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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

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CSD STRUCTURAL ENGINEERS
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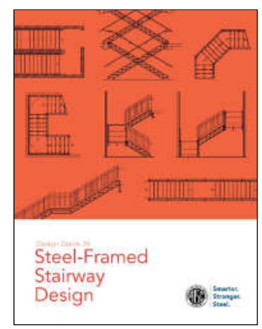
Introduction

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
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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

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

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

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

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: $a_p = 2½$, $R_p = 2½$, $\Omega_0 = 2½$

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

What is the impact?

- Design of stair elements
  - No change

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

23

Loading – ASCE 7-16

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

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

  - Maximum per Eq 13.3-2

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

24

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

$E_h = \rho Q_E$ → ρ = 1.0 for stairs → $E_h = 1.0\,F_p$

$Q_E = F_p$ for stairs

$E_v = 0.2S_{DS}D$ → $E_v = 0.2S_{DS}D$

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. $0.9-0.2S_{DS}D+F_p$

ASD

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

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

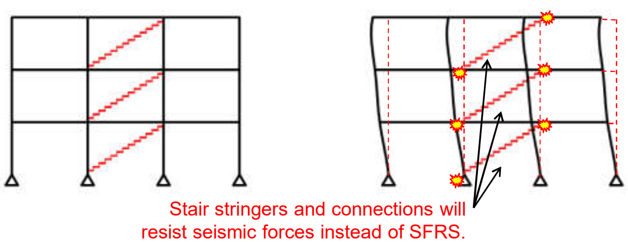
8. $1.0D+0.7(0.2S_{DS})D+0.7\Omega_0F_p$
9. $1.0D+0.525(0.2S_{DS})D+0.75L+0.525\Omega_0F_p+0.75S$
10. $0.6D-0.7(0.2S_{DS})D+0.7\Omega_0F_p$

Apply Ω_0 to seismic portion of load only

Outline – Part 2

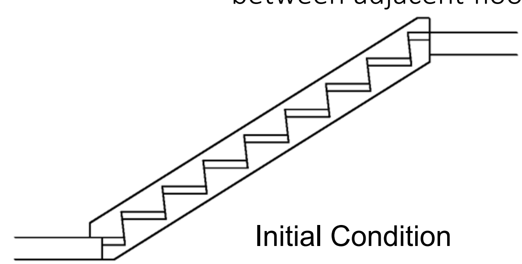
Seismic Displacement – ASCE 7-16

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

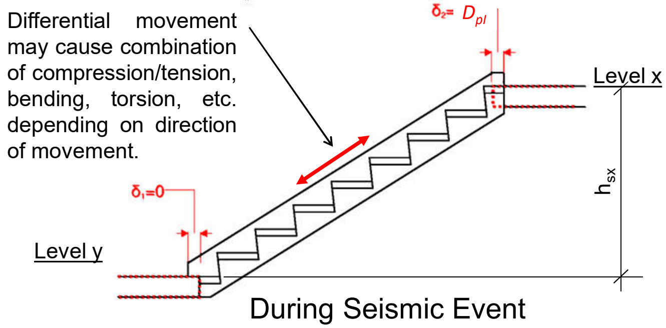


Serviceability – ASCE7-16 Section 13.3.2

- Seismic Displacement= Differential lateral movements between adjacent floors



Seismic Displacement – ASCE 7-16



33

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.

