Chapter III
Load Considerations In Furniture Design

Introduction

Before we can determine how strong to build a piece of furniture, we must first know the characteristics of the loads it will be called upon to carry in service. Once these loads are known, the furniture can then be designed to resist what are presumably the most representative load values. Selection of these values is one of the most important steps in the entire design process and requires considerable judgement and experience. If the loads selected are too light, the furniture may fail prematurely in service. If, on the other hand, the loads are too heavy, the design will be overly conservative so that materials will be needlessly wasted. Deflection of the furniture and its parts must also be considered. Cabinets with doors that won't close, sagging bookshelves, drawers with drooping bottoms, and shaky tables are all undesirable. Usually, the designer must seek to achieve a balance between strength, stiffness, and economy. Company policy may also play a part in the selection of design loads. One company may want to produce a piece of furniture that will never fail in service, whereas another company may be willing to accept occasional breakdowns provided that they do not result in personal injury.

Obviously, the more information that a designer has available to him, the greater the chances that he will be able to achieve an optimum design. Unfortunately, a systematic scientific investigation of the loads which act on furniture has never been undertaken so that relatively few service loads have been thoroughly evaluated, and there is a scarcity of pertinent quantitative data. Occasionally, service loads are quite simple in nature and can be estimated readily. More often, however, they are extremely complex and cannot be determined by any simple reasoning process. In such cases, the designer must take the steps necessary to investigate these loads by experiment.

Until load requirements for furniture are legally established, it is inappropriate to attempt to discuss specific design loads. What can be done, however, is to describe and illustrate those service loads that are known and also to discuss the loadings that are used in certain performance tests that are useful for analytical purposes.

Loads

Loads may be classified according to the effect they produce, their inherent nature, and the manner in which they are applied.
Static loads are loads which are applied gradually, build up to their maximum value, and then remain constant. The weight of a man sitting quietly in a chair is an example of a static load. The weight of books on a bookshelf and the weight of the dishes in a kitchen cabinet are other examples.

Repeated loads are loads which are successively applied and removed, usually for a large number of cycles. Such loads may cause fatigue failures in which a member or joint fails under the action of a load that is much smaller in magnitude than the static load it was designed to withstand.

Impact loads are those loads which are applied suddenly, usually by a body in motion. A child bouncing on a bed is a good example of such a load. The effect produced upon a piece of furniture by an impact load will be much greater than if this same load were applied gradually. A man dropping heavily into a chair, for example, may exert nearly twice his body weight on the chair.

Other descriptions may also be used to classify loads. A load may be either concentrated or distributed, depending on the area to which it is applied. Concentrated loads are applied to only very small areas. Often, they are treated as "point" loads; i.e., the area on which they act is assumed to be negligible. Distributed loads are applied over an area. The seat force exerted by a subject on a chair is an example of a distributed load.

Forces

There is a certain ambiguity in the term "loads" since we usually tend to think of a load as the weight of a body which a structure is supporting. But this term may also refer to a force which is applied to a structure. In general, a force may be defined as the action of one body on another. As applied to structures, we may say that a force is an action that changes the shape of the body upon which it acts. Both contact and non-contact forces exist. When one body presses directly on another, it is referred to as an applied or contact force. When the earth exerts a gravitational force on another body through space, however, it is referred to as a non-contact, or action-at-a-distance force.

The difference between external and internal forces must also be recognized. External forces are those forces which are applied to the structure by another body. Internal forces are the resisting or opposing forces which develop internally in the members of the structure in response to the external loads. External forces can be further sub-divided into applied and reactive forces. When a man sits down in a chair, for example, he is applying an external force to the chair seat. At the same time, the floor is exerting reactive forces upwards on the legs of the chair.

A force is defined by its characteristics. These include its magnitude, line of action, direction, and point of application. Forces may
be represented graphically by vector arrows which reflect these characteristics.

The positive directions of the six possible independent forces that can occur at a point are given in Figure (3-1). This coordinate system serves to define the positive directions of the six independent displacements as well as those of the forces.

When two or more forces act on a piece of furniture, Figure (3-2a), it is often convenient to replace them by a single resultant force which has the same effect on the structure as the forces it replaces. Such forces may be added quite simply to obtain a single resultant by using graphical construction methods as shown in Figure (3-2a), Figure (3-2b), and Figure (3-2c).

By using this technique, both the magnitude of the resultant force and its line of action can be found. Conversely, when a force acts upon a structure at an oblique angle, it is often convenient to replace this single force by its two components which act either parallel or perpendicular to the coordinates of the structural system as defined in Figure (3-1).

![Figure 3-1. Coordinate system used to identify forces and displacements](image)

![Figure 3-2. Resolution of forces by graphical methods.](image)

Continuing with the previous example, we see in Figure (3-2d) through (3-2e) that the single force acting obliquely on the top of the table can be resolved into a vertical x3- component of 120 pounds and a horizontal x2- component of 40 pounds.

Another important characteristic of forces is referred to as moment. In general, the moment of a force about an axis may be defined as the tendency of the force to rotate the body upon which it acts about that axis. The units of moment are usually given in pound-inches since moment is the product of a force times a distance; i.e.,
\[ F_4 = F \times d \]

where \( F_4 \) is the moment, \( F \) is the applied force, and \( d \) is the moment arm. The symbol \( F_4 \) is used for moment since it acts in the \( x_4 \) - coordinate direction; i.e., in essence it operates in a rotating direction about the \( x_1 \) - axis.

In Figure (3-3), a force of 40 pounds is shown applied to a wrench which is being used to turn a length of pipe.

