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Steel-Framed Stairway Design
Part 2 – Seismic Loads & Delegated Design
May 21, 2020

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Course Description

Steel-Framed Stairway Design – Part 2 – Seismic Loading & Delegated Design
May 21, 2020

This webinar provides information regarding code requirements for seismic loading and serviceability criteria, guard/handrail design, design examples, considerations related to construction tolerances, additional design considerations, and delegated design.

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Learning Objectives

- Describe how seismic loads are combined with gravity loads in steel stair design.
- Select details that might be used to allow for stair movement during seismic events.
- Identify the items to be included in design documents when delegating the structural design of steel stairs.
- List tolerances to be accounted for at the interface between steel stairs and concrete or masonry elements.

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Steel Framed Stairway Design

Adam Friedman
Senior Associate
CSD Structural Engineers
Milwaukee, Wisconsin

CSD STRUCTURAL ENGINEERS
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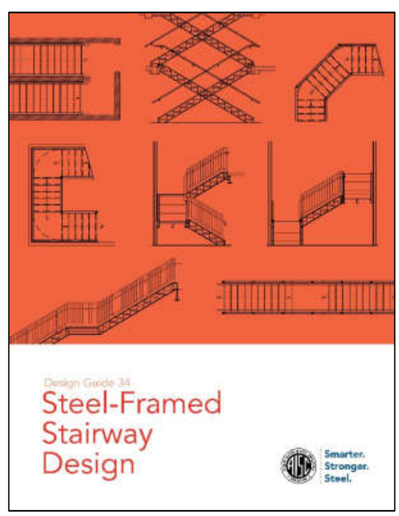
Introduction

AISC Design Guide 34: Steel Framed Stairway Design

available at
www.aisc.org/designguides
free download for members or
available for purchase



8

Outline – Part 1

Step 1 – Purpose & Design Philosophy

Step 2 – Stairway Overview

Step 3 – Code Requirements - Gravity

Step 4 – Stairway Design

Step 5 – Members & Connx

Step 6 – Examples

9

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

Step 11 – Delegated Design

Step 12 – Other Topics

10

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

Step 11 – Delegated Design

Step 12 – Other Topics

11

Applicable Codes

- International Building Code (IBC)
  - Chapter 16 "Structural Design" – Loads, Combos, & Serviceability
- ASCE/SEI 7-16 Minimum Design Loads for Buildings & Other Structures
  - Chapter 2 Combinations of Loads
  - Chapter 11 Seismic Design Criteria
  - Chapter 12 Seismic Design Criteria for Building Structures
  - Chapter 13 Seismic Design Criteria for Nonstructural Components

12

Load Combinations

- Refer to ASCE7-16 Chapter 2 for LRFD & ASD Load Combinations

LRFD
1. 1.4D
2. 1.2D+1.6L+0.5(Lr or S or R)
3. 1.2D+1.6(Lr or S or R)+1.0(L or 0.5W)
4. 1.2D+1.0W+1.0L+0.5(Lr or S or R)
5. 0.9D+1.0W
6. 1.2D+1.0Ev+1.0Eh+1.0L+0.2S
7. 0.9D-1.0Ev+1.0Eh

ASD
1. D
2. D+L
3. D+(Lr or S or R)
4. D+0.75L+0.75(Lr or S or R)
5. D+0.6W
6. D+0.75L+0.75(0.6W)+0.75(Lr or S or R)
7. 0.6D+0.6W
8. D+0.7Ev+0.7Eh
9. D+0.525Ev+0.525Eh+0.75L+0.75S
10. 0.6D-0.7Ev+0.7Eh

13

Loading – ASCE 7-16

- General Structural Integrity, Section 1.4.2 (SDC = A)
  - $F_x=0.01W_x$ (1.4-1)
- Seismic Loads (SDC = B, C, D, E, F)
  - Seismic Design Criteria (i.e. S_{DS}) per Chapter 11 or from SER General Notes drawing
    - S_{DS} = spectral acceleration, short period
  - Stairs to be designed per Chapter 13 for Nonstructural Components

14

Seismic Loading – ASCE 7-16

Horizontal Seismic Design Force, Eq. 13.3-1

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

F_p = horizontal seismic design force at component center of gravity

- I_p = component importance factor per Section 13.1.3
- SDS = spectral acceleration, short period
- z = height of component/attachment in structure
- h = roof height of structure
- Wp = component weight

Refer to Table 13.5-1

- a_p = component amplification factor
- R_p = component response modification factor

15

Seismic Loading
ASCE 7-16 Table 13.5-1

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16:

TABLE 13.5-1 Coefficients for Architectural Components

Architectural Component	a_p[a]	R_p[b]	Ω_0[c]
Egress stairways not part of the building ~~structure~~ seismic force-resisting system	1	2 ½	~~2 ½~~ 2
Egress stairs and ramp fasteners and attachments	2 ½	2 ½	2 ½

a_p = component amplification factor
R_p = component response modification factor
Ω_0 = overstrength factor for anchorage to concrete & masonry

16

Seismic Loading – ASCE 7-16

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16 - stair: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2$

Per ASCE 7-16 - fasteners: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

What is the impact for these changes??

17

Seismic Loading – ASCE 7-16

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16 - stair: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2$

Per ASCE 7-16 - fasteners: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

What is the impact?

- Design of stair elements
  - No change

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

18

Seismic Loading – ASCE 7-16

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16 - stair: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2$

Per ASCE 7-16 - fasteners: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

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

What is the impact?

- Design of stair elements
  - No change
- Design of stair fasteners (bolts/welds)
  - 250% increase in design forces (ap)

19

Seismic Loading – ASCE 7-16

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16 - stair: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2$

Per ASCE 7-16 - fasteners: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

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

What is the impact?

- Design of stair elements
  - No change
- Design of stair fasteners (bolts/welds)
  - 250% increase in design forces (ap)
- Design of stair anchorage to concrete or masonry
  - 250% increase in design forces (ap)
  - Or design for ductile yielding of support/component

20

Seismic Loading – ASCE 7-16

Previously per ASCE 7-10: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2½$

Per ASCE 7-16 - stair: $a_p = 1$, $R_p = 2½$, $\Omega_0 = 2$

Per ASCE 7-16 - fasteners: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

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

What is the impact?

- Design of stair elements
  - No change
- Design of stair fasteners (bolts/welds)
  - 250% increase in design forces (ap)
- Design of stair anchorage to concrete or masonry
  - 250% increase in design forces (ap)
  - Or design for ductile yielding of support/component
- Design of concrete or masonry elements at anchors
  - 20% reduction in design forces (Ω_0)

21

Loading – ASCE 7-16

- Horizontal Seismic Design Force, Eq. 13.3-1

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

For stairs:

- $I_p = 1.5$

Refer to Table 13.5-1

- $a_p = 1.0$
- $R_p = 2.5$

22

Loading – ASCE 7-16

- Horizontal Seismic Design Force, Eq. 13.3-1

$$F_{p,\,\text{stairs}} = 0.24 S_{DS} W_p \left(1 + 2\frac{z}{h}\right)$$

S_{DS} = short period spectral acceleration
W_p = component weight (dead load only)
z = component height from grade at point of attachment
h = average roof height
(z/h) may conservatively be taken as 1.0

Loading – ASCE 7-16

- Horizontal Seismic Design Force
  - Minimum per Eq. 13.3-3

$$F_{p,\,\text{min}} = 0.3 S_{DS} I_p W_p$$

  - Maximum per Eq 13.3-2

$$F_{p,\,\text{max}} = 1.6 S_{DS} I_p W_p$$

Loading – ASCE 7-16

- Horizontal Seismic Design Force for Stairs
  - If I_p=1.5 and (z/h)=1.0

$$F_{p,\text{ stairs, min}} = 0.45 S_{DS} W_p$$

$$F_{p,\text{ stairs}} = 0.72 S_{DS} W_p$$

$$F_{p,\text{ stairs, max}} = 2.4 S_{DS} W_p$$

Fp is to be applied independently in at least two orthogonal horizontal directions in combination with other loads.

