Availability of complete structural information enables architects and designers to make proper use of Blum's component systems to provide safe, durable handrail installations. The designer can engineer installations to conform to specific building code loading criteria or can establish design requirements for a given installation on the basis of anticipated traffic exposure.

The five major considerations for the structural design of handrails are:

1. Structural loading criteria as established by governing building codes or special design requirements.
2. Properties of railing materials and allowable stresses for design.
3. Elements of sections for railing components.
4. Load, stress, and deflection relationships expressed as formulas for engineering design.
5. Proper attachment and sound supporting structure.

CODE REQUIREMENTS AND REGULATIONS

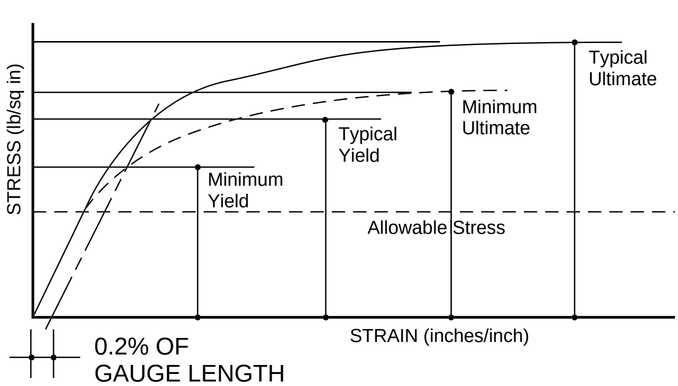
Structural requirements for railings usually are expressed in one of two ways, depending on governing codes and regulations. Some of these specify an applied loading distributed uniformly along the rail while others specify loading concentrated on the top rail. The designer should consult governing codes, local ordinances, project specifications, and regulatory authorities to determine requirements for compliance.

The Americans with Disabilities Act (ADA): Refer to page iii for information regarding handrail dimensions mentioned in the ADA Accessibility Guidelines and ANSI 117.1-2004.

ALLOWABLE STRESSES

To provide adequate safety factors, the engineering profession assigns to each material an allowable design stress which is usually expressed as a specific fraction of minimum yield, or sometimes as a smaller fraction of minimum ultimate strength. Allowable stresses vary with the composition and temper of the material and also, to some degree, with the kind of shape and the direction of stress.

Yield strength is the point of stress (in pounds per square inch) at which material fails to return to its original position after the stress has been removed and takes a permanent set. Minimum yield is defined as the test value exceeded by 99% of a large number of specimens. For non-ferrous metals, the yield point is arbitrarily defined as the point of stress at which permanent set is a specific fraction of 1% of the length of the test piece (0.2% offset as shown below or 0.5% elongation). Ultimate strength is considerably higher (see graph).



ELEMENTS OF SECTIONS

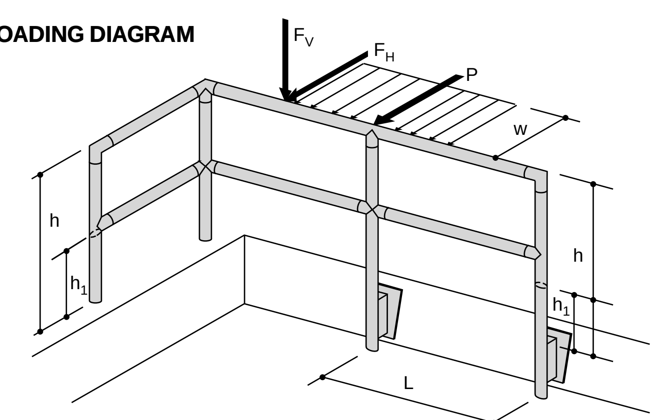
Properties of sections of **JB®** handrail mouldings, posts, and support sections are listed on page 124. For properties of bars, shapes, and tubes, see pages 105-122**.**

MECHANICAL PROPERTIES OF MATERIALS

Below is a table of metals used in the architectural components described in this catalog, together with their yields, allowable stresses, and moduli of elasticity. These mechanical properties have been established by producers of the various materials.

Material	Allowable Bending Stress for Design (psi)	Expected Minimum Yield (psi)	Modulus of Elasticity (psi x 106)
Aluminum 6061-T6, shapes major axis	19,500	35,000	10.0
shapes minor axis	27,700	35,000	10.0
Aluminum 6063-T6, shapes major axis	15,200	25,000	10.0
shapes minor axis	19,700	25,000	10.0
Aluminum 6063-T52, bars and shapes	12,600	16,000	10.0
Aluminum 6063-T52, tubing	11,300	16,000	10.0
Aluminum 6063-T832, drawn pipe	24,800	35,000	10.0
Bronze C38500, extruded	9,700	16,000	14.0
Bronze C38500, handrail moulding and tubing	14,500	24,000	14.0
Bronze C38500, rectangular tubing, bars and shapes	21,200	35,000	14.0
Red Brass C23000, drawn pipe, ASTM B43	11,000	18,000	17.0
Nickel-Silver C79800, extruded	24,000	40,000	18.0
Stainless Steel type 304, extruded, ASTM A276	15,000	25,000	28.0
Stainless Steel type 304, hot-rolled, ASTM A276	18,000	30,000	28.0
Stainless Steel type 304, cold-formed	15,100	28,000	28.0
Stainless Steel type 304 round tubing (as welded)	30,000	55,000	28.0
Carbon Steel C1010, roll-formed, ASTM A29	16,800	28,000	29.0
Carbon Steel C1010, hot-rolled, ASTM A29	16,800	28,000	29.0
Acrylic/Wood	3,760	4,975	1.8

LOADING DIAGRAM

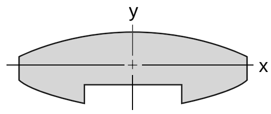


EXPLANATION OF SYMBOLS

w* = Uniform horizontal loading, perpendicular to the rail (lb/ft).
L = Span between centerlines of posts or brackets (in).
P = Horizontal force, perpendicular to rail applied at top of post (lb).
FH = Horizontal force, perpendicular to rail at any point along the railing (lb).
FV = Vertical force, perpendicular to rail at any point between posts (lb).
h = Height of post. Distance from point of load application above top of attachment (in).
h1 = Distance from top of post attachment to top of reinforcing insert (in).
Sx & Sy = Section modulus about the x- or y-axis respectively (in^3).
Ix & Iy = Moment of inertia about the x- or y-axis respectively (in^4).
k = Stiffness of member.
C = Distance from the neutral axis to the extreme fiber of any section (in).
E = Modulus of elasticity (psi x 10^6).
R = Stiffness ratio.
Pf = Load proportion factor.
Fr = Reaction Factor.

