Static Front to Back Loading Capacity of Wood Chairs and Relationship between Chair Strength and Individual Joint Strength

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The relationship between the static front to back loading capacity of chairs and the moment capacities of the joints used in their side frames was investigated. The secondary purpose of the study was to determine the effect of tenon sizes on front to back loading capacity of chairs. The moment capacities of round edge mortise and tenon L-shaped and T-shaped joints constructed of Turkish beech (*Fagus orientalis* L.) with cross sections and tenon sizes identical to those used in the chairs were first determined. Tenons varied from 30, 40, and 50 mm in width and 30, 40, and 50 mm in length. Joints were assembled with 65% solid polyvinylacetate (PVAc) adhesives. Front to back loading tests were then performed on the chairs according to the method adopted by the American Library Association (ALA). The results indicated that front to back loading capacity increases as either tenon width or length increases. Highest joint moment capacities were obtained when L-shaped joints were constructed with 50 mm wide by 50 mm long tenons and T-shaped joints were constructed with 40 mm wide by 50 mm long tenons. Finally, the strength of chairs could be reasonably predicted from the strength of joints.

Keywords: Chair; Furniture joints; Mortise and tenon joints; Front to back loading; Bending moment capacity

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INTRODUCTION

The rational design of chairs to meet demanding service requirements dictates that the design of the joints and materials used in construction of the chairs can be determined as a function of the highest loads to be expected in service. With respect to joints, this procedure requires that the moment capacity of the joints in the chair faithfully reflect the moment capacity of the joints as determined by individual joint tests. Thus, the joints that are the most critical parts of the chair frame should have enough strength to resist the forces imposed on the chair in service.

Mortise and tenon joints are commonly used in the construction of chairs. Numerous studies have been carried out to relate the strength of these joints to their geometry and the adhesives used in their construction. Furniture constructed with a round mortise and a tenon joint is highly resistant to cyclic loading (Haviarova *et al*. 2001). Tankut and Tankut (2005) investigated the strength of a round tenon and a round mortise, a rectangular tenon and a rectangular mortise, and a rectangular tenon and a round mortise joints assembled under nominally the same conditions with different end configurations. The results of the study showed that joints with rectangular mortises and tenons are about 15% stronger than both round end tenons and rectangular end tenons fitted into round end mortise joints. The results also indicated that if tenon width or length is increased, the strength of the joint increases accordingly.

Erdil *et al*. (2005) developed a predictive expression for mortise and tenon joints that took into account wood species, adhesives, and joint geometry: specifically, tenon width, tenon shoulder width, and tenon length, as shown in Eq. 1,

$$M = a \times \left[0.25 \times W + 0.50 \times D\right] \times L^{0.8} \times S \tag{1}$$

where D refers to rail width, W refers to tenon width, L refers to tenon length, S refers to shear strength of wood (psi), and a refers to regression coefficient for glue. The value of a is equal to 1.00 for joints constructed with 65% PVA, 0.74 for phenol resorcinol, 0.79 for animal, and 0.83 for urea formaldehyde adhesive.

The effect of close-fitting shoulders on the bending moment capacity of round mortise and tenon joints was investigated by Eckelman *et al*. (2006). The results showed that close-fitting shoulders increase the strength of the joints. A useful equation was developed for estimating the contribution of shoulders to the bending moment capacity of round mortise and tenon joints, namely,

$$F_s = 0.934 \times \frac{2w}{D^{1.66}} \times F_{ns} \tag{2}$$

where F_s and F_{ns} refer to bending moment capacities of joints with and without shoulders, respectively (lb), w refers to the distance from the longitudinal axis of the tenon to the lower edge of the stretcher (in), and D refers to diameter of tenon (in).

The strengths of school chairs constructed with pinned but unglued round mortise and tenon joints were compared with the strength of chairs with glued but unpinned joints by Eckelman and Haviarova (2006). The results indicated that chairs constructed with round mortise and tenon joints with small cross pins provide nearly the same strength and durability as comparable chairs constructed with glued joints; therefore, cross-pinning is an alternative method of joint construction when adhesives are in short supply. The bending and fatigue strength of rectangular mortise and tenon joints constructed of oil palm (*Elaeis guineensis*) lumber have also been investigated and compared to joints constructed of other more traditionally used wood species (Ratnasingam *et al.* 2010). The bending strength of oil palm lumber joints had about half the strength of joints constructed with traditionally used wood species. In terms of fatigue strength, joints constructed of oil palm lumber showed comparable performance with joints constructed of traditionally used wood species. The results of the study also showed that the allowable design capacity of rectangular mortise and tenon joints could be set at 20% of the ultimate static bending strength.

