Withdrawal resistance of the lag screws from Angelim vermelho (*Dinizia excelsa Ducke*)

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Abstract. *The objective of this study was to determine the withdrawal resistance of the lag screws from Angelim Vermelho (**Dinizia excelsa Ducke**). The influence of the the length of its threading part on the withdrawal resistance were investigated using commercial lag screws 3/8 inch. The analyses were performed on the universal testing machine (Pavtest) using lag screws from wet wood. The withdrawal resistance was directly proportional to the length of the threading part of the lag screws with 3/8"diameter. The maximum withdrawal load from side grain of the Dinizia excelsa Ducke for the screw of 3/8" is approximately P= 23500 N (2350 Kgf) for wet condition (saturated)*

Keywords*: fastenings, withdrawal resistance; lag screws;* ***Dinizia excelsa Ducke***

1. INTRODUCTION

The wood is a material of construction used for the man since prehistoric times. Until century XIX, the most important workmanships of engineering were constructed with rock or wood, agreeing themselves frequently the two materials.

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

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

Amongst these the screw fastenings has been detached for its easiness of assembly and dismount. The Brazilian designers have had restrictions in the use lag screws in their projects. The Brazilian norm ABNT 7190/97 does not supply necessary information to design the lag screws in joints wooden. Therefore the same norm is emissive in the design in lag screws lickings wooden. Already American norm NDS (National Design Specification) specifics the design of lag screws, therefore until for wood of specific gravity of up to 0,74. The Brazilian wood, many Amazon wood, present superior specific gravity 0,74 g/cm^3.

This work has as objective of this study was to determine the withdrawal resistance of the lag screws from Angelim Vermelho (***Dinizia excelsa Ducke***) and the influence of the length of its threading part on the withdrawal resistance using commercial lag screws 3/8.

2. BIBLIOGRAPHICAL REVISION

The mechanics property of the wood varies due the factors such as: density, wet and dry conditions, time of duration of the load and the shipment description, inclination of grain, cracks, etc. Panshin and DE Zeeuw (1980), said the specific gravity can determined the mechanical properties of the wood. When the wood has higher density it expects 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 the text of humidity of the wood depends on the relative humidity and temperature of the environment where the wood if finds displayed. In Brazil the humidity of annual average balance is around 12%.

2.1. Structural project

The design and detailing of structural project, the knowledge of the structural analysis and stress of the materials, beyond rules and recommendations established for specific norms, should used. Many countries have used in their project of structures criteria based on the Method of the allowable stress design. Some countries had later passed to adopt criteria based on the Method of the Load and Resistance Factor Design. The England has been used the British standard 5268 ´Structural use of Timber" divide two parts such "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 it substitutes NBR 7190/82.

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

2.1.1. Method allowable stress design

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

The method allowable stress design in Brazil was established the old norm NBR 7190/82. This method, among others limitations, have used of 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 Brazilian old 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 must take care of below to the lesser value of the 03 (three) options, described bellow. These options guarantee that the wood will not go to rupture by 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 then 1,5 mm.

2.1.2. Limit states design

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

2.2. Connection of Structural Member

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

In accordance with Forest Products Laboratory (1999), the strength, the stability and the conditions of use of a structure depend mainly on the fastenings that keep its together members. Each connector requires specific analysis in function of the properties of stresses 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 used wooden. It can be detached: screws, nails, connectors, glue, printed plate, and others. The connectors wooden can be made with wood or wood with another material. (Mackerle, 2005).

The fastenings, normally, is designed with axial and parallel of the grain. Wooden joint can induce a multiaxial state of stresses, and 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 have chosen the wood bolted fastening because it is easy to assembly and dismounted.

According Calil (2003), the fastenings transmit the forces of a member for another through 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 and can cause shear load in the bolt.

The NBR 7190/97 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.

