Simplified analysis and design methods for structural members of sofa frames considering fatigue effects

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Abstract

The design of upholstered sofa frames to meet the General Service Administration (GSA) performance test regimen requires that analytical method and design loads be available. A simplified analysis method using beam models to analyze and calculate bending moments of critical structural members in a three-dimensional sofa frame was explored. The GSA performance test regimen load schedules were applied to the frame, and transferred to individual structural members in terms of stepped cyclic load schedules. Maximum bending moment values of each structural member were calculated with beam models for each load level of stepped cyclic load schedules that the members were subjected to. Maximum moment values can be used for member design such as determination of member sizes and stresses. Stepped cyclic load schedules can be used for fatigue performance evaluation of full-size frame structural members. A procedure for estimating frame member sizes and deriving design loads for these members was explored. Design loads in terms of equivalent static bending moments while considering fatigue effects were derived for critical structural members of the sofa frame model.

The rational design of upholstered sofa frames to meet the General Service Administration (GSA) performance test regimen FNAE-80–214 (GSA 1998) requires that analytical methods be available to determine the sizes of their structural members. Typical sofa frame constructions and loads were analyzed and documented by Eckelman (1982). It was summarized that the best estimates of load design values for sofas can be obtained from performance test requirements contained in GSA specifications. Simplified design and analysis methods were developed for seat foundation systems. Methods of analysis and design have not been fully developed for entire sofa frames. This is because the frame itself constitutes a complex three-dimensional structure in which the characteristics and, in particular, the rigidity of the joints are largely unknown (Zhang et al. 2000). Therefore, exact solutions of structural analyses of a sofa frame may not be justifiable. A simplified analysis method is desirable for furniture engineers to perform daily quick design calculations to estimate structural member sizes without the need of assistance from expensive structural simulation software.

Strength and durability design of upholstered furniture frames to satisfy furniture performance test standards such as GSA regimen requires information such as design loads. A systematic scientific investigation of the loads that act on a sofa frame has never been undertaken in the past. Therefore, there is a scarcity of pertinent quantitative data. Fortunately, furniture frame performance test standards such as GSA performance test regimen FNAE-80–214 A are available. It is used to evaluate strength and durability performance of a furniture frame construction. Thus, the loads of performance tests could be the best available candidates for determining design loads for furniture frame components.

A procedure of deriving design loads for sofa frame members considering fatigue effects, i.e., to meet specified frame performance test requirements, for instance a GSA performance test, was explored in this study. Development of such design loads can allow furniture engineers to carry out initial frame design using simple calculations. The objectives of this study were to: 1) propose a simplified beam analysis method in estimating bending moments of structural members in a sofa frame; 2) derive cyclic stepped load schedules for fatigue

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performance evaluation of each structural member; 3) determine structural member dimensions to satisfy frame performance testing requirements; and 4) derive design loads for estimating cross sectional dimensions of structural members in a sofa frame.

Methods

Approach

In this study, a three-dimensional sofa frame structural representation consisting of critical members was proposed (**Fig. 1**). GSA bare frame performance testing regimen was proposed as external loads (**Fig. 2**) for structural analysis of the frame. The simplified structural analysis method, treating each member in the sofa frame as a beam with simple and fixed end support boundary conditions, was proposed. Then, the formulae of the maximum moment in the members as a function of applied loads were derived. Once the formula for moment calculation was obtained for each structural member, sizes of structural members were estimated based on *S-N* (applied nominal stress vs. log number of cycles to failure) curves of materials considered for the structure and their GSA stepped cyclic load schedules (Zhang et al. 2005). Finally, equivalent static ultimate moments for each structural member were calculated based on estimated member cross section dimensions by setting the stress value equal to modulus of rupture (MOR) in the stress-moment relation.

Sofa frame structural representation

A structural representation of a three-seat sofa frame (**Fig. 1**) consists of three basic structural subsystems, namely, a) seat frame system, b) back frame system, and c) side frame system. The seat frame system includes principal structural members: Front and Back Rails, Front and Back Spring Rails, and Stretchers. The back frame system consists of Back Top Rail, Back Posts, and Back Uprights. The side frame system has principal members of Front Stumps, Top Arm Rails, and Bottom Side Rails. The overall dimensions shown in **Figure 1** represent the sizes of the most common three-seat upholstered sofa furniture frames.

