8%) and 40.0 N/mm (COV = 26.5%), respectively, compared with NDS-predicted values of 16.8 N/mm and 26.5 N/mm, respectively. The values observed in this study are comparable to the average withdrawal resistance of 16.03 N/mm reported for hybrid poplar by Sinha and Avila (2014) and 14.2 N/mm reported by OWIC (2011). Wood screws exhibited an average withdrawal resistance of 54.3 N/mm (COV = 8.1%), whereas the NDS equation predicted a withdrawal capacity of 45.9 N/mm (AWC 2024). Overall, as summarized in Table 3, the NDS-predicted values (AWC 2024) were in reasonable agreement with the experimentally measured withdrawal resistance for Sugi, with close agreement for most fasteners and more conservative estimates observed for the 16d ring-shank nails and wood screws.

Dowel bearing

Dowel bearing (Hinoki)

A summary of results and associated COVs from the dowel bearing tests for Hinoki (at an average specific gravity of 0.44) in the parallel and perpendicular direction are presented in Table 4. The dowel bearing tests were analyzed using the 5% offset method to determine the dowel bearing strength. The dowel bearing strength showed a similar trend to the previous withdrawal results, with the Hinoki typically exhibiting higher dowel bearing values than those predicted by equations from the NDS (AWC 2024), as shown in Figure 4. Strengths parallel to grain tend to be greater than those perpendicular; this is a common trend because of the anatomy of wood.

The results for dowel bearing between 6 mm and 25 mm in the parallel direction aligned well with the values from the

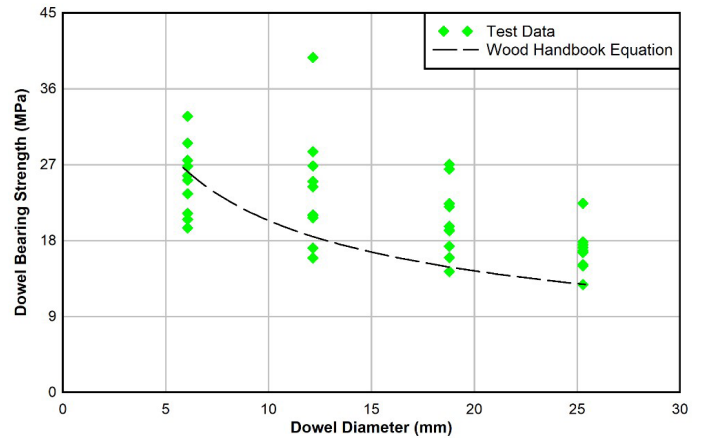


Figure 4. Variation in dowel bearing results of Hinoki perpendicular to grain with overlaid line of empirical Wood Handbook equation.

empiric equations, with in total a 3% difference between the experimental and analytical results. Tests completed with 3.5 mm diameter dowels did not show a difference of 60%. These results were unexpected due to previous models suggesting that the direction is insignificant at small dowel sizes. The larger dowel (6-25 mm) bearing strength diverged for the perpendicular direction, with smaller diameter fasteners aligning well with the equation and diverging as diameter increased. The dowel bearing strength observed for Hinoki was comparable to the dowel bearing strength of Douglas-fir (37.12 MPa) reported by Kent et al. (2004). While the results for this were conservative, this would suggest that a designer could safely design connections in Hinoki using the current equations.

Dowel bearing (Sugi)

The dowel bearing tests were analyzed using the 5% offset method to determine the dowel bearing strength and are presented in Table 5. The dowel bearing strength showed a similar

Table 4. Hinoki dowel bearing strength experimental and Wood Handbook model data (FPL 2021).

Grain direction	Dowel diameter (mm)	Nominal diameter (mm)	Dowel bearing (MPa)	COV (%)	NDS equation (MPa)	Percent difference (%)
Parallel	3.5	3.5	27.21	12.2	25.27	7.68
Perpendicular	3.5	3.5	43.86	17.8	25.27	73.58
Both	All		35.54	15	25.27	40.63
Parallel	6.1	6.4	34.43	15.9	33.98	1.35
	12.2	12.7	34.23	37.7	33.98	0.74
	18.8	19.1	33.75	22.4	33.98	-0.67
	25.3	25.4	37.89	12.8	33.98	11.53
	All		35.08	23.3	33.98	3.24
Perpendicular	6.1	6.4	25.23	16.5	25.60	-3.68
	12.2	12.7	24.03	28.3	18.49	29.95
	18.8	19.1	20.37	20.5	14.87	36.94
	25.3	25.4	16.8	14.8	12.82	31.02

trend to the previous withdrawal results, with the Sugi typically exhibiting higher dowel bearing values than those suggested by equations from the NDS (AWC 2024). This is illustrated in Figure 5 for different dowel diameters tested.