* Values for w (uniform load in lb/ft) are converted to lb/in by dividing by 12.

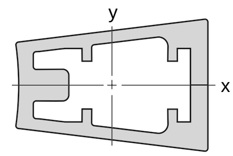
HANDRAILS



Shape	Area	Minor Axis Ix	Minor Axis Sx	Minor Axis Cx	Major Axis Iy	Major Axis Sy	Major Axis Cy
4488†	0.284	0.011	0.046	0.250	0.107	0.107	1.000
6501	1.054	0.017	0.067	0.256	0.629	0.457	1.375
6502	0.740	0.008	0.033	0.235	0.314	0.280	1.125
6503	0.739	0.014	0.050	0.341	0.126	0.168	0.750
6511†	0.386	0.006	0.031	0.238	0.189	0.137	1.375
6512†	0.291	0.008	0.034	0.236	0.136	0.121	1.125
4416	0.927	0.021	0.073	0.291	0.232	0.231	1.000
4428	0.569	0.017	0.041	0.416	0.209	0.215	0.969
4429	0.403	0.008	0.022	0.375	0.104	0.119	0.875
4435	0.746	0.018	0.044	0.406	0.349	0.328	1.062
4441	0.594	0.024	0.055	0.432	0.291	0.258	1.125
4529	0.684	0.059	0.100	0.586	0.616	0.429	1.438
4530 5530	0.779	0.023	0.052	0.449	0.300	0.267	1.125
4531	0.527	0.011	0.030	0.358	0.108	0.133	0.813
4532	0.557	0.018	0.042	0.425	0.260	0.231	1.125
4533	0.937	0.457	0.372	1.229	0.785	0.571	0.916
4534 5534	0.669	0.017	0.040	0.427	0.208	0.214	0.969
4535 5235	0.799	0.024	0.052	0.454	0.344	0.323	1.063
4536	0.434	0.017	0.040	0.423	0.171	0.176	0.969
4537	0.359	0.010	0.028	0.346	0.095	0.116	0.813
4538 5538	0.806	0.194	0.202	0.958	0.661	0.481	1.375
4539	0.670	0.013	0.035	0.369	0.175	0.200	0.875
4572 5572	0.701	0.008	0.032	0.239	0.299	0.266	1.125
4573	1.054	0.016	0.059	0.268	0.654	0.476	1.375
4574 5274	0.919	0.020	0.053	0.376	0.654	0.476	1.375
4575	0.645	0.014	0.033	0.437	0.232	0.232	1.000
6488† 5288†	0.426	0.011	0.044	0.250	0.152	0.152	1.000
6489† 5289†	0.440	0.108	0.144	1.250	0.108	0.144	1.250
6402	1.250	0.083	0.098	0.845	0.412	0.347	1.188
6407	1.680	0.088	0.104	0.844	1.311	0.807	1.625
6436†	0.741	0.159	0.268	0.594	0.422	0.386	1.094
6437†	0.879	0.210	0.336	0.625	0.799	0.532	1.500
6530	0.810	0.032	0.082	0.395	0.315	0.315	1.000
6531	0.573	0.023	0.056	0.411	0.132	0.175	0.750
6532	1.090	0.039	0.084	0.465	0.616	0.493	1.250
6540	0.628	0.312	0.284	1.099	0.034	0.068	0.500
6901	1.387	0.042	0.106	0.396	0.709	0.540	1.313
6902	1.227	0.034	0.084	0.409	0.520	0.438	1.188
6903	0.361	0.013	0.029	0.448	0.109	0.125	0.875
6904	0.726	0.072	0.118	0.612	0.519	0.377	1.375
6905	1.414	0.026	0.089	0.297	1.167	0.718	1.625
6906	2.051	0.058	0.161	0.358	2.195	1.171	1.845
6907	1.441	0.031	0.077	0.402	1.263	0.777	1.625
6929	0.557	0.018	0.042	0.425	0.260	0.231	1.125
6930	0.779	0.023	0.052	0.449	0.300	0.267	1.125
6931	0.527	0.011	0.030	0.358	0.108	0.133	0.813
6932	0.684	0.059	0.100	0.586	0.616	0.429	1.438
6933	0.670	0.013	0.035	0.369	0.175	0.200	0.875
6934	0.669	0.017	0.040	0.427	0.208	0.214	0.969
6935	0.843	0.024	0.053	0.451	0.343	0.323	1.065
6939	1.845	0.085	0.225	0.375	0.932	0.746	1.250
6984	1.079	0.021	0.056	0.367	0.676	0.492	1.375
6985	0.805	0.017	0.040	0.413	0.254	0.254	1.000
6986	2.237	0.104	0.277	0.375	1.658	1.106	1.500
6987	0.746	0.056	0.084	0.662	0.648	0.471	1.375
6988	0.946	0.019	0.075	0.250	0.285	0.285	1.000
8521/22/23	8.924	1.967	2.420	0.812	22.530	8.190	2.750
8542	5.238	1.192	1.362	0.875	5.040	3.250	1.550
8561/62	12.170	2.680	3.298	0.812	56.940	15.184	3.750
8571	1.563	0.135	0.154	0.875	1.487	0.820	1.813
8591	8.415	1.729	2.128	0.812	21.701	8.070	2.869