Kuşkun (2013) researched the effect of tenon size on the strength of chair frame joints and the relationship between the joints and assembled chair frames. The static *versus* the cyclic load capacity of the chairs were also compared, showing that cyclic load capacity amounted to 56% of static load capacity. Based on this research, Kasal *et al.* (2015) and others developed a procedure for estimating frame structure strength from the individual joint tests.

Many of the chair frames manufactured by the Turkish Furniture Industry (particularly those produced by small manufacturers) are constructed with Turkish beech (*Fagus orientalis* L.). The primary purpose of this study was to obtain practical information concerning the static front to back loading capacity of chairs constructed of

Turkish beech using different tenon sizes and to determine the relationships between static chair strength and joint strength that the furniture engineers could use in the design of future chair frames. The objectives of the study were to determine 1) how tenon size (tenon width and tenon length) affects the static front to back loading capacity of chairs and 2) if the ultimate static front to back loading capacity of chairs can be predicted from strength tests of individual joints.

EXPERIMENTAL

Plan of Study

The specimen schedule used in this study is given in Table 1.

Table 1. Specimen Schedule Used in this Study

Tenon size (width by length) (*mm*)	Whole chair frames	T-shaped joints (Back leg to side rail)	T-shaped joints (Stretchers with 30 by 30 tenon)	L-shaped joints (Front leg to side rail)
30 by 30	5 Replication	10 Replication	10 Replication	10 Replication
30 by 40	5 Replication	10 Replication		10 Replication
30 by 50	5 Replication	10 Replication		10 Replication
40 by 30	5 Replication	10 Replication		10 Replication
40 by 40	5 Replication	10 Replication		10 Replication
40 by 50	5 Replication	10 Replication		10 Replication
50 by 30	5 Replication	10 Replication		10 Replication
50 by 40	5 Replication	10 Replication		10 Replication
50 by 50	5 Replication	10 Replication		10 Replication
Totally	45 Specimens	90 Specimens	10 Specimens	90 Specimens

Altogether, 45 chair frames (3 tenon widths, 3 tenon lengths, and 5 replications of each) in a 1:1 scale were constructed of Turkish beech (*Fagus orientalis* L.). Each had a round edge mortise and tenon joints and they were subjected to static front to back loads. Likewise, about 90 L-shaped joint specimens representing the front leg to side rail joints (3 tenon widths, 3 tenon lengths, and 10 replications for each) and 100 T-shaped joint specimens (90 representing the back leg to side rail joints and 10 representing the back or front leg to stretcher joints) with cross sections and tenon sizes identical to those used in the chair frames were constructed of the same wood species and tested to determine their moment capacity.

T-shaped joints and L-shaped joints were constructed using 9 different tenon sizes of 3 tenon widths (30, 40, and 50 mm) and 3 tenon lengths (30, 40, and 50 mm). All tenons were 7 mm thick (1/3 of the rail thickness).

All of the chairs were of identical construction except for the tenon dimensions of the joints. The effect of tenon width and length on static front to back loading capacity of the chair frames was determined by static front to back load tests.

