Table 1 Mechanical Properties of Pipe

Material	Minimum Tensile Strength (psi)	Minimum Yield Strength (psi)	Allowable Yield Strength* (psi)	Modulus of Elasticity (ksi)
Aluminum 6063-T6 Pipe ASTM429	30,000	25,000	18,000**	10,100
Aluminum 6061-T6 Pipe ASTM429	38,000	35,000	24,000***	10,100
Carbon Steel Structural Tubing				
ASTM A500 Grade B	58,000	42,000	25,500	
Carbon Steel Pipe ASTM A53				
Type F Grade B	48,000	30,000	21,600	
Type E Grade B	60,000	35,000	25,000	
Hollaender Tubular Dowel 6061-T6	38,000	35,000	24,000	10,100

*The allowable yield strength of aluminum pipe in bending is defined by the Aluminum Association to be (1.17 x Minimum Yield Strength) / 1.65.

**Reduce to 8,000 within 1 inch of weld

***Reduce to 14,000 within 1 inch of weld

Table 2 Section Properties of Pipe and Reinforcing Dowel

Nominal Pipe Size (ips)	OD (in.)	ID (in.)	Wall Thickness	Area ($in.^2$)	I ($in.^4$)	S ($in.^3$)
Schedule 10						
1 ½	1.900	1.682	0.109	0.613	0.247	0.260
2	2.375	2.157	0.109	0.776	0.499	0.420
Schedule 40						
1 ¼	1.660	1.380	0.140	0.669	0.195	0.235
1 ½	1.900	1.610	0.145	0.800	0.310	0.326
2	2.375	2.067	0.154	1.075	0.666	0.561
Schedule 80						
1 ¼	1.660	1.278	0.191	0.882	0.242	0.291
1 ½	1.900	1.500	0.200	1.068	0.391	0.412
2	2.375	1.939	0.218	1.477	0.868	0.731
Hollaender Tubular Dowel	1.600	1.250	0.175	0.783	0.201	0.252

Outside Diameter (OD), Inside Diameter (ID), Moment of Inertia (I), Section Modulus (S)

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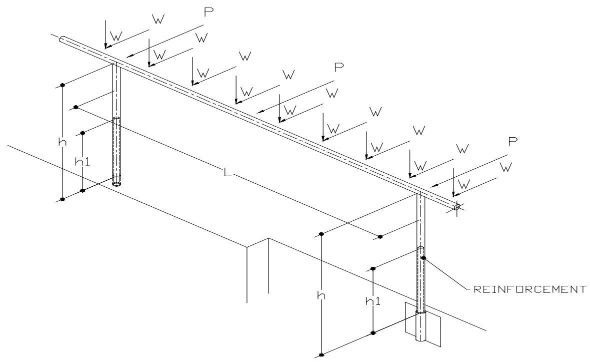
Railing System Dimensions and Loads



Symbols Used in Equations:

w = Uniform loading, (lb/ft).
L = Span between centerlines of posts or mounting brackets, (ft).
P = Concentrated load applied to the top rail, (lb).
h = Height of post from the top of the attachment to the point of load application, (in).
h_1 = Height of reinforcing insert inside post above the top of the attachment, (in).
f_b = Bending stress, (psi).
f_d = Allowable yield strength for design, (psi).
S = Section modulus, (in^3).
S_1 = Combined section modulus of post with reinforcing insert, (in^3).

Calculations for Structural Design

The calculations used here are applicable to free standing straight runs of guardrail with uniform post spacing. The loads applied to a length of guardrail are defined by building codes as either a concentrated load applied to the top rail at any point in any direction, or as a uniformly distributed load per linear foot of rail applied to the top rail either horizontally and/or vertically downward. These two types of loads are not specified to act concurrently. We will illustrate the design of a railing system using separate formulas to calculate the stresses in the posts and the rails respectively. Typically the stress in the post will be the limiting factor on post spacing, pipe size/schedule, and material.

Post Design

Loads that are applied horizontally at the top rail of a guardrail system produce the maximum bending moment on the posts. The post acts as a vertical cantilevered member in resisting the horizontal load applied to the rails or posts. The height of the rail used in the calculations is measured from the centerline of the top rail to the top of the attachment.