† Tubing

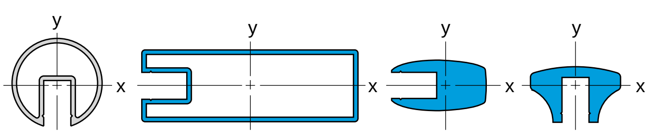
CARLSTADT® POSTS



Shape	Area	Minor Axis Ix	Minor Axis Sx	Minor Axis Cx	Major Axis Iy	Major Axis Sy	Major Axis Cy
230†	0.308	0.050	0.100	0.500	0.095	0.126	0.750
233B(294)* ††	1.021	0.052	0.133	0.390	0.146	0.223	0.655
283(295)* ††	1.412	0.072	0.184	0.390	0.385	0.426	0.905
280†	0.373	0.064	0.128	0.500	0.193	0.193	1.000
436E††	0.655	0.029	0.078	0.370	0.087	0.140	0.622
4830(830)†	0.726	0.096	0.192	0.500	0.241	0.297	0.813
6423(423)	1.555	0.201	0.321	0.625	0.201	0.321	0.625
6424(424)	3.430	0.445	0.712	0.625	2.153	1.566	1.375
6427(427)	1.926	0.208	0.303	0.687	0.496	0.409	0.789
6430(430)†	0.726	0.096	0.192	0.500	0.241	0.297	0.813
6434† 1334†	0.930	0.237	0.379	0.625	0.851	0.619	1.375
6435† ††	0.871	0.210	0.337	0.625	0.710	0.516	1.375
6458(458)† ††	1.110	0.177	0.258	0.687	0.529	0.508	1.042
6459(459)† ††	1.030	0.201	0.322	0.687	0.708	0.679	1.041
8571*	1.563	0.135	0.154	0.875	1.487	0.820	1.873

* Aluminum, for use with stainless steel posts † Tubing †† T6 temper

GLASS RAILING SECTIONS



Railing Number	Area	Minor Axis Ix	Minor Axis Sx	Minor Axis Cx	Major Axis Iy	Major Axis Sy	Major Axis Cy
1130	0.874	0.227	0.236	0.962	0.295	0.311	0.950
1132 1232	1.245	0.632	0.500	1.263	0.717	0.574	1.250
1133	2.414	0.416	0.583	0.714	0.970	0.619	1.566
1134	1.980	0.296	0.300	0.988	1.022	0.817	1.250
1135	1.632	1.910	1.030	1.855	1.947	1.113	1.750
1136	2.250	1.488	1.488	1.000	9.196	2.821	3.260
1154	1.442	1.105	0.721	1.532	1.268	0.845	1.500
1155	1.638	1.875	1.024	1.831	1.989	1.136	1.750
1430	0.501	0.142	0.154	0.927	0.183	0.192	0.950
1432 1452	0.643	0.358	0.280	1.280	0.395	0.316	1.250
1433 1453	0.712	0.630	0.386	1.632	0.643	0.429	1.500
1472 1473	0.909	1.570	0.867	1.811	1.520	0.762	2.000
1230	0.766	0.202	0.223	0.907	0.278	0.292	0.950
1231	0.980	0.518	0.409	1.177	0.585	0.468	1.250
1233 1333	1.442	1.160	0.743	1.568	1.229	0.819	1.500
1235	2.360	2.704	1.471	1.838	2.772	1.584	1.750
1330	0.840	0.236	0.262	0.901	0.324	0.340	0.950
1332	1.245	0.632	0.500	1.263	0.717	0.574	1.250
8662	11.062	3.954	3.954	1.000	30.152	9.420	3.201
1141	4.353	6.068	4.106	1.478	2.314	1.851	1.250
1142	6.828	10.206	5.449	1.873	5.121	4.097	1.250
1143	7.199	12.497	6.598	1.894	6.735	4.898	1.375

Unless designated as T6 temper, all aluminum alloy is in the T52 temper. The values of these elements of sections are approximate and—while they have been ascertained with care—they cannot be guaranteed.

See p. 129 for properties of **Connectorail®** pipe and reinforcing bars.

BENDING MOMENTS AND STRESSES

Determination of bending moments and stress in structural railing members follows conventional engineering design procedures. The resisting moment—calculated from the Section Modulus (S, which equals I/C) and ***Allowable Design Stress*** (f_S)—must equal the ***Applied Bending Moment*** (M).

$$\frac{I}{C} \times f_S = S \times f_S = M$$

This translates into railing formulas as described below.

RAILS: Connections between posts and rails are assumed to be free to pivot. Distribution of loads through multiple spans decreases maximum bending moment in horizontal members. The effect of different numbers of spans may be taken into account by varying the ***Bending Moment Constant*** (K). Calculation of ***Unit Stress*** (f) and ***Length of Span*** (L) are accomplished by using the following formulas:

1. For uniform vertical or horizontal loads (w):

$$M = \frac{w/12 \times L^2}{K} \qquad f = \frac{w/12 \times L^2}{S \times K} \qquad L = \sqrt{\frac{f \times K \times S}{w/12}}$$

$M = S \times f$

K = 8 for one or two spans
K = 9.5 for three or more spans of a continuous rail

2. For concentrated loads (F) applied at mid span:

$$M = \frac{F \times L}{K} \qquad f = \frac{F \times L}{S \times K} \qquad L = \frac{S \times K \times f}{F}$$

$M = S \times f$

K = 4 for one span
K = 5 for two or more spans of a continuous rail

Note: Values of K are defined based on the maximum bending moment developed under various numbers of spans.

POSTS: Posts act as vertical cantilever beams in resisting horizontal thrust applied at the top rail. Bending moment produced by horizontal thrust normally controls design and post spacing may be calculated using the following equations.