34

Seismic Displacement – ASCE 7-16

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

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

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

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

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

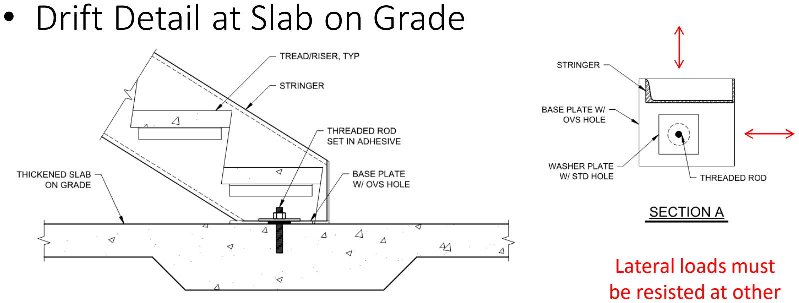
- How to accommodate seismic displacement?
  - Drift Details
  - Expansion joint or expansion gap
  - Connections / supports with rotation capacity
  - Design for imparted forces

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

Seismic Displacement – ASCE 7-16

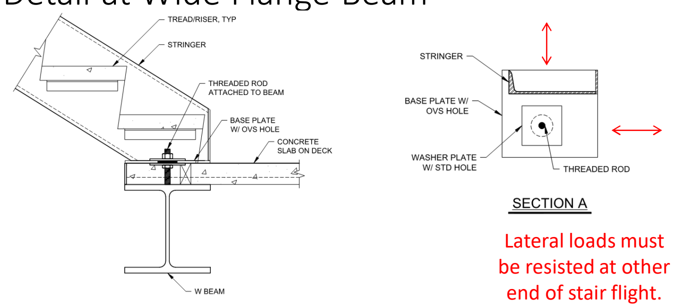
- Drift Detail at Slab on Grade



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.

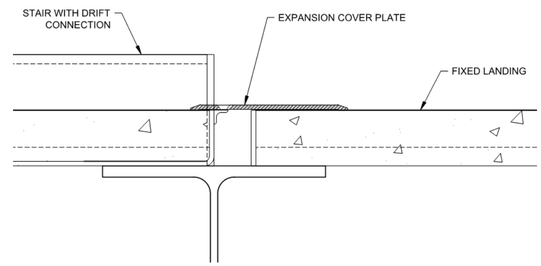
Seismic Displacement – ASCE 7-16

- 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:

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

…likely results in very large forces.

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

48

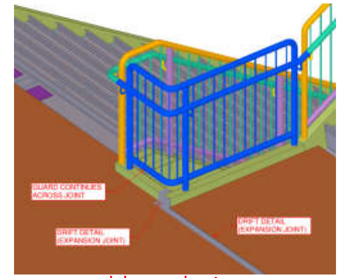
Seismic Displacement – Architectural Restraints

- 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



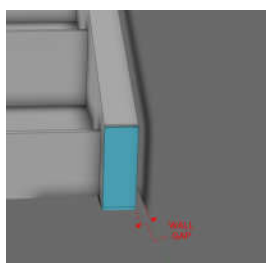
- Damage to nonstructural components caused by relative displacement is acceptable, provided that the performance goals…are achieved (e.g. life safety).

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

Step 8 – Seismic Serviceability

Step 9 – Stairway Design

Step 10 – Examples

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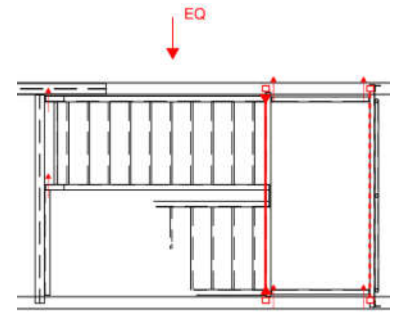
Step 12 – Other Topics

53

Horizontal Load Path

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



54

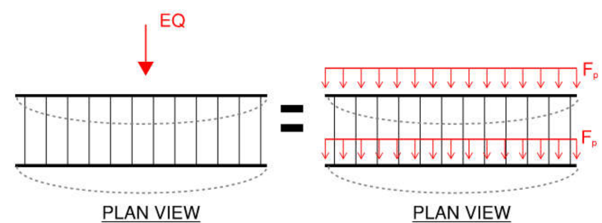
Stair Flight Assembly

- 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

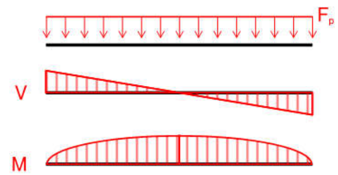
- Option 1 – Individual Simple Span Members