A concentrated load applied to the rail at a post, is distributed to the posts on either side of that post. In railing systems where posts and rail are of identical material and section, and where post spacing varies between 3 feet and 6 feet, the greatest proportion of a concentrated load carried by any one post can be estimated as follows:

End posts: 2-span rail – 85%; 3 or more spans – 82%

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Intermediate posts: 2-span rail – 65%; 3 or more spans – 60%
In single span railing systems, each post shall be designed to carry the full concentrated load.
These are called the Load Proportion Factors, (P_f).
(A span is defined as the space between posts, 2-span=3 posts, 3-span=4 posts, etc.)

A uniform load is applied to the entire length of rail, and is specified as pounds per linear foot of rail. The load carried by a given post is determined by the load per foot multiplied by the post spacing, or span, in feet. An end post will carry half the load of an intermediate post.

The formulas for post design to calculate the bending stress in the post are as follows:

Concentrated Load: $f_b = \frac{P \times P_f \times h}{S}$ Uniform Load: $f_b = \frac{w \times L \times h}{S}$

For calculations based on the allowable yield strength of the pipe, the calculated bending stress must be less than or equal to the allowable yield strength of the post material.

Example 1: Concentrated loading condition using a Hollaender #52E-8 side mount flange, with an OSHA concentrated load of 200 pounds, for a 3-span guardrail.
Pipe: 1 ½" schedule 40; S = 0.326 in^3
Rail height: h = 43 in. (from the centerline of the top rail to the top of the #52E-8 flange)
Post spacing: 6 ft.
Based on the load distribution factors, the design load for an intermediate post is 60% of 200 lb, or 120 lb, and for an end post is 82% of 200 lb, or 164 lb.

The bending stress in the intermediate post is: $f_b = \frac{200 \times .6 \times 43}{.326} = 15{,}828\,psi$

The bending stress in the end post is: $f_b = \frac{200 \times .82 \times 43}{.326} = 21{,}631\,psi$

The 6063-T6 aluminum pipe, with an allowable design strength of 18,000 psi is acceptable for the intermediate post but not the end post. We can calculate the bending stress using a schedule 80 end post to see if this is acceptable:
Pipe: 1 ½" schedule 80; S = 0.412 in^3

The bending stress for the schedule 80 end post is: $f_b = \frac{200 \times .82 \times 43}{.412} = 17{,}116\,psi$

This bending stress is less than the allowable design strength for 6063-T6 aluminum pipe.

An easier way to do this would be to calculate for the required section modulus of the post if you had already chosen the type of pipe material you wanted to use by rearranging the formula such as this:

$S = \frac{P \times P_f \times h}{f_d}$ where, f_d = the allowable design strength of the material.

Example 2: Uniform loading condition using a Hollaender #45SBC-8 base flange with a 3 inch high barrel for the post mounting, and a uniform loading condition of 50 pounds per foot applied horizontally.
Pipe material: 6061-T6 aluminum alloy; f_d = 24,000 psi
Rail height: 38 in. (from the centerline of the top rail to the top of the #45SBC-8 flange)
Post spacing: 6 ft.
There is no load distribution factor for the uniform loading condition. Each intermediate post must take the load per linear foot multiplied by the post spacing in feet.

The required section modulus is: $S = \frac{50 \times 6 \times 38}{24{,}000} = 0.475 in^3$

This exceeds the section modulus for schedule 80 pipe that is 0.412 in^3. We would either have to shorten the post spacing to 5.2 feet or reinforce the inside of the post with reinforcing dowel to increase the section

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modulus at the top of the attachment. If this were side mounted rail with a 43 in. height, the post spacing would be reduced to 4.6 feet for a schedule 80 post.

We would choose to use schedule 40 posts that would be reinforced internally with Hollaender Tubular Dowel made to fit inside a schedule 40 post. The section modulus of schedule 40 pipe and the Hollaender Tubular Dowel would be: $S = \frac{\pi(D^4 - d^4)}{32D} = \frac{\pi(1.90^4 - 1.25^4)}{32(1.9)} = 0.547 in^3$.