1. For uniform horizontal loading (w):

$$M = P \times h \qquad P = w/12 \times L \qquad M = S \times f$$

$$f = \frac{w/12 \times L \times h}{S} \qquad L = \frac{S \times f}{w/12 \times h}$$

2. For concentrated horizontal loading (F_h):

When concentrated loading is specified, the horizontal load on the top rail is distributed among several posts adjacent to the point of loading. The load distribution is a function of the relative stiffness of post and top rail and of the number of spans in the railing. For a straight run of railing it may be calculated with the aid of the graph on page 130. This calculation will show what proportion (P_f) of the total load any one post may have to sustain. To the extent that it is less than 100%, it will justify the use of lighter and more economical construction. The following equation applies:

$$M = P \times h \qquad P = F_h \times P_f$$

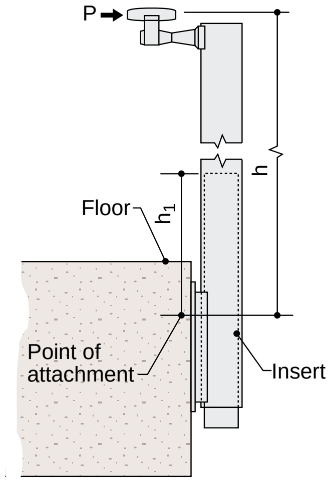
$$f = \frac{F_h \times h \times P_f}{S}$$

INTERNALLY REINFORCED POSTS

The load-carrying capacity of a post with reinforcing insert is limited by the allowable fibre stress at one of three points.

1. The post at the top of the insert, above which it is not reinforced.
2. The insert at its base, at the highest point of its attachment to the supporting structure.
3. The post at the same point of attachment.

The lowest of these three loading limits controls design for the combined post and reinforcing insert.



1. Post at top of insert:

Moment in post (top of insert): $M = P \times (h - h_1)$

Fibre stress in post (top of insert):

$$f = \frac{M}{S} = \frac{P \times (h - h_1)}{S}$$

Loading limit: $P = \dfrac{f_s \times S}{h - h_1}$

At the point of contact between the railing post and the reinforcing insert, the deflection of each is assumed to be the same but the resisting force of each is a function of its ***Moment of Inertia*** (I) and ***Modulus of Elasticity*** (E). The resultant combined ***Reaction Factor*** (F_r) at the top of the insert is determined as follows:

$$F_r = \left(\frac{h}{2 \times h_1} - 0.167\right) \div \left(\frac{E_p \times I_p}{3 \times E_r \times I_r} + 0.333\right)$$

E_r and I_r refer to the reinforcing insert
E_p and I_p refer to the post

The loading limits for points 2 and 3 are then determined as follows:

2. Insert at base:

Moment in insert: $M = P \times (h - h_1)$

Fibre stress in insert:

$$f = \frac{M}{S_r} = \frac{P \times F_r \times h_1}{S_r}$$

Loading limit: $P = \dfrac{f_s \times S_r}{F_r \times h_1}$

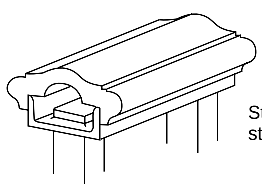
3. Post at base:
   Moment in post: $M = P \times \left[h - \left(F_r \times h_1\right)\right]$

   Fibre stress in post: $f = \dfrac{M}{S_p} = \dfrac{P \times \left[h - \left(F_r \times h_1\right)\right]}{S_p}$

   Loading limit: $P = \dfrac{f_s \times S_p}{h - \left(F_r \times h_1\right)}$

COMBINED HANDRAIL SECTIONS

When two sections of the same metal are combined by being fastened together to form a handrail (e.g. a steel moulding mounted on a steel channel), the sections develop the same deflection under load but act independently about their respective neutral axes.



Steel handrail with steel channel

I_a and I_b are the moments of inertia of the two sections. Since the ***Section Modulus*** (S) equals I/C, the combined value for S of the two sections would be:

$$S = \frac{I_a + I_b}{C_{max}}$$

(C_{max} is either C_a or C_b, whichever is greater)

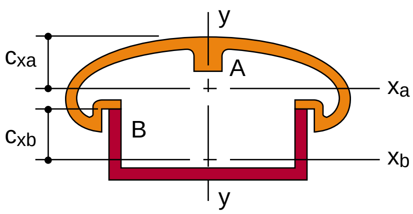
In the railing formulas, substitute the above equation for the value of S whenever combined sections of the same material are used.

COMBINED SECTIONS OF DISSIMILAR MATERIALS

To compute the loading of combined sections of dissimilar materials (e.g. a bronze handrail mounted on a steel channel) calculations involve the determination of the relative portion of the load carried by each section. The load distribution is a function of the relative stiffness of the two sections, which is determined by the ***Moments of Inertia*** (I) and their ***Moduli of Elasticity*** (E). The distribution of the total load between two sections is determined as follows:

$$\text{Load Carried by A} = \frac{\text{Total Load}}{1 + \dfrac{E_b \times I_b}{E_a \times I_a}}$$

$$\text{Load Carried by B} = \text{Total Load} - \text{Total Load Carried by A}$$



Individual calculation to determine the fibre stress for each material, using the load portion of each section, will then determine which section controls design; namely, the section giving the lesser result (see example 6 on page 128).

DEFLECTION CONSIDERATIONS

Excessive deflection of a railing under load, even though it meets strength requirements, will give the user a feeling of insecurity and may cause tripping or stumbling.

