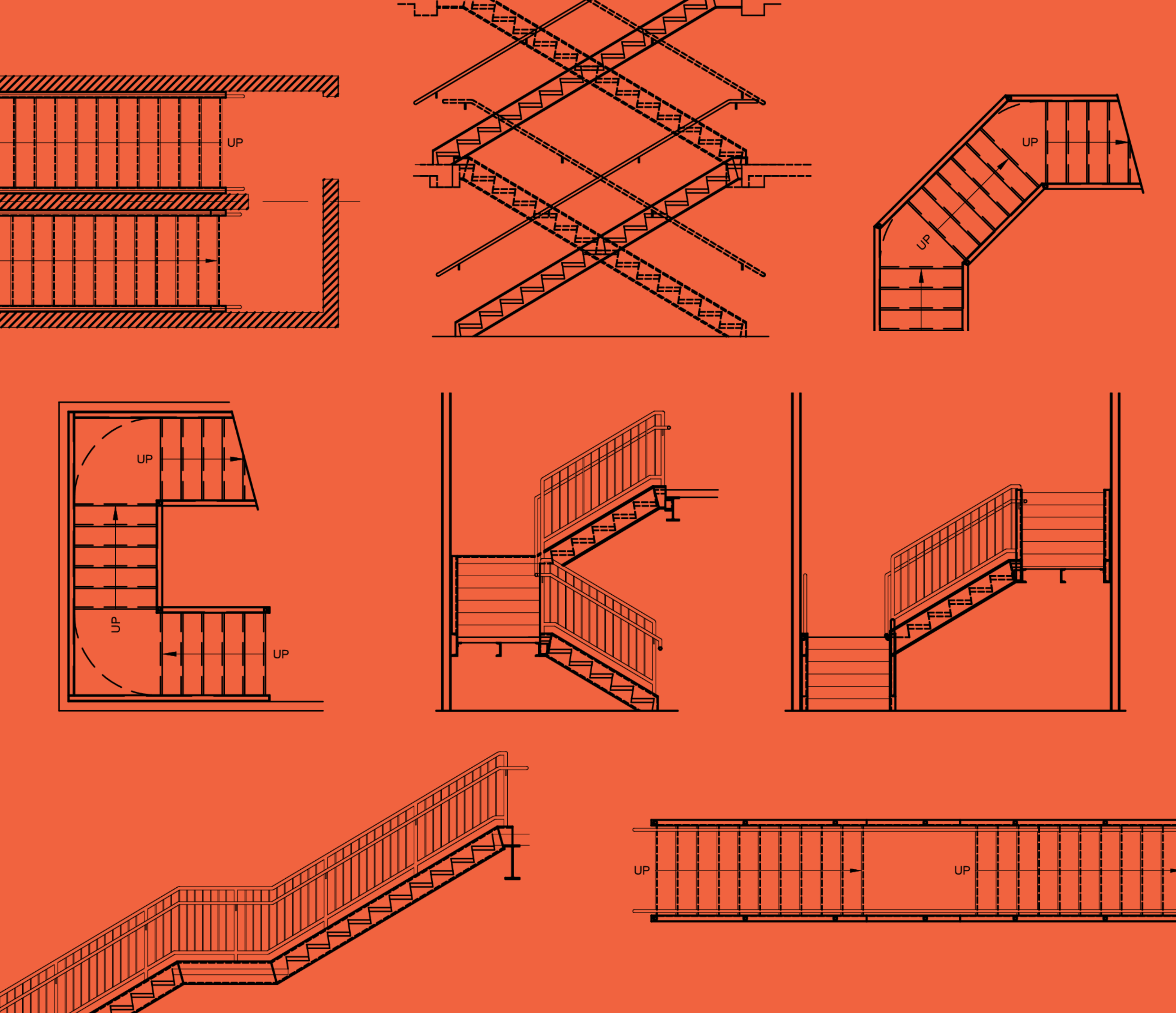

Design Guide 34

Steel-Framed Stairway Design

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Smarter.
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Steel.

Design Guide 34

Steel-Framed Stairway Design

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American Institute of Steel Construction

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Preface

This Design Guide provides guidance for the design and layout of steel elements for steel-framed stairways, guards, handrail, and related components. Background information regarding stairways, code requirements, design methods, and design examples are presented. The goal of this Design Guide is to provide sufficient information for a structural engineer to complete the design of a steel-framed stairway or provide adequate guidance to delegate this work to another engineer or stair designer.

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Purpose

This Design Guide was written in an effort to resolve common issues that occur during the planning, design, detailing, fabrication, erection and construction process related to steel stairways. Part of this effort involves providing guidance for structural engineers to apply engineering mechanics to the design of stair elements while conforming to industry standards.

The other part of this effort is to create better lines of communication and coordination between each project team member. The level of information, details and requirements for stairways can vary significantly from project to project. The following is a list of some of the more common items that should be reviewed and considered related to stairway design:

(1) Adequate stairway shaft dimensions

Determining an accurate opening size for stairways is critical early in the design development process. This Design Guide provides sizing recommendations in Section 3.4.4. These recommendations provide member suggestions, egress requirements and connection considerations to determine the preliminary opening size.

Adjustment and flexibility can also be provided in the design to accommodate changes to the stair layout or construction tolerances. Designers should provide stair connections that allow for adjustment through the use of slotted holes or adjustable bearing details. Refer to Figure 6-3 for the use of an extended plate detail with horizontal slotted holes that allow for adjustment during steel erection. This Design Guide provides several connection options in Chapter 6.

Designers can also provide a concrete slab edge angle detail that allows for adjustment by the detailer when the stair detailing is underway. Refer to Figure 6-8 for a detail that provides adjustment during detailing. Similarly the detailer, fabricator and erector can provide flexibility at opening locations by shipping the concrete slab edge angle as a loose piece to be field welded to the perimeter beams. This allows for minor adjustments without having to remove or modify fabricated steel. Final stair opening sizes should be coordinated with project team members.

Completing a field survey or creating an accurate set of as-built drawings will help to avoid field modifications. This can be especially important in existing structures or when stairs will connect to concrete or masonry construction. This Design Guide provides information regarding tolerances for different construction materials in Section 8.1.

Items to take into consideration when allocating stairway shafts in floors:

- Code requirements for egress width
- Tread width and depth
- Rise per tread
- Landing dimensions
- Space required between stair runs
- Space allocated for handrail and guards
- Space allocated for stair connections to header beam or support steel
- Allowance for the member width of stringer and landing members
- Structural support for the stair

(2) Code requirements for stairways, handrail and guards

Code requirements for a stair dictate the functional aspects of layout and design. It is imperative that accurate dimensions and clear requirements be provided by the architect to ensure the proper layout of a stairway can be achieved. Chapter 3 of this Design Guide provides an overview of various code requirements. These requirements should always be verified with the architect for each project.

For projects using delegated design submittals for structural engineering of stairways, code requirements should be confirmed with the architect before detailing work begins. The architect should review stair shop drawings for aesthetic elements and code requirements and then provide approval when all criteria are met. Adequate time for the review process should be included. Chapter 9 of this Design Guide provides additional information related to delegated design.

(3) Quality of design documents and information

The design documents should clearly show the work that is to be performed and should give sufficient dimensions and guidance to accurately convey the design intent for the work to be constructed. Designers should carefully review design documents and project specifications to ensure that there is consistency throughout.

Typical details and standard notes are often provided for stairways and guards. This level of information often leads to conflicts between the design documents and project specifications. It also leads to unnecessary delays and confusion that need to be resolved through a formal request for information process. Designers need to take care to provide accurate information throughout their design documents or defer all aspects of the design to another party. Appendix A of this Design Guide provides checklists that can help to ensure that designers have provided adequate information in their design documents.

Project team members should coordinate architectural requirements with the Architect to ensure that structural requirements can be met while maintaining aesthetic expectations. These requirements will vary based on the stair type and stair class. This Design Guide covers general stair information in Chapter 2. Additional guidance and recommendations for member types with advantages and disadvantages for each type can also be found in Chapter 4, Chapter 5 and Chapter 7.

(4) Coordination of structural support with stairway support

An often overlooked aspect of stairway design is the requirement for structural support of the stair stringers and landings. Many times, stairs are shown pictorially on drawings without consideration of how they can be supported by the main structure. Each intermediate landing must have some sort of structural support with at least two support points. It is most desirable to have the intermediate landing supported at each of its four corners. To accomplish this, the main building structural members must be present either at the level of the landing or at a location that will permit the landing to be hung from the structure above or supported from below.

Stair runs also require the same consideration. With a fully supported landing, the stair run can be supported by the intermediate landing and the lower or upper floor framing. A review of Chapter 3 of this Design Guide will aid designers in the framing layout to provide adequate support for stairways.

(5) Contractual aspects of deferred submittals, delegated design, and design-build projects

Careful thought and consideration should be put into any portion of work that is part of a deferred submittal, delegated design, or a design-build process. Each of these options has different expectations, requirements and liability. Designers should clarify their scope of work and expectations for project submittals before entering into a contract. Contractual guidance is outside of the scope of this Design Guide.

Working with the project team to overcome and resolve the issues presented here can help to avoid potential problems related to the design and construction of stairs. Structural engineers, detailers, fabricators and erectors can utilize this Design Guide along with years of experience to continue providing steel solutions for everything from simple egress stairs to unique feature stairs.

Chapter 1
Introduction

Stairways are an essential part of multi-story buildings and industrial structures that provide vertical access for occupants. This vertical access can be used to move from one level to another and provides a means of egress in an emergency. Stairways provide a safe and efficient option for traveling within a building.

Handrail and guards are additional elements that are part of the stairway. Handrails provide a graspable surface for occupants to hold while moving along a stairway. Handrail is typically wall mounted or supported on the guard. Guards are provided at or near the open side of an elevated walking surface and incorporate infill members or panels to minimize the possibility of falling to a lower level.

The design and layout of stairways is dependent on the intended use, occupant load and serviceability requirements. Proper clearances and intuitive layout are important to ensure occupants can easily and safely use a stairway.

Stairways, handrail and guards are a critical aspect of any building design, but they are often overlooked or deferred to others to complete. This Design Guide will focus on steel-framed stairway design and associated steel components in an effort to highlight code requirements, stair design methodology, and delegated design considerations. Practical design examples are included in Chapter 10 of this Guide.

1.1 OBJECTIVE AND SCOPE

The objective of this Design Guide is to assist the practicing engineer in determining the appropriate layout, loading and serviceability requirements for steel-framed stairways based on the applicable code requirements. Typical types of stairways and guards are presented along with member types and framing options. The Design Guide presents standard design methodologies for the design of steel elements for stairways, handrail, guards and associated connections. Additionally, information regarding delegated design and recommended standard practices related to stairways is provided.

When referring to the structural engineer responsible for the design of the steel structure, this Design Guide uses the term "structural engineer of record (SER)" as it is used in the AISC *Code of Standard Practice for Steel Buildings and Bridges*, hereafter referred to as the AISC *Code of Standard Practice* (AISC, 2016a). This Design Guide also makes reference to the architect, who acts as the entity that provides architectural design for stairways. When referring to the engineer responsible for the structural design of steel-framed stairways, this Design Guide uses the term "specialty structural engineer (SSE)." On some projects the SER may serve as both the structural engineer for the building steel structure and as the SSE for steel-framed stairway design.

This Design Guide illustrates methods for the layout and design of common stairway, handrail, guards and associated connections based on structural principles and presents the design basis and examples for:

(1) Load determination for gravity and seismic forces

(2) Tread and riser section

(3) Stringer design as a simple span

(4) Stringer design with integrated landing

(5) Guard and handrail assembly

(6) Typical connections

Although this Design Guide is primarily intended to assist the practicing engineer, it may also be a reference for architects, steel fabricators, steel detailers and steel erectors.

Complex and custom stairway systems, independent stairways, nonsteel elements (e.g., structural concrete, glazing, aluminum, etc.), unique architectural requirements, and other nonstandard designs are beyond the scope of this Design Guide. A valuable resource for additional information related to stairs and railings can be found in the National Association of Architectural Metal Manufacturers (NAAMM) *Metal Stairs Manual*, AMP510 (NAAMM, 1992), and *Pipe Railing Systems Manual Including Round Tube*, AMP521, hereafter referred to as the NAAMM *Railing Manual* (NAAMM, 2001).

1.2 DESIGN PHILOSPHY

The functional aspects of stairways, handrails and guards are critical to the proper layout of these elements. The layout is mandated by the appropriate code requirements and is determined based on the type and classification of the building and the needs of the occupants. The most commonly used code requirements for stairways are based on the 2015 *International Building Code* (ICC, 2015a) or the Occupational Safety and Health Administration (OSHA) 1910 Subpart D—*Walking-Working Surfaces* (OSHA, 2016). Relevant OSHA standards included under 1910 Subpart D are 1910.25, *Stairways*, 1910.28, *Duty to Have Fall Protection and Falling Object Protection*, 1910.29, *Fall Protection Systems and Falling Object Protection–Criteria and Practices*, and 1910.36, *Design and Construction Requirements for Exit Routes* (OSHA, 2014). Additional information regarding code requirements is presented in Chapter 3.

The general layout, design criteria, recommended standards, construction details and specifications for stairways, handrails and guards are covered in the governing building codes and by the NAAMM *Metal Stairs Manual* and *Railing Manual*. This Design Guide provides additional information, design methods and recommendations related to stairways, handrails and guards fabricated from steel.

Stairs and handrail are defined as "other steel items" in the AISC *Code of Standard Practice*; therefore, these elements are outside the scope of the AISC *Code of Standard Practice*. However, the criteria for the design, fabrication and erection of steel members and steel connections that are part of a stair or handrail may be subject to the same provisions within the AISC *Code of Standard Practice,* the AISC *Steel Construction Manual* (AISC, 2017), hereafter referred to as the AISC *Manual*, and the AISC *Specification for Structural Steel Buildings* (AISC, 2016b), hereafter referred to as the AISC *Specification*, if approved by the SER. Using these standards as references along with professional judgment will provide a set of reasonable design criteria that can be applied to the structural design of steel members and connections used in stairways, handrails and guards.

The level of occupant comfort is also a design consideration. Serviceability requirements for stairs are based on vertical deflection limits per the applicable code requirements or more stringent project requirements. Additional guidance related to deflections of guards is based on ASTM International (ASTM) standards. Vibration analysis may also be required based on the size and configuration of a stairway. AISC Design Guide 11, *Floor Vibrations Due to Human Activity* (Murray et al., 2016), provides additional guidance to evaluate steel-framed stairs for vibration.

Based on the sequence of construction, additional consideration should be made with regard to ease of erection, connection types (field bolting versus field welding), and the use of post-installed anchors. The decisions made during design can have a major impact with regard to fabrication and construction. This Design Guide will present some preferred construction details to facilitate the fabrication and field erection of steel-framed stairways.

Designers should consult with local detailers and fabricators to determine preferred member sizes, ideal layout, and connection details for stairways, guards and handrail. Utilizing these preferences in the design phase can typically save time and money during detailing and fabrication.

Stairways are integrated with several different building structural elements, including structural steel framing, concrete framing, cast-in-place concrete cores, masonry wall cores, and freestanding self-supporting systems. The attachments and integration of a stairway to each of these elements presents concerns related to tolerances and fit-up that need to be evaluated.

All of these considerations need to be accounted for by the SSE to provide a stairway that meets the code requirements for occupant use, provides the required level of strength and serviceability, provides an economical and constructible system, and can be integrated into the main building structure. In the situation where the stairway is part of a delegated design or design-build submittal, the SSE must also coordinate with the SER and architect to adhere to the requirements of the design documents and project specification.

Chapter 2
General Information

The NAAMM *Metal Stairs Manual* (NAAMM, 1992) provides an extensive overview of stair types and stair classes. This information is reproduced in this chapter with modifications, additional information and commentary pertaining to common steel-framed stairways used for egress and maintenance access.

In the NAAMM *Metal Stairs Manual*, metal stairs are classified according to both Type and Class. The Type designation identifies the physical configuration or geometry of the stair, while the Class designation refers to its construction characteristics, the degree of refinement of fabrication and finish, and the general nature of its usage.

2.1 STAIR TYPES

There are a variety of stair types that may be used on a project. The geometry, layout and finishes are based on the project needs and available space. Several common stair types are discussed herein, including straight stairs, circular stairs, curved stairs, alternating tread devices, and ships ladders.

2.1.1 Straight Stairs

Straight stairs are by far the most common type of stair. Although the term "straight" is self-explanatory, for purposes of classification, a straight stair is defined as one in which the stringers are straight members. The slope of straight stairs is typically less than 50°. Straight stairs may be arranged in several different ways:

(a) Straight Run
Consists of either a single flight extending between floors as shown in Figure 2-1 or a series of two or more flights in the same line with intermediate platforms between them as shown in Figure 2-2.

(b) Parallel
Successive flights which are parallel to each other and are separated by one or more intermediate platforms as shown in Figure 2-3.

(c) Angled
Successive flights placed at an angle to each other with an intermediate platform between each flight as shown in Figures 2-4 and 2-5. Stairs flights placed at an angle of 180° are classified as parallel as shown in the previous section.

(d) Scissor
A pair of straight run flights paralleling each other in plan in opposite directions on opposite sides of a dividing line as shown in Figure 2-6.

2.1.2 Circular Stairs

Circular stairs are stairs that, in plan view, have an open circular form with a single center of curvature. They may or may not have intermediate platforms between floors. Refer to Figure 2-7.

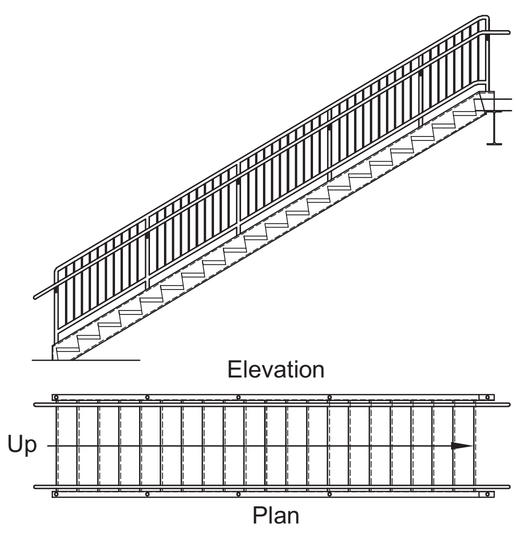


Fig. 2-1. Straight run stair.

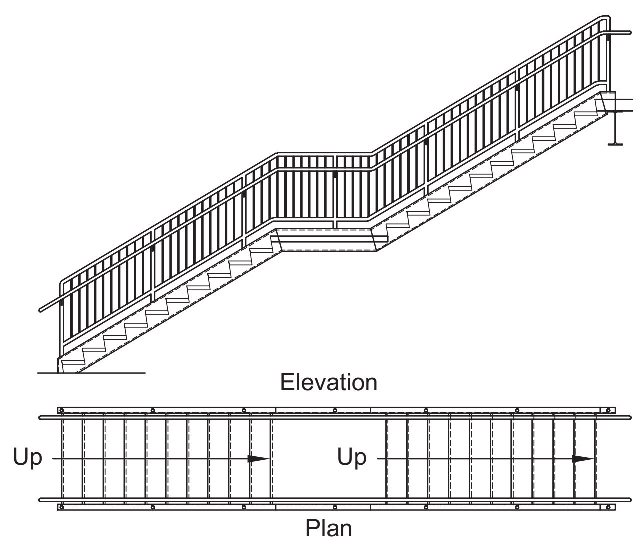


Fig. 2-2. Straight run stair with integrated landing.

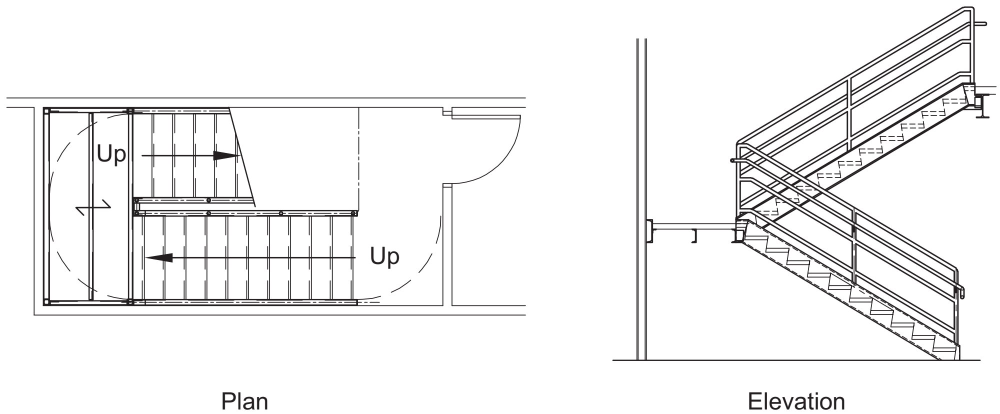


Fig. 2-3. Straight stair—parallel with intermediate landing.

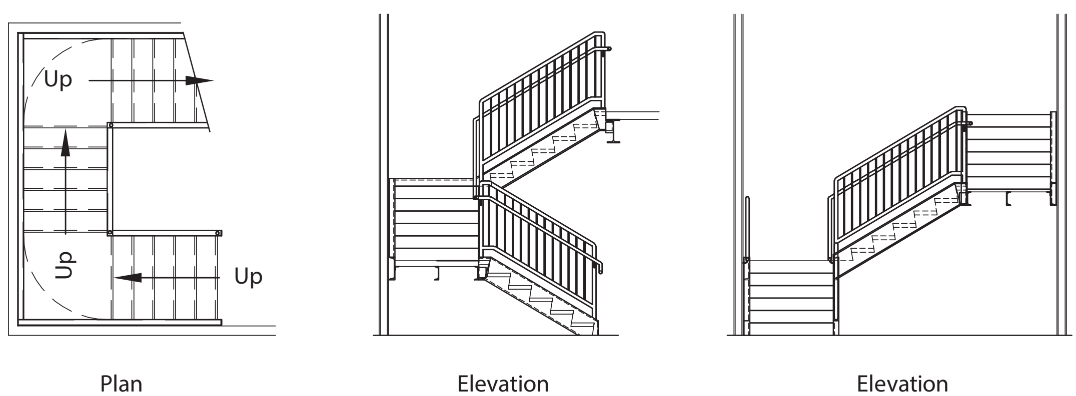


Fig. 2-4. Straight stair—angled.

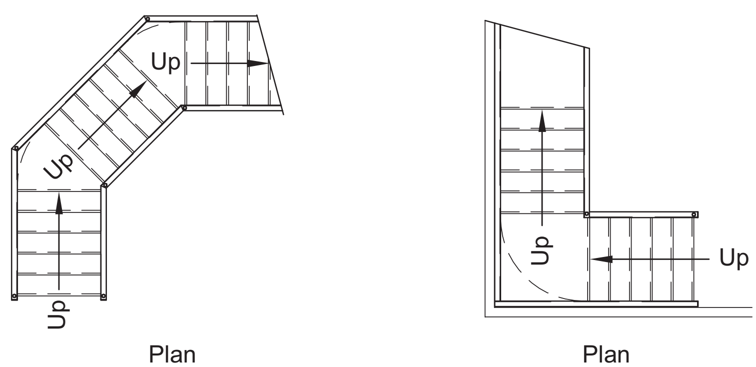


Fig. 2-5. Straight stair—angled.

2.1.3 Curved Stairs

Curved stairs are stairs that, in plan view, have two or more centers of curvature, being oval, elliptical or some other compound curved form. They also may or may not have one or more intermediate platforms between floors. Refer to Figure 2-8.

2.1.4 Alternating Tread Stairs

In this type of stair, the treads are alternately mounted on the left and right side of a center stringer. Because of this tread construction and the use of handrails on each side, these stairs permit safe descent facing outward from the stair. The pitch angles used in these stairs, typically in the range of 50° to 70°, will be much steeper than typical stairways used for means of egress. This type of stair is not acceptable as a path used for means of egress except for certain special situations. If space permits, other stair types are typically preferred. Alternating tread stairs are more commonly used for maintenance access in areas not intended for access by the general public. Refer to Figure 2-9.

2.1.5 Ship Ladders

In this type of stair the treads are flat, and handrails are typically provided on both sides. The pitch angle, in the range of 50° to 70°, is much steeper than typical stairs used for means of egress. This type of stair is not acceptable as a path used for means of egress except for certain special situations. If space permits, other stair types are typically preferred. Ship Ladders are more commonly used for maintenance access in areas not intended for access by the general public. Refer to Figure 2-10.

2.2 STAIR CLASSES

The class designation of a stairway is indicative of the type of construction; the quality of materials, details and finish; and, in most cases, the relative cost. Stairs of all classes are built to meet the same standards of performance with respect

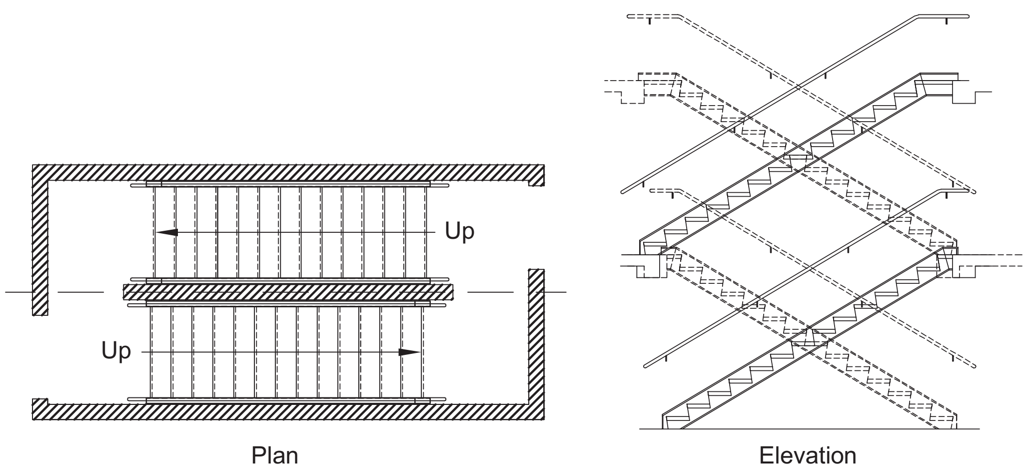


Fig. 2-6. Straight stair—scissor.

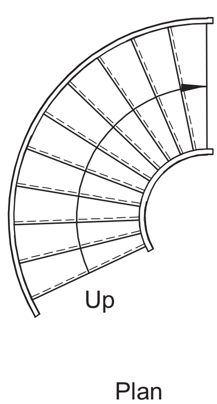


Fig. 2-7. Circular stair.

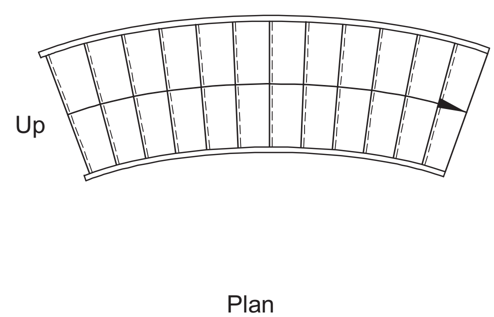


Fig. 2-8. Curved stair.

to load-carrying capacity and safety. As such, these class distinctions do not represent differences in functional value, but rather in character and appearance. It is important to recognize that where function is the prime concern and aesthetics are of minor importance, significant economies can be achieved by specifying one of the less expensive classes.

The following descriptions indicate the general construction characteristics of each class. It should be recognized that because each manufacturer has its own preferred methods of fabrication, the details of construction vary somewhat throughout the industry. The four classes of stairs are listed in the order of increasing cost (as a general rule).

2.2.1 Industrial Class

Stairs of this class are purely functional in character and, consequently, are generally the most economical. They are designed for either interior or exterior use in industrial buildings, such as factories and warehouses, or as fire escapes for emergency egress. This class does not include stairs that are integral parts of industrial equipment.

Industrial class stairs are similar in nature to light steel construction. Hex head bolts are commonly used for most connections. Welds, where used, are not ground to produce a smooth finish. Stringers may be flat plate, open channels or hollow structural section (HSS) members; treads and platforms are usually constructed of grating or floor plate; and risers are usually open, though in some cases, filled pan-type treads and steel risers may be used. Guards and handrail are usually constructed of pipe, tubing, angle or steel bar.

When used for exterior applications, the details of construction are similar, except that treads and platforms commonly utilize grating or perforated floor plate. For solid surfaces at treads and platforms, a slope to allow for drainage is also required.

2.2.2 Service Class

This class of stairs serves chiefly functional purposes. Service stairs are usually located in enclosed stairwells and provide a secondary or emergency means of travel between floors. In multi-story buildings, they are commonly used as egress stairs. They may serve employees, tenants or the public and are generally used where economy is a consideration.

Service stair stringers are generally the same type as those used for industrial class. Treads may be one of several standard types, either filled or formed of floor or tread plate, and risers are either exposed steel or open construction. Guards and handrail are typically pipe or simple bar with tubular posts, and the underside of the stair, or soffit, is usually left exposed. Connections on the underside of the stairs are commonly made with hex head bolts, and only welds in the travel area are ground smooth.

2.2.3 Commercial Class

Stairs for this class are usually for public use and are of more attractive design than those of the service or industrial classes. They may be placed in an open location or may be located in closed stairwells in public, institutional or commercial buildings.

Stringers for this class of stairs are usually exposed open channel, plate sections, or HSS members. Treads may be any of a number of standard types; risers are usually exposed steel. Guards and handrail vary from ornamental bar or HSS construction with metal handrail to simple pipe construction, and soffits may or may not be covered. Exposed bolted connections in areas where appearance is critical are made with countersunk flat or oval head bolts; otherwise, hex head bolts are used. Welds in conspicuous locations are smooth and all joints are closely fitted.

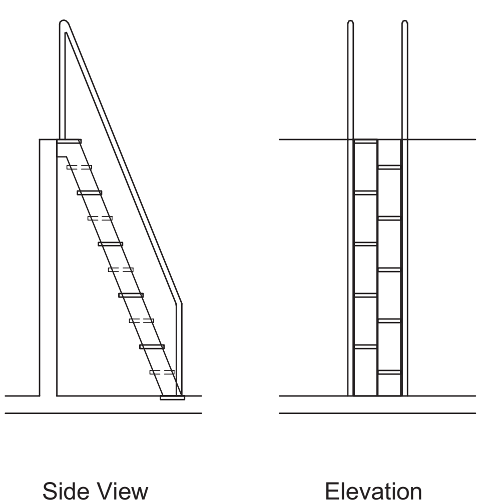


Fig. 2-9. Alternating tread device.

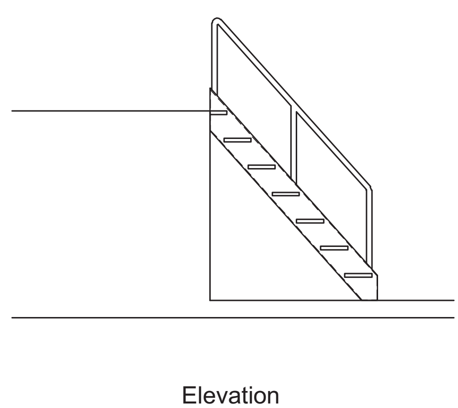


Fig. 2-10. Ship ladder.

2.2.4 Architectural Class

This classification applies to more elaborate, and usually more expensive, stairs which are designed to be architectural features in a building. They may be wholly custom designed or may represent a combination of standard parts with specially designed elements such as stringers, guards, handrail, treads or platforms. Usually this class of stair has a comparatively low pitch, with relatively low risers and correspondingly wider treads. Architectural metal stairs may be located either in the open or in enclosed stairwells in public, institutional, commercial or monumental buildings.

The fabrication details and finishes used in architectural class stairs vary widely, as dictated by the architect's design and specifications. As a general rule, construction joints are made as inconspicuous as possible, exposed welds are smooth, and soffits are covered with some surfacing material. Stringers may be special sections that are exposed or may be structural members enclosed in other materials. Guards and handrail are of an ornamental type and, like the treads and risers, will be dictated by architectural design requirements.

2.3 STAIR NOMENCLATURE

Figures 2-11 and 2-12 indicate standard nomenclature for stairways, guards and handrail. This nomenclature is used throughout the Design Guide.

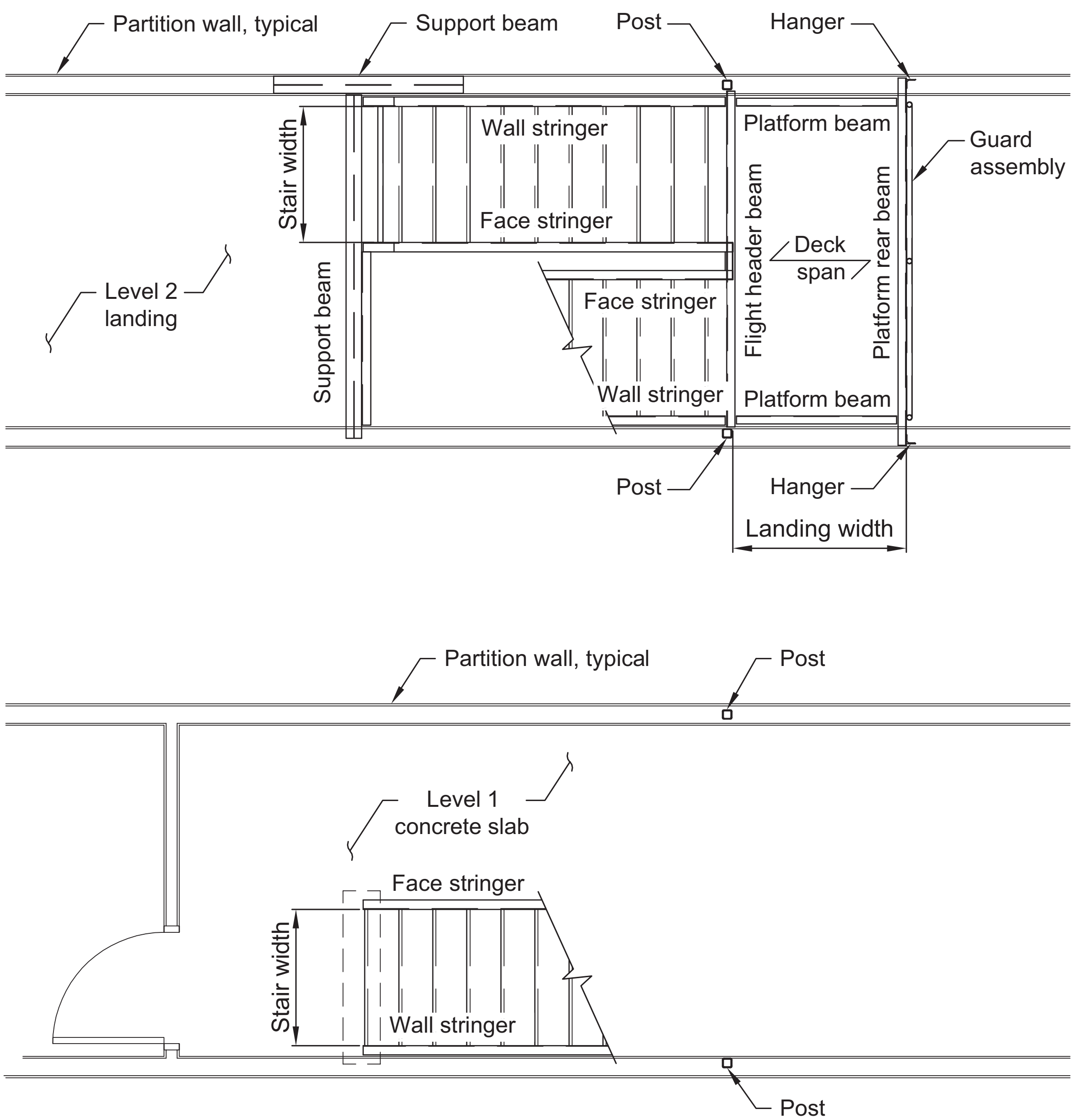


Fig. 2-11. Nomenclature—plan views.

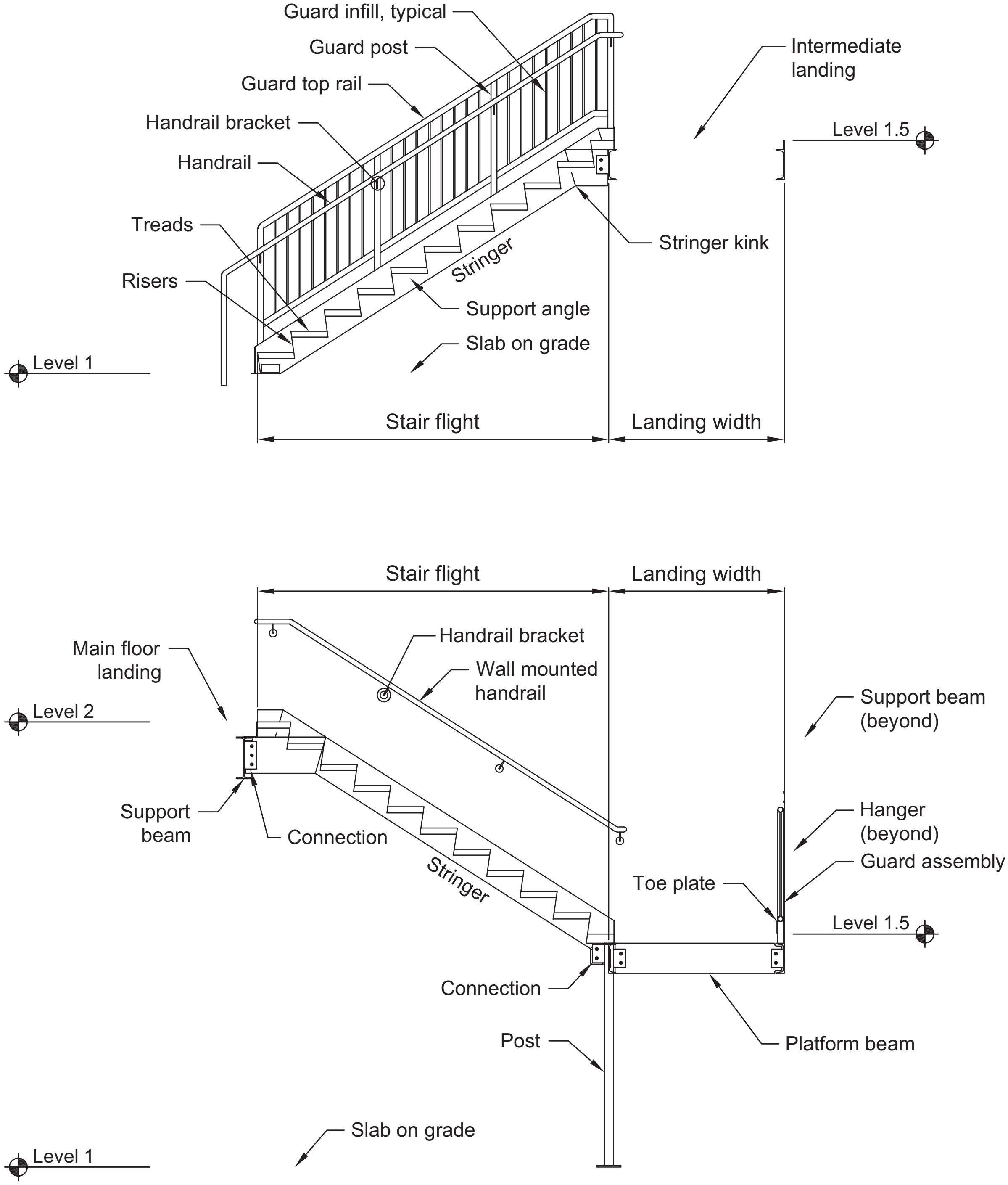


Fig. 2-12. Nomenclature—section views.