25

Seismic Loading – ASCE 7-16

Vertical Seismic Design Force per Section 13.3.1.2

$$F_{pv} = \pm 0.2 S_{DS} W_p$$

- For stairs, remember that seismic forces (vertical and horizontal) are based on the **dead load (Wp)** only in load combinations

26

Seismic Load Combos

Per Sections 2.3.6 LRFD & 2.4.5 ASD

LRFD

6. $1.2D+E_v+E_h+L+0.2S$
7. $0.9D+E_v+E_h$

ASD

8. $1.0D+0.7E_v+0.7E_h$
9. $1.0D+ 0.525E_v +0.525E_h+0.75L+0.75S$
10. $0.6D- 0.7E_v +0.7E_h$

Per Sections 12.4 & 13.3

$E_h = \rho Q_E$

$E_v = 0.2S_{DS}D$

→

$\rho = 1.0$ for stairs

$Q_E = F_p$ for stairs

→

$E_h = 1.0\ F_p$

$E_v = 0.2S_{DS}D$

27

Seismic Load Combos

Stair seismic load combinations with F_p

LRFD

6. $1.2D+0.2S_{DS}D+ F_p +L+0.2S$
7. $0.9\text{-}0.2S_{DS}D+ F_p$

ASD

8. $1.0D+0.7(0.2S_{DS})D+0.7\ F_p$
9. $1.0D+0.525(0.2S_{DS})D+0.75L+0.525\ F_p+0.75S$
10. $0.6D\text{-}0.7(0.2S_{DS})D+0.7\ F_p$

28

Seismic Load Combos - Anchorage

- Refer to Sections 2.3.6 LRFD, 2.4.5 ASD, & 12.4.3/12.4.3.1 for combinations with overstrength factor Ω_0
- Use for design of anchors at concrete/masonry
- Ω_0 = 2.0 to 2.5 (SDC = B*, C, D, E, F)

*Ω_0 = 1.0 for SDC B for concrete per ACI 318-14 section 17.2.3.1

LRFD

6. $1.2D+0.2S_{DS}D+\Omega_0F_p+L+0.2S$
7. $0.9D-0.2S_{DS}D+\Omega_0F_p$

ASD

8. $1.0D+0.7(0.2S_{DS})D+0.7\Omega_0F_p$
9. $1.0D+0.525(0.2S_{DS})D+0.75L+0.525\Omega_0F_p+0.75S$
10. $0.6D-0.7(0.2S_{DS})D+0.7\Omega_0F_p$

Apply Ω_0 to seismic portion of load only

29

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

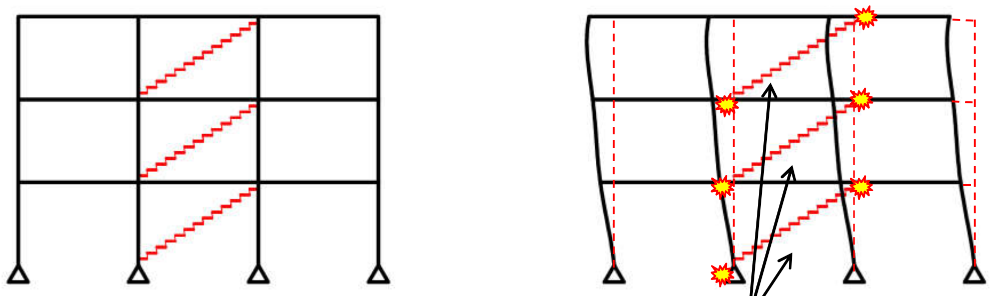
Step 11 – Delegated Design

Step 12 – Other Topics

30

Seismic Displacement – ASCE 7-16

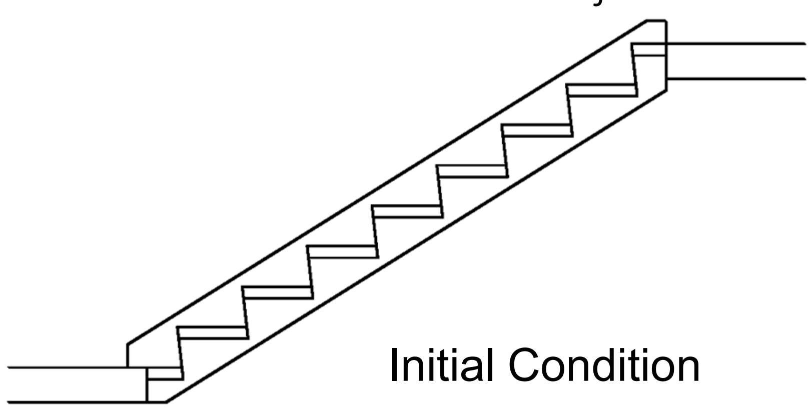
- Stairs may provide inadvertent load path which braces building structure instead of seismic force resisting system (SFRS)



31

Serviceability – ASCE7-16 Section 13.3.2

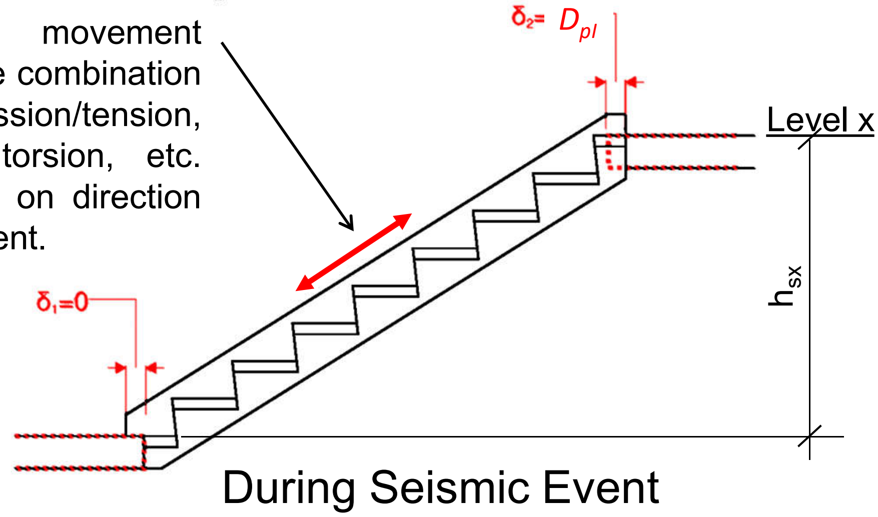
- Seismic Displacement= Differential lateral movements between adjacent floors



32

Seismic Displacement – ASCE 7-16

Differential movement may cause combination of compression/tension, bending, torsion, etc. depending on direction of movement.



Seismic Displacement – ASCE 7-16

- *Some* damage is acceptable, as long as other performance goals are not jeopardized (i.e. life safety for egress stairs). Refer to ASCE 7-16 commentary.

Seismic Displacement – ASCE 7-16

- Refer to Section 13.3.2 Seismic Relative Displacements & Displacements within Structures 13.3.2.1

$$D_{pI} = D_p I_e \quad \text{(Eq 13.3-6)}$$

I_e = importance factor in Section 11.5.1 & Table 1.5-2

$$D_p = \delta_{xA} - \delta_{yA} \quad \text{(Eq 13.3-7)}$$

δ = deflection in building at x or y level

- **For delegated design, request SER provide accurate drift values for each floor level at each stairway**

35

Seismic Displacement – ASCE 7-16

- Alternatively, ASCE 7 equation 13.3-8 & Table 12.12-1

$$D_{p,\max} = \frac{(h_x - h_y)\Delta_{aA}}{h_{sx}} = \frac{(h_x - h_y)(x h_{sx})}{h_{sx}} = (h_x - h_y)(x)$$

- h_x = height of level x
- h_y = height of level y
- h_{sx} = story height

Δ_{aA} = allowable story drift

$\Delta_{aA} = x h_{sx}$ (Table 12.12-1)

x = constant per Structure & Risk Category

- $D_{p,max}$ will result in large values that may be very difficult and costly to accommodate
- Designers can also use a linear dynamic procedure to determine D_p per Section 12.9.

36

Seismic Serviceability – ASCE 7-16

- New Section 13.5.10 Egress Stairs & Ramps
  - Shall accommodate seismic displacement, D_{pl}
    - D_{pl} may occur in any horizontal direction
      - » D_{pl} comes from Section 13.3.2
    - Positive attachment
    - Direct structural supports or mechanical connections
  - Not part of seismic force-resisting system of structure

37

Seismic Serviceability – ASCE 7-16

- Accommodate seismic displacement, D_{pl}
  - Direct structural supports or mechanical connections with following requirements:

    A. Sliding connx with holes, keepers, or stops
      - D_{pl} or ½" minimum
      - Without loss of vertical support
      - Without inducing compression

38

Seismic Serviceability – ASCE 7-16

B. Bearing style details
- $1.5D_{pl}$ or 1“ minimum
- Without loss of vertical support

C. Metal supports with rotation capacity
- $1.5D_{pl}$ or 1“ minimum
- Without loss of vertical support
- No brittle failure modes

D. Fasteners and attachments
- Design for R_p, a_p, Ω_0 per table 13.5-1

39

Seismic Serviceability – ASCE 7-16

EXCEPTION:
- If sliding or ductile connections not provided then stair must be designed in the building structural model and designed for Ω_0 of structure, but minimum 2.5.

