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**Lateral Load Transfer**  
**From Diaphragms to Resisting Elements**  
August 15, 2019



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## AISC Live Webinars

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# AISC Live Webinars

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# AISC Live Webinars

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## Course Description

Lateral Load Transfer From Diaphragms to Resisting Elements  
August 15, 2019

This webinar will examine how loads flow through building diaphragms and collectors to the vertical elements of the lateral force-resisting system. Using examples from real projects, the presentation will address the challenges that arise when connecting steel framing to various types of lateral systems, with a focus on effective detailing practices and understanding the diaphragm-specific seismic provisions of ASCE 7. Drawing from the speaker's extensive experience with major building projects, the webinar will include some monumental case studies you won't want to miss, including the attachment of diaphragms to the revolutionary SpeedCore system.



## AISC Live Webinars

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### Learning Objectives

- List the components and force effects that should be considered in the safe design of diaphragms.
- Explain why ASCE 7 prescribes different seismic lateral loads for the design of diaphragms than for the design of the lateral force-resisting system vertical elements.
- Identify building configurations that can result in significant transfer forces, which must be accounted for in the structural design.
- Describe effective detailing practices for connecting diaphragm collectors to braced frames and shear walls.



## Lateral Load Transfer From Diaphragms to Resisting Elements



Thomas R. Meyer, PE, SE  
Principal  
Magnusson Klemencic Associates  
Seattle, Washington



## Lateral Load Transfer From Diaphragms to Resisting Elements

- The Role of Diaphragms
- Diaphragm Components
- ASCE Seismic Design Force Provisions
  - Diaphragms
  - Collectors
- Diaphragms to Shear Walls
- Diaphragms to Boundary Elements
- Boundary Element to Boundary Element
- Collectors to Shear Walls



9

# The Role of Diaphragms

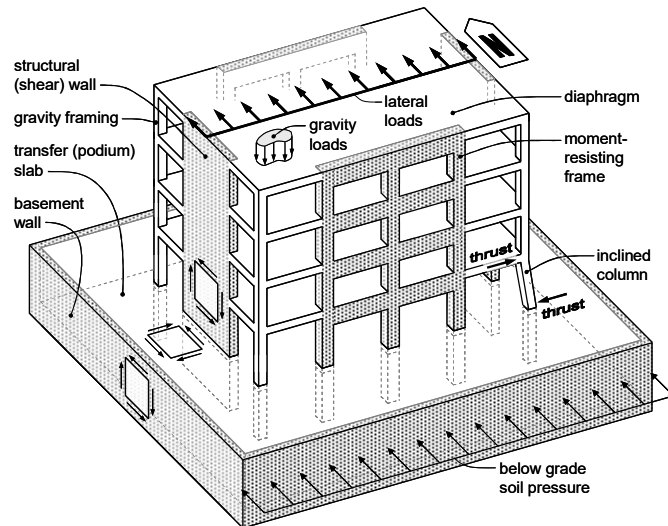


10



## The Role of Diaphragms

- Gravity Forces
- Inertial Forces
- Wind Forces
- Transfer Forces
- Thrust from Inclined Columns



## Diaphragm Components



## Diaphragm Components

AISC 360, Section B3.5

### **Design of Diaphragms and Collectors**

Diaphragms and collectors shall be designed for forces that result from loads as stipulated in Section B2. They shall be designed in conformance with the provisions of Chapters C through K, as applicable.



13

## Diaphragm Components

ASCE 7, Section 12.10.1

Diaphragms shall be designed for both the shear and bending stresses resulting from design forces. At diaphragm discontinuities, such as reentrant corners, the design shall ensure that dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm.



14



## Diaphragm Components

ASCE 7, Section 12.10.1

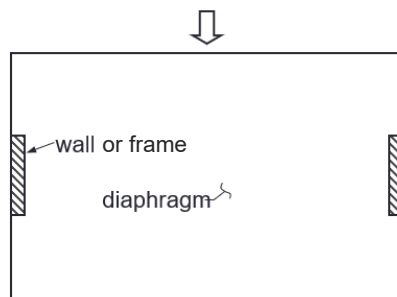
**Diaphragms shall be designed for both the shear and bending stresses resulting from design forces.** At diaphragm discontinuities, such as reentrant corners, the design shall ensure that dissipation or transfer of edge (chord) forces combined with other forces in the diaphragm is within shear and tension capacity of the diaphragm.



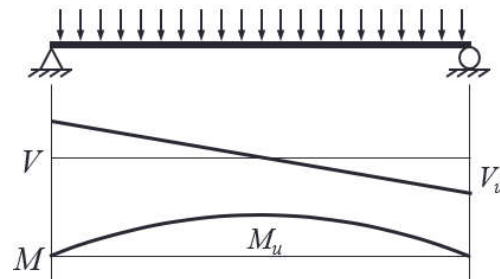
15

## Diaphragm Components

Diaphragm Idealization



(a) Plan



(b) Simple beam idealization

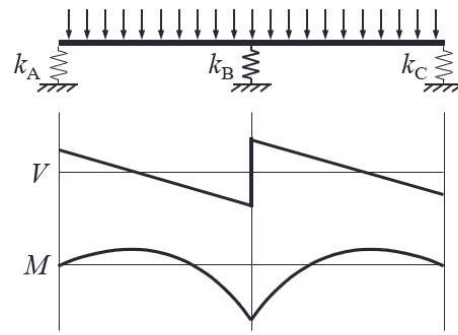
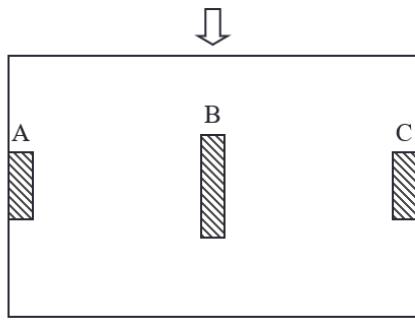


16



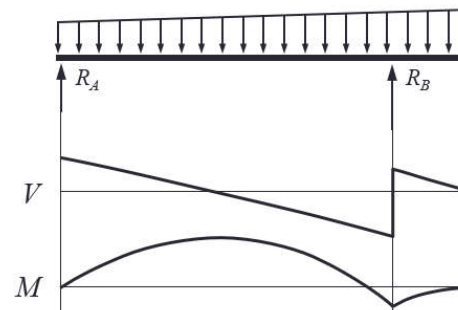
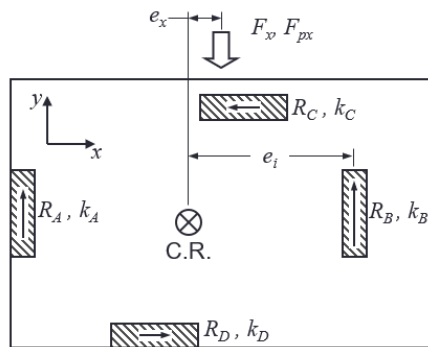
## Diaphragm Components

### Diaphragm Idealization



## Diaphragm Components

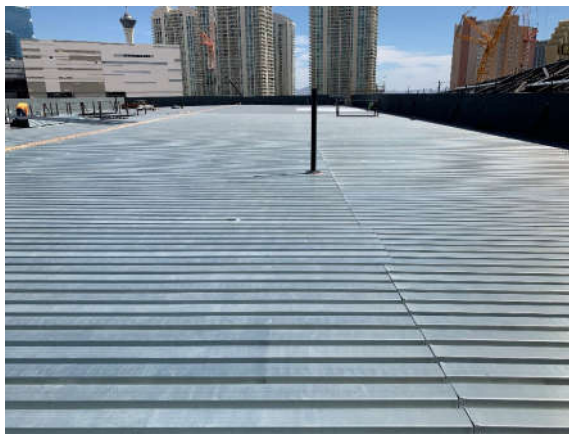
### Diaphragm Idealization



## Diaphragm Components

Flexible vs. Rigid ASCE 7-16, Section 12.3)

- Flexible
  - Prescriptive
  - Calculated

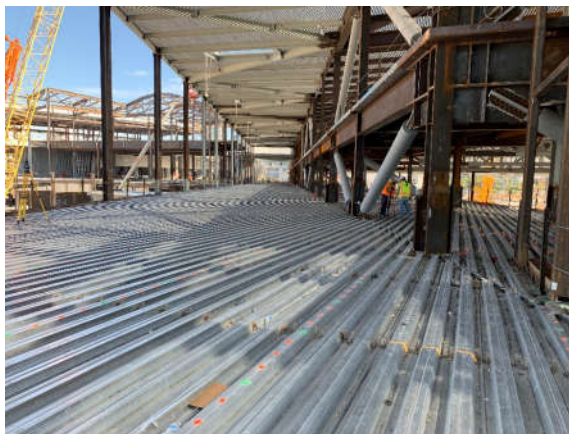


19

## Diaphragm Components

Flexible vs. Rigid ASCE 7-16, Section 12.3)

- Rigid
  - Prescriptive
  - Span-to-depth must be  $\leq 3$

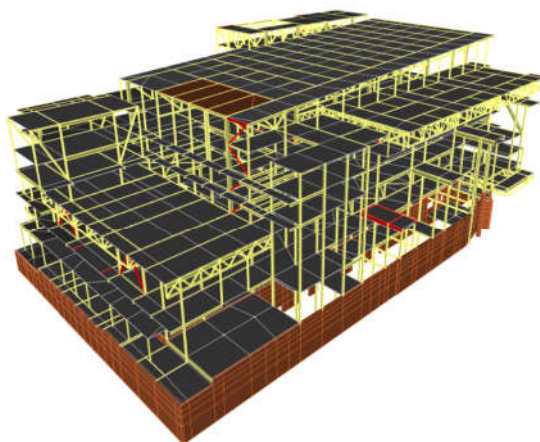


20

## Diaphragm Components

Flexible vs. Rigid ASCE 7-16, Section 12.3)

- All others (semi-rigid)
  - Diaphragm flexibility must be considered in the analysis



21

## Diaphragm Components

Slab on Steel Deck Diaphragm Approaches

AISC 341, Section D1.5a

- Details shall be provided to transfer load between the diaphragm and boundary members, collector elements, and elements of the horizontal framing system.



22



## Diaphragm Components

### Slab on Steel Deck Diaphragm Approaches

AISC 341, Section D1.5b

- Diaphragm is the topping slab above the flutes designed per ACI 318
- Diaphragm is the slab on deck assembly using in plane shear tests (such as ICC-ES or IAPMO-UES report values)



23

## Diaphragm Components

### Topping Slab Diaphragm Approaches

Topping slab designed per ACI 318

- Topping thickness
- Concrete compressive strength
- Reinforcement ratio



24

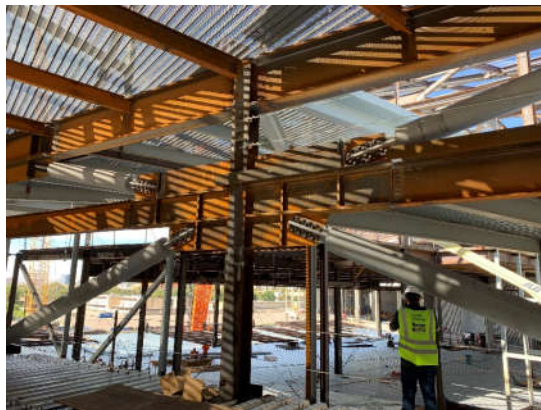


## Diaphragm Components

### Slab on Steel Deck Diaphragm Approaches

#### Slab on deck assembly

- Deck thickness (gage)
- Support (beam) spacing
- Stud count
- Deck attachments to support
- Deck sidelap attachments
- Minimum slab reinforcement



25



## Diaphragm Components

### Slab on Steel Deck Diaphragm Approaches

#### Support Fasteners

- Welds
- Mechanical fasteners



26

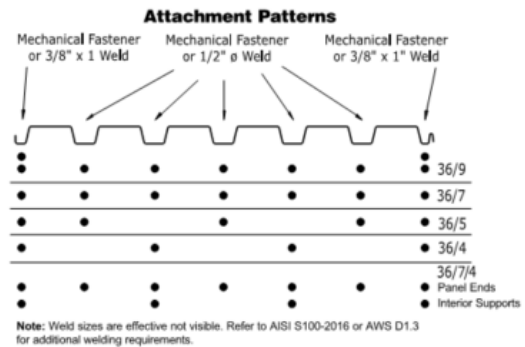


## Diaphragm Components

### Slab on Steel Deck Diaphragm Approaches

#### Support Fasteners

- Welds
- Mechanical fasteners



## Diaphragm Components

### Slab on Steel Deck Diaphragm Approaches

#### Sidelap Fasteners

- Welds
- Screws
- Proprietary systems



# Diaphragm Components

Slab on Steel Deck  
Diaphragm Approaches

## No. 12 Self-Drilling Screws to Supports with DeltaGrip® Side Seam Attachment

Diaphragm Shear in pounds per linear foot (plf)