Chapter 3
Stairway Code Requirements

The design, construction and arrangement of stairways is dictated by the applicable code requirements. Code requirements, including local amendments, are determined by the local authority having jurisdiction. The most commonly used code requirements are based on the *International Building Code* (ICC, 2015a), hereafter referred to as the IBC, or OSHA standards *Walking-Working Surfaces*, OSHA 1910 Subpart D (OSHA, 2016) and *Design and Construction Requirements for Exit Routes*, OSHA 1910.36 (OSHA, 2014). Code requirements for residential stairs in one and two family dwellings are based on the *International Residential Code for One- and Two-Family Dwellings* (ICC, 2015b), which is not covered in this Design Guide.

The Purpose section at the beginning of this Design Guide provides recommendations for designers to consider in conjunction with this chapter. Designers should consider both the loading requirements in Section 3.2 along with the stairway size and shaft dimensions of Section 3.4 as part of a complete stairway design.

The architect and structural engineer of record (SER) should thoroughly research the applicable code requirements for individual projects in conjunction with additional mandates from the local authority having jurisdiction. This chapter provides information related to code requirements for stairways but should not serve as a replacement for the required research and code study by a qualified design professional.

3.1 APPLICABLE CODES

International Building Code, Chapter 10, "Means of Egress," covers the design, construction and arrangement of stairways, handrails and guards. The IBC, where adopted by the local authority having jurisdiction, applies to all types of buildings and structures unless exempted. In most cases, stairways should be based on the requirements of the IBC and any additional local amendments.

Walking-Working Surfaces, OSHA 1910 Subpart D, may be used for the design of stairways under certain circumstances. These include stairs constructed in jurisdictions that do not use a model building code and stairs in a certain building with a use or occupancy that is exempt from the governing building code based on local amendments. Additionally, the authority having jurisdiction may grant a waiver or exemption allowing stairways to conform to the OSHA standards.

It is critical that stair designers verify the applicable code requirements with the authority having jurisdiction. Stairways conforming to IBC requirements will likely be acceptable regardless of the building use. Stairways conforming to OSHA standards may be acceptable only in certain situations or may be subject to modified requirements. Local amendments and requirements from the fire marshal may impose different criteria for stairways, handrails and guards.

Accessibility requirements and local requirements should be verified with the local authority having jurisdiction. These additional requirements may affect the recommendations and requirements given in this Design Guide.

3.2 STAIRWAY LOAD COMBINATIONS AND DESIGN LOADS

Load combinations and design loads are dictated by the governing code. Designers should determine the applicable load combinations and design loads based on the stairway usage and project requirements.

3.2.1 Load Combinations

Load combinations for stairways conform to the IBC by reference to the American Society of Civil Engineers (ASCE) *Minimum Design Loads for Buildings and Other Structures,* ASCE/SEI 7-16 (ASCE, 2016), hereafter referred to as ASCE/SEI 7. Chapter 2, "Combinations of Loads," specifies the load combinations and load factors to be used for strength design in Section 2.3 and allowable stress design in Section 2.4. Load combinations may be especially critical when environmental loads (wind, snow, ice or seismic loads) are combined with dead and live loads for the design of the stairway.

3.2.2 Dead Loads

Dead loads include self-weight of the steel framing and connections, treads and risers, guards, handrail, and landings. Additional considerations include floor finishes, soffit covers, mechanical allowances, and architectural/aesthetic elements. In some cases, stair members may also support stud walls or partitions. Minimum design dead loads can be found in ASCE/SEI 7, Commentary Chapter C3 and Table C3.1-1. An allowance of 5 to 10 psf should also be considered when mechanical, electrical, plumbing, or fire protection components will be supported from the underside of the stair. Table 3-1 includes typical components that are additive to the stairway self-weight.

Table 3-1. Typical Dead Loads for Stairways*	
Component	**Load, psf**
Floor finishes:	
• Ceramic or quarry tile on mortar bed	16–23
• Lightweight concrete fill (per inch thickness)	8
• Normal weight concrete fill (per inch thickness)	12
• Hardwood flooring	4
• Linoleum tile, ¼ in.	1
• Terrazzo (per in. thickness) directly on slab	13
Ceiling/soffit finishes:	
• Gypsum board (per ⅛-in. thickness)	0.55
• Suspended steel channel system	2
• Wood furring suspension system	2.5
Walls:	
• Wood or steel studs, ½-in. gypsum board each side	8
• Structural glass (per in. thickness)	15
Miscellaneous:	
• Mechanical allowance	5
• Mechanical allowance including ductwork	10

* From ASCE/SEI 7 (ASCE, 2016)

Table 3-2. IBC Stairway, Handrail and Guard Live Loads	
Component	**Load**
Stair tread (nonconcurrent loadings)[a]	300-lb concentrated load on 4 in.^{2} 100 psf
Stair landing[b]	100 psf
Guard—top rail (nonconcurrent loadings)[c]	200-lb concentrated force in any direction 50 lb/foot in any direction
Guard—infill and Intermediate rails[d]	50 lb over 1 ft^2
Handrail (nonconcurrent loadings)[c]	200-lb concentrated force in any direction 50 lb/ft in any direction

Note: Additional requirements related to glass handrail assemblies and guards should be checked in the applicable code.
a IBC, Table 1607.1 (ICC, 2015a) and ASCE/SEI 7, Table 4.3-1 and Section 4.1.6 (ASCE, 2016)
b IBC, Table 1607.1 (ICC, 2015a) and ASCE/SEI 7, Table 4.3-1 (ASCE, 2016)
c IBC, Sections 1607.8.1 and 1607.8.1.1 (ICC, 2015a) and ASCE/SEI 7, Sections 4.5.1 and 4.5.1.1 (ASCE, 2016)
d IBC, Section 1607.8.1.2 (ICC, 2015a) and ASCE/SEI 7, Section 4.5.1.2 (ASCE, 2016)

3.2.3 Live Loads

Live loads are specified by the governing building code. IBC, Chapter 16, and ASCE/SEI 7, Chapter 4, provide the typical live loads to be used. These live loads are summarized in Table 3-2 with respect to stairway design. For stair treads, both the concentrated loading and uniform loading should be checked. However, per IBC, these loads are nonconcurrent, and the most severe loading should be used for design. For the top rail of guards and handrails, both the concentrated loading and uniformly distributed load should be checked. However, per IBC, these loads are nonconcurrent, and the most severe loading should be used for design. The designer should verify with the local authority having jurisdiction because some local building codes require that concurrent live loads be considered for design of stairway, guard and handrail elements.

It should be noted that factory, industrial and storage occupancies in areas that are not accessible to the public and that serve an occupant load not greater than 50 are excluded from the uniform live load for guards. Refer to ASCE/SEI 7, Section 4.5.1.

It is also important to note that IBC 2009 (and later editions) do not permit allowable stress increases for the design

Table 3-3. OSHA Stairway, Handrail and Guard Live Loads	
Component	**Load**
Stair tread and landing (nonconcurrent loadings)	Five times "normal live load" or minimum 1,000-lb concentrated load
Guard/stair rail system—top rail	200-lb concentrated force in downward or outward direction
Guard/stair rail system—infill	150-lb concentrated force in downward or outward direction
Handrail	200-lb concentrated force in downward or outward direction
Toeboard	50-lb concentrated force in downward or outward direction

Table 3-4. ASTM E985 Handrail and Guardrail Live Loads		
Use / Occupancy	**Component**	**Load**
Standard	Guard top rail or handrail (nonconcurrent loadings)	200-lb concentrated force in any direction 50 lb/ft in any direction
	Guard—infill and intermediate rails	50 lb over 1 ft^2
Public assembly building with rooms designed for use by 50 or more persons simultaneously	Guard top rail or handrail (nonconcurrent loadings)	300-lb concentrated force in any direction 50 lb/ft in any direction
	Guard—infill and intermediate rails	50 lb over 1 ft^2
Public assembly building room or area protected by component	Guard top rail or handrail (nonconcurrent loadings)	365-lb concentrated force in any direction 60 lb/ft in any direction
	Guard—infill and intermediate rails	50 lb over 1 ft^2

of handrails and guards when using allowable stress design methods.

Walking-Working Surfaces, OSHA 1910 Subpart D, provides the required live loads to be used and these have been included in Table 3-3. OSHA requires that stairs be designed for five times the normal live load or a minimum 1,000-pound concentrated load per Section 1910.25(b)(6). Guard and handrail loading requirements are given in Sections 1910.29(b)(3) and 1910.29(b)(5). Toeboard loading requirements are given in Section 1910.29(k)(1)(v).

OSHA has provided an interpretation letter with regard to the normal live load, indicating that it should be applied "over the whole stair tread area." The normal live load should be based on the number of personnel that could use the stair at any time.

For example, a 3-ft-wide stair with nine treads is used to access an equipment platform by one worker weighing 300 lb (including tools). The total live load is 300 lb over approximately 27 ft^2. The uniform load is then $(300 \text{ lb})/(27 \text{ ft}^2) =$ 11.2 psf. Per OSHA, this is the normal live load. The stair should be designed for five times this value or 56 psf.

The normal live load should be based on expected usage for the stair. Stairs accessing certain maintenance platforms may only be accessed by one worker in the infrequent event that a piece of equipment breaks down, resulting in a low normal live load. On the other hand, stairs accessing an area that requires hourly checks of equipment by several employees may require a higher normal live load.

ASCE/SEI 7, Table 4.3-1, indicates that "walkways and elevated platforms (other than exit ways)" should be designed for a 60-psf uniform load. The normal live load as required by OSHA standards should be based on project specific requirements, but the author recommends using a minimum 60-psf uniform live load (nonconcurrent with concentrated load) as an additional check for the stair design.

An additional consideration for live loads includes the possibility of unbalanced loading. Depending on the configuration of framing, certain unbalanced loading situations may produce more severe loading or deflections than a balanced condition. Cantilevered stringers and fixed based cantilever columns should be checked for multiple loading conditions.

Additional requirements related to the loading of guards and handrails are provided in *Standard Specification for Permanent Metal Railing Systems and Rails for Buildings*, ASTM E985 (ASTM, 2006). At this time, ASTM E985 has been withdrawn as an active standard; however, it is still regularly referenced in project specifications. Table 3-4 summarizes these requirements.

3.2.4 Environmental Loads

For exterior stairways, additional loadings should be considered, including wind loads, snow loads, rain loads and ice loads. Depending on the size and layout of the stairway, environmental loads may control the design of individual elements.

Environmental loads should be based on the requirements of the governing building code and project specific requirements. Typically, these loads are given in ASCE/SEI 7. The commentary and recommendations presented in this section refer to requirements within ASCE/SEI 7.

3.2.4.1 Wind Loads

Wind loads should be based on the requirements of ASCE/SEI 7, Chapter 26. Stairways that are exposed to the elements will likely fall under the provisions for "Design Wind Loads: Other Structures" in ASCE/SEI 7, Section 29.4. Due to the open nature of stair framing and attached guards, determining the force coefficient, C_f, is critical. Using the values related to lattice frameworks should provide reasonable C_f values. The minimum wind load to be used is 16 psf according to ASCE/SEI 7, Section 29.7.

3.2.4.2 Snow Loads

Snow loads should be based on the requirements of ASCE/SEI 7, Chapter 7. Snow may accumulate on the surface of stairways with solid treads and landings. The minimum snow load to be used is 20 psf unless the region under consideration does not require snow loading. Snow loading may become more severe due to the effects of snow drifting. For stairways located in northern regions, load combinations including both live load and snow load may govern over load combinations using live load only. Additional consideration should be made for drainage at the treads and landings when the snow melts.

3.2.4.3 Rain Loads

An exterior stairway that incorporates sloping landings and stair treads will likely not need additional review for rain loads. However, certain situations—including landings with longer spans (where beam deflection may be larger than drainage slope), platforms incorporating drains, or where ice dams are possible—should be reviewed to determine if rain loads should be considered. In these cases, refer to ASCE/SEI 7, Chapter 8. Additional consideration should be made for drainage at the treads and landings.

3.2.4.4 Ice Loads

Lattice structures, open catwalks and platforms are all defined as "ice-sensitive structures" in ASCE/SEI 7, Chapter 10. Stairways, guards and handrail should be reviewed for the additional vertical load due to ice from freezing rain and checked for wind on the increased area due to built-up ice. Ice loads may become substantial in certain regions. Additional consideration should be made for drainage at the treads and landings when the ice melts.

3.2.5 Seismic Loads

Seismic design criteria should be based on the requirements of ASCE/SEI 7, Chapter 11, and the governing building code or from design information provided by the SER. Most stairways are not part of the seismic lateral force-resisting system, and determination of seismic forces can be determined from ASCE/SEI 7, Chapter 13, "Seismic Design Requirements for Nonstructural Components."

In ASCE/SEI 7-16, several updates have been incorporated regarding the coefficient values for determining seismic forces. Additionally, there are now multiple criteria for different components of the stairway. This includes general criteria for stairway components (i.e., beams, posts, landings, connection material) and fasteners/attachments (i.e., bolts, welds, anchors). For anchorage to masonry or concrete using the overstrength factor, different design criteria are required for the stairway component (i.e., beam, wall, slab) and fasteners/attachments (embedded elements, inserts, anchors).

Egress stairways are required to function for life-safety purposes after an earthquake and are therefore required to use the higher component importance factor, I_p, of 1.5 according to ASCE/SEI 7, Section 13.1.3.

The horizontal seismic design force, F_P, is applied at the center of gravity of the component and must be applied independently in at least two orthogonal horizontal directions. It is determined using ASCE/SEI 7, Equation 13.3-1:

$$F_P = \frac{0.4 a_p S_{DS} W_p}{\left(\dfrac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right)$$

(ASCE/SEI 7, Eq. 13.3-1)

where

I_p = component importance factor = 1.5 for egress stairs; refer to ASCE/SEI 7, Section 13.1.3

R_p = component response modification factor = 2½ for egress stairs; refer to ASCE/SEI 7, Table 13.5-1

S_{DS} = spectral acceleration, short period, *g*; refer to ASCE/SEI 7, Section 11.4.5

W_p = component operating weight, lb

a_p = component amplification factor that varies from 1 to 2½ for egress stairs; refer to ASCE/SEI 7, Table 13.5-1

h = average roof height of structure with respect to the base, in.

z = height in structure of point of attachment of component with respect to the base, in. For items at or below the base, z shall be taken as 0. The value of z/h need not exceed 1.0.

Table 3-5. Coefficients for Egress Stairways*					
Architectural Component	a_p	R_p	**Comments**	Ω_o	**Comments**
Egress stairways not part of the building seismic force-resisting system	1	2½	Applies to all components unless noted otherwise (i.e., stringers, beams, posts, landings, connection material such as plate/angle)	2	Overstrength factor applies to design of masonry or concrete member (i.e., beam, wall, slab)
Egress stairs and ramp fasteners and attachments	2½	2½	Coefficients apply to fasteners and attachments (i.e., bolts, welds, dowels)	2½	Overstrength factor applies to fastener and attachment elements anchored to concrete or masonry (i.e., embedded plate, studs, post-installed or cast-in-place anchors)
* From ASCE/SEI 7 (ASCE, 2016)					

Coefficients for architectural components for egress stairs are provided in ASCE/SEI 7, Table 13.5-1. This table has been reproduced with author commentary in Table 3-5 and includes the applicable variables related to egress stairways. For the design of stair members, the redundancy factor, ρ, is permitted to be taken as 1.0, and the overstrength factor for the seismic force-resisting system (from ASCE/SEI 7, Table 12-2.1), Ω_o, does not apply. The overstrength factor provided in ASCE/SEI 7, Table 13.5-1, is required for the design of masonry and concrete anchorage associated with stair connections.

The previous equation for the horizontal seismic design force has a maximum limit given by:

$$F_p = 1.6 S_{DS} I_p W_p$$

(ASCE/SEI 7, Eq. 13.3-2)

Additionally, ASCE/SEI 7, Equation 13.3-1 has a lower bound as given by:

$$F_p = 0.3 S_{DS} I_p W_p$$

(ASCE/SEI 7, Eq. 13.3-3)

ASCE/SEI 7, Section 13.3.1.2, also provides a formula for a concurrent vertical seismic force to be used for component design:

$$F_{pv} = \pm 0.2 S_{DS} W_p \qquad (3\text{-}1)$$

Refer to ASCE/SEI 7, Chapter 13, for variable definitions and additional guidance. Alternative analysis options are described in ASCE/SEI 7.

In many cases, stairway components are anchored to concrete or masonry elements. Component anchorage design involves additional requirements that must be followed. These requirements include provisions in ASCE/SEI 7, Section 13.4, and the material specific code requirements of ACI 318 (ACI, 2014) for concrete and TMS 402/ACI 530/ASCE 5 (MSJC, 2013) for masonry. For concrete or masonry, the anchor selected for the project must also be prequalified for seismic applications in accordance with ACI 355.2 (ACI, 2004). Also note that redundancy and overstrength factors for anchorage design may be different than the factors used for stairway member design. ASCE/SEI 7, Table 13.5-1, includes an overstrength factor, Ω_o, that varies from 2 to 2½ for the design of anchorage to masonry and concrete.

Free-standing stair tower structures should be designed based on the requirements of Chapter 12 or Chapter 15 of ASCE/SEI 7 depending on the use, size and layout of the stair structures. The requirements for these types of stairs are beyond the scope of this Design Guide.

3.2.6 Thermal Loads

Thermal loading should be considered for long runs of guards and handrail that will experience substantial temperature changes. For exterior guards and handrail, the members should be adequate for thermal loads, or expansion joints should be provided to minimize thermal effects. Interior stairways, guards and handrails may be exposed to thermal loads during the relatively short construction period. During the lifetime of these items, however, the changes in temperature are likely small if located in a conditioned space, and thermal checks are not necessary unless specifically required for the project.

The Building Research Advisory Board of the National Academy of Science published *Expansion Joints in Buildings* (Federal Construction Council, 1974), which provides guidance based on design temperature change as it relates to the maximum spacing of expansion joints. Additional commentary and formulas to determine expansion joint spacing are provided in AISC *Manual* Part 2, in a section labeled "Thermal Effects."

Equations provided in the AISC *Manual* used to determine

Table 3-6. IBC Deflection Limits[a]		
Construction	Live Load Deflection Limit	Total Load Deflection Limit
Floor members (stringers and landings)	*Span*/360	*Span*/240
Floor members supporting ceramic tile or masonry	*Span*/600[d]	*Span*/240
Cantilever guard post supporting handrail[b]	2×*Height*/120 = h/60	—
Guard infill rails, handrail, and infill panels[c]	*Span*/120	—

[a] Values from IBC (ICC, 2015a).

[b] Matches requirements for exterior walls with flexible finishes and uses twice the height of the cantilever.
[c] Matches requirements for exterior walls with flexible finishes.
[d] Author recommendation based on design of masonry members.
"—" indicates there is no total load deflection limit.

the requirements for expansion joints for buildings can also be used to determine the maximum allowable length for a guard system. Designers can determine the design temperature change based on local temperature data or project specifications. Additionally, designers can use basic principles of engineering related to thermal expansion and contraction to determine the change in length of the members and the stress change in members.

By providing discrete lengths or expansion joints for guard systems and handrails, concerns associated with thermal effects can typically be avoided. From historical experience, guards with lengths less than 50 ft have not typically presented issues due to thermal loads. Assemblies with lengths less than 50 ft are also a reasonable length for shipping.

Stairs and other gravity members should also be reviewed for possible thermal loads; however, these members tend to be shorter in length and present fewer potential thermal related issues. If the change in member length due to thermal loads is a concern, care should be taken to provide connections that allow for thermal expansion and contraction using bearing type details.

3.2.7 General Structural Integrity and Notional Loads

All structures are required to have a continuous load path and a complete lateral force-resisting system. Refer to ASCE/SEI 7, Section 1.4, for these requirements. The application of notional loads is discussed as well as its use in combination with dead and live loads. Note that in most cases, structures that are designed according to ASCE/SEI 7 for Seismic Design Categories B, C, D, E or F will already meet the requirements of Section 1.4.

For stairways that are in Seismic Design Category A, designers must account for the requirements of ASCE/SEI 7, Section 1.4, for notional loads, load combinations, load path connections, lateral forces, and connection to supports.

Lateral forces are determined using the following equation:

$$F_x = 0.01W_x \qquad \text{(ASCE/SEI 7, Eq. 1.4-1)}$$

where

F_x = design lateral force applied at story x, kips

W_x = portion of the total dead load of the structure, D, located or assigned to level x, kips

3.3 SERVICEABILITY REQUIREMENTS

Serviceability considerations are an important aspect of design for stairways, guards and handrail. In many cases, serviceability and occupant comfort will govern the design of stairway members.

3.3.1 General Requirements

Stairway systems and members should meet the minimum serviceability requirements given in the IBC deflection limits of Table 1604.3, which is reproduced in Table 3-6. The IBC does not explicitly provide requirements for deflection limits of guards and handrail. Recommendations are provided based on deflection limits for exterior walls with flexible finishes, which provides support for handrail in many cases.

Additional requirements related to guards and handrails are provided in *Specification for Permanent Metal Railing Systems and Rails for Buildings*, ASTM E985 (ASTM, 2006). These limits are provided in Table 3-7. At the time of writing, ASTM E985 has been withdrawn as an active standard; however, it is still regularly referenced in project specifications.

The deflection limits presented in ASTM E985 result in relatively large allowable deflections when considering the day-to-day use of guards and handrail to provide safety and comfort to occupants. The author recommends using the deflection limits provided in the IBC or other more stringent limits as provided by the SER.

An additional serviceability requirement that should be considered for the design of stairways is vibration. Stringers

Table 3-7. Guard and Handrail Deflection Limits per ASTM E985*	
Construction	**Deflection Limit**
Post lateral deflection	$h/12$
Rail lateral deflection	$h/24 + l/96$
* Values from ASTM E985 (ASTM, 2006) h = height of guard post, in. l = length of rail at center-to-center spacing of posts, in.	

with long spans, lightweight stairway systems, and monumental stairs can be more susceptible to vibration due to the movement of occupants. AISC Design Guide 11 (Murray et al., 2016) presents recommendations to evaluate vibration in monumental stairs.

3.3.2 Seismic Relative Displacements

Stairways in structures located in seismic regions must also consider the difference in lateral movements between adjacent floors or seismic relative displacements due to earthquakes. In the direction parallel to stair stringers, the expected movement or drift may result in axial loads being resisted by the stairway members. In the direction perpendicular to stair stringers, the seismic relative displacements may cause additional horizontal flexure and shear, as well as inducing torsion at the end connections of the stair to the supporting floor system. Slip connections or sliding connections can be utilized to avoid additional forces due to the interstory drift, but these connections must be detailed to accommodate the anticipated seismic relative displacements and possible additional movement.

Seismic relative displacements within the structure are based on ASCE/SEI 7, Sections 13.3.2 and 13.3.2.1.

Seismic relative displacement, D_{pI}, is determined using the equation

$$D_{pI} = D_p I_e$$

(ASCE/SEI 7, Eq. 13.3-6)

where

D_p = relative seismic displacement that the component must be designed to accommodate, in., determined in accordance with equations in ASCE/SEI 7, Sections 13.3.2.1 and 13.3.2.2.

= $\delta_{xA} - \delta_{yA}$ (ASCE/SEI 7, Eq. 13.3-7)

I_e = importance factor from ASCE/SEI 7, Section 11.5.1

δ_{xA} = deflection at level x, in., from ASCE/SEI 7, Section 12.8.6 and Equation 12.8-15

δ_{yA} = deflection at level y, in., from ASCE/SEI 7, Section 12.8.6 and Equation 12.8-15

The deflection at each building level, δ_x, is based on the seismic response of the main structural system. For delegated design, the SER should provide this information to the stair designer. Stair designers can then provide designs that accommodate the seismic relative displacement to ensure the stair structure can resist the resulting forces from the earthquake.

Alternatively, D_p is permitted to be determined using the linear dynamic procedures described in ASCE/SEI 7, Section 12.9. In any case, D_p is not required to be taken as greater than

$$D_p = \frac{(h_x - h_y)\Delta_{aA}}{h_{sx}}$$

(ASCE/SEI 7, Eq. 13.3-8)

where

h_x = height of level x to which upper connection point is attached, in.

h_y = height of level y to which lower connection point is attached, in.

Δ_{aA} = allowable story drift for structure supporting stair, in., as defined in ASCE/SEI 7, Table 12.12-1

h_{sx} = story height, in., used in the definition of the allowable drift, Δ_a, in ASCE/SEI 7, Table 12.12-1. Note that Δ_{aA}/h_{sx} equals the story drift index.

This value can also be used in delegated design as a maximum upper bound for design. Note that using ASCE/SEI 7, Equation 13.3-8, will likely result in connection designs that will be difficult and costly to achieve.

To ensure proper detailing to accommodate the seismic relative displacement, ASCE/SEI 7, Section 13.5.10, includes criteria that must be followed. Stairway attachment points and connections must be detailed in such a way to avoid imparted forces and to ensure no loss of vertical support. These elements must be created through connections with positive and direct structural support or by connections and fasteners with the following criteria:

(a) Sliding connections incorporating a "secured element" utilizing slotted or oversize holes, sliding bearing supports with keeper assembly or end stops, and connections that permit movement by deformation of metal attachments. To ensure proper performance, this connection type must:

- Accommodate the seismic relative displacement, D_{pI}, or a minimum 0.5 in. in any horizontal direction.
- Maintain vertical support including after seismic event.
- No imparted compression forces due to seismic displacement of stairs.

Refer to Figures 6-18 and 6-19 for examples of this type of connection.

(b) Sliding connections without a "secured element" (i.e., keeper assembly or end stop). To ensure proper performance, this connection type must:

- Accommodate 1.5 times the seismic relative displacement, $1.5D_{pI}$, or a minimum 1.0 in. in any horizontal direction.
- Maintain vertical support, including after seismic event.

Refer to Figure 6-20 for an example of this type of connection.

(c) Supports (connections or frames) designed with rotation capacity to accommodate seismic relative displacements. To ensure proper performance, this system must:

- Accommodate 1.5 times the seismic relative displacement, $1.5D_{pI}$, or a minimum 1.0 in. in any horizontal direction.
- Maintain vertical support including after seismic event.
- Not be limited by brittle failure modes (i.e., bolt shear, weld rupture, or other brittle modes).

Additionally, all fasteners and attachments must be designed in accordance with ASCE/SEI 7, Section 13.3.1 and Table 13.5-1, as discussed in Section 3.2.5 of this Design Guide.

When sliding or ductile connections are not provided to accommodate seismic relative displacement, then the stair must be incorporated into the building structural model (refer to ASCE/SEI, Section 12.7.3) with appropriate stiffness and strength for the stairway elements. Careful analysis, design and detailing are required to ensure acceptable performance. The stair must be designed with the overstrength factor for the main structure seismic force-resisting system, Ω_o, but not less than 2½.

Stairs must also be checked for lateral displacement due to seismic forces to ensure the stair components are within reasonable limits. Designers should apply the horizontal seismic forces at the center of gravity and use established methods to determine lateral displacement values. Allowable drift values can be determined from ASCE/SEI 7, Table 12.12-1, using structure type "all other structures." Based on the risk category, allowable drifts for stairs will range from span/50 to span/100.

3.4 STAIRWAY LAYOUT AND RECOMMENDATIONS

The layout of stairways, guards and handrails is presented here as a guide only. The actual requirements for stairways, guards and handrails should be confirmed with the architect, SER, and local code officials.

An overview of requirements for three types of stairways is presented in Table 3-8. The stairways included are a typical IBC egress stair (service, commercial or architectural class), an IBC stair using minimum requirements and serving less than 50 occupants (industrial class), and an OSHA stair (industrial class).

As of November 18, 2016, several OSHA standards related to stairways, guards and handrails were revised with the new requirements effective as of January 17, 2017. If any of these elements were installed before January 17, 2017, then they would follow the requirements of the previous standards.

3.4.1 Stairway Based on International Building Code

Refer to Figure 3-1 for a plan view, elevation and cross section showing minimum code requirements per IBC for typical egress stairways. Actual framing, connections and layout of stairway should be based on specific project requirements.

3.4.2 Stairway Based on Occupational Safety and Health Administration Regulations

Refer to Figure 3-2 for a plan view, elevation and cross section showing minimum code requirements per OSHA for a stairway. Actual framing, connections and layout of stairway should be based on specific project requirements.

3.4.3 Local Requirements and Special Considerations

The specialty structural engineer (SSE) should coordinate local requirements or code modifications with the authority having jurisdiction. This may also include coordination with the fire marshal. Any additional requirements should be confirmed with the architect to ensure that the stairways, guards and handrails provided meet the project criteria.

Special attention must also be paid when working with architectural class stairs due to the use of floor and wall finishes. Floor finishes may affect the rise and run of the

Table 3-8. Overview of Stairway Code Requirements

Requirement	IBC 2015, Sections 1011, 1014 and 1015	IBC 2015, Section 1011, Less than 50 Occupants, Group I-3, F, S, H	OSHA Standards 1910.25/.28/.29 and 1910.36 for Means of Egress
Stairway Requirements			
Minimum width	44 in. (1011.2)	36 in. (1011.2, Exception 1)	22 in. [1910.25(c)(4)] or 28 in. [1910.36(g)(2)]
Projections into minimum width	4½ in. at or below the handrail height each side maximum (1014.8)		
Minimum headroom at nosing edge	80 in. (1011.3)		80 in. [1910.25(b)(2)]
Risers, vertically between nosings	7 in. maximum, 4 in. minimum (1011.5.2)	Group I-3 has exception for certain cases, otherwise conform to typical requirements.	9½ in. maximum [1910.25(c)(2)]
Treads, horizontally between nosings	11 in. minimum (1011.5.2)		9½ in. minimum [1910.25(c)(3)]
Dimensional uniformity	⅜-in. variation in tread depth or riser height within stair flight (1011.5.4)		Uniform riser heights and tread depths between landings [1910.25(b)(3)]
Maximum angle from the horizontal	32.47° (based on rise over run limits)		30° minimum to 50° maximum from horizontal [1910.25(c)(1)]
Closed (solid) riser	Required (1011.5.5.3)	Not required (1011.5.5.3, Exception 2)	
Landing width	Matching stair width (1011.6)		Matching stair (platform) [1910.25(b)(4)]
Landing length	Straight run 48 in. (1011.6)		30 in. in direction of travel [1910.24(b)(4)]
Treads (solid/grating)	Solid required (openings up to ½-in. diameter maximum) (1011.7.1, Exception 1)	Solid required (openings up to 1⅛-in. diameter maximum) (1011.7.1, Exception 2)	
Vertical rise between landings	12 ft maximum (1011.8)		
Guard and Handrail Requirements			
Stairway guard minimum height measured from the nose vertically	42 in. (1015.3)		42 in. [1910.29(f)(1)(ii)(B)]
Landing/platform guard minimum height	42 in. (1015.3)		42 in. ± 3 in. [1910.29(b)(1)]
Maximum openings	<4-in. sphere from base to 36 in. high <4⅜-in. sphere from 36 in. to 42 in. <6-in. sphere at triangular opening formed by riser, tread and bottom rail (1015.4; Ex. 1; Ex. 2)	<21-in. sphere (1015.4 Ex. 4)	19 in. maximum at least dimension [1910.29(f)(4)]
Handrail location	Required at each side of stair (1011.11)		Varies—refer to Table D-2 OSHA Standard 1910.28(b)(11)(ii)
Handrail height from nosing line	34 in. minimum to 38 in. maximum (1014.2)		30 in. minimum to 38 in. maximum [1910.29(f)(1)(i)]
Handrail graspability/construction	Type I (1014.3.1) Circular cross section: 1.25 in. minimum to 2 in. maximum Not circular section: perimeter of 4 in. minimum to 6.25 in. maximum, cross-section dimension of 1 in. minimum to 2.25 in. maximum Type II (1014.3.2) Larger than type I but requires additional graspable finger recess		Finger clearance between handrail and any other object is 2-1/4 in. [1910.29(f)(2)] Smooth surface to protect from injury and prevent snagging of clothing [1910.29(f)(3)] Shape and dimension necessary to grasp handrail firmly [1910.29(f)(5)]
Handrails extensions	Must return to wall, guard, walking surface, or adjacent stair run Extend 12 in. horizontally past top riser Extend one tread length horizontally past bottom riser (may be sloping or 34 in. minimum height running horizontal) (1014.6)		The ends of handrails and stair rail systems do not present any projection hazard [1910.29(f)(6)]

Note: Refer to IBC 2015 (ICC, 2015a) and OSHA Standards 1910.25/.28/.29/.36 (OSHA, 2014; 2016) for additional requirements, exceptions and detailed information.

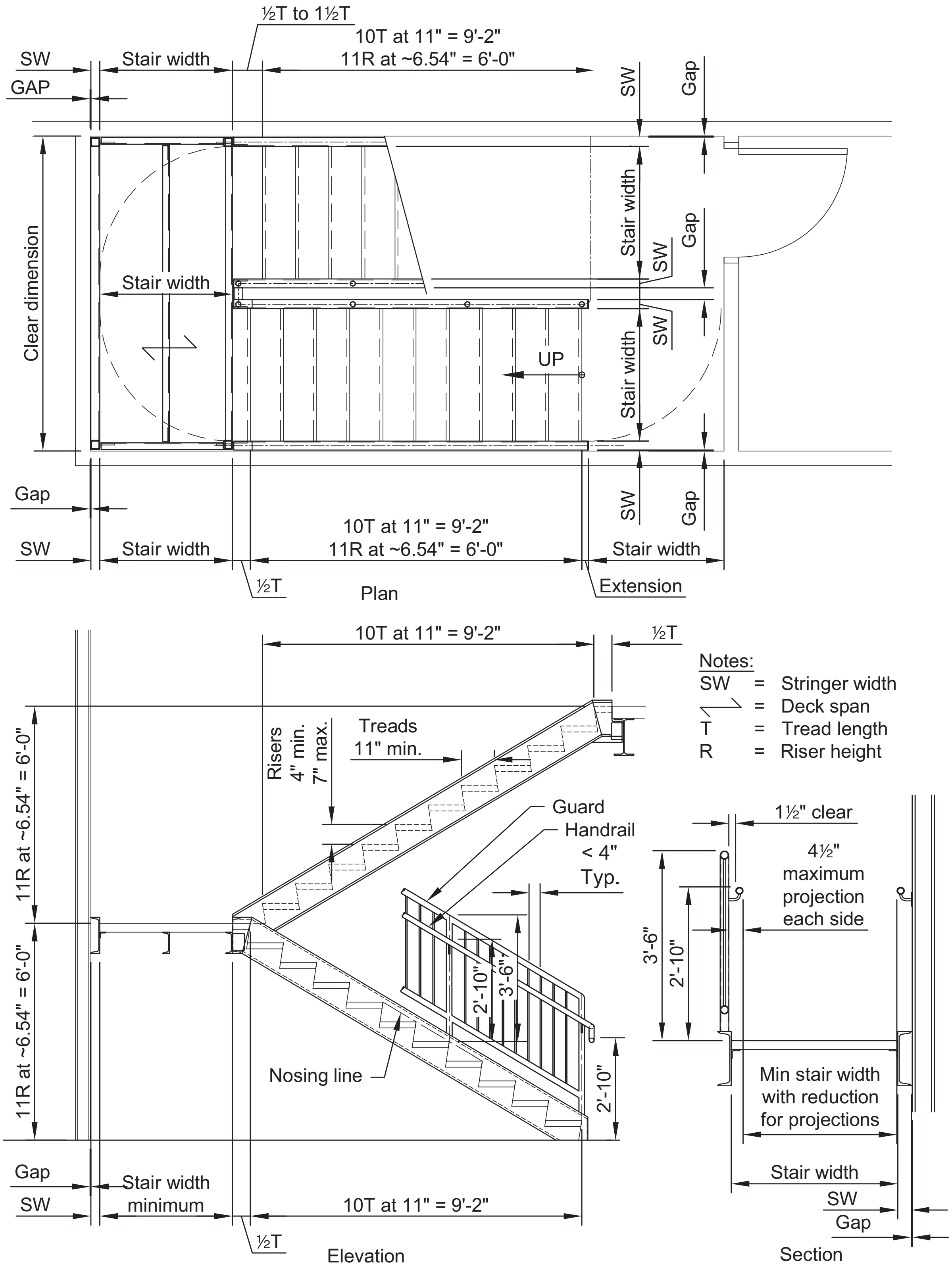


Fig. 3-1. Egress stairway based on IBC requirements.

