RELATIONSHIP BETWEEN STATIC AND CYCLIC FRONT TO BACK LOAD CAPACITY OF WOODEN CHAIRS, AND EVALUATION OF THE STRENGTH VALUES ACCORDING TO ACCEPTABLE DESIGN VALUES

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Abstract. Tests were carried out to investigate the relationship between static and cyclic strength of wooden chairs. Furthermore, cyclic front to back load performance of chairs were compared with acceptable design loads that were given in the American Library Association (ALA) specifications. For this purpose, 90

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chair frames were constructed of Turkish beech (*Fagus orientalis* L.) with round edge mortise and tenon joints, with tenons that varied from 30, 40, and 50 mm in width and 30, 40, and 50 mm in length. All joints were assembled with 65% solid polyvinyl acetate adhesive. Half of the chairs were subjected to "cyclic" loads and the other half were subjected to "static" loads based on the ALA specifications. In conclusion, it was recommended that the cyclic strength could be taken as the 56% of the static strength. According to the results, the chairs constructed with any size of tenons could meet the light-duty service (domestic usage), except for the chairs constructed with 30 by 30 mm tenons. The chairs constructed with 50 by 50 mm tenons could meet the heavy-duty service, whereas the chairs constructed with 30 by 50 mm tenons could meet the medium-duty service.

Keywords: Chair performance test, cyclic load, static load.

INTRODUCTION

Performance test of any product is generally described by using incremental load tests to estimate the capability of a product to accomplish its envisioned functions. In general, performance tests of furniture are considered to be expensive and time consuming. Therefore, it is crucial that the testing costs should be consistent with the value of the information obtained and the price of the product itself.

In furniture performance tests, the types of load should be taken into consideration in terms of applicability in the test and mode of the application. Static and cyclic loading are common types of the loading in furniture performance testing. Static loading could be performed relatively fast, but does not exactly represent the actual service loads for seating furniture; so the strength performance of chair frames should not be evaluated only by static loading. Most furniture failures occur because of the repeated loading in service rather than a one-time overloading.

Development of more realistic load models for furniture subjected to repetitive dynamic loading requires a realistic assessment of typical service history, and courses and modes of failure. During the course of its service life, furniture is subjected to repeated normal load applications along with occasional chance of abusive loadings. Although the furniture is relatively new and retains a high degree of its initial design strength, it is able to resist such loads. However, when the applied load exceeds the residual strength of materials, the product fails because its initial strength decreases in the long run, as shown in Fig 1 (ALA 1982).

The "cyclic stepped load" (Fig 1) is a recommended method to satisfy the requirements of the performance test system. In this method, a specified initial load is applied to the furniture at a given cyclic rate for a specified number of cycles. When the prescribed number of cycles is completed, the load level is increased by a given increment, and the procedure is repeated until a desired load level has been reached, nonrecoverable failure occurs on the furniture frame, or horizontal deflection exceeds 50 mm on side rail to back post joints (Eckelman 1988a; Erdil 2002).

General Service Administration (GSA) test method for upholstered sofas dictates that the incremental load test method must be applied to determine strength and durability of one part of the sofa independently from its other parts. The test procedure is that 1) a part of the sofa is subjected to a given load for 25,000 cycles at a rate of 20 cycles per minute, 2) when 25,000 cycles have been completed at this load level, the load is increased a specified amount and testing continued for next 25,000 cycles, and 3) this procedure is repeated until the tested furniture suffers disabling damage or a desired acceptance

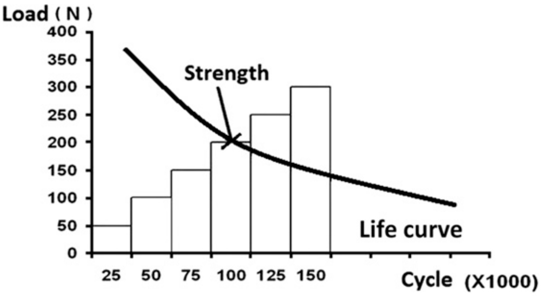


Figure 1. Sample load schedule.

level has been reached (Eckelman and Erdil 2001). A lack of information exists in the relationship between cyclic and static load strength, which is needed for design purposes, due to the fact that specified loads in GSA standard for static design purposes have not been well-addressed in the literature. Experience has shown, however, that cyclic load strength should not be assumed to be higher than 50% of static load strength (Eckelman and Erdil 1999). Haviarova et al (2001) demonstrated that furniture constructed with round mortise and tenon joint is both strong and highly resistant to cyclic loading.