### Design Tables

- Strength
- Stiffness

Gage	Support Fastener	Seam Spacing (in)	Allowable Shear, $q_n$ , Factored Shear, $q_f$ and Flexibility Factor, $F$ ( $10^6$ in/lbs)													
			Span (ft)	4	5	6	7	8	9	10	11	12				
20	36/7/4	4	q <sub>n</sub>   q <sub>f</sub>	1439   2133	1431   2115	1423   2107	1415   2099	1407   2091	1400   2083	1392   2075	1384   2067	1376   2059	1368   2051	1360   2043	1352   2035	
		F	6.0-0R	6.1-0-0R	6.2-0-0R	6.3-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R
		6	q <sub>n</sub>   q <sub>f</sub>	1329   2140	1311   2130	1293   2120	1275   2110	1257   2100	1239   2090	1221   2080	1203   2070	1185   2060	1167   2050	1149   2040	1131   2030	1113   2020
		F	6.7-1R	7.0-0R	7.2-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R	7.4-0-0R
		8	q <sub>n</sub>   q <sub>f</sub>	1230   2000	1228   1996	1226   1992	1224   1988	1222   1984	1220   1980	1218   1976	1216   1972	1214   1968	1212   1964	1210   1960	1208   1956	1206   1952
		F	7.4-2R	7.5-2-2R	8.1-3R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R	8.1-1-0R
	12	q <sub>n</sub>   q <sub>f</sub>	1076   1752	1034   1691	1003   1630	980   1569	961   1502	946   1438	934   1374	924   1310	916   1246	910   1182	906   1118	904   1054	904   990	
	F	8.3-1-0R	8.8-2R	9.3-2R	9.7-1-0R	10-1-0R	10.3-1-0R	10.5-1-0R	10.7-1-0R	10.8-1-0R	10.9-1-0R	10.9-1-0R	10.9-1-0R	10.9-1-0R	10.9-1-0R	
	18	q <sub>n</sub>   q <sub>f</sub>	972   1580	944   1533	922   1487	903   1441	888   1395	876   1349	867   1303	861   1257	857   1211	855   1165	855   1119	856   1073	858   1027	
	F	8.9-2R	9.4-2-0R	10.0-2-0R	10.6-2-0R	11.2-2-0R	11.7-2-0R	12.2-2-0R	12.7-2-0R	13.2-2-0R	13.7-2-0R	14.2-2-0R	14.7-2-0R	15.2-2-0R	15.7-2-0R	
	24	q <sub>n</sub>   q <sub>f</sub>	841   1367	826   1338	813   1309	802   1280	793   1251	787   1222	783   1193	781   1164	781   1135	782   1106	784   1077	787   1048	791   1019	
	F	9.7-3R	10.2-2-0R	10.8-2-0R	11.4-2-0R	12.0-2-0R	12.6-2-0R	13.2-2-0R	13.8-2-0R	14.4-2-0R	15.0-2-0R	15.6-2-0R	16.2-2-0R	16.8-2-0R	17.4-2-0R	
36	q <sub>n</sub>   q <sub>f</sub>	709   1167	709   1153	710   1140	712   1127	715   1114	719   1101	724   1088	730   1075	737   1062	745   1049	754   1036	764   1023	775   1010		
F	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R	11.2-3-0R		
36/4	4	q <sub>n</sub>   q <sub>f</sub>	1439   2133	1431   2115	1423   2107	1415   2099	1407   2091	1400   2083	1392   2075	1384   2067	1376   2059	1368   2051	1360   2043	1352   2035		
	F	6.0-0R	6.1-0-0R	6.2-0-0R	6.3-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R	6.4-0-0R		
	6	q <sub>n</sub>   q <sub>f</sub>	1329   2140	1311   2130	1293   2120	1275   2110	1257   2100	1239   2090	1221   2080	1203   2070	1185   2060	1167   2050	1149   2040	1131   2030		
	F	6.2-0-0R	6.3-0-0R	6.4-0-0R	6.4-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R	6.5-0-0R		
	8	q <sub>n</sub>   q <sub>f</sub>	1230   2000	1228   1996	1226   1992	1224   1988	1222   1984	1220   1980	1218   1976	1216   1972	1214   1968	1212   1964	1210   1960	1208   1956		
	F	7.2-3-0R	7.4-0-0R	7.6-0-0R	7.7-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R	7.8-0-0R		
12	q <sub>n</sub>   q <sub>f</sub>	1076   1752	1034   1691	1003   1630	980   1569	961   1502	946   1438	934   1374	924   1310	916   1246	910   1182	906   1118	904   1054			
F	8.3-3-0R	8.8-1-0R	9.3-1-0R	9.7-1-0R	10-1-0R	10.3-1-0R	10.5-1-0R	10.7-1-0R	10.8-1-0R	10.9-1-0R	10.9-1-0R	10.9-1-0R	10.9-1-0R			
18	q <sub>n</sub>   q <sub>f</sub>	972   1580	944   1533	922   1487	903   1441	888   1395	876   1349	867   1303	861   1257	857   1211	855   1165	855   1119	856   1073			
F	9.3-3-0R	9.9-1-0R	10.5-1-0R	11.1-1-0R	11.7-1-0R	12.3-1-0R	12.9-1-0R	13.5-1-0R	14.1-1-0R	14.7-1-0R	15.3-1-0R	15.9-1-0R	16.5-1-0R			
24	q <sub>n</sub>   q <sub>f</sub>	841   1367	826   1338	813   1309	802   1280	793   1251	787   1222	783   1193	781   1164	781   1135	782   1106	784   1077	787   1048			
F	10.3-2-0R	10.8-2-0R	11.4-2-0R	12.0-2-0R	12.6-2-0R	13.2-2-0R	13.8-2-0R	14.4-2-0R	15.0-2-0R	15.6-2-0R	16.2-2-0R	16.8-2-0R	17.4-2-0R			
36	q <sub>n</sub>   q <sub>f</sub>	709   1167	709   1153	710   1140	712   1127	715   1114	719   1101	724   1088	730   1075	737   1062	745   1049	754   1036	764   1023			
F	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R	11.6-3-0R			



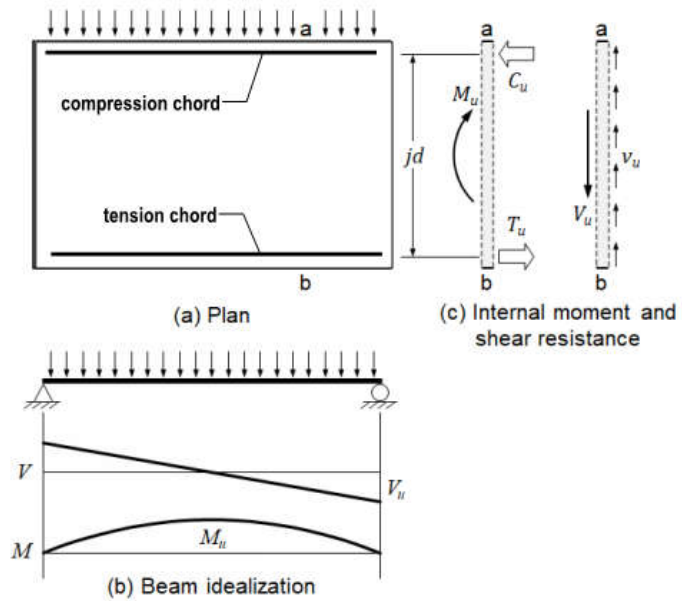
# Diaphragm Components

Steel Deck Institute Diaphragm Design Manual



# Diaphragm Components

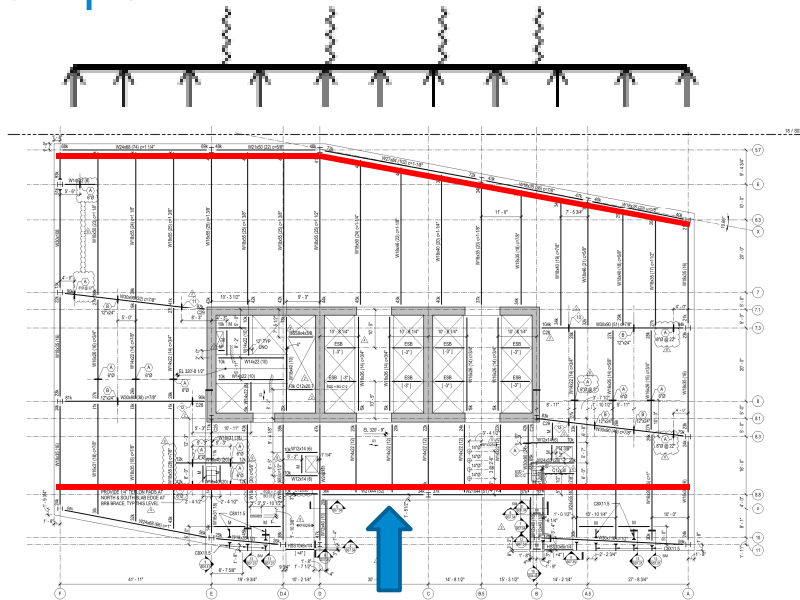
## Chords



# Diaphragm Components

## Chords

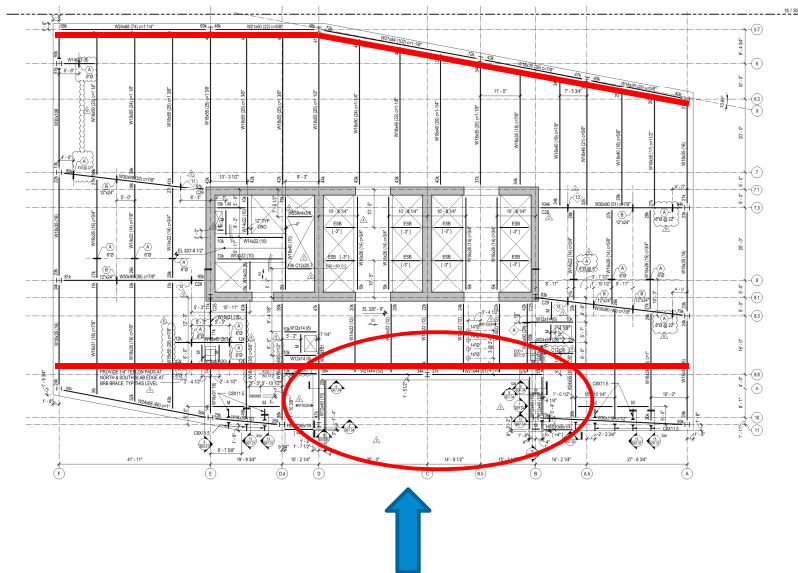
- Steel Framing
- Slab Reinforcement



## Diaphragm Components

### Chords

- Steel Framing
- Slab Reinforcement

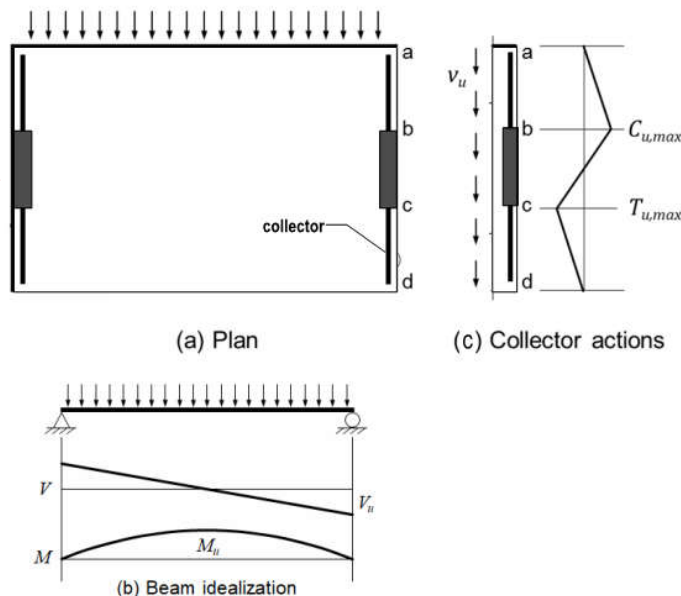


## Diaphragm Components

### Collectors (Drag Strut, Distributor)

- ASCE 7 Definition:

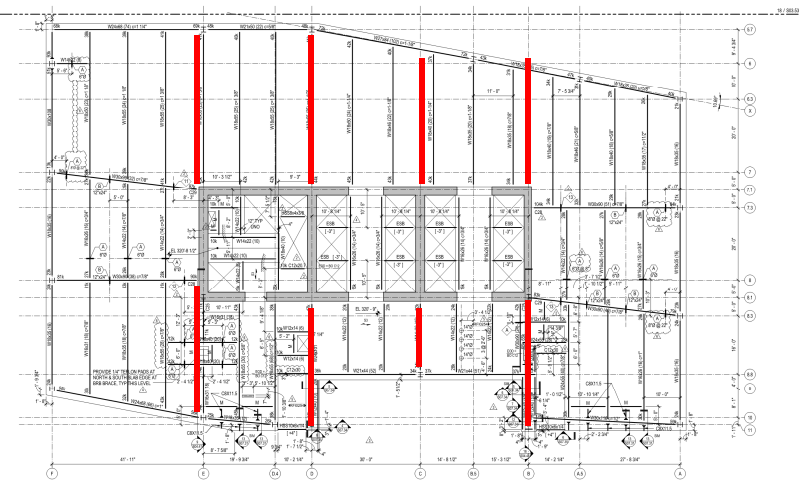
*A diaphragm or shear wall boundary element parallel to the applied load that collects and transfers diaphragm shear forces to the vertical elements of the seismic force-resisting system or distributes forces within the diaphragm or shear wall.*