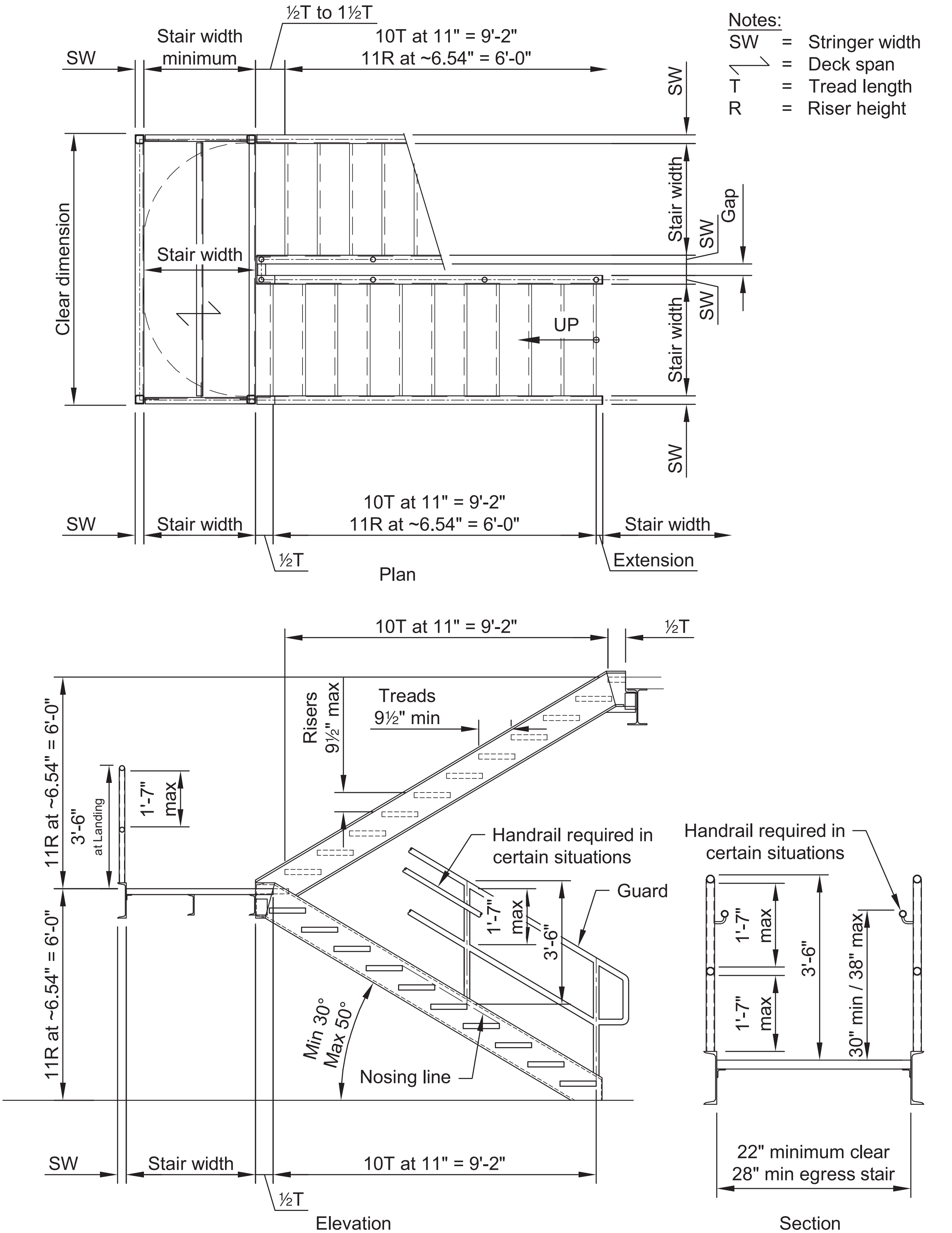


Fig. 3-2. Stairway based on OSHA regulations.

stair risers and treads. At main floor landings, a transition between different floor finishes may also present challenges. Because floor finishes will be installed after the stair is in place, it is critical that this information be confirmed before stairway layout and design begins.

The layout and construction of walls can present several challenges to the stair designer. For stairways enclosed in a fire-rated stud wall assembly, the clear opening for the stairway must also account for the presence of multiple layers of fire-rated gypsum board. In masonry and concrete construction, the wall locations will likely vary based on the allowable construction tolerances for these materials, which will require that additional clearance be provided along the wall stringers.

The author recommends that the architect and SER accurately layout stairways within a structure. This approach will save time and expense later in the project by ensuring that adequate space is provided to correctly locate the stairways in the openings provided during the steel detailing process.

3.4.4 Determining Stair Opening Size

During the design phase, the architect and SER will make design assumptions regarding the required stairway openings in the main structure. The following sections provide guidance and recommendations to establish the size of floor openings and maintain adequate clearances for the stairway. An accurate layout of the stairway and associated components is critical to ensure that the stairway will fit within the area provided.

3.4.4.1 Clear Width Minimum Opening Size

Use Equation 3-3 along with Figure 3-3 to determine the clear width minimum opening size.

$$W_{open} = 2(\text{Edge gap}) + 4(\text{Stringer width}) + 2(\text{Egress width}) + 1(\text{Center gap}) \tag{3-3}$$

where

Edge gap: ¼ in. minimum, ½ in. recommended adjacent to concrete or masonry walls.

Stringer width: For channel, use actual flange width or 3 in. recommended.
For HSS, use actual width or 2 in. recommended.
For plate, use actual thickness or ½ in. minimum at wall stringer; 2½ in. minimum at inside stringer (includes additional 2 in. for side-mounted guard).

Egress width: As required based on type of stair (see Table 3-8). Projections may reduce this width for IBC stairways.

Center gap: ½ in. minimum between elements (stringers or guards), although additional consideration should be made for erection tolerances and connection fit-up.

$$\begin{aligned} W_{open} &= 2\,(\text{Edge gap}) + 4\,(\text{Stringer width}) + 2\,(\text{Egress width}) + 1\,(\text{Center gap}) \\ &= 2\,(\tfrac{1}{2}\text{ in.}) + 4\,(3\text{ in.}) + 2\,(44\text{ in.}) + 1\,(\tfrac{1}{2}\text{ in.}) \\ &= 101\tfrac{1}{2}\text{ in. or 8 ft }5\tfrac{1}{2}\text{ in. clear dimension} \end{aligned}$$

$$\begin{aligned} W_{open} &= 2\,(\text{Edge gap}) + 4\,(\text{Stringer width}) + 2\,(\text{Egress width}) + 1\,(\text{Center gap}) \\ &= 2\,(\tfrac{1}{2}\text{ in.}) + 4\,(2\text{ in.}) + 2\,(44\text{ in.}) + 1\,(\tfrac{1}{2}\text{ in.}) \\ &= 97\tfrac{1}{2}\text{ in. or 8 ft }1\tfrac{1}{2}\text{ in. clear dimension} \end{aligned}$$

$$\begin{aligned} W_{open} &= 2\,(\text{Edge gap}) + 4\,(\text{Stringer width}) + 2\,(\text{Egress width}) + 1\,(\text{Center gap}) \\ &= 2\,(\tfrac{1}{2}\text{ in.}) + 4\,(2.5\text{ in.}) + 2\,(44\text{ in.}) + 1\,(\tfrac{1}{2}\text{ in.}) \\ &= 94\tfrac{1}{2}\text{ in. or 7 ft }10\tfrac{1}{2}\text{ in. clear dimension} \end{aligned}$$

Additional clearance should be provided for wall finishes and projections, and consideration should be made for the location of fire sprinkler risers, area of rescue assistance, and door location and swing.

3.4.4.2 Clear Length Minimum Opening Size

Use the following equations along with Figure 3-3 to determine the clear length minimum opening size.

$$L_{open} = L_{stair} + L_{landing} \tag{3-4}$$

where

$$L_{stair} = N_{tread}\,(\text{Tread length}) + (\text{Connection allowance}) \tag{3-5}$$

$$L_{landing} = N_{landing}\,[(\text{Stringer width}) + (\text{Egress width}) + (\text{End gap})] \tag{3-6}$$

$N_{landing}$ = required number of landings

N_{tread} = required number of treads

Tread length = actual tread length, in., or 11 in. minimum (IBC)

Stringer width = for channel, use actual flange width, in., or 3 in. recommended
= for HSS, use actual width, in., or 2 in. recommended
= for plate, use actual thickness, in., or ½ in. minimum at wall stringer

End gap = ¼ in. minimum, ½ in. recommended adjacent to concrete or masonry walls

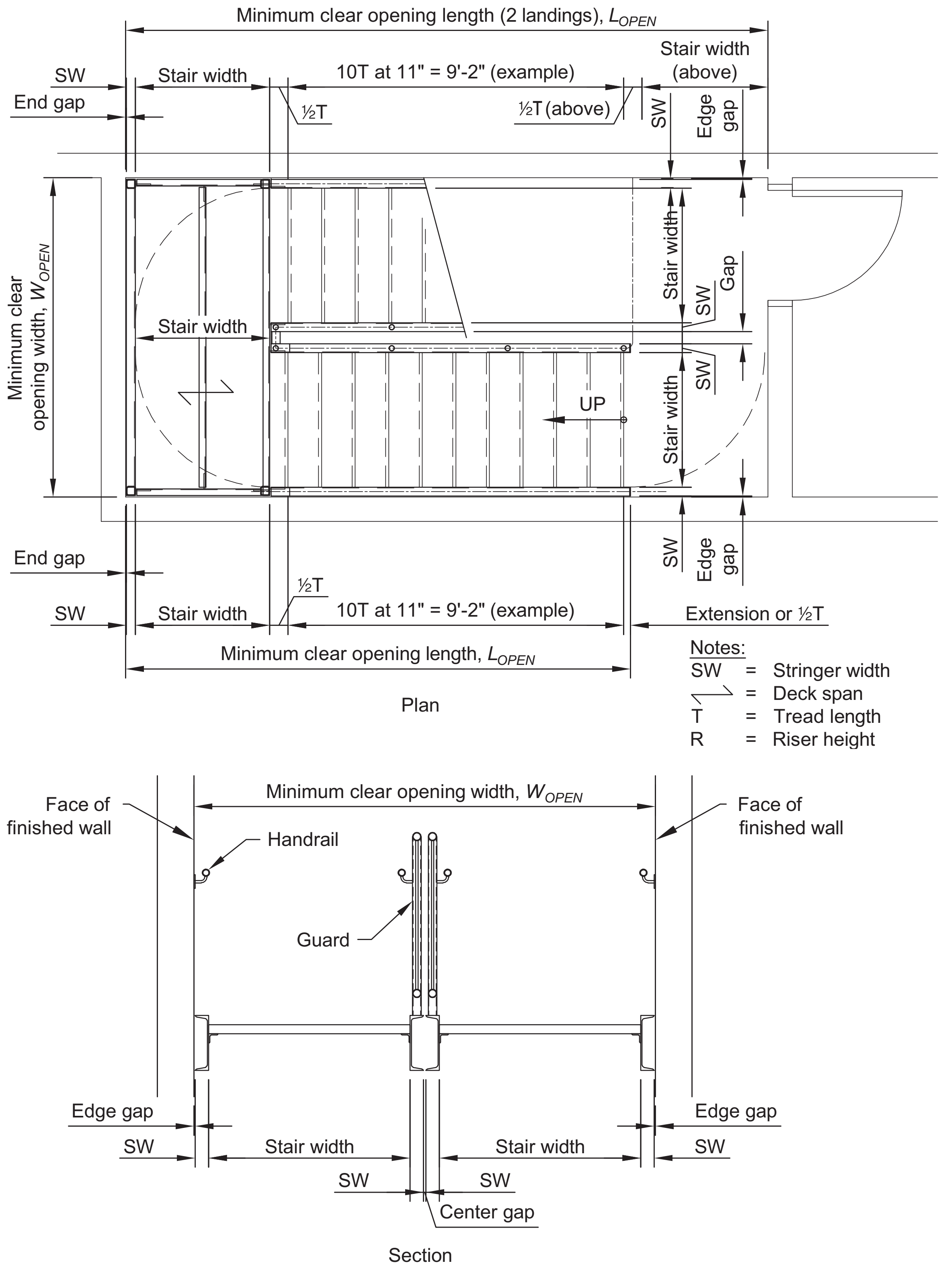


Fig. 3-3. Determination of stairway opening dimensions.

Egress width: As required based on type of stair (see Table 3-8). Projections may reduce this width for IBC stairways.

Connection allowance: Provide additional half tread length for connection at each end of stringer or actual length needed based on connection geometry, if required.

$$L_{open} = L_{stair} + L_{landing}$$
$$= [10\ (11\text{ in.}) + 2\ (5\tfrac{1}{2}\text{ in.})] + (1)\ [(3\text{ in.}) + (44\text{ in.}) + (\tfrac{1}{2}\text{ in.})]$$
$$= 168\tfrac{1}{2}\text{ in. or 14 ft. }\tfrac{1}{2}\text{ in. clear dimension}$$

Providing a half tread allows for space to include standard shear connections from the AISC *Manual* at the stringer to support beam location. It also allows additional space so that the stair riser and nosing can be set back from the walking path on the landing. The author recommends that space is provided to accommodate bolted connections for easier steel erection and fit-up in the field. Welded connections may allow for a smaller space, but designers should coordinate with the architect, SER, detailer and fabricator to determine the ideal option.

To provide a preferable layout for handrails the half tread dimension may be increased allowing for a smoother transition from one flight of stairs to another. Coordinate with the steel detailer and fabricator to determine if adjustments to tread layout can provide a better handrail configuration.

As with the calculation for clear width minimum opening size, additional clearances should be provided for wall finishes and projections, and consideration should be made for the location of fire sprinkler risers, area of rescue assistance, and door location and swing.

These equations are provided as a recommendation during the design phase to ensure proper fit-up of stairs during detailing, erection and construction. When using deferred submittals, establishing and providing the clear dimensions for stair openings is critical. Changing openings or fabricating nonstandard stairs can lead to additional costs and project delays.

3.5 STAIRWAY OPENING EXAMPLES

Example 3.1—Minimum Clear Width of Opening

Given:

For a typical IBC egress stair in a concrete core using (a) channel stringers, (b) HSS stringers, and (c) plate stringers, determine the required clear width.

Solution:

(a) For channel stringers

The clear width is:

$$W_{open} = 2\text{ (Edge gap)} + 4\text{ (Stringer width)} + 2\text{ (Egress width)} + 1\text{ (Center gap)} \tag{3-3}$$
$$= 2\ (\tfrac{1}{2}\text{ in.}) + 4\ (3\text{ in.}) + 2\ (44\text{ in.}) + 1\ (\tfrac{1}{2}\text{ in.})$$
$$= 101\tfrac{1}{2}\text{ in. or 8 ft }5\tfrac{1}{2}\text{ in. clear dimension}$$

(b) For HSS stringers

The clear width is:

$$W_{open} = 2\text{ (Edge gap)} + 4\text{ (Stringer width)} + 2\text{ (Egress width)} + 1\text{ (Center gap)} \tag{3-3}$$
$$= 2\ (\tfrac{1}{2}\text{ in.}) + 4\ (2\text{ in.}) + 2\ (44\text{ in.}) + 1\ (\tfrac{1}{2}\text{ in.})$$
$$= 97\tfrac{1}{2}\text{ in. or 8 ft }1\tfrac{1}{2}\text{ in. clear dimension}$$

(c) For plate stringers

The clear width is:

$$W_{open} = 2\text{ (Edge gap)} + 4\text{ (Stringer width)} + 2\text{ (Egress width)} + 1\text{ (Center gap)} \tag{3-3}$$
$$= 2\ (\tfrac{1}{2}\text{ in.}) + 4\ (2.5\text{ in.}) + 2\ (44\text{ in.}) + 1\ (\tfrac{1}{2}\text{ in.})$$
$$= 94\tfrac{1}{2}\text{ in. or 7 ft }10\tfrac{1}{2}\text{ in. clear dimension}$$

Example 3.2—Minimum Clear Length of Opening

Given:

For a typical IBC egress stair in a concrete core using channel stringers (using 10 treads at 11 in. length), determine the required clear length.

Solution:

The opening length required for the stair is:

$$L_{stair} = N_{tread}\,(\text{Tread length}) + (\text{Connection allowance}) \qquad (3\text{-}5)$$
$$= [10\,(11\text{ in.}) + 2\,(5\tfrac{1}{2}\text{ in.})]$$
$$= 121\text{ in.}$$

The opening length required for the landing is:

$$L_{landing} = N_{landing}\,[(\text{Stringer width}) + (\text{Egress width}) + (\text{End gap})] \qquad (3\text{-}6)$$
$$= (1)\,[3\text{ in.} + 44\text{ in.} + \tfrac{1}{2}\text{ in.}]$$
$$= 47.5\text{ in.}$$

The total opening length required is:

$$L_{open} = L_{stair} + L_{landing} \qquad (3\text{-}4)$$
$$= 121\text{ in.} + 47.5\text{ in.}$$
$$= 168\tfrac{1}{2}\text{ in. or 14 ft }\tfrac{1}{2}\text{ in. clear dimension}$$

Chapter 4
Stairway Design

The criteria for the design, fabrication and erection of steel members and steel connections that are part of a stair or handrail may be subject to the same provisions within the AISC *Code of Standard Practice* (AISC, 2016a), the AISC *Manual* (AISC, 2017), and the AISC *Specification* (AISC, 2016b) if specified on the project. Additionally, the American Iron and Steel Institute (AISI) *Cold-Formed Steel Design Manual* (AISI, 2013) and *North American Specification for the Design of Cold-Formed Steel Structural Members* (AISI, 2012), hereafter referred to as the AISI *Specification*, may be used for the design of light gauge members, including metal deck, with additional guidance from the Steel Deck Institute (SDI) *Standard for Noncomposite Steel Floor Deck* (SDI, 2010). The American Concrete Institute (ACI) *Building Code Requirements for Structural Concrete and Commentary* (ACI, 2014) can be used for the design of concrete and precast concrete elements incorporated into steel-framed stairways. Using these standards as a reference along with professional judgment will provide a set of reasonable design criteria that can be applied to the structural design of steel members and connections used in stairways, guards and handrails.

This section of the Design Guide will primarily be limited to the use of design methodologies presented in the AISC *Specification*. Alternative design methods may also be used based on historical evidence, engineering judgment, previous experience or appropriate testing.

4.1 TREAD AND RISER CONSTRUCTION

Treads and risers are responsible for carrying gravity loads between the stringers. There are several options for the construction of treads and risers, but the following are primarily used: integral light gauge steel tread and riser, steel checkered plate, prefabricated steel grating treads, and nonsteel options (e.g., precast concrete treads, wood treads, nonsteel grating).

4.1.1 Integral Pan Tread and Riser with Concrete Fill

Light-gauge steel can easily be bent and shaped to the required geometry for treads and risers. It can be directly welded to stringers or supported on carrier angles. Concrete fill can then be poured into the formed pan tread.

For design, the author recommends that the concrete is treated as a filler, which increases the self-weight of the stair but does not provide additional strength. The thickness of the tread/riser member must be checked against the required width-to-thickness limitations in the AISI *Specification*. Using welded pans and concrete fill can reduce unbraced lengths of each element to meet the width-to-thickness limits. Once an overall shape and profile are established, the AISI *Specification* can be used to determine effective section properties. The effective section properties can be used to determine design strength and deflections.

4.1.2 Steel Plate

For walking surfaces, checkered or diamond plate is typically used because it has adequate strength and provides a surface with good traction. AISC *Manual* Tables 3-18a and 3-18b list the maximum uniformly distributed service load for deflection-controlled applications and the maximum uniformly distributed load for flexural strength-controlled applications, respectively, for various thicknesses and spans for checkered plate based on ASTM A786/A786M (ASTM, 2016a). Table 3-18b presents the recommended maximum uniformly distributed load based on the stress limit of 24 ksi in LRFD and 16 ksi in ASD, including the required safety factor; Table 3-18a presents the recommended maximum uniformly distributed service load based on a deflection limit of $L/100$. Designers should verify with the fabricator or supplier the actual material grade to be purchased for checkered plate or use the minimum values provided in the tables in the AISC *Manual*. For an IBC project, the checkered plate should be checked for the deflection limits previously discussed that are required by the IBC. For an OSHA project, the deflection limit of $L/100$ may be appropriate based on engineering judgment and expected usage. In most cases, the checkered plate will act as a multi-span beam, and using appropriate beam formulas for these conditions will help to reduce overall thickness. Designers should specify span requirements to ensure that plate design assumptions are met in the final construction.

For non-walking surfaces, flat plate may be used to support concrete slabs or as a soffit. Additional stiffening elements may be provided to achieve the required design strength and stiffness. Depending on shop preferences, flat plate may be used instead of metal deck.

4.1.3 Steel Grating

Grating is typically preferred in wet environments, outdoor settings, industrial settings, and around equipment platforms.

Grating also may be used for architectural reasons. Grating allows small objects and liquids to pass through the flooring, so care should be used when grating will be above other occupied areas.

Grating design information should be verified with the manufacturer to ensure adequate strength and stiffness is provided. Connections of grating to support framing include bolting, grating clips or welding. Grating is typically purchased from a manufacturer, but designers should determine grating thickness, span direction, edge banding requirements, and other special features prior to ordering grating. Standard grating treads are made from 1¼-in. by 3⁄16-in. 19W4 serrated grating with bent checkered plate nosing. Other grating treads may be specified, but designers should discuss custom options with the supplier.

4.1.4 Nonsteel Options

Refer to the appropriate design standard or use information provided by the component supplier (i.e., precast concrete, glass, plastic or wood). Designers should consider how nonsteel options will interact with steel stair elements (i.e., wood expansion/contraction when directly attached to steel bar). Tolerances and applied forces from nonsteel components should also be reviewed.

4.2 TREAD AND RISER CONNECTIONS

The connections for treads and risers will vary based on the type of the tread and riser used on the stair. The tread and riser connections are important aspects of the stringer design as well. Tread and riser connections can be used to brace the stringer and can also provide diaphragm rigidity to the stairway and landing.

4.2.1 Direct Welding

Integral pan treads, risers and steel plate can be directly welded to steel stringers. This can be completed in the shop and is ideal when building stair flight assemblies. Disadvantages to direct welding include thin material burn-through and limited weld strength due to the thin base material. Weld design is based on the American Welding Society (AWS) *Structural Welding Code—Steel*, AWS D1.1/D1.1M (AWS, 2015), and *Structural Welding Code—Sheet Steel*, AWS D1.3 (AWS, 2008).

4.2.2 Carrier Angle or Plate

As an alternative to direct welding, carrier angles or plates can be welded to the stringers. Integral pans, steel plate, and some nonsteel options are then supported on the carrier angle or plate. The supported element is then welded or bolted in the field or in the shop.

4.2.3 Other Connection Options

Some tread options, including grating treads, can be directly bolted to the stringer. In many cases, the treads will be shop bolted to avoid completing this work in the field where access may be limited.

In some instances, the stringer type may require that the treads and risers are supported on the top flange rather than attached to the side or member web. Typical details for HSS or wide-flange members running under the treads may require a built-up plate section to provide adequate tread support.

4.3 STRINGER CONSTRUCTION

Stringers are the members supporting treads and risers and span from floor level-to-floor level of the stair. Typically, the stringer will be on an incline but may also include horizontal runs. There are several different member types that can be used for stringers. Stringer support conditions and design assumptions will vary based on end connections and the tread/riser construction.

4.3.1 Stringer Member Types

The most commonly used stringer members are channels, plate and rectangular HSS. In some cases, wide-flange members and built-up shapes are used but are less common. The typical depth range for stringers is from 10 to 15 in. A minimum 10-in. depth is typically required to accommodate the layout of the treads and risers. Deeper stringers are typically used for longer spans to limit overall deflection. Table 4-1 lists some of the advantages and disadvantages of common stringer types.

4.3.2 Design Methodology—Sloping Beam Method versus Horizontal Plane Method

In computing the dead load for sloping stringer beams, the additional length related to the sloped member self-weight must be taken into account when using the projected length. Determining the required shear strength and flexural strength of the stringer beams can be completed using the sloping beam method or the horizontal plane method.

In the sloping beam method, the gravity load is resolved into components that are parallel and perpendicular to the stringer. The values for required strength in shear and moment are based on the normal (perpendicular) component of the load and a span length equal to the full length of the sloping stringer. In the horizontal plane method, the vertical loads are applied to the stringer beam with a span that is taken as the horizontal projection of the stringer. Both methods are illustrated with the required shear and flexural strength compared in the following example.

Table 4-1. Stringer Member Overview		
Stringer Type	**Advantages**	**Disadvantages**
Channel (C or MC)	• Variety of sizes, weights and depths that are widely available • Flange can be used to support guard posts • End connections can use typical bolted simple shear connections	• Wider than plate and some HSS members
Plate	• Readily available • Narrower than other alternatives • End connections can use typical bolted simple shear connections	• Lower flexural strength than other options compared to member weight • Lower member strength for lateral loading
Rectangular HSS	• Variety of sizes, weights, and depths that are widely available • Flange can be used to support guardrail posts	• Additional fabrication required at joints and connections • More difficult end connections than other options • Typically heavier weight per foot than other options

4.3.2.1 Sloping Beam Method versus Horizontal Plane Method—Examples

Example 4.1—Required Shear and Flexural Strength Determination

Given:

Determine the required shear strength and flexural strength for the stringer beam using (a) the sloping beam method and (b) the horizontal plane method. The stair stringer member has a self-weight, SW, of 20 lb/ft; dead load, DL, of 40 psf; and live load, LL, of 100 psf. The tributary width, W, for the stringer beam is 2 ft (based on a 4-ft-wide stair).The sloping length, L, is 14.2 ft, and the horizontal plane length, L_h, is 12 ft. Because the purpose of this example is to compare the loads obtained for the two different methods, service level (unfactored) loads are used.

Solution:

(a) Sloping Beam Method

The total load is:

$$\begin{aligned} TL &= SW + DL + LL \\ &= 20 \text{ lb/ft} + (2 \text{ ft})(40 \text{ psf})(12 \text{ ft}/14.2 \text{ ft}) + (2 \text{ ft})(100 \text{ psf})(12 \text{ ft}/14.2 \text{ ft}) \\ &= 257 \text{ lb/ft} \end{aligned}$$

The load normal to the stringer beam is (refer to Figure 4-1):

$$\begin{aligned} w_{\perp} &= (12 \text{ ft}/14.2 \text{ ft})(257 \text{ lb/ft}) \\ &= 217 \text{ lb/ft} \end{aligned}$$

The load parallel to the stringer beam is:

$$\begin{aligned} w_{\parallel} &= \sqrt{(257 \text{ lb/ft})^2 - (217 \text{ lb/ft})^2} \\ &= 138 \text{ lb/ft} \end{aligned}$$

The required shear force is:

$$V = \frac{w_{\perp} L}{2}$$
$$= \frac{(217 \text{ lb/ft})(14.2 \text{ ft})}{2}\left(\frac{1 \text{ kip}}{1{,}000 \text{ lb}}\right)$$
$$= 1.54 \text{ kips}$$

The required axial compressive strength is:

$$P = \frac{w_{\parallel} L}{2}$$
$$= \frac{(138 \text{ lb/ft})(14.2 \text{ ft})}{2}\left(\frac{1 \text{ kip}}{1{,}000 \text{ lb}}\right)$$
$$= 0.980 \text{ kip}$$

The required flexural strength is:

$$M = \frac{w_{\perp} L^2}{8}$$
$$= \frac{(217 \text{ lb/ft})(14.2 \text{ ft})^2}{8}\left(\frac{1 \text{ kip}}{1{,}000 \text{ lb}}\right)$$
$$= 5.47 \text{ kip-ft}$$

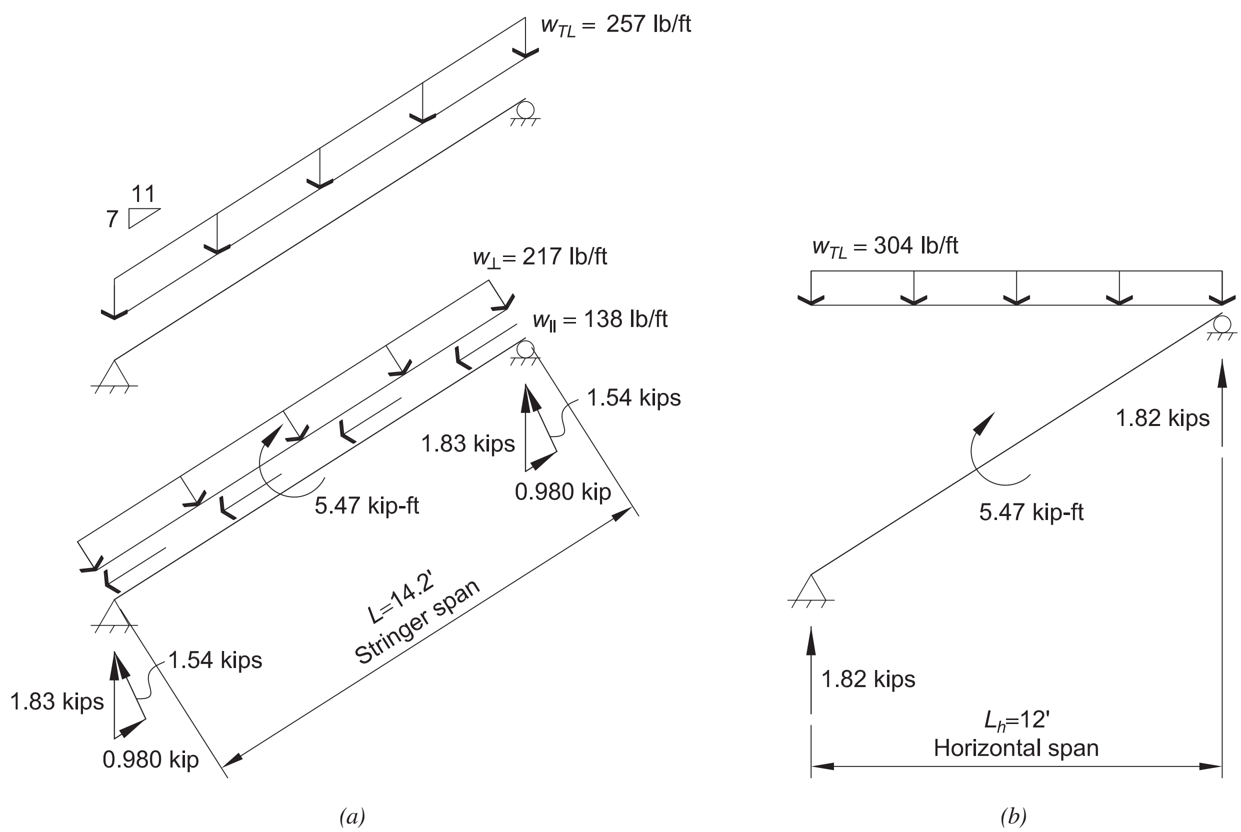


Fig. 4-1. Determination of required strengths: (a) sloping beam method; (b) horizontal plane method.

The resultant force due to shear and axial forces in the stringer is:

$$R = \sqrt{(1.54 \text{ kips})^2 + (0.980 \text{ kip})^2}$$
$$= 1.83 \text{ kips}$$

(b) Horizontal Plane Method

The total load is:

$$TL = SW + DL + LL$$
$$= (20 \text{ lb/ft})(14.2 \text{ ft/12 ft}) + (2 \text{ ft})(40 \text{ psf}) + (2 \text{ ft})(100 \text{ psf})$$
$$= 304 \text{ lb/ft}$$

The required shear strength is:

$$V = \frac{wL_h}{2}$$
$$= \frac{(304 \text{ lb/ft})(12 \text{ ft})}{2}\left(\frac{1 \text{ kip}}{1{,}000 \text{ lb}}\right)$$
$$= 1.82 \text{ kips}$$

The required flexural strength is:

$$M = \frac{wL_h{}^2}{8}$$
$$= \frac{(304 \text{ lb/ft})(12 \text{ ft})^2}{8}\left(\frac{1 \text{ kip}}{1{,}000 \text{ lb}}\right)$$
$$= 5.47 \text{ kip-ft}$$

Based on the results of this example, either design approach is acceptable. The horizontal plane method is commonly used to determine the required shear and flexural strength for inclined beams. This approach is simpler and provides an equivalent required flexural strength and conservative available shear strength compared to the sloping beam method illustrated in Figure 4-1(a). Both methods assume that the stringer is a simple span beam.

Due to the additional length of a sloping member, actual vertical deflections will range from 1.1 times to 2 times greater than deflections determined using the horizontal plane method. Accurate deflections should be calculated using the sloping beam method to ensure the stair design meets the required serviceability criteria. If using the horizontal plane method for design, the equation provided below can be used to determine approximate deflections by utilizing an additional deflection factor, F_Δ.

F_Δ accounts for the adjustment of the applied vertical loads based on the slope of the member and the perpendicular and parallel components of the load. It also incorporates variable x that accounts for the exponent applied to the stringer length based on the equations provided in AISC *Manual* Table 3-23, Item 1, "Simple Beam—Uniformly Distributed Load," or Item 7, "Simple Beam—Concentrated Load at Center." Finally, the equation includes variable y to find the vertical deflection or deflection perpendicular to the sloping member.

$$F_\Delta = \left(\frac{\sqrt{\text{Riser}^2 + \text{Tread}^2}}{\text{Tread}}\right)^x \left\{\cos\left[\tan^{-1}\left(\frac{\text{Riser}}{\text{Tread}}\right)\right]\right\}^y \quad (4\text{-}1)$$

where

Riser = riser height, in. (refer to Figure 4-2)

Tread = tread length, in. (refer to Figure 4-2)

x = 4 for uniformly distributed load
= 3 for concentrated load at mid-span

y = 2 for vertical deflection
= 1 for deflection perpendicular to sloping member

Applying the deflection factor to the vertical deflection from the horizontal plane method will result in the vertical and perpendicular deflections of the sloping stair member. Refer to Figure 4-3.

Equation 4-2 is used to determine the global vertical deflection:

$$\Delta_{vertical} = F_{\Delta}\Delta \tag{4-2}$$

where

Δ = vertical deflection using the horizontal plane method, in.

Equation 4-3 is used to determine the deflection perpendicular to the sloping member:

$$\Delta_{perpendicular} = F_{\Delta}\Delta \tag{4-3}$$

Note that the value for F_{Δ} will differ for Equations 4-2 and 4-3 based on the variable y used in Equation 4-1.

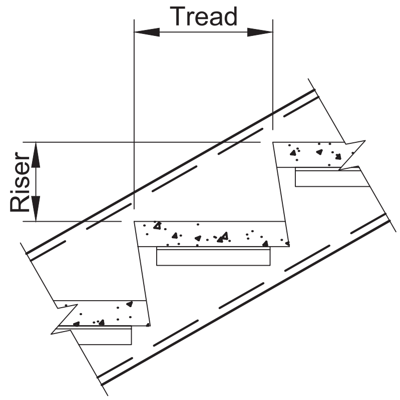


Fig. 4-2. Tread and riser layout.

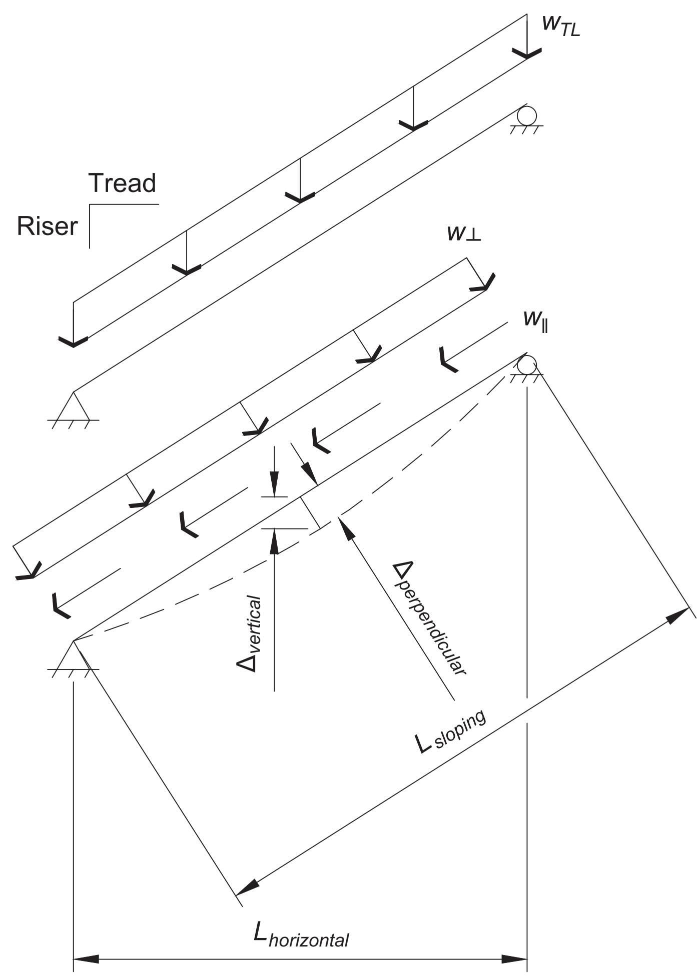


Fig. 4-3. Deflections at sloping beams.

4.3.3 Design Methodology—Simple Span versus Frame Analysis

Designers must ensure that the design assumptions for a stair match the actual conditions in the structure. Appropriate support conditions must be determined at each end of the stringer beam. Using support conditions associated with a simple span beam with a pinned base at one end and a roller base at the other end will produce reactions with shear, flexure and axial forces. Vertical deflection will be highest at midspan, and the roller base will allow for lateral deflection (typically a relatively small value due to live load).

Alternatively, support conditions can be based on frame action assuming the stringer will have pinned bases at each end. This will produce reactions with shear, flexure and axial forces. In this case, the beam will exhibit frame action behavior, thereby minimizing deflection but substantially increasing the axial reactions at each end. Both support conditions are illustrated in Figure 4-4.

The designer must decide which design method is most appropriate based on the support conditions. Details allowing for appropriate adjustment, the use of simple shear connections, and flexible supports will typically produce simple span conditions. Alternatively, a situation where a stair is connected between thick concrete walls using thick end plates will likely produce frame action with horizontal axial reactions that must be considered in the design.

In typical steel-framed building construction, the connections and framing for stairways will produce behavior somewhere between that predicted by the simple span and frame analysis method. The author recommends that designers use the simple span method to determine reactions, find beam design forces (shear and flexure), and determine vertical deflection. The designer should verify that the connections and/or support framing will provide a flexible support by using some or all of the methods described previously.

In cases where the support condition will be rigid and connections will be designed for both shear and axial forces, the author recommends that stringer member design follow the simple span method, and end-connection design (including checks on the support structure) is based on the reactions produced from a frame analysis. This will provide conservative results for deflection, will provide accurate connection design forces, and should provide adequate performance.

4.4 STRINGER UNBRACED LENGTH

An important aspect of stair stringer design is the determination of unbraced length. The type of tread and riser and their connections to the stringer should be considered when determining the unbraced length, as these elements may or may not fully brace the stringer along the length.

Based on past experience, the author recommends that when welded metal pan or checkered plate tread/risers covering the majority of the stringer web depth are used, the stringer can typically be considered to be fully braced. Figure 4-5 illustrates this situation. Configurations different than this should be investigated further using the AISC *Specification* Appendix 6, Section 6.3, to determine if the treads/risers provide sufficient strength and stiffness to brace the stringer.

