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Course Description

Load Path! The Most Common Source of Engineering Errors
Presented by Carol Drucker, S.E., P.E.

April 10, 2014

Load paths are essential to understand in structural analysis as well as connection design. Learn from an expert in the industry the most common mistakes made in assuming load paths and how they can be avoided. The session pertains to all levels of engineering experience.

Learning Objectives

- **Gain an understanding of the gravity and lateral systems for steel framed buildings.**
- **Learn and understand the load path through trusses and truss connections.**
- **Become familiar with solutions to common framing and connection issues in steel framed structures.**
- **Gain an understanding of transfer forces.**

There's always a solution in steel.

Load Path! The Most Common Source of Engineering Errors

Carol Drucker, S.E., P.E., P. Eng

Principal

Drucker Zajdel Structural Engineers, Naperville, IL

structural STEEL

Load Path

By: Carol Drucker, SE, PE, P.Eng

9

Topics

- Fundamentals
- Gravity and Lateral Systems
- Connections
- Problematic Load Paths
- Good Load Paths

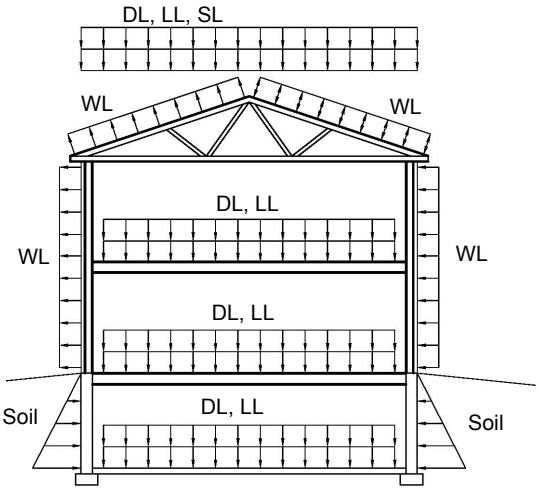
Load Path 10

Load Path Fundaments

- Load applied to structure is transferred through the structure to the foundations and ultimately to the ground
- Loads need a continuous complete load path between elements in a structure
- Each element along the path must have sufficient strength and stiffness

Load Path 11

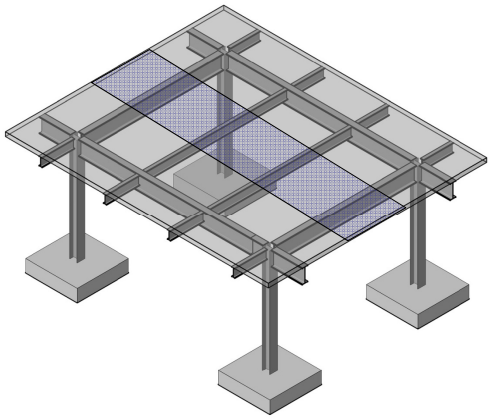
Load Path Fundamentals



- Loads on Structure
  - Dead
  - Live
  - Roof Live/Snow
  - Wind/Earthquake
  - Thermal
  - Soil
  - Ponding/Ice

Load Path 12

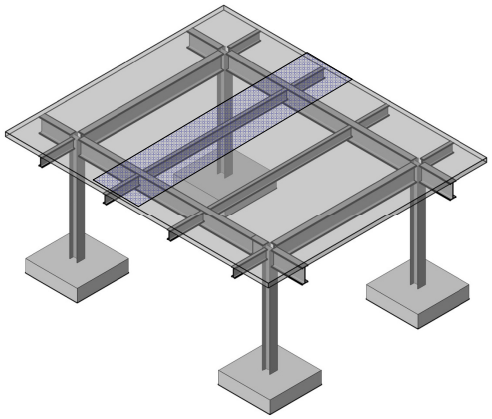
Gravity



- **Slab to Beams**
- Beams to Girders
- Girders to Columns
- Columns to Foundation

Load Path 13

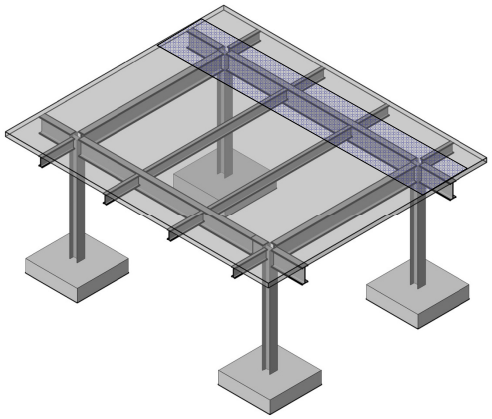
Gravity



- Slab to Beams
- **Beams to Girders**
- Girders to Columns
- Columns to Foundation

