

DETERMINATION OF THE STRENGTH PERFORMANCE OF TABLE FRAMES

Igor Džinčić^{1,}*

Tanja Palija¹

Dragan Živanić²

Vojislav Dacić³

ABSTRACT

The objective of this study was to investigate the relation of diameter of pilot hole and screw, and machining accuracy on withdrawal strengths of the screws and durability of the dining tables. For this purpose, fasteners and material types on the failure loads of dining table corner joints have been analyzed experimentally and statistically. Double ended thread bolts with different drilling regimes have been used as fastener types. A parallel investigation of rigidity and durability of tables, and withdrawal capacities in accordance with the according to current norms, was performed. According to the results, it is concluded that the diameter of the drilled hole significantly influences the value of the withdrawal strengths of the screws. By analyzing the effect of drilling diameter on the rigidity of tables, a statistically significant difference was determined. As the drilling diameter increases, the rigidity of the examined dining tables decreases.

Keywords: Durability, joints, screws, tables, withdrawal strengths.

INTRODUCTION

Determining the quality of dining tables according to the EN norms, shows that horizontal fatigue is one of the most important factors of durability. Based on the insight into testing results of the Institute for Control of Furniture Quality of the Faculty of Forestry–University of Belgrade, Serbia, (over 1000 samples), it can be said that the strength and durability are in the function of the quality of the dining tables. When we are analyzing the quality of the dining tables, we have to make a difference between tables with no extension (hereinafter referred as fix tables) and tables with the possibility of extension (hereinafter referred as XL tables). The strength and durability of fixed tables are influenced by the following factors: table size, connecting solution between rails and table top, and the way of connecting legs to the underconstruction. The strength and durability of the XL tables will depend on the type of slider, the way how it is attached to the underconstruction, the length of the draw, the size of the overlap over the slider, and the number of metal ball-retainers in the slider. According to the testing results of the Institute for Control of Furniture Quality, XL tables have two critical points in the construction which could be the cause for the potential appearance of consumer complaints: the rigidity of the system and the deflection of the table top when the table is open. On the other hand, fixed tables has no problem with table top deflection. If the main board is connected to the understructure in the proper way, the source of the problem can only be a connection of the leg and rails. In this case, the strength and durability of the table will be influenced by the choice of corner brackets, as well as factors that affect the withdrawal strengths of the screws (type of wood, wood moisture, the anatomical direction in which the screw is placed, the type and

¹Belgrade University, Faculty of Forestry, Belgrade, Republic of Serbia.

²University of Novi Sad, Faculty of Technical Sciences, Novi Sad, Republic of Serbia.

³Company Union Drvo, Belgrade, Republic of Serbia.

*Corresponding author: Igor.dzincic@sfb.bg.ac.rs

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dimensions of the hole (diameter, length) in which the screw is placed, as well as the depth of hole at which the screw is placed.

Since fixed tables are mostly located in the lowest price classes (ex-work price; source: table manufacturers that are export-oriented), and can not stand a high percentage of consumer complaints, putting under the control factors which effects its quality is crucial. The aim of the paper is to examine the impact of withdrawal strengths of the screws on the strength and durability of fixed dining tables.

As stated numerous times before, the strength of the wooden furniture manly depends on the strength of the joints and they represent critical points in the construction Skakić and Janićijević (2000), Smardzewski and Papuga (2004), Gavronski (2006), Atar and Ayhan (2008), Abdulkadir *et al.* (2014), Yuksel *et al.* (2014), Yuksel *et al.* (2015), Chen and Lyu (2018). Most of the researchers analyzed certain factors that affects the withdrawal strengths of the screws, since the connection with the screw is widely applied in furniture production: Eckelman (1975), Taj *et al.* (2009), Akyildiz and Malkoçoglu (2001), Gašparik *et al.* (2015), Tankut (2011), Dacić *et al.* (2017a). Broker and Krause (1991) investigated both static and dynamic screw withdrawal strengths on three different types of materials (particleboard, European Spruce and Birch) wood with 9 types of screws. They concluded that the screw withdrawal resistance value is linearly proportional with screw length and screw diameter. Kjucukov and Enceev (1977a) investigated screw withdrawal strengths from *Abies alba* wood in three directions varying screws lengths (13 mm ÷ 60 mm) and diameters (1,5 mm ÷ 8 mm). After extensive examination they concluded that there is a linear relationship between screw withdrawal resistance and screw diameter. In their fallowing paper Kjucukov and Enceev (1977b) repeated tests with screw variation from 1,5 mm to 6,0 mm on *Fagus orientalis* and determined that there is a linear relationship between screw withdrawal resistance and screw diameter. Akyildiz and Malkocoglu (2001), conduct their experiment on five diferent wood species at two moisture contents (12 % and 30 %). Screws used for withdrawal capacities tests were 4,5 mm x 40 mm with a lead holes of 26 mm. According to obtained results, they concluded that beech wood had highest values of screw withdrawal resistance among five tree species, and that mositure content effects withdrawal resistance.