Frame performance tests

Furniture performance tests may be defined as accelerated tests that predict the ability of a piece of furniture to fulfill its intended function. Performance test standards such as the GSA performance test regimen FNAE-80–214 A are based on a stepped cyclic load model (variable amplitude loading). This means that tested frame members and joints are subjected to a cyclic stepped load rather than a static load or a constant amplitude cycling load. **Figure 2** illustrates five test configurations for evaluating structural durability of upholstered furniture bare frames. **Table 1** gives detailed cyclic load schedules for these five tests.

In the case of the Top Rails-Front to Back test, three identical front-to-back loads are applied to the Top Back Rail of a sofa frame. These loads are applied at the center-point of the rail and at points 1/6 the length of the rail from each end. The test begins at a load level of 75 pounds per load cylinder; loads are increased in increments of 25 pounds per cylinder after 25,000 cycles have been completed at each load level. The test continues until the back frame system or side frame suffers disabling damage or until a critical level of performance has been achieved. The light-service acceptance level is 75 pounds (25,000 cycles), the medium-service level is 100 pounds (50,000 cycles), and the heavy-service level is 150 pounds (100,000 cycles).

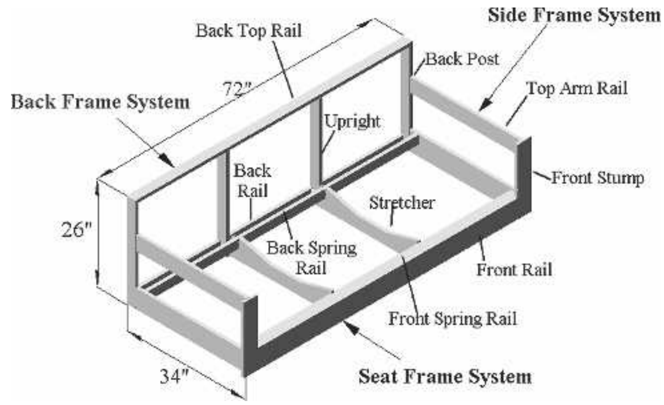

Figure 1. — Simplified three-seat sofa frame structural model.

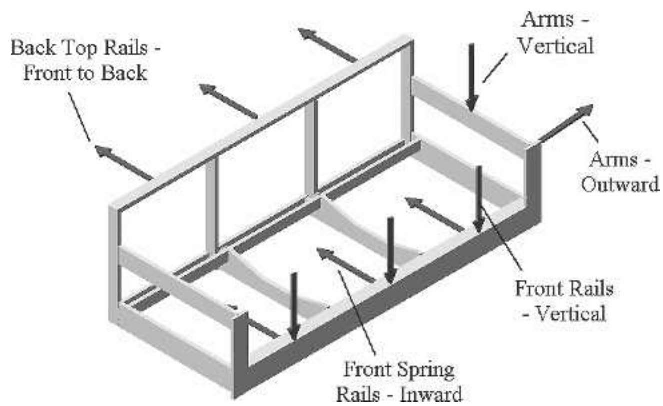

Figure 2. — Structural performance test loads of three-seat bare sofa frames.

Sofa structural member analysis models

Figures 3 to **6** illustrate the beam models proposed to estimate bending moments for structural members in a sofa frame. **Table 2** lists the structural members and their corresponding models. The span length, L, between two end supports is 72 inches, equal to the overall length of the sofa frame for the Back Top Rail, Front Rail, Front and Back Spring Rails. The span length, L, between two end supports for the Top Arm Rail beam model is 34 inches, equal to the overall depth of the sofa frame (**Fig. 1**). The cantilever beam lengths were 18, 26, and 26 inches for Front Stumps, Back Posts, and Uprights, respectively. For the beam model calculating moments in stretchers, the letter *h* is the depth of the Front Rail. The moment in the Bottom Side Rails is the same as the maximum moment in the Back Post. The method of superposition (Ugural 1991) was applied to solve the statically indeterminate beam problems.

The Back Rail was not analyzed in this study in considering bending fatigue effects since it is not subjected to significantly high bending stresses. But, it may need to be analyzed considering back-to-front impact loading.