40

Seismic Displacement – ASCE 7-16

- How to accommodate seismic displacement?
  - Drift Details
  - Expansion joint or expansion gap
  - Connections / supports with rotation capacity
  - Design for imparted forces

41

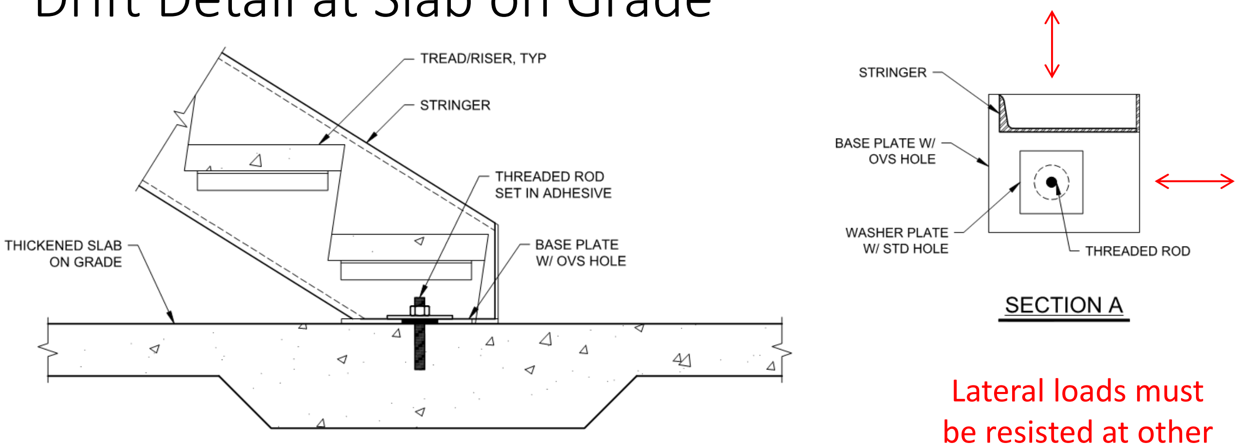
Seismic Displacement – ASCE 7-16

- Drift Details
  - Provide end connections allowing movement or drift at one end of stairway flight.
  - Other end connections must provide load path to resist lateral forces.
  - Use bearing for vertical loads.
  - Follow section 13.10.5 criteria A or B

42

Seismic Displacement – ASCE 7-16

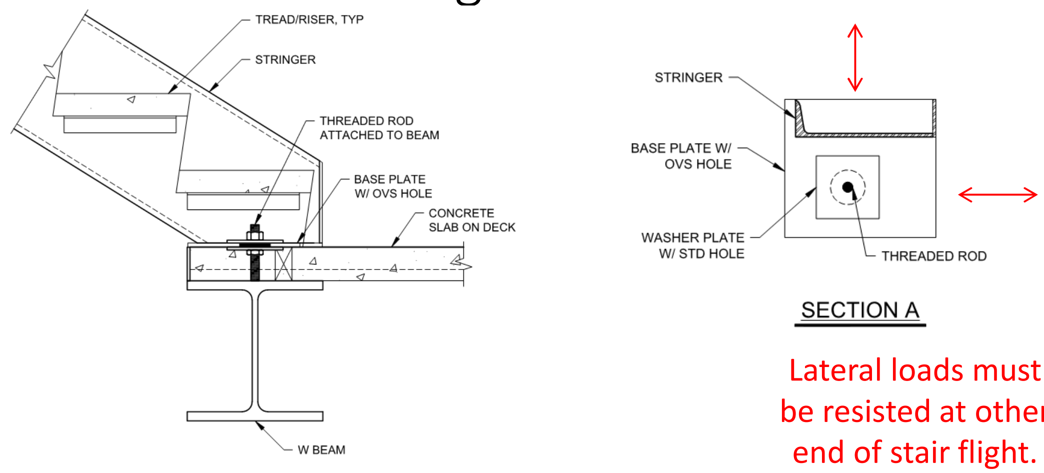
- Drift Detail at Slab on Grade



Lateral loads must be resisted at other end of stair flight.

Seismic Displacement – ASCE 7-16

- Drift Detail at Wide Flange Beam



Lateral loads must be resisted at other end of stair flight.

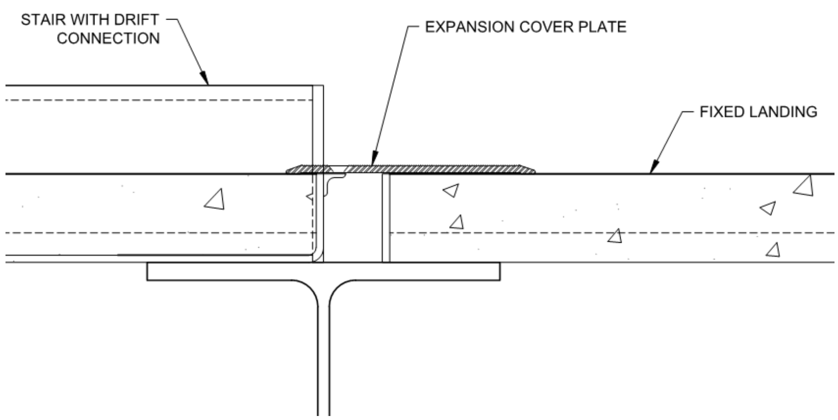
Seismic Displacement – ASCE 7-16

- Expansion joint or expansion cover
  - Likely requires input/approval from Architect
  - Provide gap allowing movement at one end of stairway flight.
  - Other end connections must provide load path to resist lateral forces.
  - Use bearing for vertical loads.
  - Follow section 13.10.5 criteria A or B

45

Seismic Displacement – ASCE 7-16

- Expansion joint or expansion cover



Lateral loads must be resisted at other end of stair flight.

46

Seismic Displacement – ASCE 7-16

- Connections / supports with rotation capacity
  - Moment frame designed for imparted seismic displacement
  - Connections (that are part of a system) allowing for lateral displacement through the use of slotted/oversized holes or ductile elements
  - Requires careful detailing and analysis to ensure intended performance for seismic event

47

Seismic Displacement – ASCE 7-16

- Design for imparted forces…

  …but remember:

$$\delta = \frac{PL}{AE} \quad \therefore \quad P = \frac{\delta AE}{L}$$

…likely results in very large forces.

- Needs to be part of building model for this analysis!

48

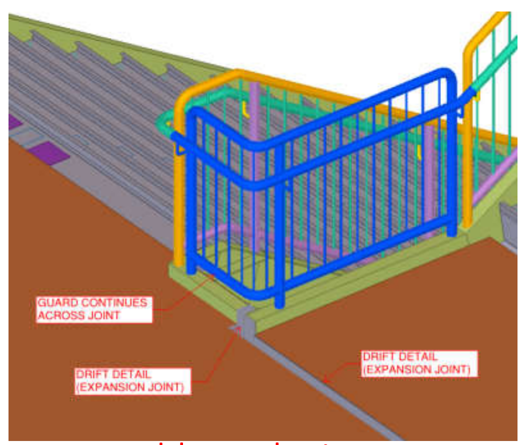
Seismic Displacement – Architectural Restraints

- What about other restraints or layout issues?
  - Handrail/guard continuity across drift details
  - Gap between stringer and adjacent walls
  - Drift requirements that exceed guard layout dimensions (e.g. openings less than 4" diameter)

49

Seismic Displacement – Architectural Restraints

- Handrail/guard continuity across drift details
  - Provide a break in guard at drift details.
  - Consider if handrail bracket can yield to allow for drift movement
  - Coordinate with Architect



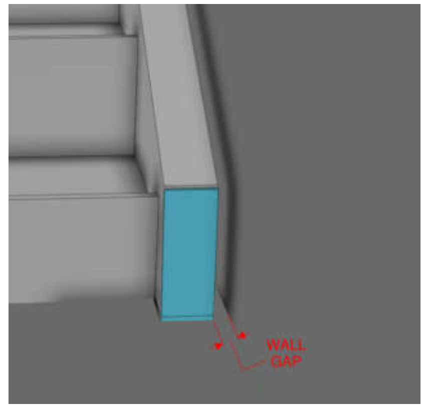
- Damage to nonstructural components caused by relative displacement is acceptable, provided that the performance goals…are achieved (e.g. life safety).

Refer to ASCE 7-16 Commentary Section C13.3.2.

50

Seismic Displacement – Architectural Restraints

- Gap between stringer and adjacent walls (gap < seismic displacement)
  - Consider wall type and if it can sustain damage (e.g. drywall on studs)
  - Consider potential for imparted forces from wall (e.g. concrete wall)
  - Coordinate with Architect



- Damage to nonstructural components caused by relative displacement is acceptable, provided that the performance goals…are achieved (e.g. life safety).