The 3.5 mm dowel bearing tests revealed a distinct difference in strength between the parallel and perpendicular grain directions, despite the governing equation not accounting for grain orientation at this diameter. The average experimental values in both directions exceeded the predicted value. For dowel sizes between 6 mm and 25 mm loaded parallel to grain, experimental results closely matched the empirical equation, with only a 3% overall difference. However, in the perpendicular direction, agreement with the equation decreased as dowel diameter increased. Smaller dowels aligned well, but larger dowels diverged, as seen in Figure 7. This indicates that the current equations tend to underestimate bearing strength at larger diameters. While conservative, these results suggest that designers can safely use the existing equations for Sugi connections.

Lateral resistance

For both Hinoki and Sugi, the lateral resistance tests exhibited fairly consistent results, as summarized in Table 6. Yield strength and displacement at yield were determined

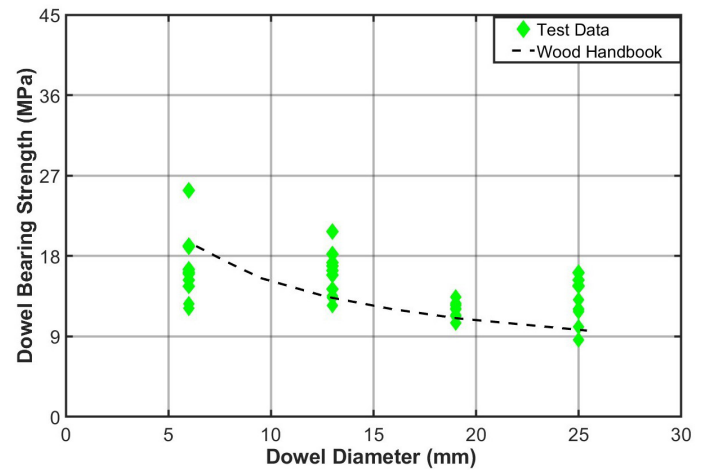


Figure 5. Variation in dowel bearing results of Sugi perpendicular to grain with overlaid line of empirical Wood Handbook equation

using the 5% offset method, while stiffness was obtained from the initial linear portion of the load-displacement curves for Hinoki and Sugi, shown in Figure 6 and 7, respectively. The ultimate strength obtained from the load-displacement curve represents the maximum load that a connection can withstand prior to failure. However, the design of connections is based on the yield strength criterion (Sinha and Miyamoto 2014). The yield strength observed for Hinoki was higher than that

Table 5. Sugi dowel bearing strength experimental and Wood Handbook empiric model data (FPL 2021).

Grain direction	Dowel diameter (mm)	Nominal diameter (mm)	Dowel bearing (MPa)	COV (%)	NDS equation (MPa)	Percent difference (%)
Parallel	3.5	3.5	31.98	16.9	17.5	103.39
Perpendicular	3.5	3.5	18.22	20.7	17.5	15.90
Both	All		25.10	18.8	17.5	59.65
Parallel	6.2	6.4	29.14	21.4	27.8	11.00
	12.2	12.7	32.11	12.3	27.8	22.28
	18.7	19.1	32.11	16.2	27.8	22.28
	25.3	25.4	28.65	15.5	27.8	9.14
	All		30.50	16.35	27.8	16.18
Perpendicular	6.2	6.4	16.69	21.7	19.12	-6.52
	12.2	12.7	15.89	15.2	13.5	25.37
	18.7	19.1	12.26	6.5	11.0	19.63
	25.3	25.4	12.83	17.7	9.6	45.48

Table 6. Experimental lateral resistance results of Hinoki and Sugi with an 8d common nail and 12.5 mm plywood side member.

