A Technical Note:
Comparison of Design Specifications for Design of Pipe and Round HSS Pedestrian Guardrail Systems

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A guardrail system is a building component located near the open side of an elevated surface for the purpose of minimizing the possibility of a fall from the elevated surface by people, equipment, or material (ASCE, 2000). A typical pedestrian guardrail is illustrated in Figure 1. While architects usually handle the specification of guardrail systems for most buildings, the structural design of these systems is generally within the area of expertise of the project structural engineer. Often, the project architect will only provide general guidance on the configuration of the guardrails, leaving the actual structural design to the fabricator. This paper is based on years of experience gained by the author as a consultant to several structural steel and miscellaneous metals fabricators designing guardrail systems.

Traditionally, when steel guardrail systems are specified; they have been designed using the AISC Allowable Stress Design Specification (AISC, 1989). Alternate, less frequently-used design specifications which are current include other specifications from the American Institute of Steel Construction (AISC), the American Iron and Steel Institute (AISI), and the National Association of Architectural Metal Manufacturers (NAAMM). Although the move to Load and Resistance Factor Design (LRFD) (AISC, 1994b) methods has been slow, this paper will compare the design of steel pipe guardrail systems using five different design specifications, two of which are LRFD specifications and three of which are ASD specifications. The design methodology discussed here is equally applicable to both pipe and hollow structural section (HSS) guardrail systems.

LOADS

Design live loads for guardrail systems are specified by the locally adopted building code, however, most codes use live load requirements similar to those specified by ASCE 7-98 (ASCE, 2000). Those loads are a uniform load of 50 pounds per linear foot, and a concentrated load of 200 pounds. These loads are to be applied in any direction, but need not be applied simultaneously. For the typical guardrail system shown in Figure 1, the critical direction of the load is horizontal. Most building codes require the guardrail to be 42 in. high. A conservative design assumption made by many designers is to consider the load to be applied at a height of 42.5 in., to take into account the fact that the guardrail may be inadvertently installed slightly higher than intended.

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DISTRIBUTION OF LOADS

The NAAMM (1995) manual provides the recommended distribution of loads for railing system posts and rails, for both uniform and concentrated load cases. Design moments in horizontal rails are based on considering the rail to be either a simply supported beam (single span condition) or a continuous beam. Design moments in the posts are based on considering the post to be a simple cantilever, fixed at the base.

Rails under concentrated load:
Single Span Rail: $M = PL/4$
Two or More Spans: $M = PL/5$

Rails under uniform load:
One or Two-Span Rail: $M = wL^2/8$
Three or More Spans: $M = wL^2/9.5$

Post under concentrated load:
All Conditions: $M = DPh$

Where D is a factor, which considers the distribution of the concentrated load to adjacent posts. NAAMM (1995)

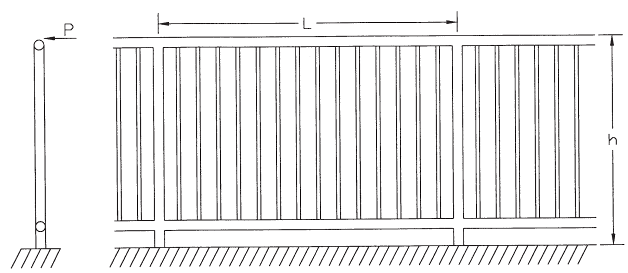

Fig. 1. Typical Guardrail.

provides graphical solutions for many cases, but for most practical cases, D may be estimated as:

End Posts:

2-span rail	0.85
3-span or greater	0.82

Intermediate Posts:

2-span rail	0.65
3-span or greater	0.60

Posts under uniform load:

End Posts:	$M = w(L/2)h$
Intermediate Posts:	$M = wLh$

For additional information on calculation of design moments in railing systems, and on calculation of load distribution factors, the reader is referred to the NAAMM manual (NAAMM, 1995).