Yorur *et al.* (2020) analyse direct screw withdrawal force from various types od wood based panels. Among other things, they concluded that existance of pilot hole has significant influence on withdrawal strength. Screws with predrilled holes was combined with two types of adhesives.

On the basis of above mentioned results new experiment was set pointing in two directions: testing withdrawal strengths of the screws varying relation of diameter of pilot hole and screw, and machining accuracu, and testing durability and rigidity of dining tables constructed with different drilling regimes. Results obtaind upon conducted experiment should give answer the following question: Is it possible to predict strength and durability of the dining tables on the basis of the value of the withdrawal strengths of the screws?

MATERIAL AND METHODS

Considering that the influence of wood species, moisture of wood and anatomical direction on the withdrawal strengths of the screws, was the subject of an analysis by other authors, in this paper two other analyzes will be performed: Examination of the impact of the diameter of hole and machining accuracy of drilling on the strength of the joint with the screw, and Testing the strength and durability of dining tables.

Withdrawal capacities of the screws

Analyzing the EU market in the last five years, it can be concluded that the dining tables are mostly made of solid wood of beech and oak, while the joints of the legs with the rails are made with metal or wooden corner brackets, using double ended thread bolt (Figure 1). Since beech is the most important industrial species in the south-eastern part of Europe, the samples will be made of this type of wood. The double ended thread bolts allows knock-down construction (flat pack), and give the appropriate strength and rigidity of the construction. Based on the review of the technical documentation of the Institute for Control of Furniture Quality of the Faculty of Forestry in the last five years, it can be concluded that there is no definition among furniture manufacturer according to a certain type of those screws. Choice is most often driven by the movement of prices on the market.



Figure 1: Double ended thread bolt.

Manufacturers usually use screw of dimensions $M8 \times 80$ mm or $M8 \times 90$ mm. For research in this paper, a screw of dimensions $M8 \times 90$ mm was used. To fix the screw in the wooden leg, it is necessary to drill the hole of the corresponding diameter. For dining room manufacturers, it is very important to have information about the diameter of the holes on the table legs, which in combination with the selected screw, will give the optimum strength of the joint.

To test the impact of the diameter and accuracy of the drilling on the withdrawal strengths of the screws, beech planks from tangential cut with a thickness of 38 mm were selected. Four groups of samples (dimension $d \times b \times l = 33 \text{ mm} \times 50 \text{ mm} \times 95 \text{ mm}$) were obtained with 20 samples within every group. The influence of the diameter of the drilling was examined on the samples of the first three groups by varying the diameter of the drilling. The influence of the drilling accuracy on the strength of the joint was examined on the samples of the third and fourth groups by varying the drilling accuracy class. Conditioning of samples was carried out at a temperature of $22 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$ and relative air humidity $40 \% \pm 3 \%$, for a period of 30 days. To test the influence of drill diameter, three groups of samples were formed, with a diameter of drilling holes of 5,0 mm; 5,55 mm and 6,0 mm respectively. Two groups of samples were formed to study the impact of the drilling accuracy on the strength of the joint with the screw. Drills used for drilling within both groups had a diameter of 6,0 mm. The diameter of 6,0 mm was used based on the production experience in the production where tables Before installing the screws, the diameter of the drilled holes was measured on all samples. Based on the measured hole diameter, the machining accuracy for both drills have been determined.

For testing the strength and durability, dining table with dimensions height x width x length= 77 cm \times 80 cm \times 120 cm was selected. The table top is made of veneered MDF. All other part (rails and legs) of the table are made of solid wood beech. Connection between legs and rails was done by metal corner brackets using double ended thread bolt. In the first group, table legs were drilled with a drill diameter of $D_B = 5,0$ mm, on the second with $D_B = 5,55$ mm, and on the third with $D_B = 6,0$ mm. Two types of drill machines were used with different machining accuracy: Drill 1 with the machining accuracy class TD6 (according to DIN 68101 (2012-02)), and Drill 2. On the fourth group, legs are drilled with a drill diameter of $D_B = 6,0$ mm, inwith the class of machining accuracy TD15. Samples were conditioned in at temperature $24 \text{ }^\circ\text{C} \pm 2 \text{ }^\circ\text{C}$ and relative air humidity $54 \% \pm 3 \%$, for a period of 30 days.

