Analysis of pull-out resisting mechanism of Lagscrewbolt and application to wooden portal frame

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At present, moment-resisting connections for glulam constructions are widely constituted as drift-pin joints with insert-steel gusset plates, as well as bolted joints. These joint systems are trusted. However they require complex design calculations. Therefore, Lagscrewbolts® (LSB) were developed by Prof. Komatsu as a simple and economical timber connector [1]. Figure 1 show details of LSB. LSB has two threads: one is a screw type thread on the outside surface and the other is a bolt or nut type thread at one end of the shank. LSB is embedded into a glulam by the screw thread and connected to other pieces by the bolt or nut thread. LSB is expected to show high pull-out ability due to the shear resistance between the top thread and glulam.

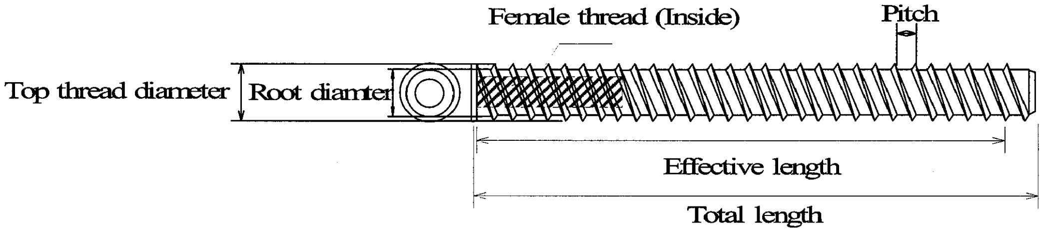

Fig.1 Details of Lagscrewbolt

A series of tests were conducted to clarify the effects of lead hole diameter, embedment depth, embedment direction and edge distance on the pull-out resistance of LSB. The results obtained were as follows: 1) the optimum lead hole diameter was defined. 2) Maximum pull-out load ($P_{\max}$) vs. embedment depths, and slip modulus (Ks) vs. embedment depths showed positive correlations. However, the proportion of the load increasing decreases with increasing an embedment depth. 3) The maximum pull-out load ($P_{\max}$) parallel to the grain was 0.75 times of that for perpendicular to the grain, and the pull-out slip modulus (Ks) parallel to the grain was 3 to 6 times of that for perpendicular to the grain. 4) The suitable edge-distance was thought to be more than $1.5d$ (d is top thread diameter of LSB) [2].

A theory on pull-out ability of an embedded LSB parallel and perpendicular to the grain direction was developed on the basis of Volkersen theory, which was originally developed for the shear stress analysis in rivet joints of aircraft technology [3]. Theoretical equations of $P_{\max}$ and Ks were derived as equation (1) and (2), receptivity. Shear strength_fv and shear stiffness Γ, both are necessary parameters in the theoretical formular, were determined by pull-out test of thin specimens made of glulam, because thin specimens were assumed that the shear stress distribution was almost uniform. Effective area of glulam (A_w) of parallel and perpendicular to the grain, also necessary parameters, were determined, respectively. A_w of parallel to the grain was an area of a circle with radius $1.5d$ [4]. A_w of perpendicular to the grain was determined by an energy equivalent concept, the deformation energy by the theory of a beam on an elastic foundation [5] or the bending theory of a short beam as being equal to the deformation energy of work at the effective area of the glulam [6]. Verification experiment was conducted by using several types of LSB, in which top threat diameter were 25, 30 and 35 mm, and influences of various embedment depths ranging from 60 to 450 mm on the pull-out properties were examined. The developed theory predicted maximum pull-out load and slip modulus well.

$$\begin{cases} P_{max} = \dfrac{fv\pi d(E_wA_w + E_sA_s)\sinh kl}{k(E_wA_w \cosh kl + E_sA_s)} & (E_sA_s \le E_wA_w) \\ P_{max} = \dfrac{fv\pi d(E_wA_w + E_sA_s)\sinh kl}{k(E_sA_s \cosh kl + E_wA_w)} & (E_wA_w \le E_sA_s) \end{cases} \cdots(1)$$

$$\begin{cases} Ks = \dfrac{\Gamma\pi d(E_wA_w + E_sA_s)\sinh kl}{k(E_wA_w \cosh kl + E_sA_s)} & (E_sA_s \le E_wA_w) \\ Ks = \dfrac{\Gamma\pi d(E_wA_w + E_sA_s)\sinh kl}{k(E_sA_s \cosh kl + E_wA_w)} & (E_wA_w \le E_sA_s) \end{cases} \cdots(2)$$

where, $$k = \Gamma \pi d\left(\frac{1}{E_w A_w} + \frac{1}{E_s A_s}\right)$$

and E: young's modulus, l: embedment depth, Subscript w: wood member, s: LSB.