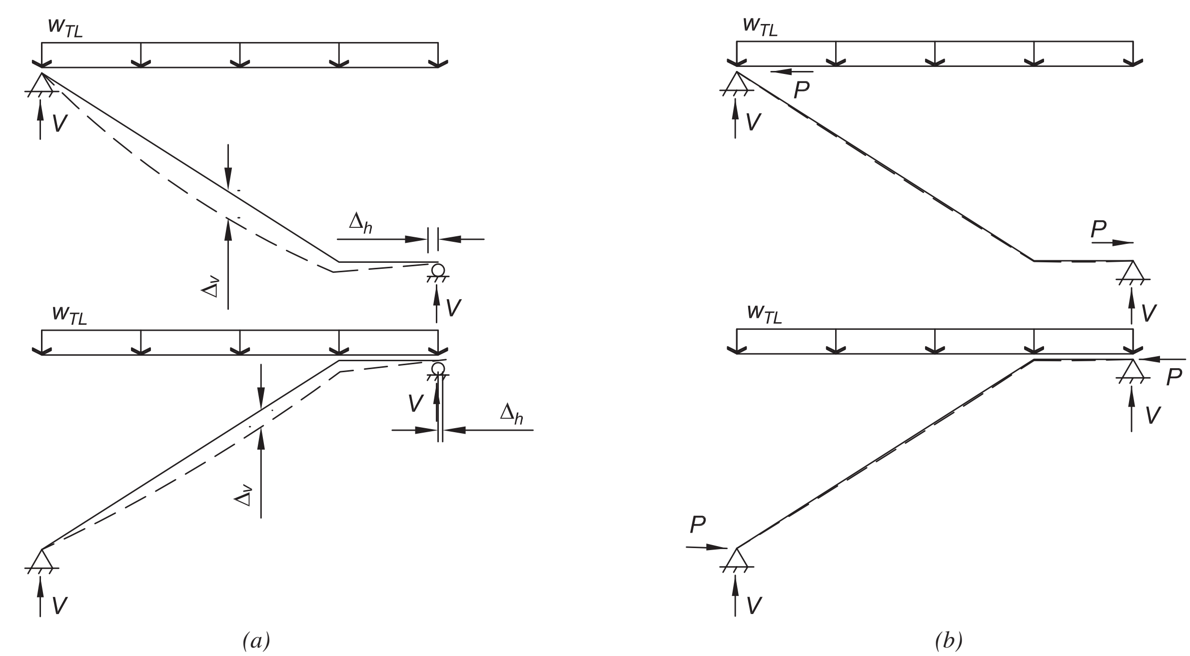


Fig. 4-4. (a) Simple span beam analysis; (b) frame analysis.

The ability of bolted grating treads to brace the stringer is more difficult to determine. Figure 4-6 illustrates bolted grating treads to a stringer. Without detailed information regarding the grating tread construction, connection layout, and bolt information, the author recommends that stringers with bolted grating treads be treated as unbraced. While such a decision is likely conservative, the potential for racking and discontinuities in the stair flight assembly are reasons to consider stringers with bolted grating treads as laterally unbraced.

4.5 LANDING CONSTRUCTION

A stair landing provides an area for occupants to stop or rest when ascending or descending a stairway. The applicable building code provides requirements regarding the size and location for landings. Based on these requirements, the stair designer can incorporate and support landings in multiple ways.

Depending on the architectural requirements, landings will typically be constructed based on one of the following:

1. Cast-in-place concrete over metal deck on landing steel framing
2. Cast-in-place concrete over stiffened plate on landing steel framing
3. Checkered plate flooring on landing steel framing
4. Steel grating (with clips or bolts) on landing steel framing
5. Precast, masonry or nonsteel flooring on landing steel framing

The design of these elements follows similar design considerations provided previously for stair treads or appropriate design resources for nonsteel elements. In many situations, the landing construction for stairways should be consistent with the design and layout of the building or structures serviced by the stairway.

4.6 LANDING SUPPORT

Landing support can be provided by several different means, several of which are described in this section. The support of landings can become complex when connecting into the building structure based on the location of structural steel, concrete elements and walls. Coordination with the architect and structural engineer of record (SER) is important to ensure that proper support can be provided without adversely affecting the building design.

In most cases, stairway support connections should be designed so as not to impose torsion on the supporting members. The use of standard shear connections from the AISC *Manual* can help to avoid this situation. Alternatively, additional support framing may be required to provide concentric support points for hangers, posts or stairway connections.

4.6.1 Integrated Landing

Integrated landings are supported by the stair framing without any connection to the building structure. Using an integrated landing can greatly simplify the design, detailing and fabrication of stairs. The integrated landing provides support members and a floor system that does not require additional support from posts or hangers; this type of landing typically results in the main stringers spanning the additional length of the landing to a support point. Figure 2-2 shows a layout for a straight stair with an integrated landing, and Figure 2-3 shows the framing layout for an integrated landing for a typical parallel stair.

4.6.2 Post-Supported Landing

A post-supported landing utilizes an independent landing with supporting posts. This type of landing is similar to typical steel-framed construction using columns, beams, and a floor system. It is important to ensure that the slab on grade

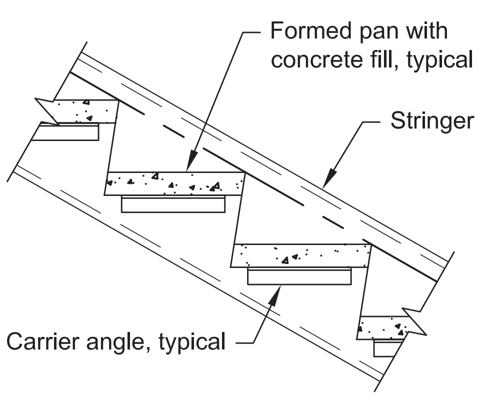


Fig. 4-5. Stringer with welded metal pan for treads and risers.

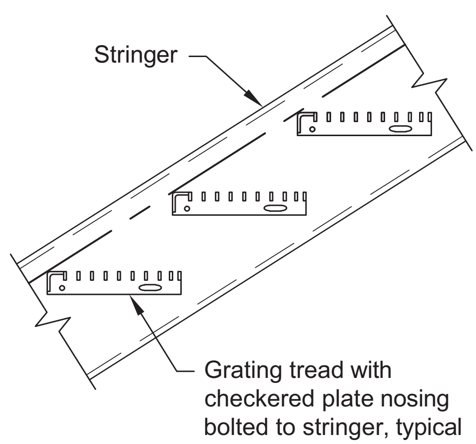


Fig. 4-6. Stringer with bolted grating treads.

or steel floor framing can adequately support the stair loads. Additional vertical bracing and utilization of a floor diaphragm may also be required to resist lateral loads.

4.6.3 Hanger-Supported Landing

A hanger-supported landing has similar framing to the post-supported landing but is connected by hangers to the supporting structure above. Various hanger members can be used, such as square or rectangular HSS, angles, pipe, and cables or rod. When using long hangers, cable or rod, additional lateral restraint should be provided to brace these elements and ensure movement of the landing does not adversely affect occupant comfort.

4.6.4 Building Supports

Many stairways are located within a core with walls that serve as part of the lateral force-resisting system for a building. Core walls are typically constructed from masonry or concrete. For masonry walls, landing framing can be supported using beam pockets that need to be coordinated with the masonry contractor during construction. Alternately, the stair can be temporarily supported with erection bracing until the masonry is in place. The masonry wall and beam pockets can then be built around the stair to provide permanent support.

Another option is to use post-installed anchors with a steel connection that would allow for installation after the core wall is complete. Where stairways are supported by masonry core walls, coordination with the SER is critical because the stair connection details may require grouted cores, bond beams or other details that must be designed and specified in the design documents.

For concrete walls, landing framing can be supported by embed plates that are installed when casting the concrete wall. Another option is to use post-installed anchors with a steel connection that would allow for installation after the core wall is complete. Where stairways are supported by concrete core walls, coordination with the SER is critical because the stair connection details may require adjustments to reinforcement or other details that must be designed and specified in the design documents.

For both masonry walls and concrete walls, stairs may be shipped in individual pieces and assembled in the field to account for tolerances in the walls. This will require more time and effort during erection.

Chapter 5
Lateral Bracing and Diaphragm Design

For lateral forces, additional considerations are required to ensure that stairways are properly braced to resist forces from wind and earthquakes. General stability requirements must also be met.

5.1 STAIR FLIGHT ASSEMBLY

The stair flight assembly is made up of the stringers, treads and risers. For lateral forces, one option for design is to assume that each stringer resists one-half of the lateral forces through weak axis shear and bending. Refer to Chapter 4 for guidance in determining the unbraced length of the stringers.

Alternatively, when using welded tread and riser construction, the assembly can be designed as a horizontal built-up beam. With thinner light gage material for the treads and risers, it may be difficult to satisfy local buckling requirements. Using thicker checkered plate, however, may allow for this type of analysis. If risers are omitted, it may be possible to design the assembly as a horizontal Vierendeel truss.

In some cases, the lateral forces may be small enough that each stringer will be adequate to resist the resultant weak axis forces independently. This is typically possible when considering general stability requirements or for lower seismic design categories (SDC A and B). Using plate stringers requires careful analysis, design and detailing to ensure that lateral forces have an adequate load path back to the support points.

5.2 LANDING DIAPHRAGMS

Stair landing design is important for load cases when large lateral forces are present. Improperly designed landings can create discontinuities in the stair with respect to resisting lateral forces. Creating a diaphragm at stair landings can provide an additional load path for resisting the lateral forces. Diaphragms can be designed using metal deck, steel plate, or concrete slab over metal deck.

5.2.1 Cast-in-Place Concrete over Metal Deck

One of the most common diaphragm options is to provide cast-in-place concrete over metal deck that is supported by the landing steel framing. This option will provide substantial diaphragm capacity based on the use of typical landing dimensions and construction. Larger landings may require additional welding or screws at side lap connections in metal decks and at supports. Metal deck diaphragm design should be based on the SDI *Diaphragm Design Manual* (SDI, 2015).

5.2.2 Cast-in-Place Concrete over Stiffened Plate

Concrete over stiffened plate is similar to cast-in-place concrete over metal deck. Consult AISC Design Guide 20, *Steel Plate Shear Walls* (Sabelli and Bruneau, 2007), for guidance related to diaphragm design for stiffened plate.

5.2.3 Checkered Plate Flooring

Checkered plate flooring can be used as a diaphragm based on principles provided in AISC Design Guide 20, *Steel Plate Shear Walls.*

5.3 VERTICAL AND HORIZONTAL BRACING

As an alternative to a landing diaphragm, horizontal bracing elements can be used. This requires that a load path for lateral forces from the landing or stair assembly be provided back to the building structure for support. Table 5-1 provides an overview of the comparative advantages and disadvantages for several bracing options.

5.3.1 Tension-Only Bracing

There are many options for tension-only bracing, but typically for stairway design, bracing is designed using cable, rod, single angle or plate. Follow the AISC *Specification* (AISC, 2016b) for slenderness limits and to determine the available strength for tension-only bracing.

5.3.2 Tension-Compression Bracing

Tension-compression bracing can be used to minimize the number of connections and braces needed. Typical options include HSS members, single angle, double angle and pipe. Follow the AISC *Specification* for slenderness limits and to determine the design strengths of tension and compression members.

5.3.3 Moment Frames

For locations that do not allow for the use of bracing, moment frames can be considered. The AISC *Specification* should be used to determine available strength. When using HSS members, refer to AISC Design Guide 24, *Hollow Structural Section Connections* (Packer et al., 2010), for HSS-to-HSS moment connections.

Table 5-1. Comparison of Bracing Types

Type	Advantages	Disadvantages
Tension-only bracing	• Smaller member sizes • Can be concealed in walls • Can fit under landings	• Will require more members and more connections
Tension-compression bracing	• Fewer members • Fewer connections • Can be concealed in walls • Can fit under landings	• Members may be heavier and larger • Splices at member intersections are needed
Moment frames	• Members do not cross path of travel (if required) • Can be concealed in walls • Beam member can also act as landing support member	• More lateral drift than other options • Connections typically more complex and more expensive

Chapter 6
Stairway Connections

Connection design for stairways will vary based on the stair class and architectural requirements. Using typical steel-framed connections can simplify the design process, make detailing and fabrication easier, and ensure the stairway members are erectable in the field. Refer to the Purpose section of this Design Guide in regard to connection adjustability and coordination of structural supports to avoid common issues that arise as part of the stairway design.

Connections to nonsteel members will be required when installing a steel stairway into a concrete or masonry core. Connecting the steel stair elements can be accomplished in a variety of ways including embed plates, beam pockets, or post-installed anchors.

6.1 STEEL STAIRWAY FRAMING INTO STEEL SUPPORT STRUCTURE

For simplicity, steel stairway members connected to a steel support structures should utilize standard connections from the AISC *Manual* (AISC, 2017) to the largest extent possible. Such connections include simple shear connections, axial connections, moment connections, bracing connections, and hanger connections. Using standard AISC connections provides familiar details for engineers, steel detailers, fabricators and erectors. The specific type of connection used at a given location will depend on the design criteria for the stairway.

Designers should coordinate with the steel detailer, fabricator and erector to select stairway connections that conform to the design requirements and provide the most economical and erectable option.

6.1.1 AISC Standard Shear Connections

AISC standard shear connections are detailed in AISC *Manual* Part 10; they include double-angle connections, shear end-plate connections, unstiffened seated connections, stiffened seated connections, single-plate connections, single-angle connections, and tee connections. For stairways designed as simple-span beams with only a shear end reaction, the use of any AISC standard shear connection may be appropriate based on stair and connection geometry and loading. Refer to AISC *Manual* Part 10 for additional guidance and design requirements for each type of shear connection. Figures 6-1 and 6-2 are, respectively, examples of single-plate and single-angle connections of a simply supported stringer to a structural support beam.

Certain AISC standard shear connections can be provided with slotted holes to allow for adjustment during steel erection. Single-plate connections using the extended configuration can be used when adjustment is needed when connecting to existing structures or to provide additional flexibility during construction. Figure 6-3 shows the use of an extended plate connection with slotted holes.

6.1.2 Axial and Hanger Connections

Axial tension connections are typically found when using hangers to support landing framing. However, other stairway connections may be required to transmit axial load as well as shear. An example occurs when a strut is used as part of a stairway to transmit lateral forces to the supporting structure and lateral force-resisting system. Double-angle connections, end-plate connections, and extended plate connections are options that provide appropriate load paths for axial- and shear-type connections.

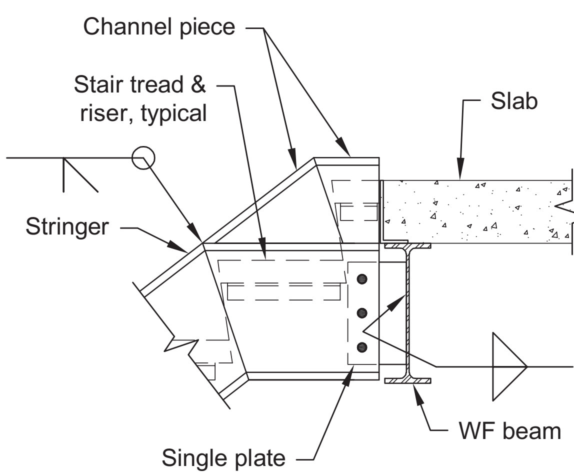


Fig. 6-1. Stair stringer with single-plate connection.

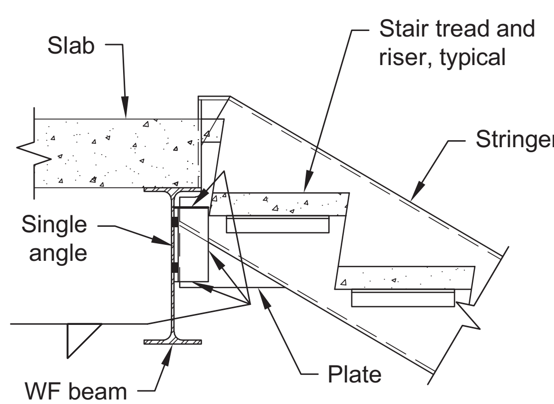


Fig. 6-2. Stair stringer with single-angle connection.

The AISC *Specification* and AISC *Manual* Part 15 provide additional guidance for the design of hanger connections. Figure 6-4 shows a typical hanger to a steel support beam.

6.1.3 Moment Connections

Complex stairway framing may require the use of moment connections. The use of bolted flange plates or bolted end-plate moment connections avoids field welding and helps to minimize field installation costs. Welded flange plates or directly welded flanges are alternative options that can be used as well.

Some stairway layouts may require that a portion of the stair or landing cantilever past a support. Moment connections can be provided to allow the stair member to pass through the support as shown in Figure 6-5. Alternatively, it may be simpler to allow the stair member to be a continuous member that passes over the top of the support member as shown in Figure 6-6.

Moment frames may be used as the lateral force-resisting system for stairs with wind or seismic loads. Moment connections will be needed in these structural systems. Shop-welded assemblies or field-bolted connections are preferred, but project requirements will vary.

The AISC *Specification* and AISC *Manual* Part 12 provide additional guidance for the design of moment connections.

6.1.4 Bracing Connections

Bracing connections will be required for stairways that utilize tension-only or tension-compression bracing to resist lateral forces. AISC *Manual* Part 13 provides guidance and requirements for the design of bracing connections. Connections will vary based on the bracing members and design forces. Additional information can be found in AISC Design Guide 29, *Vertical Bracing Connections—Analysis and Design* (Muir and Thornton, 2014). Figure 6-7 shows a typical brace connection using tension-only, single-angle bracing.

6.1.5 Connections at Stair Openings

Connections at stair openings are typically required to support the cantilever portion of suspended slabs and wall construction. The connection layout at this location dictates the overall stairway opening size. These details require careful consideration and coordination to ensure that stair openings are provided with adequate space to fit the stairway. Figure 6-8 shows a slab edge angle detail with built-in adjustment based on the stairway layout. Providing some adjustment during detailing will help to ensure that the stairway fits properly within the detailed opening. Additionally, the slab edge angle or bent plate can be sent to the field as a loose piece to be field welded once the opening size and stair position are finalized.

At the uppermost stair landing, a guard is provided to enclose the flat portion of this area. The support and attachment for the guard can vary depending on the member type and end connection layout where the stair stringer meets the landing support beam. Figures 6-9 and 6-10 show different

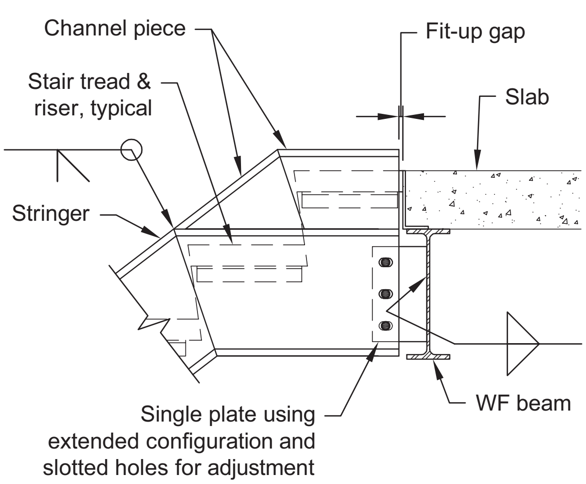


Fig. 6-3. Stair stringer with single-plate connection using extended configuration.

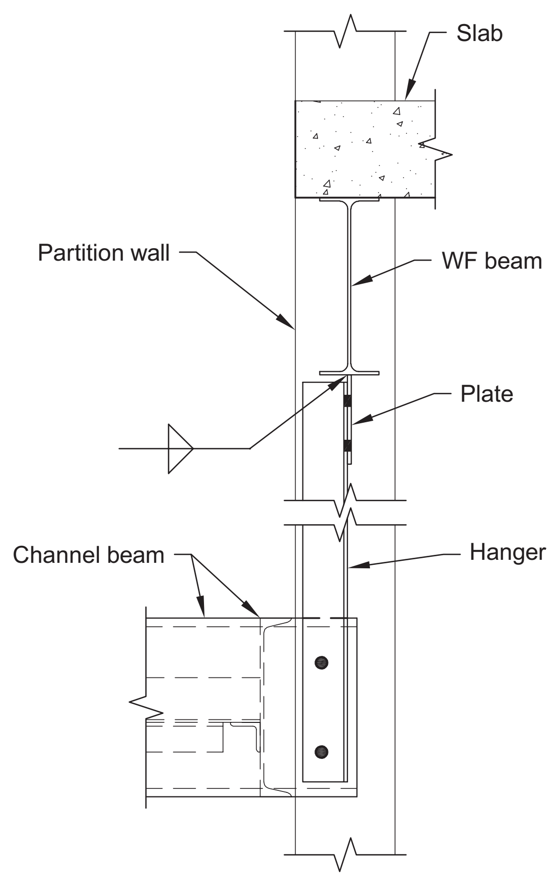


Fig. 6-4. Stair beam with hanger to support beam.

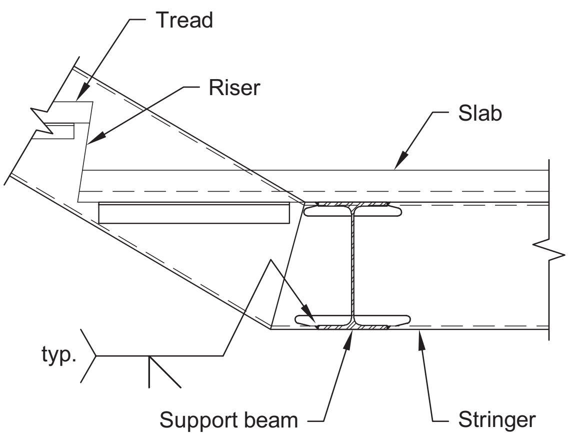


Fig. 6-5. Stair stringer with through-beam moment connection.

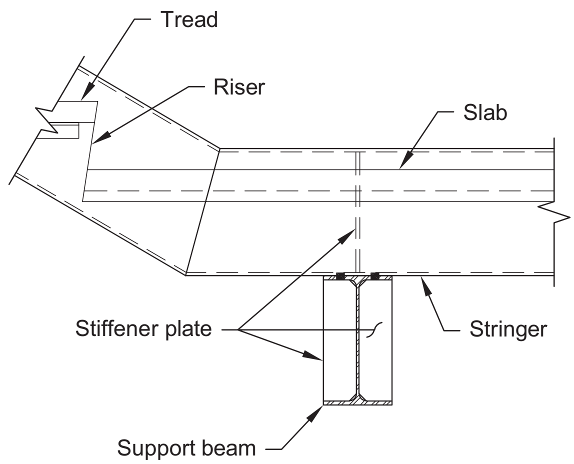


Fig. 6-6. Stair stringer continuous over support beam.

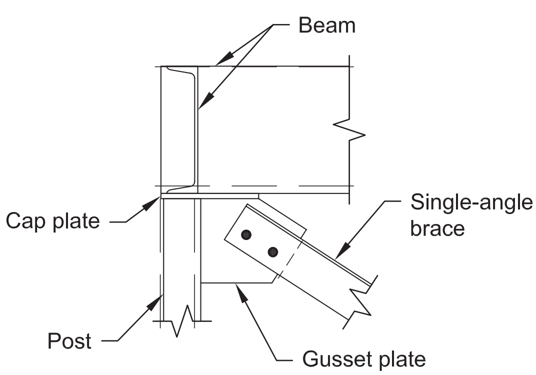


Fig. 6-7. Stair landing single-angle brace connection.

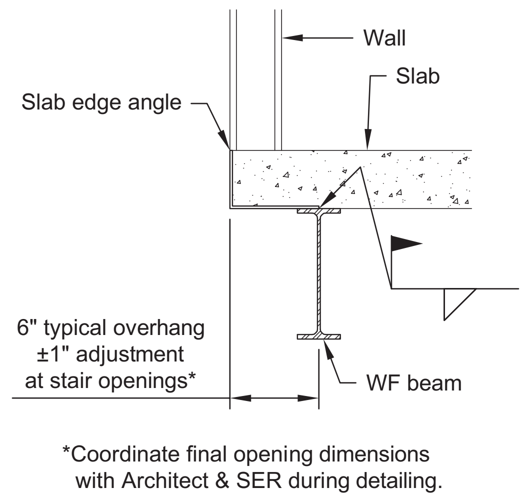


Fig. 6-8. Slab edge detail at stair opening.

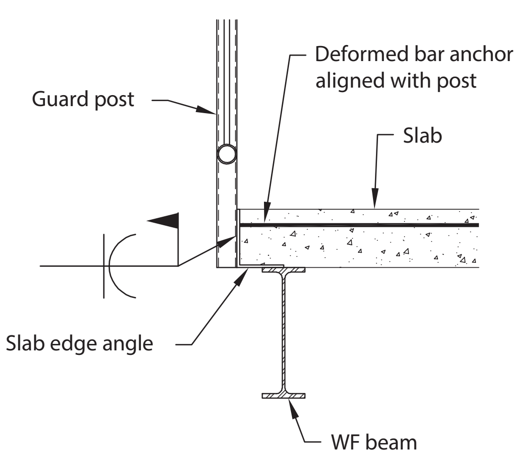


Fig. 6-9. Guard to side of slab edge.

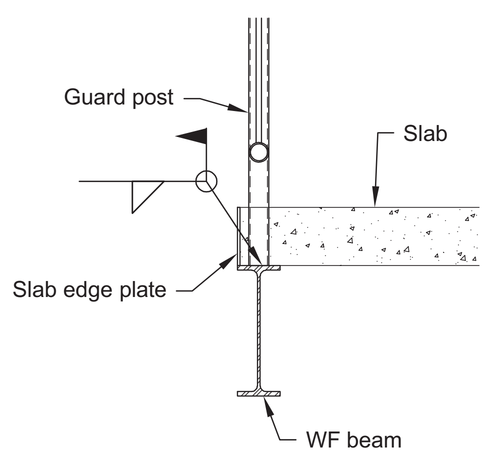


Fig. 6-10. Guard to top of support beam.

options for the guard-to-support beam connections. In some cases, aesthetic members are added that match the stringer to provide continuity in this area.

6.1.6 Erection Considerations

In many cases, stairways are installed after other construction (steel, concrete, masonry, etc.) are already in place. Designers should coordinate with the fabricator and erector to provide connection details that allow for ease of erection and provide adjustment in the field.

Top mounted bearing style connections and erection aids can allow for quick and easy erection of stair flights. Figure 6-11 provides an example of one style of erection aid. This detail allows the erector to quickly set the stair flight and release it from the crane. The final connection may require field bolting or field welding that will be completed later.

6.2 KINKED STRINGER MOMENT CONNECTION

Due to the geometry of many stairs, the stringers may require that a kink or "dog-leg" be incorporated at the junction of the sloping member and horizontal member. Figure 6-12 shows the layout of a kinked channel or HSS stringer. Plate stringers can be laid out to match the required geometry and joined with a two-sided, partial-joint-penetration (PJP) groove weld or complete-joint-penetration (CJP) groove weld.

HSS stringers can be laid out to match the required geometry and joined with a one-sided PJP weld or CJP weld. The need for backer bars should be carefully considered as the use of backer bars inside of HSS members can be difficult.

Channel stringers can be laid out to match the required geometry and joined with a CJP weld. It should be noted that the vertical neutral axis of a channel member does not coincide with the centerline of the channel web. At the kinked junction, a force perpendicular to the sloping member must be resisted by flange bending that is then transmitted back to the web of the channel. In many cases, this force is relatively small, and the thick sloping channel flanges will provide adequate resistance, but the force should be evaluated.

When wide-flange beams are used as stringers, a CJP weld can be used at the flanges and web. Additional stiffener plates may need to be added at the kinked joint to resist the perpendicular force due to the sloped member. Flange bending should be checked to determine the need for these additional stiffener plates. Refer to Figure 6-13 for a typical detail.

6.3 STEEL STAIRWAY FRAMING INTO CONCRETE OR MASONRY

Connections to concrete or masonry require additional coordination and planning. Communication between the specialty structural engineer (SSE) and field trades is critical to address sequencing of construction, requirements for temporary support, tolerances of concrete or masonry structural members, coordination of different trades, and field modifications.

It is important to provide connection details that allow for adjustment in the field and to ensure each of the trades understands their portion of work and how it may affect connections to the steel-framed stairway.

6.3.1 Embedded Plates

For cast-in-place concrete construction, embedded plates are installed before the concrete is poured. Embedded plates should be provided with adjustability in mind so that connecting elements can be shifted in the field. Embedded plates are also ideal for connections to concrete slabs with pretensioned cables, post-tensioned cables, or mild reinforcing as

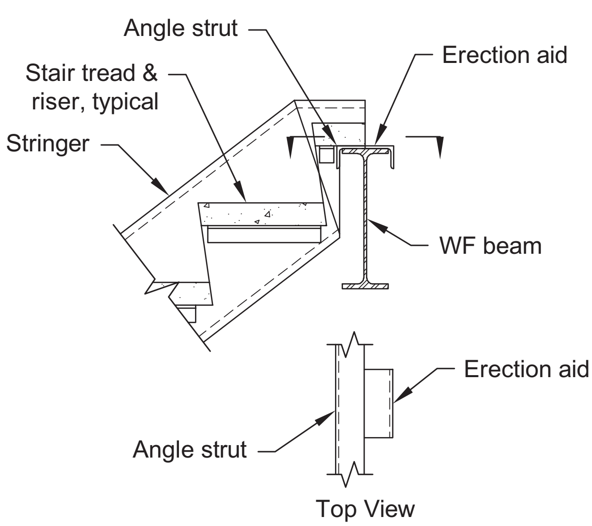


Fig. 6-11. Stair flight with erection aid.

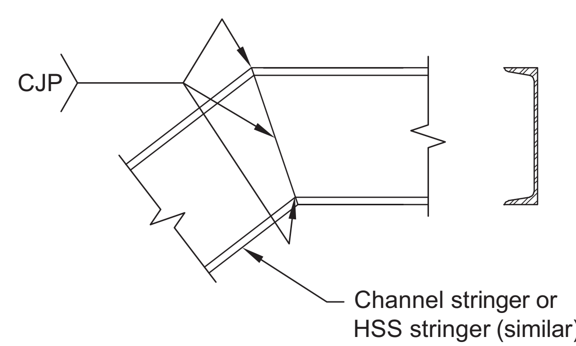


Fig. 6-12. Kinked channel stringer or HSS stringer.

the installation of post-installed anchors can be difficult at these locations.

To avoid the use of special formwork, embedded plates are usually left "clean" (without any protruding elements). After the formwork is removed, connection material can be field welded to the embedded plate to support the steel stairway framing. Figure 6-14 shows a typical connection to a concrete wall using an embedded plate. The design of the embedded plate and associated anchorage should be designed per ACI 318, *Building Code Requirements for Structural Concrete* (ACI, 2014).

6.3.2 Beam Pockets

Both masonry walls and concrete walls can be constructed to allow for beam pockets. Beam pockets should leave adequate space for installation of the steel member and access for connection to anchor rods or field welding to a base plate. Depending on the layout of beam pockets, the steel support members may need to be installed first using temporary supports or installed as beam pockets are created while the wall is under construction. This requires careful coordination between trades to determine the best way to erect the steel stairway. Figure 6-15 shows a typical beam pocket connection to a masonry wall. The design of the embedded plate and associated anchorage should be designed per ACI 530/530.1, *Building Code Requirements and Specifications for Masonry Structures* (ACI, 2013).

6.3.3 Post-Installed Anchors

In some construction projects, the concrete or fully grouted masonry structural elements may already be in place before the steel stairway is installed. Anchors attached to the face of hollow (ungrouted) masonry walls should be avoided as anchor capacity is very limited. In these cases, the only option available is to use post-installed anchors to support connection plates. There are a wide variety of mechanical

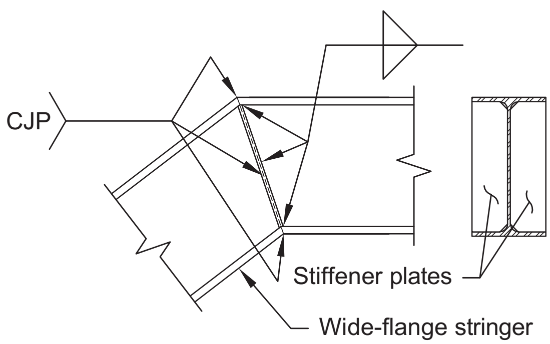


Fig. 6-13. Kinked wide-flange stringer.

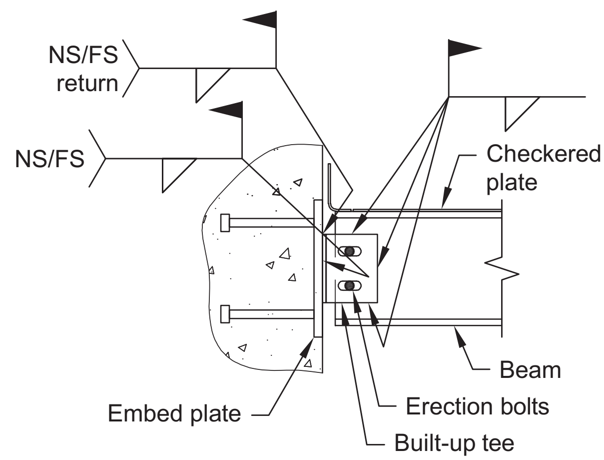


Fig. 6-14. Stair beam to embed-plate connection.

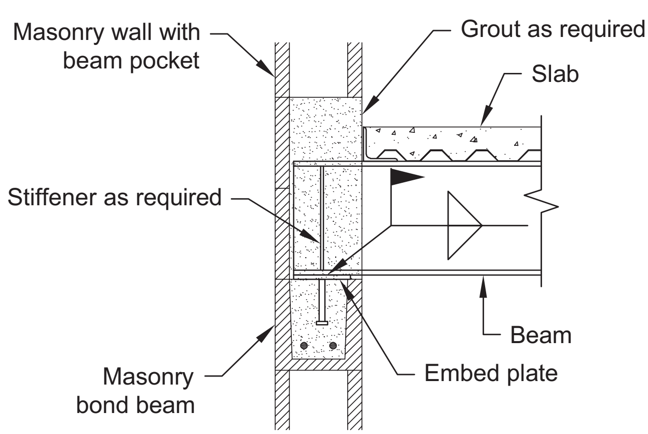


Fig. 6-15. Stair beam connection to masonry wall pocket.

and adhesive anchors available on the market. The designer should carefully choose an anchor that meets the requirements for design forces, seismic/wind approvals, compatibility with the supporting structural wall or slab, and approval by the appropriate authority. Figure 6-16 shows a single-angle connection using post-installed mechanical anchors to a grouted masonry wall.

Post-installed anchors come in many varieties, sizes, materials, finishes and applicable uses. Designers should review manufacturer literature to determine the appropriate type of post-installed anchor to be used for a specific project. Evaluation reports and associated testing are also available for most anchors.

6.3.4 Concrete and Masonry Supporting Elements

When steel stair members connect to concrete and masonry supporting elements, these elements may require additional design checks based on the appropriate codes. Requirements for stairway connections may alter these elements. A few examples include using thickened slabs at the base of a stringer, grouting hollow-core masonry walls for use with anchors and posts on walls or slabs. Refer to Figure 6-17 for a stringer base detail at a thickened concrete slab. Installation of anchors under the stair pan can be achieved by leaving access holes in the pan or having the pan field installed after the anchors are in place.

6.4 SEISMIC DISPLACEMENT CONNECTIONS

Several options are available to accommodate the seismic displacement criteria of ASCE/SEI 7, Section 13.5.10. The following examples provide conceptual connection details that could be utilized on stairways in seismic regions. Figures 6-18 and 6-19 use sliding connections with oversize holes. These details "trap" the anchor element; however, similar versions of these details can be used without a keeper or end stop. Figure 6-20 also uses a sliding connection but incorporates an expansion joint and expansion cover plate.

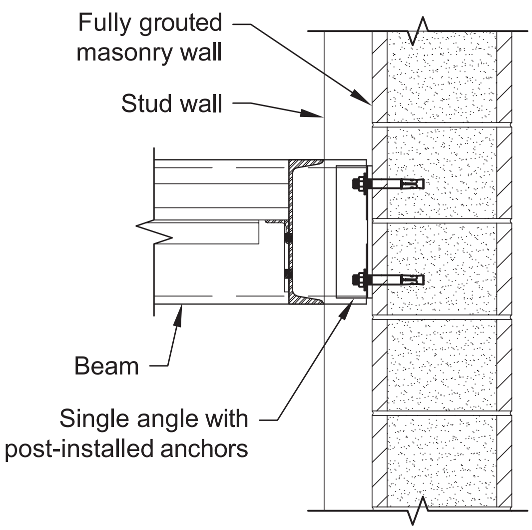


Fig. 6-16. Stair beam single-angle connection using post-installed anchors.

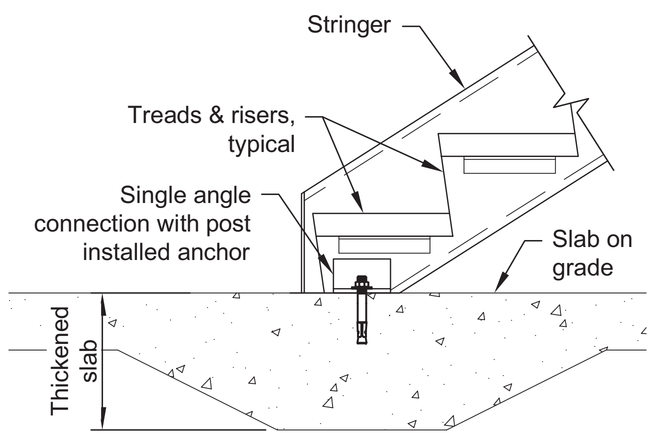


Fig. 6-17. Stringer base at thickened slab.

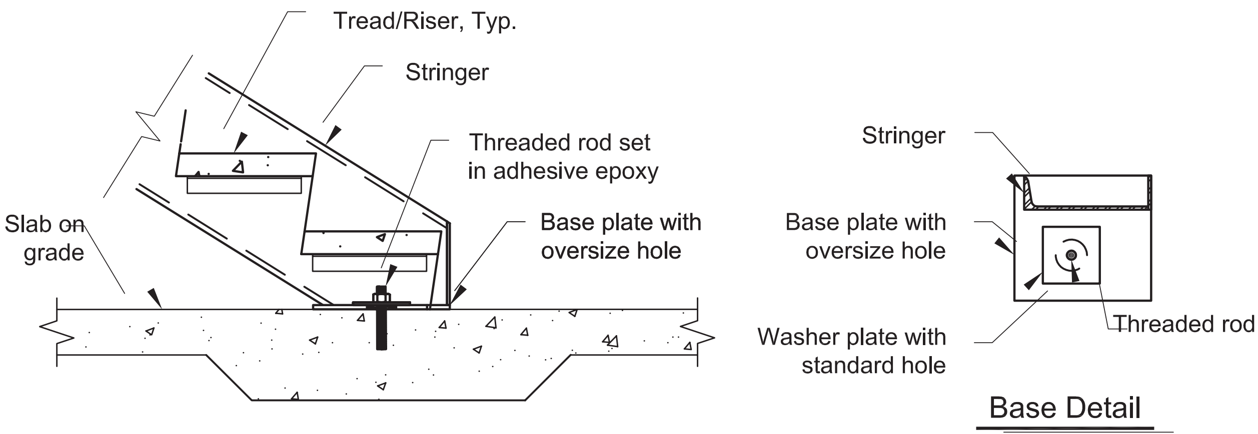


Fig. 6-18. Seismic displacement detail using sliding connection at concrete slab on grade.