56

Stair Flight Assembly

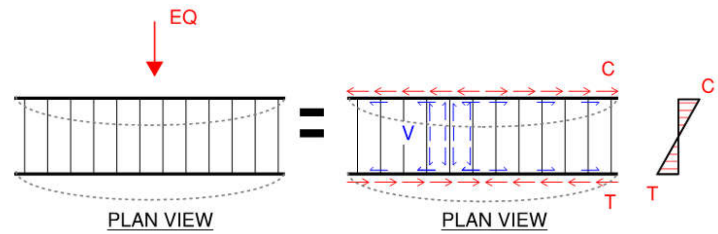
- Option 1 – Individual Simple Span Members
  - Assumes ductile connx or rotation capacity at supports
  - Treat as a simple span beam with uniformly distributed load
  - Design per AISC Spec



57

Stair Flight Assembly

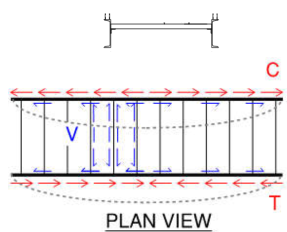
- Option 2 – Built-up Horizontal Beam



58

Stair Flight Assembly

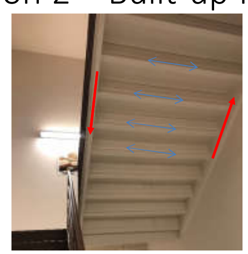
- Option 2 – Built-up Horizontal Beam
  - Assumes ductile connx or rotation capacity at supports
  - Built-up beam may not satisfy local buckling criteria at treads/risers in many cases (AISC, AISI)
  - Difficult to quantify capacity of tread/riser elements

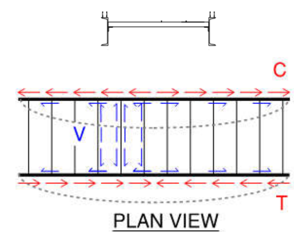


59

Stair Flight Assembly

- Option 2 – Built-up Horizontal Beam

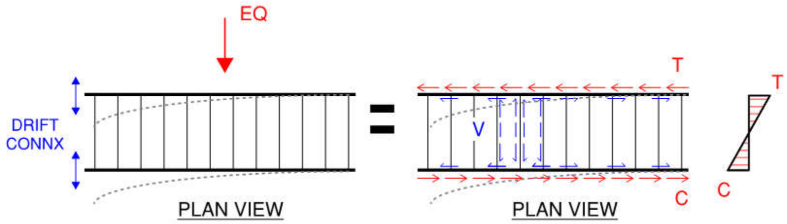




60

Stair Flight Assembly

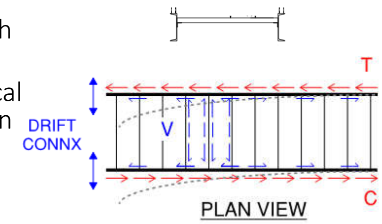
- Option 3 – Cantilever Built-up Horizontal Beam



61

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



62

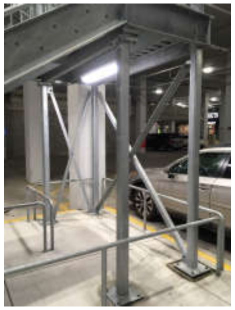
Landing Diaphragm

- 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

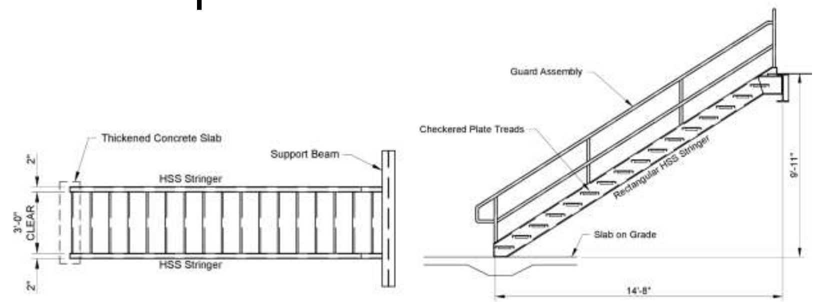
Example 1: Load Determination

Given:

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

67

Example 1: Load Determination



PLAN

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*

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

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*

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

- Minimum Horizontal Seismic Force, *Fp min*

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

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

$$F_p = 0.317 W_p$$

  - Vertical

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

75

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

76

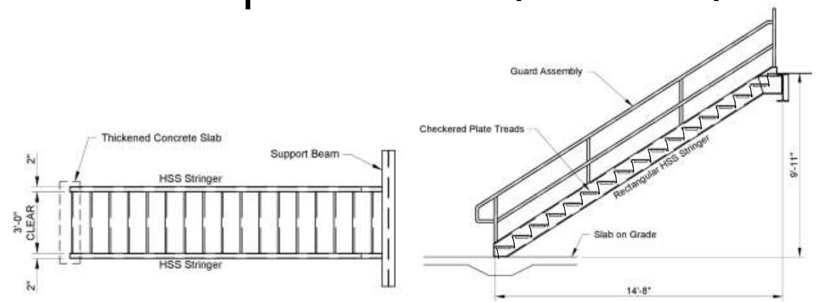
Example 2: Stringer Design

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



PLAN

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

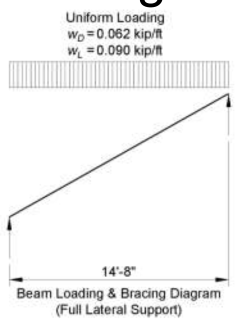
80

Example 2: Stringer Design

- Stringer Gravity Uniform Loads

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

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



Example 2: Stringer Design

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

Example 2: Stringer Design

- Stringer Point Load, 1000 lbs

Point loading	*Point loading*
$V_u = \frac{14.7\text{ ft}}{2}\left[1.2\left(0.0617\text{ kip/ft}\right)\right] + 1.6\left(1\text{ kip}\right)$ $= 2.14\text{ kips}$ GOVERNS	$V_a = \frac{14.7\text{ ft}}{2}\left(0.0617\text{ kip/ft}\right) + 1\text{ kip}$ $= 1.45\text{ kips}$ GOVERNS
$M_u = \frac{1.2\left(0.0617\text{ kip/ft}\right)\left(14.7\text{ ft}\right)^2}{8} + \frac{1.6\left(1\text{ kip}\right)\left(14.7\text{ ft}\right)}{4}$ $= 7.88\text{ kip-ft}$ GOVERNS	$M_a = \frac{\left(0.0617\text{ kip/ft}\right)\left(14.7\text{ ft}\right)^2}{8} + \frac{\left(1\text{ kip}\right)\left(14.7\text{ ft}\right)}{4}$ $= 5.34\text{ kip-ft}$ GOVERNS

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

Example 2: Stringer Design

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

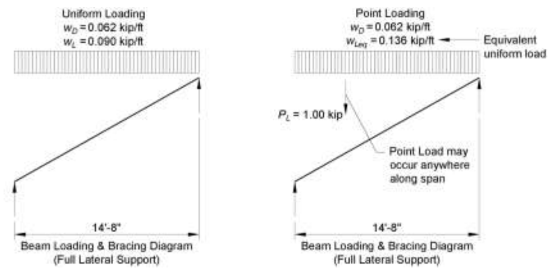
$$P_L = 1\text{ kip}$$
$$M = \frac{PL}{4} = \frac{wL^2}{8}$$

