INFLUENCE OF THE TORQUE ON THE ULTIMATE LOAD OF WOOD BOLTED JOINTS

Milton Luiz Siqueira
Department of Mechanical Engineering - University of Brasília - DF - Brazil
milton@unb.br

Cláudio Henrique Soares Del Menezzi
Department of Forest Engineering - University of Brasília - DF - Brazil
cmenezzi@unb.br

Abstract. *The objective of this work was to verify the effect of the torque on the ultimate load of structural fastenings for Angelim Vermelho wood bolted joint. The bolted joints were made using four hexagonal bolts (10mm´) and the ultimate load was evaluated according five torque levels (10, 20, 30, 40 and 50N.m) for two wood sections (6x12cm and 6x16cm) in compression parallel to wood grain. The tests were carried out using an universal test machine by applying gradual load up to failure. It was identified that the ultimate load increase as the level of torque is increased up to 40N.m, and dropping slightly up to 50N.m for 6x12cm wood section, while for 6x16 it was not identified any effect. The best model to explain this effect was the power. These results suggest that the bolted joint made from Amazonian wood, Dinizia excelsa* Ducke*, shows better performance when the screews are under squeeze torque. However, to take some advantage from this conclusion it is very important to remain the torque level of the bolted joint, because of the wood creep behavior*

Keywords*: wood fastenings, torque, bolts, parallel compression*

1. INTRODUCTION

The timber have the length limited for the size of the trees, ways of transport and, therefore, the timber is sawed in limited lengths, generally from 4 to 5 meters. To confection the structures wooden, the parts are jointed, using mechanical diverse fastenings devices, such as: nail, stample, screw, bolts and timber connection. The bolt used in the structural joint are cylindrical and smooth, having in an extremity a head and the other a thread with nut and smooth washer.

The bolt hole diameters shall be between 1/32 and 1/16 in. (0.8 and 1.6 mm) larger than the bolt diameters, and they should pressed with nuts, and to reduce the pressure of support in the surface of the wood metallic washers are used. The main requirement for joints are the strength, the fastenings must be able to transmit force of a wooden part to another one, as well as being rigid. The relative movement enters on parts must be restricted in order not to harm the functioning of the structure.

High preload is very desirable in important bolted connections it means of assuring that the torque is actually developed when the parts are assembled. The torque applied to nuts and washers has influence on the ultimate load of the structure, therefore to the measure that if applies torque the same transmits a more rigid and resistant force to the linking becoming them when requested the efforts extension and/or compression.

According to USDA (1999) the strength of a wood bolted joint can be affected by the following factors: bolt hole's dimension and quality, ratio of bolt length to diameter (L/D), wood properties and piece thickness. On the point of view that strength, it could be speculated that the tightening of bolt, or the torque applied would affect it. However, the lack of information and studies concerning the effect of torque on wood bolted joint characteristics is evident. It happens probably because wood is a viscoelastic material and its creep behavior can reduces the stiffness of the bolted joint, then the torque level should not be computed on wood structure design according to the code such as NBR (Brazil) EUROCODE (Europe), LFRP and ASD (USA). Then, in this context, this preliminary work aims to evaluate the effect of the torque on the ultimate load of wood bolted joint.

2. BACKGROUND

Methods of joining parts are extremely important in the engineering of a quality design, and it is necessary to have a thorough understanding of the performance of fasteners and joints under all conditions of use and design. (Shigley and Mischke, 1985). When a connection is desired which can be disassembled without destructive methods and which is strong enough to resist external load, moment loads, and shear loads, or a combination of these. A joint can be dangerous unless it is properly designed and assembled by a trained mechanic.

The grip of a connection or clamped zone is the total thicknesses of the clamped material; it is the sum of the thicknesses of members and washes. The physical and mechanical characteristics of the bolt contribute for the increase of the ultimate load in bolted joint, such characteristics are: thread standards, type of bolt, shipment, external force, assembly, pre-load and the shear in the joints. The bolt is preloaded by torque in the wash to produce a tensile force or clamping force. This clamping force produces tension in the bolt induces compression in the members.