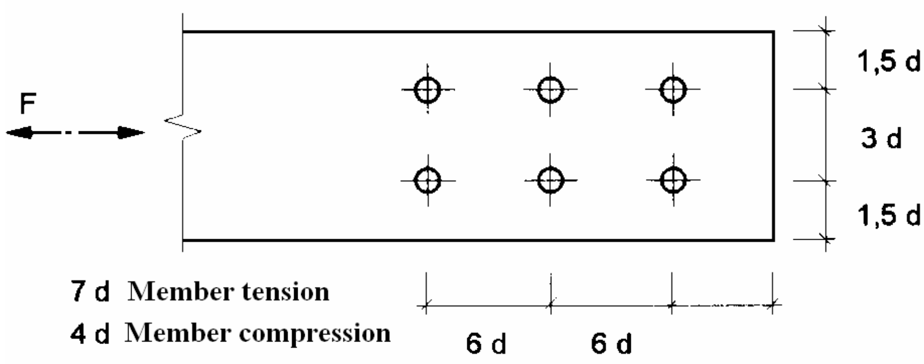

Figure 1 – Minimum placement of bolts in joint. (NBR 7190/97), with d is diameter of bolt.

2.2.1. Bolted joints - fastenings

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

When a structural 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: so that a connection is considers rigid if the bored bolt holes does not have to be bigger of what diameter more 0,5 mm and must use at least 4 bolts. In case that they are used bored bolt holes diameter biggest this dimension, the wood joint must be considered deformable.

The ASTM 1761 D, 1981 specifies that 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 o assure good bearing of the bolt. The tests shall be made on three-members joints (double cut) as shown in fig. 5, when the side members are made wood, these members are 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.

In Brazil, the use of screws in joint wooden is normally not designed, its use is the criterion of the carpenter in the assembly of the structures, such used screws in joint wooden are classified in two main types the small diameters wood screws figure 2, have used as being general purpose and slag screws, figure 3 diameters of 3/8 and ½ inches, have been used as wood structural fastenings, but without support of Brazilian norm. The first ones very are used in joinery, also called screws wooden, or to arrest metallic accessories in poles and joinery applications, they are not used in general as wood fastenings of structural parts wooden, they are used in workmanships would second or provisory structures as civil shoring.

Already the leg screw can structurally be used, as American NDS and Eurocode norms. The lag screws will be responsible in transferring the load of a 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 joint wooden. Falk (1993) recommends that the lag screw must penetrate at least the half of the threading part in the wood thickest, and must make a hole in function of the wooden type.

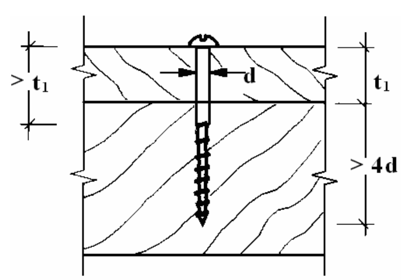

Figure 2 – Wood screw are used in joinery, d – shank diameter bolt, t_1 – lesser thickness (Pfeil and Pfeil, 2003), with penetration ≥ 4d.

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

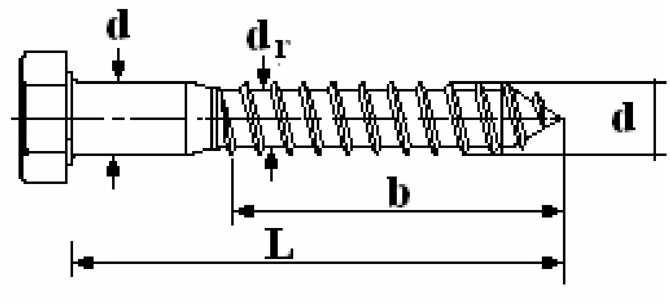

Figure 3 – Leg screw, d - shank diameter (major diameter), d_r = minor diameter (roots diameter), b = length of cut thread and L = length of lag screw.

The lag screw with magnificent thread is used mainly, where the dimensions of the transversal section of the wooden part are great or where the presence of the nut in the surface of the wood is undesirable. Such lag screws are found with diameters that vary of 5.1 mm 25,4 mm and with the 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 tension of yield of 310 MPa and an ultimate strength of 530 MPa, with well bigger properties of resistance of what of the wood. To determine the load capacity of the leg screw in joint wooden, the assays must be made in the withdrawal and lateral resistance. Table 1 relates the commercial dimensions of the lag screw available in the Brazilian market. In accordance with Forest Products Laboratory (1999), the lag screw needs that if it makes a bolt-hole diameter in compliance with the diameter of the screw. The diameter of the puncture in contact with screw shank part of the screw must the same be that the major diameter, the diameter of the puncture that will go to be in contact with the threading part of the screw varies with the density of the wood. For soft wood as pinus, the puncture in contact with threading part must be of 40 up to 70% of the nominal diameter of the screw. The Douglas fir wood and southern pine must be of 60 up to 70% and for the wood hard of 65 up to 85%. For lesser screws with diameter lesser percentages are applied and for screws with bigger diameters, bigger percentages are also applied. Lubricant the soap base or similar can be applied to facilitate its rank.