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)
$V_{u,v} = \left(\frac{14.7\text{ ft}}{2}\right)\left[1.33(0.0617\text{ kip/ft}) + 1.0(0) + (0.136\text{ kip/ft})\right] = 1.60\text{ kips}$	$V_{a,v} = \left(\frac{14.7\text{ ft}}{2}\right)\left[1.07(0.0617\text{ kip/ft}) + 0.525(0) + 0.75(0.136\text{ kip/ft})\right] = 1.23\text{ kips}$
$M_{u,v} = \frac{(14.7\text{ ft})^2}{8}\left[1.33(0.0617\text{ kip/ft}) + 1.0(0) + (0.136\text{ kip/ft})\right] = 5.89\text{ kip-ft}$	$M_{a,v} = \frac{(14.7\text{ ft})^2}{8}\left[1.07(0.0617\text{ kip/ft}) + 0.525(0) + 0.75(0.136\text{ kip/ft})\right] = 4.54\text{ kip-ft}$

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
ΦvVn = 142 k > 1.60 k OK
ΦbMp = 75.4 k-ft > 5.89 k-ft OK
ASD
Vn/Ωv = 94.6 k > 1.23 k OK
Mp/Ωb = 50.1 k-ft > 4.54 k-ft OK

HSS12x2x1/4 is adequate for imposed vertical loads

88

Example 2: Stringer Design

- Horizontal Loading

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

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)
$V_{u,h} = \left(\frac{14.7 \text{ ft}}{2}\right)[1.33(0) + 1.0(0.020 \text{ kip/ft}) + 0]$ $= 0.147 \text{ kip}$	$V_{a,h} = \left(\frac{14.7 \text{ ft}}{2}\right)\left[\begin{array}{l}1.07(0) + 0.525(0.020 \text{ kip/ft}) \\ +0.75(0)\end{array}\right]$ $= 0.0772 \text{ kip}$
$M_{u,h} = \frac{(14.7 \text{ ft})^2}{8}[1.33(0) + 1.0(0.020 \text{ kip/ft}) + 0]$ $= 0.540 \text{ kip-ft}$	$M_{a,h} = \frac{(14.7 \text{ ft})^2}{8}\left[\begin{array}{l}1.07(0) + 0.525(0.020 \text{ kip/ft}) \\ +0.75(0)\end{array}\right]$ $= 0.284 \text{ kip-ft}$

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

91

Example 2: Stringer Design

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

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

HSS12x2x1/4 is adequate for seismic loads

92

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"

99

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

100

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

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading
Step 8 – Seismic Serviceability
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Step 10 – Examples
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Step 12 – Other Topics

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

Tolerances - Concrete

- Field verify dimensions based on actual construction!

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

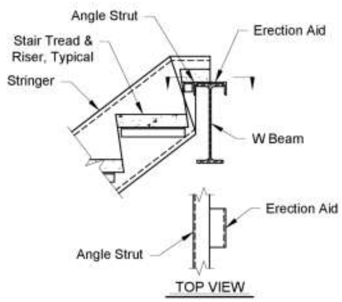
Erectability

- 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

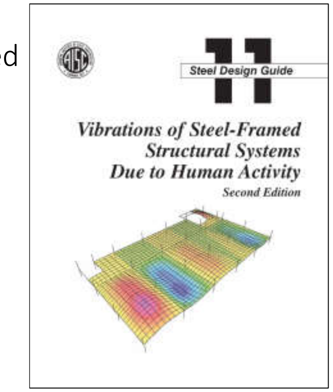
Erectability

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



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



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!

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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.

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Individual Registration

PDH Certificates

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

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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.