Since the force is applied 12 inches away from the longitudinal axis of the pipe, the moment of the force on the pipe is

\[ F_4 = 40 \text{ lb} \times 12 \text{ in} = 480 \text{ lb} \cdot \text{in} \]

The moment of the external forces acting about a given point on a piece of furniture may be found in much the same manner. Consider, for example, the 50-pound front-to-back force acting on the top of the chair side frame shown in Figure (3-4). Following the same procedure used above, the moment of this force about the point of contact of the back leg with the ground, point G, is equal to

\[ F_4 = 50 \text{ lb} \times 32 \text{ in} = 1600 \text{ lb} \cdot \text{in} \]

Support Reactions

When the resultant of all the forces which act upon a piece of furniture is zero, we say that all of the forces are in equilibrium. For a plane structure, this condition requires that the sum of the forces in the \( x_2 \)-direction, the \( x_3 \)-direction, and the sum of the moments about the \( x_1 \)-axis in the \( x_4 \)-direction must all equal zero; i.e.,

\[
\text{Sum} (F_2) = 0, \text{Sum} (F_3) = 0, \text{Sum} (F_4) = 0
\]

By making use of these equilibrium expressions, the reactions at the supports for various pieces of furniture can be found for different types of loadings. A free-body diagram is of great help in determining support reactions since it is the best means of accounting for and describing all of the forces which act upon the structure in question. A free-body diagram is simply a line drawing of a structure which has been isolated from its surroundings and which shows all of the external forces acting upon it. Two steps are usually involved in drawing free-body diagrams. First, a decision must be made as to whether the entire piece of furniture will be analyzed, or only a
part of it. Once that decision has been made, an outline of the external boundary of the desired portion of the structure is drawn. Second, all of the external forces which act upon the isolated body are drawn in their correct positions.

The physical behavior of the supports themselves must be specified. Three types of supports are generally treated in structural problems—roller, pinned, and fixed. All of the possible displacements and forces which can occur at each type of support are given in Figure (3-5). Six independent displacements along with six independent forces are possible at any support in a three-dimensional system. A support point, therefore, has six potential degrees of freedom. A pinned support allows rotational motion in the \( x_4 \), \( x_5 \), and \( x_6 \) directions but prevents linear motion in the \( x_1 \), \( x_2 \), and \( x_3 \) directions: that is, it prevents horizontal and vertical movement. In a three-dimensional system, therefore, a pinned support has three degrees of freedom and three degrees of constraint. A roller support allows both rotational and horizontal movement, in the \( x_1 \) and \( x_2 \) directions, but prevents any movement in the \( x_3 \) direction. Roller supports, therefore, have five degrees of freedom and only one degree of constraint.

When considering a two-dimensional problem, the maximum possible number of degrees of freedom decreases to three since

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*Figure 3-5.*
forces and displacements in the $x_1$, $x_2$, and $x_6$-directions are not considered. Under these conditions a pinned joint has one degree of freedom and two degrees of constraint, whereas a roller support has two degrees of freedom and one degree of constraint.

Support reaction forces for each type of support are also shown in Figure (3-5). The maximum possible number of reaction forces which can occur at a support is equal to the degrees of constraint imposed by the support. Other forces can occur at supports, however, since external forces can be applied at these points.

It is not always easy to draw a correct free-body diagram. Often, the magnitudes of the forces, their directions, and points of application will not be known. In some cases, experimental evidence may be needed before the correct free-body can be drawn. Additional information concerning free-body diagrams can be found in elementary texts dealing with statics and strength of materials (Jensen and Chenoweth, 1967; Meriam, 1957); and the reader is urged to consult one of these references for a more complete treatment of the subject.

The magnitudes of support reactions are found by applying the laws of equilibrium to the structure in question. As an example, a table side frame is shown in Figure (3-6) which is supported by a pin at one end and by a roller at the other end. The table is 60 inches long and a vertical force acts downward on it at a point 20 inches from its left end. Summing moments about the support at point G gives

$$F_y \times 60 \cdot \text{in} - 100 \cdot \text{lbs} \times 40 \cdot \text{in} = 0$$

or,

$$F_y = \frac{4000}{60} = 66.7 \cdot \text{lbs}.$$  

Similarly, summing moments about the support at point F gives

$$G_y \times 60 \cdot \text{in} - 100 \cdot \text{lbs} \times 20 \cdot \text{in} = 0,$$

or,

$$G_y = \frac{2000}{60} = 33.3 \cdot \text{lbs}.$$  

To check these values, the sum of forces in the vertical direction can also be calculated. Thus,

$$F_y = 100 \cdot \text{lbs} - 66.7 \cdot \text{lbs} - 33.3 \cdot \text{lbs} = 0$$

It should be noted that since no horizontal forces act on the table, there are no horizontal support reactions.

A more complex problem is given in Figure (3-7). In analyzing this chair side frame, it has been decided that the front leg will not carry any horizontal loads; therefore, it has been placed on a roller. It should be noted that this was the analyst's decision and would not necessarily be true.

Figure 3-6.
for every case. Summing forces in the horizontal direction gives
\[ 50 \cdot \text{lbs} - G_H = 0 \]
or,
\[ G_H = 50 \cdot \text{lbs}. \]

Summing moments about point G gives
\[ -50 \cdot \text{lbs} \times 32 \cdot \text{in} - F_v \times 20 \cdot \text{in} + 180 \cdot \text{lbs} \times 10 \cdot \text{in} = 0 \]
or,
\[ F_v = \frac{-1600 + 1800}{20} = 10 \cdot \text{lbs}. \]

The positive sign of \( F_v \) indicates, in this case, that it is operating upward as shown. The remaining vertical force, \( G_v \), is found by summing forces in the vertical direction.
\[ G_v + 10 \cdot \text{lbs} - 180 \cdot \text{lbs} = 0 \]
or,
\[ G_v = 170 \cdot \text{lbs}. \]

To further illustrate the procedures involved in evaluating support forces, let us determine the vertical and horizontal support forces, \( F_v, G_v \), and \( F_H, G_H \), respectively for the chair side frame shown in Figure (3-8).

Since the front leg is supported on a roller, we know that \( F_H = 0 \). Therefore,
\[ -G_H - 50 \cdot \text{lbs} + 100 \cdot \text{lbs} = 0, \]
or
\[ G_H = 50 \cdot \text{lbs}. \]

applied in the direction shown. Next, summing moments about point G gives
\[ -F_v \times 18 + (50 \times 16) + (190 \div 18) + (50 \times 9) + (50 \times 9) - (100 \times 32) = 0 \]
or
\[ F_v = 1920 / 18 = 106.7 \cdot \text{lbs}. \]
Similarly, summing moments about point F gives
\[ G_v \times 18 - (100 \times 32) - (50 \times 9) - (50 \times 9) + (50 \times 16) = 0 \]
or,
\[ G_v = 3300 / 18 = 183.3 \cdot \text{lbs}. \]

Summing forces in the \( x \)-direction gives
\[ F_v = 106.7 + 183.3 - 190 - 50 - 50 = 0 \cdot \text{lbs} \]
which serves as a check on our calculations.

