Mokchae Konghak 26(2) : 1~5, 1998

Influence of Earlywood, Latewood, and Nail Driving Position on Nail Withdrawal Load Behavior[*1]

Jae-Kyung Cha[*2]

ABSTRACT

Nail withdrawal tests were conducted on clear wood of radiata pine. Nails were driven into the earlywood and latewood zones of each specimen, and nail withdrawal tests were then performed. Nail withdrawal loads were strongly dependent on earlywood and latewood and on nail position. The average load values for nail withdrawal in both the tangential and longitudinal directions were higher for latewood than for earlywood. Linear and nonlinear regression analyses of nail withdrawal load with specific gravity showed no discernible differences. Good correlations were obtained between nail withdrawal load and specific gravity.

Keywords : Nail withdrawal load, earlywood, latewood, specific gravity, radiata pine

1. INTRODUCTION

Nails are the most common mechanical fastenings used in structural construction. Nail performance depends on numerous factors. For good performance, a nail must have high initial stiffness and sufficient ductility, and it must be able to transmit a fairly large force when it acts as part of a "group." Design loads have been specified accordingly, with the provision that nails are located in visually clear, defect-free wood of an appropriate density. These requirements are not always met in practice, and joints may be made at or near defects or in regions of low-density wood. These problems are particularly relevant in truss and joist fabrications where nails are used with fast-grown plantation softwood such as radiata pine. There is a need to determine possible changes in load capacity of nail joints where nails are used with juvenile and/or low-density wood, especially earlywood. A major difference in softwood structure between earlywood and latewood lies in the cell wall thickness: earlywood cell walls are 2 to 3 times thinner than latewood cell walls. This is the cause for the low specific gravity (SG) of earlywood.

There is an increasing interest in importing plantation-grown softwood lumber for structural application in Korea. Its fast growth gives this wood a distinctly different appearance to that of slow-growing softwood, which is often graded by rules that discriminate against fast growth. For in-service use, nail connection also requires joint designs adapted to the strength properties of wood along and across the grain. Nails in use resist either withdrawal loads or lateral loads, or a combination of the two. Both nail withdrawal and lateral resistance are affected by the wood, the nail, and the condition of use. Many sources (Groom, 1993; FPL,

---

[*1] Received December 1, 1997
This study was accomplished by Kookmin University research fund

[*2] College of Forestry, Kookmin University, Seoul 136-702, Korea

1987) provide empirical formulas and tables for finding the maximum nail withdrawal load. However, none of these gives maximum withdrawal loads for earlywood and latewood.

The specific gravity of earlywood and latewood would affect the performance of a nail in a connection. The main objective of this study is to determine the relative difference between nail withdrawal loads by nail orientation in longitudinal and tangential directions with respect to earlywood and latewood. In addition, this study also investigated the influence of SG on nail withdrawal load.

2. MATERIALS & METHODS

Test specimens were made from radiata pine (*Pinus radiata*) 35 by 90 by 95mm timber planks. Twenty-five kiln-dried samples (11.2% moisture content) were randomly selected from a stack in the Wood Technology Laboratory, School of Forestry, University of Canterbury. Care was taken to discard any material that had knots or other defects. From each 95-mm-long specimen, two blocks (35 by 40mm) were cut perpendicular to the longitudinal direction. Since earlywood and latewood were cut from the same growth ring without loss of one or the other type specimen to measure SG after the nail withdrawal test, the earlywood and latewood zones for different growth rings were used for driving in nails. The specimens had a uniform moisture content (MC) of 11.2%. Density varied between 0.431 and 0.619, with a mean value of 0.479.

The nails were 2mm Common with a length of 40mm and were obtained from a local supply store. Table I shows the nail shank diameter and length used for this study. Four nails were driven into each nail withdrawal test specimen. Two nails were driven in the radial surface, and two in the cross section between the earlywood and latewood zones. A total of 100 nail withdrawal tests were conducted. Since the nail driving method influences the characteristics of the joint (Groom, 1993; FPL, 1987) and to avoid splitting, the nail holes (1.5mm diameter) were predrilled in the specimen using a steel plate as a template. The nails were then manually driven by a hammer into the predrilled holes perpendicular to the surface to a depth of 2.0cm. The nails were driven in the longitudinal and tangential directions for each earlywood and latewood zone.

Table 1. Summary of test details.

Characteristics		Description
Nail	Diameter	1.94mm (0.01mm*)
	Length	41.10mm (0.12mm)
	Penetration	20.20mm (0.68mm)
Wood	Timber	25 pieces from Radiata pine from north island in New Zealand
	Density	0.479 (0.04)

* Standard deviation.