# Diaphragm Components

## Collectors

- Steel Framing
- Slab Reinforcement



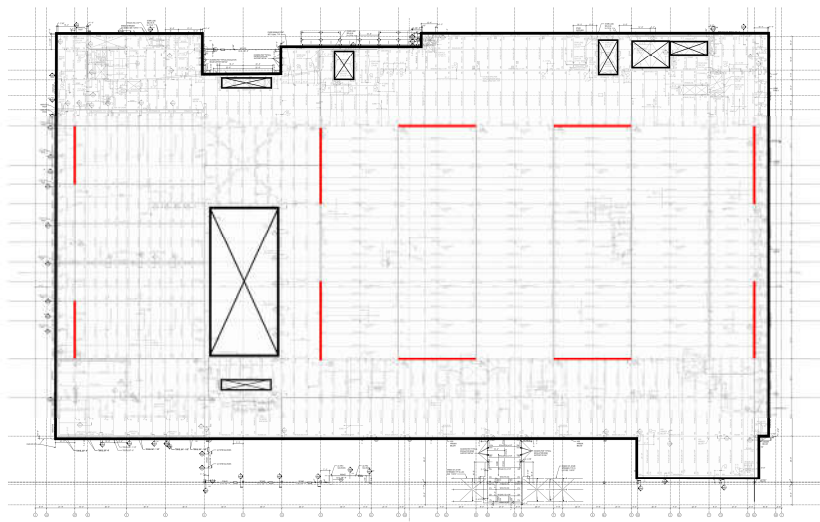
# Diaphragm Components

## Putting It Together



## Diaphragm Components

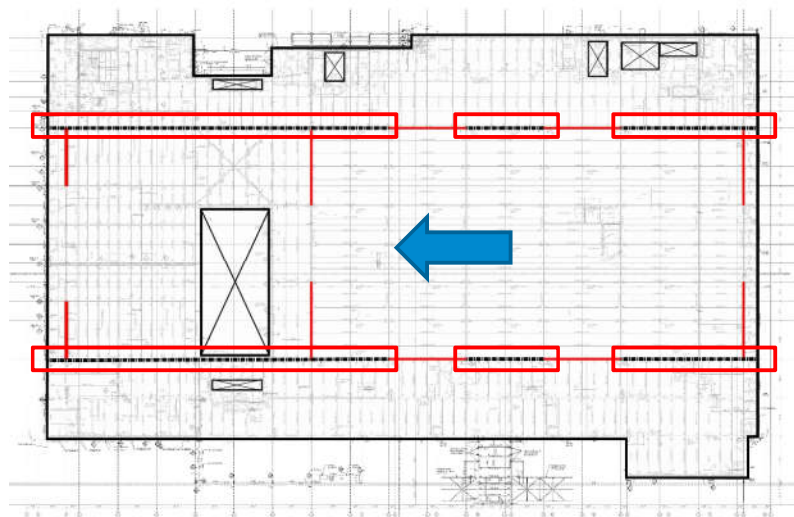
### Putting It Together



37

## Diaphragm Components

### Putting It Together - Collectors

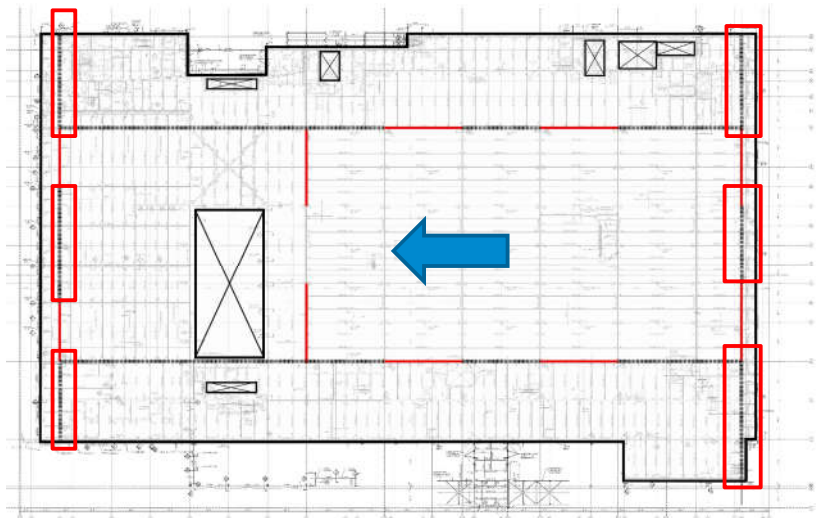


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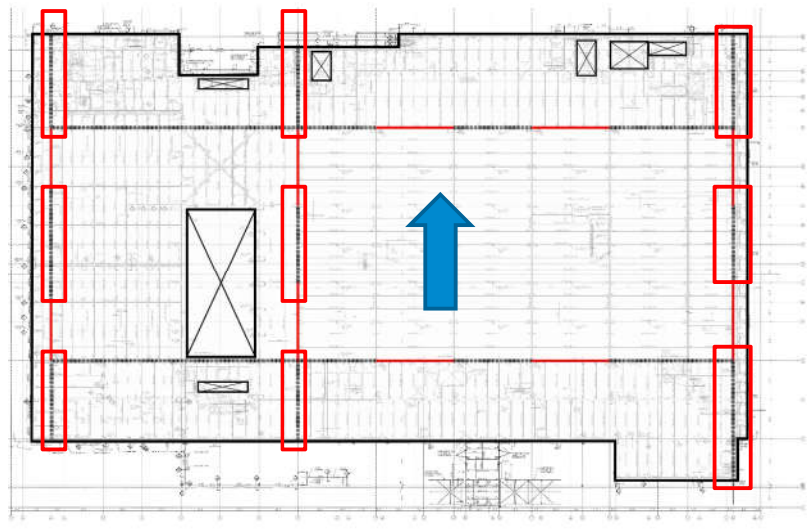
# Diaphragm Components

## Putting It Together - Chords



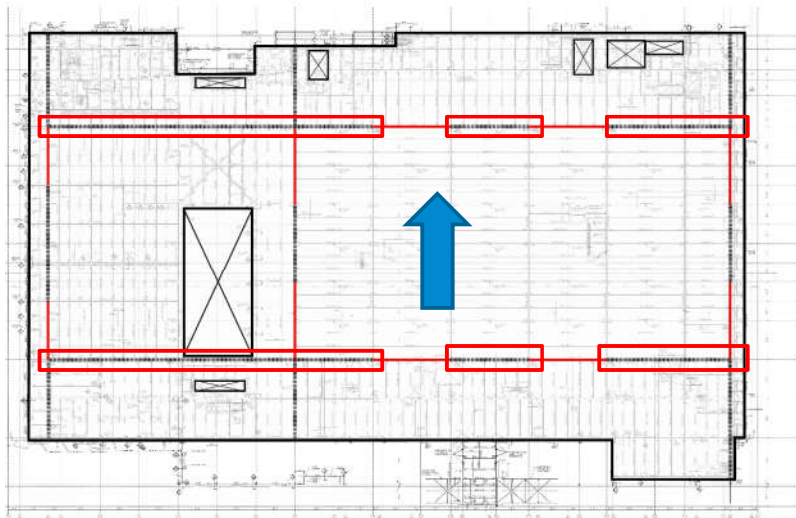
# Diaphragm Components

## Putting It Together - Collectors



## Diaphragm Components

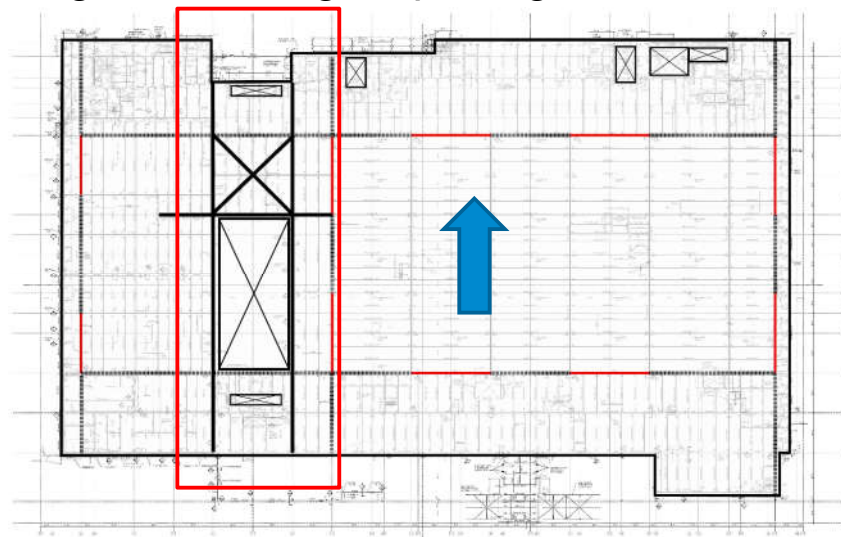
### Putting It Together - Chords



41

## Diaphragm Components

### Putting It Together – Large Openings



42



# ASCE 7 Diaphragm Seismic Force Provisions



43

## ASCE 7 Diaphragm Seismic Force Provisions

### Wind Loading vs Seismic Loading

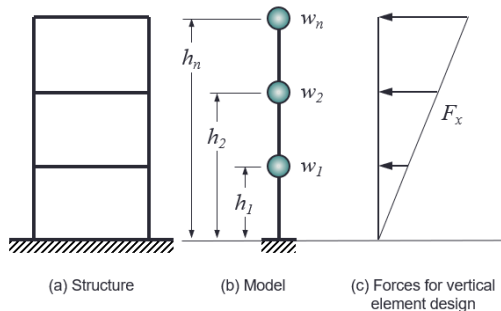
- Wind loads imposed by the cladding attachments at the exterior walls
  - IBC or ASCE 7 (other building codes)
  - Wind tunnel testing
  
- Seismic loads originate within the diaphragm and at masses being braced by the diaphragm, such as cladding
  - ASCE 7



44



## ASCE 7 Diaphragm Seismic Force Provisions

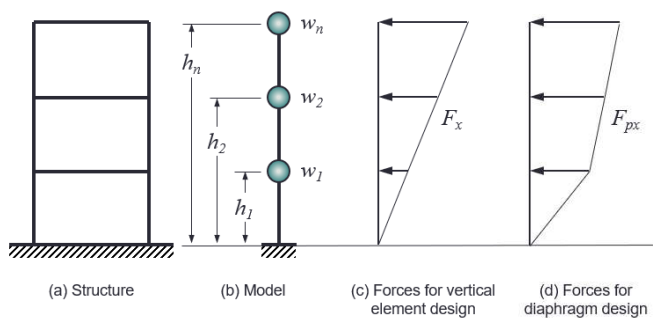


$$F_x = C_{vx} V \quad (\text{ASCE 7 Eq. 12.8-11})$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^n w_i h_i^k} \quad (\text{ASCE 7 Eq. 12.8-12})$$



## ASCE 7 Diaphragm Seismic Force Provisions



$$F_{px} = \frac{\sum_{i=x}^n F_i}{\sum_{i=x}^n w_i} w_{px} \quad (\text{ASCE 7 Eq. 12.10-1})$$

but not be less than

$$F_{px, \min} = 0.2 S_{DS} I_e w_{px} \quad (\text{ASCE 7 Eq. 12.10-2})$$

and need not exceed

$$F_{px, \max} = 0.4 S_{DS} I_e w_{px} \quad (\text{ASCE 7 Eq. 12.10-3})$$

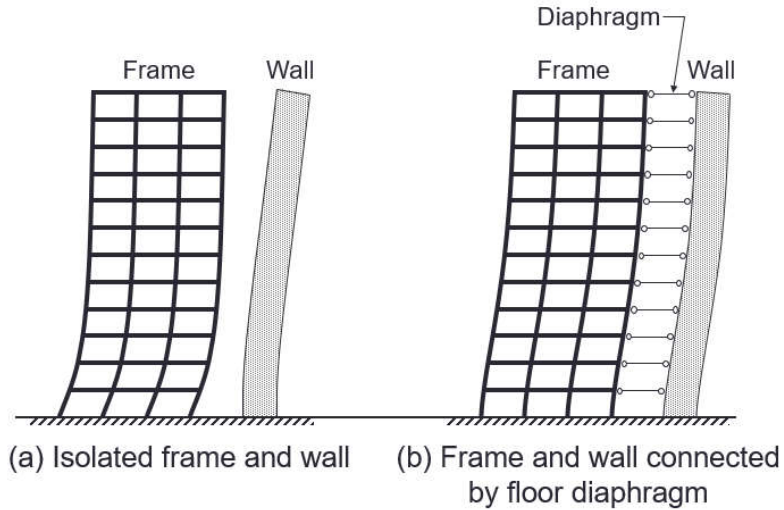
$$F_x = C_{vx} V \quad (\text{ASCE 7 Eq. 12.8-11})$$

$$C_{vx} = \frac{w_x h_x^k}{\sum_{i=1}^n w_i h_i^k} \quad (\text{ASCE 7 Eq. 12.8-12})$$