Stepped cyclic load schedules for individual frame members

Stepped cyclic load schedules for testing different subsystems of a sofa bare frame (**Table 1**) were applied to corresponding frame member beam models. Therefore, fatigue life

Table 1. —Typical cyclic loading schedule and performance-acceptance levels for furniture bare frame durability evaluation.

Test	Initial load	Load increments	Number of loads	Light-service acceptance level	Medium-service acceptance level	Heavy-service acceptance level
	----------(lb)[a]---------			-------------------------	(pound/cycle)	------------------------
Top rails—front to back	75	25	3	75/25,000	100/50,000	150/100,000
Arms—outward	50	25	1	75/50,000	150/125,000	200/175,000
Arms—vertical	100	100	1	400/100,000	600/150,000	800/200,000
Front spring rails—inward	100	100	3	300/75,000	400/100,000	600/150,000
Front rails—vertical	100	100	3	300/75,000	400/100,000	600/150,000

[a]1 pound = 4.448 N.

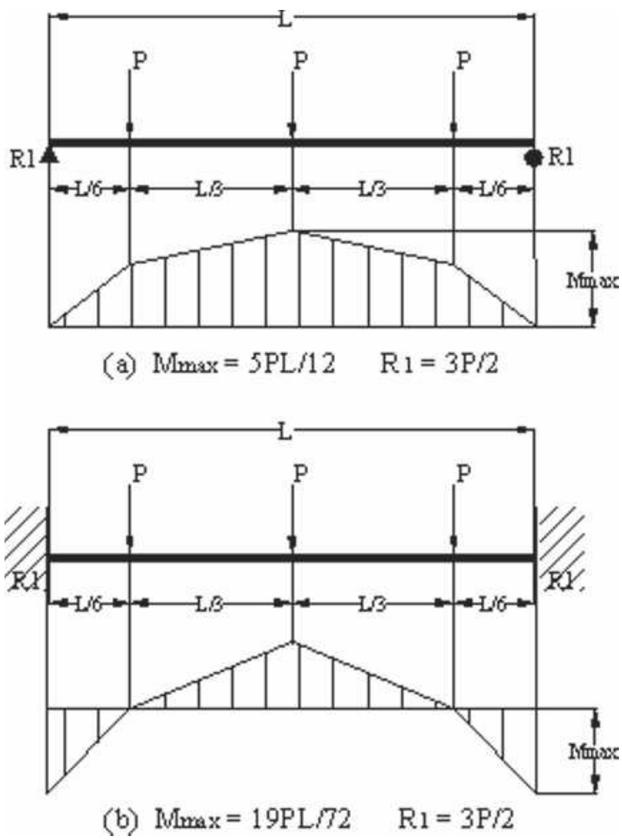

Figure 3. — Beam model 1 with end supports and three concentrated loads: (a) a simple beam, and (b) a fixed end beam.

