

## Ultimate load in wood connection: lateral resistance for lag screws

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*Abstract. Due to the importance of the wooden joints and the scarcity of studies relative to lag screws, the present study aimed to determine the ultimate load in parallel compression (lateral resistance) with double cut on the connections of the metal plate with Angelim Vermelho (*Dinizia excelsa* Ducke) wood, using lag screws in the joints. The tests were carried out in the universal test machine (Pavtest), applying axial load parallel to the fibers of the wet wood. The ultimate load of each joints content 2, 4 or 6 lag screws 3/8" of diameter, length of 60, 70, 90 and 110 mm and lag screws 1/2", length of 70, 90 and 120 mm were determined. It was verified that the penetration ( $\geq 4d$ ) of the threading part of the screw did not influence the ultimate load. Lag screws 1/2" showed ultimate load higher (about 63%) than lag screws 3/8" evidencing the influence of the screw diameter in the ultimate load. The number of screws presented in the joints did not influence the value of the ultimate load per screw. These results suggest that, similar to the finding described in the Brazilian norm NBR7190/97 for metallic bolts, the ultimate load for each lag screw does not vary in function of the amount of screws present in the joint.*

**Keywords:** wooden joints, ultimate load, parallel compression, lag screws.

### 1. INTRODUCTION

Wood is a construction material used by man since prehistoric times. Until century XIX, the most important engineering workmanships were constructed with rock or wood, frequently combining the two materials.

Compared with other materials of construction, wood presents an excellent strength/density relation and easiness of manufacture process to make industrial and artisan products and has a good term-acoustic insulation. On the other hand, wood is subject to degrading by attack of fungi, insects and other agents. As wood is a natural material, it presents a great variability in its physical and mechanical properties.

The joints are important parts in the manufacture of wooden structures, having to resist the requested efforts for which they have been projected. The engineering designs of joints have been used in timber connectors, bolts, lag screws, drift bolts, nails, spikes, wood screws, metal-plate connectors and spike grids.

Among these the screw fastenings have been detached for their easiness of assembly and dismount. The Brazilian designers have encountered restrictions in the use of lag screws in their projects. The Brazilian norm ABNT 7190/97 does not supply necessary information to design the lag screws in wooden joints. Therefore, the same norm is emissive in the design of wooden lag screw licks. American norm NDS (National Design Specification) already specifies the design of lag screws for wood of specific gravity up to 0,74. Brazilian wood, much of which is Amazonian wood, presents superior specific gravity of 0,74 g/cm<sup>3</sup>.

The present work aims at getting the ultimate load in parallel compression with double cut on the joints of the metal plate with wood, linked by lag screws. It intends to determine the influence of different lag screws diameter and penetrations of thread for lateral load, inserted lateral side of Amazon wood *Dinizia excelsa* Ducke, with specific gravity 0,83 g/cm<sup>3</sup> with different commercial cross sections.

### 2. BIBLIOGRAPHICAL REVISION

The mechanic property of the wood varies due to factors such as: density, wet and dry conditions, time of duration of the load and shipment description, inclination of grain, cracks etc. Panshin and DE Zeeuw (1980), said that the specific gravity can determine the mechanical properties of the wood. When the wood has higher density it is expected that their mechanical properties are higher, too. The saturation of wood is approximately 30% of humidity, the physical and mechanical properties of the wood are practically constant. The break-even point of textual humidity of the wood depends on the relative humidity and temperature of the environment where the wood is displayed. In Brazil the annual average balance of humidity is around 12%.

## **2.1. Structural project**

The design and detailing of a structural project, knowledge of structural analysis and stress of the materials, as well as rules and recommendations established for specific norms, should be used. Many countries have used in their structure project criteria based on the Method of Allowable Stress Design. Some countries passed later to adopt criteria based on the Method of the Load and Resistance Factor Design. In England has been used the British standard 5268 'Structural Use of Timber' dividing many parts such as "limit states design, material and workmanship" and code of practice for permissive stress design material and workmanship. In Brazil this advance occurred with the publication of NBR 7190/97 that substitutes NBR 7190/82.