DESIGN SPECIFICATIONS

Steel pedestrian guardrail systems can be designed using one of five design specifications. Each specification approaches the calculation of the cross-section strength (or resistance) in a slightly different manner.

1989 AISC-ASD

This venerable specification uses an allowable stress of $0.66F_y$ applied to the elastic section modulus, S, of the cross section. The allowable stress is reduced if the cross section is not compact, but this is not the case for most cross sections used for pedestrian guardrail systems.

1995 NAAMM

This design manual, published by the National Association of Architectural Manufacturers, is applicable to hollow circular cross sections used as guardrails. The manual uses an allowable stress of $0.72F_y$ applied to the elastic section modulus, S (Sherman, 1985). The allowable stress is reduced if the cross section is not compact, but this is not the case for most cross sections used for pedestrian guardrail systems. This higher allowable stress (compared to the 1989 AISC-ASD) is based on the realization that hollow circular cross sections have a relatively high shape factor (Z/S) of approximately 1.30, compared to approximately 1.12 for wide-flange sections.

1996 AISI-ASD / AISI-LRFD

The American Iron and Steel Institute specification is intended for cold-formed steel structural members, but is also applicable to any steel cross section whose thickness falls within the limits of this specification, which includes most cross sections used as guardrail members.

This specification is a combined ASD/LRFD specification. For most limit states, the specification calculates one nominal strength, which is then either reduced by a factor of safety, Ω, for ASD designs, or multiplied by a resistance factor, ϕ, for LRFD designs.

The basic nominal strength, M_n, for circular hollow cross sections, is calculated as

$$M_n = 1.25F_yS_f$$

For cross sections that are not fully effective, the section modulus to be used is not the full cross section modulus. For most cross sections used in pedestrian guardrail systems, however, the section is fully effective. The elastic section modulus is multiplied by 1.25 in recognition of the relatively high shape factor, similar to the NAAMM document. The resistance factor used by AISI for LRFD designs is 0.95.

1993 AISC-LRFD

This specification calculates the nominal strength of compact cross sections as

$$M_n = F_yZ$$

Using the plastic section modulus, Z, recognizes the ultimate strength of the cross section. The resistance factor used by AISC for LRFD designs is 0.90.

LRFD LOAD FACTORS

Neither the AISC (1994b), nor the AISI (1996) specifications, nor ASCE 7-98 (ASCE, 2000) specifically addresses the proper load factor to use for loads on pedestrian guardrails. Currently, the most defensible practice is to use the same load factor as for other live loads, 1.6. Some designers might consider using a lower load factor in consideration of the transient nature of the load. This is not considered to be a prudent option, considering the consequences of a guardrail failure in an assembly occupancy situation, such as a stadium. Lower load factors may, however, be reasonable in some situations, such as some industrial occupancies. At this time, without more substantial guidance, this decision is best left up to the designer-of-record.

DESIGN EXAMPLE

The different designs generated by the five specifications are best illustrated by a design example.

Determine the maximum post spacing for the following guardrail system:

> Posts and rails to be 1‰-in. nominal standard weight pipe (1‰-in. nominal schedule 40 pipe)

Rail system continuous over more than 3 spans
A53, Grade B steel (F_y = 35,000 psi)
Use section property values per AISC (1994a).
S = 0.326 in.^{3}
Z = 0.448 in.^{3}
Allowable and reduced nominal moment capacities for this cross section are listed in Table 1 for each specification.