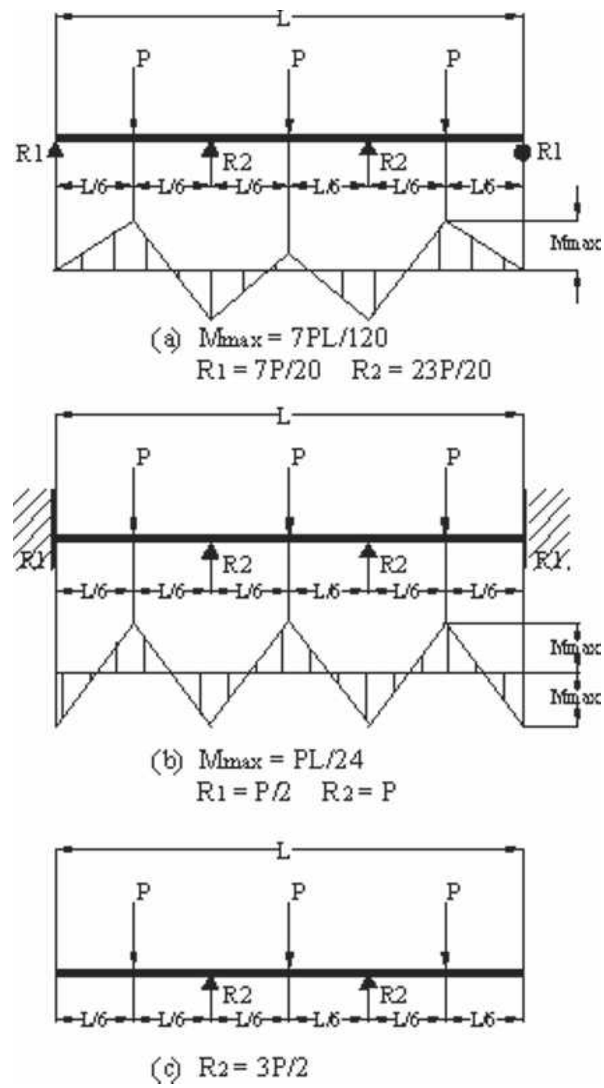

Figure 4. — Beam model 2 with four equally spaced supports and three concentrated loads: (a) a simple beam, (b) a fixed end beam, and (c) reaction forces of a simply supported beam with two supports being L/3 from the end and three concentrated loads.

evaluation schedules for frame members and applied moments corresponding to all load levels were calculated (**Tables 3** to **9**). For instance, **Table 3** gives the cyclic loading schedule for Back Top Rails. The second column of the table gives the magnitude of each of the three loads applied to the rails. The applied loads were determined by referencing to the frame test Back Top Rail-Front to Back test (**Table 1**). The maximum bending moments in the rail corresponding to each of fatigue load levels were calculated using the formulae of models 1a and 1b in **Figure 3**, which were given in the columns 5 and 6, for simply supported and fixed end boundary conditions, respectively.

For Back Posts and Uprights, the frame test schedule for Back Top Rails-Front to Back was applied. Each level of cyclic load values in **Table 8** applied to top ends of Back Posts and Uprights were equal to reaction forces calculated with beam models 1a (**Fig. 3**) and 2c (**Fig. 4**), respectively. The applied load, P, on stretchers is equal to the magnitude of the reaction force calculated from the beam model 2c.

Frame member material

The wood-based materials included in this study were 0.75-inch-thick southern yellow pine plywood, OSB, and particleboard (PB). Average edgewise MOR values were 6,600, 4,200, and 1,600 psi for plywood, OSB, and particleboard beam members cut parallel to the 8 foot direction from a full-size sheet (4 by 8 ft), respectively. Their fatigue *S-N* curves

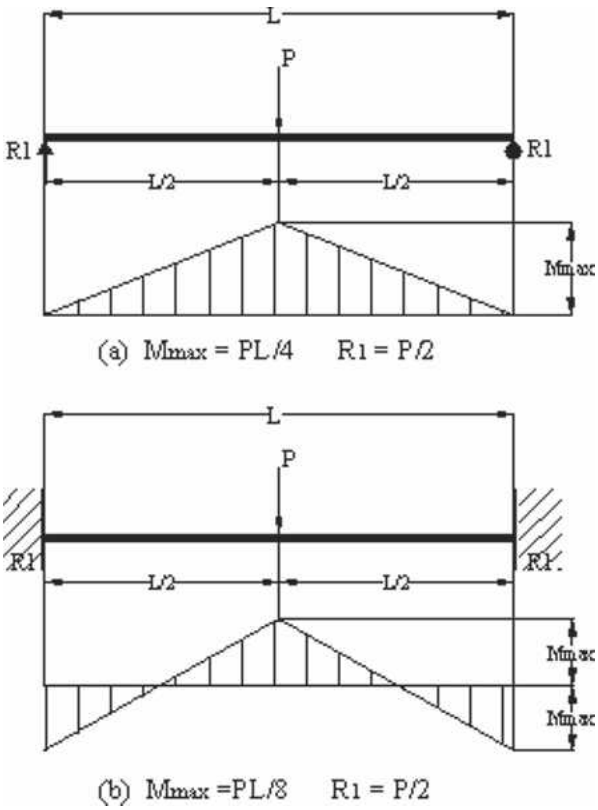

Figure 5. — Beam model 3 with concentrated center load: (a) a simple beam, and (b) a fixed end beam.