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

d - (in)		3/16	1/4	5/16	3/8	1/2
d_r - (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)

Norm NDS foresees some restrictions in the determination of the withdrawal resistance, such as the resistance of washers of the root of the screw and the penetration of the threading part that must be 7 times the nominal diameter of the screw for hard wood and the 10 until 12 times for soft wood. The top withdrawal arrives 75% of the resistance in the tangential or radial face of the wood.

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 the two. Both withdrawal loads resistance 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.

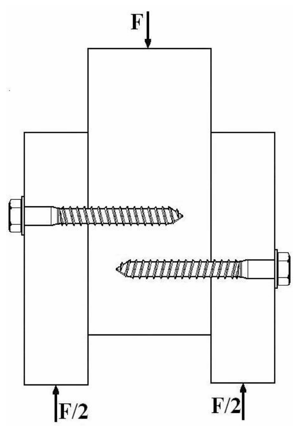

Figure 4 – Lateral resistance test - joint with lag screw connector, double cut, showing lag screw, two lateral members and main member.

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

The 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)

$$P = KD^2 \quad (1)$$

where **P** is lateral load, *D* diameter of the screw shank, and *K* a coefficient depending on the inherent characteristics of the wood species for various specifique gravity gauges. K coefficients are based on average results for several ranges of specific gravity for hardwoods and softwoods.

The available values of K for hard wood vary of 0.33 the 0.74 specific gravity. Many wood found in the Brazilian territory these specific gravity are superior the 0.74, therefore for wood with specific gravity above of this value it does not contemplate.

2.2.3 – Withdrawal Resistance (Forest Products Laboratory, 1999)

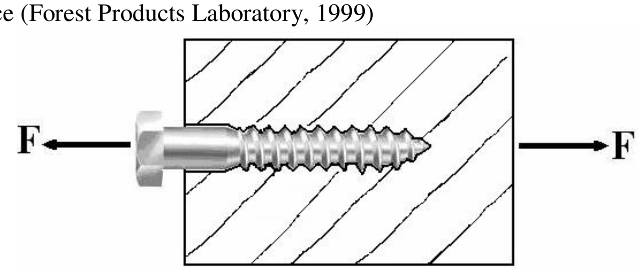

Figure 5 – Withdrawal resistance test

The results of withdrawal tests (figure 5) have shown that the maximum direct withdrawal load of lag screws from the side grain of seasoned wood may be computed as

$$p = 125.4G^{3/2}.D^{3/4}.L \quad (2)$$

where *p* is maximum withdrawal load (N), *D* shank diameter (mm), *G* specific gravity of the wood based on ovendry weight and volume at 12% moisture content, and *L* length (mm) of penetration of the threaded part.

Lag screws require prebored holes of the proper size. The lead hole for the shank should be the same diameter as the shank. The diameter of the lead hole for the threaded part varies with the density of the wood: For low-density softwoods, such as the white pines, 40% to 70% of the shank diameter and for dense hardwoods 65% to 85%. Soap or similar lubricants should be used on the screw to facilitate turning, and lead holes slightly larger than those recommended for maximum efficiency should be used with long screws.

In determining the withdrawal resistance, the allowable tensile strength of the lag screw at the net (root) section should not be exceeded. Penetration of the threaded part to a distance about seven times the shank diameter in the denser species (specific gravity greater than 0.61) and 10 to 12 times the shank diameter in the less dense species (specific gravity less than 0.42) will develop approximately the ultimate tensile strength of the lag screw.

The resistance to withdrawal of a lag screw from the end-grain surface of a piece of wood is about three-fourths as great as its resistance to withdrawal from the side-grain surface of the same piece. (NDS, 1977)

3. METHODS

Specimen

The main members were cut from Amazon wood, Angelim vermelho (*Dinizia excelsa* Ducke), all wood members were wet condition (saturated of water). The specimens were confectioned 25 cm height and transversal sections of 11cm x 15 cm. Were tested 16 specimen in total. Table 3 supplies some mechanical and physical properties of the wood of the Angelim Vermelho, characterized for the Laboratory of Forest Products, IBMA, Brazil.