Tests were conducted immediately after the nails were driven into the wood. Some of the nail shank was exposed to account for the metal in the test frame that the nail would pass through. Testing was conducted with an Instron universal testing machine. Specimens were attached to a specially designed frame that prevented horizontal movement. The fastener head was attached to a grip, which was connected to a load cell and the movable head of machine. The testing machine was operated at a constant withdrawal rate by a crosshead movement of 5mm/min. During testing, load values and displacements were recorded continuously on an x-y plotter.

After the nail withdrawal test, a small piece of the earlywood and latewood bands was cut from each specimen to determine MC and SG. Earlywood and latewood specimens were obtained from the earlywood and latewood zones into which the nails were driven. In total, 50 specimens (25 earlywood and 25 latewood specimens) were prepared to measure MC and SG using standard test methods. Volume and weight were measured for each sample. The samples were dried at 104℃ until constant weight was reached.

3. RESULTS & DISCUSSION

The results from the nail withdrawal test are summarized in Table 2. The average MC was 11.5% for earlywood and 11.3% for latewood. The SG of earlywood was determined to be 0.37, while that of the latewood was 0.53.

As shown in Table 2, nail withdrawal load was strongly dependent on nail orientation. There were also significant differences in nail withdrawal load between earlywood and latewood. In earlywood, average nail withdrawal load was 88.73 N/cm in the tangential direction and 52.41 N/cm in the longitudinal direction. In latewood, average nail withdrawal load was 157.16 N/cm and 105.83 N/cm in the tangential and longitudinal directions, respectively. The overall average ultimate withdrawal load in the tangential direction was 122.95 N/cm (70.2 lb/in) with a coefficient of variation (COV) of 35%. Tangential nail withdrawal load of latewood was 1.55 times greater that that of earlywood, which is explained by the low SG of earlywood. The influence of earlywood and latewood on nail withdrawal load is shown in Fig. l.

The design withdrawal load values for radiata pine were greater than the published values for species with similar SG using the same nail size. Based on the ultimate withdrawal load from side grain, the design withdrawal load for radiata pine is 26.1 lb/in. The National Design Specifications show a withdrawal load of 21 lb/in and 26.1 lb/in for 6d common nails in lumber with a SG of 0.45 and 0.49, respectively (NDS, 1991). However, the design withdrawal load for earlywood is 18.8 lb/in.

Many sources provide empirical formulas and tables for finding the maximum nail withdrawal load (Groom, 1993; FPL, 1987). The Wood Handbook (FPL, 1987) shows an empirical equation for withdrawal load for bright, common wire nails driven into side grain of seasoned wood. Nail withdrawal load capacity is affected by many factors, such as wood SG, diameter of nail, and length of embedment. Although the formula for nail withdrawal resistance indicates that heavy woods offer greater resistance for nail withdrawal than do light weight woods, none of these formulas gives maximum nail withdrawal loads for earlywood and latewood. Therefore, in the study reported here, both linear and nonlinear regression analyses were conducted between the nail withdrawal load values,

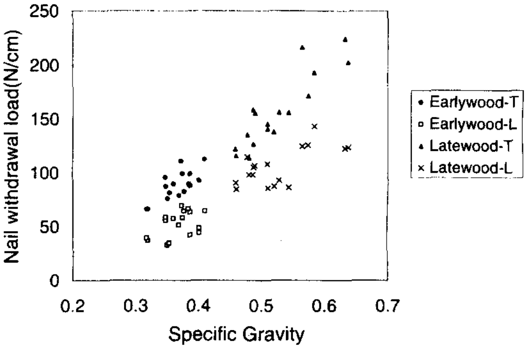

Fig. 1. The variations in nail withdrawal loads by different nail positions.

Table 2. Summary of physical properties of testing specimen and nail withdrawal loads.

Growth ring		Physical properties		Nail withdrawal load(N/cm)		
		MC (%)	SG	Tangential (T)	Longitudinal (L)	Ratio (T/L)
Earlywood	Average	11.50	0.37	88.73	52.41	1.69
	SD*	0.99	0.03	13.06	11.98	
Latewood	Average	11.30	0.53	157.16	105.83	1.49
	SD	1.48	0.06	34.11	17.53	
Combined	Average	11.40	0.45	122.95	79.12	1.55
	SD	1.25	0.09	43.04	30.88	

*Standard deviation.

Table 3. Linear regression relationships between nail withdrawal load and SG.