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Individual Registration

Course Resources

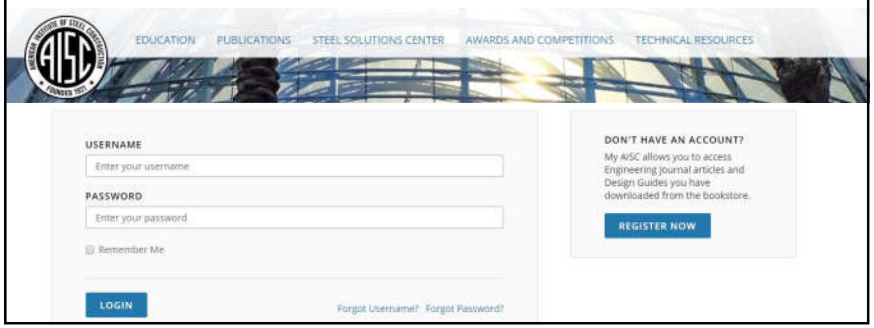
Access to video recordings and quizzes can be found on your AISC account.

Smarter. Stronger. Steel.

Individual Registration

Course Resources

Go to www.aisc.org and sign in.



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Course Resources

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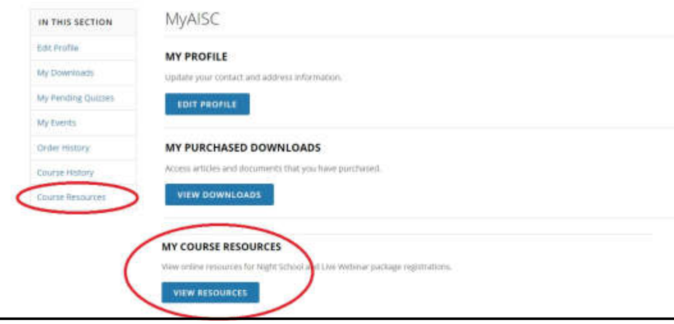
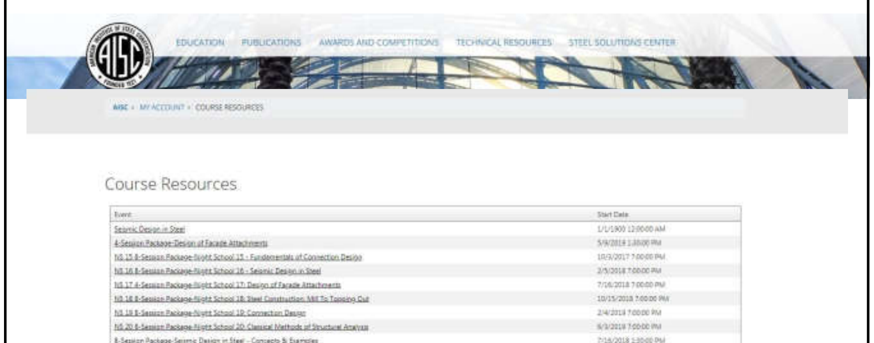


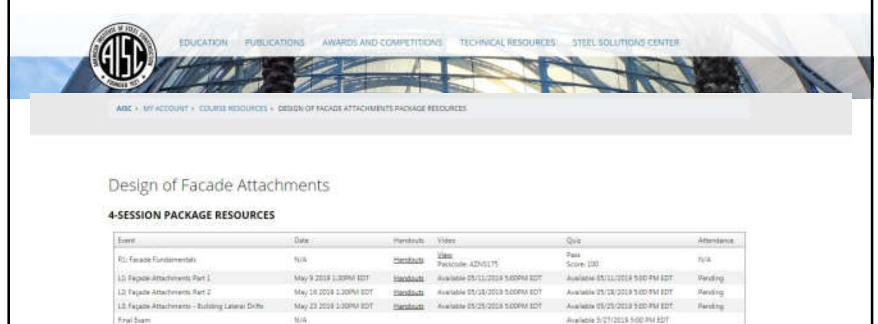
Individual Registration

Course Resources



Individual Registration

Course Resources




AISC | Thank you
Smarter.
Stronger.
Steel.