Refer to ASCE 7-16 Commentary Section C13.3.2.

51

Seismic Displacement – Architectural Restraints

- Drift requirements that exceed guard layout dimensions (e.g. openings less than 4” diameter)
  - Be sure to satisfy IBC layout requirements.
  - May require unique guard layout
  - Could consider elements that would be damaged in seismic event
    - Be sure these elements are adequate for code required loading under daily use!
  - Coordinate with Architect

52

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

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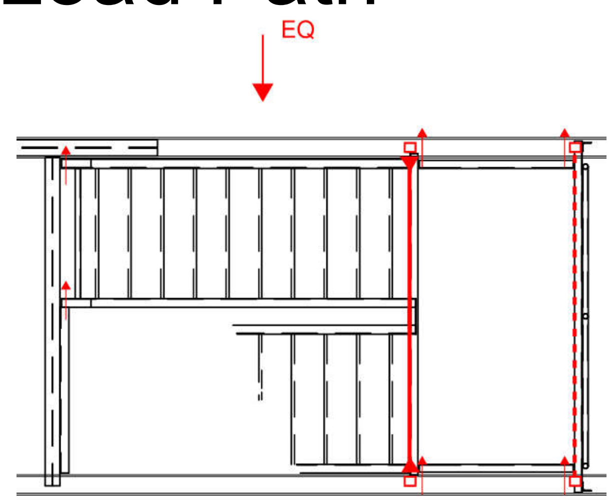
53

Horizontal Load Path

- How do we analyze stair flight?
- How are forces transferred through landings?



54

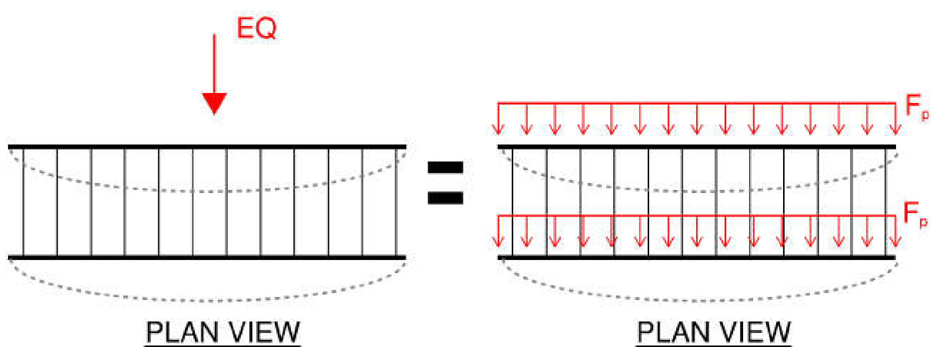
Stair Flight Assembly

- Load path for seismic forces on stair flight?
  - Option 1 – Individual Simple Span Members
  - Option 2 – Built-up Horizontal Beam
  - Option 3 – Cantilever Built-up Horizontal Beam
- Alternative options using engineering judgment

55

Stair Flight Assembly

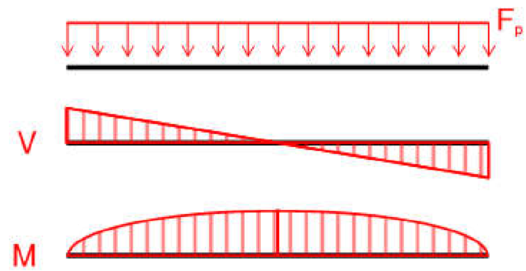
- Option 1 – Individual Simple Span Members



56

Stair Flight Assembly

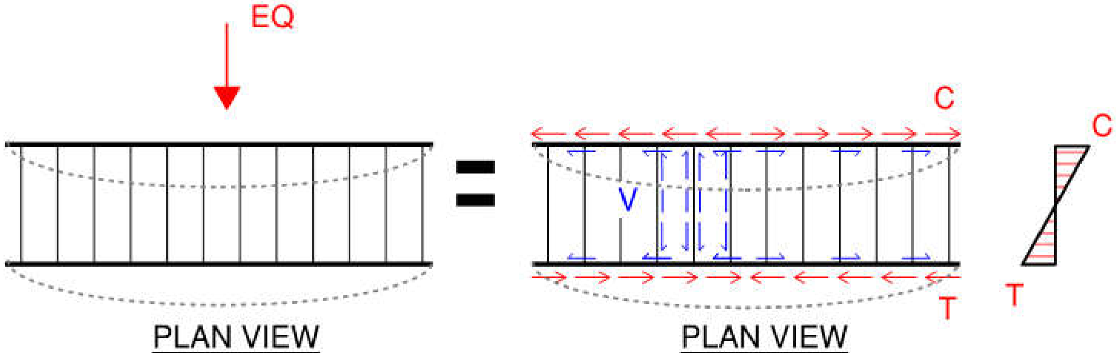
- Option 1 – Individual Simple Span Members
  - Assumes ductile connx or rotation capacity at supports
  - Treat as a simple span beam with uniformly distributed load
  - Design per AISC Spec



57

Stair Flight Assembly

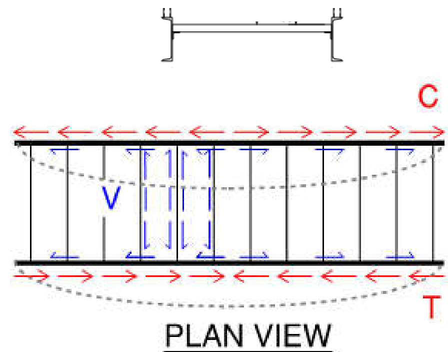
- Option 2 – Built-up Horizontal Beam



58

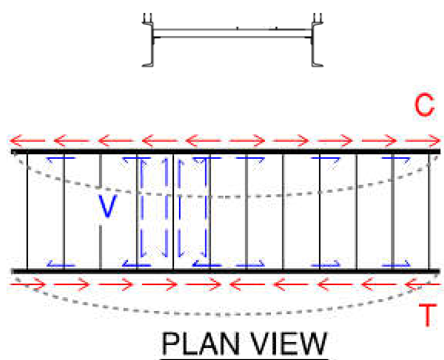
Stair Flight Assembly

- Option 2 – Built-up Horizontal Beam
  - Assumes ductile connx or rotation capacity at supports
  - Built-up beam may not satisfy local buckling criteria at treads/risers in many cases (AISC, AISI)
  - Difficult to quantify capacity of tread/riser elements



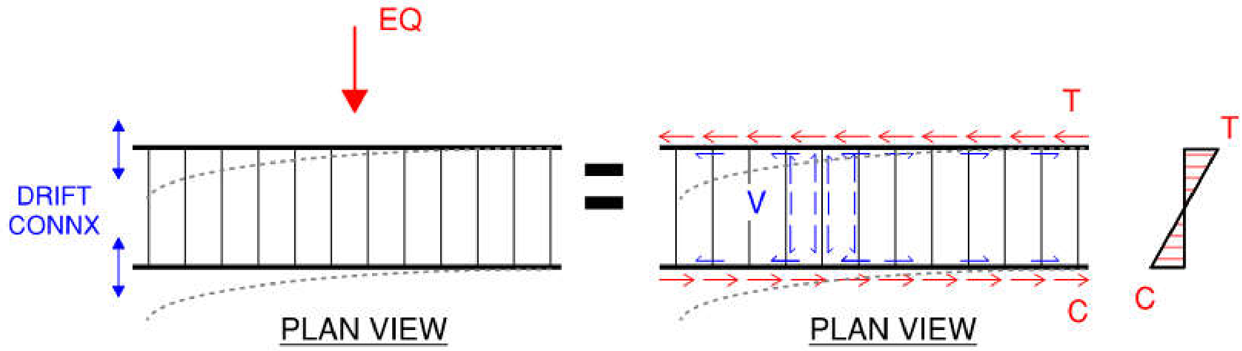
Stair Flight Assembly

- Option 2 – Built-up Horizontal Beam



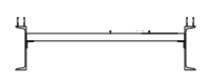
Stair Flight Assembly

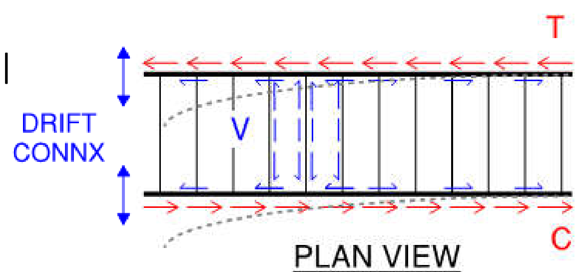
- Option 3 – Cantilever Built-up Horizontal Beam