Beam-column and column-base joints with LSBs using on optimum conditions were developed. The beam-column joint was composed of two LSBs, two M16 high tension bolts (HTB), and one steel plate. Two LSBs embedded from end of beam were connected to HTBs through a steel plate and a hole of column. Column-base joint was composed of two LSBs and two M16 HTBs. Two LSBs embedded from end of column were connected to M16HTBs which were regarded as parts of a base. The joint systems are very aesthetic constrictions, because LSBs and HTBs are hidden inside of beams and columns. Details of portal frame and test set-up are shown in Figure 2.

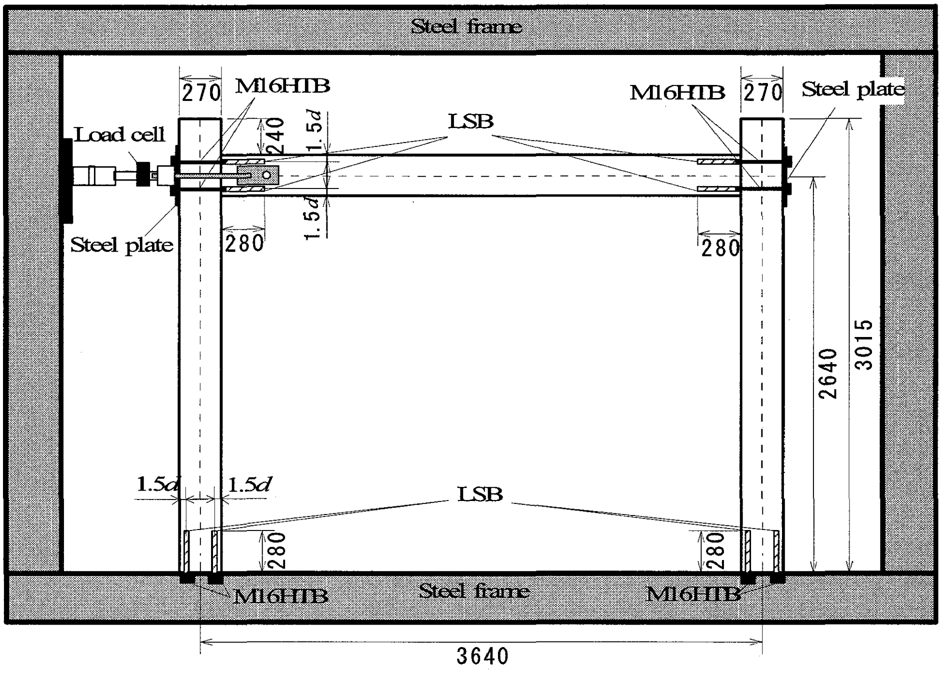

Figure 2 Geometry of wooden portal frame using LSB

Cyclic loads were applied at a beam by an oil jack. Figure 3 shows a test result and an analysis result of the portal frame. The analysis initial rigidity was predicted test results well. The analytical rigidity was derived from rotational rigidities of beam-column and column-base joints, which were derived from theoretical slip modulus of one LSB.

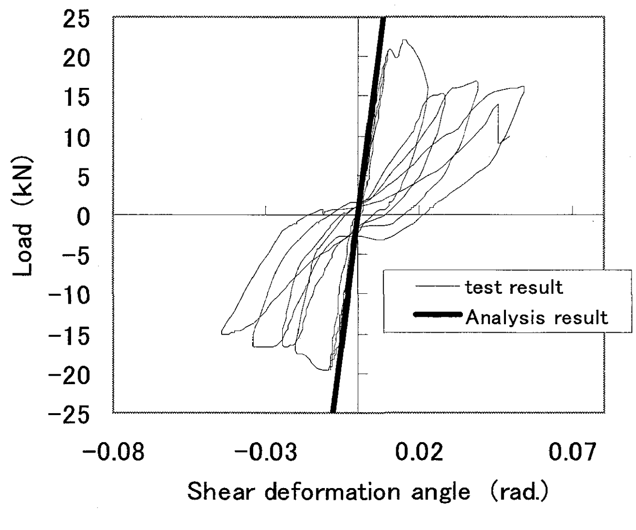

Figure 3 Test result of portal frame.

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