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Course Description

Steel Framed Stairway Design

Part 2: Seismic Loads & Delegated Design

June 6, 2018

This session 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.



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.

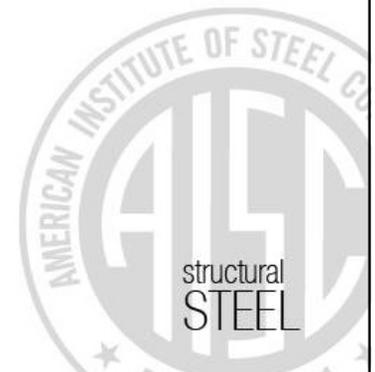


Steel Framed Stairway Design

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Presented by
Adam Friedman
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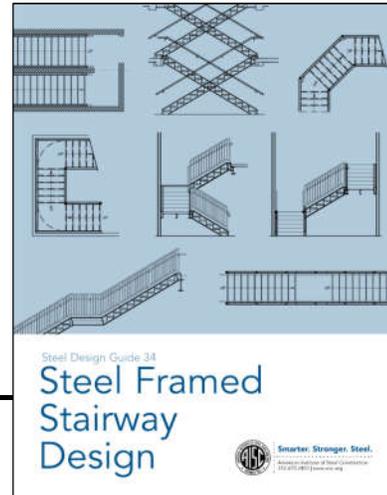


Introduction

AISC Design Guide 34: Steel Framed Stairway Design

to be published late summer / fall

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



9

Outline – Part 1 Recap

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



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

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

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Step 12 – Other Topics



12



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



Load Combinations

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

LRFD

1. $1.4D$
2. $1.2D+1.6L+0.5(Lr \text{ or } S \text{ or } R)$
3. $1.2D+1.6(Lr \text{ or } S \text{ or } R)+1.0(L \text{ or } 0.5W)$
4. $1.2D+1.0W+1.0L+0.5(Lr \text{ or } S \text{ or } R)$
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. $D+(Lr \text{ or } S \text{ or } R)$
4. $D+0.75L+0.75(Lr \text{ or } S \text{ or } R)$
5. $D+0.6W$
6. $D+0.75L+0.75(0.6W)+0.75(Lr \text{ or } S \text{ or } R)$
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



15

Loading – ASCE 7-16

- Horizontal Seismic Design Force, Eq. 13.3-1

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

F_p = horizontal seismic design force at component center of gravity

- I_p = component importance factor per Section 13.1.3

Refer to Table 13.5-1

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



16



Loading – ASCE 7-16, Table 13.5-1

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 <u>seismic force-resisting system</u>	1	2 ½	2 ½ 2
Egress stairs and ramp fasteners and attachments	2 ½	2 ½	2 ½

Previously (ASCE 7-10):

$$a_p = 1, R_p = 2\frac{1}{2}, \Omega_0 = 2\frac{1}{2}$$

a_p = component amplification factor

R_p = component response modification factor

Ω_0 = overstrength factor for anchorage to concrete & masonry



Loading – ASCE 7-16, Table 13.5-1

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R_p = component response modification factor

Ω_0 = overstrength factor for anchorage to concrete & masonry



Loading – ASCE 7-16, Table 13.5-1

- Multiple design criteria
 1. Design of members and connection material:
 - $a_p=1.0$, $R_p=2.5$
 2. Design of fasteners/attachment (bolts/welds):
 - $a_p=2.5$, $R_p=2.5$ *(250% increase in forces from 2010)*



19

Loading – ASCE 7-16, Table 13.5-1

3. Design of fasteners/attachment (anchors, embeds) in concrete/masonry:
 - $\Omega_o = 2.5$ *(250% increase in forces from 2010 due to $a_p = 2.5$)*
 - Or ductile yielding of support/component
4. Design of concrete/masonry member:
 - $\Omega_o = 2.0$ *(20% reduction in forces from 2010)*
 - Or ductile yielding of support/component



20



Loading – ASCE 7-16

- Horizontal Seismic Design Force, Eq. 13.3-1

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

For stair members:

- $I_p = 1.5$
- Refer to Table 13.5-1
- $a_p = 1.0$
- $R_p = 2.5$



21

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



22



Loading – ASCE 7-16

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

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

- Maximum per Eq 13.3-2

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



23

Loading – ASCE 7-16

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

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

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

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



24



Loading – ASCE 7-16

- Vertical Seismic Design Force per Section 13.3.1.2

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

Seismic Load Combos

Refer to Sections 2.3.6 LRFD, 2.4.5 ASD, & 12.4.2.1/12.4.2.2 for combinations with F_{pv}

