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Evaluation of Strength Properties for Bolted Connections with Lumber from Small Diameter Logs[*1]

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ABSTRACT

EYM (European Yield Model), which was adopted in NDS (National Design Specification for wood construction), has been used in Korea without any verification of the analysis of bolted wood connections. In the case of applying lumber from domestic small diameter logs, however, there are some problems with the direct application of EYM ; 1) relatively low dowel bearing strength and dimensional stability due to a large amount of immature wood, 2) effect of MC (moisture contents) on the dowel bearing strength of wood and the yield load of a bolted connection. To evaluate the strength properties of bolted connections with lumber from domestic small diameter logs, effect of MC on the dowel bearing strength of wood was investigated and double shear bolted connection tests were performed.

As the MC of wood increased, the dowel bearing strength was linearly reduced, even under 19% MC, which showed that adjustment, not considered in NDS, was required. Double shear bolted connection tests indicated that effect of MC on yield load should be considered in order to determine design value.

Keywords: European yield model, Double shear bolted connection, Domestic small diameter log, Dowel bearing strength, Yield load

1. INTRODUCTION

These days, the demand for wooden framed buildings and playground equipment is increasing in Korea. Unfortunately, the wood used in all these structures has been imported from North America and Europe. Even though there is little necessity for using imported wood in playground equipment and similar small size outdoor structures, domestic wood is still not used. This is due to the fact that standardized design data for imported wood (eg. NDS) is provided, while domestic wood has not been standardized for structural use.

Especially in connection design, such as bolted connection, EYM, which was adopted in NDS[1)], has been used without any verification.

In order to apply lumber from domestic small diameter logs to bolted connection design, it should be considered that these woods have

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relatively low dowel bearing strength and poor dimensional stability caused by the abundance of immature wood.

In the studies of bolted wood connections, Trayer (1932)[10] presented a design formula for bolted connections using side plates to connect axially loaded softwood main members. He noted that the interaction of the bending of the bolt and the crushing of the wood affected the performance of a joint. His research was the basis for the allowable bolt strength values used in designs prior to 1991. Johanson (1949)[7] proposed EYM for design and analysis of bolted connections and through the various researcher's efforts this model became a basic prediction method for bolted connections. Doyle *et al.* (1963)[6] tested three member bolted connections with one and four bolts. The bolt bearing stress of connections constructed of dry lumber was higher than that of connections which used green lumber. Moreover, the bearing strength per bolt of joints with four bolts was about the same as that of single bolted connections. In the late 1960s, it was noted that load sharing of multiple bolted connections in timber was nonuniform. Cramer (1967)[5] carried out an experiment based on theory considering deformation of timber members and bending of bolts. He found that the innermost bolts of a connection are the least stressed and the outer bolts are the most stressed. Yamamura *et al.* (1987)[12] investigated the influence of end distance, spacing, and the number of bolts on the strength properties of bolted connections in glued laminated timber. The trend was such that as the number of bolts increases, the ultimate load per bolt decreases. They also reported the effect of spacing of bolts in each L/D (end distance/bolt diameter) on the ultimate load. Mettem *et al.* (1992)[9] reported on tests conducted on both single and multiple bolted connections. They investigated how the load on a multiple bolted connection with steel side plates and glulam main member would be distributed among the individual bolts. In 1991, NDS provided a design method for bolted connections in the basis of EYM, and thereafter, this method became a standard in designing bolted connections throughout almost all countries[4]. Lee and Kim (1999)[8] reported that the attempt to analyze the behavior of single- and multiple-bolted connection should be executed using a theoretical method(semi-rigid theory) instead of experimental methods and European yield model.

In this study, in order to evaluate the strength of bolted connections with lumber from domestic small diameter logs, double shear bolted connection tests with various species of domestic lumbers were conducted. And then, for only one species, effects of MC on the dowel bearing strength of woods and yield load of bolted connection were investigated.

2. MATERIALS and METHODS

2.1 Materials

Lumber from small diameter logs of red pine (*Pinus densiflora*), Korean white pine (*Pinus koraiensis*), and Japanese larch (*Larix leptolepis*) in softwood and poplar (*Populus tomentiglandulosa*), alder (*Alnus japonica*) and oak (*Quercus variabilis*) in hardwood were used in this study. Moisture contents and specific gravity of each species were shown in Table 1.

2.2 Methods

2.2.1 Double shear bolted connection tests

Three member bolted connections were fabricated of lumber (4 cm × 10 cm cross section) and tested according to ASTM D 5652[2]. Both

Table 1. Moisture contents and Specific gravity of each species.

