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Safety Factor of Timber Bolted-Connection Designed with SNI-5 (2002)

Ali Awaludin[1)]

Abstract

This paper study the safety factor of timber connection designed with PKKI NI-5 (2002). Johansen yield model is used to evaluate the nominal design value of single bolted connection. Double-shear bolted connection, with the side members and the main member from wood, is chosen for this study. A comparison study of safety factor between SNI-5 (2002) and NDS for timber construction of U.S (1997) is also conducted. Finally, the safety factor is analyzed for both directions parallel and perpendicular to wood grain of four possible yield modes.

From the study, both SNI-5 (2002) and NDS (1997) use higher safety factor for bolted connection sustaining load perpendicular to grain than that sustaining load parallel to grain. Smaller safety factor is used in both codes when the plastic hinge of bolt is created such as the yield modes III_s and IV. However, in this case, the safety factor of NDS is significantly much higher than that of SNI-5 (2002).

Keywords : *Bolted connection, yield mode, and safety factor.*

Abstrak

Analisis angka aman sambungan baut yang dirancang dengan SNI-5 (2002) dibahas pada tulisan ini. Tahanan lateral sambungan baut dianalisis berdasarkan teori model kelelehan yang diusulkan oleh Johansen (1949). Sambungan baut dua irisan dipilih sebagai contoh kasus. Analisis angka aman sambungan yang dirancang dengan SNI-5 (2002) juga dibandingkan dengan angka aman pada peraturan NDS (1997). Selain itu, analisis angka aman juga diteliti untuk sudut gaya sejajar dan tegak lurus serat, serta berdasarkan pada moda kelelehan sambungan.

Berdasarkan hasil analisis, baik SNI-5 (2002) dan NDS (1997) menggunakan angka aman yang lebih besar pada sambungan dengan arah gaya tegak lurus terhadap serat kayu dari pada angka aman pada sambungan dengan arah gaya sejajar serat kayu. Angka aman yang lebih kecil digunakan pada kedua peraturan di atas apabila bentuk kelelehan sambungan disebabkan oleh terbentuknya sendi plastis pada baut (moda kelelehan III_s dan IV). Walaupun demikian, secara umum angka aman yang digunakan oleh SNI-5 (2002) jauh lebih kecil dari pada angka aman yang dipergunakan oleh NDS (1997).

Kata-kata kunci *: Sambungan baut, moda kelelehan, dan angka aman.*

1. Introduction

Bolts are commonly used as fasteners in timber connection. They have the advantage of being easily installed and inspected. They are also economical, and are capable of transmitting high load. Bolts can be used in single-shear (two-member) connection or double-shear (three-member) connection. Generally, connections with mechanical fasteners such as bolts are usually more ductile than that of connection with adhesive materials. Ductile connection leads to better energy dissipation of timber structures. The connection strength of bolted connection is determined by some parameters such as yield bending strength of fastener, the bearing or shear strength of wood member, and the geometry of connection itself [Breyer et al., 2003].

Strength analysis of timber connection using yield model was proposed by Johansen [1949]. In his yield model, Johansen assumed that the bearing capacity of connection is attained when either the compressive strength of wood beneath the bolt is exceeded or simultaneously the timber under the bolt becomes plastic and one or more plastic hinges are formed in the bolt. A set of equations and the corresponding

1. Lecturer in Civil Engineering Department, Gadjah Mada University, Yogyakarta.

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yield modes obtained by Johansen yield model is currently known as European Yield Model (EYM). Recently, SNI-5 [2002] and NDS [1997] introduce a set of equations to analyze the strength of timber bolted connection in the form that resemble to what Johansen did. Therefore, it is an interesting study to analysis the safety factor provided by these two codes with respect to Johansen yield model.

2. Objectives

The overall goal of this study is to find out the safety factor of bolted timber connection designed by SNI-5 [2002]. In addition, a comparison study of safety factor used in SNI-5 [2002] and NDS [1997] is also carried out. The results of this study are restricted only to double-shear bolted connection where the main member and the side members are from wood.