LRFD

- 1.2D+0.2 S_{DS} D+Q_E+L+0.2S
- 0.9-0.2 S_{DS} D+Q_E

ASD

- 1.0D+0.7(0.2 S_{DS})D+0.7Q_E
- 1.0D+0.525(0.2 S_{DS})D+0.75L+0.525Q_E+0.75S
- 0.6D-0.7(0.2 S_{DS})D+0.7Q_E

Apply to dead load only



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
- $\Omega_0 = 2.0$ to 2.5 (SDC = B*, C, D, E, F) * $\Omega_0 = 1.0$ for SDC B for concrete per ACI 318-14 section 17.2.3.1

LRFD

- 1.2D+0.2 S_{DS} D+ Ω_0 Q_E+L+0.2S
- 0.9D-0.2 S_{DS} D+ Ω_0 Q_E

ASD

- 1.0D+0.7(0.2 S_{DS})D+0.7 Ω_0 Q_E
- 1.0D+0.525(0.2 S_{DS})D+0.75L+0.525 Ω_0 Q_E+0.75S
- 0.6D-0.7(0.2 S_{DS})D+0.7 Ω_0 Q_E

Apply Ω_0 to seismic portion of load only



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



27

Seismic Serviceability – ASCE 7-16

- Section 13.5.10 Egress Stairs & Ramps
 - Shall accommodate seismic displacement, D_{pl}
 - Occur in any horizontal direction
 - Positive attachment
 - Direct structural supports or mechanical connections
 - **Not** part of seismic force-resisting system of structure



28

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



29

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



30



Seismic Serviceability – ASCE 7-16

EXCEPTION:

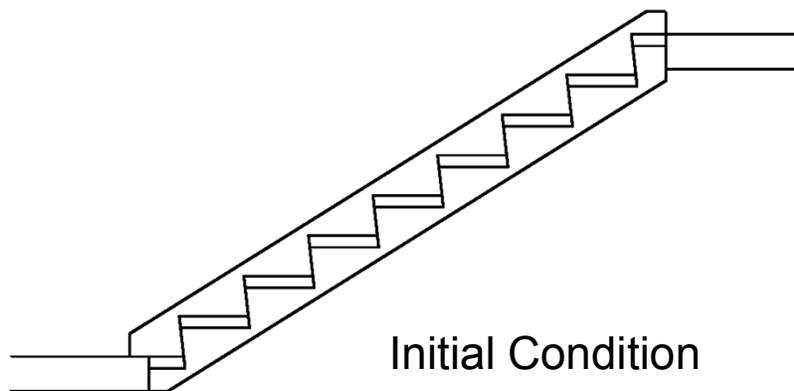
- If sliding or ductile connections not provided then stair **must be designed in the building structural model** and designed for Ω_0 of structure, but minimum 2.5.



31

Serviceability – ASCE7-16 Section 13.3.2

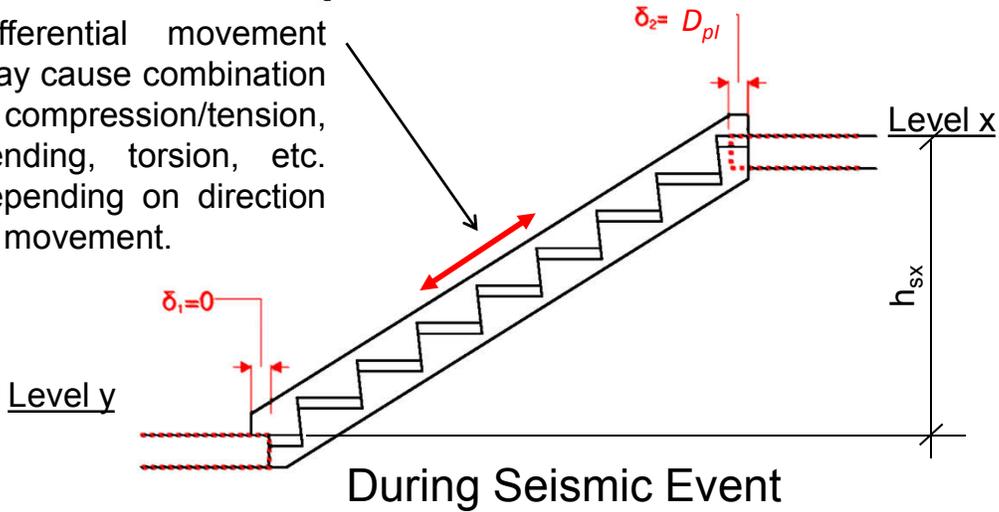
- Seismic Displacement=Differential lateral movements between adjacent floors