Stair Flight Assembly

- Option 3 – Cantilever Built-up Horizontal Beam
  - Assumes drift connx at one end
  - Force couple at opposite end with axial and weak axis connx forces
  - Built-up beam may not satisfy local buckling criteria at treads/risers in many cases (AISC, AISI)
  - Difficult to quantify capacity of tread/riser elements





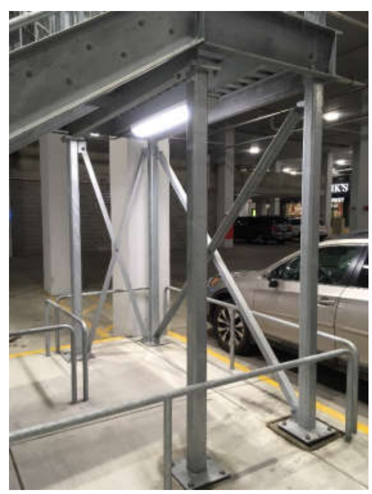
Landing Diaphragm

- Load path is more similar to conventional floor framing
  - Cast-in-place concrete over metal deck
    - Deck capacity / concrete capacity
  - Cast-in-place concrete over stiffened plate
  - Steel plate diaphragm

63

Vertical Load Path

- Best systems for stairs?
- Least impact on
  - Aesthetics
  - Space constraints
  - Cost



64

Vertical Lateral Load Resisting Systems

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	• Less members • Less 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

65

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

Step 11 – Delegated Design

Step 12 – Other Topics

66

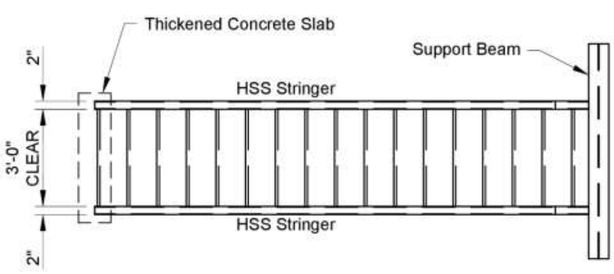
Example 1: Load Determination

Given:

- OSHA Style Industrial Stair
- Location: Southern California
- Seismic Design Category = D
- Spectral Response, S_{DS} = 0.660g

67

Example 1: Load Determination



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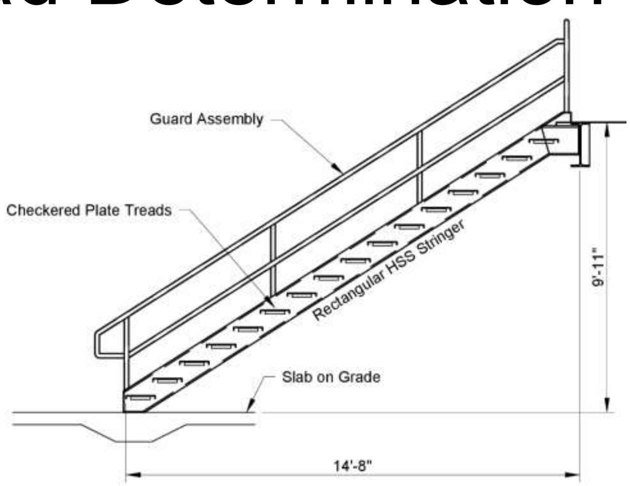


SECTION

68

Example 1: Load Determination

- Load Combinations, ASCE7-16, 2.3.1 & 2.4.1

	LRFD	ASD	
2	1.2D + 1.6L	D+L	2

69

Example 1: Load Determination

- Load Combinations, ASCE7-16, 2.3.6 & 2.4.5

	LRFD	ASD	
6	$1.2D+E_v+E_h+L+0.2S$ $=1.2D+0.2S_{DS}D+\rho Q_E+L$ $=1.2D+0.2(0.660)D+1.0Q_E+L$ $=1.33D+1.0Q_E+L$	$1.0D+0.7E_v+0.7E_h$ $=1.0D+0.7(0.2S_{DS})D+0.7\rho Q_E$ $=1.0D+0.7(0.2(0.660))D+0.7(1.0)Q_E$ $=1.09D+0.7Q_E$	8
7	$0.9D-E_v+E_h$ $=0.9D-0.2S_{DS}D+\rho Q_E$ $=0.9D-0.2(0.660)D+1.0Q_E$ $=0.768D+1.0Q_E$	$1.0D+0.525E_v+0.525E_h+0.75L+0.75S$ $=1.0D+0.525(0.2S_{DS})D+0.525\rho Q_E+0.75L$ $=1.0D+0.525((0.2)(0.660))D+0.525(1.0)Q_E+0.75L$ $=1.07D+0.525Q_E+0.75L$	9
		$0.6D-0.7E_v+0.7E_h$ $=0.6D-0.7(0.2S_{DS})D+0.7\rho Q_E$ $=0.6D-0.7((0.2)(0.660))D+0.7(1.0)Q_E$ $=0.508D+0.7Q_E$	10

70

Example 1: Load Determination

- Horizontal Seismic Force, *Fp*

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

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	= 2.5
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	= 1.0
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

71

Example 1: Load Determination

- Horizontal Seismic Force, *Fp*

$$F_p = \frac{0.4(1.0)(0.660)W_p}{\left(\frac{2.5}{1.5}\right)}\left[1 + 2\left(\frac{9.92\text{ ft}}{19.8\text{ ft}}\right)\right]$$

$$= 0.317W_p$$

72

Example 1: Load Determination

- Maximum Horizontal Seismic Force, *Fp max*

$$F_p \text{ max} = 1.6 S_{DS} I_p W_p$$
$$= 1.6(0.660)(1.5) W_p$$
$$= 1.58 W_p$$

- Minimum Horizontal Seismic Force, *Fp min*

$$F_p \text{ min} = 0.3 S_{DS} I_p W_p$$
$$= 0.3(0.660)(1.5) W_p$$
$$= 0.297 W_p$$

73

Example 1: Load Determination

- Vertical Seismic Force, *Fpv*

$$F_{pv} = \pm 0.2 S_{DS} W_p$$
$$= \pm 0.2(0.660) W_p$$
$$= \pm 0.132 W_p$$

74

Example 1: Load Determination

- Summary
  - Horizontal

$$F_p = 0.317W_p$$

  - Vertical

$$F_{pv} = \pm 0.132W_p$$

Example 2: Stringer Design

Given:

- OSHA Style Industrial Stair
- Location: Southern California
- Seismic Design Category = D
- Spectral Response, S_{DS} = 0.660g
- Provide HSS A500 Gr. C Stringer

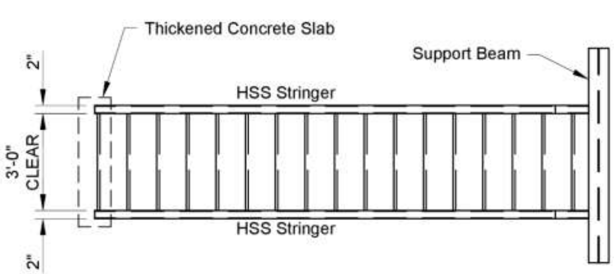
Example 2: Stringer Design

Given:

- Supports with rotation capacity to accommodate seismic displacement using ductile connections
- Checkered plate tread/risers
  - Stringer fully braced
  - For seismic lateral loads, design as individual members

77

Example 2: Stringer Design



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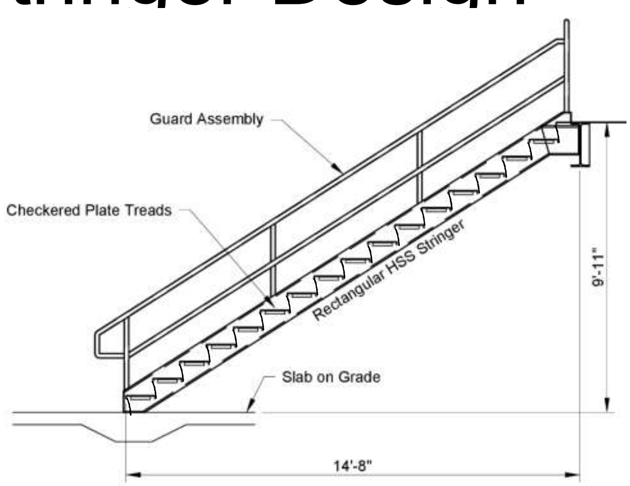