Withdrawal strengths of the screws, was carried out according to the international standard ISO 9087 (1998) using a universal tearing machine of Amsler, a capacity of 40000 N. The machine is equipped with load-measuring instruments, and the test results are monitored on a computer. Before pulling out the screws, the machine was calibrated in Newtons. This value is subtracted from each gain of the maximum force required to pull the screws. The screws are pulled out 150 minutes after placing them in the samples. According to ISO 9087 (1998), pullout time was from 60 to 120 seconds, and the specific resistance of the wood to the drawing of the screws is calculated using the Equation 1:

$$\sigma_w = \frac{F_{max}}{l \left(\frac{N}{mm} \right)} \quad (1)$$

Where:

w- mark for moisture content at the moment of testing;

F_{max} -maximum load (N);

l-screw depth (mm).

The conical ending (the tip) of the screw has a length of 6 mm, and smaller diameter than the outer diameter of the screw. The tip serves for positioning or guiding the screw during its installation in a previously drilled hole. The drilled hole has a cylindrical shape, so that the conical ending does not participate in holding the

screws. Therefore, the length of the tip is taken from the length of the screw on which the threads are stretched, so that the effective depth on which the screw is placed is obtained through the Equation 2:

$$l = L_1 - L_k \text{ (mm)} \quad (2)$$

Where:

L_1 - length of the screw with the threads (mm);

L_k - length of the conical ending (mm).

Accordingly to it $L_1 - L_k = 40 \text{ mm} - 6 \text{ mm} = 34 \text{ mm}$, so the pattern for calculating the resistance of the wood to the drawing of the screws, according to Equation 1, takes the following form Equation 3:

$$\sigma_w = \frac{F_{max}}{34 \left(\frac{N}{mm} \right)} \quad (3)$$

Durability of dining tables

During the testing of the strength and durability of dining tables, previously tested factors such as drilling diameter and drilling accuracy were varied on the legs of the table. Since the samples are taken from the regular production, the position of the annual rings on the cross-section of the leg of the table is not controlled, so the impact of the anatomical direction on durability and stiffness was not examined.

Durability of tables, was tested according to the standards EN 12521 (2015) and EN 1730 (2012), due to the effect of horizontal forces on the board table in the transverse and longitudinal direction, and is expressed by the number cycles in the mentioned directions. The attack force line is 50 mm from the edge of the table, viewed in both directions (Figure 2). The testing of durability and rigidity was carried out on the testing device (producer "Hagewald & Peschke").

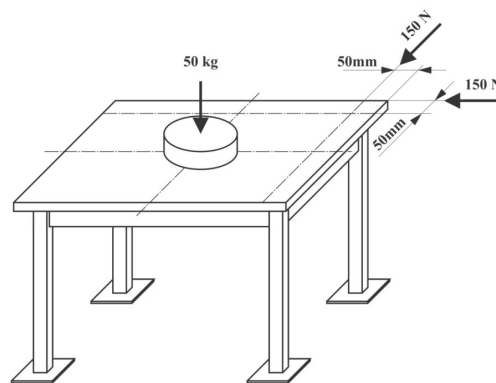


Figure 2: Setup for testing.

The testing of durability and rigidity was divided in two phases. In the first phase testing was conducted until table reaches maximum of 10000 cycles. In the second phase, which followed up right after first phase, testing is continued until table loose its rigidity, or in the case that some damages occurs.

RESULTS AND DISCUSSION

Processing statistical data obtained by research implied the application of descriptive statistics, parametric and non-parametric statistical methods, correlation and regression analysis. Parametric methods involved testing the significance of the difference, using Student's T-test for independent and dependent samples, a

single-factor analysis of the variance of repeated measurements. The basic requirement for the implementation of Student's T-test is that the samples have a normal distribution. Statistically, according to the "Central Boundary Theorem", it is assumed that in large sets (30 samples and more), the samples have a normal distribution. As there were 30 samples of samples in the examined sample assemblies, and more, the normal distribution was not statistically investigated. Non-parametric methods included testing the significance of the difference between the examined sizes, using the Kruskal-Wallis and Mann-Whitney test.