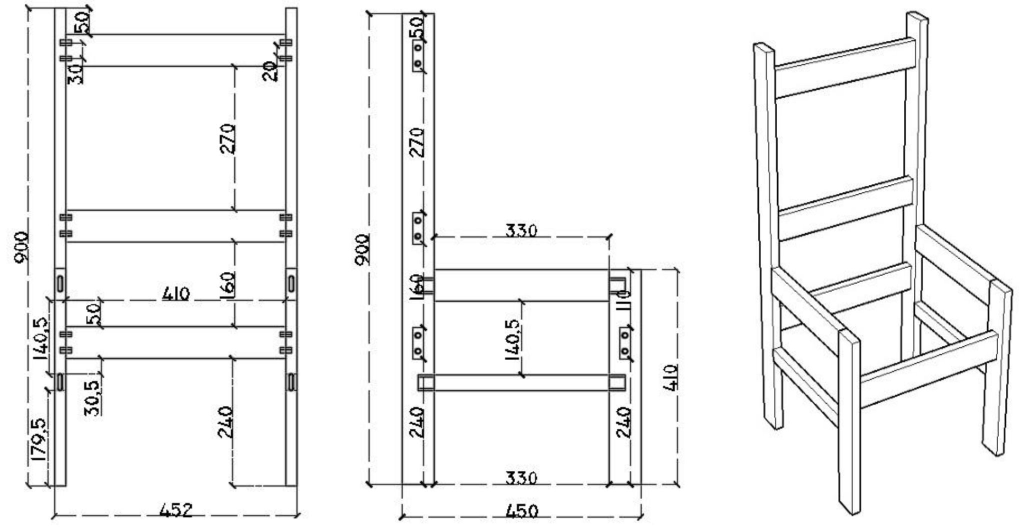
Test Materials

All of the T-shaped joint specimens, L-shaped joint specimens, and complete chair frames were constructed of Turkish beech (*Fagus orientalis* L.) which is commonly used by the Turkish furniture industry. Wood materials were obtained from commercial suppliers. The average density value was 0.62 gr /cm^3. The moisture content of wood was conditioned to and held at 12% before and during testing. Physical and mechanical properties of the wood were evaluated in accordance with the procedures described in ASTM D 4442-92 (2001) and ASTM D 143-94 (2000), respectively.

Commonly used 65% solid content polyvinyl acetate glue was utilized for assembling both the individual joint specimens and the chair frames.

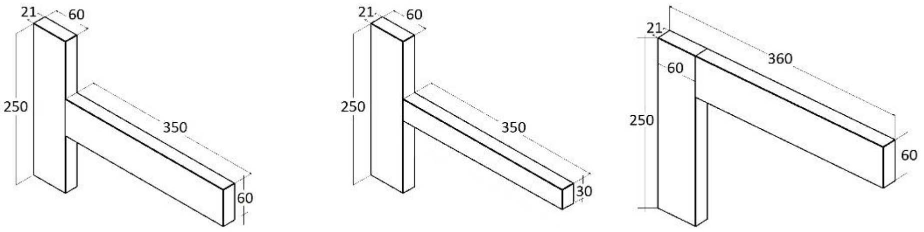
Description of Specimens

Construction of the chair frames is illustrated in Fig. 1, and construction of the joint specimens is illustrated in Fig. 2. Specific joint construction is illustrated in Fig. 3.



a. b.

Fig. 1. Front and side view (a) and perspective view (b) of chair frames tested in this study



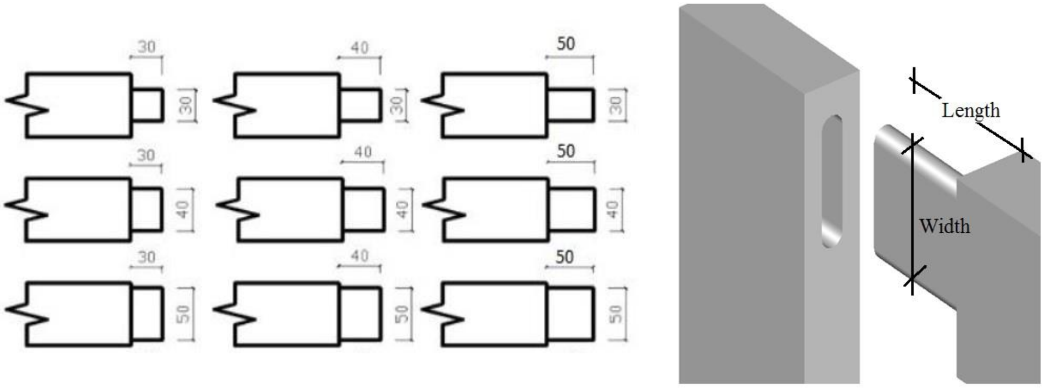
a. b. c.