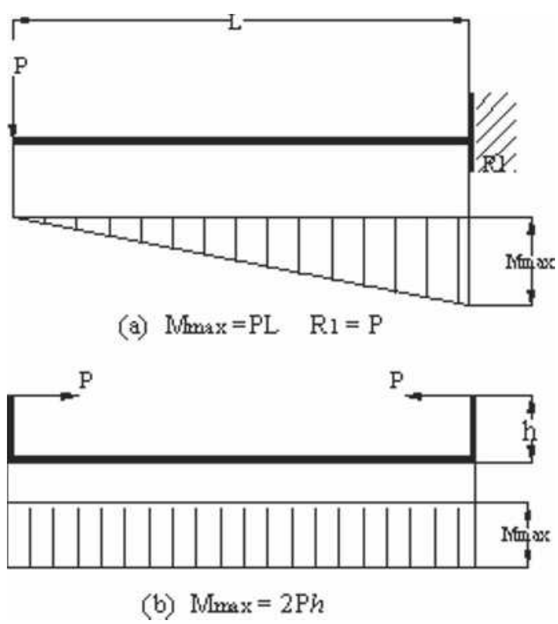

Figure 6. —Beam model 4: (a) a cantilever beam with concentrated end load, and (b) a simplified beam model for stretchers.

are expressed with the form $S = MOR\,(1 - H \times \log_{10} N_{fj})$ when the materials are loaded edge-wise. The constant H values in the equation were 0.05, 0.07, and 0.09 for plywood, OSB, and particleboard, respectively. Detailed information about the materials such as composite layer structure, resin, grade, mechanical property tests, and etc. can be found in the authors' previous work (Zhang et al. 2005).

Table 2. — Simplified beam models to estimate bending moments for structural members in a sofa frame.

Model	Figure number	Member
Model 1a	3	Front rails & back top rails (conservative results)
Model 1b	3	Front rails & back top rails (progressive results)
Model 2a	4	Front spring rails (conservative results)
Model 2b	4	Front spring rails (progressive results)
Model 2c	4	Back uprights
Model 3a	5	Top arm rails (conservative results)
Model 3b	5	Top arm rails (progressive results)
Model 4a	6	Front stumps & back posts & back uprights & side rails
Model 4b	6	Stretchers

Table 3. — Stepped cyclic loading schedule for testing fatigue life of full-size Back Top Rails, and calculated maximum moments in Back Top Rails for each fatigue load level.

				Mj	
j	Cyclic load	Cumulative cycles	Acceptance level	Simply	Fixed
	(lb)[a]			---(pound-in.)---	
1	75	25,000	Light-service	2,250	1,425
2	100	50,000	Medium-service	3,000	1,900
3	125	75,000		3,750	2,375
4	150	100,000	Heavy-service	4,500	2,850

[a]1 pound = 4.448 N; 1 pound-in. = 0.113 N · m.

Table 4. — Stepped cyclic loading schedule for testing fatigue life of full-size Front Rails, and calculated maximum moments in Front Rails for each fatigue load level.

				Mj	
j	Cyclic load	Cumulative cycles	Acceptance level	Simply	Fixed
	(lb)[a]			---(pound-in)[a] ---	
1	100	25,000		3,000	1,900
2	200	50,000		6,000	3,800
3	300	75,000	Light-service	9,000	5,700
4	400	100,000	Medium-service	12,000	7,600
5	500	125,000		15,000	9,500
6	600	150,000	Heavy-service	18,000	11,400

[a]1 pound = 4.448 N; 1 pound-in = 0.113 N · m.

Table 5. — Stepped cyclic loading schedule for testing fatigue life of full-size Spring Rails, and calculated maximum moments in Front Spring Rails for each fatigue load level.

				Mj	
j	Cyclic load	Cumulative cycles	Acceptance level	Simply	Fixed
	(lb)[a]			---(pound-in)[a]---	
1	100	25,000		420	300
2	200	50,000		840	600
3	300	75,000	Light-service	1,260	900
4	400	100,000	Medium-service	1,680	1,200
5	500	125,000		2,100	1,500
6	600	150,000	Heavy-service	2,520	1,800

[a]1 pound = 4.448 N; 1 pound-in = 0.113 N · m.

