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The Tensile Properties for Powder-driven-nail Connections for Japanese Larch Small Round Timber[*1]

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ABSTRACT

In an effort to encourage the development of value added engineered applications for small diameter round timber, research is being conducted to develop and verify design guidelines for connections with specific application to round timbers. The objective of this research is to provide potential users with a number of viable connection options applicable in the fabrication of engineered, round wood structural components and systems. Target uses include trusses, built up flange beams and space frames.

This paper presents information on a mortised steel plate connection fabricated using powder driven nails in 6 cm diameter Japanese Larch. The design load for PDN connections are around 1.3 kN per nail with strip and 0.8 kN per nail without stripe. The design model for PDN connectors could be chosen by the number of nails. If the number of nails are more than the critical number between nail bearing and wood failure, the wood failure model could be the way to design the structure safely. The wood failure model needs to be studied more but the model could be the tensile and cleavage mixed failure model.

Keywords : connection, mortised plate, design load, failure model

1. INTRODUCTION

The forest area in Korea occupies 6.4 million ha, about 65% of the entire land area in 2000. 76% of whole forest consists of young trees, which were planted less than 30 years ago. The most attractive solution to use efficiently small diameter timber is to increase market demand. Promotion of established markets and development of new ones will encourage growth of small business and help to boost sagging rural economies while preserving the resource.

The structural advantages of using small diameter timber in the round form are discussed by Wolfe (2000, 2003). Cutting small diameter log into dimension lumber, converts to low or no value slabs, chips and sawdust. The economic value of this waste material varies with the capabilities of the local infrastructure.

To expand the market for these small logs beyond the limits of simple beams, columns or wall logs, methods must be developed for their incorporation in using round members. The primary barrier to incorporating round timber in engineered components is the limited selection of applicable commodity market connections.

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Commercially produced dowel type connectors and shear plates are recognized by wood design standards, used commercially by the utility and pole frame building industries as a means of transferring shear between lapped round wood and dimension lumber elements. There are, however, no recognized standards for in line connections designed specifically to transfer axial forces or bending moments between round timbers.

A connection detail that has potential for expanding the structural uses for round timber is commonly called a flitch plate or mortised plate connection. In the glulam industry, these are normally fastened using through bolts. This is not an economically or aesthetically attractive detail for round timber, but new tools developed for driving hardened nails with a gun powder activated charge could make this option viable. Nailed connections such as this are not very labour intensive, make use of readily available materials and exhibit ductile failures but they have never been evaluated as a possible connection for round timber.

This paper presents an evaluation of powder driven nail connections as a possible solution to the connection problems, which limit development of round timber structural components. Tests were conducted to provide a basis for assigning single nail values for mode III and mode IV type nail failures as well as for predicting group tear out failure in the wood. These results were used to predict the capacity and failure mode of multi-nail connections and to provide a basis for comparing this connection to other joints which may be easily adapted to round timber.

This study is focused on nailed connections in round shape Japanese larch timbers which are mainly planted in Korea. These connections incorporate plate steel to transfer axial loads between round timber elements. The joint configuration studied in this study incorporates steel plates placed in slots cut parallel to the log diameter. In this case, the nail is loaded in double shear.

For this study, connection tests were limited to axial tension on mortised plate connections. Nailing patterns were varied to determine the point at which the joint failures begin to change from ductile nail bending and wood bearing to a brash, group tear out mode.

2. MATERIALS and METHODS

A universal testing machine (Instron IV 4206) with a load capacity of 150 kN was used to assess the stiffness and strength properties of nailed mortised plate joint configurations. A total of 50 sets of the 8 joint configurations were fabricated.

2.1. Test Joint Fabrication

Japanese larch logs used in the fabrication of test joints started out as manufactured into round shape and a uniform 60 mm diameter. They were kiln dried and stored in a conditioning room maintained at 20°C and 65% RH for a minimum of 3 months prior to the initial joint fabrication. Two 12 mm diameter holes were then drilled diametrically to receive two 12 mm steel bolt used to transfer load from the test machine to the upper end of the test specimen as shown in Fig. 1.