Fig. 2. T-shaped (a, b) and L-shaped (c) specimens (measurements in mm)

The T-shaped and L-shaped joint specimen consisted of two members, a leg and a rail/stretcher. Leg members measured 250 mm long by 60 mm wide by 21 mm thick. Rail members measured 350 mm long by 60 mm wide by 21 mm thick while the stretcher members measured 350 mm long by 30 mm wide by 21 mm thick.

During material preparation and joint and chair frame assembly, small wood-shop techniques were utilized. All wood used in this study was cut from air-dried timbers with a band saw. All of the members of the T-shaped and L-shaped joint specimens and the chair frames were first machined on a jointer and then planed to 21 mm thick on a planer. Afterwards, widths of the members were cut to 60 or 30 mm and final length sizes. Cross sections of all the members of the chair frames were the same, namely, 21 mm thick by 60 mm wide, except for the stretchers, which were 21 mm thick by 30 mm wide.

A mortising machine was used to machine the mortises; likewise, a tenoning machine was used to machine the tenons. The clearance and type of fit were not observed according to a standard or a norm. However, a snug fit (average mortise-tenon clearance of 0.076 mm ± 0.025) was obtained between tenons and mortises. Adhesive was liberally applied to all faces of the tenon and to the sides and bottom of the mortise at a rate of about 150 ± 10 g/m^2. Pieces of wax paper with mortises in them to accommodate the tenons were used to prevent any possibility of tenon shoulders adhering to the areas surrounding the mortises. Tenon configurations are given in Fig. 3.



a. b.

Fig. 3. Geometries of the various size of mortise and tenon joints (a) and detail of round edge (b) mortise and tenon (measurements in mm)

The sequence of assembly of chair frames was as follows: (a) sub-assembly of side frames and (b) assembly of the whole chair frames. The side frames were constructed first. In the side frame of the chairs, the tenons were inserted into the mortises, and the assembly then was pulled together by bar clamps.

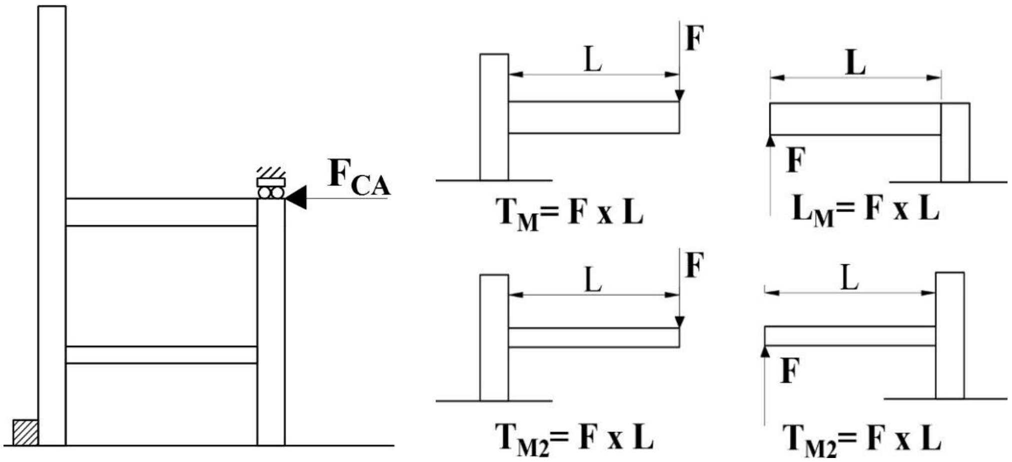
The two side frames were joined to each other by four cross rails (Fig. 1). Dowel joints were utilized in these connection points in keeping with the common practice of the Turkish furniture industry. Each cross rail was attached to a side rail by means of two dowels at each end of the rail. These dowels measured 8 mm in diameter and 35 mm in length. The dowels were located at the center of the thickness of the members. The depth of the embedment of the dowels in the end of the rails was about 20 mm; the depth of the embedment of the dowels in the face of the side frames was 15 mm. The distance between the centerlines of the two dowels was 32 mm. The dowels and dowel holes were coated with adhesive. Bar clamps were again used to pull the two side frames together and force the dowels into the holes.

Joint specimens and chair frames were cured for at least one month after assembly in an environmentally controlled conditioning room with an average equilibrium moisture content of 12%.