Withdrawal capacities of the screws

Influence of diameter of drilled hole

Based on the results of the statistical analysis (Table 1), the highest average value of the withdrawal capacities of the screws showed samples with drilled holes of diameter $D_B = 5,0$ mm. This is expected result, because this group of samples had largest contact surface between the screw and the wood. Another study showed similar results. Li *et al.* (2011) studied the effects of the screw number and contact area. Among other things they concluded that withdrawal resistance will increase with increase of contact surface. If we analyze the shape of the hole (between the hole and the root of the screw), the first group of samples has overlap. Therefore, when the screw were pulled out, these overlap formed friction between the surface of the root of the screw and the wood core, which additionally had a positive effect on the withdrawal capacities. On the other hand, for samples with a diameter of a drilled hole of 5,55 mm and 6,0 mm a gap appeared between the hole and the root of the screw (Figure 3). Similar conclusion was brought out by Broker and Krause (1991). They concluded that the screw withdrawal resistance value is linearly proportional with screw diameter. Similar conclusions was obtained by Yorur *et al.* (2020). Regarding to type of material they have used (MDF and particle boards) they showed that ratio between root of screws and predilled hole has significant influence on screw withdrawal strength. They also concluded that friction coefficient has major impact on holding strength. They didn't propose ratio between predilled hole and screw root, but from obtained results it can be concluded that similar relation which is used in this analysis ($D_B = 0,9 \cdot d_1$ (mm), where "d1" is the diameter of the root of the screw), is most effective.

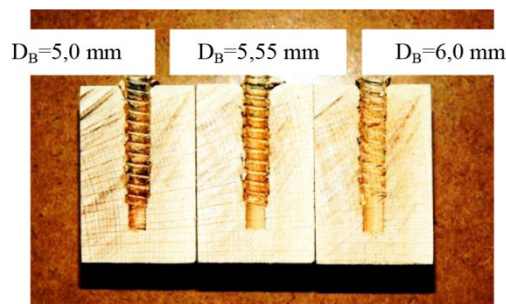


Figure 3: Crosssections of samples.

Samples where drilled holes was 5,55 mm showed a lower average value of the withdrawal capacities (from 306,02 N/mm), while the lowest average value of 300,62 N/mm was provided by samples with diameter of drilled holes of $D_B = 6,0$ mm. Comparing the coefficients of variation as a measure of variability in Table 1, it can be noticed that increase in the diameter of the drilled hole, increase is the dissipation of the values within the sample groups.

Table 1: Value of the withdrawal capacities of the screws depending on diameter of hole.

Drill diameter (mm)	N° samples	Min. (N/mm)	Maks. (N/mm)	\bar{x} (N/mm)	$\sigma_{\bar{x}}$ (N/mm)	σ (N/mm)	v (%)
5,0	76	251,50	418,68	313,79	3,81	33,21	10,58
5,55	76	249,32	389,94	306,02	3,79	33,03	10,79
6,0	76	239,74	417,50	300,62	3,92	34,14	11,36

By single-factor analysis of variance of repeated measurements, the values of withdrawal capacities were compared when drilled hole was 5,0 mm, 5,55 mm and 6,0 mm. Table 2 shows the results of statistical analysis. A significant influence of the diameter of the drilling was determined (Wilks lambda = 0,682; $F(2, 74) = 17,283$; $p < 0,0005$), with the effect size $\varepsilon^2 = 0,318$, on the basis of which it can be concluded that approximately 32 % of withdrawal capacities is influenced by the diameter of the drill hole. Based on the results of the post-hoc test, the least significant difference shown in Table 2 found that there was a statistically significant difference in withdrawal capacities for all three examined groups of samples.

Table 2: The results of post-hoc test.

(I) Hole diameter (mm)	(J) Drill diameter (mm)	Difference between standard deviations (I-J) (N/mm)	Standard deviation (N/mm)	p-value
5,0	5,55	7,766*	1,709	0,000
	6,0	13,171*	2,327	0,000
5,55	5,0	-7,766*	1,709	0,000
	6,0	5,405*	1,998	0,008
6,0	5,0	-13,171*	2,327	0,000
	5,55	-5,405*	1,998	0,008