The test connections were fabricated by cutting slots parallel to the log axis to a depth of 180 mm from the end. Steel plates, 60 mm wide by 300 mm long and 3 mm thick, cold rolled (1018) steel (f_y,= 248 MPa) were inserted in these mortises. They were fastened in place using ballistic point nails 61 mm long and 3.7 mm diameter. These nails, provided by Hilti Co, were made from AISI steel type 1070 modified specified as having average bending yield

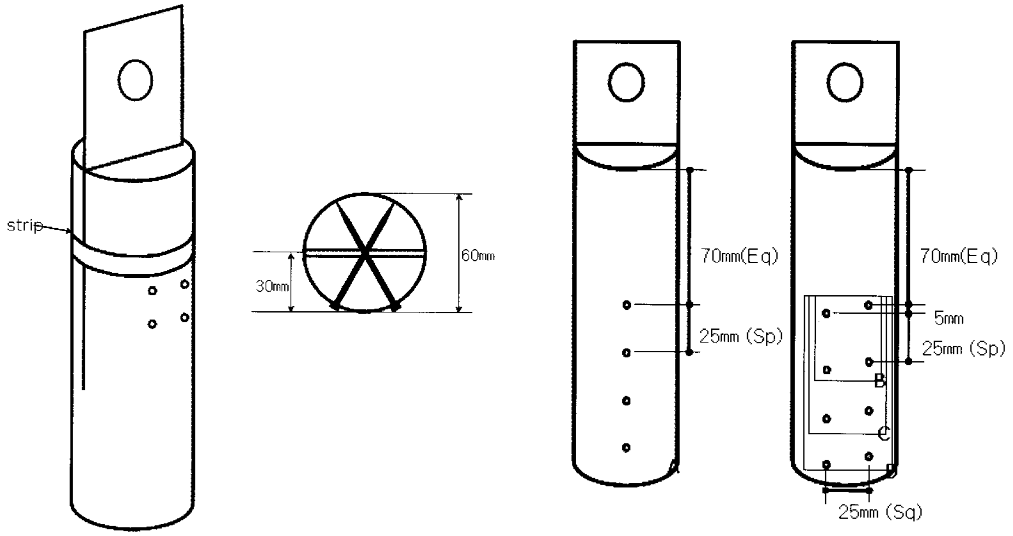

Fig. 1. Patterns of PDN connector.

strength of 1.8 Gpa and a Rockwell hardness C52-58. These were driven radially using a Hilti gun powder actuated driver (model #DX 450). The objective of this connection was to load each nail in double shear and to cause a mode IV (double bend) yield of the nail on each side of the plate.

The nail patterns were generally rectangular. In referring to these patterns, the lines of nails oriented parallel to the grain are referred to as rows and those perpendicular to the grain are referred to as columns. The spacing between rows, (distance perpendicular to the grain) is designated S_q and spacing parallel to the grain is S_p.

A two letter designation was used to identify each joint pattern. The first letter designates the number of nails in the pattern (A = 4, B = 4, C = 6, and D = 8). The second letter designates the usage of strip to enforce the load carrying capacity (S = strip, N = none). The S_p is 25 mm in all cases. The joints were fabricated by first attaching a printed pattern to the surface of the log to assure a consistent pattern and a 75 mm distance from the end of the log to the first column of nails. A plate was then placed in the 3 mm mortise and the nails were aligned with locations on the printed pattern.

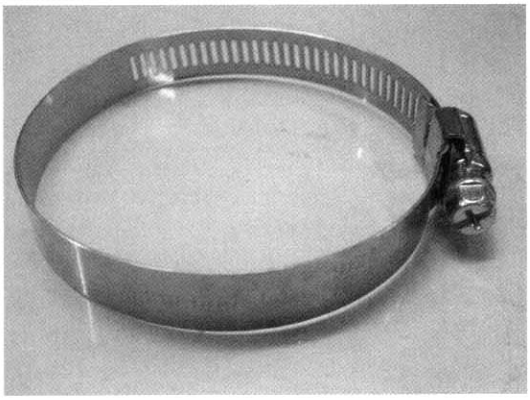

Fig. 2. Configuration of the strip.

Those types were classified into two groups which with or without strip. S designates the connections with strip and N is for without strip. A total of 50 sets of the 8 joint configurations were fabricated.

2.2. Test Procedure

Tests were initially conducted to obtain strength and stiffness of the nails. These tests were conducted following the procedures given in ASTM (F1575) to verify yield moment of nails.