Method of Tests

All front to back loading tests of the chair frames and the bending tests of the T-shaped and L-shaped joints were carried out on a 50 kN capacity universal testing machine (Mares 2007, Turkey) at a load rate of 6 mm/min under static loading. Moisture content (MC) specimens were cut from the specimens and weighed immediately after each test.

Front to back loading tests of all chair frames were conducted using the test set up shown in Fig. 4a and 5. Horizontal front to back loads (F_{CA}) were applied at a point that was 410 mm (L_C) above the floor supports (Fig. 4a).



a. b.

Fig. 4. Side view illustration of front to back loading of chair (a), and loading configurations of individual joints (b)

In the tests, reaction brackets were placed behind each of the back legs to prevent the chair from sliding backwards. A steel rope attached to the load head of the universal testing machine passed over the seat from front to back. The other end of the steel rope was dropped over an angle iron that rested on the tops of the front legs; it was allowed to hang vertically and was attached to the floor located directly below the front edge of the seat. This steel rope provided the reactive force required to keep the chair from overturning; it was placed in a perfectly vertical position. Loading was continued until the chairs suffered catastrophic failure.

In the case of individual joint tests, a concentrated load was applied to the rail/stretcher of each specimen at a point of 300 mm away from the front edge of the leg, *i.e.*, the moment arm was 300 mm (Fig. 4b). Loading was continued until a breakage or separation occurred in the specimens.

The ultimate loads carried by the joints were recorded in Newtons (N). Ultimate loads were converted to corresponding bending moment values for each individual joints by the following expressions;

a) T-shaped rail joints:

$$T_M = F \times L \tag{3a}$$

b) L-shaped rail joints:

$$L_M = F \times L \tag{3b}$$

c) T-shaped stretcher joints:

$$T_{M2} = F \times L \tag{3c}$$

where T_M , L_M , and T_{M2} refer to the bending moment capacity of the back leg to side rail (T-shaped), front leg to side rail (L-shaped), and back or front leg to stretcher (T-shaped) individual joints, respectively (Nm), F refers to the ultimate applied force (N), and L refers to the moment arm (m).

Statistical Analyses

Full linear model (Equation 4) for the two-way factorial experiments were considered to determine the effects of tenon width and tenon length on the front to back loading capacity of chair frames. The model is as follows,

$$Fc_{ijk} = \mu_1 + A_i + B_j + (AB)_{ij} + \varepsilon_{ijk} \tag{4}$$

where Fc_{ijk}, refers to the front to back loading capacity (N) values of chair frames; μ_1 refers to the population mean for the front to back loading capacity (N) for all tenon width-tenon length combinations; A refers to the discrete variable representing the effect of tenon width; B refers to the discrete variable representing the effect of tenon length; (AB) refers to the effect of the two-way interaction among the two variables; ε refers to the random error term; i refers to the index for tenon width, 1,...,3; j refers to the index for tenon length, 1,...,3; and k refers to the index for the replicate, 1,...,5.

A two-way analysis of variance (MANOVA) general linear model procedure was performed for ultimate front to back loading capacity data of the chair frames to analyze main effects and interaction on the mean of ultimate front to back loading capacity. The least significant difference (LSD) multiple comparisons procedure at the 5% significance level was performed to determine the mean differences of front to back loading capacity values of chairs tested considering tenon width–tenon length interaction in the MANOVA results. The MSTATC software was utilized for the statistical analyses.

RESULTS AND DISCUSSION

Static Front to Back Loading Capacity of Chair Frames

In general, the chair frames failed completely in 4 and 5 min (Fig. 5). Normally, joint failures occurred suddenly.

In the chair frames constructed with narrow but long tenons, failures occurred due to fractures of the tenons at their points of entry into the walls of the back and front legs.

In the case of frames constructed with short tenons, joints failed because of glue line fractures. As a result, the short tenons withdrew completely from the front and back leg members. In the case of frames constructed with wide but long tenons, the common reason for failure was the pull-out of tenons from the front and back leg members with some core wood materials still attached to the tenon. Opening failures started at the edge of the tenon and then propagated towards the other edge of the tenon as the load increased. As the glue bond failed, the tenons began to be loaded in bending.