Species	Property	Yield strength (N)	Displacement at yield (mm)	Stiffness (N/mm)	Ultimate strength (N)	Displacement at ultimate (mm)
Hinoki	Mean	725.6	0.39	3159.5	2334.7	16.03
	COV (%)	17	22.1	58.4	7	17
Sugi	Mean	666	0.97	971.9	1165.7	12.0
	COV (%)	10.6	25.9	45.4	16.8	67.3

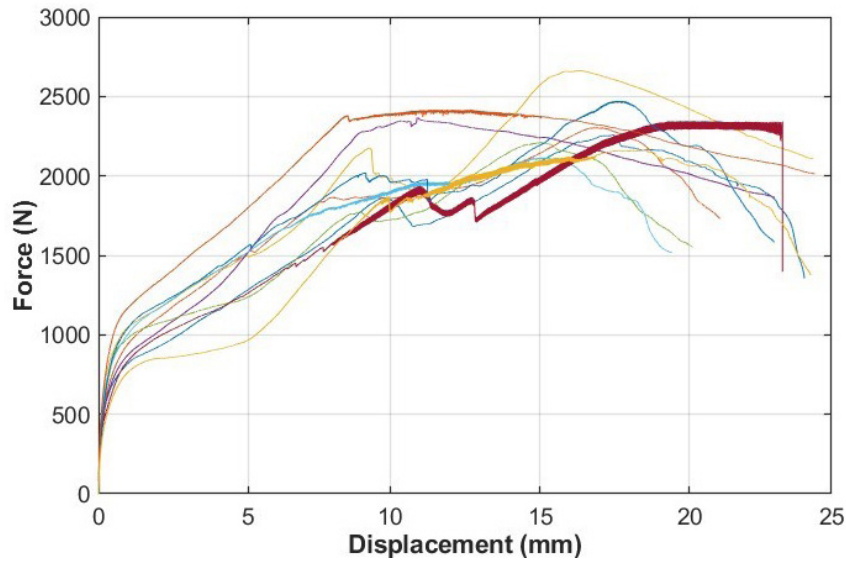


Figure 6. Load-displacement curve (Hinoki lateral test).

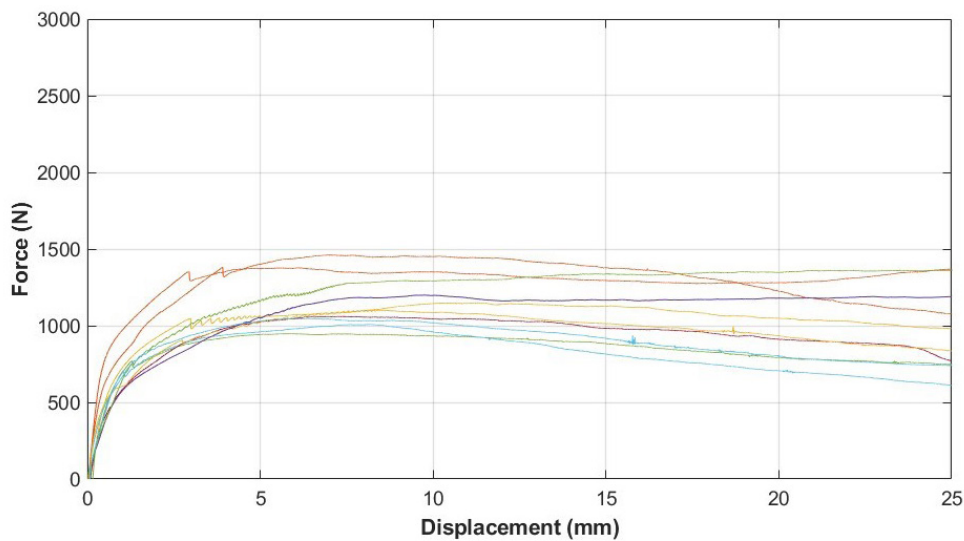


Figure 7. Load-displacement curves (Sugi lateral test).

of Sugi, which may be attributed to Hinoki's greater density and its influence on the embedment strength of the material surrounding the fastener (Huang et al. 2021). The coefficients of variation (COVs) observed in this study were relatively low for Hinoki (10.6%) and moderate for Sugi (17%). By comparison, similar level of variability has been reported in past studies, with COV in the range of 16% to 21% (Sinha et al. 2011; Sinha and Avila 2014) and values of 17% to 28% (Kent et al. 2004). Higher variability has also been documented, including COVs of 22% to 34% (Morris et al. (2018).