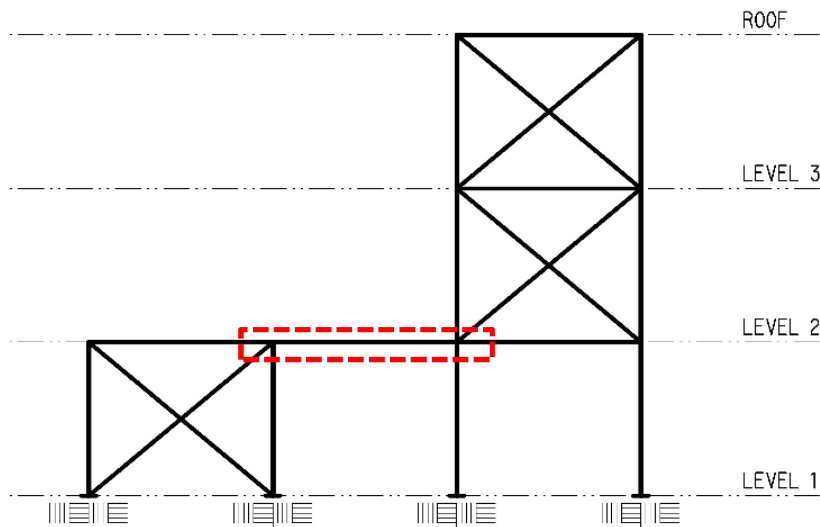
# ASCE 7 Diaphragm Seismic Force Provisions

## Transfer Forces



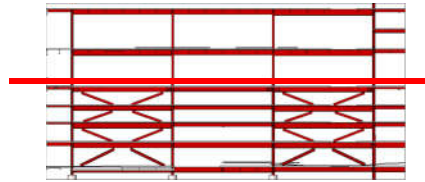
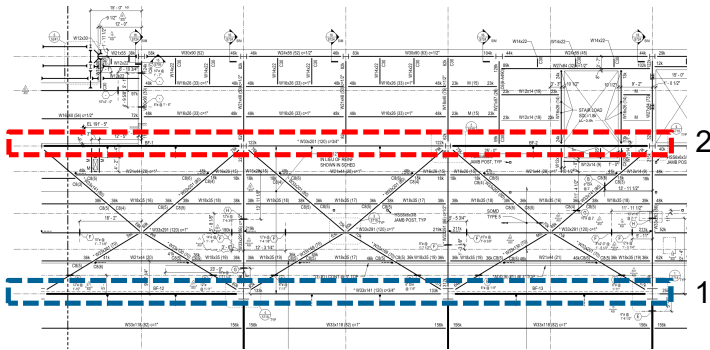
# ASCE 7 Diaphragm Seismic Force Provisions

## Transfer Forces

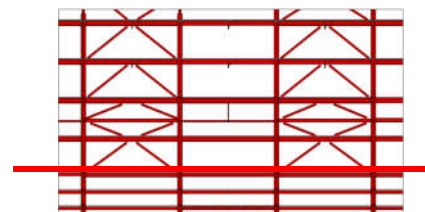


# ASCE 7 Diaphragm Seismic Force Provisions

## Transfer Forces



Elevation 2



Elevation 1

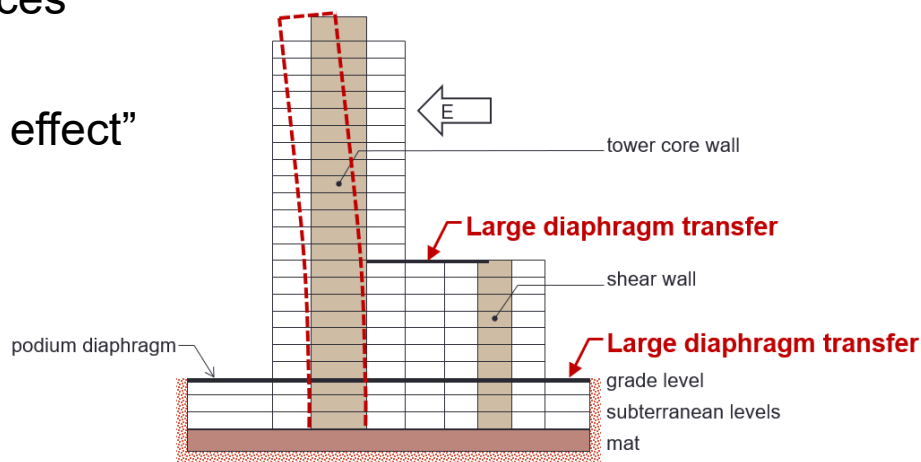
Plan



# ASCE 7 Diaphragm Seismic Force Provisions

## Transfer Forces

- “Backstay effect”



Elevation



## ASCE 7 Diaphragm Seismic Force Provisions

Transfer Forces for both diaphragms and collectors are...

- Additive to inertial forces
- Subject to the redundancy factor  $\rho$ , **except**
- Subject to the **overstrength factor  $\Omega_0$**  where Out-of-Plane Offset irregularities exist (Type 4 Horizontal Structural Irregularities per Table 12.3-1)



51

## ASCE 7 Collector Force Provisions

Section 12.10.2.1

For structures assigned to SDC C through F,  
**collector design forces** are the maximum of (a), (b), and (c):

- (a) Forces resulting from application of  $F_x$  using the load combinations with **overstrength factor  $\Omega_0$**  of ASCE 7 Section 12.4.3.1;
- (b) Forces resulting from application of  $F_{px}$  using the load combinations with **overstrength factor  $\Omega_0$**  of ASCE 7 Section 12.4.3.1;
- (c) Forces resulting from application of  $F_{px,min}$  in the basic load combinations of ASCE 7 Section 12.4.2.

Transfer forces as previously described are additive



52



## ASCE 7 Diaphragm Seismic Force Provisions

Irregularities – SDC D-F

- Horizontal Irregularities (ASCE 7, Table 12.3-1)
  - Type 1a, Type 1b, Type 2, Type 3, Type 4
  - Torsional, Extreme Torsional, Reentrant Corner, Diaphragm Discontinuity, Out-of-Plane Offset
- Vertical Irregularities (ASCE 7, Table 12.3-2)
  - Type 4
  - In-Plane Discontinuity in Vertical LFR Element
- **Inertial forces** calculated per ASCE 7, 12.10.1 design forces shall be increased by 25% for connections of diaphragms to vertical elements and collectors and their connections to vertical elements
- Transfer forces subject to overstrength factor



53

## Diaphragm to Shear Wall Connections

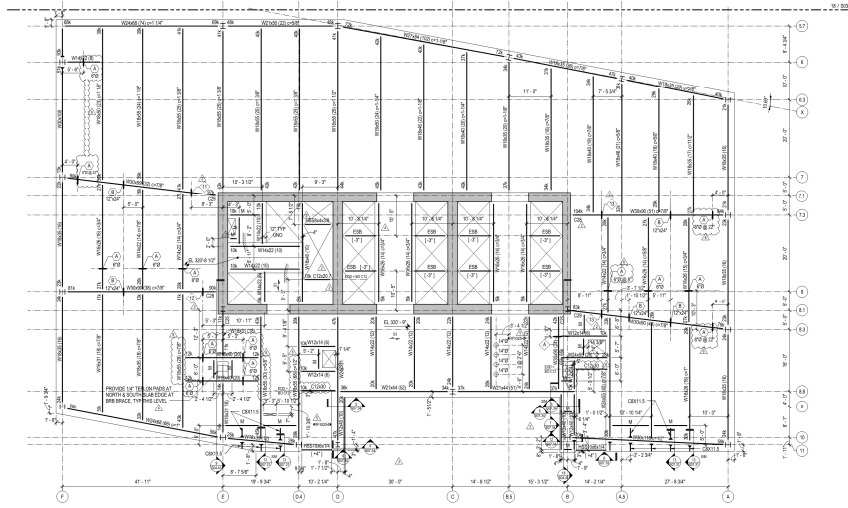


54



## Diaphragm to Shear Walls

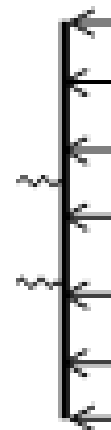
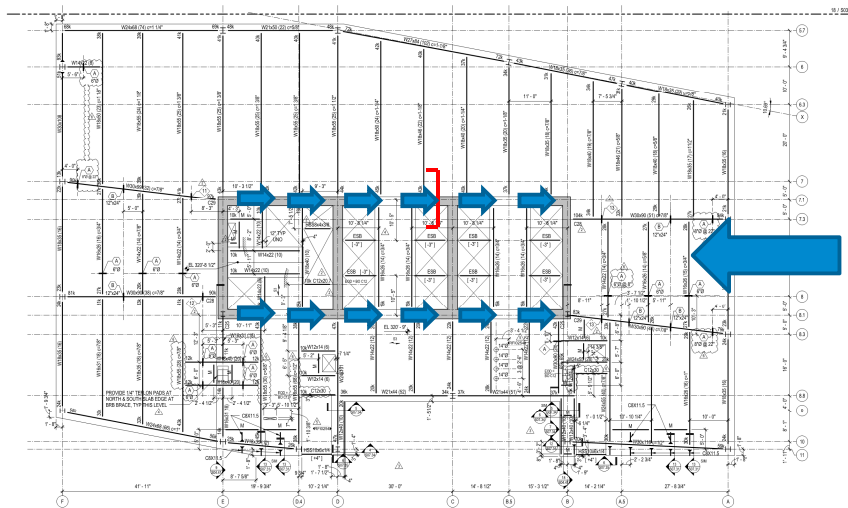
### Diaphragm to Concrete



55

## Diaphragm to Shear Walls

### Diaphragm to Concrete

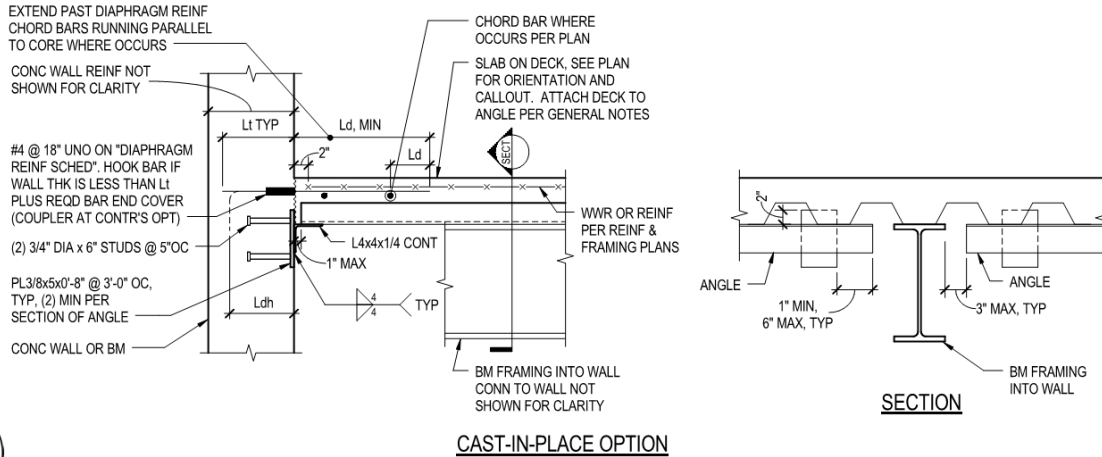


56



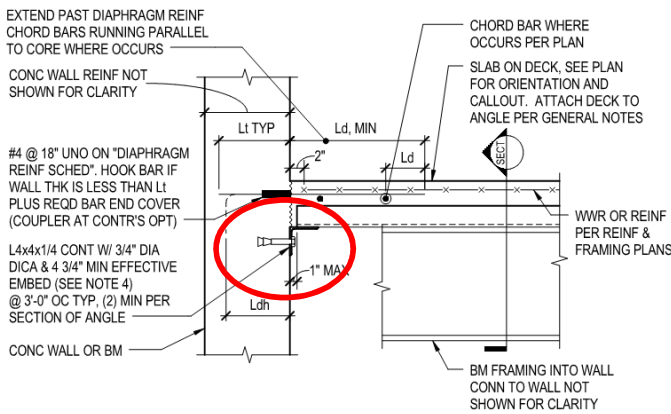
# Diaphragm to Shear Walls

## Diaphragm Connection to Concrete Wall



# Diaphragm to Shear Walls

## Diaphragm Connection to Concrete Wall



## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

- Shear Friction Provisions per ACI 318

$$\phi V_n = \phi \mu A_{vf} f_y \quad (\text{ACI 318 22.9.4.2})$$

- Subject to upper limits per ACI 318 Table 22.9.4.4
- Typically  $V_n \leq 0.2 f'_c A_c \leq 800 A_c$  unless concrete is intentionally roughened