In contrast to the back leg to side rail joint failures, in the case of the front leg to side rail joints, occasional splits occurred on the top of the front leg due to the forcing of the tenons under shear in the direction of parallel to grain. After the ultimate capacity of the joints was reached and a permanent drop-off in load was observed, the front to back loading of chair frames were terminated.

Fig. 5. The general failure modes of the chair frames after static front to back loading test

The physical and mechanical properties of the wood species determined in this study are given in Table 2. Results of the ultimate front to back loading capacity of whole chair frames with their coefficients of variation are given in Table 3. Analysis of variance results are given in Table 4.

Table 2. Physical and Mechanical Properties of Beech Used in the Study

Wood species	MOE* (*N/mm²*)	Tension strength (*N/mm²*)	Compression strength (*N/mm²*)	Shear strength (*N/mm²*)	MOR* (*N/mm²*)	Density (*g/cm³*)	MC* (*%*)
Turkish Beech	11183	118.4	60.7	10.31	115.9	0.60	10.8
COV* (%)	14.67	15.25	3.85	6.32	10.49	2.05	3.75

*MOE: modulus of elasticity; MOR: modulus of rupture; MC: moisture content; COV: coefficients of variation

The MANOVA results indicated that the main factors (tenon width and tenon length) and two-factor interaction for ultimate front to back loading capacity values were statistically significant at the 5% significance level.

The least significant difference (LSD) multiple comparisons procedure at the 5% significance level was performed to determine the mean differences of front to back loading capacity values of chairs tested considering tenon width and tenon length interaction in the MANOVA results.

Table 5 gives mean comparisons of front to back loading capacity values of chair frames for tenon width and tenon length under separate covers. The single LSD values were 124.5 N for both tenon width and tenon length.

Table 3. Mean Front to Back Loading Capacities of Whole Chair Frames with their Coefficients of Variation*

Tenon width (mm)	Tenon length (mm)	Front to Back Loading Capacity (*N*)		
		Mean	COV* (%)	HG
30	30	2292	8.59	F
	40	2564	1.66	DE
	50	2386	9.26	EF
40	30	2502	8.06	EF
	40	2835	6.62	C
	50	2505	8.35	EF
50	30	2751	6.31	CD
	40	3133	3.24	B
	50	3545	2.03	A

* HG. Homogenous group; values followed by the same capital letter are not significantly different.

Table 4. Summary of the ANOVA Results for Front to Back Loading Tests

Source	Degrees of Freedom	Sum of Squares	Mean Squares	F Value	Prob. (Sig)
Tenon width	2	4258644.434	2129322.217	75.2870	0.0000
Tenon length	2	991107.681	495553.840	17.5214	0.0000
Width x length	4	1146513.948	286628.487	10.1344	0.0000
Error	36	1018177.882	28282.719		
Total	44	7414443.946			

Table 5. Mean Comparisons for Tenon Width and Tenon Length on Front to Back Loading Capacity

Tenon Width (mm)	Front to Back Loading Capacity (N)		Tenon Length (mm)	Front to Back Loading Capacity (*N*)	
	Mean	(HG)		Mean	(HG)
30	2414	C	30	2515	B
40	2614	B	40	2844	A
50	3143	A	50	2812	A

Results indicated that the front to back loading capacities of the chair frames increased as tenon width increased. In addition, tenon width had a greater effect on front to back loading capacity of chair frames than tenon length. Tests results of the previous studies related to individual joint strength (Kasal *et al.* 2013; Kasal *et al.* 2015a,b) agree with this study. The front to back loading capacities of chair frames constructed with 50 mm wide tenons were 8% higher than chair frames constructed with 40 mm wide tenons, and were 30% higher than the chair frames constructed with 30 mm tenons. Finally, increasing the tenon width from 40 to 50 mm, increased the front to back loading capacity of the chair frames by about 12%.

In the case of tenon length, front to back loading capacity values increased by 13% as the tenon length increased from 30 to 40 mm, whereas increasing the tenon width from 40 to 50 mm had no significant effect on the front to back loading capacity.

Overall, according to the results of Table 5, the tenon width had a greater effect on front to back loading capacity of chair frames than the tenon length.