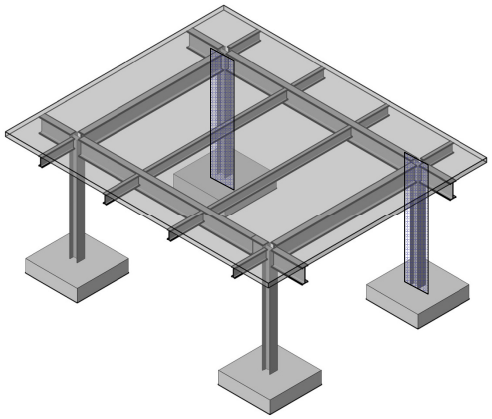
Load Path 14

Gravity



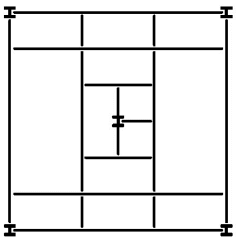
- Slab to Beams
- Beams to Girders
- **Girders to Columns**
- Columns to Foundation

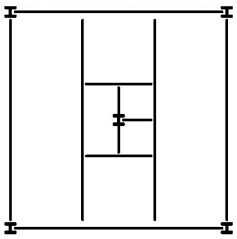
Gravity

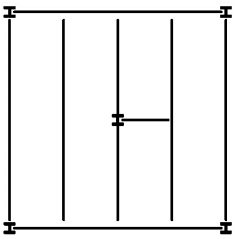


- Slab to Beams
- Beams to Girders
- Girders to Columns
- **Columns to Foundation**

Load Path Fundamentals

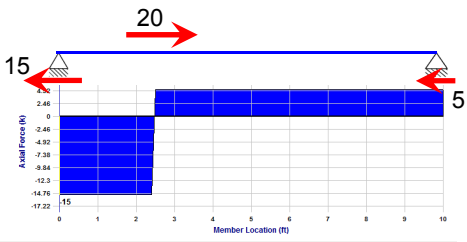




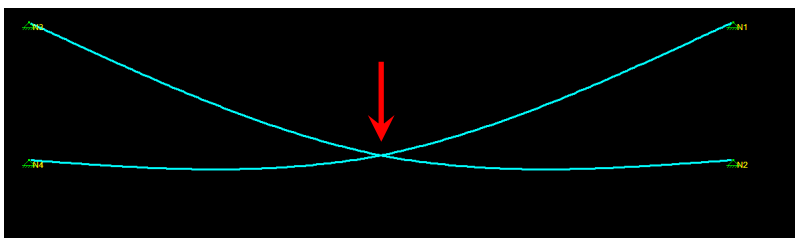


- Shortest Load Path is typically best

Load Path Fundamentals

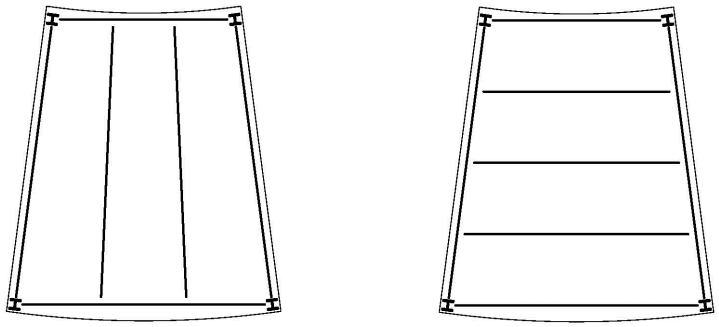


- Consider element stiffness
- Stiffness attacks load



Load Path Fundamentals

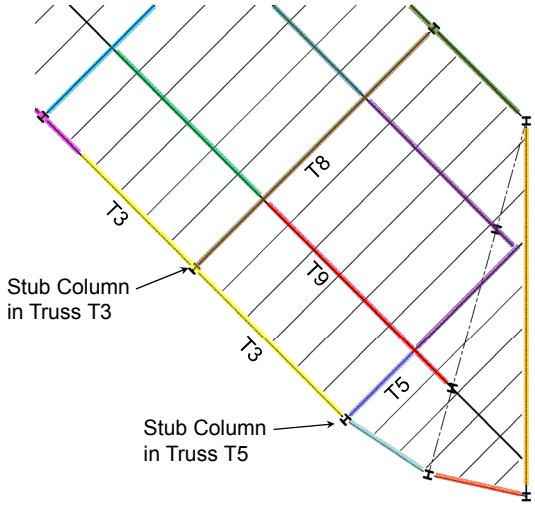
- Higher loaded members have shorter spans