**General Design Considerations**

As previously stated, design loads for furniture have never been established legally. In the absence of a definitive code of loadings, it is largely the responsibility of the designer.
to select the loads that will be used in the design of a piece of furniture. Selection of such loads is a process requiring extensive experience and a comprehensive knowledge of the history of development and use of the piece of furniture in question. The designer must also be acutely aware of the changing attitudes of the public and of the courts of law with respect to expected service life and the consequences of failure, particularly if bodily injury is involved. Undoubtedly, the public prefers the strongest, stiffest, and most durable furniture it can have - furniture that will last a lifetime. The question that the designer must answer is whether or not the public is willing to pay for it.

In making the decisions that are prerequisite to the selection of design loads, it is helpful to specify expected use categories since this thought process will often help to define the expected minimum and maximum limits of strength and durability. Many different categories of use could be proposed, but the author has found the following five to be useful:

a) Light duty household
b) Medium duty household
c) Heavy duty household or light duty institutional
d) Medium duty institutional
e) Heavy duty institutional.

Sample Analytical Loadings

A number of known service loads are described in this section along with a number of pertinent loadings that are specified in various performance tests. Because of the magnitude of the subject, no attempt is made in this section to treat either all types of possible loadings or all types of furniture. Instead, material is presented and discussions given which should aid the designer and manufacturer in selecting the loads most appropriate for each design problem. It must be emphasized here, however, that none of the loads discussed are suggested as actual design loads; rather they are presented for analytical purposes only.

Side Chairs

Vertical Seat Loads

Vertical seat loads for a subject at rest would be expected to be closely related to body weight; i.e., the heavier the subject, the greater the seat load. The distribution of weights of a number of subjects evaluated in one extensive survey gave a 95th percentile value of 217 pounds and a 99th percentile value of 241 pounds for lightly clothed male subjects (Damon, et al., 1966). According to these values, therefore, no more than five percent of lightly clothed males weigh more than 217 pounds and only one percent weigh more than 241 pounds. Although traditional statistics provide good estimates of the maximum static seat loads to be expected on chairs, recent weight trends must be taken into account. Recent data, for example, indicates that some 4 percent of office workers
weigh over 400 pounds. This group represents a sufficiently large number that some manufacturers are producing chairs specifically designed to meet their needs.

Dynamic seat loads that occur when a person sits down or arises from a chair must also be considered. Tests by the author indicate that in sitting down forcefully, a person can exert nearly twice his body weight on a chair seat. This result indicates that a subject weighing 241 pounds could, therefore, be expected to exert a momentary seat load of nearly 500 pounds, and some proprietary tests do, in fact, call for a static load on the seat of 500 pounds. Other specifications (Anon. 4) for office chairs call for dropping a sand bag weighing from 175 to 300 pounds from a height of 6 inches onto the seat of a chair. Tests carried out by the author indicate that a sand bag dropped from a height of 6 inches may exert an impact force of about seven times its own weight. A 300 pound sand bag would, therefore, be expected to generate a momentary vertical seat force of one ton. Performance specifications (Anon. 1, 2, and 5) also call for applying loads of from 175 to 282 pounds to the seat.

From a structural viewpoint, an important question to be answered is how the loads are transferred from the seat to the chair frame. In the case of solid wood seats and slip seats with plywood bases, the loads may be transferred to the tops of the front legs and to the back rail. With other seats, loads may be transferred primarily to front and back rails, to side rails, or to a combination of both. If webbing is attached to the rails such as in chairs with padded seats, a vertical seat load will cause both vertical and horizontal forces to act on all of the rails.

A chair with the seat load equally distributed to all four rails is shown in Figure (3-9a) and Figure (3-9b) for purposes of analysis. The floor supports for this type of loading should be such that the legs are free to spread apart. Based on performance test specifications which many chairs must satisfy, loads of about 225 to 500 pounds would seemingly be appropriate for analytical design purposes.

The acceptance levels specified in the standard method of test for library chairs promulgated by the American Library Association (1983) provides a good indication of appropriate loads for chairs used in severe service environments. Loads for solid wood seats range form a low of 600 to a high of 1000 pounds. Comparable values for upholstered spring seats range from a low of 300 to a high of 400 pounds. These

![Figure 3.9](f3-9ab.jpg)
values are for cyclic rather than static load tests, but they do provide a
reasonable indication of the loads the chairs must resist.

Back Loads

Loads are normally applied to chair backs when a person sits down
in a chair and leans backward. Hart (1967) reports that under normal
conditions of use, a person exerts a back load of about 60 pounds,
irrespective of his weight. When a back was deliberately heavily loaded,
however, back loads were found to be related to body weight, and it was
found that a 224 pound man could be expected to exert a back force of
140 pounds. In keeping with these findings, one performance
specification calls for a back load of 112 pounds (Anon. 1). More recent
specifications (Anon. 5) call for back loads which range from about 90
pounds for medium duty household chairs to 300 pounds for heavy duty
institutional chairs. By way of comparison, U.S. specifications for office
furniture (Anon. 2 and 4) call for back loads of 150 to 300 pounds.
Significant back loads are also imposed on a chair back when a subject
simply tilts backward in the chair. Under these conditions, the author
(1966) found that a 200 pound subject could exert a 98 pound back force.
This type of loading is particularly significant in that it causes a high
bending force to act on the side rail-to-back post joint. There are probably
more chairs damaged by being used in this way than from any other single
cause.

In addition to sitting on the seats of chairs, people will also sit on
the backs with their feet on the seats. This type of use usually occurs at
meetings when someone in the back of the room wishes to obtain a better
view of the speaker. Depending on the body movements of the subject
and the angle of the back, a damaging force can be exerted on the chair
back by the subject.

If a chair is accidentally tipped over, the back will be subjected to
impact loads which may be sufficient to break either the top rail or the
back posts. Since impact loads are of a different nature
than the static loads we are considering here, they will
not be treated in this discussion, but they should be
included in any design process.

A consideration of the back loads which have
been discussed above indicates that for analytical
purposes, side chairs should be designed to carry back
loads which vary in magnitude from 75 to 300 pounds.
These values would correspond to furniture which
ranges in strength and durability from light duty
household to heavy duty institutional.

For purposes of analysis, the back loads should
be applied to the chair in a symmetrical manner.
Usually, one-half of the total back load can be applied to
each of the back posts. The point of application of the load is of critical

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importance; a vertical distance, h, of 16 inches measured from the point of load application to the center of the side rail-to-back post joint has been found appropriate in many cases, Figure (3-10), but should be evaluated individually for each frame. Note that for the loading shown, the front legs are on rollers. The back legs, therefore, carry horizontal floor reaction forces which are equal in magnitude to the back force.