The constant of spring or constant of rigidity of an elastic part as a bolt is the reason enters the force applied to the part and the deformation that the force produces in the same one, can be used the equation suggested for Shigley and Mischke (1985) to find the constant of rigidity of the joint.

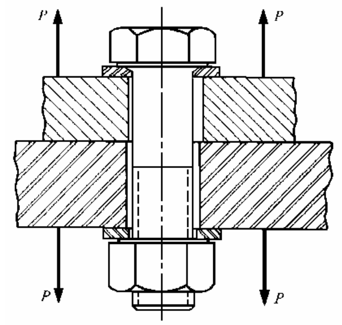

Figure 1. Bolted connection loaded in tension by the forces P. (Shigley et al. 2005)

Consider an external tensile load P, as in Fig. 1, is applied to a bolted connection. It is to be assumed that preload has been correctly applied by tightening the nut before P is applied. Note the use of two washers. A simplified conventional method is used to represent the screw threads. Note how the threads extend into the body of the connection. This is usual and is desired.

High preload is very desirable in important bolted connections, we must consider of ensuring that the preload is actually developed when the parts are assembled. Then the nut is simply tightened until the bolt elongates. This elongates ensures that the preload has been attained. The elongation of a screw cannot usually be measured, in such cases the wrench torque required to develop the specified preload must be estimated. Then torque wrenching, pneumatic-impact wrenching, or the turn-of-the nut method may be uses. The torque wrench has a built-in dial which indicates the proper torque. (Shigley and Mischke, 1989)

Table 1 is included to provide some information on the relative values of the stiffnesses encountered. The grip contains only two members, both of steel, and no washers. The ratios C and 1-C are the coefficients. They describe the proportion of the external load taken by the bolt and by the members, respectively. In all cases, the members take over 80 percent of external load. Note also that making the grip longer causes the members to take an even greater percentage of external load.

Table 1. Computation of bolt and member stiffnesses. Steel members clamped using a 1/2"-13 NC steel bolt. (Shigley and Mischke, 1989)

Bolt grip, in	Stiffnesses, Mlb/in.		joint constant $C = k_b / (k_b + k_m)$	Members constant 1 - C
	k_b	k_m		
2	2.57	12.69	0.168	0.832
3	1.79	11.33	0.136	0.864
4	1.37	10.63	0.114	0.886

The use of wood in many structural and other applications often involves the use of mechanical fasteners, such as nails, screws, bolts, lag screws, and connections. Data on the strength and performance of such fasteners are frequently needed for design and for comparative purposes. Tests of mechanical fasteners have been generally regarded as special tests and have not been included in the standard methods already established for evaluating the properties of wood. The use of standard methods for bolt test is recommended as a way of obtaining comparable data and of eliminating variables in test results because of variations in testing methods (ASTM D1761-88). The joint may be the weakest link in timber construction, while the strength of bolted joints can be determined by standard methods of testing.

The testing bolted timber joint provides a suitable procedure for evaluating the strength and rigidity of timber joints fastened with bolts. The test serves as a basis for developing design criteria and for determining the effect of various factors on the strength and efficiency of the joint. Specimens consisting of three-member (double cut) or two-member (single cut) wood joints fastened with bolt and timber connectors are evaluated for their capacity to resist compressive or tensile forces.

The tests described by ASTM D1761-88 will permit obtaining data on the strength and rigidity of timber joints under the influence of any or all of the bellow mentioned factors. Such variables as member thickness, member width, end and edge margins, type of fastener and number of units, spacing between fastener units, moisture content of wood, preservative or fire-retardant treatment of the wood, and species of wood. When joints are used where the wood remain wet in service, design values shall be multiplied by the 0.67 modification factor for moisture content from Table 8.1.B NDS standards.

3. EXPERIMENTAL PROCEDURE

3.1 Wood Material and Samples Preparation

Were used three member joints in which the side members were less each one-half the thickness of the main member. Two types of joints member length were used in this study (Table 2). All joints were loaded parallel to the grain and all members were 30 cm long. Three replications of each combination of variables were evaluated. The wood members were selected, and the fasteners positioned in them in such Brazilian norm NBR7190 (1997). The selected members were clear and straight grained.