More efficient

Less efficient

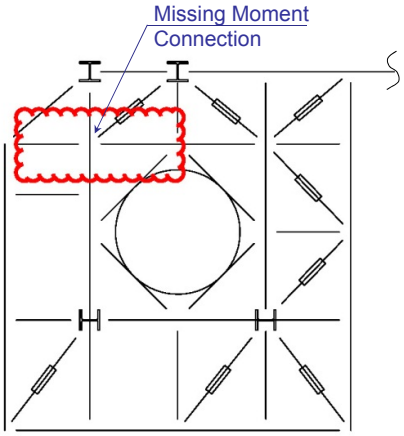
Close the Loop and Watch Erection



The problem:
-T5 supported by T9
-T9 supported by T8
-T8 supported by T3
-T3 supported by T5

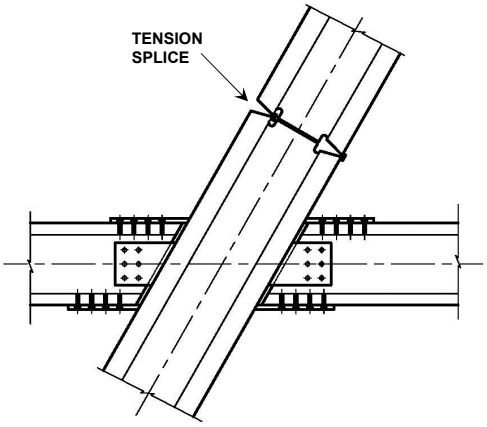
Close the Loop and Watch Erection

Gravity – Remember Statics

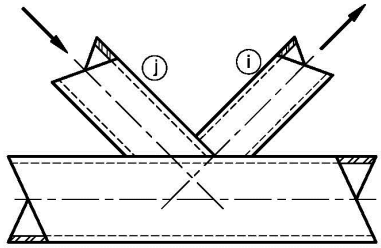


- Missing moment connection for stability at overhang

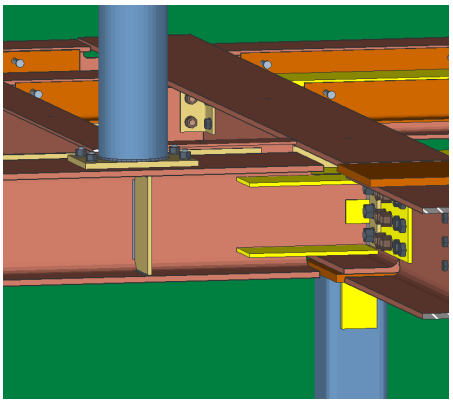
Framing



- Typically larger member with greater load should be continuous

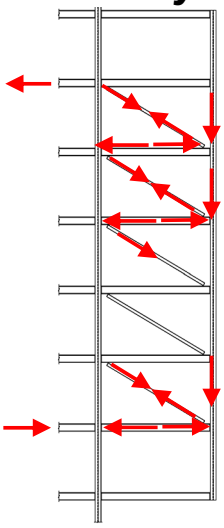


Gravity – Discontinuous Element



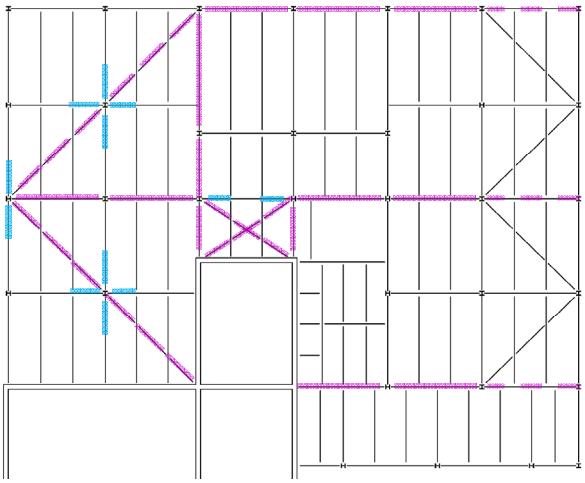
- Follow Load Path

Gravity – Discontinuous Element



- Overhang produces thrust
- Thrust resisted by lateral system
- Must have sufficient continuous load path for applied thrust load to lateral force resisting system