3. Theoretical Background

Mechanical connections are constructed using two general fastener types: dowel and bearing. Dowel type fasteners such as nails, screws and bolts, transmit either lateral or withdrawal loads. Lateral loads are transmitted by bearing stress developed between the fastener and the members of connection. Withdrawal loads are loads parallel to the fastener axis transmitted through friction or bearing to the connected materials. Bearing type connections transmit lateral load only. Bearing type fasteners, such as shear plate and split ring connection, transmit shear force through bearing of the connected materials. Each connection must be designed to transmit forces adequately and provide satisfactory performance for the life of the structure without causing splitting, cracking, or excessive deformation of the wood members.

The first attempt to discover design values for bolted timber joints was conducted by Trayer [1932]. Trayer's work focused on developing load-slip curve that can be used to find three important values: the proportional limit load, yield load, and ultimate load. Trayer's conclusion is derived as an empirical fit of experimental results. This is due to the complexity of the interaction of a bolt in orthotropic non-homogenous material [Gatesco, 1998]. Some of the major conclusions reached by Trayer are: (1) the *l/D* ratio is the governing parameter, where *l* is the length of bolt in main member and *D* is the bolt diameter, (2) connection with steel side plates achieves 20% higher capacity than connection with wood side members for parallel-to-grain loading, and (3) connection with steel side plates and connection with wood side members loaded perpendicular to grain have equal capacities.

The capacity of single bolt depends on the bearing strength of wood, the bending strength and the slenderness ratio of bolt. The slenderness ratio of bolt is the length of bolt in main member divided by the bolt diameter. For bolted-connection with low slenderness ratio, the bolt is relatively stiff and the full bearing strength of wood is developed. As the slenderness increases, bolt stiffness is reduced and bending will occur before full bearing strength is achieved, reducing the capacity of connection [Soltis et al., 1996].

Yield model for strength analysis of bolted timber connection was proposed by Johansen [1949]. The bearing capacity of connection is attained when either the compressive strength of wood beneath the bolt is exceeded or simultaneously the timber under the bolt becomes plastic and one or more plastic hinges are formed in the bolt. Yield modes I_s and I_m are the results of wood fiber crushing in side members and main member, respectively. Yield mode III_s is the result of bolt yielding in one plastic hinge, and yield mode IV is the result of bolt yielding in more than one plastic hinges. These yield modes are shown in **Figure 1**. Please note that only a half of connection is shown due to symmetric configuration. From these following series of failure modes of connection, lateral load resistances for single fastener connection are given in **Table 1**.

4. Analysis

The allowable design value of bolted connection (Z') is stated in **Equation (1)** in terms of the adjustment factor (C) and the nominal design value (Z). The adjustment factor actually reflects the safety factors which consider the possibility of structures being overload, timber imperfections, early-splitting failure of multiple-bolt connection, and special environments. SNI-5 [2002] and NDS [1997] obtain the adjustment factor from **Equations (2.a)** and **(2.b)**, respectively. According to SNI-5 [2002], the value of (connection

Table 1. Lateral load resistance of wood to wood bolted connection [Johansen, 1949]

Yield mode	Lateral load resistance (Z)
I_s	$2Dt_sF_{es}$
I_m	Dt_mF_{em}
III_s	$\dfrac{2k_3Dt_sF_{em}}{(2+R_e)}\left[-1+\sqrt{\dfrac{2(1+R_e)}{R_e}+\dfrac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^{\,2}}}\right]$
IV	$2D^2\sqrt{\dfrac{2F_{em}F_{yb}}{3(1+R_e)}}$

resistance factor) is equal to 0.65. The nominal design values of single bolt connection for both SNI-5 [2002] and NDS [1997] are given in **Table 2**.

$$Z' \leq CZ \quad (1)$$

$$C_{SNI} = \phi_z \lambda C_g C_\Delta \quad (2.a)$$

$$C_{NDS} = C_D C_M C_t C_g C_\Delta \quad (2.b)$$

Table 2. Lateral load resistance of wood to wood bolted connection [SNI-5 [2002] and NDS [1997]]