	Species	Moisture contents (%)	Specific gravity (g/cm^2)
Softwood	Red pine	14.3	0.46
	Korean white pine	14.3	0.39
	Japanese larch	14.7	0.48
Hardwood	Poplar	14.6	0.38
	Alder	14.4	0.46
	Oak	16.4	0.74

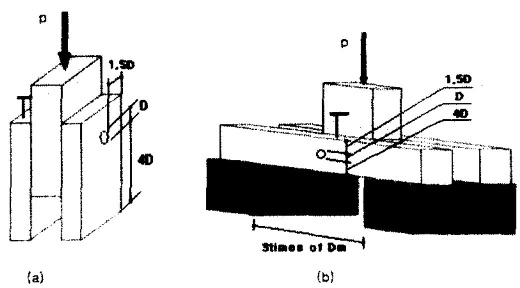
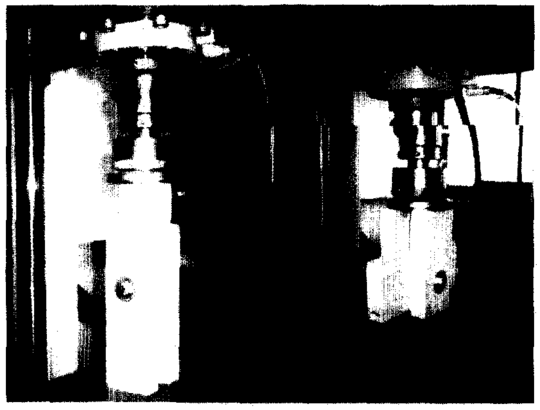


Fig. 1. Configuration of double shear bolted connections (a : parallel to grain, b : perpendicular to grain).

the main and side members were wood. Assemblies for bolted connection tests are shown in Fig. 1. The diameters of the bolts were 12.4 mm and 15.9 mm. For Japanese larch, 9.5 mm diameter bolts were tested additionally.

In the bolted connections, if the bolt holes are too small, an excessive amount of driving will be required to install the bolts and splitting of the wood may occur. Obviously, splitting will greatly reduce the shear capacity of a bolted connection. On the other hand, if bolt holes are too large, nonuniform bearing stresses may occur. So, the excess of bolt hole diameter over bolt diameter was 0.8 mm for 13 mm of less in diameter and 1.6 mm for bolts of larger diameter. The manner in which the holes are bored into the wood also has an effect on load capacity. A bolt hole with a smooth surface



(a) (b)

Fig. 2. Test setup for double shear bolted connections (a : parallel to grain, b : perpendicular to grain).

develops a higher load and less deformation than on that has a rough surface. Thus, sharp drill bits, proper drill speed, and slow rate of feed needed to be maintained to obtain a smooth surface.

Moreover, end distance should be at least four times bolt diameter (4D) in the bolted connections parallel to grain and perpendicular to grain loading. Clear distance between the supports should be at least 3 times the depth of the transverse member perpendicular to grain loading.

The load was applied continuously at the rate of 1 mm/min. The tests were terminated when failure occurred or maximum slip reached 15.2 mm. The test setup of the bolted connection parallel and perpendicular to grain were shown Fig. 2. The yield load was determined by the intersection of the load-deformation curve and 5% offset line from the straight line in the initial linear portion of the load-deformation curve.

2.2.2 Dowel bearing strength tests

The property of wood that affects the load capacity of bolted connection is known as dowel bearing strength. It is related to the crushing strength of the wood member under loading from a dowel subjected to a shear load and varies with the specific gravity of the wood and relative size of the dowel, and the angle of load to grain. In the NDS, the formulae for dowel bearing strength was provided as follows.

Large dowels
- parallel to grain loading : $F_{e\|} = 11,200\ (G)$
- perpendicular to grain loading : $F_{e\perp} = 6,100\ G^{1.45}\ D^{-0.5}$
- at an angle of load to grain θ :

$$F_{e\theta} = \frac{F_{e\|} F_{e\perp}}{F_{e\|} \sin^2\theta + F_{e\perp} \cos^2\theta}$$

Small dowels
- all angles of load to grain : $F_e = 16,600\ G^{1.84}$

(where, G is specific gravity of wood, D is shank diameter of bolt)

Above formulae did not consider any change of MC in wood members. However, in bolted connection under real outdoor condition, MC of wood members could be variable. This fact indicated that verification of these formulae by considering MC change should be performed.

So, dowel bearing strength of wood in various MC conditions was tested to evaluate the applicability of NDS' formulae in domestic wood. Among six species used in double shear bolted connection tests, Japanese larch was selected. 9.5 mm diameter bolts were used for dowel bearing strength tests by considering applicability in wooden playground equipment and outdoor structures with domestic wood members. Specimens for this tests were 10 mm × 10 mm × 10 mm, and half-circle shaped holes were made on the top surface as shown in Fig. 3. Prior to testing, all specimens were conditioned to reach the target MC levels (10% or lower, 13-18%, 20% or higher). Parallel to grain and perpendicular to grain loading were applied at the rate of 1 mm/min (ASTM D 5764)[3].