Comparative bending and fatigue strength of rectangular mortise and tenon joints constructed of oil palm (*Eleais guineensis*) were evaluated. Results showed that the bending strength of oil palm joints was half of the strength of the joints constructed of rubberwood, nyatoh, meranti, and sepetr. In terms of fatigue strength, joints constructed of oil palm lumber showed comparable performance with the other wood materials. The results of the study also showed that the allowable design stresses of rectangular mortise and tenon joints could be set at 20% of its bending strength (Ratnasingam et al 2010).

Likos et al (2012) investigated the effect of cross-sectional tenon geometry on static and cyclic load capacities of side chairs constructed with mortise and tenon joints. Results showed that ratios between static loading and cyclic loading of chairs with mortise and tenon joints constructed with round, rectangular, and diamond shaped tenons were 56.5%, 66.8%, and 69.2%, respectively. Kuskun (2013) and Kasal et al (2015b) studied the effect of tenon size on strength of chair joints, along with the relationship between the static and cyclic loading forms. A simple approach was developed for estimating the whole structure strength from the individual joint tests, and results demonstrated that the cyclic performance of a chair is equivalent to 56% of the static strength (Kuskun 2013; Kasal et al 2015b).

Cyclic load tests are effective methods to evaluate the performance of chair frames. However, in practice, the cyclic incremental load tests require much more equipment and much longer time to complete rather than those of static loading tests. The question comes into attention that if there is any relationship between static and cyclic loading capacity of wooden frames. The primary purpose of this study was to obtain practical comparative information concerning the ultimate static and cyclic front to back load capacity of identical chairs constructed of Turkish beech (*Fagus orientalis* L.) with different tenon sizes. The overall objective is to determine the relationship between static and cyclic chair strength that the furniture engineers could use in the engineering design of chair frames.

MATERIALS AND METHODS

Ninety chair frames [3 tenon width, 3 tenon length, and 10 replications (five replications for static and five replications for cyclic tests) for each] in 1/1 scale were constructed with round edge mortise and tenon joints and 45 chairs were subjected to static loads, whereas the other 45 were subjected to cyclic front to back loads.

Chair frames were constructed of Turkish beech (*F. orientalis* L.) wood, which is widely used in the Turkish furniture industry. Material for construction of chairs was obtained from the commercial suppliers. Average density value was 0.60 gr/cm^3 with standard deviation of 0.0123 gr/cm^3 (coefficients of variation = 2.05%). The EMC of wood was conditioned to and held at 12% before and during testing. The faces of tenons and the walls of mortises were coated with the 65% solid content polyvinyl acetate (PVAc) glue.

Some physical and mechanical properties of the wood were evaluated in accordance with the procedures described in ASTM (2000) and ASTM (2001), respectively.

Preparation of the Chair Frames

General configuration and dimensions of the chair frames used in the tests are illustrated in Fig 2.

The members of the chair frame were cut by standard woodworking equipment from air-dried