Mean front to back loading capacity values along with LSD comparison test results for two-way interactions are given in Table 3. The single LSD value was 215.7 N. As can be seen in Table 2; the chair frames constructed with 50 by 50 mm tenons had the highest front to back loading capacity, whereas the chair frames constructed with 30 by 30 mm tenons had the lowest front to back loading capacity. Increasing the tenon length for each tenon width substantially increased the front to back loading capacity of a chair frame. For the chair frames constructed with 30 and 40 mm tenon width, increasing the tenon length from 30 to 40 mm or 40 to 50 mm increased the front to back loading capacity by approximately 10%. In the case of the chair frames constructed with 50 mm wide tenons, increasing the tenon length from 30 to 40 mm increased the front to back loading capacity by only 5%, whereas increasing tenon length from 40 to 50 mm increased front to back loading capacity by 42%. For the chair frames constructed with 30 and 40 mm tenon length, increasing the tenon width from 30 to 40 mm increased the front to back loading capacity by 13%. However, increasing tenon width from 40 to 50 mm decreased the front to back loading capacity by an average of 9% for these same chair frames. In the case of the chair frames constructed with 50 mm tenon lengths, increasing the tenon width from 30 to 40 mm or 40 to 50 mm increased the front to back loading capacity by 13%.

Relationship between the Strengths of Chair Frames and Individual Joints

An approximate method of relating the front to back load capacity of a chair, F_{CE}, (Fig. 5) to the sum of the moment capacities of the individual joints in the two side frames of the chair which is facilitated by the semi-rigid characteristics (Hajdarevic and Busuladzic 2015) of the joints is to relate the internal vertical shear forces, V_R and V_S, exerted by the side rails and the stretchers on the inside surfaces of the front legs of the chair to the vertical force, F_V, where F_V is the vertical force acting on the front edge of the seat at the same point as F_{CE} that in effect keeps the chair from overturning. The relationship between F_V and F_{CE} is given by the expression,

$$F_V = \frac{L_C}{L_D} \times F_{CE} \qquad (5)$$

where F_{CE} refers to the horizontal front to back force exerted on the chair, L_C is the distance from the bottom of the front leg to the line of action of the front to back force, and L_D refers to the distance from the rear edge of the back leg to the front edge of the front leg of the chair. The vertical force exerted on the inside surface of a front leg by a rail is given by the expression,

$$V_R = \left(\frac{T_M + L_M}{L_R}\right) \qquad (6)$$

where T_M and L_M refer to the maximum moment capacities of the T-shaped and L-shaped rail joints and L_R is the length of the side rail. Likewise, the vertical force exerted on the inside surface of a front leg by a stretcher is given by the expression;

$$V_S = \left(\frac{T_{M2} + T_{M2}}{L_S}\right) \qquad (7)$$

where T_{M2} refers to the maximum moment capacity of the T-shaped stretcher joints and L_S is the length of the stretcher. Combining these two expressions gives;

$$V_{RS} = \left(\frac{T_M + L_M}{L_R} + \frac{T_{M2} + T_{M2}}{L_S}\right) \qquad (8)$$

where V_{RS} refers to the sum of the internal vertical forces acting on the inside surface of one front leg of the chair. The absolute value of the external vertical force, F_V, acting on the chair is given by the expression,

$$F_V = 2 \text{ x } V_{RS} \tag{9}$$

so that the estimated front to back loading capacity of the chair, F_{CE}, is given by the following expression:

$$F_{CE} = 2\times\left(\frac{T_M+L_M}{L_R}+\frac{T_{M2}+T_{M2}}{L_S}\right)\times\frac{L_D}{L_C} \tag{10}$$

The dimension nomenclature of the chair frames used is shown in Fig. 6.