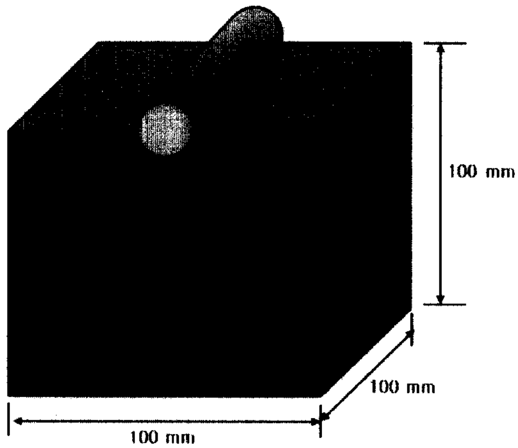


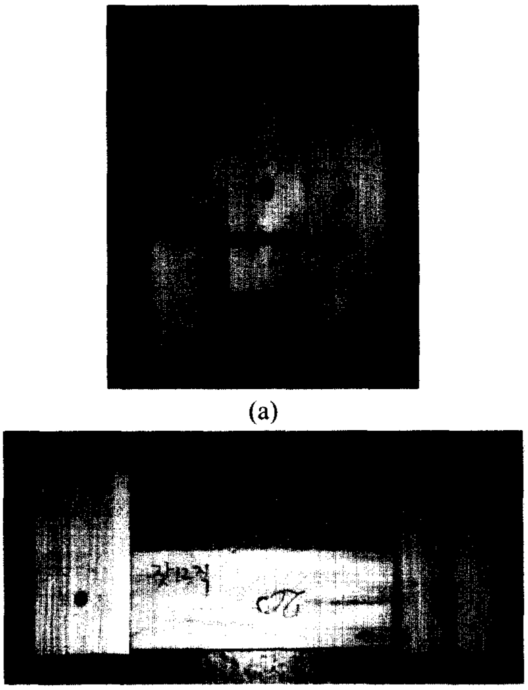
Fig. 3 Specimen for dowel bearing strength tests.

3. RESULTS and DISCUSSION

3.1 Double shear bolted connection

In this study, double shear bolted connections with domestic wood members and 2 types of bolts were tested. Depending on bolt diameter, failure mode of bolted connections was different regardless of member species or loading directions. The failure mode of bolted connections using 12.4 mm diameter bolts was a combination of the crushing of the main member and the bending of the bolt. In the case of 15.9 mm diameter bolts, failure occurred when the main member alone crushed (Fig. 4 and 5).

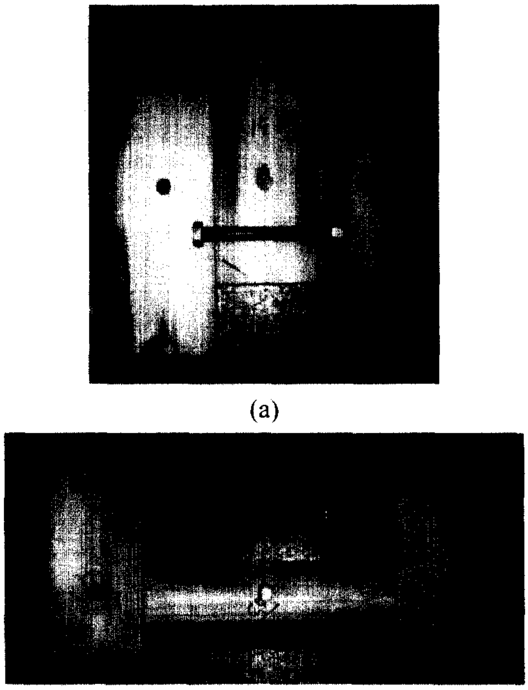
The values of yield load of bolted connections using softwood and hardwood members were listed in Table 2. As shown in Table 2. yield load of bolted connections using Japanese larch and oak were higher than that of other softwood and hardwood species, respectively.



(a)

(b)

Fig. 4. Failure mode for double shear bolted connections with 12.4 mm diameter bolts (a : parallel to grain, b : perpendicular to grain).



(a)

(b)

Fig. 5. Failure mode for double shear bolted connections with 15.9 mm diameter bolts (a : parallel to grain, b : perpendicular to grain).

3.2 Dowel bearing strength

Dowel bearing strength of wood (Japanese larch) was tested to evaluate the effect of MC. Tested results and calculated values from NDS' formulae were compared in Table 3.