Shigley, 1989, said the designer can choose safety factors or permissible working stresses. The permissible stresses are bases on the yield strength of the material instead of the ultimate strength.

### **2.1.1. Allowable stress design method**

In USA this method may currently be designed. The standard corresponding is the National Design Specification for wood construction. This standard is currently the most widely used.

The allowable stress design method in Brazil was established by the former norm NBR 7190/82. This method, among other limitations, used only one safety factor to establish the uncertainties and its origins. In accordance with Pfeil and Pfeil (2003), these uncertainties must be the kind of loading, the mechanical characteristics of the materials, to the imperfections in the execution and the model of calculation of efforts due to the actions in service. The previous Brazilian norm establishes criteria to determine the load of rupture of connectors for the method of allowable stress design. To establish the permissible load in wood connectors one must take care of below to lesser values of the three options described bellow. These options guarantee that the wood will not go to rupture by the bearing condition, that the screw will not go yield, as well as the maximum relative displacement of the parts in the joints:

- 20% of the ultimate load;
- 50% of the proportional limit;
- relative displacement of the connected parts should be less than 1,5 mm.

### **2.1.2. Limit states design**

The wood and timber structures in USA may be designed using the Load and Resistance Factor Design (LRFD) for engineered wood construction. This theory, as previously alluded to, was developed in Europe. Some modification has been made since its original formulation in order to make the model appropriate for incorporation into the U.S. design specifications.

## **2.2. Connection of Structural Members**

The bolt connection must be capable of transferring the force of a member to another one, by means of a bolt. In the neighborhood of the connection the stresses distribution becomes intent or strangled. (Resende, 2005).

In accordance to FOREST PRODUCTS LABORATORY, 1999, the strength, stability and conditions of use of a structure depend mainly on the fastenings that keep its members together. Each connector requires specific analysis in function of stress properties of the wood in use, if the moisture service conditions of the wood change the size of timber change too. Some materials and types of connectors in structural fastenings are of wood. It can be detached: screws, nails, connectors, glue, printed plate, and others. The wooden connectors can be made with wood or wood with another material. (Mackerle, 2005).

The fastenings are normally designed axial and parallel of the grain. Wooden joints can induce a multi-axial state of stresses and therefor should reduce the load capacity of the fastenings.

Recently (Mackerle, 2005) said: The fastening is the main source of toughness of the wooden structure, mainly nailed and bolted.

The designers choose the wood bolted fastening because it is easy to assemble and dismount.

According to (Calil, 2003), the fastenings transmit the forces of a member to another one through a small area. The connectors induce to a convergence of stresses in this area. The transmission of the load by the fastenings of one member to another one can cause shear load in the bolt.

The NBR 7190/97 that establishes the width of the fastener group shall be considered as the minimum placement of the fasteners. Requirements for bolt placement are given in Figure 1.

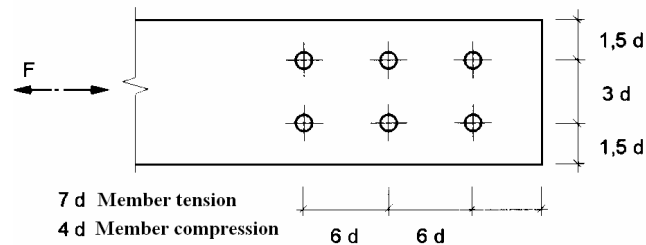


Figure 1 – Minimum placement of bolts in a joint. (NBR 7190/97), with  $d$  being the diameter of bolt.

### 2.2.1. Bolted joints - fastenings

When a dismantable union without using permanent methods is desired and that it is resistant enough to support tensile external loads and of shear or the combination of the same ones, bolted fastenings can be used with nut and lag screws.