32

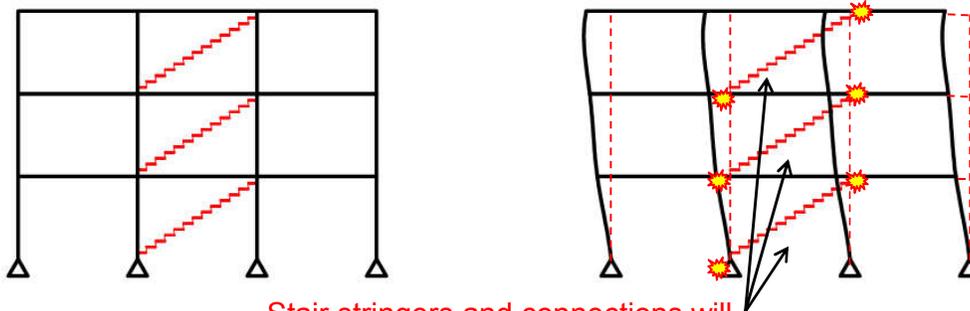
Seismic Displacement – ASCE 7-16

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



Seismic Displacement – ASCE 7-16

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



Stair stringers and connections will resist seismic forces instead of SFRS.



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.



35

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**



36



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.



37

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



38



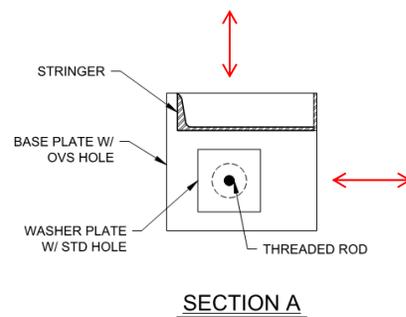
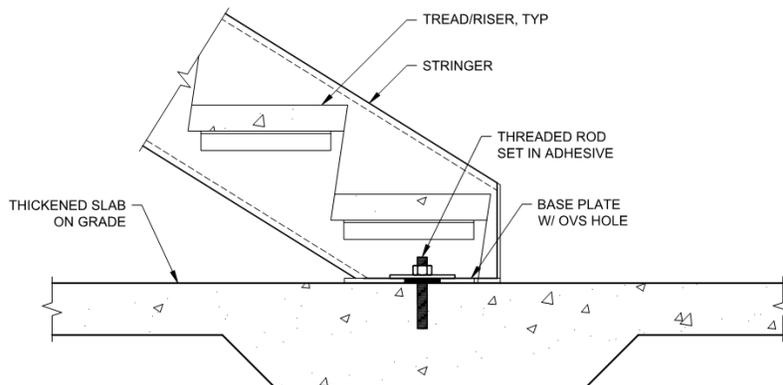
Seismic Displacement – ASCE 7-16

- 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

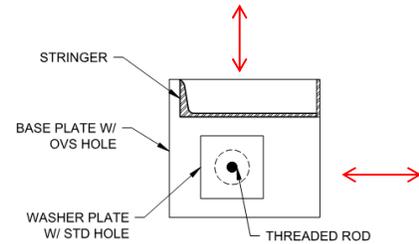
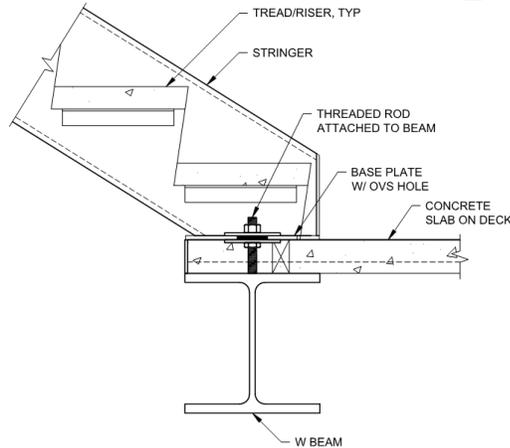


Lateral loads must be resisted at other end of stair flight.