1. Determine post spacing based on railing strength
Concentrated Load: $M = PL/5 = 200L/5 = 40L$ in.-lbs
Uniform Load: $M = wL^2/9.5 = (50/12)L^2/9.5 = 0.439L^2$ in.-lbs

A. 1989 AISC-ASD
Concentrated Load: 7,531 in.-lbs = $40L$
$\rightarrow L_{max}$ = 188.3 in.*
Uniform Load: 7,531 in.-lbs = $0.439L^2$
$\rightarrow L_{max}$ = 131.0 in.*

B. 1995 NAAMM
Concentrated Load: 8,215 in.-lbs = $40L$
$\rightarrow L_{max}$ = 205.4 in.*
Uniform Load: 8,215 in.-lbs = $0.439L^2$
$\rightarrow L_{max}$ = 136.8 in.*

C. 1996 AISI-ASD
Concentrated Load: 8,541 in-lbs = $40L$
$\rightarrow L_{max}$ = 213.5 in.*
Uniform Load: 8,541 = $0.439L^2$
$\rightarrow L_{max}$ = 139.5 in.*

D. 1993 AISC-LRFD
Concentrated Load: 1.6 ($40L$) = 14,112 in.-lbs
$\rightarrow L_{max}$ = 220.5 in.*
Uniform Load: 1.6 ($0.439L^2$) = 14,112 in.-lbs
$\rightarrow L_{max}$ = 141.7 in.*

E. 1996 AISI-LRFD
Concentrated Load: 1.6 ($40L$) = 13,549 in.-lbs
$\rightarrow L_{max}$ = 211.7 in.*
Uniform Load: 1.6 ($0.439L^2$) = 13,549 in.-lbs
$\rightarrow L_{max}$ = 138.9 in.*

2. Determine post spacing based on intermediate post strength
Concentrated Load: $M = D\,P\,h$ = 0.60 (200) (42.5) = 5,100 in.-lbs
Uniform Load: $M = wLh$ = (50/12)L (42.5) = 177.1L in.-lbs

A. 1989 AISC-ASD
Concentrated Load:
5,100 in.-lbs < 7,531 in.-lbs **OK**
Uniform Load: 7,531 = 177.1L
$\rightarrow L_{max}$ = 42.5 in.

B. 1995 NAAMM
Concentrated Load:
5,100 in-lbs < 8,215 in.-lbs **OK**
Uniform Load: 8,215 = 177.1L
$\rightarrow L_{max}$ = 46.4 in.

C. 1996 AISI-ASD
Concentrated Load:
5,100 in-lbs < 8,541 in.-lbs **OK**
Uniform Load: 8,541 = 177.1L
$\rightarrow L_{max}$ = 48.2 in.

D. 1997 AISC-LRFD
Concentrated Load:
1.6 (5,100) = 8,160 in-lbs < 14,112 in.-lbs **OK**
Uniform Load: 1.6 (177.1L) = 14,112 in.-lbs
$\rightarrow L_{max}$ = 49.8 in.

E. 1996 AISI-LRFD
Concentrated Load:
1.6 (5,100) = 8,160 in.-lbs < 13,549 in.-lbs **OK**
Uniform Load: 1.6 (177.1L) = 13,549 in.-lbs
$\rightarrow L_{max}$ = 47.8 in.

3. Determine post spacing based on end post strength.
Concentrated Load: $M = DPh$ = 0.82(200)(42.5) = 6,970 in.-lbs
Uniform Load: $M = w(L/2)h$ = (50/12) (L/2) (42.5) = 88.6L in.-lbs

A. 1989 AISC-ASD
Concentrated Load:
6,970 in-lbs < 7,531 in.-lbs **OK**
Uniform Load: 7,531 = 88.6L
$\rightarrow L_{max}$ = 85.0 in.

B. 1995 NAAMM
Concentrated Load:
6,970 in.-lbs < 8,215 in.-lbs **OK**
Uniform Load: 8,215 = 88.6L
$\rightarrow L_{max}$ = 92.7 in.

C. 1996 AISI-ASD
Concentrated Load:
6,970 in.-lbs < 8,541 in.-lbs **OK**
Uniform Load: 8,541 = 88.6L
$\rightarrow L_{max}$ = 96.4 in.

D. 1997 AISC-LRFD
Concentrated Load:
1.6 (6,970) = 11,152 in.-lbs < 14,112 in.-lbs **OK**
Uniform Load: 1.6 (88.6L) = 14,112 in.-lbs
$\rightarrow L_{max}$ = 99.6 in.