When a joint contains two or more fastenings of the same type, each of the same or miscellaneous sizes, the design value for the joint shall be the sum of the design values for each individual up to 8 bolts in same direction load line. Among the steel bolts must be made its characteristic resistance of minimum of 240 MPa, and the minimum diameter of the bigger or equal screw either 10 mm.

Appropriate dimensions and shape of the bolt holes shall be accurately cut or bored to conform to the bolts and shall be oriented in contacting faces. NBR 7190/97 establishes: A connection to be considered rigid if the bored bolt holes do not have to be bigger of what diameter more 0,5 mm and must use at least 4 bolts. In case that one uses bored bolt holes diameter biggest this dimension, the wood joint must be considered deformable.

Bolt-hole diameters shall be between 0,8 and 1.6 mm larger than the bolt diameters and roles shall be carefully bored perpendicular to the surface, so that the surface of the hole is smooth and uniform to assure good bearing of the bolt. The tests shall be made on three-member joints (double cut), as shown in Fig. 4; when the side members are made of wood, these members must approximately have the half of the central part. For joints involving metal or other side members, the thickness should be that anticipated in service as shown in Fig. 5. (ASTM 1761 D, 1981).

In Brazil, the use of screws in wooden joints is normally not designed, its use is the criterion of the carpenter in the assembly of the structures; such screws used in wooden joints are classified into two main types. The small diameter wood screws (Figure 2) have been used for general purposes, and slag screws (Figure 3) diameters of 3/8 and 1/2 inches, have been used as wood structural fastenings, but without support of Brazilian norm. The first ones are much used in joinery, also called wooden screws, or to arrest metallic accessories in poles and joinery applications; they are not used in general as wood fastenings of structural wooden parts, they are used in workmanship as second or provisory structures as civil shoring.

But the lag screw can structurally be used, as American NDS and Eurocode norms prescribe. The lag screws will be responsible in transferring the load of one part to another one. Therefore, they must have a minimum penetration in the main part. Norm NDS recommends for lag screw a minimum penetration of  $7d$  in wooden joints. (Falk, 1993) recommends that the lag screw must penetrate at least half of the threading part in the thickest wood part, and must be made a hole in function of the wooden type.

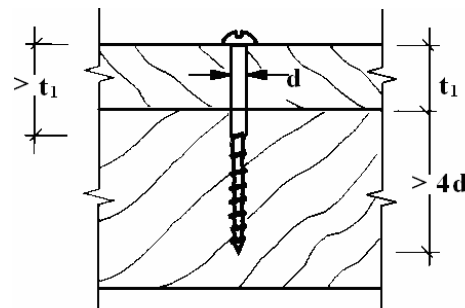


Figure 2 – Wood screws are used in joinery,  $d$  – shank diameter bolt,  $t_1$  – lesser thickness (Pfeil and Pfeil, 2003), with penetration  $\geq 4d$ .

Brazilian norm NBR 7190/97 does not contemplate the lag screws, as connecting of wooden structural parts. In turn, the European and American norms (EUROCODE 5 and NDS), respectively, present criteria for lag screws design on fastening (Pfeil and Pfeil, 2003).

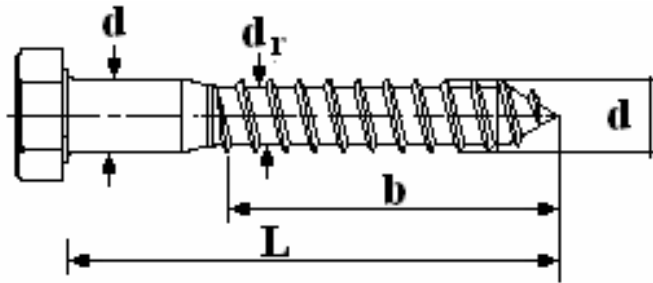


Figure 3 – Leg screw,  $d$  - shank diameter (major diameter),  $d_r$  = minor diameter (roots diameter),  $b$  = length of cut thread and  $L$  = length of lag screw.