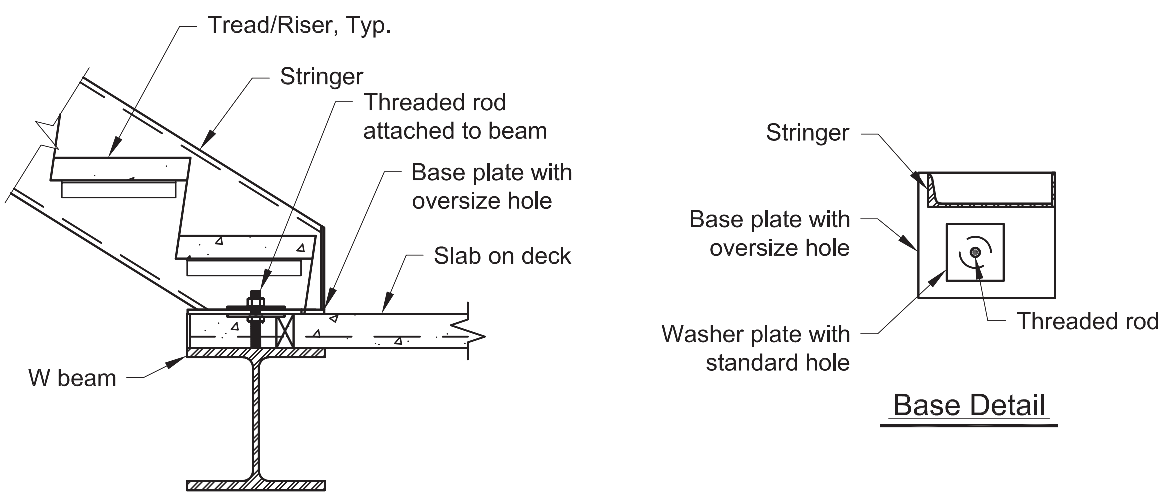


Fig. 6-19. Seismic displacement detail using sliding connection at concrete slab on deck.

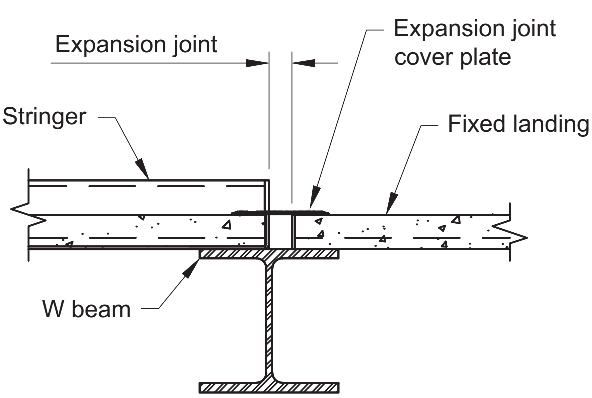


Fig. 6-20. Seismic displacement detail using expansion joint.

Chapter 7
Guard and Handrail Design

Guards act as a barrier to prevent possible fall hazards for stair occupants. Guards are provided along open sides of a stairway and open sides of landings and platforms. Guards may also be provided under sloping stairs or other areas with low overhead clearance to prevent occupants from colliding with low overhead structure. Handrails provide a gripping surface to assist occupants as they travel up or down a stair. Handrails are required on the sloping run of a stair and are sometimes provided at stair landings. Stairways and associated landings use different styles of guards and handrails depending on the stair type and class.

The NAAMM *Pipe Railing Systems Manual Including Round Tube* (NAAMM, 2001) provides an extensive overview of pipe railing (including round HSS). Some information included herein is reproduced from this NAAMM Manual with modifications, additional information, and commentary pertaining to steel guards and handrails.

Additional design recommendations and overview are based on the article "Holding On" (Baer, 2009).

7.1 MEMBER TYPES

Guard and handrail members can vary substantially based on the stair type and class. Architectural considerations are also important when it comes to guards that are exposed to view. In these instances, the guards and handrails must serve their intended safety purpose and provide the required structural strength in addition to satisfying the aesthetic requirements.

7.1.1 Pipe and Round HSS

Pipe and round HSS members are commonly used for guards and handrail. Typical member sizes are 1¼-in. pipe and 1½-in. pipe, which have actual outside diameters of 1.660 in. and 1.900 in., respectively, when used for rails. Other sizes and grades of steel round members are available but are not standard AISC shapes. Pipe is referenced by its nominal dimension and is available in three different wall thickness categories: Standard Weight (Std.), Extra Strong (x-Strong), and Double-Extra Strong (xx-Strong). Pipe is available in ASTM A53 Grade B with a yield stress F_y = 35 ksi. Pipe for rails should be specified as "non-hydro" because pipe used to hold fluid requires additional testing and may have unwanted coatings.

Round HSS members are usually the ideal member option when used for round rails due to improved strength characteristics. Round HSS is available in multiple grades: ASTM A500 Grade B (F_y = 42 ksi), ASTM A500 Grade C (F_y = 46 ksi), and ASTM A1085 Grade A (F_y = 50 ksi). ASTM A500 Grade C is the preferred material specification. Round HSS members come in similar sizes and wall thicknesses to pipe but are available with the higher yield stress. Many times, ASTM A500 members are available as dual certified, meaning that the member will meet the requirements of either Grade B or Grade C specifications. ASTM A1085 members do not require a reduction for design wall thickness in calculations as ASTM A500 material does, resulting in ASTM A1085 material providing larger section properties than ASTM A500 for the same size member. Designers should verify with the fabricator which member sizes and grades are available when using round HSS members.

7.1.2 Rectangular HSS

Rectangular HSS members (including squares) are commonly used as guards. They are more frequently used with infill panels. In some cases, smaller rectangular HSS members are used than those given in AISC *Manual* Table 1-12. For these members, refer to *HSS Design Manual, Volume I: Section Properties and Design Information* (STI, 2015) from the Steel Tube Institute of North America.

7.1.3 Angle

Single-angle members are often used for guards along platforms and attached to stairways in industrial settings. The construction and attachment of single-angle guards allows for field-welded assemblies. Care should be taken when using angle members as a top rail and integrated handrail so that graspability is not an issue when using larger angle sizes.

7.1.4 Plate, Bar and Rod

Solid plate, bar or rod can be used as guards and handrail in certain applications. The ability to cut specific geometry into plate allows for flexibility in architectural design. Solid steel members may be heavier than other alternatives but may be an ideal choice to balance architectural needs with structural demands.

7.1.5 Nonsteel Options

A variety of nonsteel materials are commonly used exclusively or combined with steel elements for guards and handrail. In many cases, wood members will be combined with steel elements to form the top rail of guards and to act as handrail. Additionally, glass, aluminum, bronze and plastic may all be used in certain instances.

7.2 GUARD CONSTRUCTION

The guard consists of the following elements: top rail, bottom rail, post and infill and may also include handrail (for stairway guards) and/or toe plate. Refer to Figures 7-1 and 7-2 for the typical layout for an IBC-style guard. Refer to Figures 7-3 and 7-4 for the typical layout for an OSHA-style guard. Each of these elements is treated differently for design and serves a specific purpose as part of the guard system.

7.2.1 Top Rail

The top rail defines the uppermost portion of the guard. Refer to the applicable project code to determine the height at which to set the top rail of the guard above the walking surface. The top rail must have the strength and stiffness to span from support point-to-support point (typically posts) for vertical, lateral and axial loads.

7.2.2 Bottom Rail

The bottom rail defines the lower portion of the guard, typically leaving an opening from the underside of the bottom rail to the landing or stair stringer. Design checks for the bottom rail are similar to the top rail, although the code required design forces are based on the infill loading. Spacing of the bottom rail must conform to the applicable code and occupancy to ensure the resultant openings are within allowable sizes.

7.2.3 Post

The post provides a support for the top rail, bottom rail, infill and handrail. It also provides resistance for vertical, lateral and axial forces. The post must have adequate strength and stiffness to support the guard and handrail loads. The post is typically connected to the top or side of stair stringers or landing framing.

7.2.4 Infill

The infill is bounded by the top rail, bottom rail and posts to provide a barrier to prevent occupants or other objects from falling through the guard. Infill can be provided using pickets, solid panels, mesh panels, cables, or additional rail members. Spacing of infill members must conform to the applicable code and occupancy requirements to ensure openings are within allowable sizes. Typically, for an IBC-compliant stair, openings do not allow for passage of a 4-in.-diameter sphere. In certain cases, the allowable opening

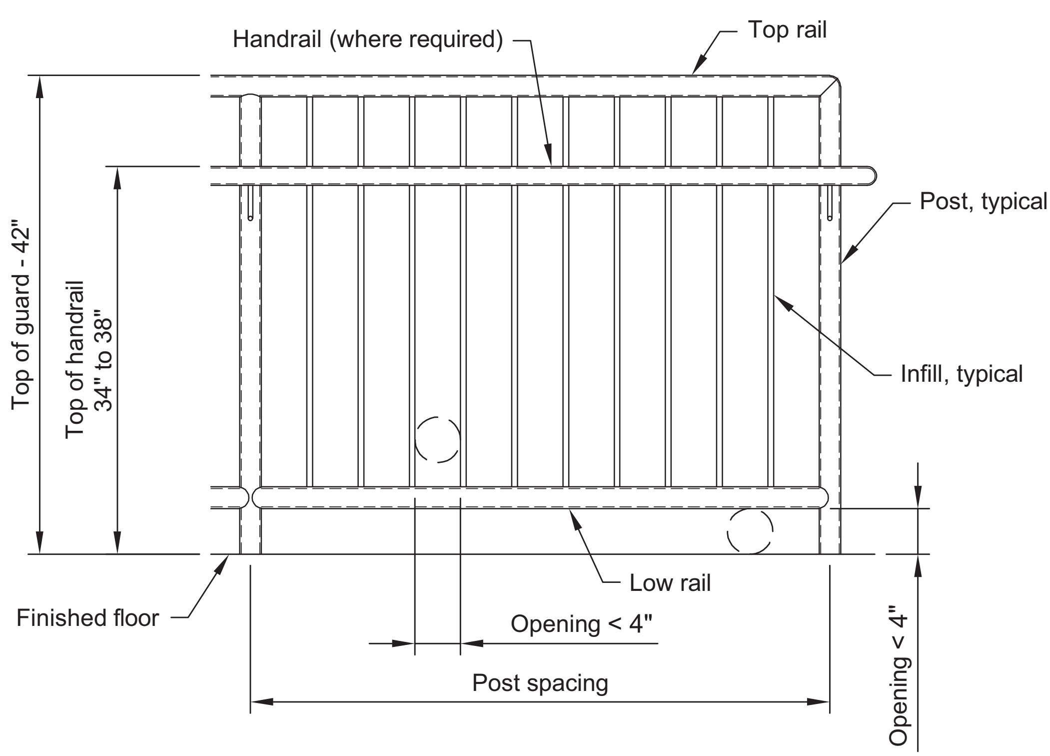


Fig. 7-1. IBC-style guard, elevation view.

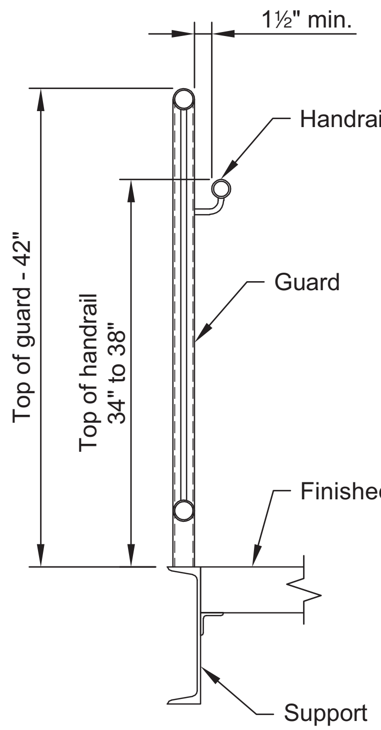


Fig. 7-2. IBC-style stairway guard, section view.

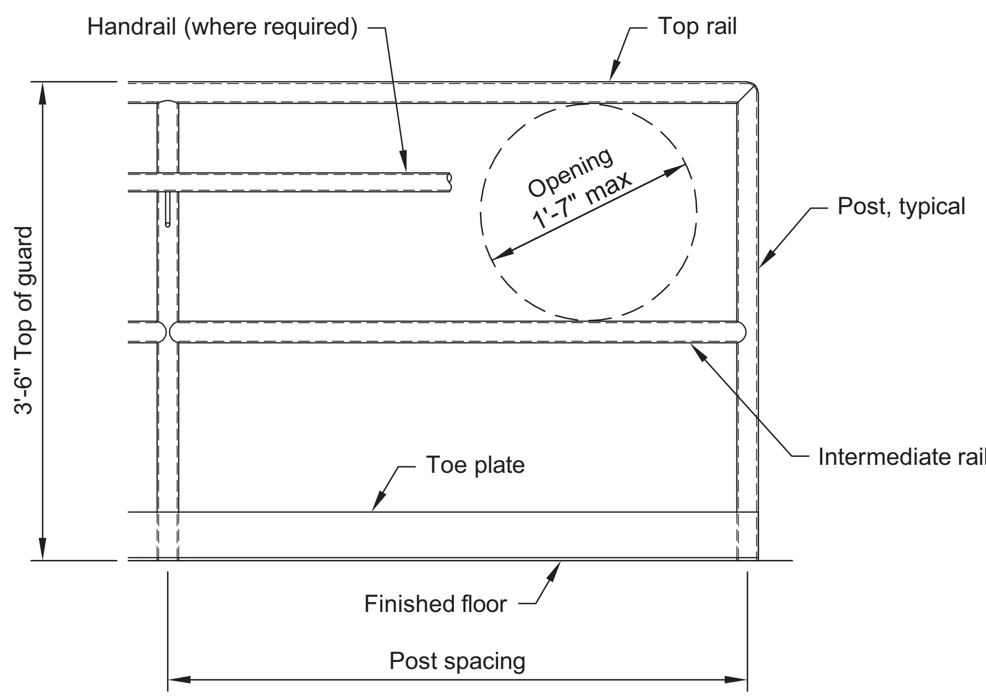


Fig. 7-3. OSHA-style guard, elevation view.

size is larger based on occupancy and use. For an OSHA-compliant stair, openings cannot exceed 19 in. in the smallest dimension.

Consideration should also be made to the layout of infill members to avoid creating a ladder effect. The ladder effect exists when infill members are oriented in a manner that allows an occupant (most likely young children) to climb the infill members. It is the responsibility of the architect to determine when the ladder effect could pose a concern based on the project type and occupancy.

7.2.5 Handrail

The handrail is provided for guidance and support of occupants traveling on the stairway. The handrail may be supported from the guard or wall mounted. Refer to the applicable project code to determine the height range at which to set the handrail above the walking surface and required clearances from obstructions. The applicable code will also provide graspability requirements that dictate the size and layout of the handrail. The handrail must have the strength and stiffness to span from support point-to-support point for vertical, lateral and axial forces.

7.2.6 Toe Plate

Toe plate or toeboard is provided to prevent debris or objects from falling off of the stairway or landing to the area below. Toe plate is typically required for OSHA-compliant stairways, landings and platforms. Toe plate should be provided in any situation where falling debris could pose a concern. Commercial stairs may not need toe plate in an occupancy where there is minimal risk of objects falling (i.e., office building). Designers should verify the need for toe plate with the architect. Alternatively, some stairway and guard designs will adjust the top of steel of the support member, shifting the top of steel above the finished floor, to act as the toe plate.

7.3 GUARD AND HANDRAIL CONNECTIONS

Connections for the guard and handrail system will vary based on the members being used. Most often steel guard and handrail assemblies are shop welded to the largest shippable size and then field welded or bolted to the stair stringer or other supporting structure.

7.3.1 Rail-to-Rail Joints

Steel members comprising the sloping or horizontal rails, vertical posts and infill pickets can be joined by welding. Fillet welds and butt welds are the most typical welds used to join these elements. Finishing of these welds is also important. Refer to the NAAMM *Pipe Railing Systems Manual Including Round Tube* for guidance on the levels of finish required at these joints.

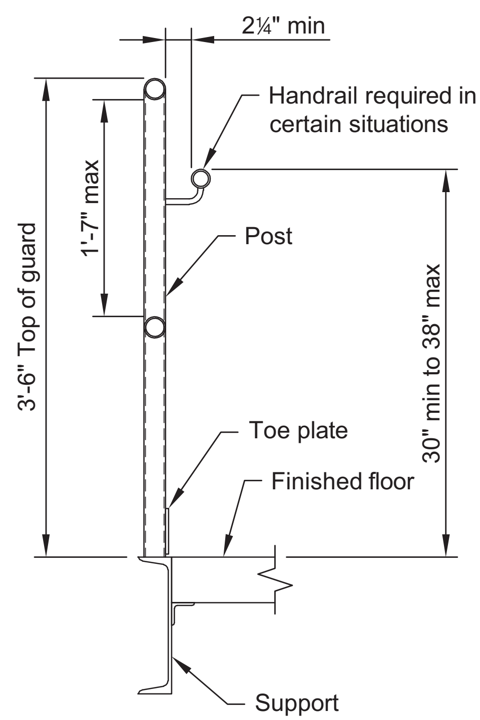


Fig. 7-4. OSHA-style stairway guard, section view.

7.3.2 Handrail Support Brackets

Support brackets for handrail can be fabricated from steel bar or rod and can also be purchased from a manufacturer. Designers should verify that the bracket and its fasteners are adequate to support the loads imposed on handrails, accounting for both vertical and lateral forces.

Support brackets purchased from manufacturers should come with testing documentation showing that the brackets meet the requirements of *Standard Test Methods for Performance of Permanent Metal Railing Systems and Rails for Buildings,* ASTM E935 (ASTM, 2013) and *Standard Specification for Permanent Metal Railing Systems and Rails for Buildings*, ASTM E985 (ASTM, 2006). Other appropriate testing to verify the brackets meet the load and deflection requirements of the code may also be acceptable. Note that at the time of writing, ASTM E985 has been withdrawn.

7.3.3 Post-to-Stringer

The guard post-to-stringer connection will most typically resist the largest design forces of all the elements and connections in the guard system. The post may be mounted to the face of a plate stringer or HSS member, as shown in Figure 7-5. Alternately, the post may be mounted to the top of a channel stringer or HSS member, as shown in Figure 7-6.

For posts mounted to the face of the stringer, welding or bolting to the stringer should be designed to provide the required strength to resist the vertical, lateral and torsional forces. Designers should ensure that the torsion in the stringer can be resisted by the member and end connections. One option to do so is to use the risers and treads to resist any force couples.

For posts mounted to the top of the stringer, welding is more common. Designers should carefully select a post size and weld that will fit on the top flange of the stringer and that also provides adequate strength for the combined forces.

Additional design requirements related to testing of railing systems is provided in *Standard Test Methods for Anchorage of Permanent Metal Railing Systems and Rails for Buildings*, ASTM E894 (ASTM, 2018). This ASTM standard provides the specifications for testing of a guard and handrail system to ensure it meets the governing building code.

When using pipe for the post, fillet welds are the easiest and most common option for connecting to the top flange of the stringer. When space is limited, a one-sided complete-joint-penetration (CJP) square groove weld in a butt joint configuration can also be used. However, this type of weld is not an AWS prequalified weld unless a backer bar is provided. If a backer bar is not used, the fabricator may be required to qualify the weld procedure and welders in accordance with AWS D1.1/D1.1M (AWS, 2015).

As noted previously, the applied moment at the top of the stringer should be considered by the designer. For channel stringers, additional checks should be made to determine if the top flange is adequate or if a stiffener plate should be provided at the location of the moment.

Based on past experience and finite element analysis, the author suggests using the following formula to establish the effective width of a channel flange when analyzing the stringer for the imposed moment from a guard post. The formula utilizes a 2.5:1 distribution to determine the effective width of the resisting element.

$$B_{eff} = N + 2(2.5)\left[\left(k - \frac{t_f}{2}\right) + b_f\right] \tag{7-1}$$

where

N = guard post diameter, in.

b_f = flange width, in.

k = beam fillet dimension, in.

t_f = flange thickness, in.

Utilizing Equation 7-1 for a single post mounted to the top flange of a channel without consideration of frame action or load sharing in the guard system, the author recommends

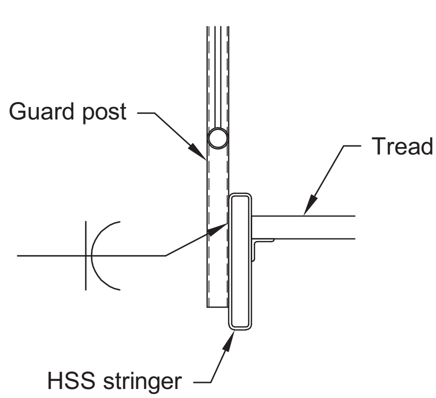


Fig. 7-5. Guard post mounted to side of HSS member.

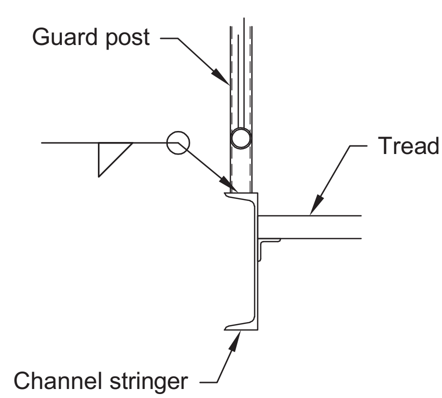


Fig. 7-6. Guard post mounted to top of channel.

that channel members with webs equal to or thinner than ¼-in. thickness should be fitted with a stiffener plate below the post to the channel to resist the applied moment. A more detailed analysis or alternative methods may show that the stiffener is not required. Engineering judgment should be used to determine the appropriate details at the post-to-channel flange junction.

7.3.4 Post or Handrail at Concrete or Masonry

Posts may be set into concrete slabs and floor systems in core-drilled holes filled with grout. This can be an effective detail for interior environments as long as adequate concrete depth is provided and the post location is away from concrete edges. This detail can also be used for exterior stairs, but material finish and concern for rust or failure at the steel-to-grout and concrete joint should be considered. This may be a maintenance issue that must be addressed over time and should be discussed with the end user or owner during design.

Wall brackets can effectively be used at concrete and masonry walls to support handrail. Refer to the previous section for general information regarding handrail support brackets. The use of approved, post-installed screw anchors is typical for attachment to concrete or masonry walls.

7.3.5 Handrail at Stud Wall

The use of handrail support brackets-to-stud walls is typical. Designers should ensure that additional blocking or support members are provided within wood or metal stud walls that can provide adequate resistance to the required loads. Attachment directly to gypsum board or wood sheathing is rarely adequate to support the code required loads. Fasteners must also be checked to ensure they are adequate to resist the imposed handrail forces. Refer to the previous section for general information regarding handrail support brackets.

Chapter 8
Additional Considerations

The wide use and variety of stairways presents a challenge for designers because there is not a single "typical" stair that can be provided for each project. Each stairway has its own set of challenges and project-specific requirements. Presented in this chapter are several additional items that require consideration in the design of steel-framed stairways.

8.1 CONSTRUCTION TOLERANCES

Construction tolerances of different materials can present a major challenge when designing, detailing, fabricating and erecting a steel stairway. Tolerances vary for steel, concrete, masonry and other materials. The designer should refer to material specific standards or guides for information on construction tolerances. Additionally, the *Handbook of Construction Tolerances* (Ballast, 1994) provides a valuable resource for the different tolerances for each material type and use.

It is important to recognize that stair layout and geometry must be maintained as required by the governing building code when tolerances for the support structure alter the layout as detailed. It is critical that dimensional uniformity is maintained and that maximum and minimum required dimensions for stair geometry are maintained. This may require that the support structure or the stairway be modified to ensure that the stair layout remains code compliant.

The recommendations presented herein are based on best practices and experience related to the design, fabrication and construction of steel stairways. In unique or unusual situations, designers must use their own judgment to determine appropriate design and construction criteria. Designers should consult with stair suppliers for additional input and recommendations.

8.1.1 Steel

Steel stairways connected to steel structures typically use a variety of framing arrangements, including stringers attached to main floor beams, intermediate landings with posts, hangers from main floor beams, and stairway perimeters enclosed by stud walls. Tolerances affecting steel members include mill variations, fabrication tolerances and erection tolerances. All of these items can affect both the supporting steel structures and the steel stairways.

Mill variations are based on tolerances provided in ASTM A6/A6M (ASTM, 2016a). Rolled shapes with acceptable mill tolerances may create fit-up issues unless connection details allow for adjustment. Additional information and tolerance limits can be found in AISC *Code of Standard Practice* Section 5.1 (AISC, 2016a). Conformance to this AISC standard should avoid most issues due to mill variations.

Fabrication tolerances are presented in AISC *Code of Standard Practice* Section 6.4. In most cases, providing connections with adjustability consisting of slotted holes or shim gaps should help to minimize issues related to fabrication. Conformance to the AISC *Code of Standard Practice* should avoid most issues due to fabrication tolerances.

Erection tolerances for the steel structure are presented in AISC *Code of Standard Practice* Section 7.13. In many cases, the position of structural members near stairways will be based on a maximum placement tolerance limit of 1/500 of the distance between working points. For most stairways, providing a gap from ¼ in. to ⅜ in. between the stairway member and the support structure (or stud walls) will provide sufficient clearance, but individual cases may vary. The *Handbook of Construction Tolerances* also recommends a tolerance of ±⅜ in. for horizontal and vertical positioning of secondary steel elements.

Additional tolerances related to architecturally exposed structural steel (AESS) are presented in the AISC *Code of Standard Practice*; fabrication and erection tolerances are covered in Sections 10.2 through 10.6.

The combination of these tolerances can create problems if allowances are not provided during design and detailing. Common allowances include providing a gap between stairway members and steel structures or stud walls, using connections with slotted holes or shim gaps, and welded connections with adjustment for fit-up. Addressing tolerance issues in advance will reduce the chance of problems arising during construction, but in some cases, field fixes will be unavoidable.

8.1.2 Cast-in-Place Concrete

Specification for Tolerances for Concrete Construction and Materials, ACI 117 (ACI, 2010), indicates that concrete construction allows for a ¼-in. variation over 10 ft of length from plumb in the placement of columns and walls. Distances between walls, columns, partitions and beams may vary by up to ¼ in. per 10 ft of distance but not more than ½ in. in any one bay. For many stairways, providing a gap of ¼ in. to ½ in. will provide sufficient clearance from the adjacent concrete structure, but individual cases may vary.

The design should also note that individual cast-in-place members can also have permissible variations. Column sections, beam sections and floor openings are examples.

According to the *Handbook of Construction Tolerances,* cross sections up to 12 in. can vary +⅜ in. to −¼ in., and floor openings can vary by +1 in. to −¼ in. and may be misplaced in plan by ±½ in. in each direction.

Due to these variations, it is recommended to field verify critical dimensions before fabrication commences. Using connection details with adjustability at locations framing to concrete can also avoid fit-up issues in the field.

8.1.3 Masonry

ASTM C90 (ASTM, 2016b) provides the tolerances for hollow load-bearing concrete masonry. Concrete masonry units are produced in nominal dimensions with the actual dimensions set to ⅜ in. less to accommodate a mortar joint. In the field, concrete masonry units can vary by ±⅛ in. in width, height and length.

Masonry construction allows for ±¼ in. variation in 10 ft, ±⅜ in. in 20 ft, and up to ±½ in. maximum for plumbness of walls and columns. Columns and walls continuing from one story to another may vary in alignment by ±¾ in. for nonloadbearing walls or columns and by ±½ in. for bearing walls or columns. For many stairways, providing a gap from ¼ in. to ½ in. will provide sufficient clearance from the adjacent masonry structure, but individual cases may vary.

Due to these variations, it is recommended to field verify critical dimensions before fabrication commences. Using connection details with adjustability at locations framing to masonry can also avoid fit-up issues in the field.

8.2 GALVANIZED STAIRWAYS

Galvanizing steel provides an exterior coating that gives members enhanced corrosion protection in certain environments. Galvanizing produces a different aesthetic finish and also requires additional considerations for design and construction. Some of these considerations when specifying galvanizing include:

- Field welding should be avoided. Welding galvanized members requires that the galvanized coating be removed to perform the weld, and members must be touched up after welding is complete. Field bolting is typically preferred.
- Bolt hole size considerations. The galvanizing process creates a coating on all member surfaces that may reduce the size of bolt holes. Coordinate with the fabricator and galvanizer to determine appropriate hole size. Providing oversized holes will typically provide adequate clearance for bolt installation but will also require the use of a slip-critical joint, which requires additional preparation.
- Hardware and weld metal matching. Use the appropriate galvanized bolts, hardware and weld materials to avoid issues with dissimilar metals in contact.
- Unsafe environments. Galvanized stairways should not be used in highly acidic environments, highly alkaline environments, or very high temperatures (over 400°F).
- Limitations on size of piece or assembly to be galvanized. Consult with the galvanizer for limits.
- Drain hole/air hole required in closed sections for galvanizing process.
- Distortion. Galvanizing may cause distortion of certain shapes or assemblies.

Galvanized stairways may be a desirable option for certain environments, but designers and fabricators must take care to ensure that proper details are used. Galvanizing will likely be more expensive for fabrication and installation but may be a good option for long-term maintenance and performance.

8.3 LONG-SPAN STAIRWAYS

Stairways with long simple spans will require additional structural analysis to ensure adequate stiffness. Long-span stairs typically incorporate plan bracing at the bottom flange of stringer members to stiffen the stairway to minimize lateral movements due to occupant loads. Cambering stringers for the dead load deflection may also help to meet serviceability requirements. Vibration can also be of greater concern with long-span stairways.

8.4 VIBRATION IN STAIRWAYS

Vibration analysis should be considered based on the size, use and configuration of a stairway. AISC Design Guide 11, *Vibrations of Steel-Framed Structural Systems Due to Human Activity* (Murray et al., 2016), provides additional guidance to evaluate steel-framed stairs for vibration.

8.5 ARCHITECTURALLY EXPOSED STRUCTURAL STEEL

Architecturally exposed structural steel (AESS) requires additional effort in design, detailing, fabrication and erection to ensure that the architectural design intent is met. Coordination among all parties involved is critical. Refer to AISC *Code of Standard Practice* Section 10 for recommendations and guidelines when using AESS for stairways, guards and handrails.

8.6 ERECTABILITY AND TEMPORARY SUPPORT

Similar to any steel-framed structure, erectability and temporary support must be considered when using steel-framed stairways. Stairways installed adjacent to a concrete or masonry core wall may limit access for bolted connections.

Similarly, phasing of construction activities for masonry construction may require that temporary support be provided for steel-framed stairways.

Stair designers should coordinate with the general contractor, architect, and structural engineer of record (SER) to determine project-specific limitations and concerns.

Chapter 9
Delegated Design

Delegated design provides an opportunity for the architect and the structural engineer of record (SER) to delegate the design of stairways to the fabricator. Depending on the project notes and specifications, delegated design may allow the fabricator to dictate all aspects of design for the stairway (architectural and structural) or the architect and/or SER will provide specific criteria for the fabricator to follow. For some projects, the fabricator will also be required to provide calculations and drawings sealed by a professional engineer for the structural design. Refer to the Purpose section of this Design Guide for common issues that should be considered as part of the delegated design process.

Delegated design can also be a point of confusion based on contractual obligations and design responsibility. Pryse et al. (1996) provided recommendations regarding delegated design in the *Modern Steel Construction* article "Metal Stairs and Railings: Will the Responsible Designer Please Step Forward?"

9.1 RECOMMENDED DELEGATED DESIGN INFORMATION

It is important for the architect and SER to provide clear and concise requirements for the fabricator when using delegated design for stairways, guards and handrail. The architect should provide design requirements for the egress provisions according to the governing building code. Accordingly, the architect should provide information regarding dimensional layout for stairways, guards, handrails, required clear dimensions, and other related information. The SER should provide information related to loading (or indicate code minimum loadings), preferred member type/size, restrictions for stairway supports or connection types, and other related information.

Included in Appendix A are checklists that will assist architects, structural engineers and component suppliers in providing the appropriate information to the fabricator for delegated design for stairways.

9.1.1 Design Documents

Design documents should provide adequate information to ensure that the stairway fabricator, detailer, and specialty structural engineer (SSE) have adequate information to meet the project architectural and structural design requirements. At a minimum, this information should consist of:

- Plans, sections and elevations at each stairway
- Stairway dimensional requirements
  - Clear distances at stairs
  - Clear distances at landings
  - Guard layout
  - Handrail position
- Preferred or required member types
- Layout of stair elements
- Slab openings
- Details where stairs attach to the building structure (fully detailed or conceptual)
- Any other special requirements

Many times, design documents may only show the general design intent for the stairways. The architect and SER should provide additional information as needed when special details or design elements are to be incorporated into the stairway. If the SER provides complete connection design for the stairs, then the drawings and details should include the information required in AISC *Code of Standard Practice* Section 3.1 (AISC, 2016a).

9.1.2 Project Specifications

Project specifications should provide additional information and guidance for the design of stairways in conjunction with the design documents. It is important that specifications are properly reviewed and accurately match the design documents to avoid questions and delays due to discrepancies.

It is particularly important that architectural requirements be provided by the architect and structural requirements be provided by the SER. Specifications for stairways and guard/handrail should reflect the specific project requirements.

9.2 CODE COMPLIANCE

Stairways, guards and handrail are critical components related to life safety. It is of the utmost importance that these elements are designed, detailed, fabricated and erected properly to meet the appropriate code requirements. The architect and SER are the design professionals most familiar with the requirements related to the building project.

Fabricators, detailers, erectors and the SSE do not generally have the knowledge and expertise that the architect has with respect to egress requirements and specific building requirements of the governing building code. The architect should provide adequate direction to ensure that the delegated design will be in general conformance with the design and code requirements.

The industry in general has recognized that only the owner's designated representative for design (typically the architect and SER) has all the information necessary to evaluate the total impact of deferred or delegated design details on the overall structural and architectural design of the project. This authority traditionally has been exercised during the approval process for the delegated design submittal (via structural calculations, shop drawings, etc.). Irrespective of delegated design submittals, the owner's designated representative for design retains responsibility for the adequacy and safety of the entire structure. This does not relieve the SSE of his or her design responsibility for the deferred submittal. It is intended to ensure that the deferred submittal is coordinated with the rest of the project, which only the owner's designated representative for design can verify and confirm.

9.3 SUBMITTAL REVIEW AND SHOP DRAWING REVIEW

The author recommends that engineers subcontracted to provide engineering analysis of structural performance and serviceability criteria for stairways (the SSEs) provide sealed calculations and stairway drawings to the fabricator. This package should be similar in content to a set of sealed design drawings that would be provided to the fabricator for a typical steel building project. The fabricator would use this package to create shop and erection drawings. It is also recommended that the SSE provide shop drawing review related to the stairway design during the approval process. This combined package of sealed calculations and stairway drawings, along with the fabricator's shop and erection drawings, should be adequate as a deferred submittal.

A requirement for the SSE to seal and sign each sheet of the shop and erection drawings produced by the fabricator is discouraged. Furthermore, sealing drawings produced by others is not permitted under laws in certain states. Requiring the SSE to seal shop drawings produced by the fabricator does not change the designer's professional responsibility and does not replace the shop drawing approval process. The owner's designated representative for design is still required to review the stairway shop and erection drawings during the approval process for conformance with the specified criteria and compatibility with the design of the primary structure.

9.4 QUALITY ASSURANCE

For delegated design of stairways, guards and handrail, the author recommends that all parties adhere to the requirements of the NAAMM *Metal Stairs Manual* (NAAMM, 1992) and *Railing Manual* (NAAMM, 2001).

Specifically related to steel members, the author recommends that all parties agree to follow the AISC *Code of Standard Practice* (AISC, 2016a) as a framework for delegated design of stairways, guards and handrail. These provisions are not intended for stairs but do provide reasonable criteria for trade practices related to steel stairways.

Using these recommendations will help to ensure that all involved parties have the same expectations for the architectural design, structural design, detailing, fabrication and erection of steel-framed stairways.

Chapter 10
Design Examples

In many cases, the selection of members and connections for stairways, guards and handrail are based on architectural requirements, fabrication preferences, and erection considerations rather than sizes required for strength or serviceability. The design examples are intended to provide design guidance for a particular element. Designers should select member sizes after considering all of these requirements.

Two design examples are presented in this chapter: a commercial stairway design and an industrial stairway design.

The following conventions are used throughout both examples:

1. Deflection calculations, for uniform loads, have been rearranged and conversion factors applied so that the conventional units in the problem can be directly inserted into the equation for steel design. It is as follows:

   Simple beam:

$$\Delta = \frac{5(w\text{ kip/in.})(L\text{ in.})^4}{384(29{,}000\text{ ksi})(I\text{ in.}^4)}$$

$$= \frac{(w\text{ kip/ft})(L\text{ ft})^4}{1{,}290(I\text{ in.}^4)} \tag{10-1}$$

2. Required moment of inertia can be determined using the deflection limits and rearranging the simple beam deflection formula. It is as follows:

$$I_{req'd} = \frac{(w\text{ kip/ft})(L\text{ ft})^4}{1{,}290(\Delta\text{ in.})} \tag{10-2}$$

10.1 DESIGN OF COMMERCIAL STAIRWAY

This section illustrates the load determination and selection of members that are part of a commercial stairway. The design is completed in accordance with the 2016 AISC *Specification for Structural Steel Buildings* (AISC, 2016b) and the 15th Edition AISC *Steel Construction Manual* (AISC, 2017). Loading criteria are based on ASCE/SEI 7-16 (ASCE, 2016).

The stairway being analyzed is a commercial stairway located within a two-story office building in a midwestern city. IBC stairway requirements are given in the design examples. Seismic and wind loads are not applicable.

The design sequence is presented as follows:

Example 10.1.1—Determination of required opening size to accommodate code compliant stairway, and load determination and deflection criteria

Example 10.1.2—Design of stringers

Example 10.1.3—Design of landing header beam

Example 10.1.4—Design of landing rear beam

Example 10.1.5—Design of landing post

Example 10.1.6—Design of landing hanger

Example 10.1.7—Design of guard assembly

Example 10.1.8—Check guard post-to-stringer top flange connection

Table 10-1. Deflection Limits		
Construction	**Live Load Deflection Limit**	**Total Load Deflection Limit**
Floor members (stringers/landings)	*Span*/360	*Span*/240
Cantilever guard post supporting handrail	h/60	—
Guard infill rails, handrail, and infill panels	*Span*/120	—
h = height of guard post, in.		

The architect provides the following requirements:

1. Provide the minimum required egress width of 44 in. at stair flights and landings.
2. Treads are concrete-filled pans with closed risers of light gauge material.
3. Riser height is 7 in. and tread length is 11 in.
4. Preferred stringer member type is an ASTM A36 channel.
5. Preferred guard and handrail member type is ASTM A500 Grade C round HSS.

The general layout of the stairway is provided in Figures 10-1, 10-2 and 10-3. The layout of this stair is provided for example purposes and may not represent a typical framing layout.

Load combinations

From ASCE/SEI 7, Chapter 2, the following combinations will govern design for gravity cases:

LRFD	ASD
$12D + 1.6L$	$D + L$

Deflection criteria

The deflection limits are summarized in Table 10-1.