**Vertical Loads On Stretcher**

In reaching for books on a shelf, or in carrying out similar activities, people will frequently stand on the stretcher of a chair. In so doing, loads are imposed on the stretcher that are at least as great and usually much greater than the weight of the person involved. For design purposes this load should be treated as a vertical load acting at mid span of the stretcher. A specification for school furniture calls for loads of 86 to 147 pounds on stretchers (Anon. 12). Another performance specification (Anon. 1) calls for stretchers to withstand a vertical load of 224 pounds. From a practical point of view, this is probably a realistic loading to use for analytical purposes. The application of such a load to a chair side frame is shown in Figure (3-11). Similar loads can also occur on front and rear stretchers.

**Torsional Loads On Seats**

Often a chair is tilted backwards and then twisted from side to side. Such an action applies a torsional force to the chair frame system which can be quite damaging since essentially all of the joints are subjected to out-of-plane bending forces in addition to the normal in-plane forces. Performance tests (Anon. 1; Anon. 3) call for the application of a 75 foot-lb. torsional force to the seat while the chair is tilted backward with a vertical load of 175 pounds simultaneously applied to the front edge of the seat. In analyzing the effect of torsional forces, the chair should be supported in such a manner that the front legs are unsupported, Figure (3-12).

**Side Thrust Loads On Arms**

When a person arises from a chair, he is likely to push downward and outward on the arms. This action causes side thrust forces to operate on the arms. Side thrust forces are also exerted on the arms of chairs when people sit on them. This type of loading is particularly severe in those types of chairs where the posts (and spindles if present) are slanted outward. Another type of side thrust loading often occurs in restaurants and similar places of business when a patron reaches out and grabs the arm of the chair next to him in order to pull the chair and its occupant.

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closer in order to facilitate conversation. Such action produces large internal forces on the arm stump as well as large side thrust forces on the legs of the chair.

In tests carried out by the author, it was found that outward side thrust forces of 55 to 69 pounds could readily be exerted on the arms of a chair by subjects of 210 to 220 pounds weight as they arose from the chair. Performance tests (Anon. 1, 3, and 5) call for side thrust loads which range in magnitude from 45 pounds to about 200 pounds. When evaluating the structural effect of such loads, the chair should be supported as shown in Figure (3-13).

**Vertical Loads On Arms**

Vertical loads on arms occur when a subject pushes down on the arms as he arises from the chair. Vertical loads also occur when people sit on the arms. Presumably, a person pushing down on the arms would exert a relatively small force. A person sitting on an arm could likely exert a much greater force that could be nearly as great as his body weight.

Performance tests call for loads of less than 100 to more than 400 pounds (Anon. 2 and 5). These loads apply to chairs that range in strength from light duty household to heavy duty institutional. From a structural viewpoint, it is perhaps questionable whether the higher load levels called for in these tests have any relationship to actual strength requirements.

The chair frame should be analyzed with the load at three different points: the arm to stump joint, the arm to back post joint, and at the mid span point of the arm. Floor reactions should allow for lateral movement of all legs as shown in Figure (3-14).

**Side Thrust Forces On Front And Rear Legs**

Side thrust forces on the front legs of chairs may result from a number of service loads. When a person tilts backward in a chair and then drops forward, for example, side thrust forces are exerted on the front legs of a chair with flared legs. When such chairs are used on carpeting, this action may
not cause a problem, but if the legs drop onto a waxed hardwood or tile floor, considerable side thrust forces may develop.

When people pull sideways on the arm of a chair, as was discussed in the section on side thrust loads on arms, floor reaction forces act on the legs -- either pushing them in or pulling them out. People also tilt sideways on chairs, and this action causes side thrust forces on the legs. Various performance tests call for the application of slightly more than 50 up to 175 pounds per leg (Anon. 4 and 5). The loads of lower magnitude are applied to household furniture; the highest values apply to heavy duty institutional furniture.

In keeping with the intent of these performance tests, the chair should be analyzed with the loads applied in a symmetrical manner, Figure (3-15). Loads should be applied both in an inward and outward direction. This type of loading produces heavy stresses on the front rail to front post joint. In arm-type side chairs without a front stretcher this joint is a frequent source of trouble so that design of this joint should not be neglected.

**Horizontal Front To Back Forces On Front Legs**

Generally speaking it does not seem that the front legs of a chair would be subjected to significant front to back forces. Chairs can be deliberately heavily loaded in this manner, however. It is not unusual, for example, for a person standing behind a chair to tilt it forward and then lean downward heavily on the top rail. Children will also push heavily on the back of a chair trying to dislodge someone sitting on it. When the legs of a chair are flared forward, horizontal forces are also exerted on the front legs if someone tilts backward in the chair and then drops forward. Various performance specifications call for front to back loads, and vice versa, of 35 to 150 pounds per leg with loads applied simultaneously to both legs. In analyzing the effects of these loads, the chair should be supported as shown in Figure (3-16).

**Horizontal Front To Back Forces On Rear Legs**

Since the backs of chairs are ordinarily most heavily loaded when the chair is tilted backwards, the back legs, acting collectively, should be able to resist the same front to back forces as the chair back. As was discussed previously under the heading of back loads, the magnitude of these forces would range from 75 to 300 pounds, or, 37.5 to 150 pounds per leg, Figure (3-17).

**Easy Chairs**
Vertical Seat Loads

Since easy chairs can easily be heavily loaded either by someone sitting down heavily or by someone sitting on another person's lap, it seems advisable to design such chairs to resist substantial seat loads, Figure (3-9). Tests by the author indicate that a person dropping heavily into an easy chair can exert a force on the seat of the chair which is nearly equal to double his body weight. For a 225 pound man, this would amount to a force of 450 pounds. One set of performance tests (Anon. 5) calls for somewhat lighter loads ranging in magnitude from about 175 to 280 pounds. Another proprietary performance test, however, calls for the repeated application of a load somewhat greater than 400 pounds on the seat. The GSA performance test for upholstered sofas and chairs calls for the application of cyclic loads that range from a low of 300 pounds to a high of 437.5 pound.