The lag screw with magnificent thread is mainly used, where the dimensions of the transversal section of the wooden part are great or where the presence of the nut in the wooden surface is undesirable. Such lag screws are found with diameters that vary from 5.1 mm to 25,4 mm, and with a 125,0 length of 25.4 mm, the threading part varies with the size of the screw (FOREST PRODUCTS LABORATORY, 1999). Such screws have a yield tension of 310 MPa and an ultimate strength of 530 MPa, with well higher resistance properties of the wood. Table 1 relates the commercial dimensions of the lag screw available on the Brazilian market.

To determine the load capacity of the leg screw in wooden joints, the assays must be made in the withdrawal and lateral resistance parallel to grain.

**Table 1** – Commercial lag screws on Brazilian market (only available in dark color).

d - (in)		3/16	1/4	5/16	3/8	1/2
d <sub>r</sub> - (in)		0,120	0,173	0,227	0,265	0,371
length of lag screw (in)	length of cut thread (mm)					
1	full					
1.1/4	25					
1.3/8	25					
1.1/2	32					
1.3/4	38					
2	38					
2.1/4	45					
2.3/8	45					
2.1/2	45					
2.3/4	50					
3	50					
3.1/8	57					
3.1/2	57					
4	63					
4.1/2	70					
5	76					

$d$  - Shank diameter (major diameter),  $d_r$  = minor diameter (roots diameter)

### 2. 2. 2. Strength of lateral bolted connection

NDS for wood construction permits the designer to determine effects of member thickness, member strength, fastener size, and faster strength on lateral connection values for the majority of connections found in wood construction (American Forest & Paper Association, 1999).

Lag screw in use resists withdrawal loads, lateral loads, or a combination of both. Both withdrawal and lateral loads resistances are affected by the wood, the lag screw, and the condition of use.

Lag screws are commonly used because of their convenience, particularly where it would be difficult to fasten a bolt or where a nut on the surface would be objectionable.

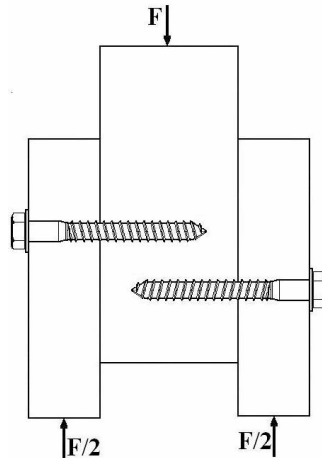


Figure 4 – Joint with lag screw connector, double cut, showing lag screw, two lateral members and main member.

The determination of wooden lateral resistance in joints can be obtained by using two parts (simple cut) or with three parts (double cut), as shows Figure 4.

The FPL general equations (1) apply to calculation of lateral values for single type fastener connections between wood-based members and connections of wood-based members to steel ( Forest Products Laboratory, 1999).

$$P = KD^2 \tag{1}$$

where **P** is lateral load (N), **D** diameter of the screw shank (mm), and **K** a coefficient depending on the inherent characteristics of the wood species for various specific gravity gauges, as listed in Table 2.

According to NDS norm, the lag screw can be fixed perpendicular to the wood fiber. The load capacity of the fastenings is determined by the equation (1) being that the samples were done dry with 12% humidity:

(FOREST PRODUCTS LABORATORY, 1999) supplies Table 2 to get the values of coefficients K, using lag screw. The load is applied in the parallel direction to staple grain, with dry wood 12% humidity. This table gives the coefficient only specified for wooden species with specific weight up to 0,74 g/cm<sup>3</sup>.

K coefficients are based on average results for several ranges of specific gravity for hardwoods and softwoods. The loads given by this equation apply when the thickness of the side member is 3.5 times the shank diameter of the lag screw, and the depth of penetration in the main member is seven times the diameter in the harder woods and 11 times the diameter in the softer woods.