The tests were made on three-member joints (double cut) as shown in Figs. 2 and 3. The wood samples of joints were made from *Dinizia excelsa* Ducke were obtained at Distrito Federal´s home depot, Brazil. This species is known as angelim vermelho and it grows in Amazon Region at Pará´s State. It has the following characteristics: heavy wood, hard to cut, heartwood and sapwood with the same color, smooth texture, right to irregular grain, with characteristic smell when wet and tasteless. It can be dried fast and it has density (12% moisture content) about 0.83g/cm^3 to 0.99g/cm^3 and wet density about 1.26g/cm^3.

Table 2. Type of joints and member dimensions.

Type of joint	Members	Thickness (cm)	width (cm)	length (cm)	bolt diameter (in)
6x12x30 cm	Main member	6	12	30	**3/8**
	Side member	2,5			
6x16x30 cm	Main member	6	16		
	Side member	2,5			

Low-carbon steel machine bolts were used with round steel washers under both the head and nut – 3/8” – 16 UNC (3/8 inch - nominal major diameter, 16 – threads per inch, UNC – Coarse series) this data was compiled from ANSI B1.1-1974. Minimum bots and edge distance requirements in NBR9190/97 can be seen in figure 3, for parallel to grain loading. The wood sections dimensions were determined according NBR7190 (1997). The wood samples were gripped and then two holes lines were drilled at perpendicular and parallel directions (Fig. 2). The spacing between holes lines was 6,0cm and 3,0cm from the end of the piece for 6x12cm wood section and 8,0cm and 4,0cm for 6x16cm, respectively.

Figure 2. Assembly for testing bolted joint parallel to grain in compression.

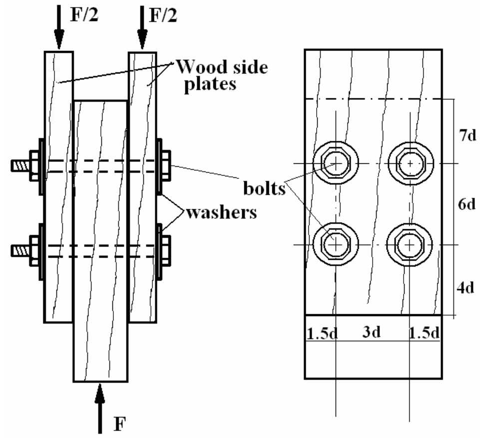

Figure 3. Testing arrangement with three member joints bolted with for bolts.

The experimental arrangements for three members joint are shown in fig. 3. All joints were loaded in compression following ASTM procedures where applicable. Loading was stopped after a total joint deformation. To aims to evaluate the effect of the torque on the ultimate load of wood bolted joint, were establish five level of torque value they are 10, 20, 30, 40 and 50 N.m. For each evaluated rations of torque and wood sections were prepared three repetitions, totalizing 30 samples. After the production of the samples, they were immersed in a water tank for saturation for 10 days. It was done to certify the samples would be evaluated at wet condition, which is the wood condition more available at local market. Preliminaries tests were executed to evaluate the maximum torque level the wood joint could support and the value obtained was about 50N.m. At this torque level the washer come in the wood piece, compressing it. This way, it was defined five torque levels which values were varying from the maximum up to minimum torque level: 50, 40, 30, 20 and 10N.m. The tightening of the hexagonal bolt was calibrated using a torquimeter GEDORE (4506 RX-200, scale 40-200N.m).

3.2 Mechanical Test

The mechanical tests were done according to NBR 7190/97 (Appendix C) using the procedures to determine the ultimate load of wood bolted joint under parallel compression loading and were conducted at the Laboratory of Materials, Department of Civil Engineering, Instituto de Ensino Superior Planalto (Brasília, DF). The samples were tested using a compression machine model PavTest (Contenco), which has a 1.2 MN dynamometer, until to final rupture (Fig. 4).