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

Properties	Condition	Kgf/cm^2 (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 strenght	Dry	180 (18)
	Green	134 (13.4)
Dry density = 0.97 g/cm^3		
Green density = 1.26 g/cm^3		
Basic density = 0.83 g/cm^3		

Four replications were created for each combination of variables. Table 4 supplies the length, size of the threading part and the number of the 3/8” lag screws used in the experiments.

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

Table 4 - 3/8” Lag screws were in the experiments.

length of lag screw (mm)	length of cut thread (mm)	Amount of screws
60	40	4
70	50	4
90	55	4
110	60	4

The lead hole for the shank has the same diameter as the shank lag screws, and the same depth as the length of unthreaded shank. The lead hole for the threaded portion have a diameter equal 75% of the shank of lag screws (Table 5)

Table 5 – Lead for the shank and threaded part for 3/8" and ½" 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

The threaded portion of the screw was inserted in its lead hole by turning with a wrench, was used soap on the screws and in the lead hole, to facilitate insertion and prevent damage to the screw.

The lag screws of material conforming to ASTM Standard A 307, Low-carbon Steel and Internally Threaded Standard Fasteners. (made by CISER).

Experimental Procedure

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

The test procedures for perpendicular-to-grain loading (fig. 6) generally followed those give in ASTM D1761-88. Tension loading was used. The tests were terminated at member failure.

Specific gravity and moisture content were determined for each specimen.

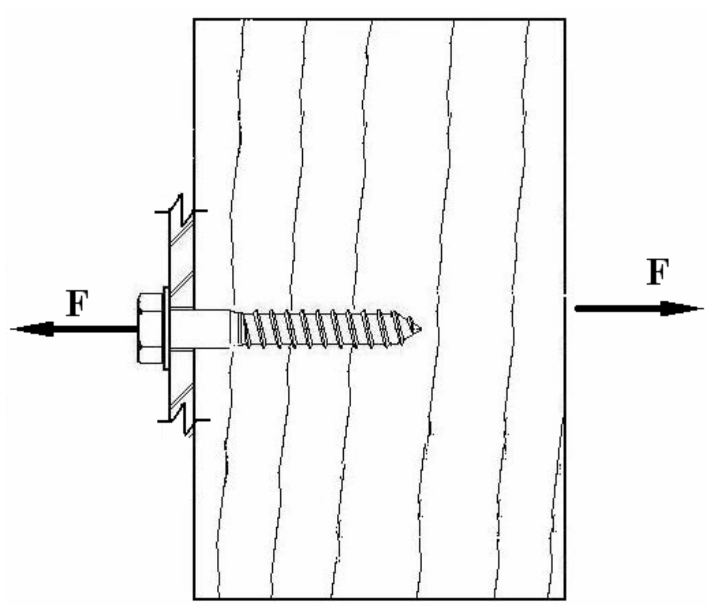

Figure 6 – Withdrawal resistance test of the lag screws from the side grain of member wood. Edge margin and end margin as specified by NBR-7190/97.

4. RESULTS

Table 6 details the samples of the tested 3/8" lag screws, where it defines the lengths total, so great of thread and the average and standard deviation of ultimate withdrawal load of screws. It was gotten the average and standard deviation of these 4 repetitions (columns 4ª and 5ª).

Table 6 - It represents ultimate withdrawal load of the 16 tested lag screws. Were lag screws of 3/8".

Specimen	length of lag screw mm	length of cut thread (mm)	Average Ultimate load N	standard deviation N
1, 2, 3, 4	60	40	15000	6.808

5, 6, 7, 8	70	50	20500	4.025
9, 10, 11, 12	90	55	24756	4.619
13, 14, 15, 16	110	60	24200	1.007
Average			21114	

5. DISCUSSION

Figure 7 shows when it increases the penetration of 3/8" lag screw threading part can be verified an increase in the pulling up ultimate withdrawal load until 5.8d of penetration. It had certain stability in the pulling up load when the penetration goes 5.8d until 6.3d. In this in case that, an increase of the penetration is associated the increase, also, of the ultimate withdrawal load.