Design value predictions based on NDS

Table 7 presents the average experimental yield strengths, failure modes, and coefficient of variation for Hinoki and Sugi. This allowed meaningful comparison between the experimental results and the values predicted by the dowel bearing and NDS equations (AWC 2024). Observed yield strength was dictated by the 5% offset in testing. Both the dowel bearing and the NDS prediction are derived using the equation presented in Table 12.3.1A of the NDS Publication for Wood Construction, which as previously noted, is based on the European Yield

Table 7. Predictions using National Design Specification (AWC 2024) yield models for Hinoki and Sugi (N).

Yield strength predictions		Observed			Dowel bearing			NDS prediction		
Species	Yield strength	Yield mode	COV	Yield strength	Yield mode	Design index	Yield strength	Yield mode	Design index	
Hinoki	726	III, IV	17	727	III	1.00	681	III	1.07	
Sugi	666	III, IV	10	673	III	0.99	613	III	1.09	

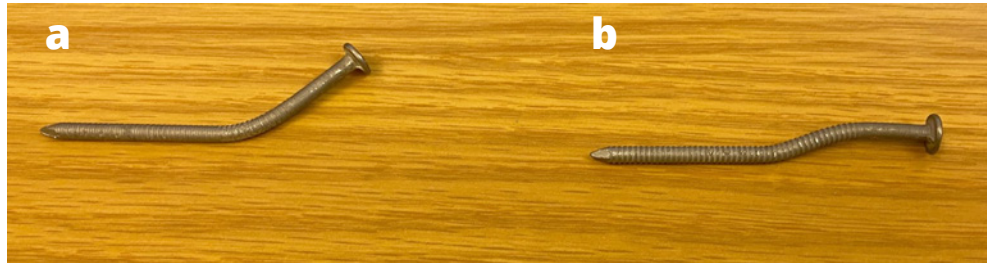


Figure 8. Yield modes observed. (a) Mode III; (b) Mode IV.

Model (Johansen 1949). The values used are either the NDS-predicted values, corresponding to the dowel diameter, or the experimentally determined values from the dowel bearing tests.

To quantify the predictive accuracy, a design index, defined as the ratio of observed to predicted yield load, was employed. A design index greater than 1.0 indicates conservative or under-prediction, while values less than 1.0 suggest overestimation. For Hinoki, the design index was 1.00 for the dowel bearing model and 1.07 for the NDS model (Table 7), indicating that both approaches provided conservative estimates of connection strength. Similarly, Sugi exhibited design index of 0.99 and 1.09 for the dowel and NDS models, respectively, further confirming that both models yielded safe and conservative predictions

Previous studies by Sinha and Avila (2014) and Morris et al (2018) have reported strong agreement between NDS predictions and experimental results for various wood species, and the present findings align with these observations, demonstrating comparable agreement for Hinoki. This suggests that the NDS model offers a reasonable approximation of yield strength for common nail connections involving Hinoki and a typical sheathing material.

In addition to predicting the yield strength, the NDS yield model also identifies expected failure modes. For both Hinoki and Sugi, the predominant observed yield modes were III and IV. According to NDS definitions (AWC 2024), mode III corresponds to plastic hinging of the fastener within the

main (framing) member, while mode IV involves bending of the fastener across both the framing and sheathing members, accompanied by the formation of plastic hinges at characteristic locations along the dowel (Figure 8).

The predicted and observed yield modes were consistent for both Hinoki and Sugi. Mode III and IV were the predominant failure modes observed experimentally, while the EYM predicted mode III for both species. The occurrence of mode IV in some cases may be attributed to factors such as the presence of knots or manufacturing imperfections. Overall, the findings suggest that the model provides a reliable prediction of both yielding modes, and to a reasonable extent, the yield load for connections involving Hinoki and Sugi.

Conclusion

This study evaluated the performance of Hinoki and Sugi in dowel-type connections through withdrawal tests, dowel-bearing strength measurements, and laterally loaded connection tests with standard sheathing materials.

Experimental withdrawal tests characterized the behavior of both species, demonstrating generally higher resistance than predicted by NDS-based equations and confirming the practical reliability of these species at the single-fastener level. Dowel bearing tests revealed that parallel-to-grain loading aligned well with predictions, whereas perpendicular-to-grain loading showed higher strength for larger dowels, suggesting that current equations may underestimate bearing capacity in some cases.

Design indices confirmed that the models provided conservative and safe estimates of connection strength for both species. Predicted and observed yield modes were consistent, with experimental behavior reflecting expected failure mechanisms. Collectively, these experimentally validated results support the reliable use of Hinoki and Sugi in U.S. structural design practices and provide guidance for the design of wood connections using these species.

Acknowledgement

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