Lateral deflection of posts or vertical deflection of horizontal rails under load are computed as follows—**these formulas must be used with caution:**

For posts without reinforcing insert:

$$\Delta = \frac{P \times h^3}{3 \times E \times I} \text{ or } \frac{w/12 \times L \times h^3}{3 \times E \times I}$$

For posts with reinforcing insert of similar or dissimilar material:

$$\Delta = \frac{P \times \left(h - h_1\right)^3}{3 \times E_p \times I_p} + \frac{P \times \left[h^3 - \left(h - h_1\right)^3\right]}{3 \times \left[\left(E_p \times I_p\right) + \left(E_r \times I_r\right)\right]}$$

Where E_p and I_p apply to post
E_r and I_r apply to reinforcing insert

For rails (concentrated load, F):

$$\Delta = \frac{F \times L^3}{K \times E \times I}$$

where K = 48 for simple span
66 for two or more spans, load on end span
87 for three or more spans, load on intermediate span

For rails (uniform load, w):

$$\Delta = \frac{5 \times w/12 \times L^4}{384 \times E \times I} \quad \text{for simple spans}$$

$$\Delta = \frac{w/12 \times L^4}{145 \times E \times I} \quad \text{for two or more spans}$$

There are few, if any, regulations or code requirements limiting deflection in a railing but ASTM has put forth the following criteria regarding Maximum Allowable Deflection (Δmax) in their specification E985.

For horizontal load at midspan:

$$\Delta_{max} = h/24 + L/96$$

For horizontal load at top of post:

$$\Delta_{max} = h/12$$

For vertical load at midspan:

$$\Delta_{max} = L/96$$

In many instances, the anchorage of the railing to the floor, tread or fascia is subject to a degree of rotation which will add an indeterminate amount to the deflection on the post and rail. **Anchorage and supporting structure must be as secure and rigid as possible.**

These sample problems demonstrate how engineering data provided by **Julius Blum & Co. Inc.** can be used to obtain solutions to practical handrail design problems. Problems are solved by equating the maximum bending moment resulting from applied loading to the resisting moment determined from geometrical section properties and allowable stress. This method can be used to obtain solutions for most installation and loading conditions.

EXAMPLE 1:
DETERMINE MAXIMUM POST SPACING
REQUIREMENTS:
Uniform load, w = 50 lb./ft.
Railing height, h = 38 in.
MATERIAL SPECIFIED:
Post: #423 aluminum, 6063-T52
Allowable stress, f_s = 12,600 psi (refer to page 123);
Section modulus, S = .321 in³ (refer to page 124).
DETERMINE:
Maximum post spacing (simple span), L (in)
Resisting bending moment, $M_{(resisting)} = f_s \times S$
Applied bending moment, $M_{(applied)} = w/12 \times L \times h$
$M_{(resisting)}$ must equal $M_{(applied)}$

$$f_s \times S = w/12 \times L \times h$$

$$L = \frac{f_s \times S}{w/12 \times h}$$

$$L = \frac{12,600 \times .321}{50/12 \times 38}$$

$$L = 25.60 \text{ in}$$

EXAMPLE 2:
DETERMINE REQUIRED SECTION MODULUS OF POST
REQUIREMENTS:
Concentrated load, F = 200 lbs.
Railing height, h = 42 in.
MATERIAL SPECIFIED:
Post: Steel tubing
allowable stress, f_s = 16,800 psi (refer to page 123).

DETERMINE:
Section modulus, S, and select a suitable section
Resisting bending moment, $M_{(resisting)} = f_s \times S$
Applied bending moment, $M_{(applied)} = F \times h$
$M_{(resisting)}$ must equal $M_{(applied)}$

$$f_s \times S = F \times h$$

$$S = \frac{F \times h}{f_s}$$

$$S = \frac{200 \times 42}{16,800}$$

$$S = 0.500 \text{ in}^3$$

EXAMPLE 3:
DETERMINE MAXIMUM SPAN FOR HANDRAIL MOULDINGS, CONCENTRATED LOAD
REQUIREMENTS:
Concentrated load, F = 200 lbs.
MATERIAL SPECIFIED:
Handrail moulding: #6489, 1½" O.D. bronze tubing
f_s = 14,500 psi; S_x = .144 in³
The railing will be installed with more than two consecutive spans, therefore the Bending Moment Constant, K = 5 (refer to page 125).

DETERMINE:
Maximum span for handrail moulding, L (in)

$$\text{Resisting bending moment, } M_{(resisting)} = f_s \times S$$

$$\text{Applied bending moment, } M_{(applied)} = \frac{F \times L}{K}$$

$M_{(resisting)}$ must equal $M_{(applied)}$

$$f_s \times S = \frac{F \times L}{K}$$

$$L = \frac{f_s \times S \times K}{F}$$

$$L = \frac{14,500 \times .144 \times 5.0}{200} = 52.2 \text{ in}$$

EXAMPLE 4:
DETERMINE MAXIMUM SPAN FOR A COMBINED HANDRAIL SECTION USING SECTIONS OF THE SAME METAL
REQUIREMENTS:
Concentrated load, F = 200 lbs.
MATERIALS SPECIFIED:
Handrail moulding: #6932, aluminum, 6063-T52
f_s = 12,600 psi; I_{xa} = .059 in⁴; C_{xa} = .586 in
Support channel: 2" × ½" × ⅛" aluminum channel
f_s = 12,600 psi; I_{xb} = .006 in⁴; C_{xb} = .369 in
C_{max} = .586 in (greater of C_{xa} vs. C_{xb})
The railing will be installed with more than two consecutive spans, therefore the Bending Moment Constant, K = 5 (refer to page 125).

DETERMINE:
Maximum span for combined handrail section, L (in)

$$\text{Resisting bending moment, } M_{(resisting)} = f_s \times \left(\frac{I_{xa} + I_{xb}}{C_{max}}\right)$$

$$\text{Applied bending moment, } M_{(applied)} = \frac{F \times L}{K}$$

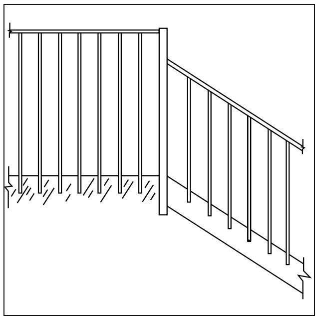
$M_{(resisting)}$ must equal $M_{(applied)}$

$$f_s \times \left(\frac{I_{xa} + I_{xb}}{C_{max}}\right) = \frac{F \times L}{K}$$

$$L = \frac{f_s \times (I_{xa} + I_{xb}) \times K}{F \times C_{max}}$$

$$L = \frac{12,600 \times (.059 + .006) \times 5.0}{200 \times .586} = 35 \text{ in}$$

EXAMPLE 5: CONCENTRATED LOAD
LOAD DISTRIBUTION AMONG POSTS



DESCRIPTION:
Railing for an air terminal public area—heavy pedestrian traffic is expected.