This is acceptable because it exceeds the required section modulus of 0.475 in^3 for the #45SBC-8 base flange, and the required section modulus of 0.538 in^3 for a 43 inch rail height using the #52E-8 side mount flange. This will also reduce the cost of the rail since there will be fewer posts by holding the 6 foot post spacing vs. reducing the post spacing to meet the load. Also, the Hollaender Tubular Dowel is 60% lighter than the standard solid aluminum reinforcing dowel that is normally specified, further reducing the cost of the rail. An added benefit of the Hollaender Tubular Dowel over the solid dowel is that a weep hole is not required to let water drain from the post.

The required height of the Hollaender Tubular Dowel inside the schedule 40 post is given by:

$$h_1 = h - \frac{f_d \times S}{w \times L} = 38 - \frac{24{,}000 \times 0.326}{50 \times 6} = 11.92 in$$, say 12 inches.

This is the height of the dowel above the top of the #45SBC-8 base flange, which would make the total length of dowel for this flange to be 15 inches.

For the #52E-8 side mount flange the dowel still has to reach the same height inside the post but it is longer because of the depth of the flange. The reinforcing dowel would be 22 inches long because the flange is 5 inches deep and the top of the flange is 2 inches below the walking surface.

Rail Design

After we have designed the posts, we need to verify that the rail will take the loads specified by the applicable building code. These loads will be the same as specified for the post design, i.e. concentrated or uniform.

A concentrated load applied to the top rail at any point, in any direction creates the maximum bending moment in the rail when applied at the mid-span of the rail between posts. The distribution of loads over multiple spans of rail decreases the maximum bending moment in rails. A bending moment constant (k) is used in the formulas depending on the number of spans in the length of rail. The formula to calculate the bending stress in the rail for concentrated loading at mid-span is as follows:

For single span rail k = 4, for two or more spans k = 5; $f_b = \frac{P \times L}{S \times k}$

Example 3: Concentrated loading condition for a two span length of rail, with an OSHA concentrated load of 200 pounds.

Pipe: 1 ½" schedule 40, 6063-T6 aluminum; S = 0.326 in^3, f_d = 18,000 psi
Post spacing: 72 in..
Bending moment constant: k = 5

The bending stress in the rail is: $f_b = \frac{200 \times 72}{0.326 \times 5} = 8{,}834 psi$

The bending stress in the rail is less than the allowable yield strength of 6063-T6 aluminum pipe. If we increase the post spacing to the 8 foot maximum allowed by OSHA, and this was a single span rail, the bending stress in the rail would be 14,723 psi which is still less than the allowable yield strength of 6063-T6 aluminum pipe.

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However, even though OSHA allows for a maximum 8 ft. post spacing, all of the model building codes, BOCA, SBC, and UBC for guardrail, specify a uniform load of 50 lb/ft, and require that the loading conditions specified must not exceed the allowable design working stress of the material. Therefore the post spacing will be limited to the most stringent requirement which is the values determined from the post design calculations for a uniform load.

With a uniform load, the rail load is proportional to the rail span, which has been established by the post design calculation. As in the concentrated load formulas, a bending moment constant is used to allow for the distribution of loads over multiple spans. The formula to calculate the bending stress in the rail for uniform loading is as follows:

For one or two span rail k = 96, for three or more spans k = 114; $f_b = \frac{w \times L^2}{S \times k}$

Example 4: Uniform loading condition of 50 pounds per foot horizontally and 100 pounds per foot vertically downward. This combined load resolves into 111.8 pounds at 63 degrees from horizontal.

Pipe: 1 ½" schedule 40, 6061-T6 aluminum; S = 0.326 in^3, f_d = 24,000 psi
Post spacing: 72 in.
Bending moment constant: k = 114

The bending stress in the rail is: $f_b = \frac{111.8 \times 72^2}{0.326 \times 114} = 15{,}594\, psi$

The bending stress in the rail is less than the allowable yield strength of 6061-T6 aluminum pipe, so the 6 foot post spacing is acceptable with 1 ½" schedule 40 pipe for the rail.

References:

"Pipe Railing Systems Manual, Including Round Tube", third edition, Architectural Metal Products Division of The National Association of Architectural Metal Manufacturers, ANSI/NAAM AMP 521-95, December 19, 1995

"Metal Rail Manual", second edition, 1986, National Ornamental & Miscellaneous Metal Association