Seismic Displacement – ASCE 7-16

- Drift Detail at Wide Flange Beam



SECTION A

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



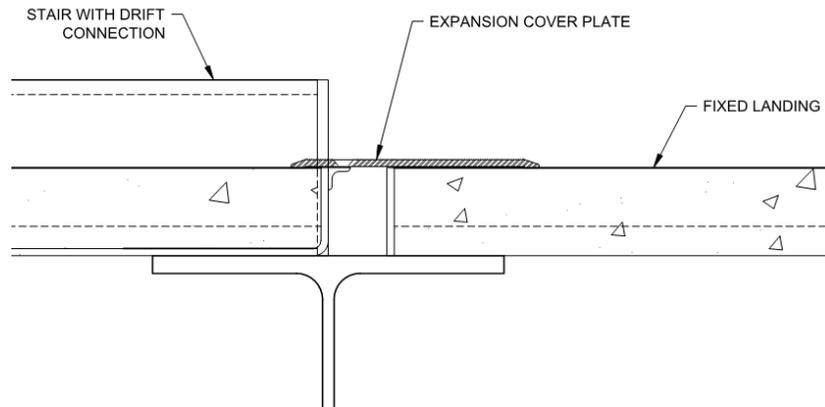
Seismic Displacement – ASCE 7-16

- 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



Seismic Displacement – ASCE 7-16

- Expansion joint or expansion cover



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



43

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



44



Seismic Displacement – ASCE 7-16

- Design for imparted forces...
...but remember:

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

...likely results in very large forces.

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



45

Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

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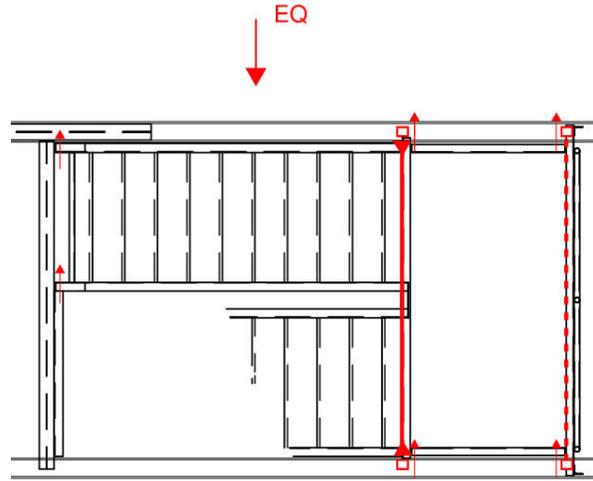