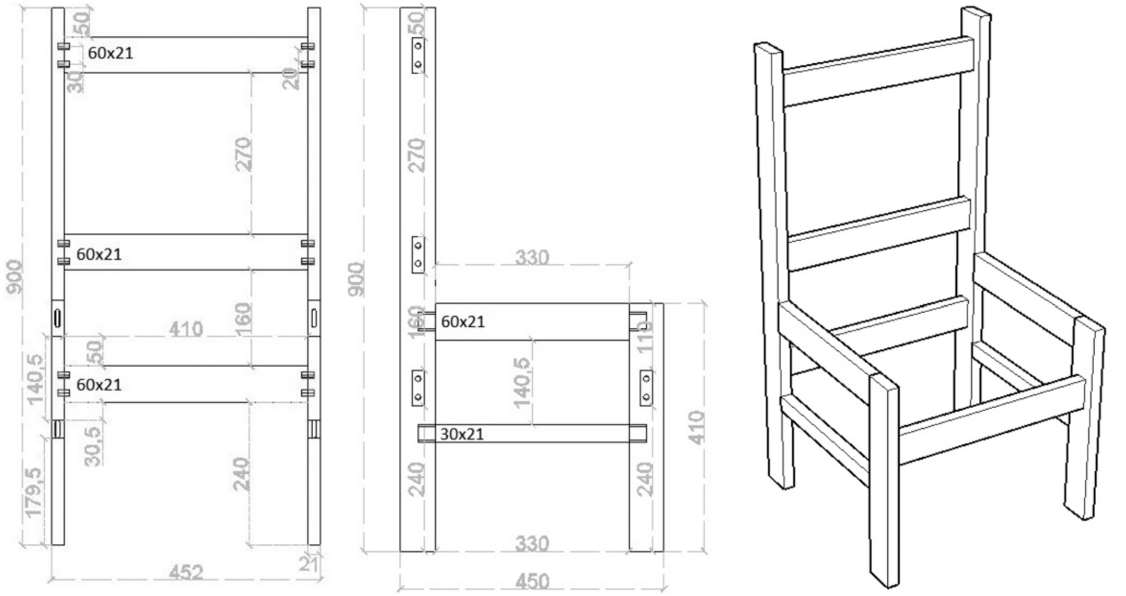
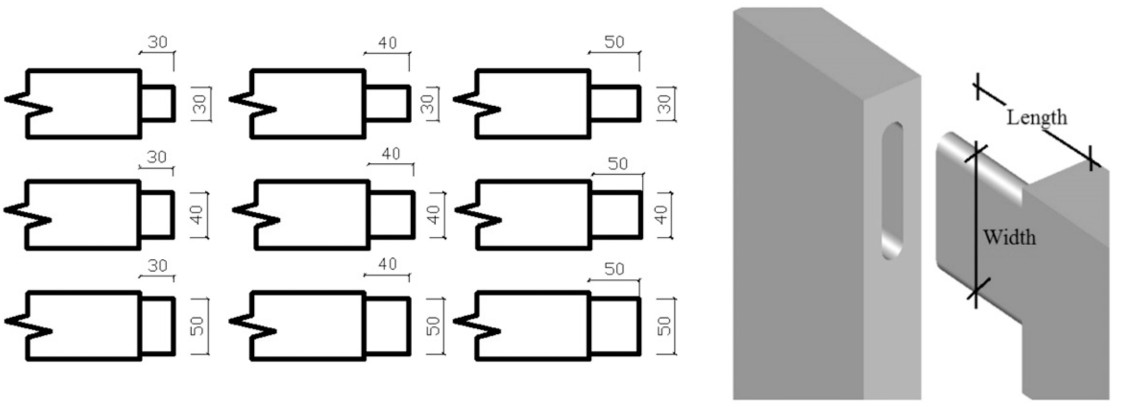


Figure 2. The design of the tested chair frames.

lumber. Mortise and tenon machines were used to process the mortises and tenons for chair joints. The clearance and joint fit were not observed according to a standard or a norm. However, a snug fit (average mortise-tenon clearance of 0.076 ± 0.025 mm) was obtained between walls of tenons and mortises. PVA adhesive was liberally applied to all faces of the tenon and mortise at the rate of 150 ± 10 g/m^2. Pieces of wax paper were used between the post and faces of tenon shoulders to prevent any possibility of tenon shoulders adhesion to the areas surrounding the mortises. Tenon sizes are given in Fig 3.

Cross-section sizes of all chair frame members were 21 mm thick and 60 mm wide, whereas stretchers were 21 mm thick by 30 mm wide.