Table 2 – Coefficients for computing test loads for lag screws in seasoned wood (with a moisture content of 15% - wood hand book – 1999).

Specific gravity range*	Lateral load coefficient K
<b>Hardwoods</b>	
0.33 – 0.47	26.34
0.48 – 0.56	29.51
0.57 – 0.74	34.13
<b>Softwoods</b>	
0.29 – 0.42	23.30
0.43 – 0.47	26.34
0.48 – 0.52	29.51

\* - Specific gravity base on oven-dry weight and volume at 12% moisture content.

As can be verified in Table 2, the available values of K for hardwood vary from 0.33 to 0.74 specific gravity. For many wood species found in the Brazilian territory these specific gravity values are superior to 0.74, therefore, Table 2 does not contemplate wood with specific gravity above this value.

FPL general equation (1) does not consider additional variables that influence lateral connection values, including: fastener type; fastener failure modes; fastener spacing, edge, and end distance; connection fabrication and tolerances; connection geometry; multiple fasteners and group action; member strength and the connection; and adjustments for end use. The above mentioned variables are provided in the NDS for wood construction.

Values for lateral resistance as computed by the preceding methods are based on complete penetration of the unthreaded shank into the side member but not into the main member.

When lag screws are used with metal plates, the lateral loads parallel to the grain may be increased 25%, provided the plate thickness is sufficient so that the bearing capacity of the steel is not exceeded. No increase should be made when the applied load is perpendicular to the grain.

Lag screws should not be used in end grain, because splitting may develop under lateral load. If lag screws are so used, however, the loads should be taken as two-thirds of those for lateral resistance when lag screws are inserted into side grain and the loads act perpendicular to the grain.

The spacings, end and edge distances, and net section for lag screw joints should be the same as those for joints with bolts of a diameter equal to the shank diameter of the lag screw.

Lag screws should always be inserted by turning with a wrench, not by driving with a hammer. Soap, bee wax or other lubricants applied to the screw, particularly with the denser wood species, will facilitate insertion and prevent damage to the threads without affecting performance of the lag screw.

### 3. METHODS

#### 3.1 Specimens

Three-member connections loaded both parallel to the grain were evaluated. Each connection consisted of a wood main member and steel side members fastened with two, four and six bolts.

Bolts diameters were 3/8 and 1/2 in.; steel side member thickness was 1/2 in.

The main members were cut from Amazon wood, Angelim vermelho (*Dinizia excelsa* Ducke); all wood members were in wet condition (water saturated). The specimens were confectioned at 25 cm height and transversal sections of 5 cm x 15 cm, 8 cm x 15 cm, 10 cm x 15 cm and 11 cm x 15 cm. In total, 63 specimens were tested, being 36 with screws of 3/8" and 27 samples using screws of 1/2". Table 3 supplies some mechanical and physical properties of Angelim Vermelho wood characterized by the Laboratory for Forest Products, IBAMA.

Table 3 – Mechanical and Physical properties of timber *Dinizia excelsa* Ducke (IBDF- IBAMA)

Properties	Condition	Kgf/cm <sup>2</sup> (Mpa)
Modulus of elasticity for static bending	Dry	173000 (17300)
	Green	153000 (15300)
Modulus of rupture for static bending	Dry	1600 (160)
	Green	1220 (122)
Maximum compression parallel to the grain	Dry	876 (87.6)
	Green	615 (615)
Maximum tension perpendicular to the grain	Dry	39 (3.9)
	Green	53 (5.3)
Maximum shear strength	Dry	180 (18)
	Green	134 (13.4)
Dry density = 0.97 g/cm <sup>3</sup>		
Green density = 1.26 g/cm <sup>3</sup>		
Basic density = 0.83 g/cm <sup>3</sup>		

Three replications were created for each combination of variables for a total of 63 parallel-to-grain specimens.

The connection configurations were made to exceed NBR 7190/96 requirements for end and edge distance.