Gravity – Discontinuous Element



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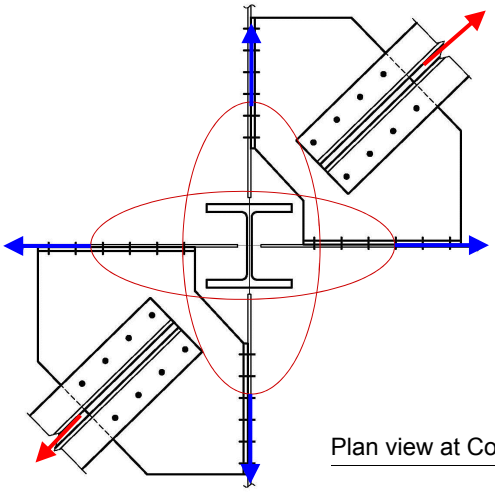
Gravity – Discontinuous Element

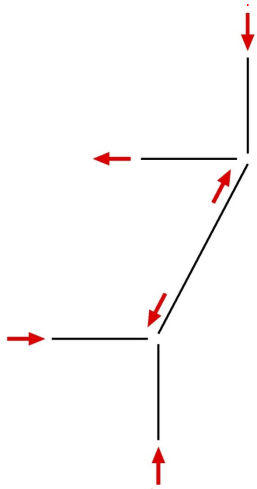


- Need a complete load path (i.e. load needs to pass through column)

Plan view at Column

Load Path 27

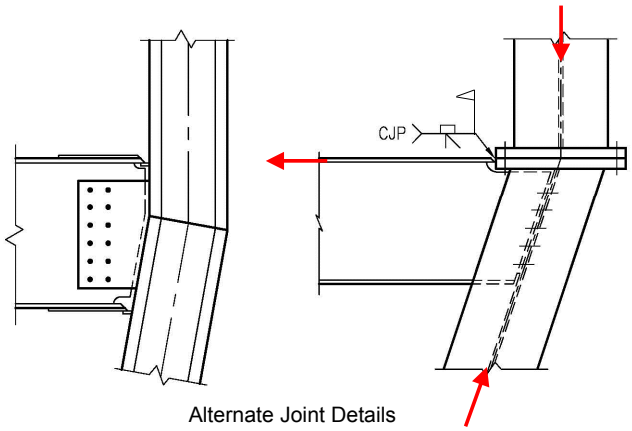
Remember Joint Equilibrium - Sloping Column



- Equilibrium of sloped column produces thrust
- Floor beams resist axial load at sloping column
- From beam to diaphragm
- From diaphragm to lateral force resisting system
- From LFRS to foundations

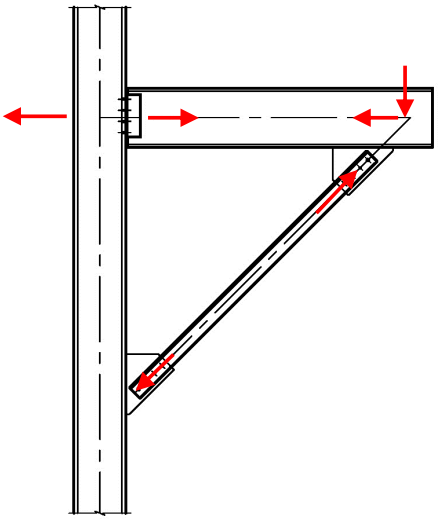
Load Path 28

Remember Joint Equilibrium - Sloping Column



Alternate Joint Details

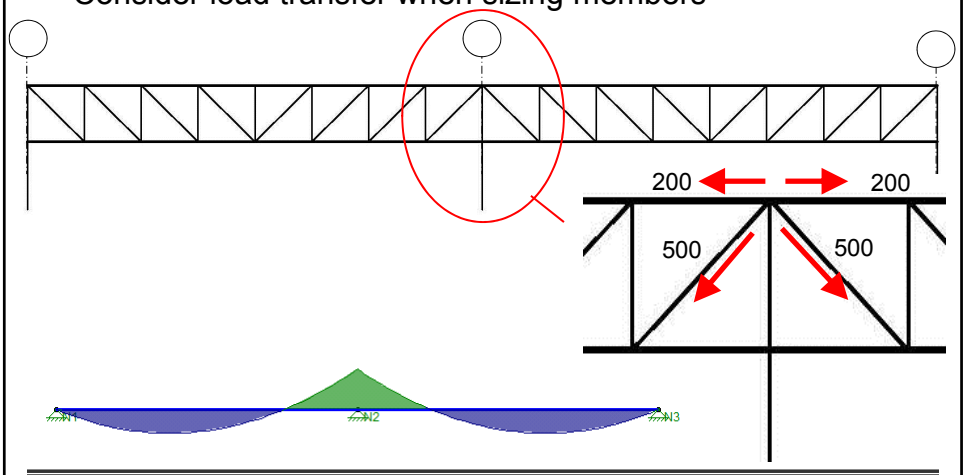
Remember Joint Equilibrium



- Kickers induce tension in floor beams
- Put axial load on drawings
- Complete load path