Example 10.1.1—Opening Size Determination

Given:

Determine the code-required minimum opening size for the stairway.

Loads

Stair dead load:

Self-weight of steel framing	= to be determined
12-ga treads/risers with 2-in. concrete fill	= 30 psf
Superimposed mechanical, electrical, plumbing (MEP) loads	= 5 psf
Total	= 35 psf (plus member self-weight)

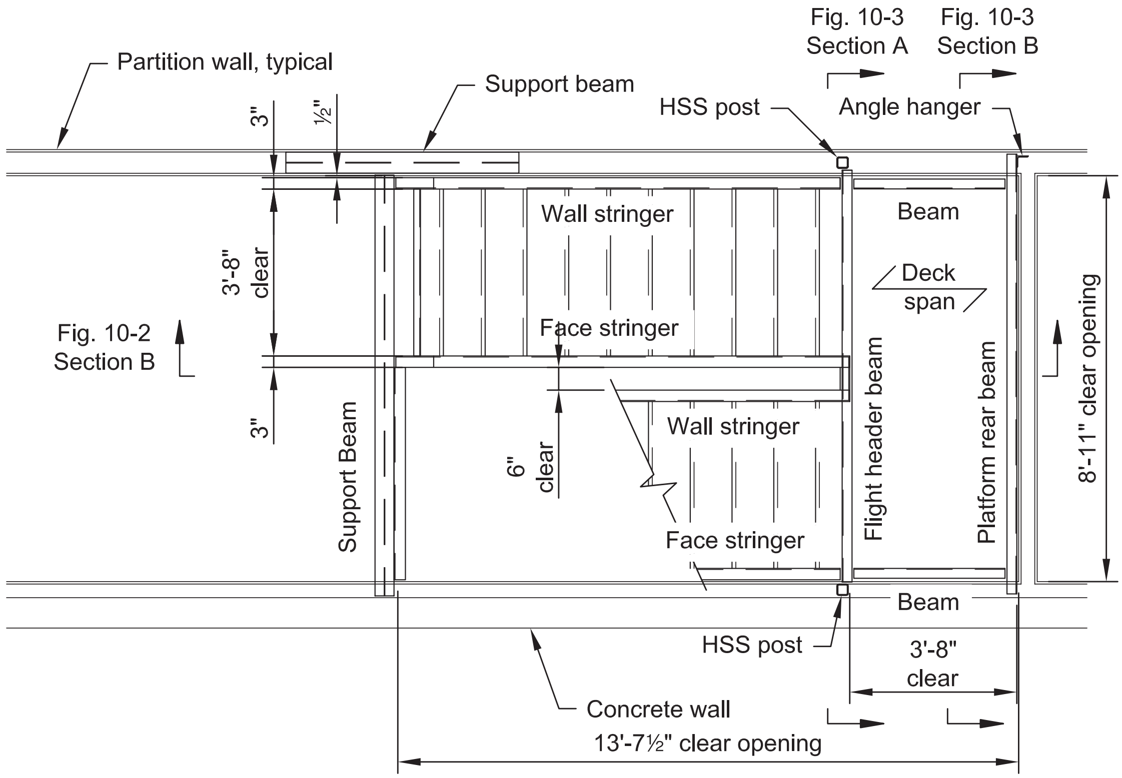
Stair live load:
Live load cases are nonconcurrent.

Case 1—Uniform load

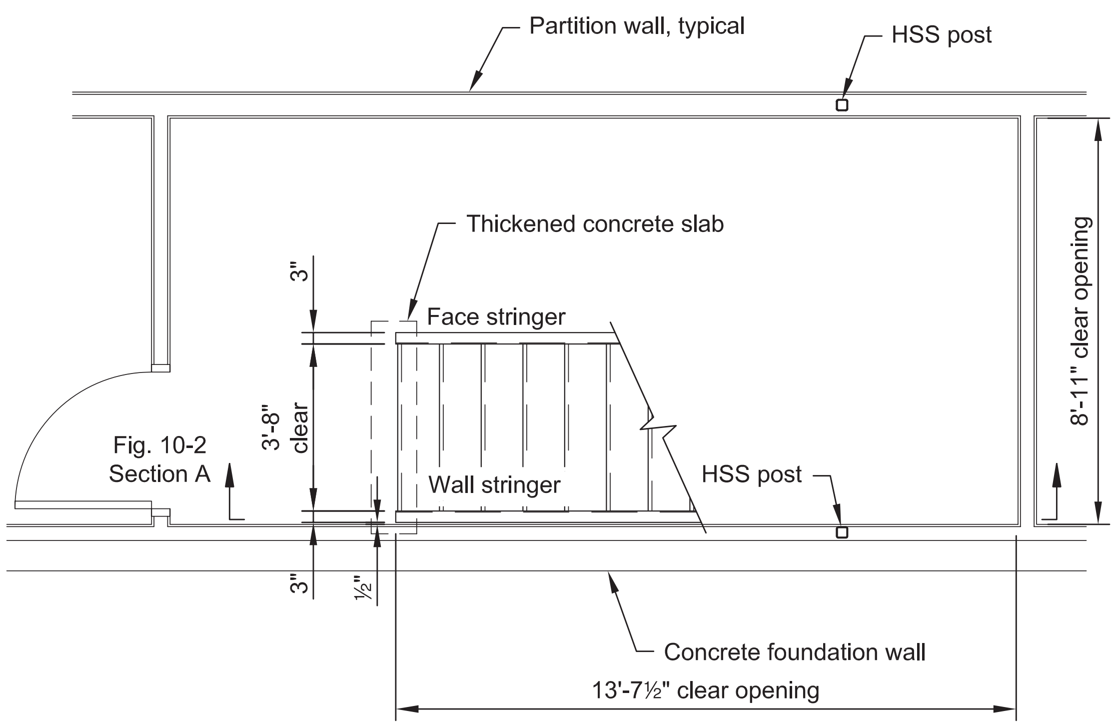
Live load = 100 psf

Case 2—Concentrated load at treads only

Live load = 300 lb over 4 in.^{2}



(a)



(b)

Fig. 10-1. Commercial stairway plans: (a) intermediate landing plan; (b) first floor plan.

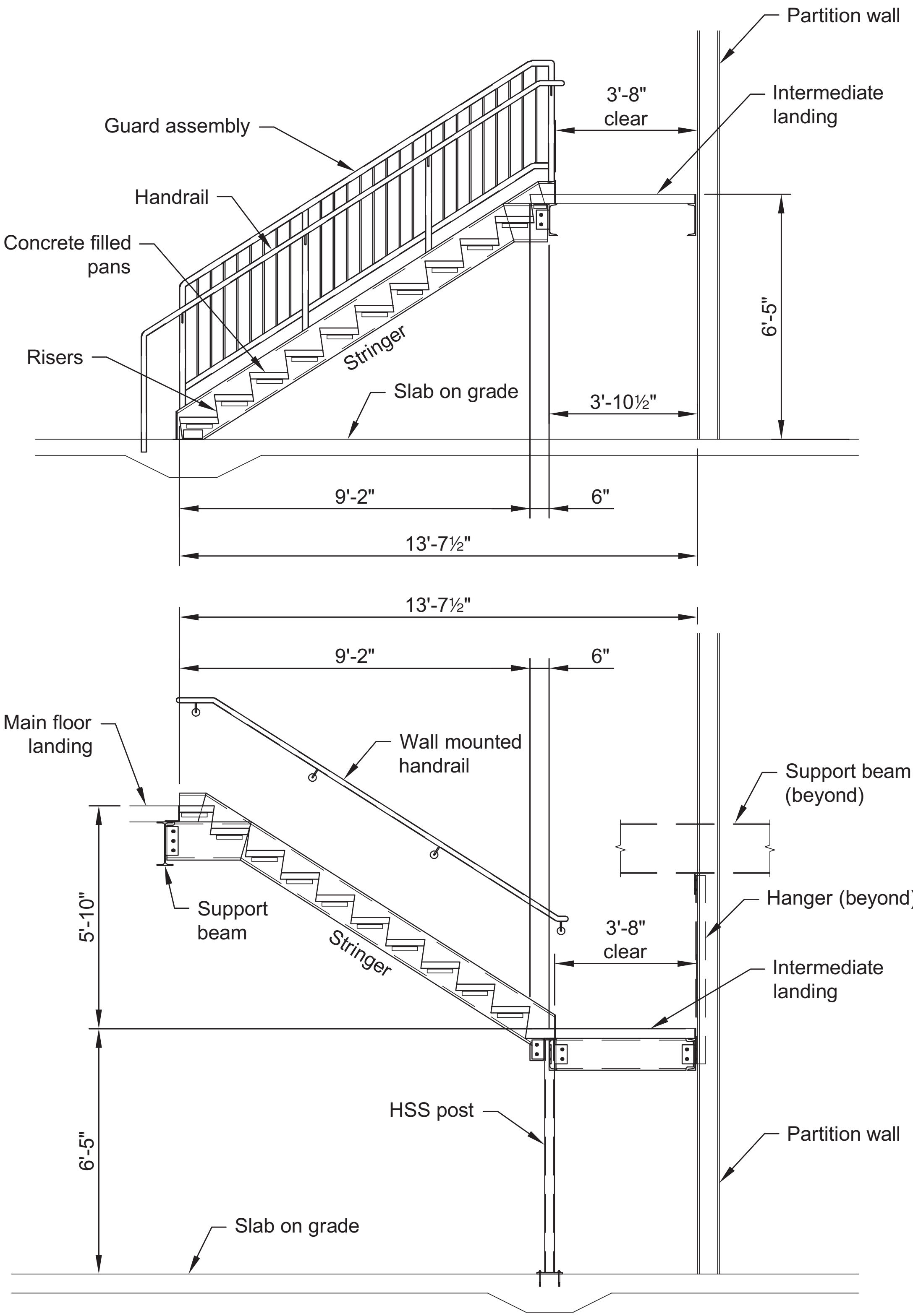


Fig. 10-2. Commercial stairway sections for Figure 10-1.

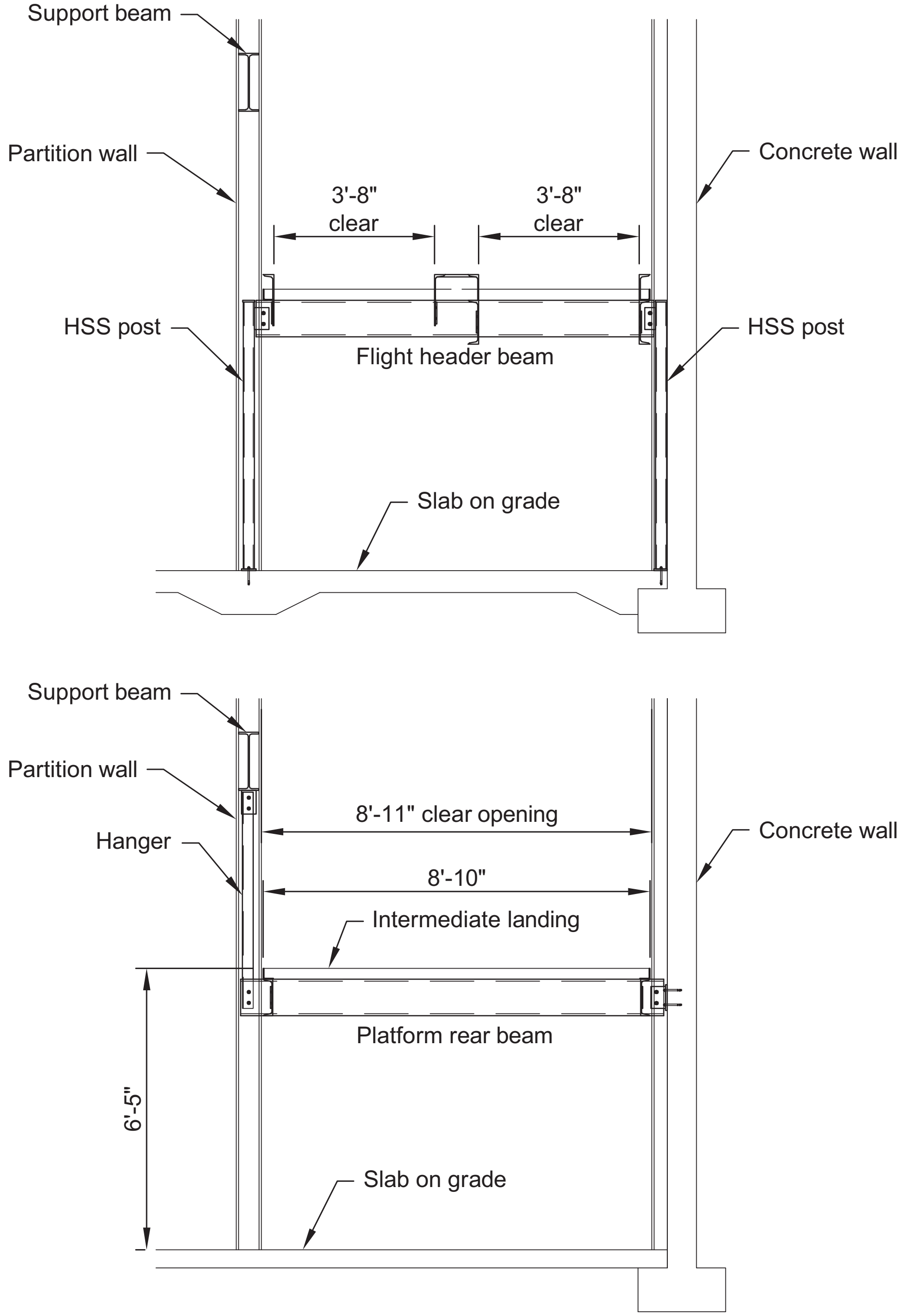


Fig. 10-3. Commercial stairway sections for Figure 10-1.

Landing dead load:

Self-weight of steel framing	= to be determined
3-in. total thickness, concrete slab over metal deck	= 32 psf
Superimposed MEP loads	= 5 psf
Total	= 37 psf (plus member self-weight)

Landing live load:
Live load = 100 psf

Guard dead load:
Self-weight of members = to be determined

Guard live load:
Live load cases are nonconcurrent.

Case 1—Uniform load applied in any direction at top of guard or handrail

Live load = 50 plf

Case 2—Concentrated load applied in any direction at top of guard or handrail

Live load = 200 lb

Solution:

Refer to Section 3.4.4 for overview of formulas and recommendations.

Clear width minimum opening size

$$W_{open} = 2\,(\text{Edge gap}) + 4\,(\text{Stringer width}) + 2\,(\text{Egress width}) + 1\,(\text{Center gap}) \tag{3-3}$$

where

Center gap = 6 in. per Figure 10-1
Edge gap = ½ in.
Egress width = 44 in., minimum
Stringer width = 3 in., minimum for channel

and

$$\begin{aligned} W_{open} &= 2\,(\tfrac{1}{2}\text{ in.}) + 4\,(3\text{ in.}) + 2\,(44\text{ in.}) + 1\,(6\text{ in.}) \\ &= 107\text{ in. or 8 ft 11 in. clear dimension} \end{aligned}$$

Clear length minimum opening size

$$L_{open} = L_{stair} + L_{landing} \tag{3-4}$$

$$L_{stair} = N_{tread}\,(\text{Tread lendth}) + (\text{Connection allowance}) \tag{3-5}$$

$$L_{landing} = N_{landing}\,[(\text{Stringer width}) + (\text{Egress width}) + (\text{End gap})] \tag{3-6}$$

where

Connection allowance = 6 in. at one end of stringer
Egress width = 44 in., minimum
End gap = ½ in.
$N_{landing}$ = 1 intermediate landing at 44 in., minimum
N_{tread} = 10 full treads
Stringer width = 3 in., minimum for channel
Tread length = 11 in., typical

and

$$L_{open} = 10(11 \text{ in.}) + (6 \text{ in.}) + (1)\left[(3 \text{ in.}) + (44 \text{ in.}) + (\tfrac{1}{2} \text{ in.})\right]$$
$$= 163\tfrac{1}{2} \text{ in. or } 13 \text{ ft } 7\tfrac{1}{2} \text{ in. clear dimension}$$

Provide minimum opening size for code compliant stair of 8 ft 11 in. wide by 13 ft 7½ in. long.

Example 10.1.2—Stringer Beam Design

Given:

Calculate forces and select member sizes for the stringers at the lower and upper stair flight ("face stringers" and "wall stringers" shown in Figure 10-1), using the horizontal plane method. The loading diagram is shown in Figure 10-4. The stair stringer is fully braced by welded tread/riser pans. Riser height is 7 in., and tread length is 11 in.

For this design example, an ASTM A36 C12×20.7 was selected as the stringer beam based on nonstructural considerations.

Solution:

From AISC *Manual* Table 2-4, the material properties are as follows:

ASTM A36
$F_y = 36$ ksi
$F_u = 58$ ksi

From AISC *Manual* Table 1-5, the geometric properties are as follows:

C12×20.7
Self-weight = 20.7 lb/ft
$I_x = 129 \text{ in.}^4$

Due to the beam slope, the member self-weight is modified to account for the additional weight on a per foot basis.

$$\text{Slope ratio} = \sqrt{(7 \text{ in.})^2 + (11 \text{ in.})^2}\left(\frac{12 \text{ in./ft}}{11 \text{ in.}}\right)\left(\frac{1 \text{ ft}}{12 \text{ in.}}\right)$$
$$= 1.19$$

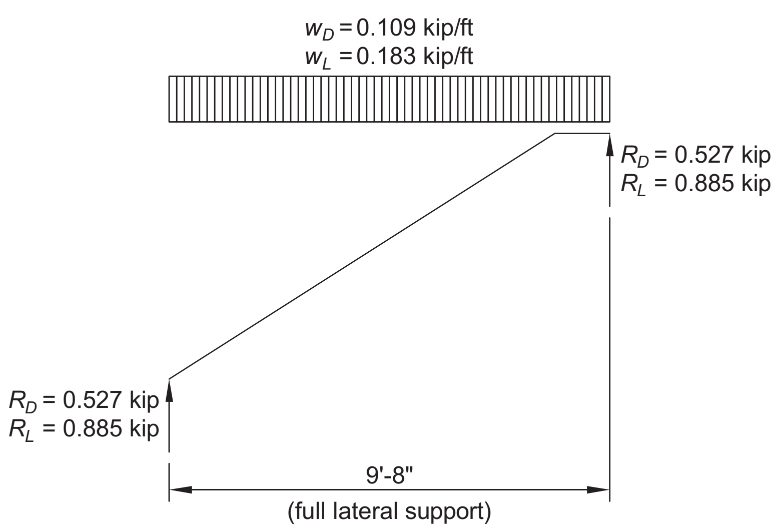


Fig. 10-4. Beam loading and bracing diagram.

Member self-weight at sloping stringer:

$$w_{sw} = 1.19(20.7 \text{ lb/ft})(1 \text{ kip/1,000 lb})$$
$$= 0.0246 \text{ kip/ft}$$

Because the inside stringer will also support the weight of the guard and handrail assembly, an additional dead load of 20 lb/ft is added.

Calculate the required strengths using ASCE/SEI 7, Chapter 2, load combinations:

LRFD	ASD
$w_u = \left(\dfrac{3.67 \text{ ft}}{2}\right)\left[1.2(0.0350 \text{ kip/ft}^2)+1.6(0.100 \text{ kip/ft}^2)\right]$ $+1.2(0.0246 \text{ kip/ft} + 0.0200 \text{ kip/ft})$ $= 0.424 \text{ kip/ft}$	$w_a = \left(\dfrac{3.67 \text{ ft}}{2}\right)\left[(0.0350 \text{ kip/ft}^2)+(0.100 \text{ kip/ft}^2)\right]$ $+(0.0246 \text{ kip/ft}+0.0200 \text{ kip/ft})$ $= 0.292 \text{ kip/ft}$
$R_u = \dfrac{w_u l}{2}$ $= \left[\dfrac{(0.424 \text{ kip/ft})(9.67 \text{ ft})}{2}\right]$ $= 2.05 \text{ kips}$	$R_a = \dfrac{w_a l}{2}$ $= \left[\dfrac{(0.292 \text{ kip/ft})(9.67 \text{ ft})}{2}\right]$ $= 1.41 \text{ kips}$
$M_u = \dfrac{w_u l^2}{8}$ $= \dfrac{(0.424 \text{ kip/ft})(9.67 \text{ ft})^2}{8}$ $= 4.96 \text{ kip-ft}$	$M_a = \dfrac{w_a l^2}{8}$ $= \dfrac{(0.292 \text{ kip/ft})(9.67 \text{ ft})^2}{8}$ $= 3.41 \text{ kip-ft}$

Assume the stringer is fully braced by the stair treads and risers. From AISC *Manual* Table 3-8, for a C12×20.7 with continuous bracing, the available flexural strength is:

LRFD	ASD
$\phi_b M_n = \phi_b M_p$ $= 69.1 \text{ kip-ft} > 4.96 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = \dfrac{M_p}{\Omega_b}$ $= 46.0 \text{ kip-ft} > 3.41 \text{ kip-ft}$ **o.k.**

From AISC *Manual* Table 3-8 for a C12×20.7, the available shear strength is:

LRFD	ASD
$\phi_v V_n = 65.8 \text{ kips} > 2.05 \text{ kips}$ **o.k.**	$\dfrac{V_n}{\Omega_v} = 43.8 \text{ kips} > 1.41 \text{ kips}$ **o.k.**

Check the member deflection against the allowable deflection limits provided in Table 10-1.

Live load:

From Table 10-1, the live load deflection limit is:

$$\Delta_{LL\ allowable} = \frac{Span}{360}$$
$$= \left(\frac{9.67 \text{ ft}}{360}\right)\left(\frac{12 \text{ in.}}{1 \text{ ft}}\right)$$
$$= 0.322 \text{ in.}$$

From Figure 10-4, $w_{LL} = 0.183$ kip/ft, and the live load deflection is:

$$\Delta_{LL} = \frac{(w \text{ kip/ft})(L \text{ ft})^4}{1{,}290\,(I \text{ in.}^4)} \tag{10-1}$$

$$= \frac{(0.184 \text{ kip/ft})(9.67 \text{ ft})^4}{1{,}290\,(129 \text{ in.}^4)}$$

$$= 0.00967 \text{ in.}$$

To account for the sloping length of the member, a deflection factor is applied to determine the approximate vertical deflection using the horizontal plane method:

$$F_\Delta = \left(\frac{\sqrt{(7 \text{ in.})^2 + (11 \text{ in.})^2}}{11 \text{ in.}}\right)^4 \left\{\cos\left[\tan^{-1}\left(\frac{7 \text{ in.}}{11 \text{ in.}}\right)\right]\right\}^2$$

$$= 1.40$$

Therefore, the live load deflection is:

$$\Delta_{LL} = F_\Delta \Delta$$

$$= 1.40(0.00962 \text{ in.})$$

$$= 0.0140 \text{ in.} < 0.322 \text{ in.} \qquad \textbf{o.k.}$$

Total load:

From Table 10-1, the total load deflection limit is:

$$\Delta_{TL\,allowable} = \frac{Span}{240}$$

$$= \left(\frac{9.67 \text{ ft}}{240}\right)\left(\frac{12 \text{ in.}}{1 \text{ ft}}\right)$$

$$= 0.484 \text{ in.}$$

From Figure 10-4, $w_{TL} = 0.104$ kip/ft + 0.183 kip/ft = 0.292 kip/ft, and the total load deflection is:

$$\Delta_{TL} = \frac{(w \text{ kip/ft})(L \text{ ft})^4}{1{,}290\,(I \text{ in.}^4)} \tag{10-1}$$

$$= \frac{(0.292 \text{ kip/ft})(9.67 \text{ ft})^4}{1{,}290\,(129 \text{ in.}^4)}$$

$$= 0.0153 \text{ in.}$$

To account for the sloping length of the member, the deflection factor is applied to determine the approximate vertical deflection:

$$\Delta_{TL} = F_\Delta \Delta$$

$$= 1.40(0.0153 \text{ in.})$$

$$= 0.0214 \text{ in.} < 0.484 \text{ in.} \qquad \textbf{o.k.}$$

Use a C12×20.7 for stringer beams at the lower and upper stair flight (face stringers and wall stringers shown in Figure 10-1).

Example 10.1.3—Flight Header Beam Design

Given:

Calculate forces and select member size for the flight header beam at the intermediate landing shown in Figure 10-1. The header beam has full lateral support from the steel deck. The loading diagram is shown in Figure 10-5. Assume member self-weight to be 15.3 lb/ft.

Solution:

Determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations and select the header beam.

LRFD	ASD
$w_u = \left[1.2(0.0153\text{ kip/ft})\right] + \left(\frac{3.67\text{ ft}}{2}\right)\left[1.2(0.0370\text{ kip/ft}^2) + 1.6(0.100\text{ kip/ft}^2)\right] = 0.393\text{ kip/ft}$	$w_a = \left[0.0153\text{ kip/ft}\right] + \left(\frac{3.67\text{ ft}}{2}\right)\left[(0.0370\text{ kip/ft}^2) + (0.100\text{ kip/ft}^2)\right] = 0.267\text{ kip/ft}$
$R_u = \frac{(0.393\text{ kip/ft})(9.17\text{ ft})}{2} + \frac{4\left[(1.2)(0.527\text{ kip}) + (1.6)(0.885\text{ kip})\right]}{2} = 5.90\text{ kips}$	$R_a = \frac{(0.267\text{ kip/ft})(9.17\text{ ft})}{2} + \frac{4\left[(0.527\text{ kip}) + (0.885\text{ kip})\right]}{2} = 4.05\text{ kips}$
$M_u = \frac{(0.393\text{ kip/ft})(9.17\text{ ft})^2}{8} + (1.2)(0.527\text{ kip})\left(\frac{5\text{ in.}}{12\text{ in./ft}}\right) + (1.6)(0.885\text{ kip})\left(\frac{5\text{ in.}}{12\text{ in./ft}}\right) + (1.2)(0.527\text{ kip})\left[3.67\text{ ft} + \left(\frac{5\text{ in.}}{12\text{ in./ft}}\right)\right] + (1.6)(0.885\text{ kip})\left[3.67\text{ ft} + \left(\frac{5\text{ in.}}{12\text{ in./ft}}\right)\right] = 13.4\text{ kip-ft}$	$M_a = \frac{(0.267\text{ kip/ft})(9.17\text{ ft})^2}{8} + (0.527\text{ kip})\left(\frac{5\text{ in.}}{12\text{ in./ft}}\right) + (0.885\text{ kip})\left(\frac{5\text{ in.}}{12\text{ in./ft}}\right) + (0.527\text{ kip})\left[3.67\text{ ft} + \left(\frac{5\text{ in.}}{12\text{ in./ft}}\right)\right] + (0.885\text{ kip})\left[3.67\text{ ft} + \left(\frac{5\text{ in.}}{12\text{ in./ft}}\right)\right] = 9.17\text{ kip-ft}$

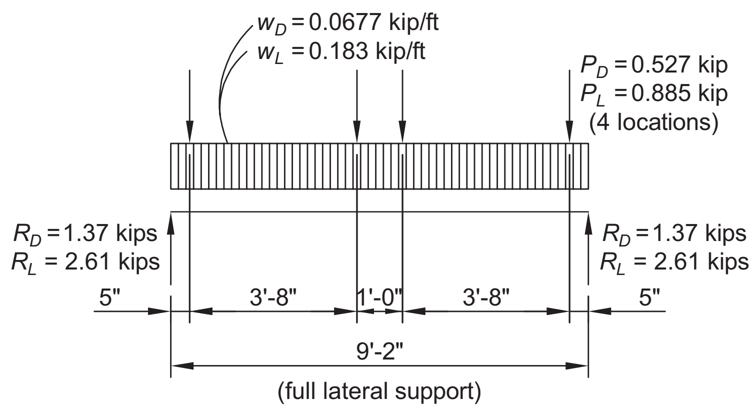


Fig. 10-5. Flight header beam loading and bracing diagram.

Check the member deflection against the allowable deflection limits provided in Table 10-1. The equivalent uniformly distributed load based on the unfactored moment is determined as follows.

$$\begin{aligned} w_{eq} &= \frac{8M}{L^2} \\ &= \frac{8(9.17 \text{ kip-ft})}{(9.17 \text{ ft})^2} \\ &= 0.872 \text{ kip/ft} \end{aligned}$$

From Table 10-1, the total load deflection limit is:

$$\begin{aligned} \Delta_{TL\ allowable} &= \frac{Span}{240} \\ &= \left(\frac{9.17 \text{ ft}}{240}\right)\left(\frac{12 \text{ in.}}{1 \text{ ft}}\right) \\ &= 0.459 \text{ in.} \end{aligned}$$

The required moment of inertia based on the allowable deflection is determined as follows:

$$I_{req'd} = \frac{(w \text{ kip/ft})(L \text{ ft})^4}{1{,}290(\Delta \text{ in.})} \tag{10-2}$$

$$\begin{aligned} &= \frac{(0.872 \text{ kip/ft})(9.17 \text{ ft})^4}{1{,}290(0.459 \text{ in.})} \\ &= 10.4 \text{ in.}^4 \end{aligned}$$

From AISC *Manual* Table 1-5, select a C10×15.3 with $I_x = 67.3 \text{ in.}^4$

From AISC *Manual* Table 3-8 for a C10×15.3 with continuous bracing, the available flexural strength is:

LRFD	ASD
$\phi_b M_n = \phi_b M_p$ $= 42.9 \text{ kip-ft} > 13.4 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = \dfrac{M_p}{\Omega_b}$ $= 28.6 \text{ kip-ft} > 9.17 \text{ kip-ft}$ **o.k.**

From AISC *Manual* Table 3-8 for a C10×15.3, the available shear strength is:

LRFD	ASD
$\phi_v V_n = 46.7 \text{ kips} > 5.90 \text{ kips}$ **o.k.**	$\dfrac{V_n}{\Omega_v} = 31.0 \text{ kips} > 4.05 \text{ kips}$ **o.k.**

A C10×15.3 is acceptable for the header beam at the intermediate landing.

Example 10.1.4—Platform Rear Beam Design

Given:

Calculate forces and select a member size for the platform rear beam at the intermediate landing shown in Figure 10-1. The platform beam has full lateral support from the steel deck. The loading diagram is shown in Figure 10-6. Assume member self-weight to be 15.3 lb/ft.

Solution:

Determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations and select the rear beam.

LRFD	ASD
$w_u = [1.2(0.0153 \text{ kip/ft})] + \left(\frac{3.67 \text{ ft}}{2}\right)[1.2(0.0370 \text{ kip/ft}^2) + 1.6(0.100 \text{ kip/ft}^2)]$ $= 0.393 \text{ kip/ft}$	$w_a = 0.0153 \text{ kip/ft} + \left(\frac{3.67 \text{ ft}}{2}\right)[(0.0370 \text{ kip/ft}^2) + (0.100 \text{ kip/ft}^2)]$ $= 0.267 \text{ kip/ft}$
$R_u = \frac{(0.393 \text{ kip/ft})(9.17 \text{ ft})}{2}$ $= 1.80 \text{ kips}$	$R_a = \frac{(0.267 \text{ kip/ft})(9.17 \text{ ft})}{2}$ $= 1.22 \text{ kips}$
$M_u = \frac{(0.393 \text{ kip/ft})(9.17 \text{ ft})^2}{8}$ $= 4.13 \text{ kip-ft}$	$M_a = \frac{(0.267 \text{ kip/ft})(9.17 \text{ ft})^2}{8}$ $= 2.81 \text{ kip-ft}$

Check the member deflection against the allowable deflection limits. From previous calculations, $\Delta_{TL\,allowable} = 0.459$ in. and the required moment of inertia, I, is determined as follows:

$$I_{req'd} = \frac{(w \text{ kip/ft})(L \text{ ft})^4}{1{,}290\,(\Delta \text{ in.})} \tag{10-2}$$

$$= \frac{(0.267 \text{ kip/ft})(9.17 \text{ ft})^4}{1{,}290\,(0.459 \text{ in.})}$$

$$= 3.19 \text{ in.}^4$$

From AISC *Manual* Table 1-5, select a C10×15.3 with $I_x = 67.3$ in.^{4}

From AISC *Manual* Table 3-8 for a C10×15.3 with continuous bracing, the available flexural strength is:

LRFD	ASD
$\phi_b M_n = \phi_b M_p$ $= 42.9 \text{ kip-ft} > 4.13 \text{ kip-ft}$ **o.k.**	$\frac{M_n}{\Omega_b} = \frac{M_p}{\Omega_b}$ $= 28.6 \text{ kip-ft} > 2.80 \text{ kip-ft}$ **o.k.**

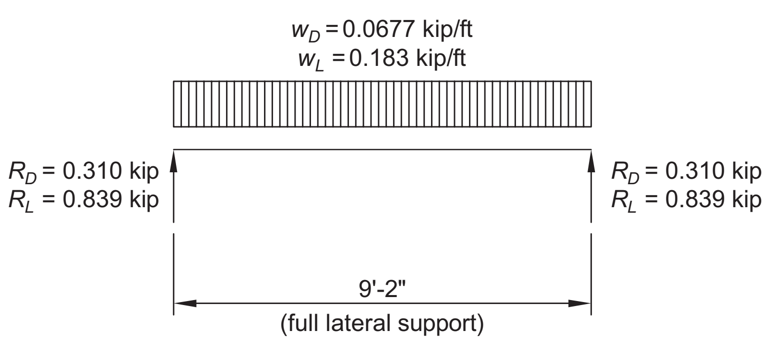


Fig. 10-6. Platform rear beam loading and bracing diagram.

From AISC *Manual* Table 3-8 for a C10×15.3, the available shear strength is:

LRFD	ASD
$\phi_v V_n = 46.7 \text{ kips} > 1.80 \text{ kips}$ **o.k.**	$\dfrac{V_n}{\Omega_v} = 31.0 \text{ kips} > 1.22 \text{ kips}$ **o.k.**

A C10×15.3 is acceptable for the platform rear beam at the intermediate landing. Conservatively use the design of the platform rear beam for the remaining intermediate landing infill beams.

Example 10.1.5—Landing Post Design

Given:

Select an ASTM A500 Grade C square HSS for the landing post ("HSS post" in Figure 10-1).

Elevation of intermediate landing slab: 106.42 ft
Elevation of first floor slab: 100.00 ft
Column unbraced length: $L_{cx} = L_{cy} \approx 6.5$ ft

Solution:

From AISC *Manual* Table 2-4, the material properties are as follows:

ASTM A500 Grade C rectangular
$F_y = 50$ ksi
$F_u = 62$ ksi

From Figure 10-5, the dead and live load reactions are:

$R_D = 1.37$ kips
$R_L = 2.61$ kips

Determine the required strength using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
$P_u = 1.2(1.37 \text{ kips}) + 1.6(2.61 \text{ kips})$ $= 5.82 \text{ kips}$	$P_a = 1.37 \text{ kips} + 2.61 \text{ kips}$ $= 3.98 \text{ kips}$

Using AISC *Manual* Table 4-4 with $L_c = 6.5$ ft, proceed across the table until reaching the lightest size that has sufficient available strength. Additionally, to provide for connection fit-up, the minimum flange size should be 3 in. or greater, and the minimum thickness should be 3⁄16 in. Try an HSS3×3×3⁄16.

LRFD	ASD
$\phi_c P_n = 60.4 \text{ kips} > 5.82 \text{ kips}$ **o.k.**	$\dfrac{P_n}{\Omega_c} = 40.2 \text{ kips} > 3.98 \text{ kips}$ **o.k.**

Use HSS3×3×3⁄16 for the landing post.

Example 10.1.6—Landing Hanger Design

Given:

Select an ASTM A36 single angle for the landing hanger ("angle hanger" shown in Figure 10-1).

Elevation of intermediate landing slab: 106.42 ft
Elevation of second floor slab: 112.25 ft
Hanger unbraced length: $L_{cx} = L_{cy} \approx 5.83$ ft

Solution:

From Figure 10-6, the dead and live load reactions are:

$R_D = 0.310$ kip
$R_L = 0.839$ kip

Determine the required strength using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
$P_u = 1.2(0.310 \text{ kip}) + 1.6(0.839 \text{ kip})$ $= 1.71 \text{ kips}$	$P_a = 0.310 \text{ kip} + 0.839 \text{ kip}$ $= 1.15 \text{ kips}$

From AISC *Manual* Table 5-2, all listed single angles have sufficient available strength. To provide for connection fit-up, the minimum flange size should be 3 in. or greater, and the minimum thickness should be 3⁄16 in. Try a L3×3×3⁄16.

LRFD	ASD
Tension yielding $\phi_t P_n = 35.3 \text{ kips} > 1.71 \text{ kips}$ **o.k.**	Tension yielding $\dfrac{P_n}{\Omega_t} = 23.5 \text{ kips} > 1.15 \text{ kips}$ **o.k.**
Tension rupture $\phi_t P_n = 35.6 \text{ kips} > 1.71 \text{ kips}$ **o.k.**	Tension rupture $\dfrac{P_n}{\Omega_t} = 23.7 \text{ kips} > 1.15 \text{ kips}$ **o.k.**

Use L3×3×3⁄16 for the landing hanger.

Example 10.1.7—Guard Assembly Design

Given:

Calculate forces for the selected member sizes for the guard assembly. A layout of the guard and loading is shown in Figure 10-7. Design the members for the worst case loading. Use ASTM A500 Grade C round HSS members and ASTM A36 plate.

Guard members: HSS1.900×0.145
Handrail member: HSS1.660×0.140
Infill members: PL ½ in. × ½ in.
Handrail bracket: PL ½ in. × ½ in.

The guard top rail and handrail have loads that include the member self-weight, plus a uniform live load of 0.05 kip/ft or point live load of $P = 0.2$ kip applied in any direction.

The guard post must resist the imposed loading from the guard top rail or handrail. At a minimum, the guard post should be designed to resist a point live load of $P = 0.2$ kip applied in any direction.

The guard infill has a live load of 0.05 kip applied normal to the infill on an area not to exceed 12 in. × 12 in. to produce the maximum load effect.