A screw type test machine was used to apply an axial tension load at a load head displacement of 1 mm per minute. At this rate, the maximum load was reached in 5 to 10 min. Loads were measured using a 150 kN load cell and two LVDTs were used to measure average displacement of the plates with respect to the end of the log. Load and displacement data were digitally recorded and stored for each joint. Observations made during the test were recorded with reference to the load at which they occurred. Observations about the failures included ductility, cleavage of surface fibers, group tear out and tensile failures. For each connection, growth rate, specific gravity was recorded.

3. RESULTS and DISCUSSION

3.1. Log Properties

The specific gravities ranged from 0.49 to 0.58 and the average was 0.54. Moisture contents were not exceeded 12%. Average ring width was 4.6 mm and there was apparent correlation between growth rate and density.

3.2. Connection Failures

Connections are designed on the basis of their load capacity which is a function of material properties, joint configuration, and the load and boundary conditions. Another important consideration, however, is failure ductility. In the rare event that the load on an engineered structure exceeds the capacity, it is desirable that the structure continues to support load as it deforms. The property that represents a connection's ability to sustain load after its load capacity has been exceeded is its ductility. This property can be quantified as the area under the load displacement curve beyond the point of maximum load.

Failure mechanisms are broadly classified as nail vs. wood failures. Nail failures involve displacement of the nail relative to the wood in the form of lateral displacement, bending or rotation. This is accompanied by bearing deformation in the wood and ultimately either splitting of the wood or lateral nail withdrawal. Nail failures are further classified into "modes" (NDS) depending on the combination of nail and wood deformation. The nail failures observed in this study were primarily of mode III where the nails exhibit one bend per shear plane. Wood failures are characterized by breaking of wood fiber in some combination of shear, tension and bending.

Loading the connections beyond the maximum load resulted in a couple more failure mechanisms, but these did not appear to have an influence on joint capacity. One of these appears as a wood failure pattern best described as cleavage. In a few instances, some of the nails were not bent, suggesting that the splits were present prior to the test, possibly due to drying. For tests where the splitting did not occur, the greater resistance of the nail head to being drawn through the wood resulted in an eccentric load on the plate, causing it to rotate outward at the top. As this was associated with deformation beyond the joint yield limit it had little effect on connection yield or ultimate strength.

The strip was used to increase load resistance and induce the ductile failure. As the results, BN, without strip, showed the brash failure while BS, with strip, showed the ductile failure. As nail load displacement curves are continuously non-linear, the yield value is determined by 5% offset.

Maximum loads, yield load and design load per nail, are shown in Table 1. Strip enforced connections could resist higher load. Strip enforcing effects were considerable that load resistance of the connections were more than

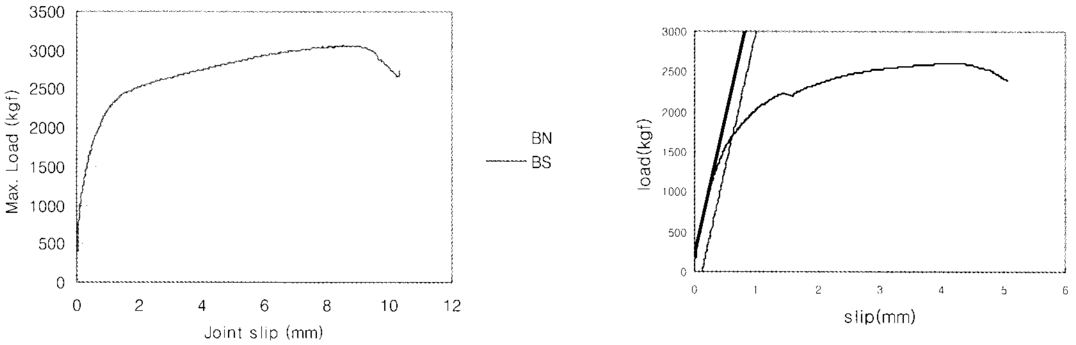

Fig. 3. Load-slip characteristics for the connections by strip.

Table 1. Characteristics of load resistance

(unit: kN)

Connection Type	Maximum Load		European Yield Load		Design Load per nail	
	Max.	per Nail	Yield	per Nail	by Max. Load	by Yield Load
AS	11.3	2.8	6.2	1.5	0.85	0.68
AN	3.9	1.0	3.1	0.8	0.30	0.36
BS	25.6	6.4	16.6	4.1	1.94	1.86
BN	13.4	3.4	8.0	2.0	1.03	0.91
CS	28.3	4.7	17.4	2.9	1.42	1.32
CN	17.2	2.9	12.8	2.1	0.88	0.95
DS	35.2	4.4	22.0	2.8	1.33	1.27
DN	20.5	2.6	17.0	2.1	0.79	0.95

100%. It is because of resisting against wood cleavage along the line of nails. In the same number of nail connections (A and B type), rectangular nail pattern had resisted higher load due to load bearing plane or tensile resistance of load bearing plane.