59

## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

- What is coefficient of friction,  $\mu$ ?
- ACI 318 Table 22.9.4.2
  - $0.6\lambda$  concrete placed against hardened concrete
  - $1.0\lambda$  concrete placed against intentionally roughened surface
  - $\lambda$  lightweight concrete factor (0.75 to 0.85)



60



## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

- What is  $\phi$ ?
- ACI 318 21.2.1
  - $\phi = 0.75$
- ACI 318 21.2.4
  - For seismic loads,  $\phi = 0.6$  when the vertical elements are special moment frames or special structural walls



61

## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

- Representative Project
- Special Concrete Walls Not Intentionally Roughened
  - Where  $\phi = 0.6$
  - $\mu = 0.6\lambda$
- 4-1/2" NWT topping
- 5-1/4" LTWT topping
  - $f'_c = 4,000 \text{ psi}$



62



## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

4-1/2" NWT

REINF	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$
#4@18"	.0025	2.8	$0.8\sqrt{f'_c}$			
#4@12"	.0037	4.3	$1.3\sqrt{f'_c}$			
#5@12"	.0057	6.5	$1.9\sqrt{f'_c}$			
#5@6"	.0115	13.0	$3.8\sqrt{f'_c}$			
#5@4"	.0172	19.4	$5.7\sqrt{f'_c}$			



63

## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

4-1/2" NWT

REINF	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$
#4@18"	.0025	2.8	$0.8\sqrt{f'_c}$			
#4@12"	.0037	4.3	$1.3\sqrt{f'_c}$			
#5@12"	.0057	6.5	$1.9\sqrt{f'_c}$			
#5@6"	.0115	13.0	$3.8\sqrt{f'_c}$			
#5@4"	<b>.0172</b>	<b>19.4</b>	<b><math>5.7\sqrt{f'_c}</math></b>			

$$\phi V_{n,max} = \phi 8 \sqrt{f'_c} A_c$$



64



## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear

4-1/2" NWT

5-1/4" LTWT

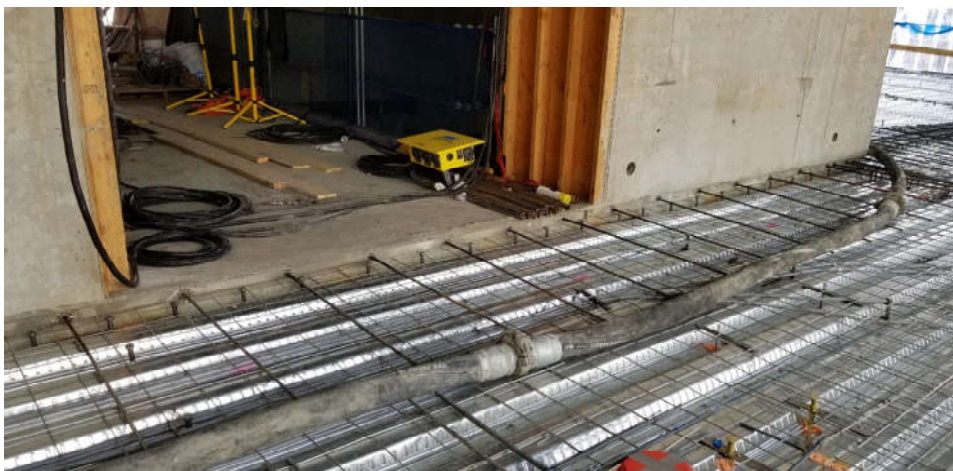
REINF	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$	$\rho$	$\phi V_n$ (K/FT)	$\phi v_n$
#4@18"	.0025	2.8	$0.8\sqrt{f'_c}$	.0025	2.5	$0.6\sqrt{f'_c}$
#4@12"	.0037	4.3	$1.3\sqrt{f'_c}$	.0037	3.8	$1.0\sqrt{f'_c}$
#5@12"	.0057	6.5	$1.9\sqrt{f'_c}$	.0057	5.7	$1.4\sqrt{f'_c}$
#5@6"	.0115	13.0	$3.8\sqrt{f'_c}$	.0115	11.3	$2.9\sqrt{f'_c}$
#5@4"	.0172	19.4	$5.7\sqrt{f'_c}$	.0172	17.0	$4.3\sqrt{f'_c}$



65

## Diaphragm to Shear Walls

### Connection Design for Diaphragm Shear



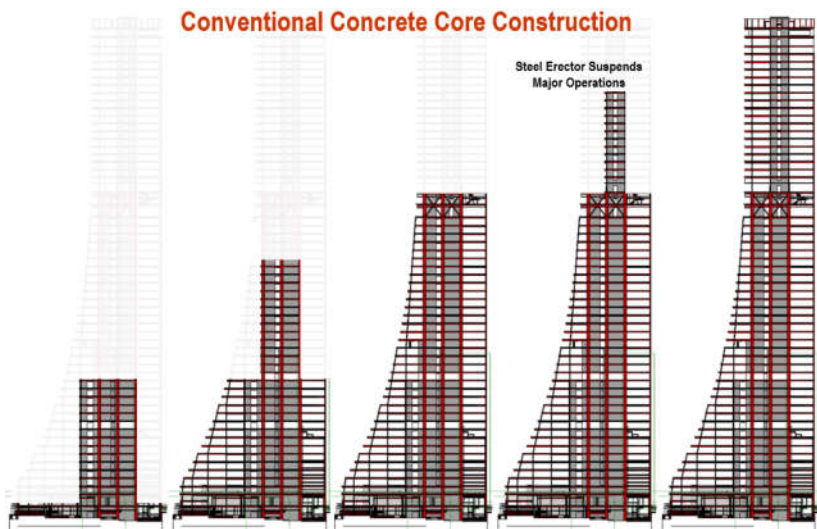
66





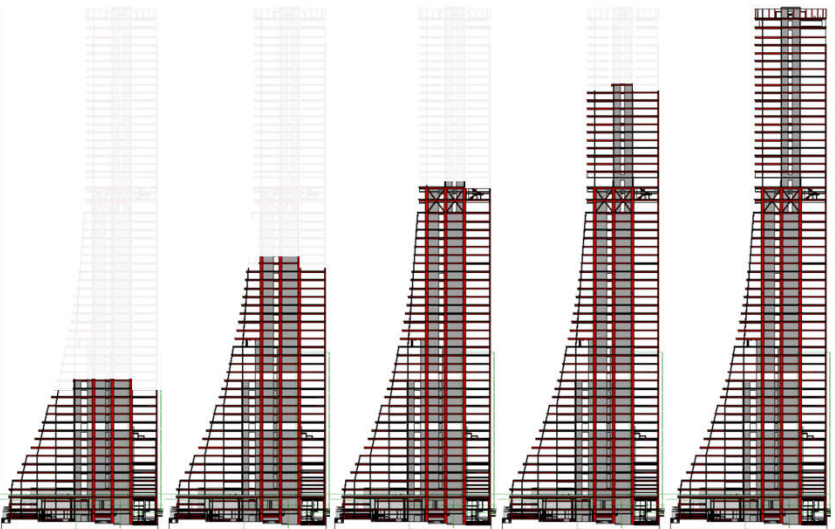
# Diaphragm to CPSW (SpeedCore)

Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)



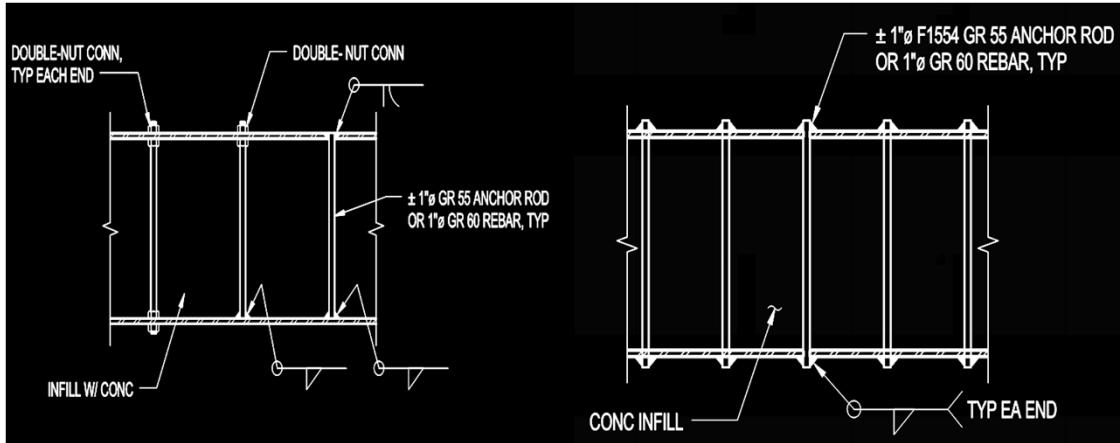
# Diaphragm to CPSW (SpeedCore)

Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)



## Diaphragm to CPSW (SpeedCore)

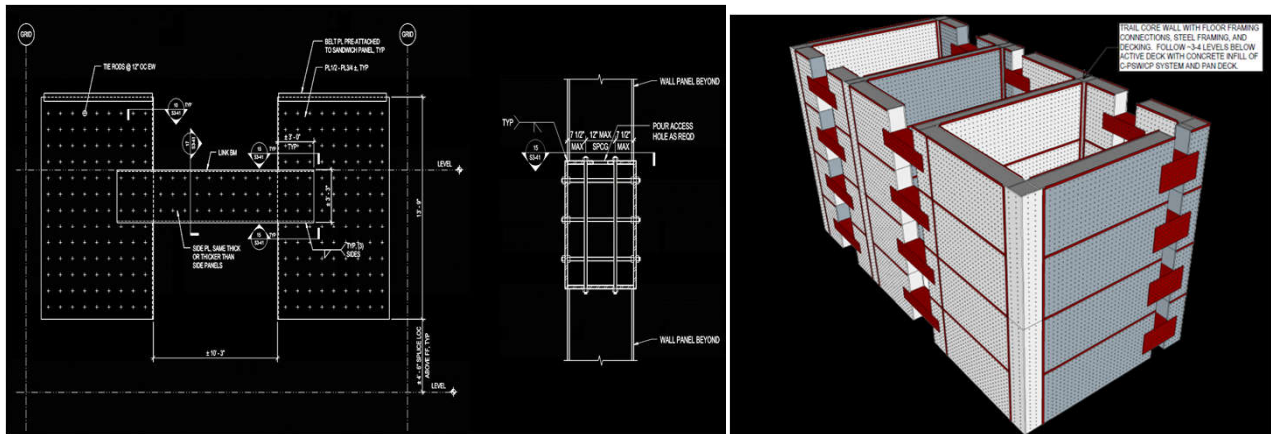
### Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)



71

## Diaphragm to CPSW (SpeedCore)

### Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)

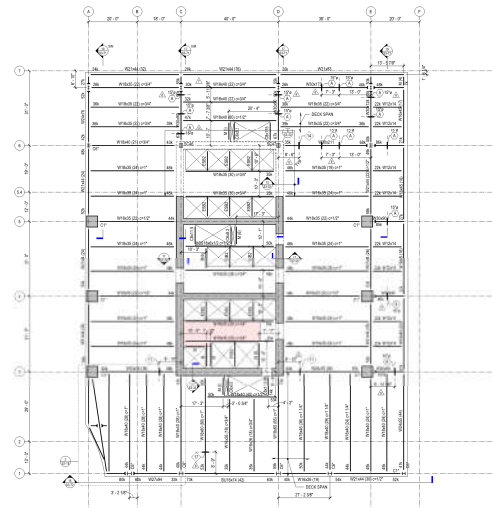


72



## Diaphragm to CPSW (SpeedCore)

### Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)



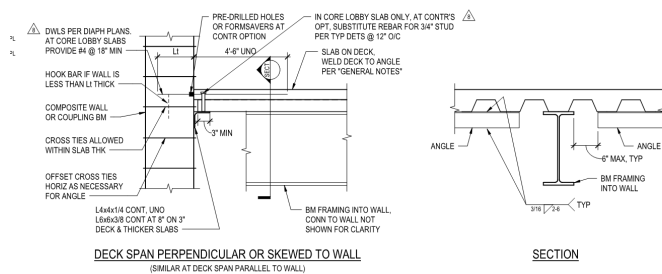
73



## Diaphragm to CPSW (SpeedCore)

### Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)

- Ledger angle shop welded to wall
- Pre-drilled holes for reinforcement



NOTES:  
 1. ROOF DECK IS SIMILAR.  
 ④ TYPICAL DECK SUPPORT AT CPSW OR COMPOSITE COUPLING BEAM

74



## Diaphragm to CPSW (SpeedCore)

Diaphragm Connection to Composite Plate Shear Wall (SpeedCore)