Table 6 supplies the diameters, length, size of the threading part and the number of lag screws used in the experiments. They were tested in a total of 63 joints.

Table 4 - Lag screws used in the experiments

Lag screw diameter (in.)	length of cut thread (mm)	length of lag screw (mm)	Number of lag screws in the joint
3/8	44	60	2, 4 e 6
	50	70	2, 4 e 6
	68	90	2, 4 e 6
	72	110	2, 4 e 6
1/2	45	70	2, 4 e 6
	60	90	2, 4 e 6
	70	120	2, 4 e 6

The load carried by Pavtest Testing machine - Supplier: Contenco Ind. and Subdivision - 400N.

Lag screws require prebored holes of proper size. The lead hole for the shank was the same diameter as the shank. The diameters of the lead hole for the threaded part were 75% for the 3/8" bolt and 78,7% for the 1/2" bolt of the lag screws shank (Table 7).

Table 5 – Lead for the shank and threaded part for 3/8" and 1/2" lag screws.

Lag screws (in.)	Lead hole for the shank (in.)	Lead hole for the threaded part (mm)	% of the shank diameter
3/8	3/8	7	75
1/2	1/2	10	78,7

### Experimental Procedure

The test procedures for parallel-to-grain loading (Fig. 5) generally followed those given in ASTM D1761-88. Compression loading was used. The tests were terminated at member failure.

Specific gravity and moisture content were determined for each bolted connection.

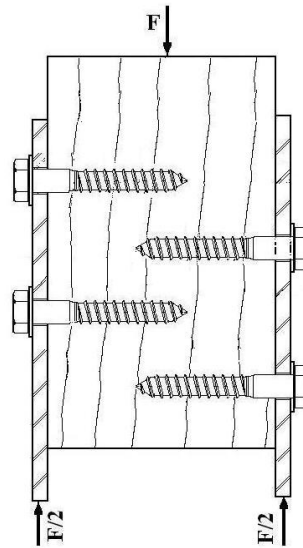


Figure 5 – Three-member connections compression loaded both parallel to the grain were evaluated. Each connection consisted of a wooden main member and steel side members fastened with lag bolts. Edge margin, end margin and row spacing as specified by NBR-7190/97.

### 4. RESULTS

Table 6 details the samples of the tested joints, where it defines the diameters, the lengths' total, so great of thread and amounts of screws.

The average was obtained and standard deviation of these 3 repetitions (columns 7<sup>a</sup> and 8<sup>a</sup>). In column 9 was unit load, that is, the average maximum load that each screw supported until rupture. Already in column 10 the average of the maximum unit load took off that a screw of one determined thread length supported. The last column represents the maximum unit load that the 3/8 screws of 1/2 in. supported.

### 5 - DISCUSSION

Figures 6 and 7 show the length of the threading part of the lag screw that was fixed in the wood and ultimate load that each screw supported using joints with screws of 3/8" and 1/2" with 2, 4 and 6 lag screws. Thus, in Figures 6 and 7 it can be verified little variation of the results using joints with 2, 4 and 6 screws of 3/8 in. and 1/2 in.

Statistic analysis was made to verify if the influence of the penetration 4.6d, 5.2d, 7.1d and 7.6d (Fig. 6) and the influence of the penetration, 3.5d, 4.7d and 5.5d (Fig. 7) of the screw in the sample with the unit load exists. It used the test of correlation of Pearson with program SPSS/PC 12 and verified that there was no influence of these penetrations on the unit load of the joints, as much as 3/8" and 1/2" lag screws diameters; nor had the unit load any influence on the amount of lag screws (2, 4 and 6) used in the joint.

Table 6 - represents loads of ruptures of the 63 tested joints. Lag screws of 3/8 and 1/2 bolt inches were used.