In the assembly of chair frames, side frames were constructed first by inserting the full length of the tenons into the mortises and then clamping. Then,



(a) (b)

Figure 3. Geometries of (a) the various sizes of tenons and (b) round edge mortise and tenon joints (measurements in mm).

full chair frames were assembled by connecting the side frames with 8 mm diameter and 35 mm long dowels on the top, back, and front rails, and then clamping. The distance of the centerlines of dowels was 32 mm and the distance between edge of the rail and center of the upper dowel was 14 mm. Depth of the dowels embedment on the face of the post was 15 mm, whereas at the end of the rails it was 20 mm. The face of the dowels and walls of the dowel holes were coated with 65% solid content PVAc. Then, the chair frames were clamped to force the dowels into the dowel holes.

Before performance testing, to eliminate MC variations, chairs were allowed to cure for 1 mo after assembly in an environmentally controlled conditioning room for 12% EMC.

Static and Cyclic Front to Back Loading Tests

Static front to back loading tests of chair frames were carried out on a 50 kN capacity universal testing machine (Mares 2007; Turkey) with a 6 mm/min loading rate under static loading, whereas the cyclic tests were performed on the furniture performance testing equipment system (Mates 2011; Turkey) at the mechanical testing laboratory in The Wood Science and Industrial Engineering Department of Muğla Sıtkı Koçman University. When performing the cyclic stepped increasing loading procedure, "initial starting load," "load increment," "loading rate," and "load cycles at each load level" practiced in the study are given in Table 1. Twenty-five thousand cycles at each load level took almost 21 h in cyclic loading for chair frames.

Static and cyclic front to back load tests of the all chair frames were conducted using the test setups shown in Fig 4. Chair frames were tested according to the principles of the American Library Association (ALA 1982) specifications by applying front to back loads, which the chair can be imposed on in service. In the tests, reaction brackets were placed behind each of the back legs to prevent the chair from sliding backward. 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, allowed to hang vertically, and 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 vertical position. Load was applied until chairs suffered from catastrophic failure.

Table 1. Loading program of cyclic front to back tests for chair frames.

Test	Initial starting load (N)	Load increment (N)	Loading rate (cycle/min)	Load cycles at each load level
Front to back loading	223	112	20	25,000

RESULTS AND DISCUSSION

Relationship between the Static and Cyclic Strengths of Chair Frames

In general, the chair frames failed completely in 4-5 min under static load test, whereas the cyclic stepped increasing load tests took approximately 7-9 da. Similar modes of failures were observed under both loading types—sudden joint failures. In the chair frames constructed with narrow but long tenons, failures occurred owing to fracture of the tenons at their point of entry into the walls of

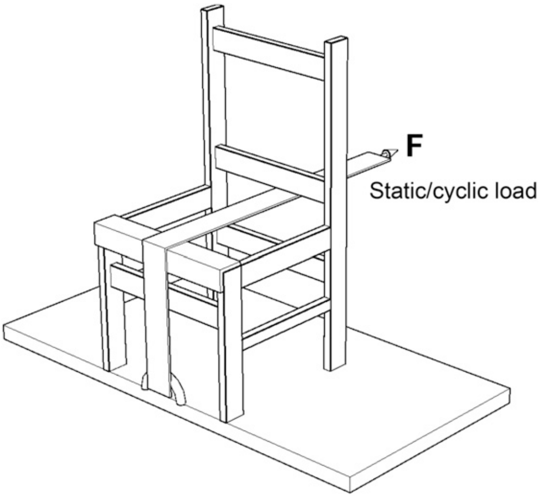


Figure 4. Static/cyclic front to back load testing of the chair frames.

Table 2. Physical and mechanical properties of beech wood used in the study.

Wood species	MOE (N/mm^2)	Tension strength (N/mm^2)	Compression strength (N/mm^2)	Shear strength (N/mm^2)	MOR (N/mm^2)	Density (g/cm^3)	MC (%)
Turkish beech	11,183	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

COV, coefficients of variation.

the back and front legs. In the case of frames constructed with short tenons, joints failed because of the glue line fracture, ie tenons withdrew completely from the front and back leg members. In the case of frames constructed with wide but long tenons, the common mode of failure was the tenons' withdrawal from the front and back leg member with some core wood materials attached to the tenon.