Figure 4. Compression machine loading a sample.

The results were evaluated by running a factorial analysis of variance (ANOVA) to identify the effect of the torque level (T), the wood sections (W) and the combined effect (TxW) on the ultimate load. It was determined the best regression model to explain the relationship between ultimate load (dependent variable) and torque level (independent variable). Seven simple regression models were tested (linear, quadratic, cubic, power, logarithmic compound and exponential) and the best equation was chosen according its coefficient of determination (r^2) and level of significance. The whole statistic analysis was run using the software SPSS 13.0 for Windows.

4. RESULTS AND DISCUSSION

The values of ultimate load according to the torque level for both wood sections are presented in Fig. 5. The rupture of joint is related to the ultimate limit where excessive load causes the collapse of structure. The cracks happened on the side where washers and nuts were, which was a point of stress concentration, and the shear was evident at parallel direction of the wood.

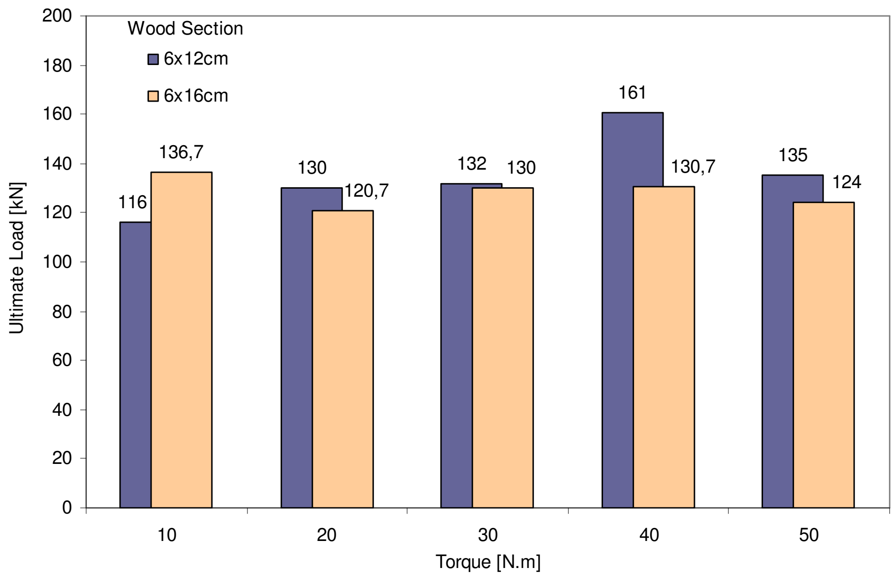

Figure 5. Ultimate load according to the torque level for both wood sections tested.

It can be observed on Fig. 5 that the ultimate load is increased with the rise in the torque level. Then, it can be stated that the torque improve the strength of the bolted joint. However, this behavior is more evident for 6x12cm wood section, while for 6x16cm section it does not seem clear. Some explanations of these results can be stated. Since bolt is stiffer and stronger than wood, the main wood property governing the ultimate load of a joint is the compression strength parallel to grain. All the engineering equations used to design wood bolted joint refers to this property. Nevertheless, when the bolt is squeezed, nuts and washers cause an additional stress done by the wood compression at perpendicular direction which can contribute to improve the ultimate load. Additionally, tightening of the bolt approximates both central and side pieces, improving the attrition between them which could have a positive effect on the ultimate load. The result of the factorial ANOVA is presented on Table 4. In this work the isolated effect of the torque or the wood section was not identified. On the other way, the interaction of both factors (sources of variation) was highly significant and then the effect of the torque level depends on which wood section is evaluated.

Table 4. Summary of the factorial analysis of variance.