REQUIREMENTS:
Loading, F = 300 lbs.
Railing height = 42" at platforms; 34" at stairs
Post height, h: Posts are fascia mounted; top of post attachment is 2" below walking surface. Therefore post height is railing height plus 2".
Maximum opening to be no more than 4"; 12 or more spans between posts.

MATERIALS SPECIFIED:
Handrail moulding: #6901, aluminum 6063-T52
f_s = 9,700 psi; E = 10 × 10⁶; I_y = .709 in⁴; S_y = .540 in³
Intermediate posts: #430, aluminum 6063-T6
f_s = 15,200 psi; E = 10 × 10⁶; I_x = .241 in⁴; S_x = .297 in³
End posts: 2½" × 2½" × 3⁄16" square aluminum – 6061-T6 – tubing
f_s = 19,500 psi; E = 10 × 10⁶; S = 1.247 in³

DETERMINE:
Structural compliance of proposed construction.

1. **Stress at base of end posts** (end posts are dissimilar from intermediate posts—they have to resist 100% of horizontal load):

$$f = \frac{P \times h}{S} = \frac{300 \times 44}{1\,247} = 10,585 \text{ psi}$$

(19,500 psi allowable)

2. **Stress at base of intermediate posts at platform** (L= 4 in, h = 44 in.):

A. Stiffness ratio:

$$R = \frac{E_r \times I_r}{L} \div \frac{E_p \times I_p}{h} = \frac{.709 \times 44}{4 \times .241} = 32.36$$

B. Load proportion factor: (see graph, p. 130) = .230
C. Load per post: 300 × .230 = 69 lb.
D. Stress at base of post:

$$f = \frac{P \times h}{S} = \frac{69 \times 44}{.297} = 10,222 \text{ psi}$$

(15,200 psi allowable)

3. **Stress at base of intermediate post at stairs** (L= 4 in, h = 36 in.):

A. Stiffness ratio:

$$R = \frac{E_r \times I_r}{L} \div \frac{E_p \times I_p}{h} = \frac{.709 \times 36}{4 \times .241} = 26.47$$

B. Load proportion factor: (see graph, p. 130) = .238
C. Load per post: 300 × .238 = 73.5 lb.
D. Stress at base of post:

$$f = \frac{P \times h}{S} = \frac{73.5 \times 36}{.297} = 8,909 \text{ psi}$$

(15,200 psi allowable)

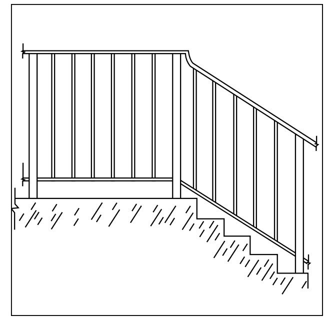
4. **Stress on handrail at mid-span:**

$$f = \frac{F_h \times L}{S \times K} = \frac{300 \times 4}{.540 \times 5} = 444 \text{ psi}$$

(9,700 psi allowable)

Railing meets structural designer's requirements.

EXAMPLE 6: UNIFORMLY DISTRIBUTED LOAD
COMBINED HANDRAIL SECTION OF DISSIMILAR MATERIALS



DESCRIPTION:
Stair railing of steel balusters, mounted between steel channel top and bottom rails, attached to square steel posts, with a bronze handrail.

REQUIREMENTS:
Loading, w = 50 lb./ft., horizontal and vertical.
Railing height, h = 34" at stair, 42" at landings.
Post spacing, L = 40"; 3 or more spans in each run.

MATERIALS SPECIFIED:
Handrail moulding: #4530, bronze C38500
f_s = 9,700 psi; I_x = .023 in⁴; C_x = .444 in.; E = 14 × 10⁶ psi
Posts: 1½" × 1½" × .140" structural steel tubing
f_s = 27,700 psi; S = .316 in³
Sub-rails: 1½" × ½" × ⅛" steel (C1010) channel — top and bottom:
f_s = 16,800 psi; I_x = .005 in⁴; C_x = .250 in.; E = 29 × 10⁶ psi

DETERMINE:
Structural compliance of proposed construction

1. **Stress at base of post:**

$$\frac{M}{S} = \frac{w/12 \times L \times h}{S}$$

At stairs: $\frac{50 \times 40 \times 34}{12 \times .316} = 17,932$ psi

At landings: $\frac{50 \times 40 \times 42}{12 \times .316} = 22,152$ psi

(27,700 psi allowable)

2. **Stress on rail:**
Since I_y of both bronze(b) and steel(s) sections is greater than I_x, vertical load controls design.

A. Total load:

$$w/12 \times L = \frac{50 \times 40}{12} = 167 \text{ lb}$$

B. Load per foot on bronze, w_b:

$$w_b = w \div \left(1 + \frac{E_s \times 2 \times I_{xs}}{E_b \times I_{xb}}\right)$$

$$w_b = 50 \div \left(1 + \frac{29 \times 10^6 \times 2 \times .005}{14 \times 10^6 \times .023}\right) = 26.31 \text{ lb/ft}$$

C. Load per foot on steel, w_s:

$$w_s = w - w_b$$

$$w_s = 50 - 26.31 = 23.69 \text{ lb/ft}$$

D. Stress on bronze, f_{sb}:

$$f_{sb} = \frac{w_b/12 \times L^2 \times C_{max}}{I_{xb} \times K} = \frac{26.31/12 \times 40^2 \times .444}{.023 \times 9.5}$$

$$= 7,128 \text{ psi } (9,700 \text{ psi allowable})$$

E. Stress on steel, f_{ss}:

$$f_{ss} = \frac{w_s/12 \times L^2 \times C_{max}}{I_{xs} \times K} = \frac{23.69/12 \times 40^2 \times .444}{2 \times .005 \times 9.5}$$

$$= 14,763 \text{ psi } (16,800 \text{ psi allowable})$$

Design meets code structural requirements.