3.3. Connection Models

Connections are generally designed to carry a load which is roughly 1/3 of the ultimate value or 1/2 the yield strength. Timber rivets are evaluated as the ultimate strength divided by 3.3. This divisor is intended to account for duration of load, factor of safety and variability. The National Design Specification for Wood references the European yield model for nails, which uses a factor of 1/2.2 times the yield strength as a basis for design. As nail load displacement curves are continuously non-linear, the yield value is determined as the intersection point of a secant that is parallel to the initial part of the curve but offset by 5% of the nail diameter from the curve's intersection with the displacement axis.

In addition to evaluating the test results at maximum load (Table 1), yield strengths were evaluated for each curve by modelling each curve using a hyperbolic tangent model. The first derivative of this model was used to define a secant slope between 20 and 40% of the maximum load. This slope and an intercept

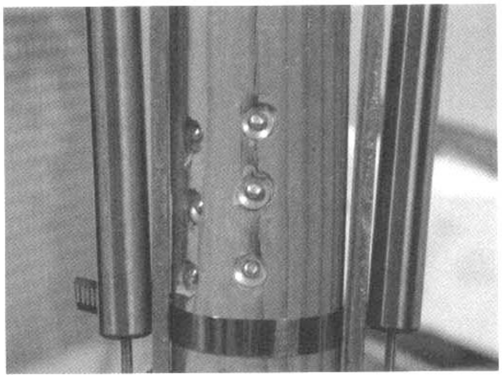

Fig. 4. Nail yield failure of the connections.

equal to 0.05 times the nail diameter defined a line whose intersection with the hyperbolic tangent model defined the yield strength and yield displacement.

For purposes of simplification, failure of the test connections have been attributed to one of two failure mechanisms: nail bearing or wood rupture. The nail failures comprised a mode Ⅲ nail bending combined with wood bearing deformation. Wood failures comprised a combination of shear and tension failure in the wood which formed the perimeter of the connection block.

3.3.1. Nail Yield Model

The nail yield model (AF&PA) provides a prediction of design load. The NDS equation for mode Ⅲ failures is as follows.

$$Z = \frac{k_2 \times D \times t_s \times F_{em}}{K_D \times (2 + R_e)} \qquad (1)$$

Where

$$k_2 = -1 + \sqrt{\frac{2 \times (1 + R_e)}{R_e} + \frac{2 \times F_{yb} \times (1 + R_e) \times D^2}{3 \times F_{em} \times t_s^2}}$$

R_e = F_{em}/F_{es}= 0.078

t_s = thickness of the side member

F_{em} = dowel bearing strength of main member

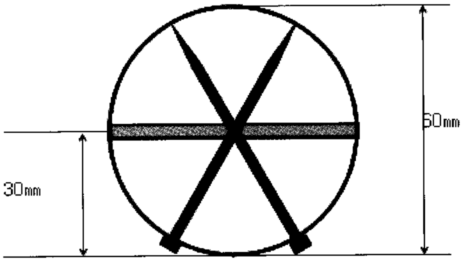

Fig. 5. Tensile area of the nail pattern.

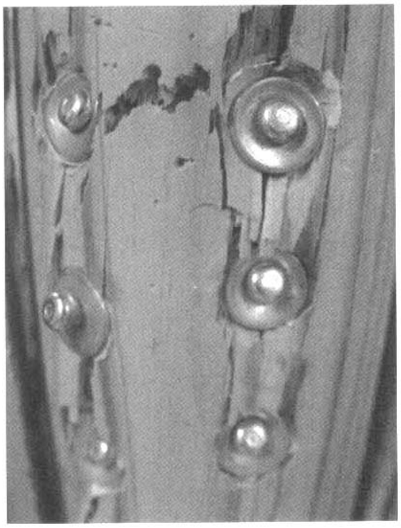

Fig. 6. Wood block shear failure.