*Per OSHA regulations, the upper limit on post spacing is 96 in. (8 ft)

Table 1. Allowable Moment Capacity and Reduced Nominal Resisting Moment Capacity

Design Specification	Moment Capacity
1989 AISC-ASD	$M_a = 0.66F_yS = 0.66(35{,}000)(0.326) = 7{,}531$ in.-lbs
1995 NAAMM	$M_a = 0.72F_yS = 0.72(35{,}000)(0.326) = 8{,}215$ in.-lbs
1996 AISI-ASD	$M_a = M_n/\Omega_b = 1.25F_yS_f/\Omega_b = 1.25(35{,}000)(0.326)/1.67 = 8{,}541$ in.-lbs
1997 AISC-LRFD	$\phi_bM_n = \phi_bF_yZ = 0.9\ (35{,}000)\ (0.448) = 14{,}112$ in.-lbs
1996 AISI-LRFD	$f_b\ M_n = f_b\ 1.25\ F_y\ S_f = 0.95\ (1.25)\ (35{,}000)\ (0.326) = 13{,}549$ in.-lbs

Table 2. Maximum Post Spacing (Based on Post Strength)

Design Specification	Maximum Post Spacing (inches)
1989 AISC-ASD	42.5
1995 NAAMM	46.4
1996 AISI-ASD	48.2
1997 AISC-LRFD	49.8
1996 AISI-LRFD	47.8

E. 1996 AISI-LRFD

Concentrated Load:
1.6 (6,970) = 11,152 in.-lbs < 13,549 in.-lbs **OK**
Uniform Load: 1.6 (88.6L) = 13,549 in.-lbs
$\rightarrow L_{max} = 95.6$ in.

DISCUSSION OF RESULTS

The results of this design are fairly typical of most pedestrian guardrails, that the post spacing is determined by the post strength, most usually the interior post strength. Occasionally, a different cross-section (thinner walled or smaller diameter) will be used for the rails, since the rail strength usually does not control the design. There are a number of variations on guardrail design, including using internal stiffeners in the posts. These variations are adequately covered in the NAAMM manual (NAAMM, 1995), and the reader is urged to refer to that manual for further information.

Referring to Table 2, it is apparent that the 1997 AISC-LRFD specification provides for the greatest allowable post spacing of 49.8 in. In this example, the allowable spacing generated by the AISC-LRFD specification is 17 percent greater than a design generated by the AISC-ASD specification. This is a typical outcome, which allows for more economical designs through using fewer posts. Additionally, this should be appealing to most architects, who in the authors experience tend to want to push post spacing to unrealistically large spacings.

CONCLUSIONS

For most situations, the AISC-LRFD specification provides for greater post spacings than any of the other design specifications considered, creating designs which are more economical and perhaps more visually appealing.

APPENDIX: NOTATION

ϕ_b = LRFD resistance factor for flexure
= 0.90 (AISC-LRFD)
= 0.95 (AISI-LRFD)
Ω = LRFD load factor
= 1.6 for live load
Ω_b = AISI-ASD factor of safety
= 1.67 AISI-ASD
D = distribution factor for concentrated loads (NAAMM, 1995)
F_b = ASD allowable flexural stress, psi
f_b = ASD computed bending stress, psi
h = height of applied load, in.
L = rail span between centerlines of posts (inches)
M = ASD design moment, in.-lbs
= service load moment, in.-lbs
M_n = nominal flexural strength, in.-lbs

M_u = LRFD required flexural strength, in.-lbs
= ΩM
P = concentrated load applied to top of rail, lbs
S = elastic section modulus, in.^{3}
S_f = elastic section modulus for full cross section, in.^{3} (AISI)
w = uniform load applied to rail, lbs/ft
Z = plastic section modulus, in.^{3}

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