Table 6. —Stepped cyclic loading schedule for testing fatigue life of full-size Top Arm Rails, and calculated maximum moments in Top Arm Rails for each fatigue load level.

j	Cyclic load	Cumulative cycles	Acceptance level	Mj Simply	Mj Fixed
	(lb)[a]			--- (pound-in)[a] ---	
1	100	25,000		850	425
2	200	50,000		1,700	850
3	300	75,000		2,500	1,275
4	400	100,000	Light-service	3,400	1,700
5	500	125,000		4,250	2,125
6	600	150,000	Medium-service	5,100	2,550
7	700	175,000		5,950	2,975
8	800	200,000	Heavy-service	6,800	3,400

[a]1 pound = 4.448 N; 1 pound-in = 0.113 N · m.

Table 7. — Stepped cyclic loading schedule for testing fatigue life of full-size Front Stumps, and calculated maximum moments in Front Stumps for each fatigue load level.

j	Cyclic load	Cumulative cycles	Acceptance level	Mj
	(lb)[a]			(pound-in)[a]
1	50	25,000		900
2	75	50,000	Light-service	1,350
3	100	75,000		1,800
4	125	100,000		2,250
5	150	125,000	Medium-service	2,700
6	175	150,000		3,150
7	200	175,000	Heavy-service	3,600

[a]1 pound = 4.448 N; 1 pound-in = 0.113 N · m.

Table 8. — Stepped cyclic loading schedule for testing fatigue life of full-size Back Posts, Uprights, and Bottom Side Rails, and calculated maximums moments in Back Posts & Uprights for each fatigue load level.

j	Cyclic load	Cumulative cycles	Acceptance level	Mj
	(lb) [a]			(pound-in)[a]
1	112.5	25,000	Light-service	2,925
2	150	50,000	Medium-service	3,900
3	187.5	75,000		4,875
4	225	100,000	Heavy-service	5,850

[a]1 pound = 4.448 N; 1 l.-i. = 0.113 N · m.

Results and discussions

Full-size frame member estimation

Fatigue life of a wood-based composite subjected to a known edge-wise stepped cyclic load schedule can be reasonably well estimated using the Palmgren-Miner rule equation (Palmgren 1924, Miner 1945) if the *S-N* curve of the material is known (Zhang et al. 2005). The Palmgren-Miner rule and *S-N* curve equations have the following forms respectively:

$$\frac{N_1}{N_{f1}} + \frac{N_2}{N_{f2}} + \frac{N_3}{N_{f3}} + \cdots = \sum \frac{N_j}{N_{fj}} = 1 \quad [1]$$

$$S = C - D \times \log_{10} N_{fj} \quad [2]$$

Table 9. — Stepped cyclic loading schedule for testing fatigue life of full-size Stretchers, and calculated maximum moments in Stretchers for each fatigue load level.

j	Cyclic load	Cumulative cycles	Acceptance level	Mj
	(lb)[a]			(pound-in)[a]
1	150	25,000		300*h*
2	300	50,000		600*h*
3	450	75,000	Light-service	900*h*
4	600	100,000	Medium-service	1,200*h*
5	750	125,000		1,500*h*
6	900	150,000	Heavy-service	1,800*h*

[a]1 pound = 4.448 N; 1 pound-in = 0.113 N · m.

where:

N_j = number of cycles applied to a member at the bending moment M_j

N_{fj} = number of cycles to failure obtained from the member material *S-N* curve for the bending moment M_j

S = applied nominal stress (psi)

C = *MOR* (psi)

D = *MOR* × *H* (psi)

Table 10 lists depths of eight structural members using three composites that satisfied stresses corresponding to GSA performance test acceptance levels: light-, medium-, and heavy-service levels, under simply supported and fixed end boundary conditions, respectively. The depths were estimated using Equation [**1**] based on known *S-N* curve equations for the materials. The depth of a Back Top Rail with a rectangular cross section for meeting heavy-service acceptance level under the simply supported condition was calculated to illustrate the steps of estimating a member size.