Loads applied to the seat are transferred to the front and back rails as vertical and horizontal loads. The magnitude of the vertical loads can be estimated by dividing the total vertical seat load equally between the front and back rails. Horizontal loads applied to the rails by the springs usually cannot be estimated but must be measured. Furthermore, the magnitude of the spring loads will depend on the type of spring construction used. As an example, in the case of sinusoidal type springs, horizontal spring forces on the rails may reach values of 50 to 150 pounds per spring.

Horizontal Back Loads

Hart (1967) reports maximum loads of about 100 pounds. The author, however, has measured abusive back loads under laboratory conditions as high as 165 pounds. A performance specification (Anon. 5) calls for the application of loads ranging in magnitude from 140 to 225 pounds. These loads are to be applied approximately 12 inches above the seat, whereas the author's load referred to a point 16 inches above the seat, Figure (3-10). The GSA specification for upholstered furniture calls for the application of cyclic loads that range in value from a low of 75 to a high of 150 pounds.

Side Thrust Forces On Arms

Side thrust forces on arms can likely be taken to be about the same as for side chairs. There is a greater tendency for people to sit on the arms of easy chairs but less tendency for someone to try to pull such a chair sideways. Performance specification values (Anon. 5) range from about 50 to 150 pounds. In selecting a load, differences in construction must necessarily be recognized. It is difficult, for example, to design an arm with a stump attached to the side rail to resist as great a side thrust as an arm with a stump attached directly to the front rail.
The GSA specification for upholstered furniture calls for the application of cyclic loads in the outward direction that range in magnitude from a low of 75 to 200 pounds.

**Vertical Forces On Arms**

It is a common practice for people to sit on the arms of easy chairs, and hence they must be designed to carry such loads. Performance specifications (Anon. 5) call for loads from about 150 to 300 pounds in magnitude. From a practical point of view it seems reasonable that an arm should be designed to carry the body weight of at least one person of 229 pounds weight, Figure (3-14).

**Table 1**

<table>
<thead>
<tr>
<th>Characteristic</th>
<th>95</th>
<th>99</th>
</tr>
</thead>
<tbody>
<tr>
<td>Shoulder breadth - inches (add 0.3 in. for light clothing; 1.5 in. for heavy)</td>
<td>20.1</td>
<td>20.7</td>
</tr>
<tr>
<td>Elbow to elbow breadth (add 0.5 in. for light clothing; 2.0 in. for medium; 4.5 in. for heavy)</td>
<td>20.1</td>
<td>21.6</td>
</tr>
<tr>
<td>Hip breadth (men) (add 0.5 in. for light clothing; 1.0 in. for medium; 2.0 in. for heavy)</td>
<td>16.1</td>
<td>17.2</td>
</tr>
<tr>
<td>Weight (men) (add 2.0 pounds for light clothing)</td>
<td>215</td>
<td>239</td>
</tr>
</tbody>
</table>

**Sofas**

**Vertical Seat Loads**

The vertical seat loads selected for the design of a sofa are of particular importance in that they will largely determine the sizes of the front and back rails. Selection of design loads is a somewhat complex process because several possible load combinations exist. The number of people that can sit on a sofa of a given length must be taken into account along with their possible weights and the probability of any given combination of individuals sitting on the sofa at a given time. Possible abusive loadings must also be taken into account. Failures have been observed in front rails, for example, when someone sits on another person's lap on a sofa that is already fully loaded. It should also be recognized that sofas can be severely loaded when people sit down in them heavily. One proprietary performance specification, which presumably takes this type of loading into account, calls for the repeated application of a 425 pound load at any point on the seat surface. Another specification (Anon. 5) calls for the application of two constant seat loads of 170 pounds and a third repeated load which may vary from about 175 pounds...
to 280 pounds. This type of loading, therefore, allows for some degree of abusive loading provided that the third load is of relatively large size.

Anthropometric data are useful in developing a seat load schedule for sofas. Shoulder breadth and elbow to elbow breadth of the subjects are of particular importance. Hip breadth should also be considered. For nude subjects the following statistics apply (Damon, et al., 1966).

In addition to these statistics, McCormick (1964), citing a study conducted by Hooton (1945), indicates that a seat allowance of 19.0 inches per person could accommodate about 85 percent of the public with reasonable comfort in multi-seating units, but that this value should be considered a minimum.

A consideration of the data given by Damon et al., for shoulder breadth and elbow breadth indicates that a lightly clothed subject between 217 and 241 pounds in weight, say 229 pounds, would require 21 inches of seating space. This amounts to a loading of nearly 11 pounds per inch. If the subjects were to sit alternately to the front and rear of the seat, a consideration of the hip-breadth data indicates that subjects of such weight might squeeze into spaces of slightly more than 17 inches. The data presented by McCormick, however, indicate that they would likely be quite uncomfortable since about 19 inches are required for reasonable comfort. An evaluation of both sets of data indicates that a seating allowance of 18 inches or slightly greater is perhaps the most reasonable value to use for a 229 pound subject. Under these conditions, the number of 229 pound subjects that could presumably be seated on sofas of different lengths would be as follows:

The distribution of seat loads from front to back is also of importance in the design of easy chairs and sofas since it will determine what proportion of the total load is carried by the front and back rails. One study of the distribution of loads on the seat and back of an easy chair (DeBat, 1966) indicated that the center of gravity of a subject is near the rear leg of the chair. The back of the chair used in this study formed an angle of about 117-118 degrees with the floor, however, which likely tended to distribute the weight of the subject more to the back of the seat.

A study carried out by Lay and Fisher (1940) on automotive seating gave a more normal distribution in which the resultant of the loads carried by the seat was

<table>
<thead>
<tr>
<th>Front Rail Length - inch.</th>
<th>No. of 229 Pound Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>54 - 71</td>
<td>3</td>
</tr>
<tr>
<td>72 - 89</td>
<td>4</td>
</tr>
<tr>
<td>90 - 107</td>
<td>5</td>
</tr>
<tr>
<td>108 - 125</td>
<td>6</td>
</tr>
</tbody>
</table>

Figure 3-18. Distribution of seat forces from front to back on an automotive type seat.
located at a point about 56 percent of the distance from the front to the rear of the seat. It should be noted that in this type of seating the subject's feet must rest firmly on the floor so that the floor carried about seventeen percent of the subject's weight. Furthermore, the angle of the chair back with respect to the floor was 111.7 degrees. Tests by the author tend to indicate that front and back legs of a sofa carry essentially equal loads regardless of whether the subjects are in the act of sitting down or sitting quietly. On the basis of this evidence, it appears reasonable to divide vertical seat loads equally between the front and back rails.