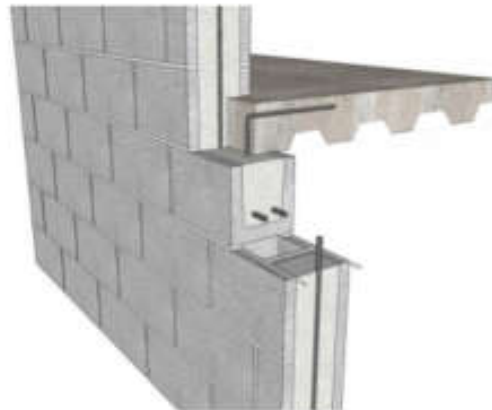


75

## Diaphragm to Shear Walls

Connection Detail to Masonry Wall

- International Masonry Institute
  - Masonry Detailing Series



76



# Diaphragm to Boundary Element Connections



77

## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements

- AISC 360 I7
  - *Composite slab diaphragms and collector beams shall be designed and detailed to transfer loads between the diaphragm, the diaphragm's boundary members and collector elements of the lateral force-resisting system*



78



## Diaphragm to Boundary Elements

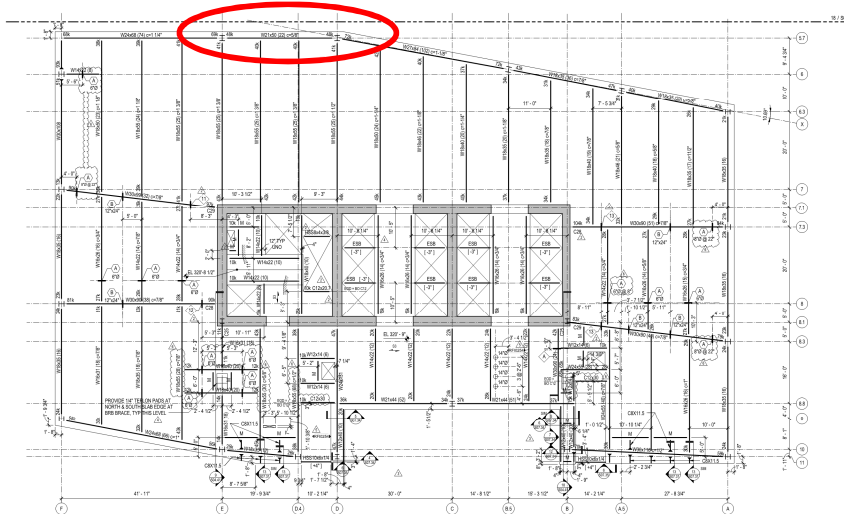
### Diaphragm to Steel Boundary Elements

- AISC 341 D1.5a
  - *Details shall be provided to transfer loads between the diaphragm and boundary members, collector elements, and elements of the horizontal framing system*



## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements



## Diaphragm to Boundary Elements

### Boundary Element Design

#### AISC 360, Section I7 Commentary

- Design for the combined effects of axial load due to diaphragm forces and flexure due to gravity and/or lateral loads
- Axial capacity typically taken as the non-composite strength
- Flexural capacity can be either the composite or non-composite flexural strength (where appropriate)



81

## Diaphragm to Boundary Elements

### Boundary Element Design

#### AISC Seismic Design Manual, 3<sup>rd</sup> Edition, Chapter 8

- Major axis buckling – full length of the member (web vertical)
- Minor axis and torsional buckling
  - Beams with bare steel deck with ribs parallel
  - Beams with bare steel deck with ribs perpendicular
  - Composite deck or slabs
- \*Constrained axis torsional buckling may control



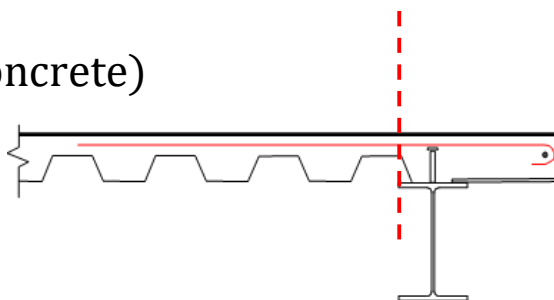
82



## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements

- Provide shear friction reinforcement at the boundary element
- $\mu = 1.4\lambda$  (monolithic concrete)



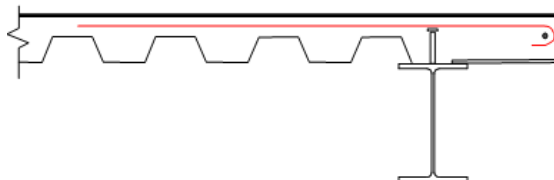
83

## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements

- 3" NLWT on 3" Deck (55 psf)
- SDL = 15 psf
- LL = 50 psf(r) + 15 psf partition
  - 50 psf reduces to 33 psf

- $S_{ds} = 0.90$
- $b_{trib} = 22'-6"$



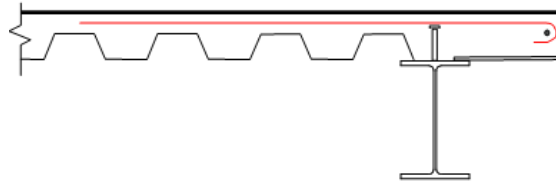
84



## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements

- Headed Studs
- Design Load Combinations
  - $1.2D+1.6L$ 
    - $U = 161 \text{ psf}$
  - $(1.2+0.2S_{ds})D + f_1L$ 
    - $f_1=0.5$
    - $U = 121 \text{ psf}$
  - ~25% reduction

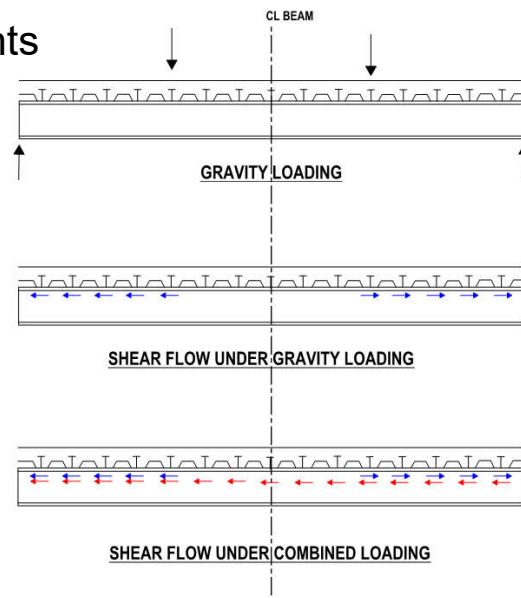


85

## Diaphragm to Boundary Elements

### Diaphragm to Steel Boundary Elements

- Headed Studs
- Design Load Combinations
  - $1.2D+1.6L$ 
    - $U = 161 \text{ psf}$
  - $(1.2+0.2S_{ds})D + f_1L$ 
    - $f_1=0.5$
    - $U = 121 \text{ psf}$
  - ~25% reduction



86



# Boundary Element to Boundary Element Connections



87

## Boundary Element to Boundary Element Steel to Steel



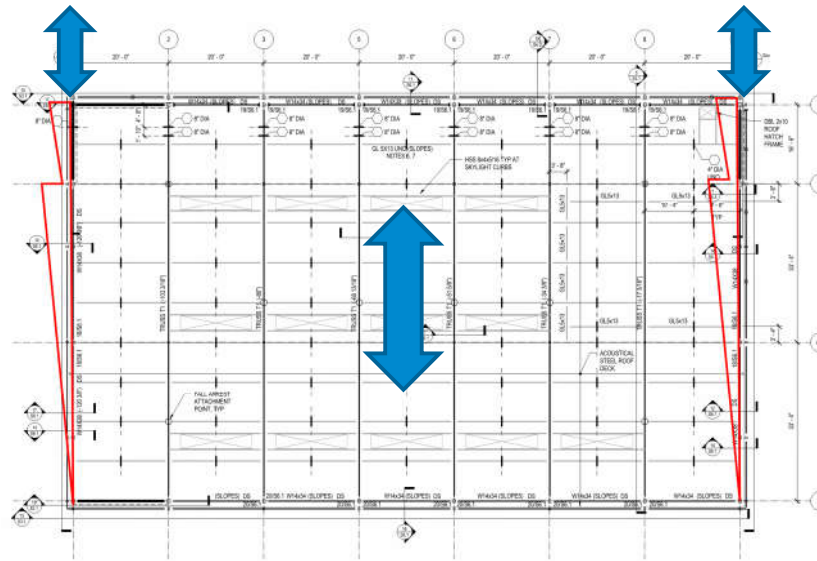
88



## Boundary Element to Boundary Element

Steel to Steel

- Uniform shear stress
- Linearly varying axial force in collector line

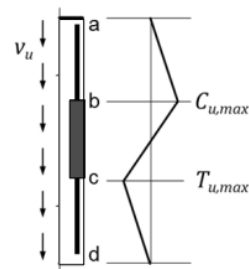
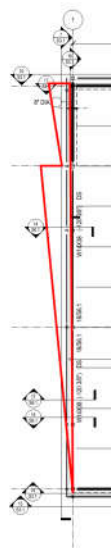


89

## Boundary Element to Boundary Element

Steel to Steel

- Uniform shear stress
- Linearly varying axial force in collector line



(c) Collector actions

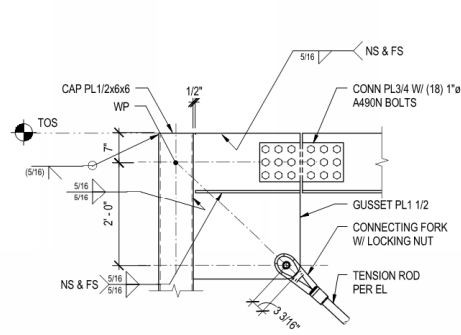


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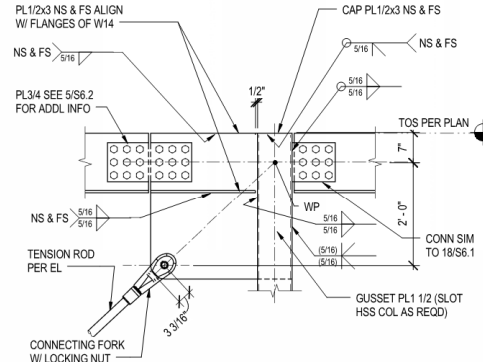


# Boundary Element to Boundary Element

## Steel to Steel – Extended Shear Plate



2 DETAIL  
3/4" = 1'-0"

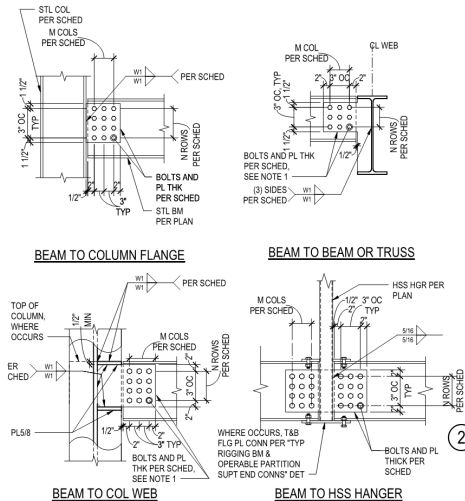


3 DETAIL  
3/4" = 1'-0"

# Boundary Element to Boundary Element

## Steel to Steel – Extended Shear Plate

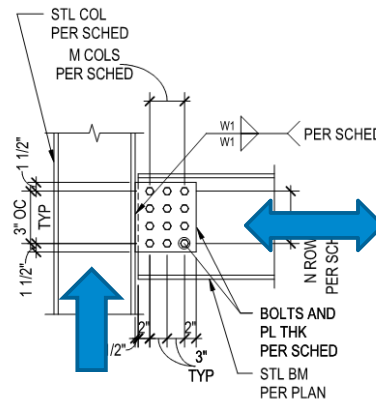
CONNECTION TYPE	BOLTS	M COLUMNS	N ROWS	PL THICKNESS (IN)	W1 (IN)	REMARKS
A	7/8" ø A325X	2	3	3/8	5/16	
B	7/8" ø A325X	2	3	1/2	5/16	
C	7/8" ø A325X	2	3	5/8	7/16	
D	7/8" ø A325X	2	4	3/8	1/4	
E	7/8" ø A325X	2	4	1/2	5/16	
F	7/8" ø A325X	2	6	1/2	5/16	
G	7/8" ø A325X	2	9	5/8	7/16	
H	7/8" ø A325X	2	10	5/8	7/16	
J	7/8" ø A325X	3	3	5/8	7/16	
K	7/8" ø A325X	3	4	3/4	1/2	
L	7/8" ø A325X	3	5	3/4	1/2	
M	7/8" ø A325X	3	11	3/4	9/16	
N	7/8" ø A325X	4	3	1	11/16	
P	1" ø A490X	2	5	1/2	3/8	
Q	1" ø A490X	2	7	3/4	1/2	
R	1" ø A490X	2	9	5/8	7/16	
S	1" ø A490X	2	10	3/4	1/2	
T	1" ø A490X	3	5	3/4	1/2	
U	1" ø A490X	4	5	3/4	1/2	



## Boundary Element to Boundary Element

### Steel to Steel – Extended Shear Plate

- AISC Manual of Steel Construction, Part 10
- Design Example Companion, Example Vol 1
  - Example II.A-19B
- Vertical shear
- Axial force
- Bolt Group
- Weld
- Eccentricities
- Net Section