Yield mode	Lateral load resistance (Z)	
	PKKI NI-5 (2002)	**NDS of U.S (1997)**
I_s	$\frac{1.66 D t_s F_{es}}{K_\theta}$	$\frac{D t_s F_{es}}{2K_\theta}$
I_m	$\frac{0.83 D t_m F_{em}}{K_\theta}$	$\frac{D t_m F_{em}}{4K_\theta}$
III_s	$\frac{2.08 k_3 D t_s F_{em}}{(2+R_e)K_\theta}$	$\frac{k_3 D t_s F_{em}}{1.6(2+R_e)K_\theta}$
IV	$\frac{2.08 D^2}{K_\theta}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$	$\frac{D^2}{1.6K_\theta}\sqrt{\frac{2F_{em}F_{yb}}{3(1+R_e)}}$

For a double-shear timber connection with single bolt, if the moisture content of timber is less than 19%, and maximum temperature of environment is less than 38° C, then **Equations (2.a)** and **(2.b)** can be simplified to become **Equations (3.a)** and **(3.b)**, respectively. C_D and λ are load duration factors, which values are depending on loading combination. The value of C_D varies from 0.9 to 1.25 [NDS, 1997], and the value of λ varies from 0.6 to 1.0 [SNI-5, 2002].

$$C_{SNI} = 0.65\lambda \quad (3.a)$$

$$C_{NDS} = C_D \quad (3.b)$$

Substituting **Equations (3)** into **Equation (1)** yields **Equations (4)**. **Equation (4.a)** and **(4.b)** are allowable design value of SNI-5 [2002] and NDS [1997], respectively. Supposed that the nominal design values of bolted connection obtained from Johansen yield mode (**equations in Table 1**) are called Z_{eym}, a coefficient (k) that relates the nominal design values (Z) of SNI-5 [2002] or NDS [1997] with is shown in **Equation (5)**. The values of k are given in **Table 3**. From **Table 3**, it is obvious that the values of k in direction perpendicular to wood grain is 1.25 times the values of k in direction parallel to wood grain.