SECTION

78

Example 2: Stringer Design

- Imposed Gravity Loading

Dead Load:			
Stringer Self weight, HSS12x2x1/4			
Guard Self weight			
3/16” Checkered Plate	=	10	psf
Total	=	10	psf
Live Load:			
Live load – Case 1	=	60	psf
Or			
Live load – Case 2	=	1000	lbs

79

Example 2: Stringer Design

- Stringer Gravity Uniform Loads

Dead Load:				
Stringer Self weight (22.42 lb/ft X 1.19 slope factor)		=	26.7	lb/ft
Guard Self weight (20 lb/ft)		=	20	lb/ft
3/16” Checkered Plate	= 10 psf X 1.5’	=	15	lb/ft
Total		=	61.7	lb/ft
Live Load:				
Live load	= 60 psf X 1.5’	=	90	lb/ft
Total		=	90	lb/ft

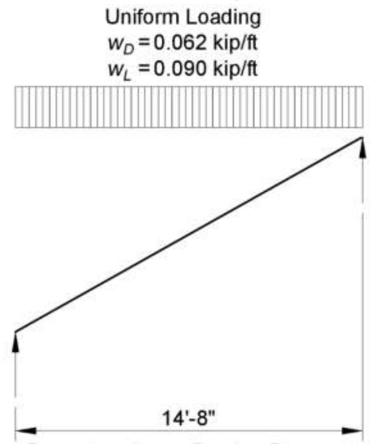
80

Example 2: Stringer Design

- Stringer Gravity Uniform Loads

$$w_D = \left(\frac{3\text{ ft}}{2}\right)\left(0.010\text{ kip/ft}^2\right) + \left(0.0267\text{ kip/ft} + 0.020\text{ kip/ft}\right)$$
$$= 0.0617\text{ kip/ft}$$

$$w_L = \left(\frac{3\text{ ft}}{2}\right)\left(0.060\text{ kip/ft}^2\right)$$
$$= 0.090\text{ kip/ft}$$



Beam Loading & Bracing Diagram
(Full Lateral Support)

81

Example 2: Stringer Design

LRFD	ASD
Uniform loading	*Uniform loading*
$w_u = \left(\frac{3\text{ ft}}{2}\right)\left[1.2\left(0.010\text{ kip/ft}^2\right) + 1.6\left(0.060\text{ kip/ft}^2\right)\right]$ $+1.2\left(0.0267\text{ kip/ft} + 0.020\text{ kip/ft}\right)$ $= 0.218\text{ kip/ft}$	$w_a = \left(\frac{3\text{ ft}}{2}\right)\left[\left(0.010\text{ kip/ft}^2\right) + \left(0.060\text{ kip/ft}^2\right)\right]$ $+\left(0.0267\text{ kip/ft} + 0.020\text{ kip/ft}\right)$ $= 0.152\text{ kip/ft}$
$V_u = \frac{14.7\text{ ft}}{2}\left(0.218\text{ kip/ft}\right)$ $= 1.60\text{ kips}$	$V_a = \frac{14.7\text{ ft}}{2}\left(0.152\text{ kip/ft}\right)$ $= 1.12\text{ kips}$
$M_u = \frac{\left(0.218\text{ kip/ft}\right)\left(14.7\text{ ft}\right)^2}{8}$ $= 5.89\text{ kip-ft}$	$M_a = \frac{\left(0.152\text{ kip/ft}\right)\left(14.7\text{ ft}\right)^2}{8}$ $= 4.11\text{ kip-ft}$

82

Example 2: Stringer Design

- Stringer Point Load, 1000 lbs

Point loading

$$V_u = \frac{14.7\text{ ft}}{2}\left[1.2(0.0617\text{ kip/ft})\right] + 1.6(1\text{ kip})$$
$$= 2.14\text{ kips}$$ GOVERNS

$$M_u = \frac{1.2(0.0617\text{ kip/ft})(14.7\text{ ft})^2}{8} + \frac{1.6(1\text{ kip})(14.7\text{ ft})}{4}$$
$$= 7.88\text{ kip-ft}$$ GOVERNS

Point loading

$$V_a = \frac{14.7\text{ ft}}{2}(0.0617\text{ kip/ft}) + 1\text{ kip}$$
$$= 1.45\text{ kips}$$ GOVERNS

$$M_a = \frac{(0.0617\text{ kip/ft})(14.7\text{ ft})^2}{8} + \frac{(1\text{ kip})(14.7\text{ ft})}{4}$$
$$= 5.34\text{ kip-ft}$$ GOVERNS

83

Example 2: Stringer Design

- Summary, Gravity Loads

	LRFD	ASD
w	0.218 k/ft	0.152 k/ft
V	2.14 k	1.45 k
M	7.88 k-ft	5.34 k-ft

Refer to *Specification* Section G1 &
Manual Table 3-12
For HSS12x2x1/4 A500 Gr. C
LRFD
ΦvVn = 142 k > 2.14 k OK
ΦbMp = 75.4 k-ft > 7.88 k-ft OK
ASD
Vn/Ωv = 94.6 k > 1.45 k OK
Mp/Ωb = 50.1 k-ft > 5.34 k-ft OK

HSS12x2x1/4 is adequate for imposed gravity loads

84

Example 2: Stringer Design

- Seismic Loading
  - Consider equivalent uniform load for concentrated point load since it will govern design

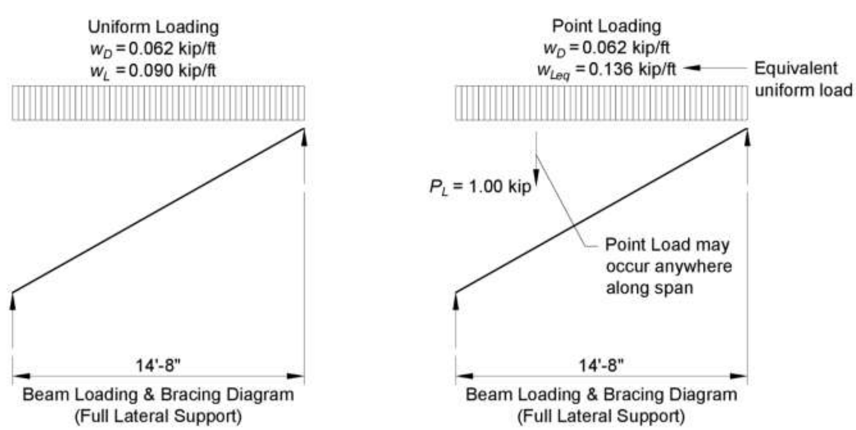
$$P_L = 1\text{ kip}$$
$$M = \frac{PL}{4} = \frac{wL^2}{8}$$

therefore…

$$w_{Leq} = \frac{2P}{L} = \frac{2(1\text{ kip})}{14.7\text{ ft}} = 0.136\text{ kip/ft}$$
$$w_{Leq} = 0.136\text{ kip/ft} > w_L = 0.090\text{ kip/ft}$$

85

Example 2: Stringer Design



86

Example 2: Stringer Design

- Stringer Vertical Loads, Seismic Load Combo

LRFD	ASD
$1.33D + 1.0Q_E + L$ (Controls for stringer design)	$1.07D + 0.525Q_E + 0.75L$ (Controls for stringer design)
$V_{u,v} = \left(\frac{14.7\text{ ft}}{2}\right)\begin{bmatrix}1.33(0.0617\text{ kip/ft})\\+1.0(0)\\+(0.136\text{ kip/ft})\end{bmatrix} = 1.60\text{ kips}$	$V_{a,v} = \left(\frac{14.7\text{ ft}}{2}\right)\begin{bmatrix}1.07(0.0617\text{ kip/ft})\\+0.525(0)\\+0.75(0.136\text{ kip/ft})\end{bmatrix} = 1.23\text{ kips}$
$M_{u,v} = \frac{(14.7\text{ ft})^2}{8}\begin{bmatrix}1.33(0.0617\text{ kip/ft})\\+1.0(0)\\+(0.136\text{ kip/ft})\end{bmatrix} = 5.89\text{ kip-ft}$	$M_{a,v} = \frac{(14.7\text{ ft})^2}{8}\begin{bmatrix}1.07(0.0617\text{ kip/ft})\\+0.525(0)\\+0.75(0.136\text{ kip/ft})\end{bmatrix} = 4.54\text{ kip-ft}$

87

Example 2: Stringer Design

- Summary - Vertical Loads, Seismic Load Combo

	LRFD	ASD
w	0.218 k/ft	0.168 k/ft
V	1.60 k	1.23 k
M	5.89 k-ft	4.54 k-ft

Refer to *Specification* Section G1 & Manual Table 3-12
For HSS12x2x1/4 A500 Gr. C