* - significant difference

Comparing values between groups of samples, based on a difference of 7,766 N/mm, it can be concluded that samples with a diameter of drilling a hole of 5,0 mm gave a higher resistance value on average by 2,5 % compared to the samples with diameter of the drill hole of 5,55 mm. Based on the difference of 13,171 N/mm, it can be concluded that the samples with a diameter of 5,0 mm drilling gave a higher resistance by an average of 4,4 % compared to samples with a drilling diameter of the hole of 6,0 mm. Also, based on the difference of 5,405 N/mm, it can be concluded that the samples with a diameter of 5,55 mm drilling diameter gave a higher resistance by an average of 1,8 % compared to samples with a drilling diameter of 6,0 mm. Based on the obtained results and their statistical analysis, it can be concluded that as the diameter of the drilled hole increases, withdrawal capacities of the screws decreases, Figure 4. This conclusion corresponds with results presented by Li *et al.* (2011), but it is not in correlation with the literatures (Eckelman 1988, Haftkhani *et al.* 2011). They indicated that withdrawal strength increases gradually as pilot hole increases until the pilot hole nears the root diameter of the screw.

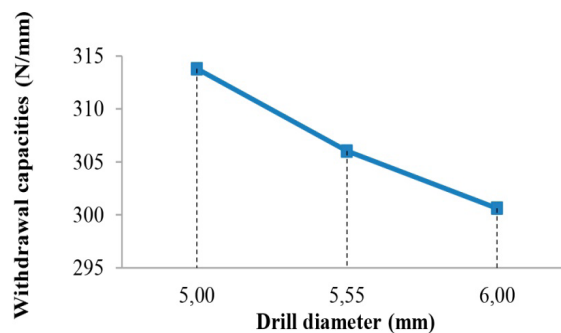


Figure 4: Influence of the diameter of the drilled hole on withdrawal capacities of the screws.

In his research Aytekin (2008) investigated withdrawal capacities of the screws from four different wood species. In experiment he was using three different types of screws: smart, serrated and conventional. Average values for oak from tangential cut was between 368 N/mm and 445 N/mm, while for fir was in a range from 200 N/mm to 266 N/mm. Among other things he concluded, that the difference between different types of screws are not notable. There is no information about relationship between hole and the screw. If we compare

obtained results with presented ones, we can see that there are some differences which can be explained by different wood species and different screw diameter.

In his study Dacić *et al.* (2017b) revealed that the withdrawal strength would be slow down while the pilot hole diameter increased. In addition, when the pilot hole diameter further increased, the withdrawal strength would be sharply reduced. With the pilot hole diameter increased from 2 mm to 3,5 mm, withdrawal resistance changed for about 25 %. This result attributed to the decrease of screw shearing.

Influence of machining accuracy on withdrawal capacities of the screws

The higher average values of the withdrawal capacities of the screws (300,07 N/mm) showed the samples drilled at machine 1 (Table 3). The variability expressed through the coefficient of variation was uniform for both groups of samples.

Table 3: Influence of machining accuracy on value of the withdrawal capacities of the screws.

Withdrawal capacities of the screws							
machine	N° samples	Min. (N/mm)	Maks. (N/mm)	\bar{x} (N/mm)	$\sigma_{\bar{x}}$ (N/mm)	σ (N/mm)	v (%)
1 (TD6)	75	239,74	417,50	300,07	3,93	34,03	11,34
2 (TD15)	75	201,03	349,65	257,48	3,52	30,50	11,85

The significance of the difference between the average values of the withdrawal capacities obtained in the two drills mentioned above was tested by the Student's T-test for the dependent samples, Figure 5. The results of the T-test have shown that there is a statistically significant difference between the samples drilled by Drill 1 and samples drilled by Drill 2, ($t = 14,918$; $df = 74$; $p < 0,0005$).

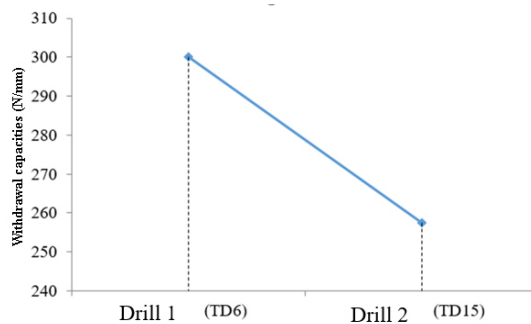


Figure 5: Average values of the withdrawal capacities.

The average value of the withdrawal capacities of the samples drilled at machine 1 is larger by an average of 16,54. Based on the above results, note that the accuracy of drilling significantly affects the withdrawal capacities. The lower accuracy of the drilling machine causes a higher diameter of the drilling, thereby reducing the contact surface between the threads of the screw and the wood. These results corresponds with results presented by other researchers working on different types of joints Prekrat and Smardzewski (2010), Rüdiger *et al.* (1995), Smardzewski and Papuga (2004). All of them concluded that machining accuracy has positive impact on joint strength. As in previous test explanation is very much the same. Lower level of machining accuracy will lead to a smaller contact surface between the screw and the wood indicating lower values of the withdrawal capacities.