Note: Resistance to vertical loading of upper and lower steel channels is additive. Therefore the value of I_{xs} is doubled. The additional resistance to vertical load by the truss action of the balusters has not been considered, making the result of the calculation more conservative.

MECHANICAL PROPERTIES

Material	Allowable Stress (psi)	Minimum Yield (psi)	Modulus of Elasticity (psi × 10^6)
Aluminum*			
6061-T6	19,500	35,000	10.0
6063-T52 pipe	11,300	16,000	10.0
6063-T832 pipe	24,800	35,000	10.0
Red Brass C23000	11,000	18,000	17.0
Stainless• Type 304	30,000	55,000	28.0

* Aluminum Association Specifications for Aluminum Structures.
• American Iron & Steel Institute Stainless Steel Cold-Formed Structural Design Manual.

SECTION PROPERTIES

Connectorail® Pipe (Aluminum, Bronze, Stainless)

Nominal Size	Sched.	OD	Wall	Area	I	S
1¼"	10	1.660"	.109"	.531	.161	.193
1¼"	40	1.660"	.140"	.669	.195	.235
1¼"	40	1.660"	.146"	.695	.201	.242
1½"	5	1.900"	.062"	.375	.158	.166
1½"	10	1.900"	.109"	.614	.247	.260
1½"	40	1.900"	.145"	.800	.310	.326
1½"	40	1.900"	.150"	.825	.318	.335

Connectorail® Reinforcing Bars (6061-T6)

No.	Sched.	Nominal Size	OD	Area	I	S
7292/7295	10	1½"	1.667"	2.183	.379	.455
7192	10	1¼"	1.427"	1.599	.204	.285
7292/7295	10	1½"	1.667"	2.183	.379	.455
7492	40	1¼"	1.328"	1.452	.168	.247
7592/7595	40	1½"	1.585"	1.973	.310	.391
9392**	5	1½"	1.750"	.615	.205	.239

** Tubing with .120" wall, type 304 Stainless Steel

NOTE ON WELDED PIPE RAILINGS

An important consideration for welded pipe railings is the effect of welding heat on the structural properties of aluminum handrail pipe. For example, extruded pipe of aluminum alloy 6063-T52 has an allowable design stress of 11,300 psi. After welding, the allowable stress must be reduced to 8,000 psi within 1" of the weld. Since maximum bending moment generally occurs at points of support or attachment, the reduced stress will often control design. This consideration does not apply to non-welded **Connectorail®**.

LOADING TABLES

The values tabulated in the following page apply to installations fabricated and erected in accordance with **Connectorail®** specifications and using **Connectorail®** components exclusively. Chart values have been determined by assuming that reinforcing inserts are included with fascia mounted railings and with railings set into the floor, except where no insert is indicated.

For these tables, various post heights have been selected arbitrarily. Values of maximum post spacing for other post heights can be interpolated easily.

When **Connectorail®** posts are surface mounted on floors, treads or stringers, using a floor flange, the entire bending moment of the post is transferred to the reinforcing insert and the allowable post loading has to be computed accordingly. The allowable load will be determined by the resisting moment of the reinforcing insert alone or the unreinforced post above the insert ($h - h_1$), whichever is less.

CONNECTORAIL® TEST RESULTS

1½" Aluminum and Stainless Steel Pipe—Single Span

	RAIL										POST					
Span (L) or Height (h)	57"		75"		96"		96"		96"		42" w/24" re-bar		42" w/24" re-bar		42" w/24" re-bar	
Schedule	10		40		10		40		5		10		40		5	
Alloy and Temper	6063-T52		6063-T52		6063-T832		6063-T832		Type 304		6063-T832		6063-T832		Type 304	
Load (P)	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set	Deflection	Permanent Set
200 lbs.	.344"	.000"	.547"	.000"	1.466"	.000"	1.021"	.000"	.867"	.025"	1.389"	.000"	1.724"	.000"	1.006"	.036"
250 lbs.	.388"	.000"	.669"	.000"	1.818"	.000"	1.317"	.000"	1.120"	.040"	1.659"	.000"	2.122"	.000"	1.160"	.056"
300 lbs.	.496"	.000"	.845"	.000"	2.214"	.000"	1.594"	.000"	1.395"	.128"	1.926"	.000"	2.537"	.000"	1.369"	.080"
350 lbs.	.565"	.000"	.998"	.000"	2.483"	.000"	1.882"	.000"	1.728"	.205"	2.206"	.000"	2.849"	.000"	1.633"	.112"
400 lbs.	.739"	.047"	1.189"	.000"	2.984"	.000"	2.178"	.000"	1.992"	.322"	2.601"	.000"	3.211"	.000"		
450 lbs.	1.368"	.488"	1.654"	.151"	3.464"	.047"	2.488"	.000"	2.563"	.652"	2.811"	.000"	3.603"	.000"	2.131"	.238"
500 lbs.			1.990"	.656"	4.510"	.406"	2.775"	.000"	2.972"	.994"	3.122"	.000"	4.278"	.109"	2.270"	.452"
550 lbs.							3.080"	.000"	4.176"	1.726"	3.484"	.000"	4.868"	.266"		
600 lbs.							3.424"	.000"	5.591"	2.886"	3.860"	.146"			2.765"	
650 lbs.							3.754"	.031"			4.267"	.391"				
700 lbs.							4.213"	.192"							3.880"	
0.2% Specified Permanent set load	430 lbs.		440 lbs.		470 lbs.		700 lbs.		350 lbs.		590 lbs.		490 lbs.		340 lbs.	