Continuous Trusses

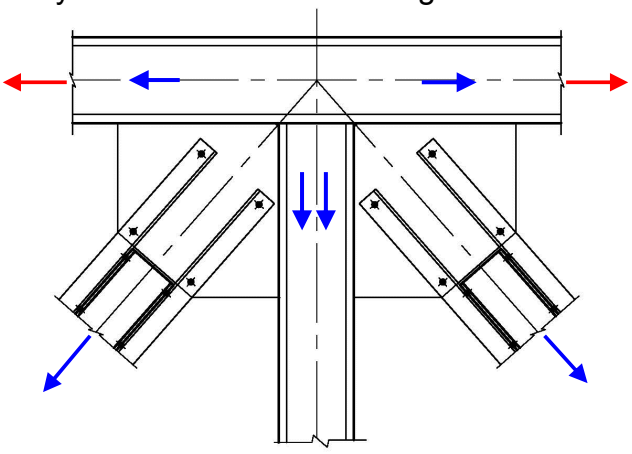
- Consider load transfer when sizing members



Load Path 31

Continuous Trusses

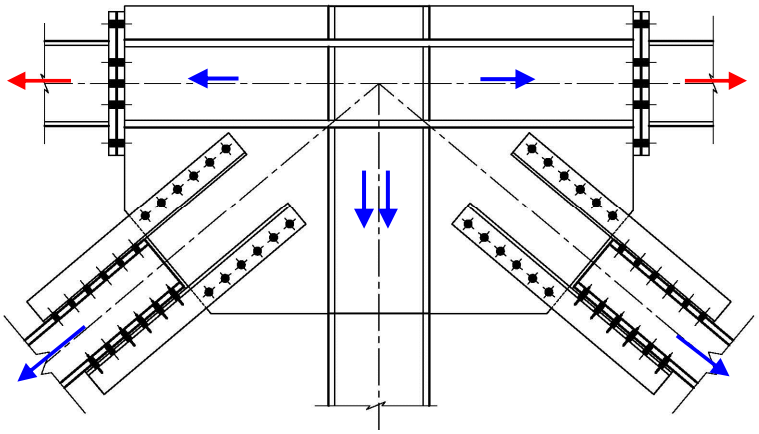
- Chord may not have sufficient strength at connection