Source	DF	Fcalc.	Significant
Torque (T)	4	2.751	0.057
Wood section (W)	1	2.095	0.163
T x W	4	3.431	0.027
Error	20		
Total	29		

It was run an ANOVA for each wood section separately and the results confirmed those statement: the torque had effect only on the ultimate load of 6x12cm wood section. It was not identified any effect of the torque on the 6x16cm wood section. It can be observed on Fig. 5 that ultimate values of 6x12cm wood sections are higher than those observed for 6x16cm mainly at higher level torque. However, as can be observed on Table 1, wood section did not have effect on the ultimate load. This results were observed in despite of that 6x16cm had a higher superficial contact between the central and the side pieces, which could improve the attrition between them (as explained above). Then, this result was not expected and it will be necessary complementary studies to explain this behavior.

To explain the effect of the torque on the ultimate load of 6x12cm wood section it was run an analysis of regression. The Fig. 6 presents the goodness of fit for the best model chosen, that it was the power model. According to this model the torque level affects positively the ultimate load of the joint up to 50N.m, in despite of the observed in Fig. 5. According to this figure the ultimate load is increased up to 40N.m, and then it is decreased, and it would be expected that a quadratic model could be better to explain the data variation. However, none of the quadratic model coefficients were statistically significant, so it could not explain the data observed. As stated above the torque did not have effect on ultimate load of the 6x16cm wood section, this way was not possible to fit any suitable model.

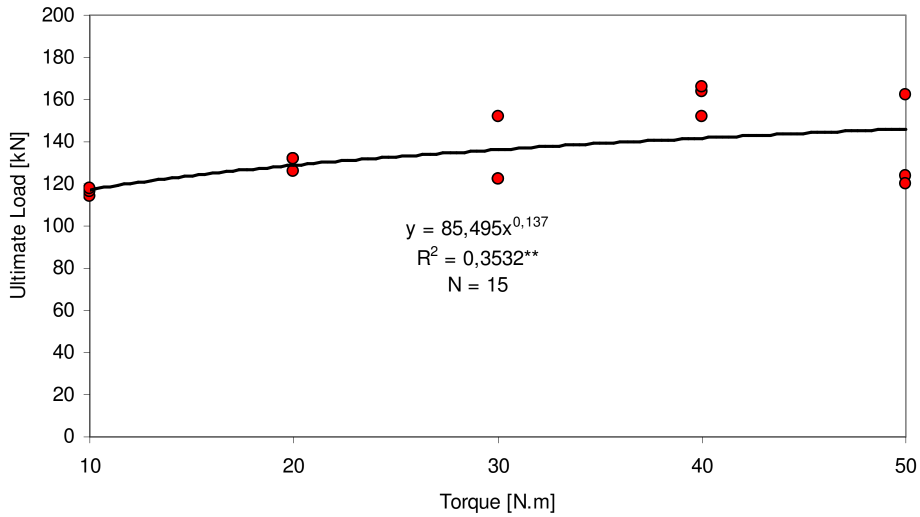

Figure 6. Effect of the torque level on the ultimate load of wood bolted joint (6x12cm wood section). (** significant at 1% of probability)

According to the results obtained in this work it can be argued that the application of the torque on wood bolted joint made with 6x12cm wood section could be advantageous. It would permit the design of more slender and consequently lighter wood structures. Nevertheless, wood is a viscoelastic material and this way creep happens (Bodig and Jayne, 1993) which can slacken the wood joint and consequently torque would not be effective. Additionally, wood shrinks and swells as function of the environmental conditions changes and it has the same expected effect from creep behavior. To avoid it, is very important to remain the torque level during the service life of the wood structure.

5. CONCLUSIONS

It was observed that torque had effect on ultimate load of wood bolted joint. The more squeeze the torque the higher the ultimate load. However, this effect was significant only for 6x12cm section, while for 6x16cm it was not clear the effect. Higher torque level (50N.m) decreased ultimate load for both wood sections evaluated. This way, it can be stated that torque could be used to improve the ultimate load of this kind of wood jointing. Nevertheless it is very important to maintain the torque during the structure life, because wood is a viscoelastic material and its creep behavior can reduce the stiffness of the joint. Additional tests will be conducted to clarify the effect of the torque on wood bolted joint.

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7. RESPONSIBILITY NOTICE