Physical and mechanical properties of the wood species used in the chair frames construction are given in Table 2. Static and cyclic front to back load capacity values of the tested chair frames are presented with the corresponding tenon size in Table 3. The comparative results of static and cyclic front to back load capacity of the chair frames are shown in Fig 5.

According to test results, and as expected, it was observed that static front to back load capacity of the chair frames were higher than those of the front to back load capacity of the chair frames tested under cyclic loading.

The Pearson correlation analyses were performed to the static and cyclic front to back load capacity values of the chairs for determining the relationship between static and cyclic strengths. In the analyses, the following hypotheses were investigated:

H_0: There is no positive correlation between the static and cyclic front to back load capacity values in the chair frames,
H_1: There is a positive correlation between the static and cyclic front to back load capacity values in the chair frames.

Finally, a reasonable coefficient that could be used to estimate the relationship between the static and cyclic front to back load capacity of the chair frames was obtained.

The correlation analyses were performed by using the front to back load capacities of all nine groups. According to results of the Pearson correlation analyses that were performed to determine and measure the relationship between the static and cyclic strength of the chair frames, there was a meaningful relationship (0.77) between the two variables at a 5% significance level (Table 4).

Evans (1996) suggested the following list for interpreting the Pearson correlation coefficient obtained:

0.00-0.19 "very weak correlation"
0.20-0.39 "weak correlation"
0.40-0.59 "moderate correlation"
0.60-0.79 "strong correlation"
0.80-1.00 "very strong correlation."

According to the results of the analyses, the hypothesis H_0 (there was no positive correlation between the static and cyclic front to back loading capacity values of the chair frames) was rejected, and it could be said that there is a "strong positive" correlation between the two loading types (Evans 1996).

Table 3. Static and cyclic front to back load capacity of chairs tested.

	Static front to back loading capacity (N)		Cyclic front to back loading capacity (N)	
Tenon size (mm)	Mean	COV (%)	Mean	COV (%)
30 by 30	2292	8.59	1312	17.28
30 by 40	2564	1.66	1423	7.65
30 by 50	2386	9.26	1557	10.1
40 by 30	2502	8.06	1379	12.07
40 by 40	2835	6.62	1379	6.45
40 by 50	2505	8.35	1446	16.3
50 by 30	2751	6.31	1423	7.65
50 by 40	3133	3.24	1468	7.42
50 by 50	3545	2.03	2180	4.08

COV, coefficients of variation.

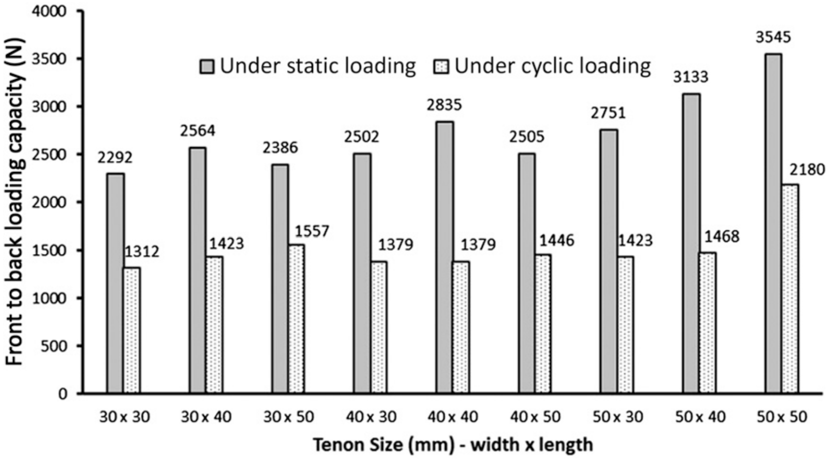


Figure 5. Comparative static and cyclic front to back load capacities of chair frames.

Ratios of average cyclic front to back load capacity to the average static front to back load capacity of chair frames were given along with the statistical values corresponding to each tenon size in Table 5.