Strength and durability of tables

All samples fulfilled demands according to durability test. This means that the diameter of the drilling and the accuracy of the drilling do not significantly affect the durability of the dining tables. In the statistical analysis of rigidity, the factor of the cycle number is ignored, since at all tables in both groups there are 10000 cycles. Sizes of deflection was recorded after 100, 500, 2500 and 10000 cycles, both in the transverse, and

in the longitudinal direction (Table 4).

Table 4: Durability results.

Durability (cycles)	direction (mm)						drill diameter (mm)	Machining accuracy
	I		II		III			
	transverse	longitudinal	transverse	longitudinal	transverse	longitudinal		
100	7	6	6	6	6	5	5,0	TD 6
500	7	6	6	5	6	5		
2500	7	6	6	5	6	5		
10000	7	6	6	5	6	5		
100	8	6	7	5	6	5	5,55	
500	7	5	7	5	6	5		
2500	7	5	7	5	6	5		
10000	7	5	7	5	6	5		
100	7	6	7	6	8	7	6,0	
500	7	6	8	7	7	6		
2500	7	6	7	6	7	6		
10000	7	6	7	6	7	6		
100	8	7	8	7	8	7	6,0	TD15
500	8	7	8	7	8	7		
2500	8	6	8	6	8	7		
10000	8	6	8	7	8	7		

The Mann–Whitney test showed that the size of the deflection between the groups of tables of different drilling accuracy classes (TD6 and TD15) differed considerably in the transverse ($z = -4,05$; $n = 12$; $p < 0,0005$) and the longitudinal direction ($z = -2,81$; $n = 12$; $p < 0,005$). Higher values of rigidity were given by a group of tables where the holes in the legs were drilled in the higher accuracy class TD6 in relation to the accuracy class TD15 in both directions.

The Kruskal Wallis test revealed a statistically significant difference in the transverse rigidity between three groups of tables with a different diameter of the hole drilling on the legs ($D_B = 5,0$ mm, $n = 12$; $D_B = 5,55$ mm, $n = 12$; $D_B = 6,0$ mm, $n = 12$), $\chi^2(2, n = 36) = 11,95$; $p < 0,05$. Also, the test revealed a statistically significant difference in the longitudinal stiffness between the three groups of tables with a different diameter of the hole drill hole, $\chi^2(2, n = 36) = 20,78$, $p < 0,05$.

The analyzed factors did not affect the durability of the tables, so the differences in the size of the defect as a factor of rigidity between groups of tables can be considered negligible. Therefore, the correlation between the withdrawal capacities and testing the stiffness and durability of the dining tables can not be predicted.

CONCLUSIONS

In this study, the effect of relation of diameter of pilot hole and screw, and machining accuracy on withdrawal strengths of the screws and durability of the dining tables were investigated. The performed investigations revealed following conclusions:

The diameter of the drilled hole significantly influences the value of the withdrawal strengths of the screws. With the increase in the diameter of the drilling, withdrawal strengths decrease;

On the basis of the obtained results, the formula for calculating the drilling diameter of the hole $D_B = 0,9 d_1$ (mm), where “ d_1 ” is the diameter of the root of the screw, can be taken as a recommendation;

By controlling the ratio of the diameter of the drilled hole and the diameter of the root of the screw, it can significantly affect the strength of the joint;

Drilling accuracy significantly influenced the value of wood resistance by pulling the screws. With a fall in the drilling accuracy class, the resistance of the wood to pulling the screws decreases;

Drilling holes with machines operating in a higher class of accuracy can significantly affect the wood resistance by pulling the screws;

By analyzing the effect of drilling diameter on rigidity of tables, a statistically significant difference was determined. As the drilling diameter increases, the rigidity of the examined dining tables decreases;

An analysis of the impact of drilling accuracy on table rigidity revealed a statistically significant difference. Drilling in a lower class of accuracy, the rigidity of the examined dining tables decreases.

Bearing in mind the results of the performed test and statistical calculations, the following conclusions were drawn. The analyzed factors did not affect the durability of the tables, so the differences in the size of the defect as stiffness measurements between groups of tables can be considered negligible. The correlation between the withdrawal strengths of the screws and testing the stiffness and durability of dining tables can not be predicted.

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