F_{es} = dowel bearing strength of side member

F_{yb} = bending yield strength of the nail or spike

D = nail or spike diameter

KD= 2.2

3.3.2. Wood Failure Model

The wood failure model basically estimates the tensile and cleavage capacities of wood planes which surround the wood block volume defined by the area of the nailing pattern. This sector is split into two parts by the 3 mm thick mortise oriented parallel to the center radius of the sector. The cross section of this sector defines the tensile surface.

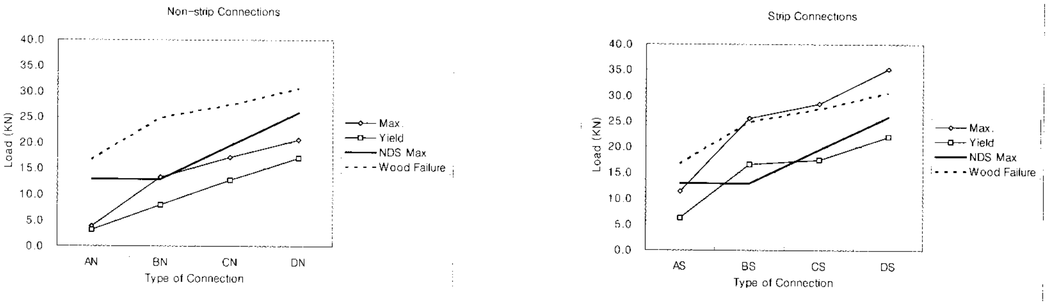

Fig. 7. Maximum load and European yield load.

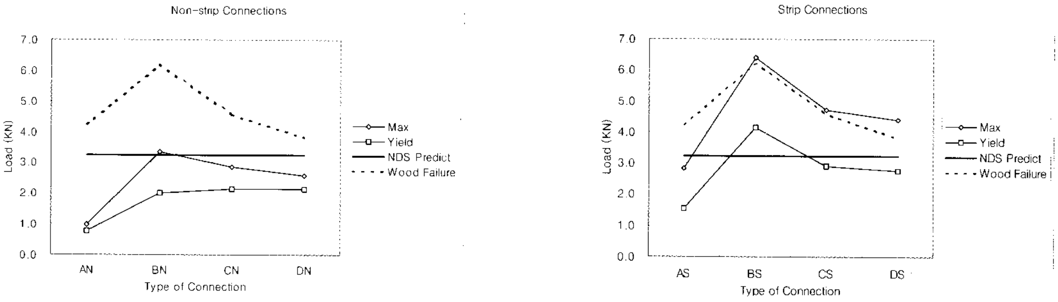

Fig. 8. Maximum load and European yield load per nail.

$$P_{ult} = F_t A_t + F_c A_c$$

where, F_t = tensile stress
F_c = cleavage stress
A_t = effective tensile area
A_c = effective cleavage area

The wood block shear failure consisted of both cleavage and tension failures. Those figures show the maximum load by experiment, prediction by NDS and Wood Failure model, and yield load for non-strip and striped connections. For the non-striped connections, the predicted maximum load by NDS was similar to experimental maximum load for BN, CN, DN type. But in the case of AN connection, the yield load and maximum load had big difference because of the cleavage failure of wood.

For the striped connections, the predicted maximum load by wood failure model was similar to experimental maximum load. This is because the stripe arrests the cleavage failure of wood before wood tensile failure.

In the case of per nail values, the predicted NDS maximum load per nail is the same. Except the NDS, as the number of nails are increased, the load resistance per nail is decreased.

In the case of the design load for NDS connections, the design load calculated from maximum load, yield load and NDS has no big different in non-striped connection. But the design load calculated from wood failure model was overestimated the design load.

In the case of striped connections, the design load calculated from maximum load, yield load and wood failure load were similar. But the NDS design value was underestimated.

If the number of nail is increased, the design load calculated by wood failure model and NDS model is crossed at some number of nails. If a

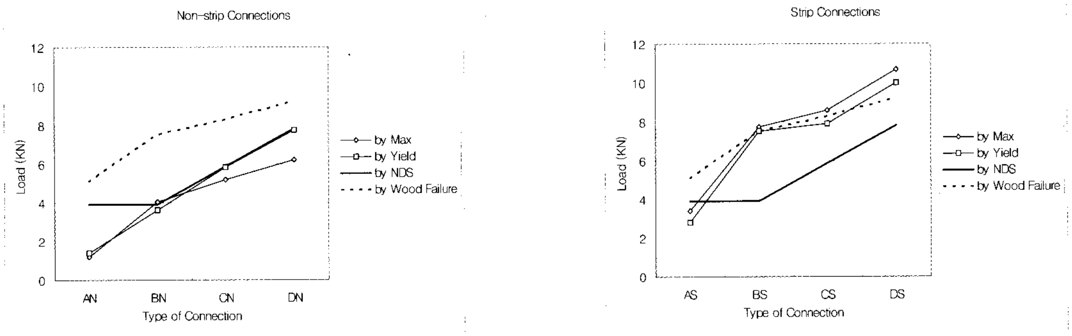

Fig. 9. Design load of connections by NDS.