LRFD
$\Phi_v V_n$ = 142 k > 1.60 k OK
$\Phi_b M_p$ = 75.4 k-ft > 5.89 k-ft OK

ASD
V_n/Ω_v = 94.6 k > 1.23 k OK
M_p/Ω_b = 50.1 k-ft > 4.54 k-ft OK

HSS12x2x1/4 is adequate for imposed vertical loads

88

Example 2: Stringer Design

- Horizontal Loading

$$
\begin{aligned}
F_{ph} &= 0.317W_p \\
&= 0.317(0.062 \text{ kip/ft}) \\
&= 0.020 \text{ kip/ft}
\end{aligned}
$$

89

Example 2: Stringer Design

- Horizontal Loads, Seismic Load Combo

LRFD	ASD
$1.33D + 1.0Q_E + L$ (Controls for stringer design)	$1.07D + 0.525Q_E + 0.75L$ (Controls for stringer design)
$V_{u,h} = \left(\frac{14.7 \text{ ft}}{2}\right)\left[1.33(0) + 1.0(0.020 \text{ kip/ft}) + 0\right] = 0.147 \text{ kip}$	$V_{a,h} = \left(\frac{14.7 \text{ ft}}{2}\right)\left[1.07(0) + 0.525(0.020 \text{ kip/ft}) + 0.75(0)\right] = 0.0772 \text{ kip}$
$M_{u,h} = \frac{(14.7 \text{ ft})^2}{8}\left[1.33(0) + 1.0(0.020 \text{ kip/ft}) + 0\right] = 0.540 \text{ kip-ft}$	$M_{a,h} = \frac{(14.7 \text{ ft})^2}{8}\left[1.07(0) + 0.525(0.020 \text{ kip/ft}) + 0.75(0)\right] = 0.284 \text{ kip-ft}$

90

Example 2: Stringer Design

- Summary - Horizontal Loads, Seismic Load Combo

	LRFD	ASD
w	0.020 k/ft	0.0105 k/ft
V	0.147 k	0.077 k
M	0.540 k-ft	0.284 k-ft

Refer to *Specification* Section G1 & Manual Table 3-12
For HSS12x2x1/4 A500 Gr. C
LRFD
ΦvVn = 16.4 k > 0.147 k OK
ΦbMp = 13.3 k-ft > 0.540 k-ft OK
ASD
Vn/Ωv = 10.9 k > 0.077 k OK
Mp/Ωb = 8.87 k-ft > 0.284 k-ft OK

Example 2: Stringer Design

- Check Interaction
  - Because $P_r/P_c < 0.2$, use AISC *Specification* Equation H1-1b:

LRFD	ASD
$\frac{P_r}{2P_c}+\left(\frac{M_{rx}}{M_{cx}}+\frac{M_{ry}}{M_{cy}}\right)\leq 1.0$	$\frac{P_r}{2P_c}+\left(\frac{M_{rx}}{M_{cx}}+\frac{M_{ry}}{M_{cy}}\right)\leq 1.0$
$0+\left(\frac{5.89\text{ kip-ft}}{75.4\text{ kip-ft}}+\frac{0.540\text{ kip-ft}}{13.3\text{ kip-ft}}\right)\leq 1.0$	$0+\left(\frac{4.54\text{ kip-ft}}{50.1\text{ kip-ft}}+\frac{0.284\text{ kip-ft}}{8.87\text{ kip-ft}}\right)\leq 1.0$
$0.119 < 1.0$ **o.k.**	$0.123 < 1.0$ **o.k.**

HSS12x2x1/4 is adequate for seismic loads

Example 2: Stringer Design

- Not quite done…
  - Consider seismic loads parallel to stair flight resulting in axial forces (and vertical loads)
  - Connection design
    - Remember that anchorage to concrete or masonry requires the use of load combinations with overstrength factor, Ω_0

93

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

Step 11 – Delegated Design

Step 12 – Other Topics

94

Delegated Design

- Design Team (architect/SER) request contractor or fabricator to complete an aspect of design. For stairs:
  - Option 1 – Delegate all aspects of design
    - Contractor makes all design decisions with code input from design documents
  - Option 2 – Delegate structural engineering *(most common)*
    - Use design documents for architectural & code
  - Option 3 – Design-build
    - Use design documents and coordination with Design Team to establish parameters

95

Delegated Design – Required Information

Design Drawings

- Plans, sections, & elevations of each stair
- Dimensions for clear distances at stairs/landings
- Guard layout with handrail position
- Preferred/required member types (C, HSS, Plate)
- Slab openings
- Conceptual layout of stair elements
- Conceptual connection details

Clearly indicate if details are suggestions or required

96

Delegated Design – Required Information

Project Specification

- Performance requirements (loading / serviceability)
- Materials, member, & fasteners criteria
- Fabrication instructions
- Finishes

Carefully review for conflicts between drawings and specification

97

Delegated Design – Code Compliance

- Stairways, guard, and handrail are critical components related to life safety.
- Architect/SER are the most knowledgeable about the specific project requirements (and code requirements)
- Architect & SER are responsible for providing code parameters and reviewing submittals for conformance.

98

Delegated Design

- Delegated Design ≠ "Not my problem"

Delegated Design – Shop Drawings

- Shop drawings should be created by Fabricator/Detailer based on information provided by the specialty structural engineer (SSE) and design documents
- Provide shop drawings to SSE for review and comment
- Do not request SSE to seal shop drawings if they are created by others
  - Not allowed in some jurisdictions
  - Insurance typically will not allow SSE to do this

Delegated Design – Submittals

- Submittal to Design Team & AHJ:
  - Shop & Erection drawings from Fabricator/Detailer
    - Reviewed by SSE
  - Sealed structural engineering calculations from specialty structural engineer (SSE)
    - Should include any plans, sketches, and details as required

Be sure to clarify scope of work and expectations before submittals are made

101

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

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Step 12 – Other Topics

102

Tolerances

- Steel
  - Mill Variations, ASTM A6 / AISC *COSP* Section 5.1
  - Fabrication Tolerances, AISC *COSP* Section 6.4
  - Erection Tolerances, AISC *COSP* Section 7.13
  - AESS, AISC *COSP* Sections 10.2-10.6

103

Tolerances - Concrete

- Field verify dimensions based on actual construction!

104

Tolerances

- Concrete (ACI117 & *Handbook of Construction Tolerances*)
  - ± 1/4” over 10 feet from plumb for walls
  - ± 1/4” to 1/2” variation in distance between members
  - +3/8” to -1/4” for cross sections
  - +1” to -1/4” variation in floor openings
  - ± 1/2” member misplaced in plan
- Field verify dimensions based on actual construction!

105

Tolerances

- Masonry (ASTM C90 & *Handbook of Construction Tolerances*)
  - ± 1/8” for cross sections
  - ± 1/4” to ± 1/2” from plumb for walls
  - ± 1/2” alignment for bearing walls
- Field verify dimensions based on actual construction!

106

Galvanizing

- For exterior locations or environments that need additional corrosion protection
- Consider:
  - Avoid field welding
  - Provide bolted connections
  - Match fasteners & metals
  - Limit on size of piece/assembly
  - Potential distortion or warpage (ASTM A384)

107

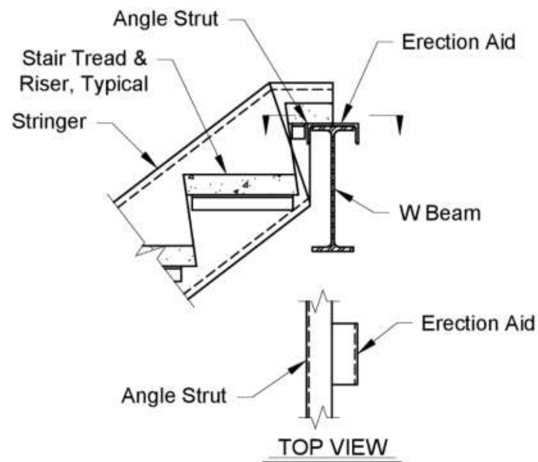
Erectability

- Think about installation
  - Stringers adjacent to concrete/masonry walls may have limited access to install bolts
  - Will masonry supports be in place?
- Erector preferences
  - Bolting versus Welding

108

Erectability

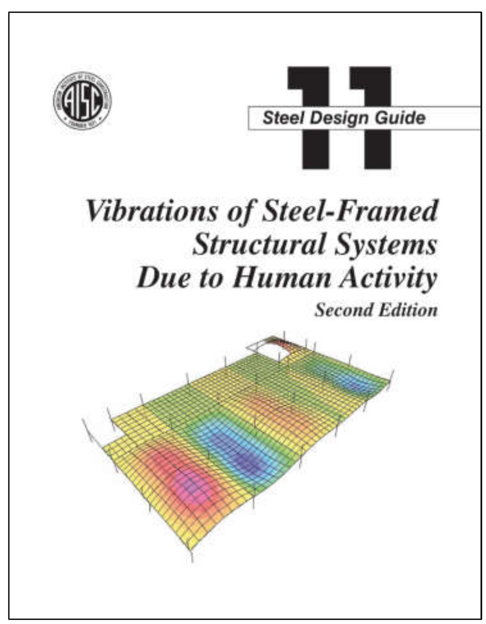
- Maximize repetition in framing and connections
- Erection aids
- Adjustability and fit-up in connections



109

Vibration

- Refer to AISC Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity (Second Edition)
- Vibration is all about perception and comfort
- Discuss project goals as it relates to vibration



110

Thank you!