As shown in Table 3, because dowel bearing strength was different between two loading directions, the 9.5 mm diameter bolt used in this study should be assumed to be large dowel. Calculated values from NDS' formulae were closed to the tested values according to air-dried

Table 2. Yield load of double shear bolted connections.

Species	Yield load (kgf)			
	12.4 mm diameter bolt		15.9 mm diameter bolt	
	Parallel to grain	Perpendicular to grain	Parallel to grain	Perpendicular to grain
Red pine	935	377	1,171	423
Korean white pine	830	316	1,040	355
Japanese larch	1,050	441	1,303	494
Poplar	725	259	909	301
Alder	921	366	1,159	414
Oak	1,460	725	1,828	811

Table 3. Dowel bearing strength of Japanese larch.

Loading direction	Dowel bearing strength (kgf/cm²)				
	Tested value(at each MC level)			Calculated value	
	~ 10%	13 ~ 18%	20% ~	Large dowel	Small dowel
$F_{e\parallel}$	499	345	296	378	302
$F_{e\perp}$	291	238	222	242	

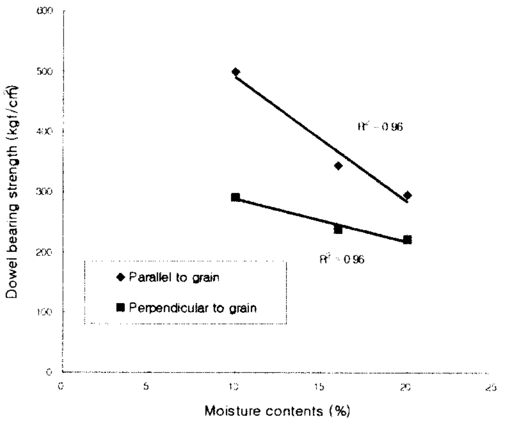


Fig. 6. Relationship between dowel bearing strength and moisture contents.

MC conditions. Test results indicated that dowel bearing strength of wood was affected by MC significantly. Compared to air-dried condition (13~18%), dowel bearing strength decreased by 14% for parallel to grain orientation and 4% for perpendicular to grain orientation for conditions with higher MC (higher than 20%). On the contrary, for conditions with lower MC (lower than 10%) dowel bearing strength increased by 45% and 22%, respectively. This results showed that NDS' formulae should be verified by considering effect of the wood's MC. In Fig. 6, relationship between dowel bearing strength and MC was shown.

As shown in Fig. 6, dowel bearing strength changed linearly through all the MC levels. From the tested results, verified formulae were presented as followed using the least square method.

Table 4. Effect of moisture contents on yield load.

Moisture contents	Z (Yield load, kgf)	
	$Z_{\parallel}$	$Z_{\perp}$
lower than 10%	601	537
13~18%	635	549
higher than 20%	539	534

Parallel to grain loading : $F_{e\parallel} = 6{,}050\ GM^{-0.76}$
Perpendicular to grain loading :

$$F_{e\perp} = 2{,}070\ G^{1.45}\ D^{-0.5}\ M^{0.4}$$

(where, M is MC(%) of wood)

3.3 Effect of MC on yield load

In order to evaluate the effect of MC on yield load of bolted connections, double shear bolted connection tests with Japanese larch and 9.5 mm diameter bolts were performed in each MC level. Tested results were shown in Table 4.

As shown in Table 4, the yield load of bolted connection changed according to MC and a maximum value was obtained in an air-dried condition for both loading directions. Therefore, to determine the design value for bolted connections, the effect of MC should be considered even in conditions of low MC.

4. CONCLUSIONS

In order to evaluate the strength properties of bolted connections with lumber from domestic small diameter logs, double shear bolted connection tests with various species of domestic lumber were conducted. And then, for only one species, effects of MC on the dowel bearing strength of wood and the yield load of bolted connection were investigated. From the results of this study, conclusions were summarized as :

1) Regardless of member species and loading directions, failure modes of bolted connections were related to bolt diameter.

2) The yield load of bolted connections using Japanese larch and oak was higher than that of other softwood and hardwood species, respectively.

3) Calculated dowel bearing strength of wood from NDS' formulae was close to the tested value in air-dried conditions.

4) Tested results indicated that dowel bearing strength of wood was affected by MC significantly.

5) From the tested results, verified formulae for dowel bearing strength, by considering MC, were presented as followed using the least square method.

- Parallel to grain loading :
  $F_{e\parallel} = 6{,}050\ GM^{-0.76}$
- Perpendicular to grain loading :
  $F_{e\perp} = 2{,}070\ G^{1.45}\ D^{-0.5}\ M^{0.4}$

6) To determine the design value for bolted connections, effects of MC should be considered not only in higher but also in lower MC condition.

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