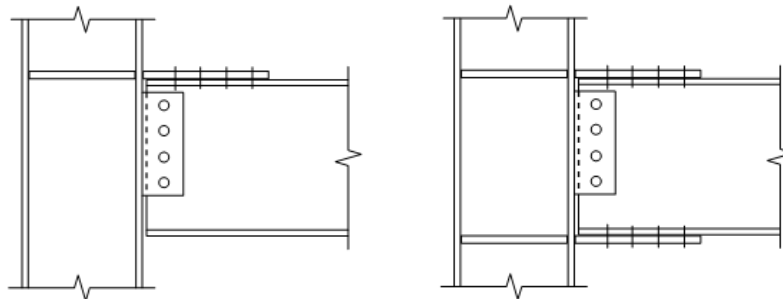
BEAM TO COLUMN FLANGE



## Boundary Element to Boundary Element

### Steel to Steel – Flange Plates

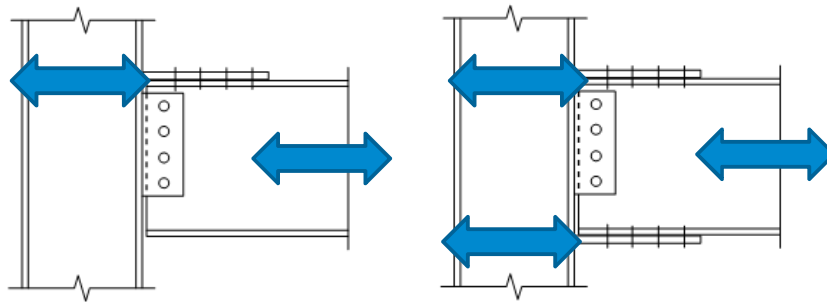
- Vertical shear
- Axial force
- Bolt Group
- Weld
- Eccentricities
- Net Section
- Shear Lag
- Concentrated Forces (Stiffeners)



## Boundary Element to Boundary Element

### Steel to Steel – Flange Plates

- Vertical shear
- Axial force
- Bolt Group
- Weld
- Eccentricities
- Net Section
- Shear Lag
- Concentrated Forces (Stiffeners)



95

## Collector to Shear Wall Connections

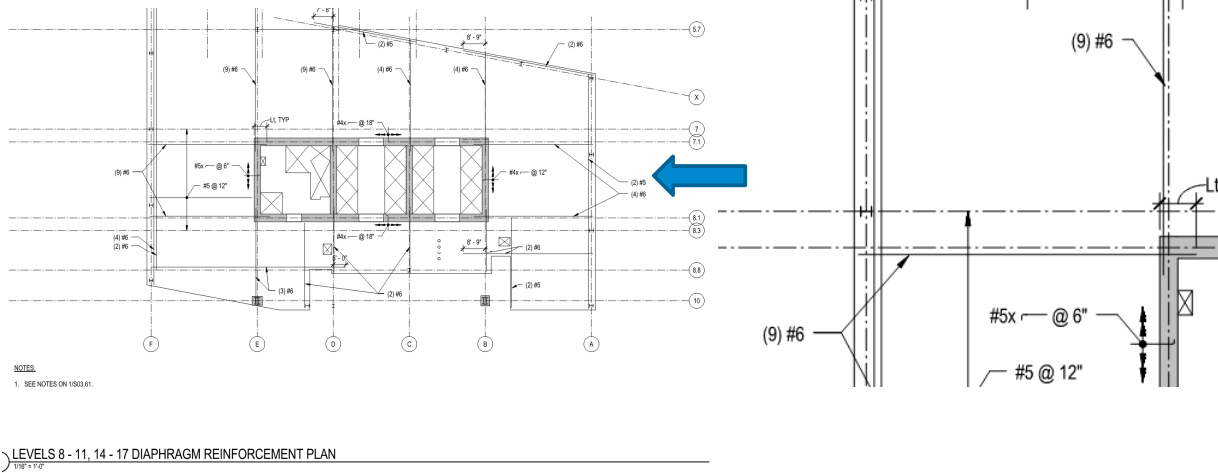


96



## Collector to Shear Walls

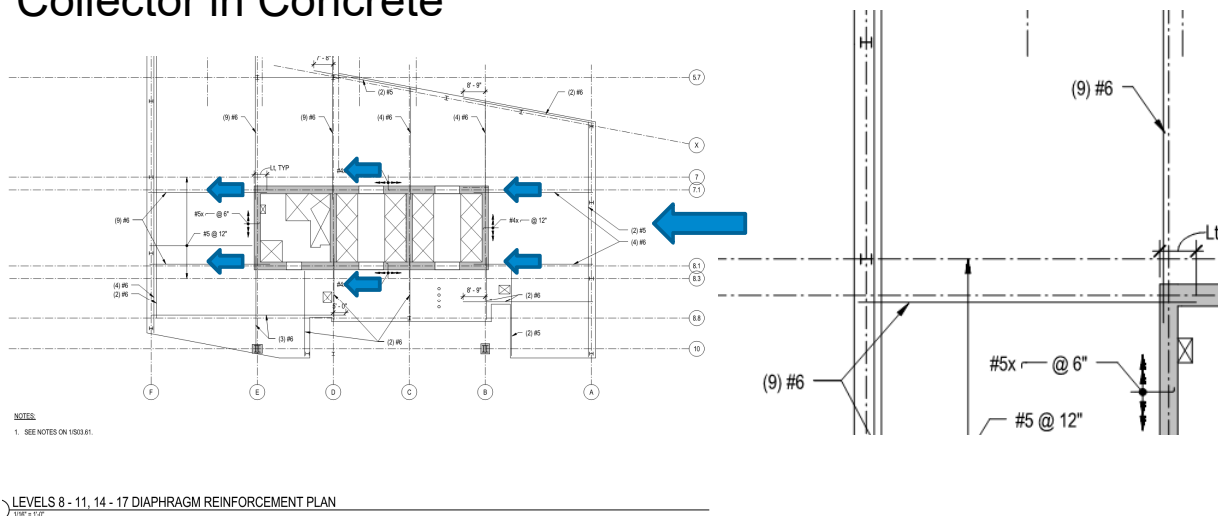
### Collector in Concrete



97

## Collector to Shear Walls

### Collector in Concrete

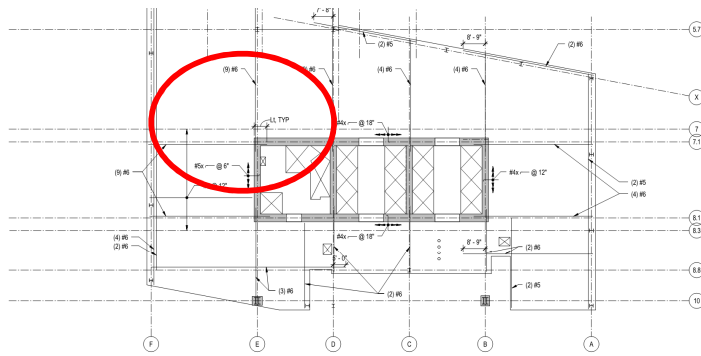


98



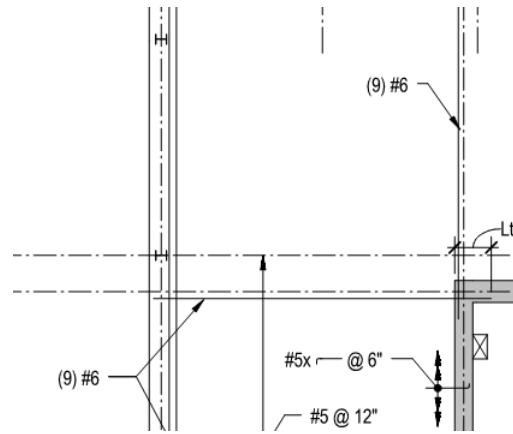
## Collector to Shear Walls

### Collector in Concrete



NOTES:  
1. SEE NOTES ON 1503.61.

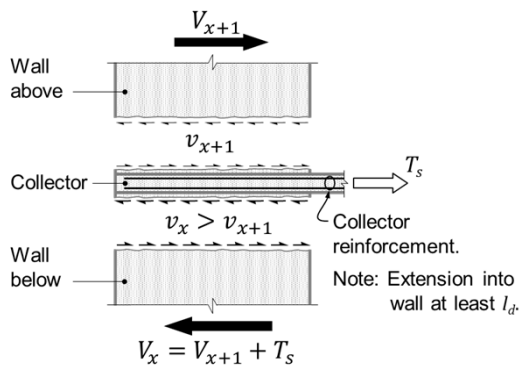
LEVELS 8 - 11, 14 - 17 DIAPHRAGM REINFORCEMENT PLAN  
1/8" = 1'-0"



## Collector to Shear Walls

### Collector in Concrete

- Develop collector into the wall



## Collector to Shear Walls

### Collector in Concrete



101

## Collector to Shear Walls

### Concrete to Concrete

- Congestion escalates quickly
  - Typically 1-bar fits within the flute and 1-bar in the opposite direction over the flutes
- ACI 318 requirements for cover and spacing
- Coordinate with all trades
  
- Use the steel framing as collectors!