Growth ring		Nail withdrawal load=A*SG+ B		R^2
		A	B	
Earlywood	Tangential	355.33	-41.82	0.52
	Longitudinal	206.88	-23.60	0.21
Latewood	Tangential	549.30	-131.42	0.80
	Longitudinal	208.51	-3.71	0.44
Overall	Tangential	451.07	-78.40	0.91
	Longitudinal	309.29	-58.94	0.83
	Combined	380.18	-68.67	0.63

Table 4. Nonlinear regression relationships between nail withdrawal load and SG.

Growth ring		Nail withdrawal load=A*SG^B		R^2
		A	B	
Earlywood	Tangential	412.24	1.54	0.57
	Longitudinal	250.04	1.58	0.23
Latewood	Tangential	502.05	1.82	0.80
	Longitudinal	202.16	1.02	0.41
Overall	Tangential	439.08	1.61	0.92
	Longitudinal	340.46	1.86	0.80
	Combined	386.63	1.74	0.61

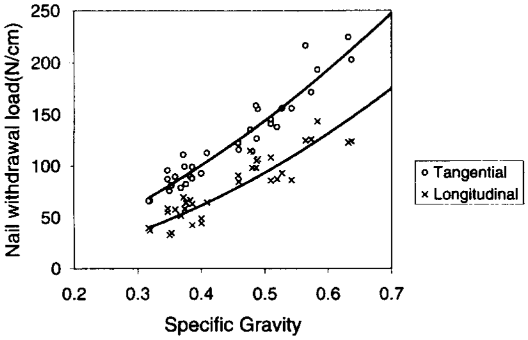

Fig. 2. The relation between nail withdrawal load and SG

and SG values for both earlywood and latewood were combined. The results of the regression analyses showed a strong relationship between SG and nail withdrawal load (Tables 3 and 4). The results of linear regression analysis showed a stronger correlation between SG and nail withdrawal for latewood than for earlywood. When all data were combined, the coefficients of determination for tangential and longitudinal directions were 0.91 and 0.83, respectively; these coefficients indicate that approximately 91% and 83%, respectively, of the observed behavior can be explained by the regression model.

To compare with the Wood Handbook equation, the nonlinear regression analyses, $Y = A(SG^B)$, was conducted between nail withdrawal load and SG. The constants (A and B) and coefficients of determination are shown in Table 4. There were no discernible differences between linear and nonlinear regression analyses. Nail withdrawal load and SG showed good correlation (Table 4, Fig. 2). When the two growth rings combined, the correlation was 0.92 and 0.80, respectively.

4. CONCLUSION

On the basis of investigations conducted on the nail withdrawal test in radiata pine, the following conclusions are drawn:

1. Average nail withdrawal load values for both tangential and longitudinal directions are higher in the latewood zone than in the earlywood zone.
2. Good correlations are obtained between nail withdrawal load and SG. However, there is no discernible difference between nonlinear and linear regression equations.
3. Special care is needed when using nails in the earlywood zone.

REFERENCES

1. American Society for Testing and Materials. 1995. Standard test method of small clear specimen of wood. ASTM D143-94. ASTM, Philadelphia
2. Groom, K. M. 1993. Load withdrawal displacement characteristics of nail. *Forest Prod. J.* 43(1) :

51~54

3. Gupta, R., and Milan Vatovec. 1996. Evaluation of Daburian larch in mechanical connections. *Forest Prod. J.* 46(9) : 89~93
4. Ivnanov, I. M, and K.V. Panferov. 1949. Deformations of springwood and summerwood of pine in compression perpendicular to grain with stresses up to 3500 kilograms per square centimeter. Academy of the Sciences of the USSR. *Transactions of the Wood Institute* 4 : 261~271 Translation No 34(1951) from Russian, Hildegard P. Kipp, USDA Forest Service, Forest Products Laboratory, Madison, Wis.
5. National Design Specification for Wood Construction. 1991. National Forest and Paper Assoc. Washington, DC. (Table 8.8B)
6. Panferov, K.V. 1949. Elasticity and strength of springwood and summerwood of pine in compression perpendicular to grain. Academy of the Sciences of the USSR. Transactions of the Wood Institute 4: 219~230. Translation No 32(1951) from Russian, Hildegard P. Kipp, USDA Forest Service, Forest Products Laboratory, Madison, Wis.
7. Forest Products Laboratory. 1987. Wood Handbook: Wood as an engineering material. USDA Agri. Handbook. 72. USDA Forest Service, Washington, DC.
8. Wilkinson, T. L. 1991. Dowel bearing strength. Res. Pap. FPL-RP-505. USDA Forest Service, Forest Products Laboratory, Madison, Wis.
9. Winistorfer, S. G. 1995. Practical considerations of dowel bearing strength and annular ring fastener orientation. *Forest Prod. J.* 45 (7/8) : 64~68