Specimen	Lag screws diameters (in.)	Length of lag screw (mm)	Length of cut thread (mm)	Penetration of thread (mm)	Number of lag screws in the joint	Average (N)	Standard deviation (N)	Unit load (N)	Unit load (N)	General average unit load (N)
1, 2, 3	3/8	60	44	4.6	2	36400	7879	18200	19046	21470
4, 5, 6					4	78267	10013	19567		
7, 8, 9					6	116233	9479	19372		
10, 11, 12		70	50	5.2	2	49100	4616	24550	24327	
13, 14, 15					4	101500	2095	25375		
16, 17, 18					6	138333	1629	23056		
19, 20, 21		90	68	7.2	2	39933	4300	19967	20998	
22, 23, 24					4	86600	1970	21650		
25, 26, 27					6	128267	3002	21378		
28, 29, 30		110	72	7.6	2	40733	4743	20367	21509	
31, 32, 33					4	95933	4310	23983		
34, 35, 36					6	121067	7218	20178		
37, 38, 39	1/2	70	45	3.5	2	74733	3523	37367	33846	35096
40, 41, 42					4	131000	12022	32750		
43, 44, 45					6	188533	3585	31422		
46, 47, 48		90	60	4.7	2	79600	5543	39800	36328	
49, 50, 51					4	138067	11987	34517		
52, 53, 54					6	208000	2750	34667		
55, 56, 57		120	70	5.6	2	78800	5557	39400	35115	
58, 59, 60					4	127067	17809	31767		
61, 62, 63					6	205067	15643	34178		

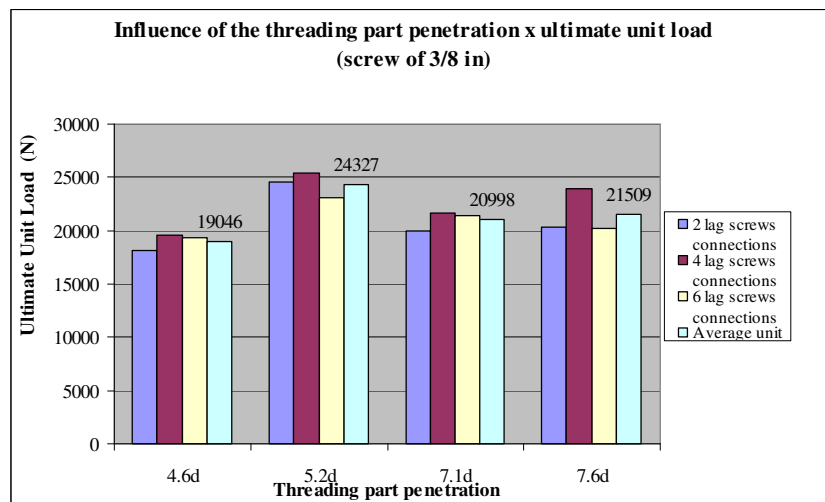


Figure 6 – Influence of the threading part penetration x ultimate unit load for 3/8 in diameter of lag screws. Penetrations 4.6d, 5.2d, 7.1d and 7.6d were studied, being d the diameter of the shank lag screw.