Statistics analysis was made to verify if the influence of the penetration, 4.2 d, 5.3d and 5.8d (Fig. 7) of the screw in the sample with the threading load exists. It used the test of correlation of Pearson with program SPSS/PC 12 and verified that it had influence of these penetrations, in the ultimate withdrawal load, for the 3/8" lag screws diameters.

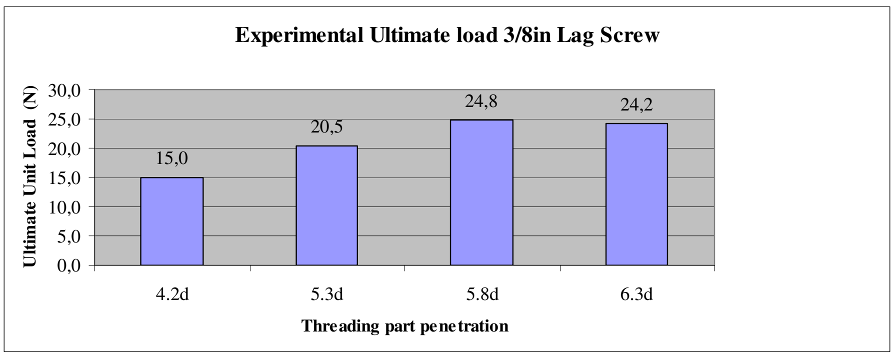

Figure 7 – Influence of the threading part penetration x ultimate withdrawal load for 3/8 in diameter of lag screws. Penetrations 4.2 d, 5.3d, 5.8d and 6.3d had been studied. Being d the diameter of the shank lag screw.

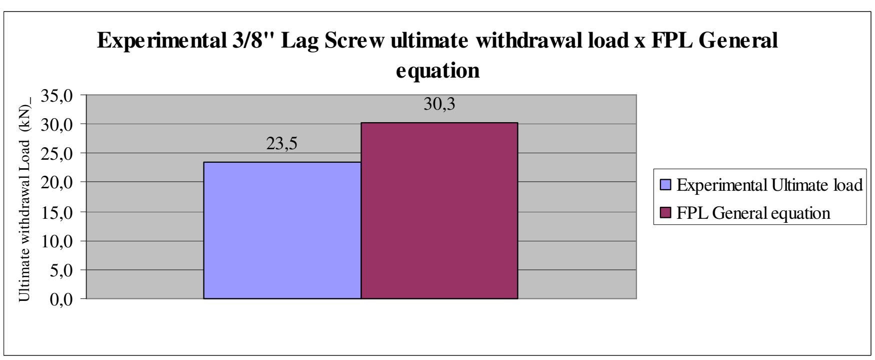

Figure 8 – Comparison between experimental ultimate withdrawal load result with theoretical FPL general equation result of 3/8" lag screw diameters.

Figure 8 compares the values of experimental ultimate withdrawal loads with theoretical FPL general equation result of 3/8" lag screw diameters. The theoretical loads were gotten using the equation (1) suggested for the FPL (Forest Products Laboratory). The wood found in the North American territory presents specific gravity maximum of 0,74, therefore equation 1 does not give to support for upper densities the 0,74 as Amazonian wood, *Dinizia excelsa* Ducke, with specific weight of 0,83 g/cm^3. The experimental ultimate withdrawal load result with theoretical FPL general equation result of 3/8" lag screw diameters.

Remembering that the samples had been made in saturated condition, waiting a value load of experimental rupture it is bigger will have become in dry condition (12%), therefore, it hope similarity of the load gotten experimentally with wood with theoretical FPL general equation load is verified in the figure 8 for dry wood, as much the lag screws of 3/8".

6. CONCLUSIONS

For 3/8" lag screw connections using *Dinizia excelsa Ducke* it can be concluded:

1 – It verified that it had influence of part threading (penetration) in the rupture load for penetration 4.2 d, 5.3d and 5.8d of the screw.

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

3 - The maximum withdraw load from side grain of the *Dinizia excelsa Ducke* for the screw of 3/8 is approximately P= 23500 N (2350 Kgf) for wet condition (saturated)

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