CONNECTORAIL® LOAD TABLES

Maximum Allowable Spans—Post Spacing

Based on bending stress in post and insert
Load: **50 lbs. per foot**, applied horizontally at top rail

Post Material Pipe size	Post height (h)	No insert	15" insert $h_1 = 9"$	$h_1 = 12"$	25" insert $h_1 = 19"$
Aluminum	30"	38"	55"	64"	85"
6063-T832	34"	34"	46"	52"	73"
1¼" Sch. 10	38"	30"	40"	44"	61"
	42"	27"	35"	38"	50"
	46"	25"	31"	34"	43"
Aluminum	30"	47"	67"	78"	89"
6063-T832	34"	41"	56"	64"	77"
1¼" Sch. 40	38"	37"	48"	54"	67"
	42"	33"	42"	47"	59"
	46"	30"	38"	41"	52"
Aluminum	30"	52"	74"	86"	126"
6063-T832	34"	46"	62"	70"	108"
1½" Sch. 10	38"	41"	53"	60"	81"
	42"	37"	47"	52"	67"
	46"	34"	42"	46"	57"
Aluminum	30"	65"	92"	108"	131"
6063-T832	34"	57"	78"	88"	112"
1½" Sch. 40	38"	51"	67"	75"	98"
	42"	46"	59"	65"	84"
	46"	42"	52"	57"	72"
Bronze (Red Brass)	30"	21"	30"		34"
C23000	34"	18"	25"		31"
1¼" Sch. 40	38"	16"	21"		28"
	42"	15"	19"		26"
	46"	13"	17"		23"
Bronze (Red Brass)	30"	29"	41"		51"
C23000	34"	25"	34"		46"
1½" Sch. 40	38"	23"	30"		42"
	42"	21"	26"		37"
	46"	19"	23"		32"

	Post height (h)	No insert	$h_1 = 18"$	26" insert $h_1 = 20"$
Stainless Steel	30"	40"	83"	85"
Type 304	34"	35"	71"	73"
1½" Sch. 5	38"	32"	62"	64"
	42"	29"	50"	54"
	46"	26"	43"	46"

Maximum Allowable Spans—Handrail

Based on bending stress in rail.
Load: **50 lbs. per foot**

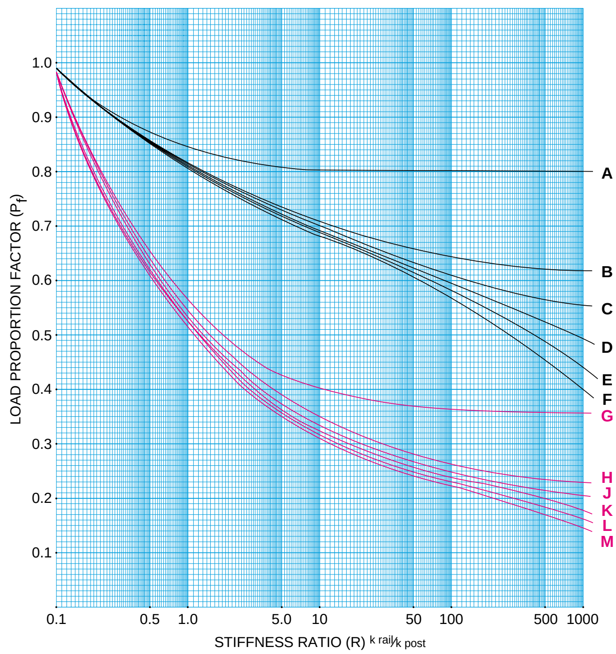
	1 or 2 spans	3 or more spans
Aluminum 6063-T52		
1¼" Sch. 10	65"	71"
1¼" Sch. 40	71"	78"
1½" Sch. 10	75"	82"
1½" Sch. 40	84"	92"

If it is desired to use longer rail spans than allowed by the limits above, alloy 6063-T832 pipe should be used. Allowable rail span for 6063-T832 pipe is usually greater than allowable post spacing.

	1 or 2 spans	3 or more spans
Bronze (Red Brass) C23000		
1¼" Sch. 40	70"	77"
1½" Sch. 40	83"	90"
Stainless Steel Type 304		
1½" Sch. 5	98"	107"

LOAD DISTRIBUTION CONSIDERATIONS

The graph below is used to determine railing load distribution. It has been determined by computer analysis and confirmed by laboratory test. The formula used in determining the graph assumes that all posts are of identical material and section.



The Stiffness (k) of a rail or post is: $k_r = \frac{E \times I}{L}$ for the rail

$k_p = \frac{E \times I}{h}$ for the post

(see page 123 for definition of symbols)
The Stiffness Ratio (R) is determined as: $R = \frac{k_r}{k_p}$

The Stiffness Ratio is then plotted on the graph to obtain a Load Proportion Factor (P_f). When the load proportion factor has been determined, it is multiplied by the total load to determine the load one post must sustain.

If one or both ends of the railing are free standing, the end loaded condition must be assumed. If both ends of the run are laterally braced by a change in direction or attachment to a firm structure, the center loaded load proportion factor may be used.

NOTE: If end posts differ from intermediate posts in strength, the load distribution pattern becomes indeterminate and end posts should then be designed to carry 100% of the concentrated load. Intermediate posts may then be designed to the center loaded condition.

In single span railings, each post must be designed to carry the full concentrated load. When posts and rails are of identical material and section (as in pipe railing), and post spacing varies between 3 and 6 feet while post height is between 30 and 42 inches, load distribution is fairly uniform. In this situation, the greatest proportion of a concentrated load carried by any post can be estimated as follows:

End posts:		Intermediate posts:	
2 span railing	$P_f = 0.85$	2 span railing	$P_f = 0.65$
3 or more spans	$P_f = 0.82$	3 or more spans	$P_f = 0.60$

Thus, if a 200 lb concentrated load is specified for a pipe railing, actual design load to be applied at the top of the end post is .82 × 200 lb (164 lb) while design load to be applied to intermediate posts is .60 × 200 lb (120 lb). If railing posts are reinforced, the load proportion factor for posts is about 3 percentage points higher.