The mean, standard deviation, and median values of average cyclic to average static front to back load test of chairs are 0.56, 0.06, 0.56, respectively. As a result; the mean value (0.56) was recommended to predict the cyclic front to back loading capacity values from the static front to back load capacity values.

Evaluation of Strength Values with Acceptable Design Load Levels

Obtained cyclic front to back load capacity values of chair frames for each tenon size were compared with the acceptable light, medium, and heavy-duty design load levels that were given by the ALA (1982) specifications. The specified acceptable cyclic front to back load capacities are 1335 N, 1557 N, and 2002 N for light, medium, and heavy services, respectively. The acceptable light-duty service loads represent domestic service conditions in practice. The evaluation results of the chair frames are given in Table 6 for each tenon size.

According to results, chairs constructed with the 50 by 50 mm tenons could meet the acceptable heavy-duty service load requirements, whereas chairs constructed with the 30 by 50 mm tenons could resist acceptable medium-duty service load requirements. The chairs constructed with any size of tenon could satisfy the acceptable light service load requirements (domestic usage) except

Table 4. The correlation results between static and cyclic front to back loading capacities of chair frames.

	Static loading capacity (N)	Cyclic loading capacity (N)
Static loading capacity (N)	1.00	0.77
Cyclic loading capacity (N)	0.77	1.00

$p < 0.05$.

Table 5. The ratio of average cyclic to average static front to back loading capacity for chairs.

Tenon size (width by length) (mm)	Static strength (N)	Cyclic strength (N)	Cyclic/static ratio
30 by 30	2292	1312	0.57
30 by 40	2564	1423	0.56
30 by 50	2386	1557	0.65
40 by 30	2502	1379	0.55
40 by 40	2835	1379	0.49
40 by 50	2505	1446	0.58
50 by 30	2751	1423	0.52
50 by 40	3133	1468	0.47
50 by 50	3545	2180	0.61
Mean	—	—	0.56
Standard deviation	—	—	0.06
Median	—	—	0.56

Table 6. Evaluation of the cyclic front to back load capacity values of chairs with the acceptable design service loads.

Tenon size (width by length) (mm)	Cyclic strength (N)	Acceptable light-duty service load (N)	Result	Acceptable medium-duty service load (N)	Result	Acceptable heavy-duty service load (N)	Result
30 by 30	1312	1335	Failed	1557	Failed	2002	Failed
30 by 40	1423		Passed		Failed		Failed
30 by 50	1557		Passed		Passed		Failed
40 by 30	1379		Passed		Failed		Failed
40 by 40	1379		Passed		Failed		Failed
40 by 50	1446		Passed		Failed		Failed
50 by 30	1423		Passed		Failed		Failed
50 by 40	1468		Passed		Failed		Failed
50 by 50	2180		Passed		Passed		Passed

for chairs constructed with the 30 by 30 mm tenons. Chairs constructed with the 30 by 30 mm tenons need to be reinforced.

CONCLUSIONS

In this study, it was aimed to obtain a coefficient which could be used to estimate cyclic front to back load capacities of chairs by means of their static front to back load capacities.

According to the results of this study, it was found that a relationship exists between the static and cyclic front to back load capacity of chair frames. This relationship could simplify the design process of chairs that must pass cyclic performance tests. Accordingly, technical and economic advantages could be provided by means of the recommended coefficient.

At the end of the study, it is recommended that the cyclic stepped increasing load capacities could be taken as 56% of the maximum static load capacities for chair performance tests for engineering design purposes. Experimental results show that a coefficient of 0.56 could be used to predict cyclic front to back load capacity of chairs from the actual static front to back load test results. This recommended value is consistent with the values, 0.50 and 0.56, that are given in the literature (Eckelman and Erdil 1999; Likos et al 2012).

The chairs constructed with any size of tenons could meet the acceptable light-duty service load requirements, except for the chairs constructed with the 30 by 30 mm tenons. Therefore, these chairs could be recommended to be used only as household chairs. The chairs constructed with the 50 by 50 mm tenons could meet the heavy-duty acceptable service load requirements, whereas the chairs constructed with the 30 by 50 mm tenons could meet the acceptable medium-duty service load requirements.

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