The GSA test method provides both magnitude of load and point of load application from which the forces acting on the front and back rails can be determined. This specification calls for the application of cyclic loads that range in magnitude from 300 pounds for a light acceptance level to a high of 437.5 pounds for the high acceptance level. The centroid of the load is located at a point xx inches to the rear of the front edge of the sofa.

### Horizontal Back Loads

The loads applied to the back of a sofa would be expected to be similar in nature to those applied to the back of an easy chair. Since multiple loadings are involved, however, a schedule is needed to determine how many loads should be applied per unit length of sofa. The schedule developed for seat loads should apply equally well to back loads; Table 3.

<table>
<thead>
<tr>
<th>Top Rail Length - inch</th>
<th>No. of 229 Pound Subjects</th>
</tr>
</thead>
<tbody>
<tr>
<td>54 - 71</td>
<td>3</td>
</tr>
<tr>
<td>72 - 89</td>
<td>4</td>
</tr>
<tr>
<td>90 - 107</td>
<td>5</td>
</tr>
<tr>
<td>108 - 125</td>
<td>6</td>
</tr>
</tbody>
</table>

Several different back loads may be used with this schedule. Typically the author has used 75, 150, or 225 pound loads for light, medium, and heavy duty furniture. It seems questionable whether loads of less than 75 pounds should be used with this design schedule. Performance specifications, for example, call for the simultaneous application of two back loads, regardless of the length of the sofa, which may range in magnitude from 140-225 pounds (Anon. 5). This loading gives a total back load of 280 to 450 pounds as compared to a total load of only 225 pounds when three 75 pound loads are used.

The GSA specification calls for the application of cyclic back loads that range in magnitude from 75 pounds per position for the light acceptance level to 150 pounds for the heavy acceptance level. In this test, front to back loads are to be applied to the center of the top rail in each of the seat positions.

In addition to strength, backs and top rails should be analyzed for front to back deflection. Many top rails are largely unsupported along
their length and may deflect excessively if they are not designed for stiffness as well as strength.

3.6.3.3 Side Thrust Forces On Arms

The loads given for easy chairs, Figure (3-13), should apply here also, however, the GSA specification for upholstered furniture provides excellent estimates of loads. This specification calls for the application of cyclic loads in the outward direction that range from 75 pounds for the light acceptance level to 200 pounds for the heavy acceptance level. The loads are to be applied at the most forward position on the arm, for example, adjacent to the front post.

Vertical Loadings On Arms

The loads given for easy chairs, Figure (3-14) should apply here also.

Side Thrust Forces On Wings

When sofas are transported while standing on end, the wings are often subjected to substantial side thrust forces. Because of the nature of their construction, it is usually difficult to design wings to resist side thrust forces of any great magnitude. One performance specification (Anon. 1) calls for the application of 28 pound side thrust forces. Realistically, however, it seems that somewhat larger values -- perhaps at least as great as 50 pounds should be used.

Book Shelves and Other Shelving

Vertical Loads

The loads that can be placed on a bookshelf per unit length depend primarily on the width of the shelf and the free space above it; i.e., the height to the next shelf. In many cases, however, shelves must be sized to carry the largest books regularly expected in service so that all of the shelves in a library, for example, may have the same width and overhead space. Assuming a shelf width of about nine inches and a free overhead height of 12 inches, one specification calls for loads of about 27 pounds per foot of shelf (Anon. 7). Another specification (Eckelman, 1) calls for a loading of 45 pounds per square foot of shelf. For a nine-inch wide shelf this would amount to about 34 pounds per foot. In tests carried out by the author, it was found that ordinary books in a college library weighed about 20 pounds a foot. Bound periodicals, however, averaged about 40 pounds a foot, and some weighed as much as 60 pounds. A proprietary specification calls for loads of 48 pounds per foot for library shelves. Sparkes (1974) recommends test loads of 31.75 pounds per square foot for evaluating household.

<table>
<thead>
<tr>
<th>Table 3</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Shelf Width</strong></td>
</tr>
<tr>
<td><strong>Inches</strong></td>
</tr>
<tr>
<td>7.1</td>
</tr>
<tr>
<td>7.1 - 8.7</td>
</tr>
<tr>
<td>over 8.7</td>
</tr>
</tbody>
</table>

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bookshelves and 51.25 pounds per square foot for library bookshelves. Mid span deflections are limited to 1/200 of the span after a seven day loading period.

A Norwegian "Technical Protocol" (Anon. 8 and 9) calls for loads of about the following magnitudes, Table 3. Center span deflection in a "good" quality grade according to this protocol is limited to 0.35 percent of the length of the shelf. For an "excellent" quality grade, deflections are limited to 0.20 percent of shelf length. It should be noted that the loadings in this protocol apply to shelves in bookcases, wall units, and cupboards.

Other protocols can also be suggested. Experience suggests, for example, that deflection in high grade shelving should be limited to L/360 inches where L refers to the length of the shelf in inches. According to this protocol, midspan deflection of a 32-inch long shelf would be limited to 32/360, or about 0.09 inches. Allowable deflections for less demanding areas such as stacks should be limited to L/180. Work carried out by Suchova(10) indicates that the acceptable limit for deflection is about L/165. In keeping with this finding, pilot studies carried out by the author indicate that deflections of L/150 are regarded as objectionable.

When loads are applied to shelves, they should be uniformly distributed. To be conservative, each shelf should be treated as a simple beam supported only at the ends, Figure (3-19)

**Tables and Desks**

**Vertical Loads On Tops**

Vertical design loads for tables and desks depend primarily on the intended use of the tables although abusive loading must be recognized. Probably the most common example of abusive loading occurs when people sit on tables which were not designed for such service. To withstand such loads, a table should likely be designed to withstand no less than 10 pounds per inch measured along the longest length of the table. Another way of looking at this problem is simple to visualize how many 225 to 240 pound people could sit on the table in question and then use the resulting magnitude and distribution of loads for analytical purposes. In the case of metal desks, a federal specification (Anon. 10) calls for the application of a 600 pound load at the front center of the knee space, Figure (3-20) For a 60 inch desk top this amounts to a loading of 10 pounds per inch.