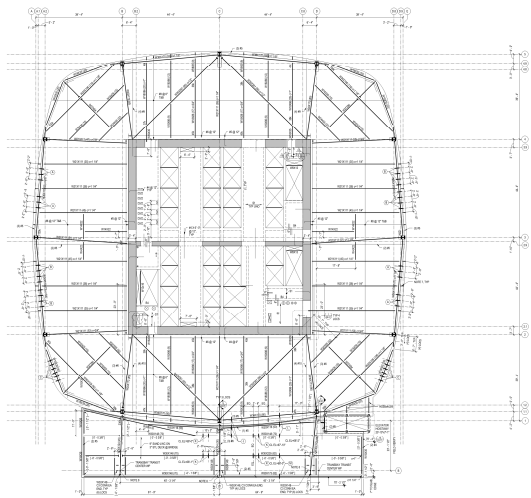
102



# Collector to Shear Walls

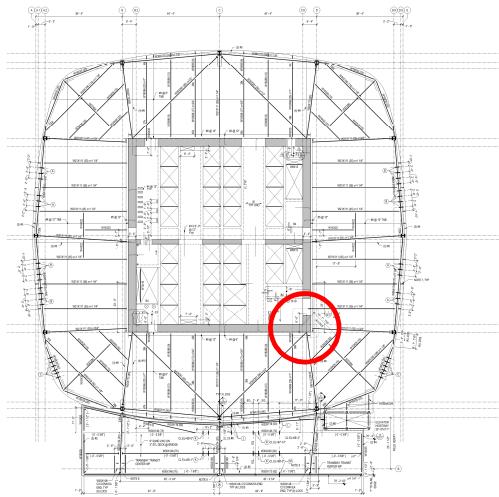
## Steel to Concrete

Photo by Jason O'Rear



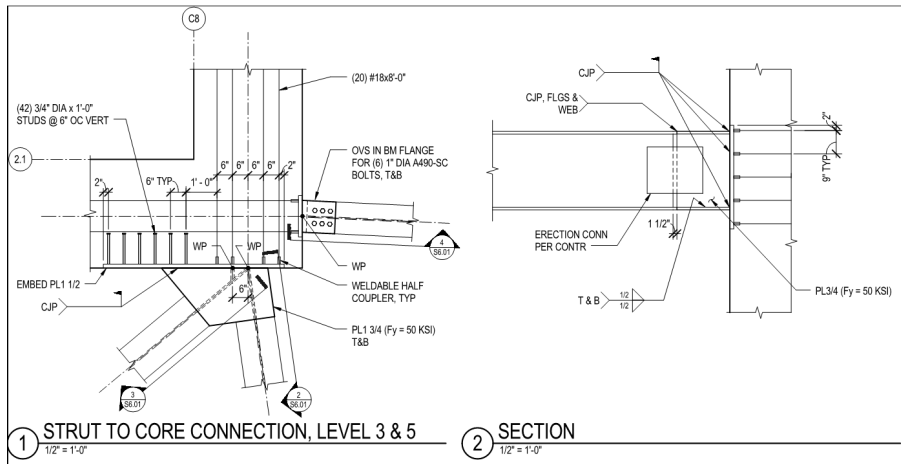
# Collector to Shear Walls

## Steel to Concrete



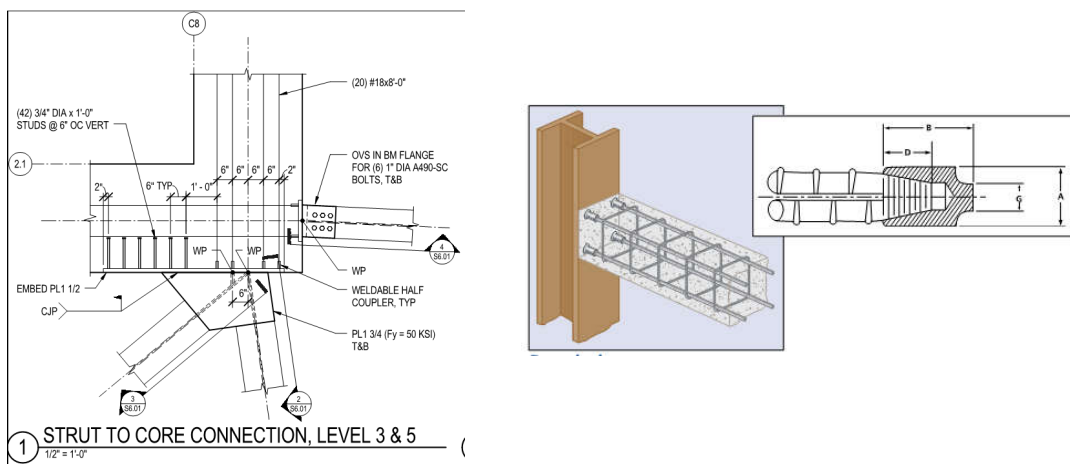
# Collector to Shear Walls

## Steel to Concrete



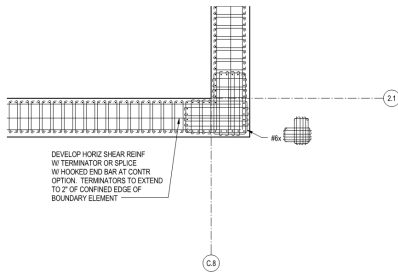
# Collector to Shear Walls

## Steel to Concrete



# Collector to Shear Walls

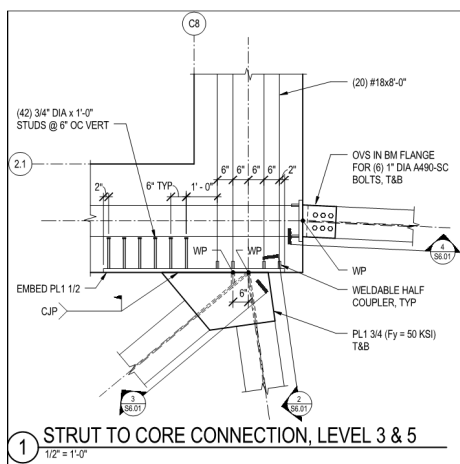
## Steel to Concrete



107

# Collector to Shear Walls

## Steel to Concrete

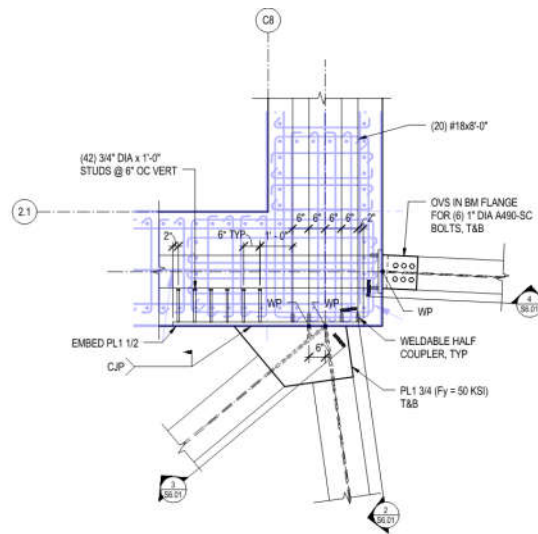
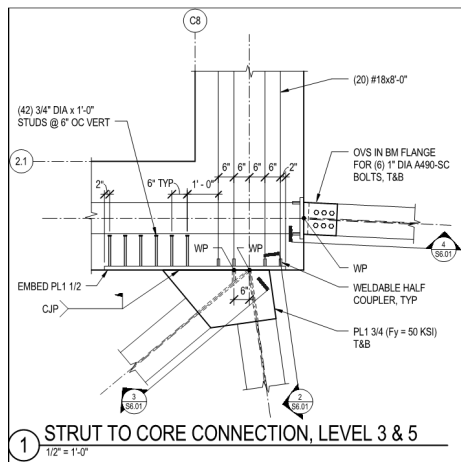


108



## Collector to Shear Walls

### Steel to Concrete

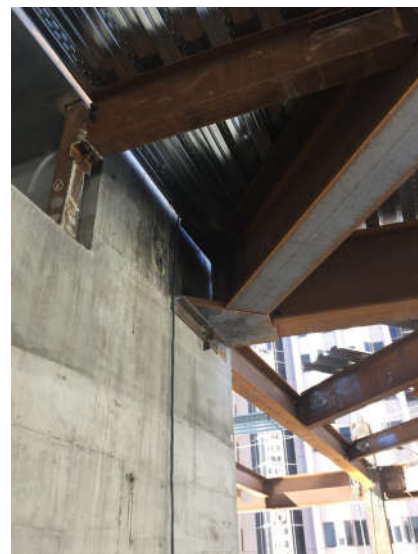


109

## Collector to Shear Walls

### Steel to Concrete

- Connections are critical
- Member sizes may be selected based on facilitating connections
- Pay attention to M/E/P/FP slab penetrations nearby
- Coordinate with wall reinforcing
- Understand the required development length



110



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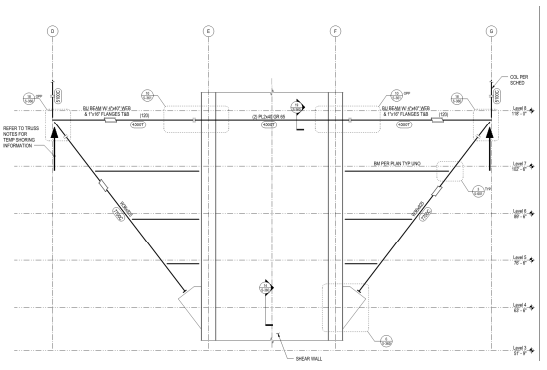
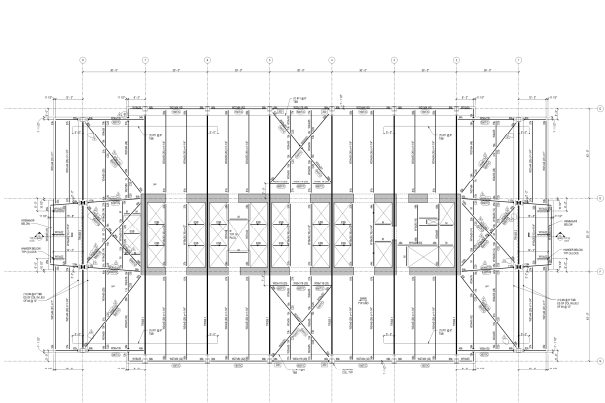
## Steel to Concrete



111

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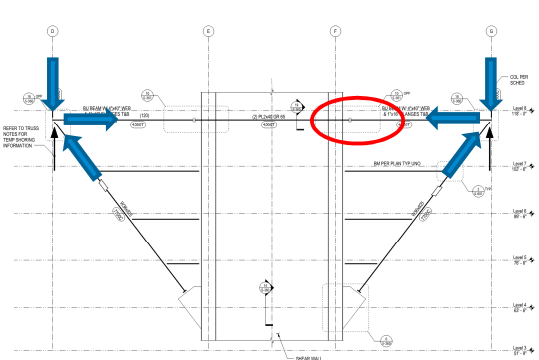
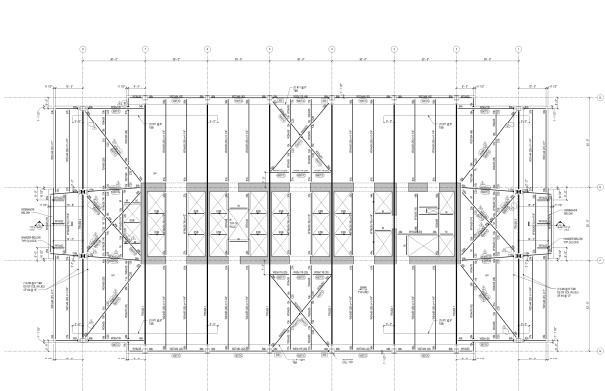


112



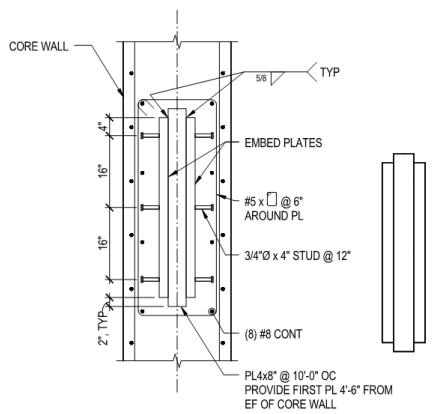
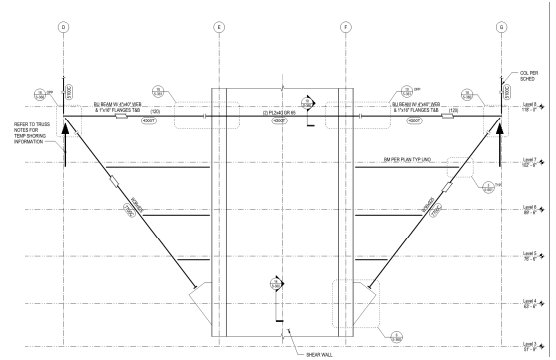
# Collector to Shear Walls

## Steel to Concrete



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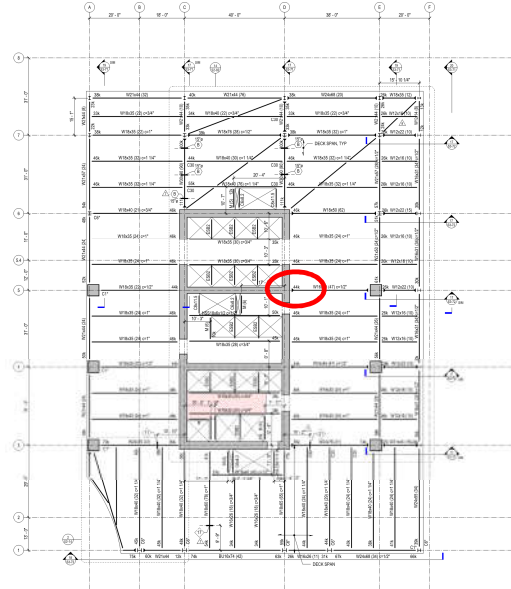
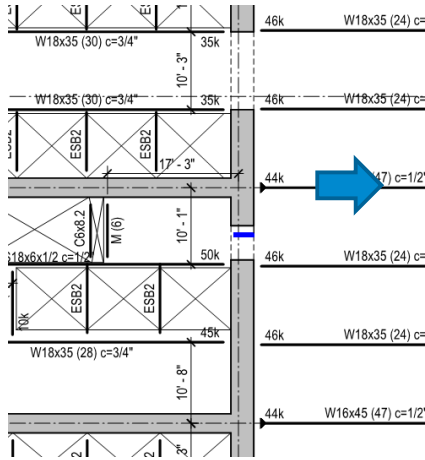
## Steel to Concrete





# Collector to CPSW (SpeedCore)

## Steel to CPSW

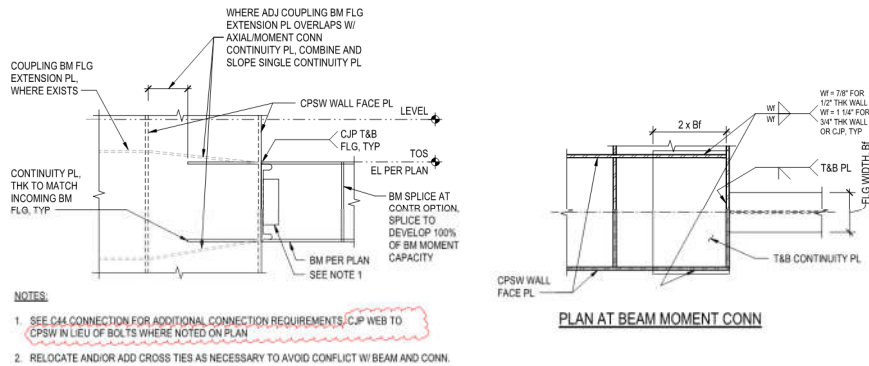


117



# Collector to CPSW (SpeedCore)

## Steel to CPSW



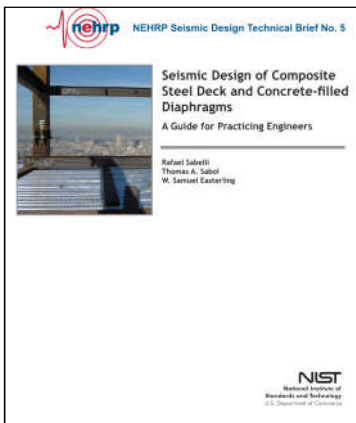
7 TYPICAL BEAM TO CPWS MOMENT CONNECTION

118



## Guidance for Designers

- AISC *Seismic Design Manual, 3<sup>rd</sup> Edition, Part 8* ([aisc.org/publications](http://aisc.org/publications))
- National Earthquake Hazards Reduction Program (<https://www.nehrp.gov/library/techbriefs.htm>)



119

AISC | Questions?



## CEU / PDH Certificates

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- You will receive an email on how to report attendance from:  
[registration@aisc.org](mailto: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!



## CEU / PDH Certificates

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





**AISC** | Thank you