Solution:

From AISC *Manual* Tables 2-4 and 2-5, the material properties are as follows:

Guard and handrail members
ASTM A500 Grade C round
$F_y = 46$ ksi
$F_u = 62$ ksi

Infill and handrail bracket members
ASTM A36
F_y = 36 ksi
F_u = 58 ksi

From AISC *Manual* Table 1-13, the geometric properties are as follows:

Guard members (top rail, post)
HSS1.900×0.145
SW = 2.72 lb/ft
t = 0.135 in.
A = 0.749 in.^{2}
D/t = 14.1
I = 0.293 in.^{4}
S = 0.309 in.^{3}
r = 0.626 in.
Z = 0.421 in.^{3}

Handrail member
HSS1.660×0.140
SW = 2.27 lb/ft
t = 0.130 in.
A = 0.625 in.^{2}
D/t = 12.8
I = 0.184 in.^{4}
S = 0.222 in.^{3}
r = 0.543 in.
Z = 0.305 in.^{3}

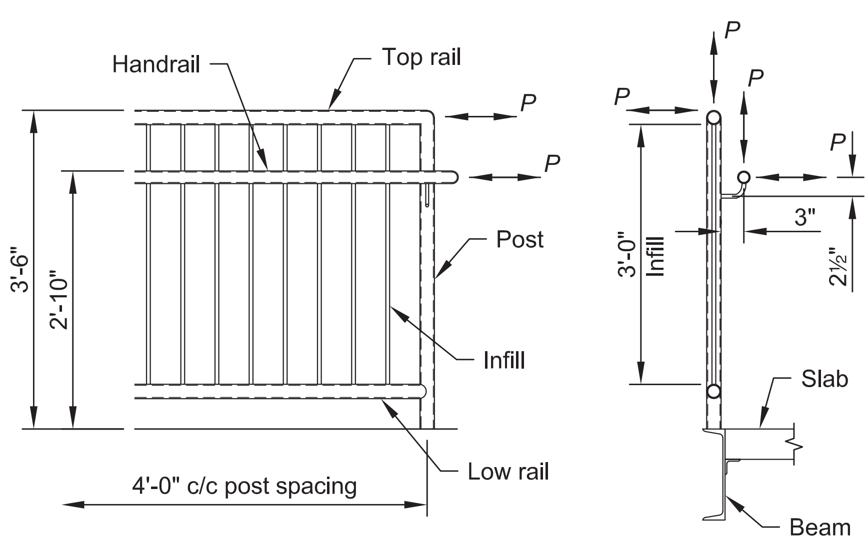


Fig. 10-7. Guard layout and loading diagram.

Determined using AISC *Manual* Table 17-27, the geometric properties about the center of the plate are as follows:

Infill and handrail bracket members
PL ½ in. × ½ in.

$SW = 0.851$ lb/ft
$A = 0.250$ in.^{2}
$I = 0.00521$ in.^{4}
$S = 0.0208$ in.^{3}
$Z = 0.0313$ in.^{3}

Determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations.

Guard Top Rail and Handrail

The required strengths due to self-weight plus the 0.2-kip concentrated load are as follows:

LRFD	ASD
$P_u = 1.6(0.200 \text{ kip})$ $= 0.320 \text{ kip}$ $V_u = 1.2\left[\dfrac{(4 \text{ ft})(0.00272 \text{ kip/ft})}{2}\right] + 1.6(0.200 \text{ kip})$ $= 0.327 \text{ kip}$ $M_u = 1.2\left[\dfrac{(0.00272 \text{ kip/ft})(4 \text{ ft})^2}{8}\right] + 1.6\left[\dfrac{(0.200 \text{ kip})(4 \text{ ft})}{4}\right]$ $= 0.327 \text{ kip-ft}$	$P_a = 0.200 \text{ kip}$ $V_a = \dfrac{(4 \text{ ft})(0.00272 \text{ kip/ft})}{2} + 0.200 \text{ kip}$ $= 0.205 \text{ kip}$ $M_a = \dfrac{(0.00272 \text{ kip/ft})(4 \text{ ft})^2}{8} + \dfrac{(0.200 \text{ kip})(4 \text{ ft})}{4}$ $= 0.205 \text{ kip-ft}$

The required strengths due to self-weight plus the 0.05 kip/ft uniform live load are as follows:

LRFD	ASD
$P_u = 1.6(4 \text{ ft})(0.0500 \text{ kip/ft})$ $= 0.320 \text{ kip}$ $V_u = 1.2\left[\dfrac{(4 \text{ ft})(0.00272 \text{ kip/ft})}{2}\right] + 1.6\left[\dfrac{(4 \text{ ft})(0.0500 \text{ kip/ft})}{2}\right]$ $= 0.167 \text{ kip}$ $M_u = 1.2\left[\dfrac{(0.00272 \text{ kip/ft})(4 \text{ ft})^2}{8}\right]$ $+1.6\left[\dfrac{(0.0500 \text{ kip/ft})(4 \text{ ft})^2}{8}\right]$ $= 0.167 \text{ kip-ft}$	$P_a = (4 \text{ ft})(0.0500 \text{ kip/ft})$ $= 0.200 \text{ kip}$ $V_a = \dfrac{(4 \text{ ft})(0.00272 \text{ kip/ft})}{2} + \dfrac{(4 \text{ ft})(0.0500 \text{ kip/ft})}{2}$ $= 0.105 \text{ kip}$ $M_a = \dfrac{(0.00272 \text{ kip/ft})(4 \text{ ft})^2}{8} + \dfrac{(0.0500 \text{ kip/ft})(4 \text{ ft})^2}{8}$ $= 0.105 \text{ kip-ft}$

The required strengths due to the self-weight plus the 0.2-kip concentrated load control for the guard top rail and handrail.

Guard Top Rail—HSS1.900×0.145

Available compressive strength

The available compressive strength of the guard top rail is determined as follows.

Determine the wall limiting slenderness ratio, λ_r, from AISC *Specification* Table B4.1a, Case 9:

$$\begin{aligned}\lambda_r &= 0.11\frac{E}{F_y}\\ &= 0.11\left(\frac{29{,}000\text{ ksi}}{46\text{ ksi}}\right)\\ &= 69.3\end{aligned}$$

Because $D/t < \lambda_r$, the HSS1.900×0.145 is nonslender.

The available strength in axial compression is determined using AISC *Specification* Section E3. The critical stress, F_{cr}, is determined as follows.

$$\begin{aligned}\frac{L_c}{r} &= \frac{KL}{r}\\ &= \frac{(4\text{ ft})(12\text{ in./ft})}{0.626\text{ in.}}\\ &= 76.7\end{aligned}$$

$$\begin{aligned}4.71\sqrt{\frac{E}{F_y}} &= 4.71\sqrt{\frac{29{,}000\text{ ksi}}{46\text{ ksi}}}\\ &= 118\end{aligned}$$

Because $\frac{L_c}{r} < 4.71\sqrt{\frac{E}{F_y}}$, AISC *Specification* Equation E3-2 applies.

$$\begin{aligned}F_e &= \frac{\pi^2 E}{\left(\frac{L_c}{r}\right)^2} && \text{(Spec. Eq. E3-4)}\\ &= \frac{\pi^2(29{,}000\text{ ksi})}{(76.7)^2}\\ &= 48.7\text{ ksi}\end{aligned}$$

$$\begin{aligned}F_{cr} &= \left(0.658^{\frac{F_y}{F_e}}\right)F_y && \text{(Spec. Eq. E3-2)}\\ &= \left(0.658^{\frac{46\text{ ksi}}{48.7\text{ ksi}}}\right)(46\text{ ksi})\\ &= 31.0\text{ ksi}\end{aligned}$$

From AISC *Specification* Section E3, the nominal compressive strength is:

$$\begin{aligned}P_n &= F_{cr}A_g && \text{(Spec. Eq. E3-1)}\\ &= (31.0\text{ ksi})(0.749\text{ in.}^2)\\ &= 23.2\text{ kips}\end{aligned}$$

From AISC *Specification* Section E1, the available compressive strength of the HSS1.900×0.145 is:

LRFD	ASD
$\phi_c = 0.90$ $\phi_c P_n = 0.90(23.2 \text{ kips})$ $= 20.9 \text{ kips} > 0.320 \text{ kip}$ **o.k.**	$\Omega_c = 1.67$ $\dfrac{P_n}{\Omega_c} = \dfrac{23.2 \text{ kips}}{1.67}$ $= 13.9 \text{ kips} > 0.200 \text{ kip}$ **o.k.**

Available shear strength

From AISC *Specification* Section G5, the available shear strength of the HSS1.900×0.145 is determined as follows.

$$\begin{aligned} F_{cr} &= 0.6F_y \\ &= 0.6(46 \text{ ksi}) \\ &= 27.6 \text{ ksi} \end{aligned}$$

Note: AISC *Specification* Equations G5-2a and G5-2b will not typically control for sections used as part of a guard or handrail, except when high-strength steel is used or the span is unusually long.

Calculate the nominal shear strength using AISC *Specification* Section G5.

$$V_n = \frac{F_{cr} A_g}{2} \qquad \text{(}\textit{Spec}\text{. Eq. G5-1)}$$

$$\begin{aligned} &= \frac{(27.6 \text{ ksi})(0.749 \text{ in.}^2)}{2} \\ &= 10.3 \text{ kips} \end{aligned}$$

From AISC *Specification* Section G1, the available shear strength of the HSS1.900×0.145 is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_v V_n = 0.90(10.3 \text{ kips})$ $= 9.27 \text{ kips} > 0.327 \text{ kip}$ **o.k.**	$\Omega_v = 1.67$ $\dfrac{V_n}{\Omega_v} = \dfrac{10.3 \text{ kips}}{1.67}$ $= 6.17 \text{ kips} > 0.205 \text{ kip}$ **o.k.**

Available flexural strength

From AISC *Manual* Table 3-14, the available flexural strength of the HSS1.900×0.145 is:

LRFD	ASD
$\phi_b M_n = 1.45 \text{ kip-ft} > 0.327 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = 0.966 \text{ kip-ft} > 0.205 \text{ kip-ft}$ **o.k.**

The HSS1.900×0.145 guard top rail member is adequate for design loads.

Handrail—HSS1.660×0.140

Available compressive strength

Determine the wall limiting slenderness ratio, λ_r, from AISC *Specification* Table B4.1a, Case 9:

$$\lambda_r = 0.11\frac{E}{F_y}$$
$$= 0.11\left(\frac{29{,}000\text{ ksi}}{46\text{ ksi}}\right)$$
$$= 69.3$$

Because $D/t < \lambda_r$, the HSS is nonslender.

The critical stress, F_{cr}, is determined as follows:

$$\frac{L_c}{r} = \frac{KL}{r}$$
$$= \frac{(4\text{ ft})(12\text{ in./ft})}{0.543\text{ in.}}$$
$$= 88.4$$

$$4.71\sqrt{\frac{E}{F_y}} = 4.71\sqrt{\frac{29{,}000\text{ ksi}}{46\text{ ksi}}}$$
$$= 118$$

Because $\frac{L_c}{r} < 4.71\sqrt{\frac{E}{F_y}}$, AISC *Specification* Equation E3-2 applies.

$$F_e = \frac{\pi^2 E}{\left(\frac{KL}{r}\right)^2} \qquad \text{(\textit{Spec}. Eq. E3-4)}$$
$$= \frac{\pi^2(29{,}000\text{ ksi})}{(88.4)^2}$$
$$= 36.6\text{ ksi}$$

$$F_{cr} = \left(0.658^{\frac{F_y}{F_e}}\right)F_y \qquad \text{(\textit{Spec}. Eq. E3-2)}$$
$$= \left(0.658^{\frac{46\text{ ksi}}{36.6\text{ ksi}}}\right)(46\text{ ksi})$$
$$= 27.2\text{ ksi}$$

From AISC *Specification* Section E3, the nominal compressive strength is:

$$P_n = F_{cr}A_g \qquad \text{(\textit{Spec}. Eq. E3-1)}$$
$$= (27.2\text{ ksi})(0.625\text{ in.}^2)$$
$$= 17.0\text{ kips}$$

From AISC *Specification* Section E1, the available compressive strength of the HSS1.660×0.140 is:

LRFD	ASD
$\phi_c = 0.90$ $\phi_c P_n = 0.90(17.0\text{ kips})$ $= 15.3\text{ kips} > 0.320\text{ kip}$ **o.k.**	$\Omega_c = 1.67$ $\frac{P_n}{\Omega_c} = \frac{17.0\text{ kips}}{1.67}$ $= 10.2\text{ kips} > 0.200\text{ kip}$ **o.k.**

Available shear strength

From AISC *Specification* Section G5, the available shear strength of the HSS1.660×0.140 is determined as follows.

$$\begin{aligned} F_{cr} &= 0.6F_y \\ &= 0.6(46 \text{ ksi}) \\ &= 27.6 \text{ ksi} \end{aligned}$$

Note: AISC *Specification* Equations G5-2a and G5-2b will not typically control for sections used as part of a guard or handrail, except when high-strength steel is used or the span is unusually long.

Calculate the nominal shear strength using AISC *Specification* Section G5.

$$V_n = \frac{F_{cr}A_g}{2} \qquad \text{(Spec. Eq. G5-1)}$$

$$\begin{aligned} &= \frac{(27.6 \text{ ksi})(0.625 \text{ in.}^2)}{2} \\ &= 8.63 \text{ kips} \end{aligned}$$

From AISC *Specification* Section G1, the available shear strength of the HSS1.660×0.140 is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_v V_n = 0.90(8.63 \text{ kips})$ $= 7.77 \text{ kips} > 0.327 \text{ kip}$ **o.k.**	$\Omega_v = 1.67$ $\dfrac{V_n}{\Omega_v} = \dfrac{8.63 \text{ kips}}{1.67}$ $= 5.17 \text{ kips} > 0.205 \text{ kip}$ **o.k.**

Available flexural strength

From AISC *Manual* Table 3-14, the available flexural strength of the HSS1.660×0.140 is:

LRFD	ASD
$\phi_b M_n = 1.05 \text{ kip-ft} > 0.327 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = 0.700 \text{ kip-ft} > 0.205 \text{ kip-ft}$ **o.k.**

The HSS1.660×0.140 handrail member is adequate for design loads.

Guard Post—HSS1.900×0.145

Determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
$P_u = 1.2(3.5 \text{ ft})(0.00272 \text{ kip/ft}) + 0.327 \text{ kip}$ $= 0.338 \text{ kip}$ $V_u = 1.6(0.200 \text{ kip})$ $= 0.320 \text{ kip}$ $M_u = 1.6(0.200 \text{ kip})(3.5 \text{ ft})$ $= 1.12 \text{ kip-ft}$	$P_a = (3.5 \text{ ft})(0.00272 \text{ kip/ft}) + 0.205 \text{ kip}$ $= 0.215 \text{ kip}$ $V_a = 0.200 \text{ kip}$ $M_a = (0.200 \text{ kip})(3.5 \text{ ft})$ $= 0.700 \text{ kip-ft}$

From the previous calculations for the guard top rail, the guard post available strength is as follows:

LRFD	ASD
Available shear strength $\phi_v V_n = 9.27 \text{ kips} > 0.320 \text{ kip}$ **o.k.**	Available shear strength: $\frac{V_n}{\Omega_v} = 6.17 \text{ kips} > 0.200 \text{ kip}$ **o.k.**
Available flexural strength: $\phi_b M_n = 1.45 \text{ kip-ft} > 1.12 \text{ kip-ft}$ **o.k.**	Available flexural strength: $\frac{M_n}{\Omega_b} = 0.966 \text{ kip-ft} > 0.700 \text{ kip-ft}$ **o.k.**

Available compressive strength

The available compressive strength of the guard post is determined as follows.

Determine the wall limiting slenderness ratio, λ_r, from AISC *Specification* Table B4.1a, Case 9:

$$\lambda_r = 0.11\frac{E}{F_y}$$
$$= 0.11\left(\frac{29{,}000 \text{ ksi}}{46 \text{ ksi}}\right)$$
$$= 69.3$$

Because $D/t < \lambda_r$, the HSS1.900×0.145 is nonslender.

The available strength in axial compression is determined using AISC *Specification* Section E3. The critical stress, F_{cr}, is determined as follows using $K = 2$.

$$\frac{L_c}{r} = \frac{KL}{r}$$
$$= \frac{2(3.5 \text{ ft})(12 \text{ in./ft})}{0.626}$$
$$= 134$$

$$4.71\sqrt{\frac{E}{F_y}} = 4.71\sqrt{\frac{29{,}000 \text{ ksi}}{46 \text{ ksi}}}$$
$$= 118$$

Because $\frac{L_c}{r} > 4.71\sqrt{\frac{E}{F_y}}$, AISC *Specification* Equation E3-3 applies.

$$F_e = \frac{\pi^2 E}{\left(\frac{L_c}{r}\right)^2} \qquad \text{(Spec. Eq. E3-4)}$$
$$= \frac{\pi^2(29{,}000 \text{ ksi})}{(134)^2}$$
$$= 15.9 \text{ ksi}$$

$$F_{cr} = 0.877F_e \qquad \text{(Spec. Eq. E3-3)}$$
$$= 0.877(15.9 \text{ ksi})$$
$$= 13.9 \text{ ksi}$$

From AISC *Specification* Section E3, the nominal compressive strength is:

$$P_n = F_{cr}A_g \qquad \text{(Spec. Eq. E3-1)}$$
$$= (13.9 \text{ ksi})(0.749 \text{ in.}^2)$$
$$= 10.4 \text{ kips}$$

From AISC *Specification* Section E1, the available compressive strength of the HSS1.900×0.145 guard post is:

LRFD	ASD
$\phi_c = 0.90$ $\phi_c P_n = 0.90(10.4 \text{ kips})$ $= 9.36 \text{ kips} > 0.320 \text{ kip}$ **o.k.**	$\Omega_c = 1.67$ $\dfrac{P_n}{\Omega_c} = \dfrac{10.4 \text{ kips}}{1.67}$ $= 6.22 \text{ kips} > 0.200 \text{ kip}$ **o.k.**

The HSS1.900×0.145 guard post is adequate for design loads.

Infill Member—PL ½ in. × ½ in.

Determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
$V_u = 1.6(0.05 \text{ kip})$ $= 0.0800 \text{ kip}$ $M_u = \dfrac{1.6(0.05 \text{ kip})(3 \text{ ft})}{4}$ $= 0.0600 \text{ kip-ft}$	$V_a = 0.05 \text{ kip}$ $M_a = \dfrac{(0.05 \text{ kip})(3 \text{ ft})}{4}$ $= 0.0375 \text{ kip-ft}$

Available shear strength

Calculate the nominal shear strength using AISC *Specification* Section G4.

$$h/t = \frac{\text{½ in.}}{\text{½ in.}}$$
$$= 1$$

$$1.10\sqrt{\frac{k_v E}{F_y}} = 1.10\sqrt{\frac{(5)(29{,}000 \text{ ksi})}{(36 \text{ ksi})}}$$
$$= 69.8$$

Because $h/t < 1.10\sqrt{\dfrac{k_v E}{F_y}}$, AISC *Specification* Equation G2-9 applies.

$$C_{v2} = 1.0 \qquad \text{(Spec. Eq. G2-9)}$$

$$V_n = 0.6F_y A_w C_{v2} \qquad \text{(Spec. Eq. G4-1)}$$
$$= 0.6(36 \text{ ksi})(\text{½ in.})(\text{½ in.})(1.0)$$
$$= 5.40 \text{ kips}$$

From AISC *Specification* Section G1, the available shear strength is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_v V_n = 0.90(5.40 \text{ kips})$ $= 4.86 \text{ kips} > 0.0800 \text{ kip}$ **o.k.**	$\Omega_v = 1.67$ $\dfrac{V_n}{\Omega_v} = \dfrac{5.40 \text{ kips}}{1.67}$ $= 3.23 \text{ kips} > 0.05 \text{ kip}$ **o.k.**

Available flexural strength

Calculate the nominal flexural strength using AISC *Specification* Section F11.

Check the limits from AISC *Specification* Section F11.1:

$$\begin{aligned}\frac{L_b d}{t^2} &= \frac{(3 \text{ ft})(12 \text{ in./ft})(\tfrac{1}{2} \text{ in.})}{(\tfrac{1}{2} \text{ in.})^2} \\ &= 72.0\end{aligned}$$

$$\begin{aligned}\frac{0.08E}{F_y} &= \frac{0.08(29{,}000 \text{ ksi})}{36 \text{ ksi}} \\ &= 64.4\end{aligned}$$

$$\begin{aligned}\frac{1.9E}{F_y} &= \frac{1.9(29{,}000 \text{ ksi})}{36 \text{ ksi}} \\ &= 1{,}530\end{aligned}$$

Because $\dfrac{0.08E}{F_y} < \dfrac{L_b d}{t^2} < \dfrac{1.9E}{F_y}$, the limit state of yielding does not apply. The limit state of lateral-torsional buckling is checked using AISC *Specification* Section F11.2. The nominal flexural strength is limited by the plastic moment, determined as follows.

$$\begin{aligned}M_p &= F_y Z \\ &= (36 \text{ ksi})(0.0313 \text{ in.}^3)(1\text{ft}/12\text{in.}) \\ &= 0.0939 \text{ kip-ft}\end{aligned}$$

$$M_n = C_b\left[1.52 - 0.274\left(\frac{L_b d}{t^2}\right)\left(\frac{F_y}{E}\right)\right]M_y \le M_p \qquad (\textit{Spec.} \text{ Eq. F11-2})$$

$$\begin{aligned}&= 1.0\left[1.52 - 0.274(72.0)\left(\frac{36 \text{ ksi}}{29{,}000 \text{ ksi}}\right)\right](36 \text{ ksi})(0.0208 \text{ in.}^3) \\ &= 1.14 \text{ kip-ft} > 0.0939 \text{ kip-ft}\end{aligned}$$

Therefore, $M_n = 0.0939$ kip-ft

From AISC *Specification* Section F1, the available flexural strength is:

LRFD	ASD
$\phi_b = 0.90$ $\phi_b M_n = 0.90(0.0939 \text{ kip-ft})$ $= 0.0845 \text{ kip-ft} > 0.0600 \text{ kip-ft}$ **o.k.**	$\Omega_b = 1.67$ $\dfrac{M_n}{\Omega_b} = \dfrac{0.0939 \text{ kip-ft}}{1.67}$ $= 0.0562 \text{ kip-ft} > 0.0375 \text{ kip-ft}$ **o.k.**

The PL ½ in. × ½ in. infill member is adequate for design loads.

Handrail Bracket Member—PL ½ in. × ½ in.

Determine the required strengths using ASCE/SEI 7, Chapter 2 load combinations.

$$DL = \frac{(4\text{ ft})(0.00227\text{ kip/ft})}{2} + (0.000851\text{ kip/ft})\left(\frac{3\text{ in.}}{12\text{ in./ft}}\right)$$
$$= 0.00475\text{ kip}$$

LRFD	ASD
$V_u = 1.2(0.00475) + 1.6(0.200\text{ kip})$ $= 0.326\text{ kip}$ $M_u = [1.2(0.00475\text{ kip}) + 1.6(0.200\text{ kip})]\left(\frac{3\text{ in.}}{12\text{ in./ft}}\right)$ $= 0.0815\text{ kip-ft}$	$V_a = 0.00475\text{ kip} + 0.200\text{ kip}$ $= 0.205\text{ kip}$ $M_a = (0.00475\text{ kip} + 0.200\text{ kip})\left(\frac{3\text{ in.}}{12\text{ in./ft}}\right)$ $= 0.0512\text{ kip-ft}$

Available shear strength

Calculate the nominal shear strength using AISC *Specification* Section G4. From previous calculations, $C_{v2} = 1.0$.

$$V_n = 0.6F_yA_wC_{v2} \qquad (\textit{Spec}.\text{ Eq. G4-1})$$
$$= 0.6(36\text{ ksi})(\tfrac{1}{2}\text{ in.})(\tfrac{1}{2}\text{ in.})(1.0)$$
$$= 5.40\text{ kips}$$

From AISC *Specification* Section G1, the available shear strength is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_vV_n = 0.90(5.40\text{ kips})$ $= 4.86\text{ kips} > 0.326\text{ kip}$ **o.k.**	$\Omega_v = 1.67$ $\frac{V_n}{\Omega_v} = \frac{5.40\text{ kips}}{1.67}$ $= 3.23\text{ kips} > 0.205\text{ kip}$ **o.k.**

Available flexural strength

Calculate the nominal flexural strength using AISC *Specification* Section F11.

Check the limits from AISC *Specification* Section F11.1:

$$\frac{L_bd}{t^2} = \frac{(0.25\text{ ft})(12\text{ in./ft})(\tfrac{1}{2}\text{ in.})}{(\tfrac{1}{2}\text{ in.})^2}$$
$$= 6.00$$

$$\frac{0.08E}{F_y} = \frac{0.08(29{,}000\text{ ksi})}{36\text{ ksi}}$$
$$= 64.4$$

Because $\frac{L_bd}{t^2} < \frac{0.08E}{F_y}$, the limit state of lateral-torsional buckling does not apply. The limit state of yielding is checked using

Section F11.1, and the nominal flexural strength is determined using AISC *Specification* Equation F11-1.

$$M_n = M_p = F_y Z \leq 1.6 F_y S_x \qquad (Spec.\ \text{Eq. F11-1})$$
$$= F_y Z \leq 1.6 F_y S$$
$$= (36\text{ ksi})(0.0313\text{ in.}^3)(1\text{ ft/12 in.}) \leq 1.6\,(36\text{ ksi})(0.0208\text{ in.}^3)(1\text{ ft/12 in.})$$
$$= 0.0939\text{ kip-ft} < 0.0998\text{ kip-ft}$$

Therefore, $M_n = 0.0939$ kip-ft

From AISC *Specification* Section F1, the available flexural strength is:

LRFD	ASD
$\phi_b = 0.90$ $\phi_b M_n = 0.90(0.0939\text{ kip-ft})$ $= 0.0845\text{ kip-ft} > 0.0815\text{ kip-ft}$ **o.k.**	$\Omega_b = 1.67$ $\dfrac{M_n}{\Omega_b} = \dfrac{0.0939\text{ kip-ft}}{1.67}$ $= 0.0562\text{ kip-ft} > 0.0512\text{ kip-ft}$ **o.k.**

Therefore, the handrail bracket member is adequate for design loads.

Example 10.1.8—Guard Post-to-Stringer Top Flange Checks

Given:

Calculate forces for the guard post base connection, as shown in Figure 10-8. Check the stringer beam for the imposed moment. The HSS post is ASTM A500 Grade C material and the channel is ASTM A36 material.

Guard post: HSS1.900×0.145
Support stringer beam: C12×20.7

The guard post has an applied point load of 200 lb located 42 in. above the base of the post. The point load may occur in any direction. The critical loading scenario for the channel is based on a load applied perpendicular to the channel span (out of plane).

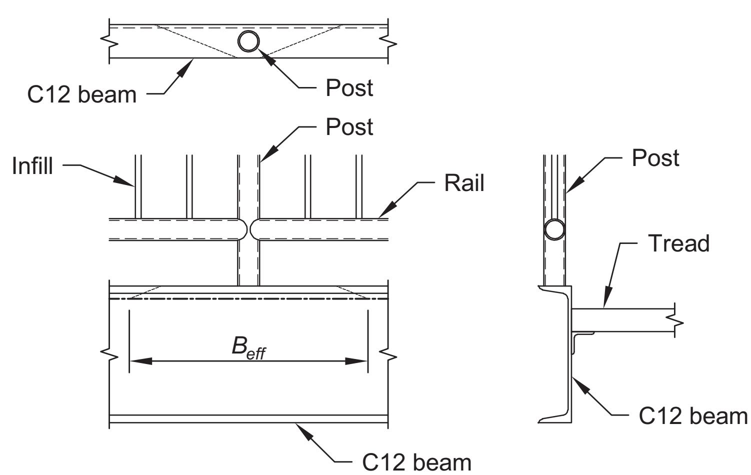


Fig. 10-8. Guard post to channel flange diagram.

Solution:

From AISC *Manual* Table 2-4, the material properties are as follows:

Guard post
ASTM A500 Grade C round
$F_y = 46$ ksi
$F_u = 62$ ksi

Stringer beam
ASTM A36
$F_y = 36$ ksi
$F_u = 58$ ksi

From AISC *Manual* Table 1-5, the geometric properties are as follows:

Stringer beam
C12×20.7
$t_w = 0.282$ in.
$b_f = 2.94$ in.
$t_f = 0.501$ in.
$k = 1\frac{1}{8}$ in.

Determine the required flexural strength at the stringer beam top flange due to the applied point load, using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
$M_u = 1.6(0.200 \text{ kip})(42 \text{ in.})$ $= 13.4$ kip-in.	$M_a = (0.200 \text{ kip})(42 \text{ in.})$ $= 8.40$ kip-in.

Determine the effective width, B_{eff}, of the channel top flange:

$$B_{eff} = N + 2(2.5)\left[\left(k - \frac{t_f}{2}\right) + b_f\right] \qquad (7\text{-}1)$$

$$= 1.90 \text{ in.} + 2(2.5)\left[\left(1\tfrac{1}{8} \text{ in.} - \frac{0.501 \text{ in.}}{2}\right) + 2.94 \text{ in.}\right]$$

$$= 21.0 \text{ in.}$$

Determine the section modulus of the effective web:

$$Z = \frac{B_{eff} t_w^2}{4}$$

$$= \frac{(21.0 \text{ in.})(0.282 \text{ in.})^2}{4}$$

$$= 0.418 \text{ in.}^3$$

$$S = \frac{B_{eff} t_w^2}{6}$$

$$= \frac{(21.0 \text{ in.})(0.282 \text{ in.})^2}{6}$$

$$= 0.278 \text{ in.}^3$$

Determine the nominal flexural strength of the channel web, assuming it behaves as a rectangular bar using AISC *Specification* Section F11:

$$M_n = M_p = F_y Z \le 1.6 F_y S_x \quad \text{(Spec. Eq. F11-1)}$$
$$= (36 \text{ ksi})(0.418 \text{ in.}^3) \le 1.6\,(36 \text{ ksi})(0.278 \text{ in.}^3)$$
$$= 15.0 \text{ kip-in.} < 16.0 \text{ kip-in.}$$

Therefore, $M_n = 15.0$ kip-in.

From AISC *Specification* Section F1, the available flexural strength is:

LRFD	ASD
$\phi_b = 0.90$ $\phi_b M_n = 0.90(15.0 \text{ kip-in.})$ $= 13.5 \text{ kip-in.} > 13.4 \text{ kip-in.}$ **o.k.**	$\Omega_b = 1.67$ $\dfrac{M_n}{\Omega_b} = \dfrac{15.0 \text{ kip-in.}}{1.67}$ $= 8.98 \text{ kip-in.} > 8.40 \text{ kip-in.}$ **o.k.**

Therefore, the C12×20.7 stringer is adequate for the imposed guard post forces.

10.2 DESIGN OF INDUSTRIAL STAIRWAY

This section illustrates the load determination and selection of members that are part of an industrial stairway. The design is completed in accordance with the 2016 AISC *Specification* and the 15th Edition AISC *Manual*. Loading criteria are based on ASCE/SEI 7-16.

The stairway being analyzed in this design example is located in a warehouse building in southern California. OSHA stairway requirements are given in the design example. Wind loads are not applicable.

DESIGN SEQUENCE

The design sequence is presented as follows:

Example 10.2.1—Load determination and deflection criteria
Example 10.2.2—Design of checkered plate tread
Example 10.2.3—Design of stringer

The design example is a stairway located within a warehouse in southern California. The stair accesses an elevated maintenance platform in an area that is not accessible to the public. The general layout of the stairway is provided in Figure 10-9 and the following requirements are given:

1. Provide the minimum width of 36 in. at stair flights and landings.
2. Treads are steel checkered plate.
3. Open risers will be utilized.
4. Riser height is 7 in. and tread length is 11 in.
5. Preferred stringer member type is ASTM A500 Grade C rectangular HSS.
6. Preferred guard and handrail member type is ASTM A53 Grade B pipe.
7. The platform elevation is 9 ft 11 in. above the finished floor.
8. The average roof height of the building is 19 ft 10 in. above the finished floor.
9. The design earthquake spectral response acceleration parameter at short period, S_{DS}, is 0.660g.
10. The redundancy factor, ρ, is 1.0.
11. The overstrength factor for the design of concrete anchorage associated with stairway connections, Ω_o, is 2.5.

Example 10.2.1—Load Determination and Deflection Criteria

Given:

Determine the loading and deflection criteria for the stairway.

Loading and Design Criteria

Loads

Stair dead load:
Self-weight of steel framing = to be determined

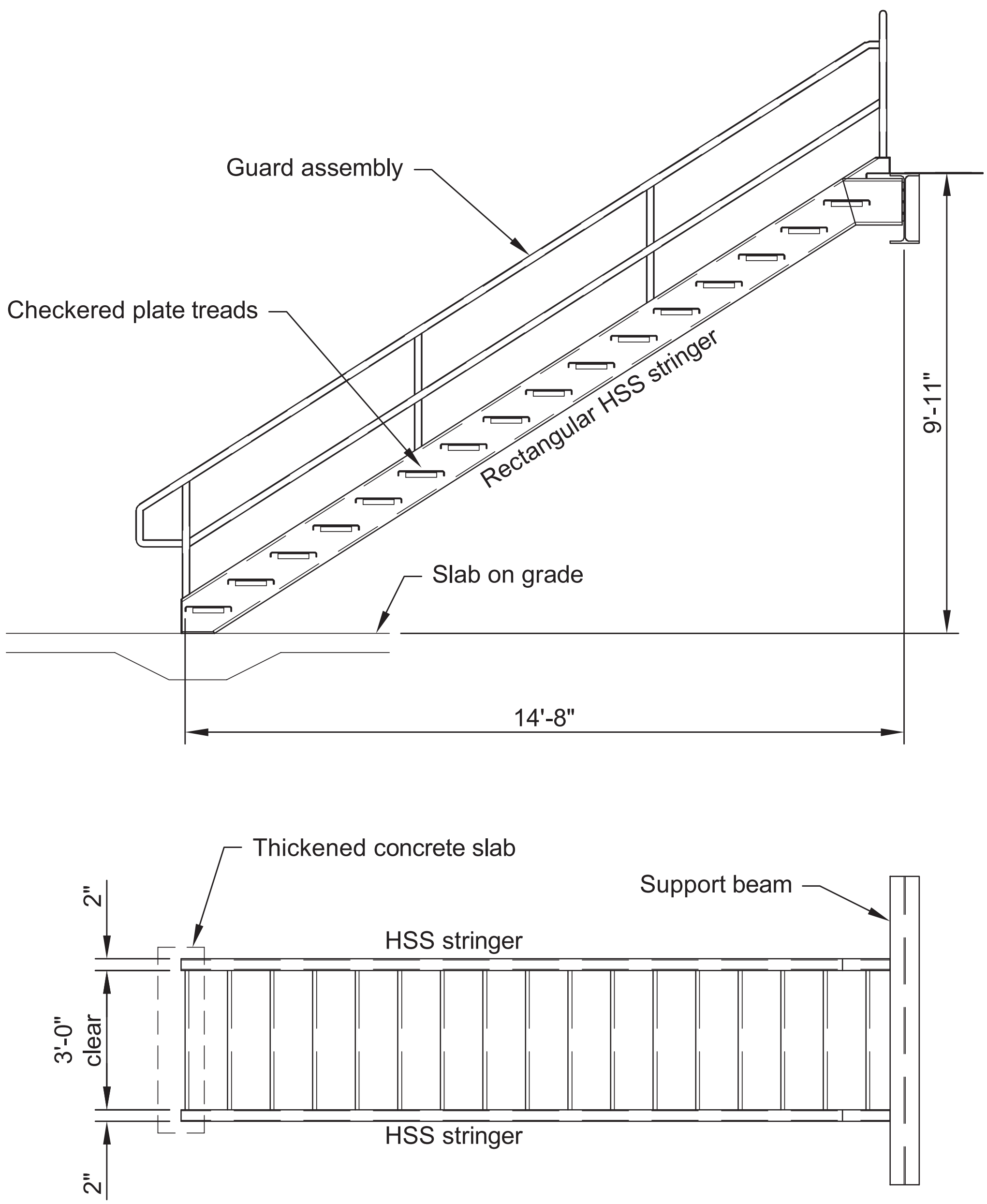


Fig. 10-9. Industrial stairway section and plan.

$\frac{3}{16}$ in. checkered plate tread	= 10 psf
Total	= 10 psf (plus member self-weight)

Stair live load:

Live load cases are nonconcurrent.

Case 1—Uniform load:
Live load = 60 psf
Case 2—Concentrated load:
Live load = 1,000 lb

Guard dead load:
Self-weight of members = to be determined

Guard live load:
Live load = 200 lb

Solution:

Load Combinations

From ASCE/SEI 7, Chapter 2, the following combinations will govern design for gravity cases:

LRFD	ASD
$1.2D + 1.6L$	$D + L$

For seismic cases, the following combinations will be checked as specified in ASCE/SEI 7, Section 2.3.6 for LRFD and Section 2.4.5 for ASD, incorporating the seismic load effect given in Sections 12.4.2.1 and 12.4.2.2:

LRFD	ASD
$1.2D + E_v + E_h + L + 0.2S$ $= 1.2D + 0.2S_{DS}D + \rho Q_E + L + 0.2S$ $= 1.2D + 0.2(0.660)D + 1.0Q_E + L + 0.2S$ $= 1.33D + 1.0Q_E + L + 0.2S$	$1.0D + 0.7E_v + 0.7E_h$ $= 1.0D + 0.7(0.2S_{DS})D + 0.7\rho Q_E$ $= 1.0D + 0.7\left[0.2(0.660)\right]D + 0.7(1.0)Q_E$ $= 1.09D + 0.7Q_E$
$0.9D - E_v + E_h$ $= 0.9D - 0.2S_{DS}D + \rho Q_E$ $= 0.9D - 0.2(0.660)D + 1.0Q_E$ $= 0.768D + 1.0Q_E$	$1.0D + 0.525E_v + 0.525E_h + 0.75L + 0.75S$ $= 1.0D + 0.525(0.2S_{DS})D + 0.525\rho Q_E + 0.75L + 0.75S$ $= 1.0D + 0.525\left[(0.2)(0.660)\right]D + 0.525(1.0)Q_E$ $+ 0.75L + 0.75S$ $= 1.07D + 0.525Q_E + 0.75L + 0.75S$ $0.6D - 0.7E_v + 0.7E_h$ $= 0.6D - 0.7(0.2S_{DS})D + 0.7\rho Q_E$ $= 0.6D - 0.7\left[(0.2)(0.660)\right]D + 0.7(1.0)Q_E$ $= 0.508D + 0.7Q_E$

For seismic cases, the following combinations, provided for reference, should be used for the design of anchorage in concrete specified in ASCE/SEI 7, Sections 2.3.6 for LRFD and Section 2.4.5 for ASD, incorporating the seismic load effect with overstrength given in Sections 12.4.3 and 12.4.3.1:

Table 10-2. Deflection Limits		
Construction	**Live Load Deflection Limit**	**Total Load Deflection Limit**
Floor members (stringers and landings)	*Span*/360	*Span*/240
Cantilever guard post supporting handrail	*h*/60	—
Guard infill rails, handrail, and infill panels	*Span*/120	—

LRFD	ASD
$1.2D + E_v + E_{mh} + L + 0.2S$ $= 1.2D + 0.2S_{DS}D + \Omega_o Q_E + L + 0.2S$ $= 1.2D + 0.2(0.660)D + 2.5Q_E + L + 0.2S$ $= 1.33D + 2.5Q_E + L + 0.2S$ $0.9D - E_v + E_{mh}$ $= 0.9D - 0.2S_{DS}D + 2.5Q_E$ $= 0.9D - 0.2(0.660)D + 2.5Q_E$ $= 0.768D + 2.5Q_E$	$1.0D + 0.7E_v + 0.7E_{mh}$ $= 1.0D + 0.7(0.2S_{DS})D + 0.7\Omega_o Q_E$ $= 1.0D + 0.7[0.2(0.660)]D + 0.7(2.5)Q_E$ $= 1.09D + 1.75Q_E$ $1.0D + 0.525E_v + 0.525E_{mh} + 0.75L + 0.75S$ $= 1.0D + 0.525(0.2S_{DS})D + 0.525\Omega_o Q_E + 0.75L + 0.75S$ $= 1.0D + 0.525[0.2(0.660)]D + 0.525(2.5)Q_E$ $+ 0.75L + 0.75S$ $= 1.07D + 1.31Q_E + 0.75L + 0.75S$ $0.6D - 0.7E_v + 0.7E_{mh}$ $= 0.6D - 0.7(0.2S_{DS})D + 0.7\Omega_o Q_E$ $= 0.6D - 0.7[0.2(0.660)]D + 0.7(2.5)Q_E$ $= 0.508D + 1.75Q_E$

Calculate the horizontal seismic design force, F_p, from ASCE/SEI 7, Section 13.3.

$$F_p = \frac{0.4 a_p S_{DS} W_p}{\left(\dfrac{R_p}{I_p}\right)}\left(1 + 2\frac{z}{h}\right) \quad \text{(ASCE/SEI 7, Eq. 13.3-1)}$$

where

I_p = component importance factor from ASCE/SEI 7, Section 13.1.3
= 1.5

R_p = component response modification factor from ASCE/SEI 7, Table 13.5-1
= 2½ for egress stairs

S_{DS} = spectral acceleration, short period, determined from ASCE/SEI 7, Section 11.4.5
= 0.660g

a_p = component amplification factor from ASCE/SEI 7, Table 13.5-1
= 1

h = average roof height of structure with respect to base
=19.8 ft

z = height in structure of point of attachment of component with respect to base
= 9.92 ft

and

$$F_p = \frac{0.4(1)(0.660)W_p}{\left(\dfrac{2.5}{1.5}\right)}\left[1 + 2\left(\frac{9.92\text{ ft}}{19.8\text{ ft}}\right)\right]$$

$$= 0.317W_p$$

Calculate the maximum limit for the seismic design force:

$$F_p = 1.6 S_{DS} I_p W_p \qquad \text{(ASCE/SEI 7, Eq. 13.3-2)}$$
$$= 1.6(0.660)(1.5)W_p$$
$$= 1.58W_p$$

Calculate the minimum limit for the seismic design force:

$$F_p = 0.3 S_{DS} I_p W_p \qquad \text{(ASCE/SEI 7, Eq. 13.3-3)}$$
$$= 0.3(0.660)(1.5)W_p$$
$$= 0.297W_p$$

Calculate concurrent vertical seismic force to be used for design from ASCE/SEI 7, Section 13.3.1.2:

$$F_{pv} = \pm 0.2 S_{DS} W_p \qquad (3\text{-}1)$$
$$= \pm 0.2(0.660)W_p$$
$$= \pm 0.132W_p$$

Deflection Criteria

The deflection criteria used are listed in Table 10-2.