46



Horizontal Load Path

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



47

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

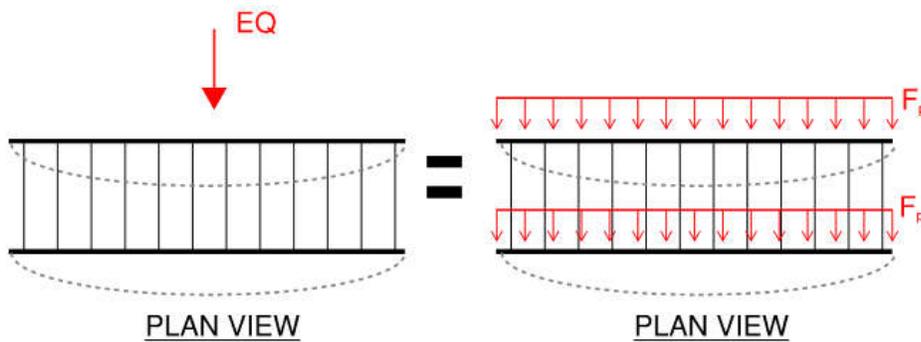


48



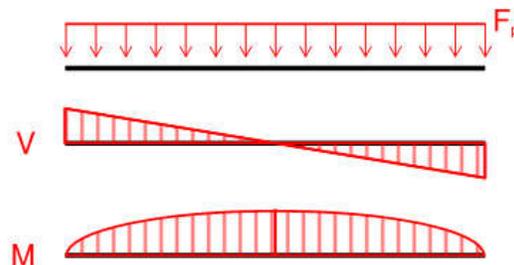
Stair Flight Assembly

- Option 1 – Individual Simple Span Members



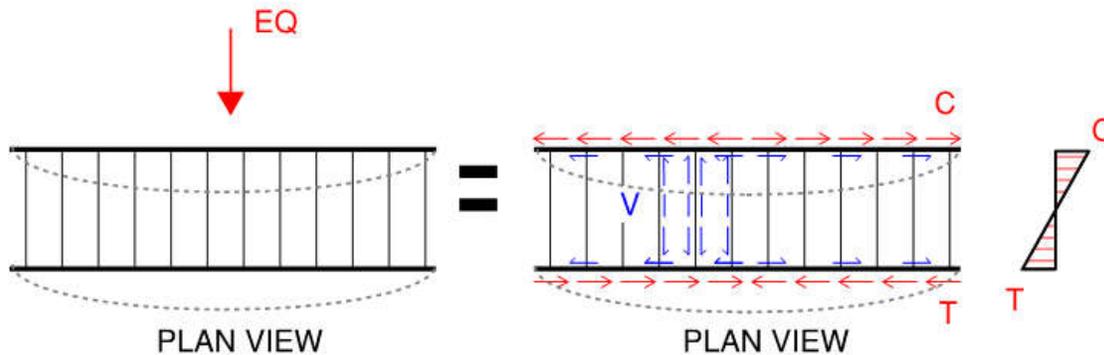
Stair Flight Assembly

- 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



Stair Flight Assembly

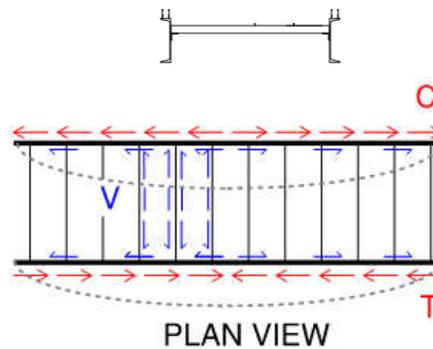
- Option 2 – Built-up Horizontal Beam



Stair Flight Assembly

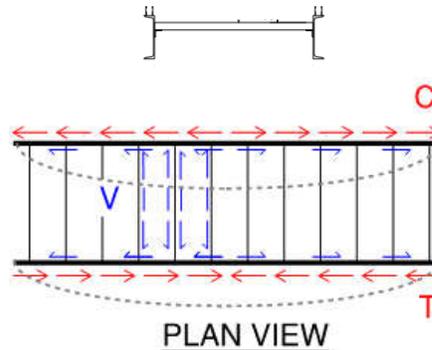
- Option 2 – Built-up Horizontal Beam

- 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



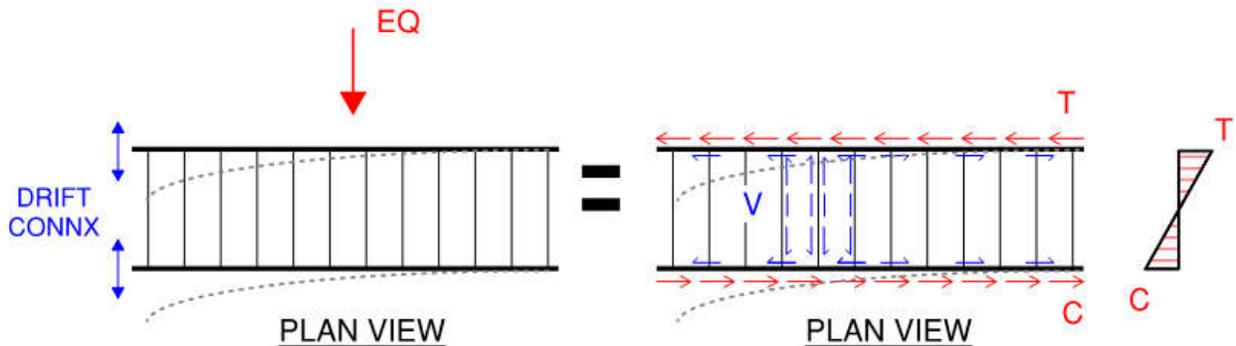
Stair Flight Assembly

- Option 2 – Built-up Horizontal Beam



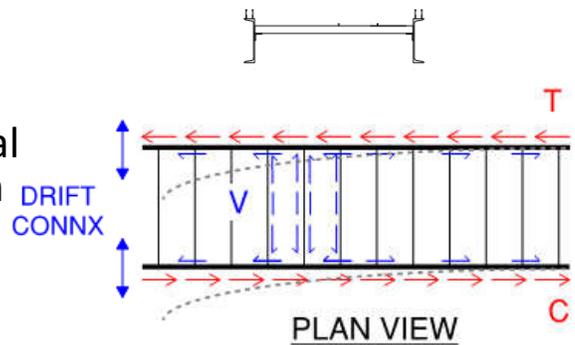
Stair Flight Assembly

- 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



55

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

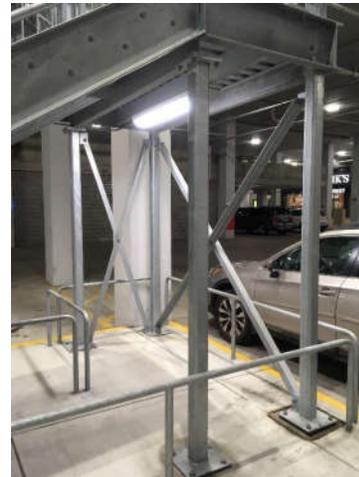


56



Vertical Load Path

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



Vertical Lateral Load Resisting Systems

Type	Advantages	Disadvantages
Tension Only Bracing	<ul style="list-style-type: none"> • Smaller member sizes • Can be concealed in walls • Can fit under landings 	<ul style="list-style-type: none"> • Will require more members and more connections
Tension-Compression Bracing	<ul style="list-style-type: none"> • Less members • Less connections • Can be concealed in walls • Can fit under landings 	<ul style="list-style-type: none"> • Members may be heavier and larger • Splices at member intersections are needed
Moment Frames	<ul style="list-style-type: none"> • Members do not cross path of travel (if required) • Can be concealed in walls • Beam member can also act as landing support member 	<ul style="list-style-type: none"> • More lateral drift than other options • Connections typically more complex and more expensive