$$Z' \leq 0.65\lambda Z \quad (4.a)$$

$$Z' \leq C_D Z \quad (4.b)$$

$$Z = \frac{1}{k} Z_{EYM} \quad (5)$$

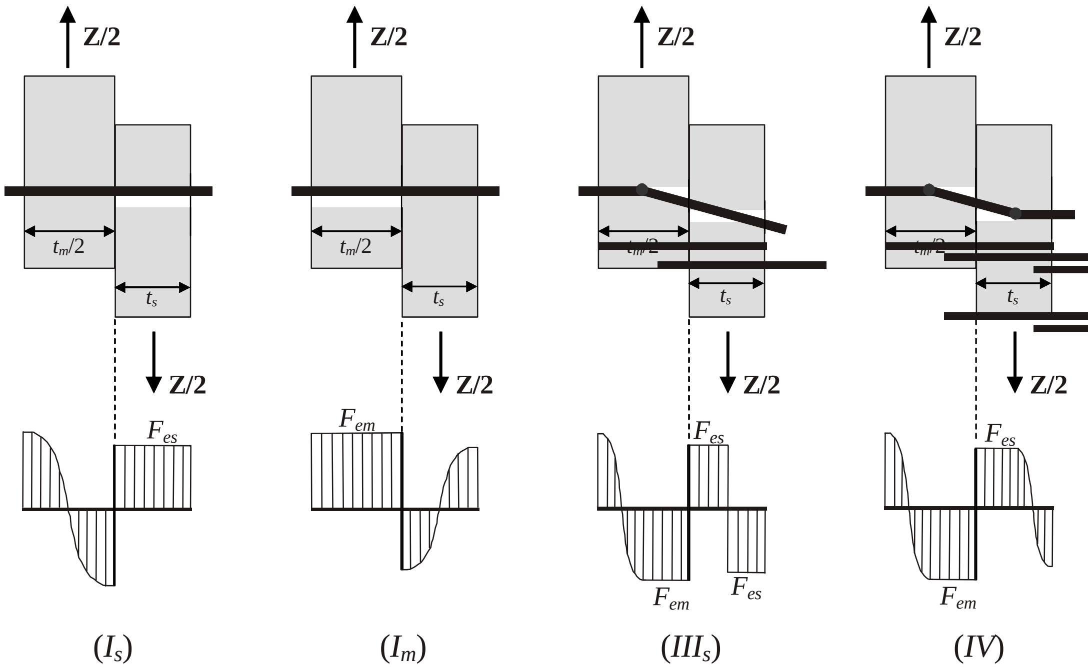

Figure 1. Failure modes and its bearing stress distribution of timber bolted-connection

Table 3. Values of k

Yield mode	Parallel to wood grain		Perpendicular to wood grain	
	SNI-5 (2002)	NDS (1997)	SNI-5 (2002)	NDS (1997)
I_s and I_m	1.2	4.0	1.5	5.0
III_s and IV	0.96	3.2	1.2	4.0

Substituting **Equation (5)** and the values of k in **Table 3** for direction parallel to wood grain into **Equation (1)** yields **Equations (6)** and **(7)**. **Equations (6.a)** and **(6.b)** are allowable design value of SNI-5 (2002) when the connection failed without plastic hinge in the bolt (yield modes l_s and l_m) and with plastic hinge (yield modes III_s and IV), respectively. Similarly with **Equation (7.a)** and **(7.b)**, these two Equations are allowable design value of NDS [1997] when the connection failed without and with plastic hinge in the bolt, respectively. By introducing the values of λ and C_D into **Equations (6)** and **(7)**, we will come out with one general equation that contain the safety factor (*SF*) of connection as shown in **Equation (8)**. The exact value of safety factor will lie in safety margin of **Table 4**, and also depending on the type of loading combination. From **Table 4**, it can be concluded that NDS [1997] gives higher safety factor than SNI-5 [2002].

$$Z' \leq 0.54 \lambda Z_{EYM} \quad (6.a)$$

$$Z' \leq 0.68 \lambda Z_{EYM} \quad (6.b)$$

$$Z' \leq 0.25 C_D Z_{EYM} \quad (7.a)$$

$$Z' \leq 0.31 C_D Z_{EYM} \quad (7.b)$$

5. Conclusions

Both SNI-5 [2002] and NDS [1997] use higher safety factor for a bolted connection sustaining load in direction perpendicular to grain than that sustaining load in direction parallel to grain. Safety factor for direction perpendicular to grain is 1.25 times of safety factor for direction parallel to grain. Smaller safety factor is used in both codes when the failure modes of connection are III_s and IV (failure modes with plastic hinge in the bolt). However, in this case, the safety factor of NDS [1997] significantly much higher than that of SNI-5 [2002].

Table 4. Safety factor of timber bolted connection

Yield mode	of SNI-5 (2002)	of NDS (1997)
I_s and I_m	1.85 – 3.0	3.23 – 4.44
III_s and IV	1.47 – 2.45	2.56 – 3.57

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Notation

C_D, λ = load duration factors

C_g = multiple-bolt adjustment factor

C_M = wet-service adjustment factor

C_t = temperature adjustment factor

C_Δ = connection geometric factor

D = bolt diameter

F_{es}, F_{em} = dowel bearing strength of side member and main member, respectively

F_{yb} = fastener yield stress

K_θ = $1 + \theta/360$

M_y = plastic moment of bolt

R_e = ratio of F_{em} to F_{es}

t_s, t_m = thickness of side member and main member, respectively

θ = angle of load to wood grain

k_3 = $$-1+\sqrt{\frac{2(1+R_e)}{R_e}+\frac{2F_{yb}(2+R_e)D^2}{3F_{em}t_s^{\;2}}}$$