**Side Thrust Forces On Tops**

Side thrust forces are exerted on tables in a variety of ways, such as when someone pushes a table across a floor. Should a leg hit an obstacle, damaging side thrust forces may occur. As the table is pushed in one direction, floor reaction forces push against the ends of the legs in the
opposite direction. These reaction forces cause large bending forces to act on the legs at their point of attachment to the remainder of the table frame. Abusive forces are also placed on table legs when a table is picked up at one end and "walked" across the floor. This action produces the same effect as if a side thrust force were applied to the table. This abusive use of tables becomes more understandable when it is realized that tables and desks are often loaded on end on dollies in order to move them. Desks, in particular, are often transported in this way, and the free end of a single pedestal desk can often be damaged if the desk is transported with the unsupported end down.

In tests carried out by the author, it was found that the maximum horizontal pushing force that could be exerted on a table by an individual was about 240 pounds. The objective here was to obtain a measure of an upper limit for force. These values would be far too great for those types of tables which should not be subjected to side thrust forces. For other types of tables such as "office landscape" type desk-tables, they may be appropriate, however.

Performance specifications call for side thrust forces of about 50-100 pounds (Anon. 12 and 13). These specifications also call for the application of a 50 pound force with only two legs restrained from moving. Such loadings would apply to both household and school furniture.

When considering side thrust forces, the proportion of force transmitted to each leg must be determined. Do all four legs, for example, carry equal shares or do only two legs carry the load? Obviously, the answer to the above question has a significant bearing on the design of the table since one condition doubles the leg and joint forces. Also, if a single leg hits an obstacle, the forces on that particular leg may be quite great, and if such loadings are apt to occur, the legs of the tables must be designed to resist them. As an example, tests of one relatively well-made office type worktable showed that the legs could withstand horizontal floor reaction forces of 100 pounds each. This level of strength was needed in this particular case because the table was moved relatively frequently across a carpeted floor.

In keeping with the previous discussions, a total side-thrust force of 50 to 200 pounds appears appropriate when the table is supported as shown in Figure (3-21). Only two of the legs are
restrained from moving so that side thrust forces on each leg would amount to 25 to 100 pounds.

**Drawers**

Loads for drawers can be calculated by multiplying the useable space in each drawer by a conversion factor of 40 pounds per cubic foot. This conversion factor represents the weight of paper-type materials that could be loaded into such spaces (Bryson and Goss, 1968). Federal specifications for metal desks (Anon. 10) call for loads of 20 pounds in storage drawers and 50 pounds in file drawers. These values are lower than if calculated on a 40 pound per cubic foot basis.

**File Cabinets**

**Drawer Loads**

Loads for drawers in file cabinets can be calculated by multiplying the useable space by a conversion factor of 40 pounds per cubic foot (Bryson and Goss, 1968). If we assume that a manila file folder has a useable height of 9 inches, then a 12 by 27 inch file drawer contains 1.69 cubic feet of useful space so that the load for the drawer would be 67.5 pounds. This loading is in close agreement with federal performance specification AA-F-359 (Anon. 11) which calls for a uniformly distributed load of 64 pounds for letter size drawers and 84 pounds for legal size. For lateral or side opening drawers, loads can be calculated on a 40 pound per cubic foot basis.

**Concluding Remarks**

It seems worthwhile to again emphasize that none of the loadings discussed in the previous sections should be treated as proposed or accepted design loads. Rather, these loads have been presented for analytical purposes only in order to aid the designer in developing and selecting the set of loads which are most appropriate for his particular piece of furniture. Because of the extensive scope of the subject, it is impractical to attempt to describe every possible loading for a specific piece of furniture or to even try to cover general loadings for all types of furniture in a single chapter such as this. Case and cabinet furniture, for example, have not been treated although sources of information concerning loadings for this type of furniture exist (Anon. 14 and 15). Many proprietary load specifications also exist, and where manufacturers are willing to share their knowledge, this information can be of great help.

**Bending Moments and Moment Equations**

When an external force or a reaction acts on, or is applied to, some part of a piece of furniture, internal reactive forces are developed in the part that may include axial, shear, and bending forces. Bending forces are of particular concern because they are most often the cause of structural failure in furniture.
In Figure 3-22, a horizontal force is shown acting on the backpost of a chair. The backpost of the chair is represented as a free body in Figure 3-22b. The symbol "V" represents the shear force acting on the section at point (b), "C" represents the resultant of the compressive stresses acting on the back surface of the upright, and "T" represents the resultant of the tensile stresses acting on the front face of the backpost. The algebraic sum of the moments about point (b) of the external forces (and reactions if present) acting on the backpost is termed the external or bending moment at the point. The moment of the couple formed by forces C and T is called the internal or resisting moment at the section. Equilibrium requires that the internal resisting moment must balance the external moment. Equilibrium, therefore, requires that the internal resisting moment be equal in magnitude but opposite in direction to the external bending moment.

In Figure 3-22b, the following moment equation may be written to express the relationship between the external bending moment and the internal resisting moment, $f_4(bc)$, i.e.,

$$f_4(ba) = F_T \times 18 \text{ in} = 0,$$

or,

$$f_4(ba) = F_H \times 18 \text{ in}.$$

Thus, for a back load of 100 lb,

$$f_4(bc) = 100 \text{ lb} \times 18 \text{ in} = 1800 \text{ in-lb}.$$

Notice that this force acts in a counterclockwise direction and the assumed direction of action is, therefore, correct.

Likewise, the internal bending force acting on the b-end of the chair side rail, Figure 3-22a, is given by the expression

$$f_4(bc) + F_V \times 16.75 \text{ in} - R_L \times 16.75 \text{ in} = 0,$$

or,

$$f_4(bc) = -F_V \times 16.75 \text{ in} + R_L \times 16.75 \text{ in}.$$

For the case in which the chair is tilted slightly backwards so that the front leg is lifted off the floor, $F_V = 200 \text{ lb}$ and $R_L = 0$, so that

$$f_4(bc) = -F_V \times 16.75 \text{ in} = 100 \text{ lb} \times 16.75 \text{ in} = 1675 \text{ in-lb}.$$

Again, note that a positive value is obtained, which indicates that the assumed direction of action of $f_4(bc)$ is correct.