Outline – Part 2

Step 7 – Code Requirements – Seismic Loading

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59

Example 1: Load Determination

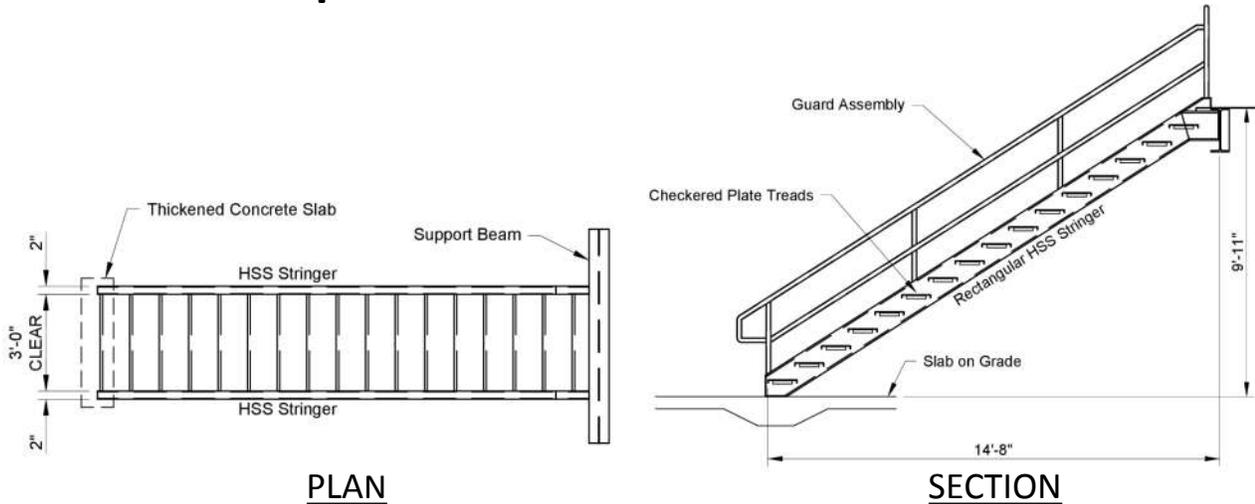
Given:

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



60

Example 1: Load Determination



Example 1: Load Determination

- Load Combinations, ASCE7-16, 2.3.1 & 2.4.1

LRFD
 $\geq 1.2D + 1.6L$

ASD
 $D+L \geq$



Example 1: Load Determination

- Load Combinations, ASCE7-16, 2.3.6 & 2.4.5

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



Example 1: Load Determination

- Horizontal Seismic Force, F_p

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

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



Example 1: Load Determination

- Horizontal Seismic Force, F_p

$$F_p = \frac{0.4(1.0)(0.660)W_p}{\left(\frac{2.5}{1.5}\right)} \left[1 + 2 \left(\frac{9.92 \text{ ft}}{19.8 \text{ ft}} \right) \right]$$
$$= 0.317W_p$$



65

Example 1: Load Determination

- Maximum Horizontal Seismic Force, $F_p \text{ max}$

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

- Minimum Horizontal Seismic Force, $F_p \text{ min}$

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



66

Example 1: Load Determination

- Vertical Seismic Force, F_{pv}

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



67

Example 1: Load Determination

- Summary

- Horizontal

$$F_p = 0.317 W_p$$

- Vertical

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

Remember, this is built
into load combinations



68

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



69

Example 2: Stringer Design

Given:

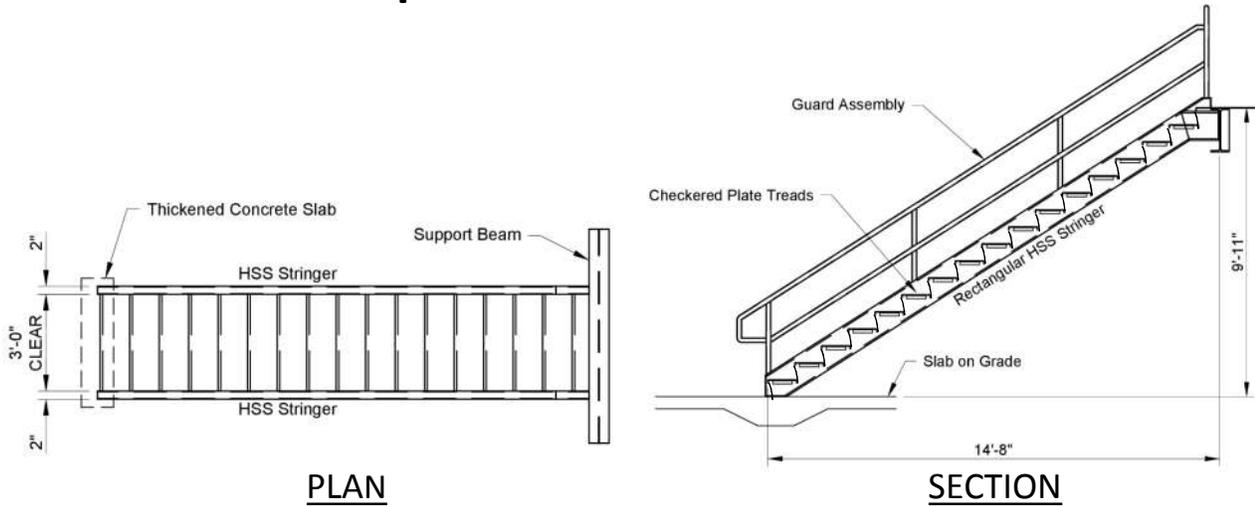
- Supports with rotation capacity to accommodate seismic displacement using ductile connections
- Checkered plate tread/risers
 - Stringer fully braced
 - For seismic lateral loads, design as individual members



70



Example 2: Stringer Design



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



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



Example 2: Stringer Design

- Stringer Gravity Uniform Loads

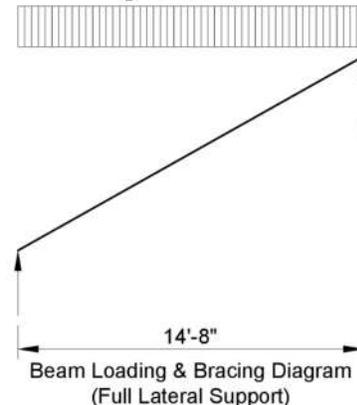
$$w_D = \left(\frac{3 \text{ ft}}{2}\right)(0.010 \text{ kip/ft}^2) + (0.0267 \text{ kip/ft} + 0.020 \text{ kip/ft})$$