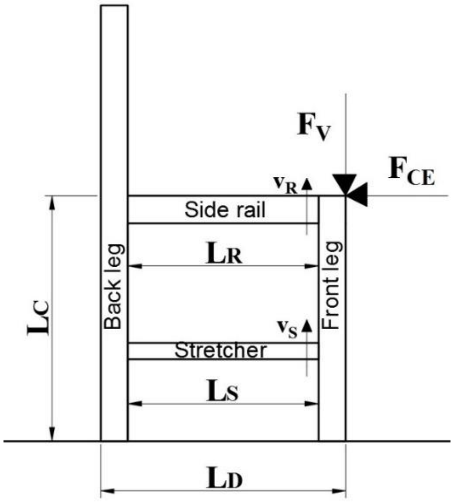


Fig. 6. Dimension nomenclature of a chair frame

To illustrate the use of Equation 10, the predicted front to back loading capacity of the chairs with 30 mm wide by 30 mm long tenons (using the ultimate individual joint moment capacity values from Table 6) would be:

$$\mathrm{F_{CE}} = 2\times\left(\frac{104.48+100.26}{0.330}+\frac{65.23+65.23}{0.330}\right)\times\frac{450}{410} = 2230 \text{ N} \tag{11}$$

The ratio of the corresponding test value (2292 N) to the predicted value (2230 N) is 1.027. Equation 10 would also hold for chairs with sloping rear legs; thus if the back leg is sloped to the rear so that L_D was 500 mm and L_s was 355 mm, the front to back loading capacity of the chair would be predicted to be:

$$\mathrm{F_{CE}} = 2\times\left(\frac{104.8+100.26_{\mathrm{m}}}{0.330}+\frac{65.23+65.23}{0.355}\right)\times\frac{500}{410} = 2412 \text{ N} \tag{12}$$

The experimentally determined moment capacities of the T-shaped and L-shaped joints along with the front to back load capacities of the chairs are given in Table 6. Estimated front to back loading capacities of chair frames are compared to comparable test values in Table 6, as well.

Table 6. Moment Capacities of T-Shaped and L-Shaped Joints and Comparison of the Actual Front to Back Loading Capacity of Chair Frames with the Estimated Front to Back Loading Capacity

Tenon Size (width by length) (mm)	Individual joint moment capacities			Estimated front to back loading capacity F_{CE} (N)	Actual front to back loading capacity F_{CA} (*N*)	Actual / Estimated F_{CA} / F_{CE}
	Side rail joints		Stretcher joints			
	T_M (Nm)	L_M (Nm)	T_{M2} (Nm)			
30 by 30	104.48	100.26	65.23	2230	2292	1.03
30 by 40	87.92	96.66	65.23	2098	2564	1.22
30 by 50	158.93	129.69	65.23	2790	2386	0.86
40 by 30	107.05	104.99	65.23	2280	2502	1.10
40 by 40	196.70	136.20	65.23	3084	2835	0.92
40 by 50	212.93	140.25	65.23	3221	2505	0.78
50 by 30	81.23	98.96	65.23	2067	2751	1.33
50 by 40	117.35	178.42	65.23	2838	3133	1.10
50 by 50	169.59	220.36	65.23	3464	3545	1.02
Mean	-	-	-	-	-	1.04
SD*	-	-	-	-	-	0.18

Note: Values obtained from individual test results (Kasal *et al*. 2015). *SD, standard deviation

As shown in Table 6, useful results were obtained using the developed approach. In all tenon size groups, close approximations were obtained between actual and estimated results, except for the 40 mm width and 50 mm length mortise and tenon size group. The ratios of test values to estimated values varied from a low of 0.78 to a high of 1.33. Overall, the ratio of the experimentally obtained capacities to the estimated capacities averaged 1.047 with a standard deviation of 0.175.

Given the low ratio of 0.78, it follows that “working design’’ values must be taken as only a fraction of predicted values. If the working level is taken as 75% of the predicted levels, then none of the chairs had capacities less than the predicted values.

Based on these results of the study and up to date research data regarding joint strength and joint design, designer and furniture engineers could get good estimates of the strength of whole chairs before even doing actual joint or full size chair tests.

CONCLUSIONS

1. Tenon width and tenon length both affect the chair front to back loading capacity—the chair front to back loading capacity increased as either tenon width or tenon length increased.
2. Front to back loading capacity of chairs themselves were most affected by tenon width.
3. A simple approximate procedure could be used to estimate the front to back load capacity of a chair as a function of the capacities of the joints in the side frames. The developed expression is in fact not only for mortise and tenon joints but it is valid for any kinds of furniture joinery.

4. Overall, results of the study indicate that designers and furniture engineers may obtain good estimates of the front to back loading capacity of chairs from a consideration of the moment capacities of the joints used in construction of the side frames.

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