AISC | Questions?

Smarter.
Stronger.
Steel.

Group Registration

PDH Certificates

- You will receive an email on how to report attendance from: registration@aisc.org.
- Be on the lookout: Check your spam filter! Check your junk folder!
- Completely fill out online form. Don't forget to check the boxes next to each attendee's name!

Smarter.
Stronger.
Steel.

Group Registration

PDH Certificates

- Reporting site (URL will be provided in the forthcoming email).
- Username: Same as AISC website username.
- Password: Same as AISC website password.

Smarter.
Stronger.
Steel.

Individual Registration

PDH Certificates

One certificate will be issued at the conclusion of the course.

Smarter.
Stronger.
Steel.

Individual Registration

Attendance and PDH Certificates

- You have two options to receive credit for each session.
    - Option 1: Watch the live session.
    - Option 2: Watch the recording and pass the associated quiz.

Video and Recording Access

- Access is provided within two business days after the live air date.
- Video recordings and quizzes for both sessions are available until 8:00 a.m. ET on June 18 (4 weeks after the completion of the course).

Distribution of Certificates

- All certificates will be issued after the course is completed.
- Only the registrant will receive a certificate for the course.

Smarter. Stronger. Steel.

Individual Registration

Course Resources

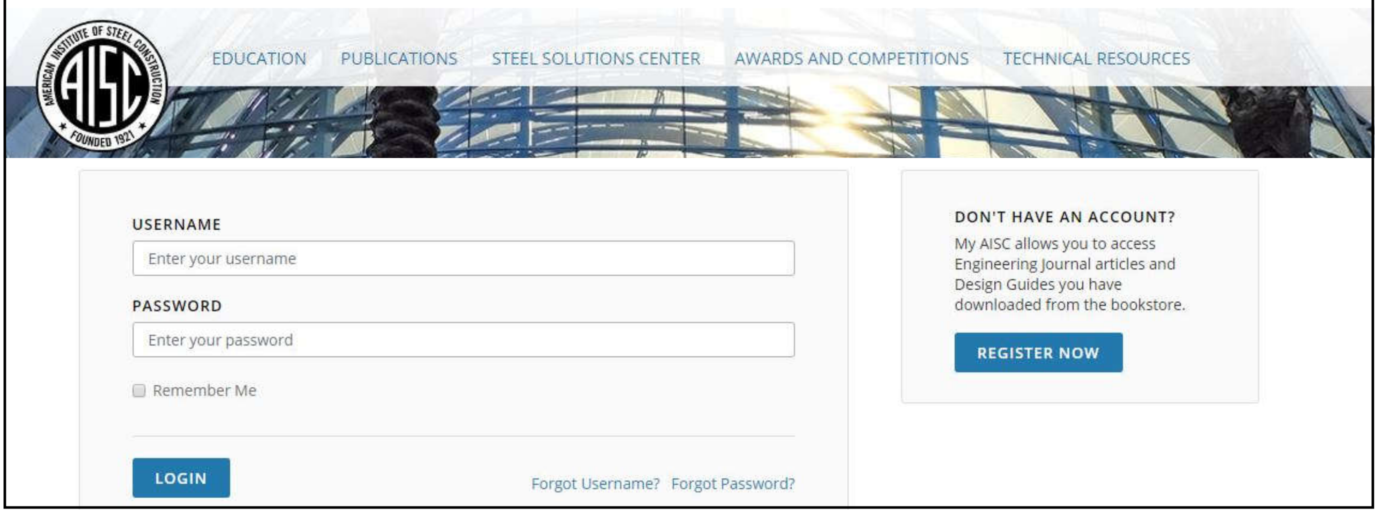
Access to video recordings and quizzes can be found on your AISC account.

Smarter. Stronger. Steel.

Individual Registration

Course Resources

Go to www.aisc.org and sign in.



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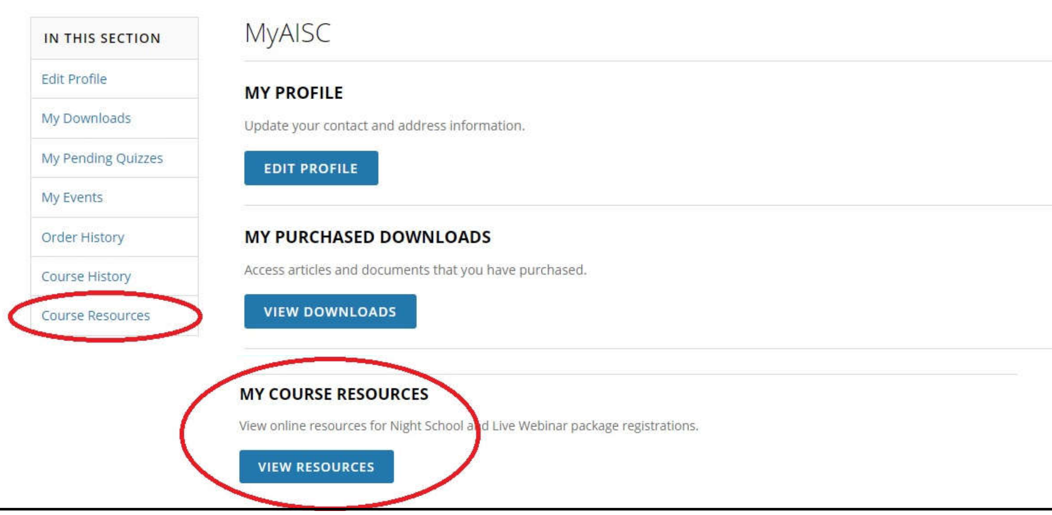

Individual Registration

Course Resources

EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER

AISC › MY ACCOUNT › COURSE RESOURCES

Course Resources

Event	Start Date
Seismic Design in Steel	1/1/1900 12:00:00 AM
4-Session Package-Design of Façade Attachments	5/9/2019 1:30:00 PM
NS 15 8-Session Package-Night School 15 - Fundamentals of Connection Design	10/3/2017 7:00:00 PM
NS 16 8-Session Package-Night School 16 - Seismic Design in Steel	2/5/2018 7:00:00 PM
NS 17 4-Session Package-Night School 17: Design of Façade Attachments	7/16/2018 7:00:00 PM
NS 18 8-Session Package-Night School 18: Steel Construction: Mill To Topping Out	10/15/2018 7:00:00 PM
NS 19 8-Session Package-Night School 19: Connection Design	2/4/2019 7:00:00 PM
NS 20 8-Session Package-Night School 20: Classical Methods of Structural Analysis	6/3/2019 7:00:00 PM
8-Session Package-Seismic Design in Steel - Concepts & Examples	7/16/2018 1:30:00 PM

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EDUCATION PUBLICATIONS AWARDS AND COMPETITIONS TECHNICAL RESOURCES STEEL SOLUTIONS CENTER

AISC › MY ACCOUNT › COURSE RESOURCES › DESIGN OF FACADE ATTACHMENTS PACKAGE RESOURCES

Design of Facade Attachments

4-SESSION PACKAGE RESOURCES

Event	Date	Handouts	Video	Quiz	Attendance
R1: Facade Fundamentals	N/A	Handouts	View Passcode: AZNS175	Pass Score: 100	N/A
L1: Façade Attachments Part 1	May 9 2019 1:30PM EDT	Handouts	Available 05/11/2019 5:00PM EDT	Available 05/11/2019 5:00 PM EDT	Pending
L2: Façade Attachments Part 2	May 16 2019 1:30PM EDT	Handouts	Available 05/18/2019 5:00PM EDT	Available 05/18/2019 5:00 PM EDT	Pending
L3: Façade Attachments - Building Lateral Drifts	May 23 2019 1:30PM EDT	Handouts	Available 05/25/2019 5:00PM EDT	Available 05/25/2019 5:00 PM EDT	Pending
Final Exam	N/A			Available 5/27/2019 5:00 PM EDT	

AISC | Thank you

Smarter.
Stronger.
Steel.