$$= 0.0617 \text{ kip/ft}$$

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

$$= 0.090 \text{ kip/ft}$$

Uniform Loading
 $w_D = 0.062 \text{ kip/ft}$
 $w_L = 0.090 \text{ kip/ft}$



Example 2: Stringer Design

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



Example 2: Stringer Design

- Stringer Point Load, 1000 lbs

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



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

$$\Phi_v V_n = 142 \text{ k} > 2.14 \text{ k OK}$$

$$\Phi_b M_p = 75.4 \text{ k-ft} > 7.88 \text{ k-ft OK}$$

ASD

$$V_n / \Omega_v = 94.6 \text{ k} > 1.45 \text{ k OK}$$

$$M_p / \Omega_b = 50.1 \text{ k-ft} > 5.34 \text{ k-ft OK}$$

HSS12x2x1/4 is adequate for imposed gravity loads



Example 2: Stringer Design

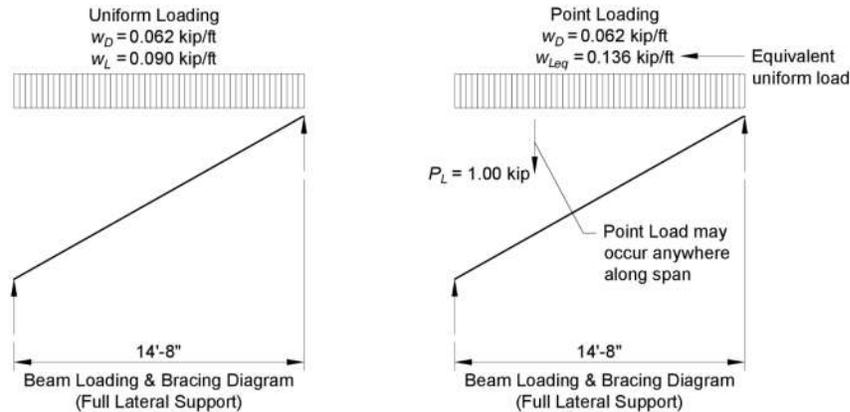
- Seismic Loading

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

$$\begin{aligned}
 P_L &= 1 \text{ kip} \\
 M &= \frac{PL}{4} \\
 &= \frac{wL^2}{8}
 \end{aligned}
 \quad \text{therefore...}
 \quad
 \begin{aligned}
 w_{Leq} &= \frac{2P}{L} \\
 &= \frac{2(1 \text{ kip})}{14.7 \text{ ft}} \\
 &= 0.136 \text{ kip/ft} \\
 w_{Leq} &= 0.136 \text{ kip/ft} > w_L = 0.090 \text{ kip/ft}
 \end{aligned}$$



Example 2: Stringer Design



Example 2: Stringer Design

- Stringer Vertical Loads, Seismic Load Combo

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



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

$$\Phi_v V_n = 142 \text{ k} > 1.60 \text{ k OK}$$

$$\Phi_b M_p = 75.4 \text{ k-ft} > 5.89 \text{ k-ft OK}$$

ASD

$$V_n / \Omega_v = 94.6 \text{ k} > 1.23 \text{ k OK}$$

$$M_p / \Omega_b = 50.1 \text{ k-ft} > 4.54 \text{ k-ft OK}$$

HSS12x2x1/4 is adequate for imposed vertical loads



Example 2: Stringer Design

- Horizontal Loading

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



Example 2: Stringer Design

- Horizontal Loads, Seismic Load Combo

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



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

$$\Phi_v V_n = 16.4 \text{ k} > 0.147 \text{ k OK}$$

$$\Phi_b M_p = 13.3 \text{ k-ft} > 0.540 \text{ k-ft OK}$$

ASD

$$V_n / \Omega_v = 10.9 \text{ k} > 0.077 \text{ k OK}$$

$$M_p / \Omega_b = 8.87 \text{ k-ft} > 0.284 \text{ k-ft OK}$$



Example 2: Stringer Design

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

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

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



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



87

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



88



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



89

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



90



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.



91

Delegated Design

- Delegated Design ≠ “Not my problem”



92



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



93

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



94



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



95

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



96



Tolerances - Concrete



- Field verify dimensions based on actual construction!



97

Tolerances

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



98



Tolerances

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



99

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)



100



Erectability

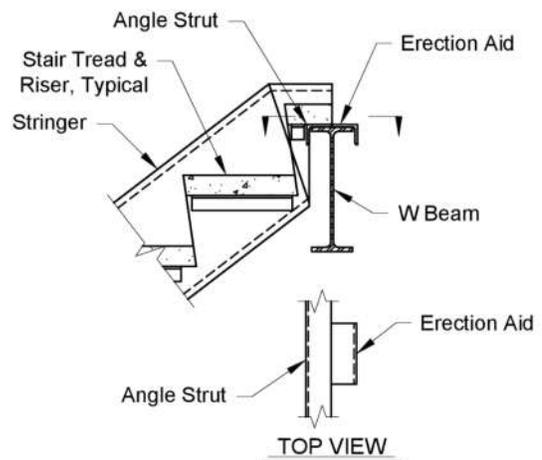
- Think about installation
 - Stringers adjacent to concrete/masonry walls may have limited access to install bolts
 - Will masonry supports be in place?
- Erector preferences
 - Bolting versus Welding



101

Erectability

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

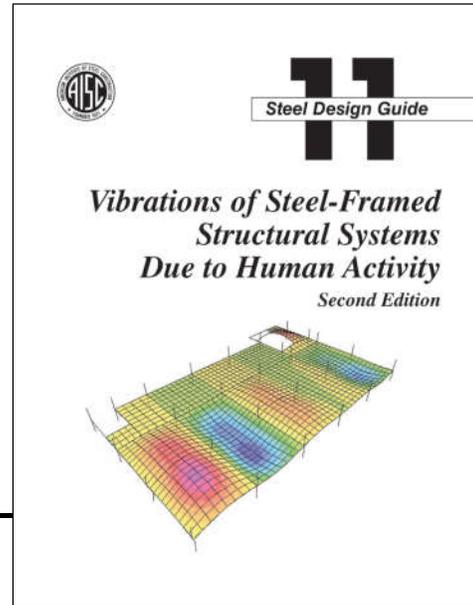


102



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



103

Questions?

104



PDH Certificates

Within 2 business days...

- 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!
-



PDH Certificates

Within 2 business days...

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



There's always a solution in steel.

Thank You

Please give us your feedback!
Survey at conclusion of webinar.