Example 10.2.2—Checkered Plate Tread Design

Given:

Determine loading for the treads and verify the bent plate geometry shown in Figure 10-10 is adequate for the design loads. The treads are raised pattern floor plate conforming to ASTM A786.

Solution:

From AISC *Manual* Table 3-18, "Design Table Discussion," the maximum bending stress for ASTM A786 floor plate is:

LRFD	ASD
$\phi F_y = \dfrac{24\text{ ksi}}{\phi}$ $= \dfrac{24\text{ ksi}}{0.90}$ $= 26.7\text{ ksi}$	$F_y = (16\text{ ksi})\Omega$ $= (16\text{ ksi})(1.67)$ $= 26.7\text{ ksi}$

The geometric properties, determined using computer software, for the bent plate in Figure 10-10 are as follows:

PL 3⁄16 in.
$SW = 0.010\text{ kip/ft}^2$

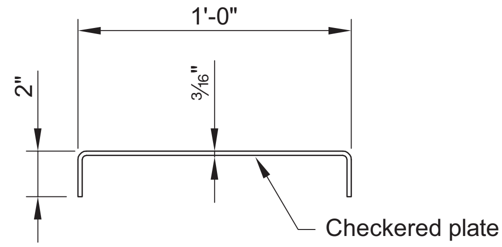


Fig. 10-10. Checkered plate geometry.

A_g = 2.88 in.^{2}
t_w = 3⁄16 in.
h/t_w = 9.65 in.
I_x = 0.711 in.^{4}
S_x = 0.426 in.^{3}
Z_x = 0.773 in.^{3}

The checkered plate treads are subject to gravity loading only; therefore, determine the required strengths using ASCE/SEI 7, Chapter 2, load combinations.

For uniform live loading on the stair treads, the required strengths are determined as follows.

$$w_D = (1\text{ ft})\left(0.0100\text{ kip/ft}^2\right)$$
$$= 0.0100\text{ kip/ft}$$

$$w_L = (1\text{ ft})\left(0.0600\text{ kip/ft}^2\right)$$
$$= 0.0600\text{ kip/ft}$$

LRFD	ASD
$V_u = \dfrac{(3\text{ ft})\left[1.2(0.0100\text{ kip/ft})+1.6(0.0600\text{ kip/ft})\right]}{2}$ $= 0.162\text{ kip}$ $M_u = \dfrac{\left[1.2(0.0100\text{ kip/ft})+1.6(0.0600\text{ kip/ft})\right](3\text{ ft})^2}{8}$ $= 0.122\text{ kip-ft}$	$V_a = \dfrac{(3\text{ ft})\left[(0.0100\text{ kip/ft})+(0.0600\text{ kip/ft})\right]}{2}$ $= 0.105\text{ kip}$ $M_a = \dfrac{\left[(0.0100\text{ kip/ft})+(0.0600\text{ kip/ft})\right](3\text{ ft})^2}{8}$ $= 0.0788\text{ kip-ft}$

For concentrated live loading on the stair treads, the required strengths are determined as follows:

LRFD	ASD
$V_u = \dfrac{(3\text{ ft})\left[1.2(0.0100\text{ kip/ft})\right]}{2}+1.6(1\text{ kip})$ $= 1.62\text{ kips}$ $M_u = \dfrac{1.2(0.0100\text{ kip/ft})(3\text{ ft})^2}{8}+\dfrac{1.6(1\text{ kip})(3\text{ ft})}{4}$ $= 1.21\text{ kip-ft}$	$V_a = \dfrac{(3\text{ ft})(0.0100\text{ kip/ft})}{2}+1\text{ kip}$ $= 1.02\text{ kips}$ $M_a = \dfrac{(0.0100\text{ kip/ft})(3\text{ ft})^2}{8}+\dfrac{(1\text{ kip})(3\text{ ft})}{4}$ $= 0.761\text{ kip-ft}$

Calculate the nominal shear strength using AISC *Specification* Section G2.

$$1.10\sqrt{\frac{k_vE}{F_y}} = 1.10\sqrt{\frac{5.34(29{,}000\text{ ksi})}{(26.7\text{ ksi})}}$$
$$= 83.8$$

Because $h/t_w < 83.8$:

$$C_{v1} = 1.0 \qquad \text{(}\textit{Spec}\text{. Eq. G2-3)}$$

$$V_n = 0.6F_yA_wC_{v1} \qquad \text{(}\textit{Spec}\text{. Eq. G2-1)}$$
$$= 0.6F_y\left[(2)(3/16\text{ in.})(2.00\text{ in.})\right](1.0)$$
$$= 0.450F_y$$

The available shear strength is determined as follows. Note that the yield stress, F_y, is based on an approximate yield stress for ASTM A786 material. Designers should verify the actual yield stress to be used for design.

LRFD	ASD
$\phi_v V_n = 0.450(\phi F_y)$ $= 0.450(24 \text{ ksi})$ $= 10.8 \text{ kips} > 1.62 \text{ kips}$ **o.k.**	$\dfrac{V_n}{\Omega_v} = 0.450\left(\dfrac{F_y}{\Omega}\right)$ $= 0.450(16 \text{ ksi})$ $= 7.20 \text{ kips} > 1.02 \text{ kips}$

Calculate the nominal flexural strength using AISC *Specification* Section F6.

Check width-to-thickness ratio for flanges:

$$\frac{b}{t} = \frac{2.00 \text{ in.}}{3/16 \text{ in.}}$$
$$= 10.7$$

From AISC *Specification* Table B1.4b, Case 13:

$$\lambda_p = 0.38\sqrt{\frac{E}{F_y}}$$
$$= 0.38\sqrt{\frac{29{,}000 \text{ ksi}}{26.7 \text{ ksi}}}$$
$$= 12.5 > 10.7$$

Because $\lambda_p > \dfrac{b}{t}$, the flanges are compact and the limit state of flange local buckling does not apply. For the limit state of yielding, the nominal flexural strength is:

$$M_n = M_p = F_y Z_x \le 1.6 F_y S_y \qquad (\textit{Spec}. \text{ Eq. F6-1})$$
$$= F_y\left(0.773 \text{ in.}^3\right) \le 1.6F_y\left(0.426 \text{ in.}^3\right)$$
$$= F_y\left(0.773 \text{ in.}^3\right) > F_y\left(0.682 \text{ in.}^3\right)$$

Therefore, $M_p = F_y\left(0.682 \text{ in.}^3\right)$.

The available flexural strength is:

LRFD	ASD
$\phi_b M_n = (0.682 \text{ in.}^3)(\phi F_y)$ $= (0.682 \text{ in.}^3)(24 \text{ ksi})\left(\dfrac{1 \text{ ft}}{12 \text{ in.}}\right)$ $= 1.36 \text{ kip-ft} > 1.21 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = (0.682 \text{ in.}^3)\left(\dfrac{F_y}{\Omega}\right)$ $= (0.682 \text{ in.}^3)(16 \text{ ksi})\left(\dfrac{1 \text{ ft}}{12 \text{ in.}}\right)$ $= 0.909 \text{ kip-ft} > 0.761 \text{ kip-ft}$ **o.k.**

The checkered plate tread is adequate for the design forces.

Example 10.2.3—Stringer Beam Design

Given:

Select beams for the stringers using the horizontal plane method. Beam loading is shown in Figure 10-11. Use ASTM A500 Grade C rectangular HSS for the stringer beams.

Because the stringer will also support the weight of the guard assembly, an additional dead load of 20 lb/ft is added.

Solution:

From AISC *Manual* Table 2-4, the material properties are as follows:

Rectangular HSS
ASTM A500 Grade C rectangular
$F_y = 50$ ksi
$F_u = 62$ ksi

Due to the beam slope, the member self-weight is modified to account for the additional weight on a per foot basis.

$$\text{Slope ratio} = \left(\sqrt{(7\text{ in.})^2 + (11\text{ in.})^2}\right)\left(\frac{12\text{ in./ft}}{11\text{ in.}}\right)\left(\frac{1}{12\text{ in.}}\right)$$
$$= 1.19$$

Based on design criteria, try using an HSS12×2×¼ for the stringer. From AISC *Manual* Table 1-11, the nominal weight of the stringer is 22.42 lb/ft.

Member self-weight at sloping stringer:

$$w_{sw} = 1.19(22.42\text{ lb/ft})(1\text{ kip/1,000 lb})$$
$$= 0.0267\text{ kip/ft}$$

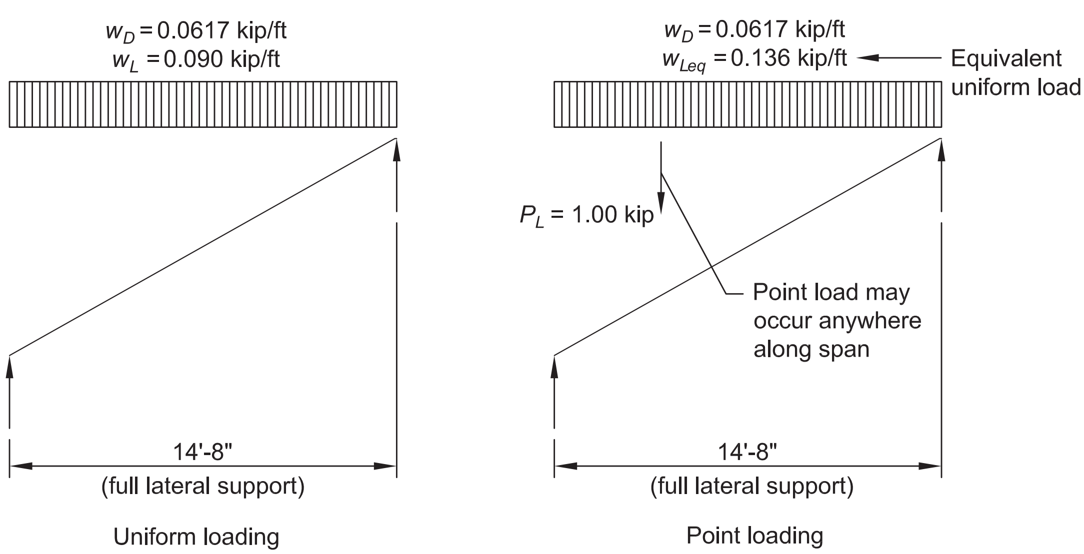


Fig. 10-11. Beam loading and bracing diagrams.

Vertical Loading

$$w_D = \left(\frac{3\text{ ft}}{2}\right)(0.0100\text{ kip/ft}^2) + (0.0267\text{ kip/ft} + 0.0200\text{ kip/ft})$$
$$= 0.0617\text{ kip/ft}$$
$$w_L = \left(\frac{3\text{ ft}}{2}\right)(0.0600\text{ kip/ft}^2)$$
$$= 0.0900\text{ kip/ft}$$

Calculate the required strengths for gravity loading using ASCE/SEI 7, Chapter 2, load combinations.

LRFD	ASD
Uniform live loading $w_u = \left[1.2(0.0100\text{ kip/ft}^2) + 1.6(0.0600\text{ kip/ft}^2)\right]\left(\frac{3\text{ ft}}{2}\right)$ $+ 1.2(0.0267\text{ kip/ft} + 0.0200\text{ kip/ft})$ $= 0.218\text{ kip/ft}$ $V_u = \frac{14.7\text{ ft}}{2}(0.218\text{ kip/ft})$ $= 1.60\text{ kips}$ $M_u = \frac{(0.218\text{ kip/ft})(14.7\text{ ft})^2}{8}$ $= 5.89\text{ kip-ft}$	Uniform live loading $w_a = \left[(0.0100\text{ kip/ft}^2) + (0.0600\text{ kip/ft}^2)\right]\left(\frac{3\text{ ft}}{2}\right)$ $+ (0.0267\text{ kip/ft} + 0.0200\text{ kip/ft})$ $= 0.152\text{ kip/ft}$ $V_a = (0.152\text{ kip/ft})\left(\frac{14.7\text{ ft}}{2}\right)$ $= 1.12\text{ kips}$ $M_a = \frac{(0.152\text{ kip/ft})(14.7\text{ ft})^2}{8}$ $= 4.11\text{ kip-ft}$
Point live loading $V_u = \left\{\frac{1.2(0.0617\text{ kip/ft})(14.7\text{ ft})}{2}\right\} + 1.6(1\text{ kip})$ $= 2.14\text{ kips}$ $M_u = \frac{1.2(0.0617\text{ kip/ft})(14.7\text{ ft})^2}{8}$ $+ \frac{1.6(1\text{ kip})(14.7\text{ ft})}{4}$ $= 7.88\text{ kip-ft}$	Point live loading $V_a = \left[\frac{(0.0617\text{ kip/ft})(14.7\text{ ft})}{2}\right] + 1\text{ kip}$ $= 1.45\text{ kips}$ $M_a = \frac{(0.0617\text{ kip/ft})(14.7\text{ ft})^2}{8} + \frac{(1\text{ kip})(14.7\text{ ft})}{4}$ $= 5.34\text{ kip-ft}$

From AISC *Manual* Table 1-11, the geometric properties are as follows:

HSS12×2×¼
$t_{des} = 0.233\text{ in.}$
$b/t = 5.58$
$h/t = 48.5$

Calculate the nominal shear strength using AISC *Specification* Section G4.

$$h = (h/t)t_{des}$$
$$= (48.5)(0.233\text{ in.})$$
$$= 11.3\text{ in.}$$

$$A_w = 2ht$$
$$= 2(11.3 \text{ in.})(0.233 \text{ in.})$$
$$= 5.27 \text{ in.}^2$$

$$k_v = 5$$

Calculate C_{v2} from AISC *Specification* Section G2.2.

$$1.10\sqrt{\frac{k_v E}{F_y}} = 1.10\sqrt{\frac{5(29{,}000 \text{ ksi})}{50 \text{ ksi}}}$$
$$= 59.2$$

Because $\dfrac{h}{t} < 1.10\sqrt{\dfrac{k_v E}{F_y}}$, AISC *Specification* Equation G2-9 applies.

$$C_{v2} = 1.0 \qquad \text{(}Spec\text{. Eq. G2-9)}$$

From AISC Specification Section G4, the nominal shear strength is:

$$V_n = 0.6F_y A_w C_{v2} \qquad \text{(}Spec\text{. Eq. G4-1)}$$
$$= 0.6(50 \text{ ksi})(5.27 \text{ in.}^2)(1.0)$$
$$= 158 \text{ kips}$$

From AISC *Specification* Section G1, the available shear strength is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_v V_n = 0.90(158 \text{ kips})$ $= 142 \text{ kips} > 2.14 \text{ kips}$ **o.k.**	$\Omega_v = 1.67$ $\dfrac{V_n}{\Omega_v} = \dfrac{158 \text{ kips}}{1.67}$ $= 94.6 \text{ kips} > 1.45 \text{ kips}$ **o.k.**

From AISC *Manual* Table 3-12, the available flexural strength about the *x*-axis is:

LRFD	ASD
$\phi_b M_n = 75.4 \text{ kip-ft} > 7.88 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = 50.1 \text{ kip-ft} > 5.34 \text{ kip-ft}$ **o.k.**

Calculate the required strengths for seismic loading using ASCE/SEI 7, Chapter 2, load combinations and select the stringer beams.

Equivalent Uniformly Distributed Load

$$P_L = 1 \text{ kip}$$
$$M = \frac{PL}{4}$$
$$= \frac{wL^2}{8}$$

Therefore:

$$
\begin{aligned}
w_{Leq} &= \frac{2P}{L} \\
&= \frac{2(1 \text{ kip})}{14.7 \text{ ft}} \\
&= 0.136 \text{ kip/ft}
\end{aligned}
$$

$w_{Leq} = 0.136 \text{ kip/ft} > w_L = 0.900 \text{ kip/ft}$

LRFD	ASD
$1.33D + 1.0Q_E + L$ (Controls for stringer design) $V_{u,v} = \begin{bmatrix} 1.33(0.0617 \text{ kip/ft}) \\ +1.0(0) \\ +(0.136 \text{ kip/ft}) \end{bmatrix}\left(\frac{14.7 \text{ ft}}{2}\right)$ $= 1.60 \text{ kips}$ $M_{u,v} = \begin{bmatrix} 1.33(0.0617 \text{ kip/ft}) \\ +1.0(0) \\ +(0.136 \text{ kip/ft}) \end{bmatrix}\frac{(14.7 \text{ ft})^2}{8}$ $= 5.89 \text{ kip-ft}$	$1.07D + 0.525Q_E + 0.75L$ (Controls for stringer design) $V_{a,v} = \begin{bmatrix} 1.07(0.0617 \text{ kip/ft}) \\ +0.525(0) \\ +0.75(0.136 \text{ kip/ft}) \end{bmatrix}\left(\frac{14.7 \text{ ft}}{2}\right)$ $= 1.23 \text{ kips}$ $M_{a,v} = \begin{bmatrix} 1.07(0.0617 \text{ kip/ft}) \\ +0.525(0) \\ +0.75(0.136 \text{ kip/ft}) \end{bmatrix}\frac{(14.7 \text{ ft})^2}{8}$ $= 4.54 \text{ kip-ft}$

From the previous calculations, the available shear and flexural strengths are:

LRFD	ASD
$\phi_v V_n = 142 \text{ kips} > 1.60 \text{ kips}$ **o.k.** $\phi_b M_n = 75.4 \text{ kip-ft} > 5.89 \text{ kip-ft}$ **o.k.**	$\frac{V_n}{\Omega_v} = 94.6 \text{ kips} > 1.23 \text{ kips}$ **o.k.** $\frac{M_n}{\Omega_b} = 50.1 \text{ kip-ft} > 4.54 \text{ kip-ft}$ **o.k.**

Horizontal Loading

$$
\begin{aligned}
w_D &= \left(0.0100 \text{ kip/ft}^2\right)(1.5 \text{ ft}) + (0.0270 \text{ kip/ft} + 0.0200 \text{ kip/ft}) \\
&= 0.062 \text{ kip/ft}
\end{aligned}
$$

$Q_E = F_{ph}$

where

$$
\begin{aligned}
F_{ph} &= 0.317W_p \\
&= 0.317(0.0620 \text{ kip/ft}) \\
&= 0.0200 \text{ kip/ft}
\end{aligned}
$$

LRFD	ASD
$1.33D + 1.0Q_E + L$ (Controls for stringer design) $V_{u,h} = [1.33(0) + 1.0(0.0200 \text{ kip/ft}) + 0]\left(\dfrac{14.7 \text{ ft}}{2}\right)$ $= 0.147 \text{ kip}$ $M_{u,h} = \dfrac{[1.33(0) + 1.0(0.0200 \text{ kip/ft}) + 0](14.7 \text{ ft})^2}{8}$ $= 0.540 \text{ kip-ft}$	$1.07D + 0.525Q_E + 0.75L$ (Controls for stringer design) $V_{a,h} = \begin{bmatrix} 1.07(0) + 0.525(0.0200 \text{ kip/ft}) \\ + 0.75(0) \end{bmatrix}\left(\dfrac{14.7 \text{ ft}}{2}\right)$ $= 0.0772 \text{ kip}$ $M_{a,h} = \begin{bmatrix} 1.07(0) + 0.525(0.0200 \text{ kip/ft}) \\ + 0.75(0) \end{bmatrix}\dfrac{(14.7 \text{ ft})^2}{8}$ $= 0.284 \text{ kip-ft}$

Calculate the nominal shear strength using AISC *Specification* Section G4.

$$\begin{aligned} b &= (b/t)t_{des} \\ &= (5.58)(0.233 \text{ in.}) \\ &= 1.30 \text{ in.} \end{aligned}$$

$$\begin{aligned} A_w &= 2bt \\ &= 2(1.30 \text{ in.})(0.233 \text{ in.}) \\ &= 0.606 \text{ in.}^2 \end{aligned}$$

$$k_v = 5$$

Calculate C_{v2} from AISC *Specification* Section G2.2.

$$\begin{aligned} 1.10\sqrt{\frac{k_v E}{F_y}} &= 1.10\sqrt{\frac{5(29{,}000 \text{ ksi})}{50 \text{ ksi}}} \\ &= 59.2 \end{aligned}$$

Because $b/t < 1.10\sqrt{\dfrac{k_v E}{F_y}}$, AISC *Specification* Equation G2-9 applies.

$$C_{v2} = 1.0 \qquad \text{(Spec. Eq. G2-9)}$$

From AISC *Specification* Section G4, the nominal shear strength is:

$$\begin{aligned} V_n &= 0.6F_y A_w C_{v2} \qquad \text{(Spec. Eq. G2-1)} \\ &= 0.6(50 \text{ ksi})\left(0.606 \text{ in.}^2\right)(1.0) \\ &= 18.2 \text{ kips} \end{aligned}$$

From AISC *Specification* Section G1, the available shear strength is:

LRFD	ASD
$\phi_v = 0.90$ $\phi_v V_n = 0.90(18.2 \text{ kips})$ $= 16.4 \text{ kips} > 0.147 \text{ kip}$ **o.k.**	$\Omega_v = 1.67$ $\dfrac{V_n}{\Omega_v} = \dfrac{18.2 \text{ kips}}{1.67}$ $= 10.9 \text{ kips} > 0.0772 \text{ kip}$ **o.k.**

From AISC *Manual* Table 3-12, the available flexural strength about the *y*-axis is:

LRFD	ASD
$\phi_b M_n = 13.3 \text{ kip-ft} > 0.540 \text{ kip-ft}$ **o.k.**	$\dfrac{M_n}{\Omega_b} = 8.87 \text{ kip-ft} > 0.284 \text{ kip-ft}$ **o.k.**

Check the interaction using AISC *Specification* Section H1. Because $P_r/P_c < 0.2$, use AISC *Specification* Equation H1-1b:

LRFD	ASD
$\dfrac{P_r}{2P_c} + \left(\dfrac{M_{rx}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1.0$	$\dfrac{P_r}{2P_c} + \left(\dfrac{M_{rx}}{M_{cx}} + \dfrac{M_{ry}}{M_{cy}}\right) \leq 1.0$
$0 + \left(\dfrac{5.89 \text{ kip-ft}}{75.4 \text{ kip-ft}} + \dfrac{0.540 \text{ kip-ft}}{13.3 \text{ kip-ft}}\right) \leq 1.0$	$0 + \left(\dfrac{4.54 \text{ kip-ft}}{50.1 \text{ kip-ft}} + \dfrac{0.284 \text{ kip-ft}}{8.87 \text{ kip-ft}}\right) \leq 1.0$
$0.119 < 1.0$ **o.k.**	$0.123 < 1.0$ **o.k.**

Note: Although not included in this design example, stair designers should also consider seismic forces parallel to the stringer resulting in axial tension or compression in conjunction with other loads as required by the governing load combinations.

An HSS12×2×¼ stringer is adequate for the required forces.

10.3 ADDITIONAL DESIGN CHECK REFERENCES

The following section provides references for the specialty structural engineer (SSE) to complete nonsteel checks of the stairway design examples:

1. Design cold-formed metal pans in accordance with the AISI *North American Specification for the Design of Cold-Formed Steel Structural Members* (AISI, 2012).
2. Design welds for cold-formed metal pans-to-stringer in accordance with the AISI *North American Specification for the Design of Cold-Formed Steel Structural Members* and *Structural Welding Code—Steel*, AWS D1.1/D1.1M (AWS, 2015).
3. Design the intermediate landing metal deck in accordance with the SDI *Standard for Noncomposite Steel Floor Deck* (SDI, 2010).
4. Design the intermediate landing slab in accordance with the SDI *Standard for Noncomposite Steel Floor Deck* and ACI *Building Code Requirements for Structural Concrete*, ACI 318-14 (ACI, 2014).
5. Design steel connections in accordance with the AISC *Specification* and the AISC *Manual*.
6. Design handrail brackets from the manufacturer in accordance with ASTM *Standard Specification for Permanent Metal Railing Systems and Rails for Buildings,* ASTM E985 (ASTM, 2006).
7. Design embedded plates and anchorage in accordance with the AISC *Specification* and *Manual* and ACI *Building Code Requirements for Structural Concrete*, ACI 318-14.
8. Design post-installed anchors in accordance with the manufacturer's requirements, approved anchor test data report, and ACI *Building Code Requirements for Structural Concrete*, ACI 318-14.

Appendix A
Designer Checklists

STAIRWAY DELEGATED DESIGN CHECKLIST FOR ARCHITECTS

The following items should be provided in the design documents by the architect:

Stairway

_____ Number and length of treads (refer to Section 3.4)

_____ Number and height of risers (refer to Section 3.4)

_____ Clear width between stringers (refer to Section 3.4)

_____ Clear width at landings (refer to Section 3.4)

_____ Finish floor-to-floor dimension, including floor and landing elevations

_____ Required floor finishes at treads, landings and adjacent floors

_____ Wall construction and wall finishes adjacent to stairway and stair support members

_____ Stair class or required quality of finishes (refer to Sections 2.1 and 2.2)

_____ Special requirements (e.g., areas of refuge, accommodations for utility chase/sprinkler standpipe, etc.)

_____ Member types and construction (refer to Chapter 4)

Guard/Handrail

_____ Member types and construction (refer to Chapter 7)

_____ Member layout and appearance (refer to Section 7.2)

_____ Dimensional requirements

_____ Required quality of finishes

_____ Special requirements

STAIRWAY DELEGATED DESIGN CHECKLIST FOR STRUCTURAL ENGINEERS

The following items should be provided in the design documents by the project structural engineer of record:

Stairway

_____ Required loading (refer to Chapter 3 and local authority having jurisdiction)

_____ Required deflection limit (refer to Section 3.3)

_____ Limitations for stairway supports-to-building structure

_____ Member types or size limits

_____ Special details at building structure (i.e., thickened slab at stringer base, embeds/slab edge at concrete slabs supporting stair stringer)

Guard/Handrail

_____ Required loading (refer to Chapter 3 and local authority having jurisdiction)

_____ Required deflection limits (refer to Section 3.3)

STAIRWAY DELEGATED DESIGN CHECKLIST FOR COMPONENT SUPPLIERS

The following items should be provided by the component supplier:

Stairway

Precast concrete treads and landing plank

_____ Self-weight of component

_____ Imposed forces at support point or anchorage

_____ Allowable deflection limits for component supported by steel stairway

_____ Allowable connections from component-to-steel stairway

_____ Structural properties of component (or indicate that component is nonstructural)

Grating treads and plank

_____ Self-weight of component

_____ Imposed forces at support point

_____ Allowable deflection limits for component supported by steel stairway

_____ Allowable connections to component

Specialty floor finishes

_____ Self-weight of component

Guard/Handrail

Nonsteel Guard System or Guard Infill (i.e., cables, glazing, wire mesh, wood, etc.)

_____ Self-weight of component

_____ Imposed forces at support point or anchorage

_____ Allowable deflection limits for component supported by steel stairway

_____ Allowable connections to component

Handrail bracket

_____ Testing report or approval as required by project specification or ASTM standards

_____ Allowable connections to guard, wall or support

Glossary of Terms

Many terms in this glossary are reproduced from the NAAMM *Metal Stairs Manual*, NAAMM *Railing Manual*, IBC *International Building Code*, and AISC *Specification.* Refer to these documents for additional information or more detailed definitions.

Allowable strength. Nominal strength divided by the safety factor, R_n/Ω.

Anchor. Any device used to secure a stair, guard, handrail or structural member to concrete or masonry construction.

Applicable building code. Building code under which the stairway, guard or handrail is designed.

ASD (allowable strength design). Method of proportioning structural components such that the allowable strength equals or exceeds the required strength of the component under the action of ASD load combinations.

ASD load combinations. Load combination in the applicable building code intended for allowable strength design.

Authority having jurisdiction (AHJ). Organization, political subdivision, office or individual charged with the responsibility of administering and enforcing the provisions of the applicable building code.

Available strength. Design strength or allowable strength, as appropriate.

Beam. Nominally horizontal structural member that has the primary function of resisting bending moments.

Bracing. Member or system that provides stiffness and strength to limit the out-of-plane movement of another member at a brace point.

Carrier angle. An angle connected to the inside face of a stringer to support the end of a tread or riser.

Carrier bar/plate. A plate connected to the inside face of a stringer to support the end of a tread or riser.

Checkered plate. A steel plate having a raised pattern to provide a nonslip surface.

Connection. Combination of structural elements and joints used to transmit forces between two or more members.

Deferred submittal. Those portions of the design that are not submitted at the time of the application and that are to be submitted to the building official within a specified period.

Deflection. A displacement of a structural member.

Design documents. The design drawings or, where the parties have agreed in the contract documents to provide digital model(s), the design model. A combination of drawings and digital models also may be provided.

Design drawings. Graphic and pictorial documents showing the design, location and dimensions of the work. These documents generally include plans, elevations, sections, details, schedules, diagrams and notes.

Design load. Applied load determined in accordance with either LRFD load combinations or ASD load combinations, whichever is applicable.

Design strength. Resistance factor multiplied by the nominal strength, ϕR_n.

Diaphragm. A horizontal system acting to transmit lateral forces to vertical elements of the lateral force-resisting system.

Egress width. The required clear width for the stair or landing provided for occupants.

Expansion joint. A control joint designed to allow for differential movement of the joining parts due to expansion or contraction.

Factored load. Product of a load factor and the nominal load.

Flight. An uninterrupted series of steps.

Flight rise. The vertical distance between the floor or platforms connected by a flight.

Flight run. The horizontal distance between the faces of the first and last risers in a flight.

Guard. A railing system provided for protection of building occupants at or near the outer edge of a stair, ramp, landing, platform, balcony, or roof to guard against accidental fall or injury.

Handrail. The member that is normally grasped by the hand for support. This member may be part of the railing system or may be mounted on the wall. When used in conjunction with a stairway, it parallels the slope of the stair flight.

Handrail bracket. A device attached to a wall or other surface to support a handrail.

Hanger. A load-carrying structural tension member used to support framing below.

Header. A horizontal structural member at a floor or landing that supports stringers.

Headroom. The minimum vertical distance from the top surface of a tread or landing to the ceiling, soffit, or overhead obstruction. Measured at the nosing line of the tread or landing.

Hot dip galvanizing. The process or result of applying a protective coating to ferrous metal by dipping in a bath of molten zinc.

Infill beams. A horizontal structural member at a floor or landing but carrying no stringers.

Landing. A horizontal surface having a dimension parallel to the stringer greater than a tread width, either at a floor level or between floors.

LRFD (load and resistance factor design). Method of proportioning structural components such that the design strength equals or exceeds the required strength of the component under the action of the LRFD load combinations.

LRFD load combinations. Load combinations in the applicable building code intended for strength design (load and resistance factor design).

Moment connection. Connection that transmits bending moment between connected members.

Moment frame. Framing system that provides resistance to lateral forces and provides stability to the structural system.

Nominal strength. Strength of a structure or component (without the resistance factor or safety factor applied) to resist the load effects.

Nosing. The part of a tread or landing that projects as a square, rounded or molded edge at the forward part of the tread where it meets the riser.

Post. A structural member that resists axial compression forces. A post may also be part of the guard assembly resisting applied guard and handrail loads.

Railing system. A framework of vertical, horizontal or inclined members or panels, or some combination of these, supporting a handrail and located at the edge of a flight, landing or floor as a safety barrier.

Required strength. Forces, stresses and deformations acting on a structural component, determined by either structural analysis, for the LRFD or ASD load combinations, as appropriate.

Resistance factor, ϕ. Factor that accounts for unavoidable deviations of the nominal strength from the actual strength and for the manner and consequences of failure.

Riser. The vertical or inclined face of a step, extending from the back edge of one tread to the outer edge of the tread or lower edge of the nosing next above it.

Riser, open. A term used to describe a stair having open spaces rather than solid risers between the treads.

Riser height. The vertical distance between the top surfaces of two successive treads.

Safety factor, Ω. Factor that accounts for deviations of the actual strength from the nominal strength, deviations of the actual load from the nominal load, uncertainties in the analysis that transforms the load into a load effect, and for the manner and consequences of failure.

Soffit. The underside of a stair, whether exposed construction or an applied finish material.

Specifications. Written documents containing the requirements for materials, standards and workmanship.

Stair/stairway. One or more flights of stairs, either exterior or interior, with the necessary landings and platforms connecting them, to form a continuous and uninterrupted passage from one level to another.

Steel deck. Steel cold formed into a decking profile used as a permanent concrete form.

Story height. The vertical distance, in a building, between one finished floor and the next.

Stringer. An inclined structural member supporting a flight, or a structural member having an inclined section with a horizontal section at one or both ends, supporting a flight and one or two landings.

Toe plate. A vertical plate forming a lip or low curb at the open edge of a landing or floor or at the back edge of open end of a tread with open risers.

Tread. The horizontal member on the stair.

Tread length. The dimension of a tread measured perpendicular to the normal line of travel on a stair.

Symbols

A_g Gross area of member, in.^{2}

A_w Area of web, the overall depth times the web thickness, dt_w, in.^{2}

B Overall width of rectangular steel section along face transferring load, in.

B_{eff} Effective width of resisting element, in.

C_b Lateral-torsional buckling modification factor for nonuniform moment diagrams when both ends of the segment are braced

C_f Wind force coefficients

C_v Web shear strength coefficient

D Outside diameter of pipe, in.

D Nominal dead load

D_p Relative seismic displacement that the component must be designed to accommodate, in.

E Modulus of elasticity of steel = 29,000 ksi

E Nominal earthquake load

F_{cr} Critical stress, ksi

F_e Elastic buckling stress, ksi

F_n Nominal stress, ksi

F_p Horizontal seismic design force, kips

F_{pv} Vertical seismic design force, kips

F_u Specified minimum tensile strength, ksi

F_x Lateral force, kips

F_y Specified minimum yield stress, ksi

H Overall height of rectangular HSS member, in.

I Moment of inertia in the plane of bending, in.^{4}

I_e Importance factor

I_p Component importance factor

K Effective length factor

L Length of member or span, in.

L Nominal live load

L_h Horizontal plane length, ft

M_a Required flexural strength using ASD load combinations, kip-in.

M_n Nominal flexural strength, kip-in.

M_p Plastic bending moment, kip-in.

M_u Required flexural strength using LRFD load combinations, kip-in.

M_y Yield moment about the axis of bending, kip-in.

N Guard post diameter, in.

P_c Available axial strength, kips

P_n Nominal axial strength, kips

P_r Required axial compressive strength using LRFD or ASD load combinations, kips

P_u Required axial strength in compression using LRFD load combinations, kips

Q_E Effects of horizontal seismic forces

R Seismic response modification coefficient

R_p Component response modification factor

S Elastic section modulus about the axis of bending, in.^{3}

S Nominal snow load, psf

S_{DS} Spectral acceleration, short period

SW Member self-weight, lb/ft

V_c Available shear strength, kips

V_n Nominal shear strength, kips

V_r Required shear strength using LRFD or ASD load combinations, kips

W_p Component operating weight, kips

W_x Dead load located at level x, kips

W Nominal wind load, psf

Z Plastic section modulus about the axis of bending, in.^{3}

a_p Component amplification factor

b_f Width of flange, in.

d Full nominal depth of the member, in.

d Diameter, in.

d_b Depth of beam, in.

h Height of shear element, in.

h Average roof height of structure with respect to base, in.

k Distance from outer face of flange to the web toe of fillet, in.

k_c Coefficient for slender unstiffened elements

k_v Web plate shear buckling coefficient

r Radius of gyration, in.

t Thickness of element, in.

t_f Thickness of flange, in.

t_w Thickness of web, in.

w Width of plate, in.

z Height in structure of point of attachment of component with respect to the base, in.

Δ Deflection or story drift, in.

Ω Safety factor

Ω_b Safety factor for flexure

Ω_c Safety factor for compression

Ω_v Safety factor for shear

Ω_o Overstrength factor

δ Deflection

λ Width-to-thickness ratio for the element

ρ Redundancy factor

ϕ Resistance factor

ϕ_b Resistance factor for flexure

ϕ_c Resistance factor for compression

ϕ_v Resistance factor for shear

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