For a rectangular cross section beam subjected to a bending moment, its maximum bending stress, *S*, and moment applied has the following relation (Ugural 1991):

$$S = \frac{6 \cdot M_j}{b \cdot h^2} \quad [3]$$

where:

M_j = applied moment (pound-in.), values given in **Table 3**

b = beam member width (in)

h = beam member depth (in)

Substituting the stress-moment relation [**3**] into the *S-N* curve Equation [**2**] yields the following relationship:

$$N_{fj} = 10^{\left(\frac{C}{D} - \frac{6M_j}{Dbh^2}\right)}$$

Then, substituting N_{fj} into Equation [**1**] yields the following equation:

$$\frac{25{,}000}{10^{\left(\frac{C}{D} - \frac{6M_1}{Dbh^2}\right)}} + \frac{25{,}000}{10^{\left(\frac{C}{D} - \frac{6M_2}{Dbh^2}\right)}} + \frac{25{,}000}{10^{\left(\frac{C}{D} - \frac{6M_3}{Dbh^2}\right)}} + \frac{25{,}000}{10^{\left(\frac{C}{D} - \frac{6M_4}{Dbh^2}\right)}} = 1$$

For the Back Top Rail oriented edge-wise to resist the in-plane bending moment and made of pine plywood, the

Table 10. — Sofa frame structural member depths calculated based on the assumption that members are subjected to stepped load schedules.

Frame member	Performance-acceptance level[a]		
	Light	Medium	Heavy
	(in)[b]		
Front rails			
Pine plywood	3.739/2.976	4.318/3.436	5.288/4.208
OSB	4.976/3.960	5.747/4.573	7.041/5.603
PB	8.631/6.869	9.972/7.936	12.237/9.737
Front spring rails			
Pine plywood	1.413/1.182	1.632/1.365	1.998/1.672
OSB	1.881/1.573	2.172/1.817	2.661/2.226
PB	3.262/2.729	3.768/3.153	4.625/3.869
Stretchers			
Pine plywood	2.286/2.040	2.837/2.531	3.845/3.430
OSB	3.510/3.131	4.356/3.886	5.908/5.270
PB	8.019/7.154	9.958/8.883	13.536/12.074
Back top rails			
Pine plywood	1.869/1.488	2.159/1.718	2.644/2.104
OSB	2.488/1.980	2.873/2.286	3.520/2.801
PB	4.315/3.434	4.986/3.967	6.118/4.868
Back posts & back uprights & side rails			
Pine plywood	2.131	2.461	3.015
OSB	2.837	3.276	4.014
PB	4.920	5.684	6.976
Front stumps			
Pine plywood	1.448	2.048	2.365
OSB	1.927	2.727	3.151
PB	3.343	4.739	5.486
Top arm rails			
Pine plywood	2.298/1.625	2.815/1.990	3.251/2.298
OSB	3.059/2.163	3.748/2.650	4.331/3.062
PB	5.308/3.753	6.513/4.605	7.540/5.332

[a]Simply supported/fixed end.
[b]1 pound-in = 0.113 N · m.

Table 11. — Equivalent static moments considering fatigue effects for calculation of structural member sizes of the sofa frame model.

Frame member	Performance-acceptance level[a]		
	Light	Medium	Heavy
	(pound-in)[b]		
Front rails			
Pine Plywood	11,537/7,307	15,383/9,742	23,075/14,614
OSB	13,003/8,235	17,340/10,982	26,032/16,487
PB	14,901/9,438	19,889/12,596	29,951/18,965
Front spring rails			
Pine Plywood	1,648/1,154	2,198/1,538	3,297/2,308
OSB	1,858/1,300	2,477/1,734	3,719/2,603
PB	2,129/1,490	2,841/1,989	4,278/2,995
Stretchers			
Pine Plywood	4,314/3,433	6,642/5,285	12,202/9,710
OSB	6,470/5,149	9,965/7,930	18,329/14,586
PB	12,862/10,236	19,834/15,784	36,646/29,160
Back top rails			
Pine Plywood	2,884/1,827	3,846/2,436	5,769/3,654
OSB	3,251/2,059	4,335/2,745	6,508/4,122
PB	3,724/2,359	4,972/3,149	7,487/4,741
Back posts & back uprights & side rails			
Pine Plywood	3,749	5,000	7,500
OSB	4,226	5,636	8,460
PB	4,841	6,464	9,733
Front stumps			
Pine Plywood	1,731	3,461	4,616
OSB	1,951	3,905	5,215
PB	2,235	4,492	6,021
Top arm rails			
Pine Plywood	4,358/2,179	6,538/3,269	8,719/4,360
OSB	4,913/2,457	7,376/3,688	9,849/4,925
PB	5,635/2,818	8,485/4,243	11,372/5,686

[a]Simply supported/fixed end.
[b]1 pound-in = 0.113 N · m.

constants C and D are 6,600 and 330, respectively. Solving the equation yielded a rail depth of 2.644 inches.