Similar expressions can be written for tables. Thus, in Figure 3-23,
the bending forces acting at joint (c), for example can be found by first
finding the external bending moments acting on this joint. Summing
forces in the x₂-direction, it can be seen that the horizontal floor reaction
force acting on joint (d) is equal,
but opposite in sign, to the
sidethrust force applied to the top
of the table. The internal bending
force acting on the top of leg (cd),
that is, \( f_4(cd) \) may then be found
from the expression
\[
f_4(cd) = 100 \text{ lb} \times 28 \text{ in} = 2800 \text{ in} - lb
\]
Since the forces must be in
equilibrium, the internal bending
force acting on the c-end of the
rail, i.e., \( f_d(cb) \), must equal \( f_4(cd) \).
This bending force may also be
found by summing moments acting
on the c-end of the rail. To do this,
however, the vertical floor reaction
force acting on joint (a) must first
be determined. This can be done
by summing moments about joint
(d). If we assume that the floor
reaction force acting on joint (a) acts upward, then the following expression
results.
\[
F_v \times 50 \text{ in} + 100 \text{ lb} \times 28 \text{ in} = 0,
\]
or,
\[
F_v = -2800 \text{ in} - lb / 50 \text{ in} = -56 \text{ lb}.
\]
The negative result indicates that the
force acts down rather than up as
originally assumed. Summing bending
moments about joint (d) gives
\[
-f_4(cb) + 56 \text{ lb} \times 50 \text{ in} = 0, \quad \text{or,}
\]
\[
f_4(cb) = 2800 \text{ in} - lb.
\]
The positive answer obtained indicates that the
direction of the internal bending force
shown in Figure 3-23, i.e., clockwise,
was correct.
The same techniques may be
used to obtain the internal resisting
moment acting at any point along the
length of any member of a piece of

\[\text{Figure 3-23.}\]

\[\text{Figure 3-24.}\]
furniture. Consider the table frame shown in Figure 3-24 that has a single vertical load acting on the rail. The vertical floor reaction force acting at joint (a) may be found by summing forces about joint (d), i.e.,

$$-F_v(a) \times 50 \text{ in} + 240 \text{ lb} \times 30 \text{ in} = 0,$$

or,

$$F_v(a) = (240 \text{ lb} \times 30 \text{ in}) / 50 \text{ in} = 144 \text{ lb}$$

In like manner, summing forces about point (a) gives

$$F_v(d) \times 50 \text{ in} - 240 \text{ lb} \times 20 \text{ in} = 0,$$

or,

$$F_v(d) = (240 \text{ lb} \times 20 \text{ in}) / 50 \text{ in} = 96 \text{ lb}$$

The internal resisting bending moment acting along the rail from joint (b) to point (e) is found by summing moments about the desired point. Thus, at point (f), the internal resisting bending force is

$$f_4(x) - 144 \text{ lb} \times 10 \text{ in} = 0$$

or,

$$f_4(x) = 144 \text{ lb} \times 10 \text{ in} = 1440 \text{ in} - \text{lb}$$

In like manner, the internal resisting bending force at point (e) is

$$f_4(x) - 144 \text{ lb} \times 20 \text{ in} = 0$$

or,

$$f_4(x) = 144 \text{ lb} \times 20 \text{ in} = 2880 \text{ in} - \text{lb}$$

Similarly, the internal resisting bending moment at point (g) is

$$f_4(x) - 144 \text{ lb} \times 35 \text{ in} + 240 \text{ lb} \times 15 \text{ in} = 0$$

or,

$$f_4(x) = 144 \text{ lb} \times 35 \text{ in} - 240 \text{ lb} \times 15 \text{ in} = 1440 \text{ in} - \text{lb}$$

Finally, the internal resisting bending force at joint (c) is

$$f_4(x) - 144 \text{ lb} \times 50 \text{ in} + 240 \text{ lb} \times 30 \text{ in} = 0$$

or,

$$f_4(x) = 144 \text{ lb} \times 50 \text{ in} - 240 \text{ lb} \times 30 \text{ in} = 7200 \text{ in} - \text{lb} - 7200 \text{ in} - \text{lb} = 0,$$

as it must.

When more than one load acts on the structure as shown in Figure 3-25, the same procedure is followed, i.e., the bending moments of all the forces are summed about the point in question. Proceeding as before, the vertical floor reaction force, $F_v$, is found by summing moments about point (g), i.e.,

$$-F_v(a) \times 60 \text{ in} + 100 \text{ lb} \times 40 \text{ in} + 150 \text{ lb} \times 24 \text{ in} = 0,$$

or,

$$F_v(a) = (100 \text{ lb} \times 40 \text{ in} + 150 \text{ lb} \times 24 \text{ in}) / 60 \text{ in} = 126.7 \text{ lb}.$$  

The internal resisting moment acting at point (e), for example is then found by summing moments about this point, i.e.,

$$f_4(e) - 126.7 \text{ lb} \times 48 \text{ in} + 100 \text{ lb} \times 28 \text{ in} + 150 \text{ lb} \times 12 \text{ in} = 0,$$

or,

$$f_4(e) = 126.7 \text{ lb} \times 48 \text{ in} - 100 \text{ lb} \times 28 \text{ in} - 150 \text{ lb} \times 12 \text{ in} = 1482 \text{ in} - \text{lb},$$

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In the case of line loads, such as the load shown acting on the rail of the table in Figure 3-26, that portion of the load acting on the section of the rail in question is replaced by a resultant force that acts through the centroid of that portion of the load acting on the section. The total load exerted on the rail by the line load amounts to \(5 \text{ lb/in} \times 60 \text{ in} = 300 \text{ lb}\). Owing to symmetry, half of this load is transferred to each reaction point so that \(F_v = G_v - 150 \text{ lb}\). The internal resisting bending force at point (f), \(f_a(f')\), for example, may then be found from the expression

\[f_a(f') - 150 \text{ lb} \times 30 \text{ in} + 150 \text{ lb} \times 15 \text{ in} = 0,
\]

or,

\[f_a(f') = 150 \text{ lb} \times 30 \text{ in} - 150 \text{ lb} \times 15 \text{ in} = 2250 \text{ in-lb}.
\]

Figure 3-25.

Figure 3-26.
Examples

1. Calculate the vertical floor reaction forces. Calculate the bending force acting at the center of the table top.

2. Calculate the vertical and horizontal floor reaction forces. Calculate the bending moment acting at joint d.

3. Calculate the vertical floor reaction forces and the bending moments acting at the center and at the third points along the length of the table top.

Figure 3-ap1.
4. Calculate the vertical and horizontal floor reaction forces. Calculate the bending moment acting at joint $d$ and at the center of the table top.

References


Anon. 4. 1964. Interim Federal Specifications AA-C-00275d, General Services Adm., Washington, D.C.


Anon. 11. AA-F-359.


Selected References