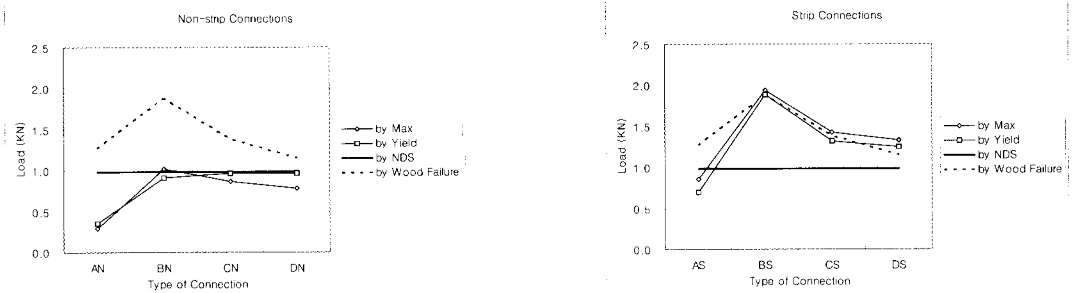

Fig. 10. Design load of connections by NDS per nails.

connection has more nails than the critical number of nails, the connection could be failed not by nail bearing but by wood failure. The load resistance will be controlled not by nail but by wood tensile and cleavage strength.

Based on the results of this study, design load determination for connections could be improved not to waste timber resources and fasteners. There is a critical point between nail failure and wood failure however, it depends on the type of connection, fastening materials and species or densities of timbers.

4. CONCLUSIONS

In an effort to encourage the development of value added engineered applications for small diameter round timber, research is being conducted to develop and verify design guidelines for connections with specific application to round timbers. The objective of this research is to provide potential users with a number of viable connection options applicable in the fabrication of engineered, round wood structural components and systems. Target uses include trusses, built up flange beams and space frames. This paper presents information on a mortised steel plate connection fabricated using powder driven nails in 60 mm diameter Japanese Larch.

1) The design load for PDN connections are around 1.3 kN per nail with strip and 0.8 kN per nail without stripe.

2) The design model for PDN connectors could be chosen by the number of nails. If the number of nails are more than the critical number between nail bearing and wood failure, the wood failure model could be the way to design the structure safely.

3) The wood failure model needs to be studied more but the model could be the tensile and cleavage mixed failure model.

REFERENCES

1. Lukindo A. R., J. P. Chastain, and K. A. Janni. 1997. Techniques for Making Connections in Small Diameter Roundwood Members. Wood Design Focus. Spring. 14～22.
2. ASTM 1995, Standard Test Method for Determining Bending Yield Moment of Nails, American Society for Testing and Materials, Conchohoken, PA.
3. ASTM Standard test Method for Determining Yield Moment of Nails, ASTM F1575 Vol 03.01, ASTM West Conchohocken, Pa. describing test setup or ASTM.
4. John J. Zahn. 1991. Design Equation for Multiple Fastener Wood Connections. Journal of Structural Engineering, 117(11): 3477～3486.
5. Richard Burton, Michael Dickson, and Richard Harris. 1998. The use of roundwood thinning in buildings - a case study. Building Research & Information 26(2), 76～93.
6. Ronald W. Wolfe. 2000. Research challenges for structural use of small-diameter round timber. Forest Prod. J. 50(2), 21～29.
7. Ronald W. Wolfe, KugBo Shim, and Marshall Begel. 2003. Powder-Driven-Nail Connections for Round Timber. Proceeding of IAWPS2003. Vol. 1 80～87.
8. Stephen F. Duff, R. Gary Black, Stephen A. Mahin, and Marcial Blondet. 1996. Parameter Study of an Internal Timber Tension Connection. Journal of Structural Engineering / APRIL 446～452.