Member depth values calculated based on fixed end boundary condition can be viewed as progressive sizes for the frame design, and the results from simply supported condition can be viewed as the conservative design values. Optimum design values for member sizes considering joint rigidity effect should lie between these two values.

Equivalent static moments

Based on member depth values in **Table 10**, the equivalent maximum static moment, M_u, can be calculated using the stress-moment relation [**3**]. By setting maximum bending stress in the equation equal to the MOR value of the material selected, the moment is:

$$M_u = \frac{MOR \cdot b \cdot h^2}{6}$$

Therefore, with the given $b = 3/4$ in and depth h of each member in **Table 10**, the corresponding equivalent static moments for each member were calculated (**Table 11**).

It was observed that for a given performance-acceptance level the ratios of the equivalent static moments to the corresponding fatigue moments were 1.28, 1.45, and 1.66 for plywood, OSB, and PB, respectively. For instance, if pine plywood was selected for a Back Top Rail, the ratio for satisfying light performance-acceptance level was 1.28, which was calculated by 2,884/2,250. The equivalent static moment value of 2,884 pound-in was found from **Table 11**, while the fatigue moment value of 2,250 pound-in was from **Table 3**. These values suggest that for design of a sofa frame member to satisfy a specified fatigue moment level, a static design moment value can be derived by multiplying a constant by the fatigue moment to which the member was subjected. The ratios calculated from this study show that these constants are different among different types of wood composites. Particleboard had the highest ratio among the three materials.

Conclusions

A simplified analysis method was presented for using beam models to analyze moments of structural members in a three-dimensional sofa frame model. The method for applying the simply supported beam model was proposed to estimate the moment value of a structural member in a sofa frame, which yielded conservative estimated member sizes. The fixed end beam model was considered to obtain the moment that can be used to estimate the progressive sizes of a sofa frame member.

Stepped cyclic load schedules applied to critical structural members in a sofa frame were developed. Maximum bending moments within those members were also calculated based on their beam models and GSA loads and boundary conditions they were subjected to. The load schedules, including calculated moment values, can be used for member design purposes such as determination of member sizes and stresses, and also for fatigue performance evaluation of full-size frame structural members.

A procedure for estimating member sizes based on known material *S-N* curves and member fatigue load schedules was proposed. Design loads in terms of equivalent static bending moments considering fatigue effects were derived for both conservative and progressive estimation of frame member sizes. This simplified method of calculating member size ranges can help furniture engineers quickly size members.

In conclusion, the rational design of furniture frames to satisfy durability requirements, such as GSA performance tests, would benefit from information such as design loads and material fatigue property data. The procedure and analysis technique explored in this study would be incorporated into the current furniture product design process. This would enable furniture engineers to obtain a first estimate of frame member sizes.

Literature cited

Eckelman, C.A. 1982. Product engineering and strength design manual for furniture. Furniture Res. Center, West Lafayette, Indiana.

General Serv. Administration (GSA). 1998. FNAE-80-214A. Upholstered furniture test method. Furniture Commodity Center, Federal Supply Services. Washington. D. C.

Miner, M.A. 1945. Cumulative damage in fatigue. J. Appl. Mech. 12(3): 159-164.

Palmgren, A. 1924. Die lebensdauer von kugallagern (The service life of ball bearings). Zeitschrift des Vereines Deutscher Ingenieure 68(14): 339-341.

Ugural, A.C. 1991. Mechanics of materials. McGraw-Hill, Inc, New York.

Zhang, J., B. Chen, and S.R. Daniewicz. 2005. Fatigue performance of wood-based composites as upholstered furniture frame stock. Forest Prod. J. 55(6):53-59.

__________, F.C. Lin, C. Eckelman, and H. Gibson. 2000. A structural design model for sofa seat frames equipped with sinusoidal-type springs. Forest Prod. J. 50(3):49-57.