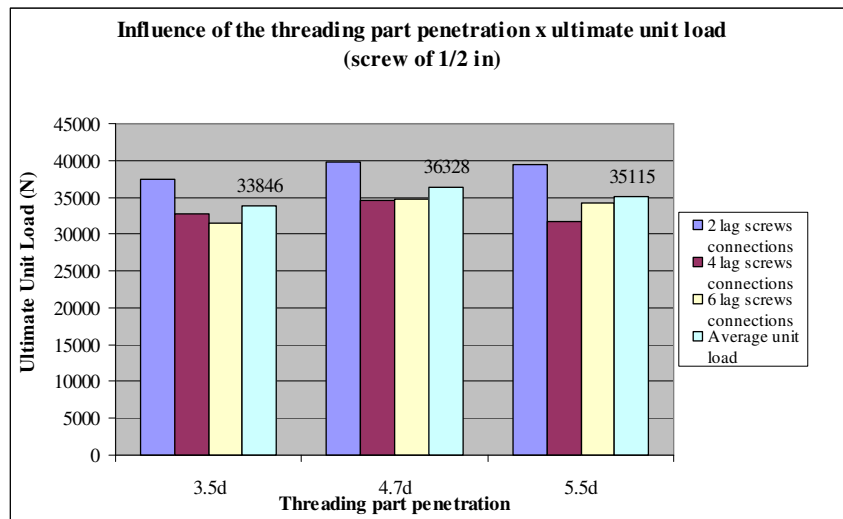


Figure 7 – Influence of the threading part penetration x ultimate unit load for 1/2” diameter of lag screws. Penetrations 3.5d, 4.7d and 5.5d were studied, being d the diameter of the shank lag screw.

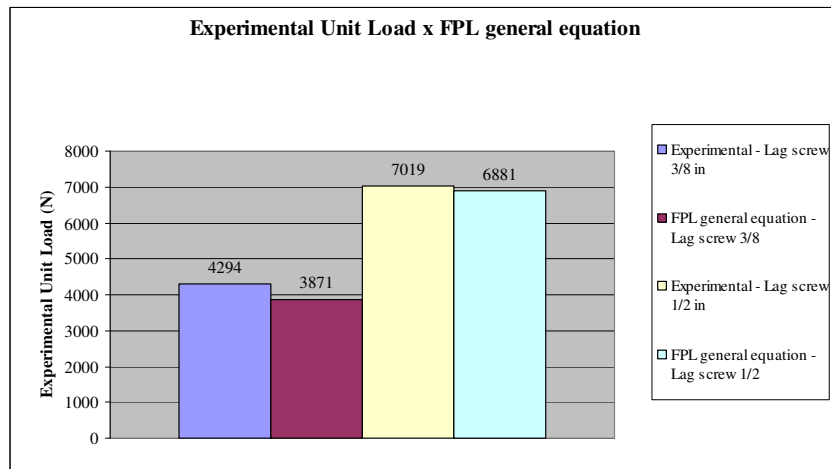


Figure 8 – Comparison between experimental unit load result with theoretical FPL general equation result of 3/8” and 1/2” lag screw diameters.

Figure 8 - compares the values of experimental unit loads with theoretical loads. The theoretical loads were obtained using equation (1) suggested by FPL (Forest Products Laboratory). As Table 2 does not supply the value of K wood with specific weight of 0,83 g/cm<sup>3</sup> (*Dimizia excelsa* Ducke), it opted on using a K=34,13 coefficient for specific hard wood with weight 0,57 and 0,74 g/cm<sup>3</sup>, as follows below:

$$P = KD^2 = 34,13.D^2$$

Where: D – shank diameter (mm) and P – is proportional limit lateral load (N).

When lag screws are used with metal plates, the lateral loads parallel to the grain may be increased 25%.

The values of ultimate load were obtained in laboratory, and the allowed load was obtained applying safety coefficient for a factor 5 as established for NBR 7190/82; remembering that the samples were made in saturated condition, waiting a value load of experimental rupture it is bigger will have become in dry condition (12%).

Much similarity of the load obtained experimentally with saturated wood with theoretical FPL general equation load is verified in Figure 8 for dry wood, as much the lag screws of 3/8” as 1/2”.

## 6. CONCLUSIONS

For lag screw connections using *Dinizia excelsa Ducke* it can be concluded:

1 - For the test of Pearson it was verified that where the penetration as well as the amount of screws used in a linking of 2, 4 and 6 lag screws, had no influence on the maximum unit load.

2 - The equation established for FPL for dry wood can be applied on the wet *Dinizia excelsa Ducke*.

3 - The maximum lateral load of the *Dinizia excelsa Ducke* for the screw of 3/8 is approximately  $P=4200$  N, and for the screw of 1/2 count is  $P=7000$  N. Lag screws 1/2" showed maximum lateral load higher (about 63%) than lag screws 3/8" evidencing the influence of the diameter of the screw in the ultimate load.

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