Load Path 32

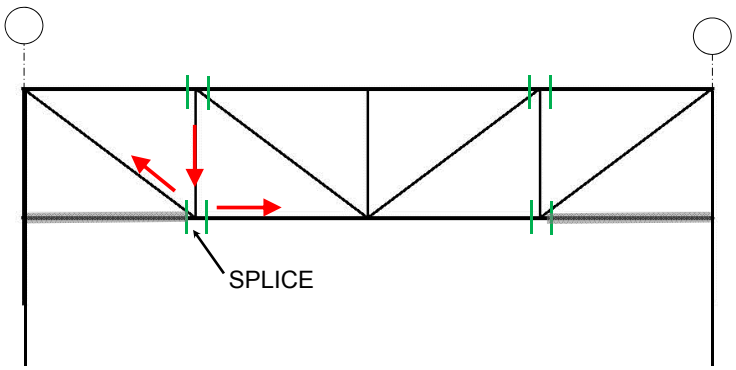
Continuous Trusses

- Chord may not have sufficient strength at connection



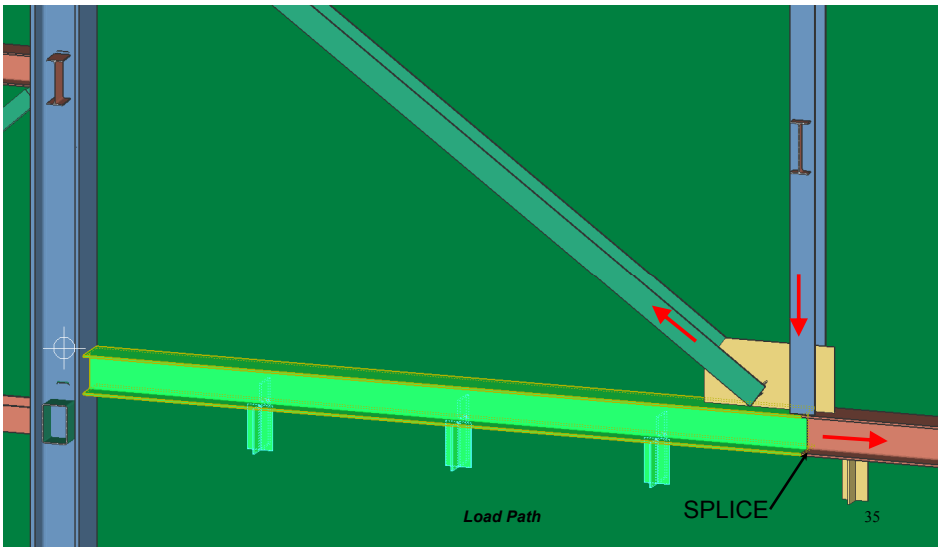
Truss Chords

- Consider load transfer when sizing members

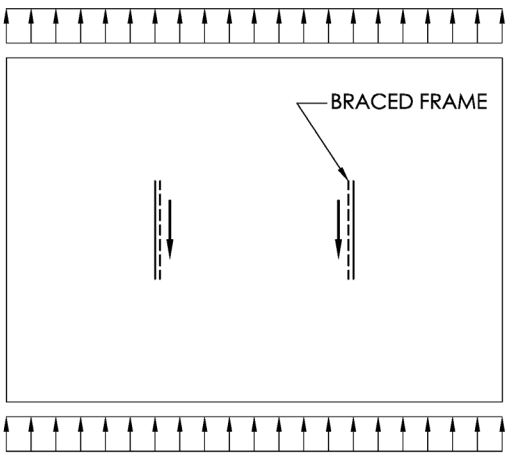


Truss Chords

- Consider load transfer when sizing members

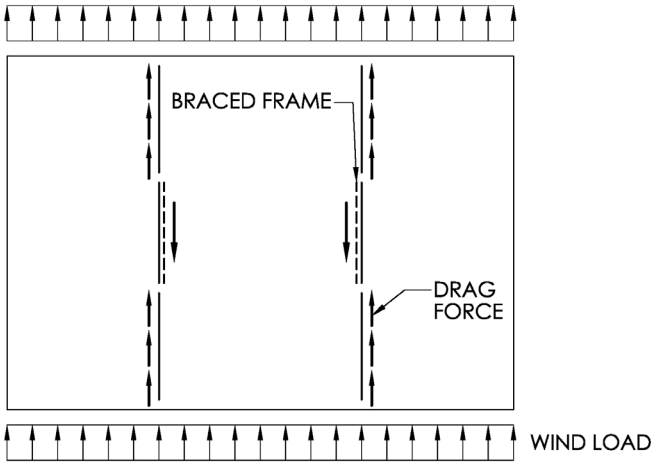


Lateral - Wind

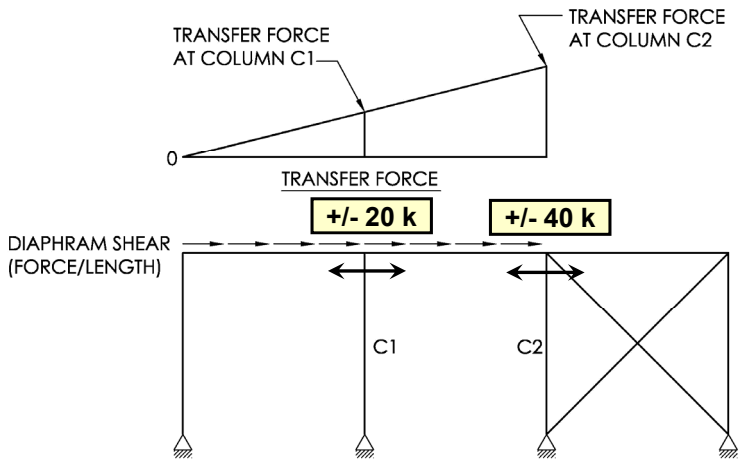


- Wind on Façade
- Façade to structure (e.g. beams or diaphragms)
- Diaphragms to LFRS
- LFRS to Foundations

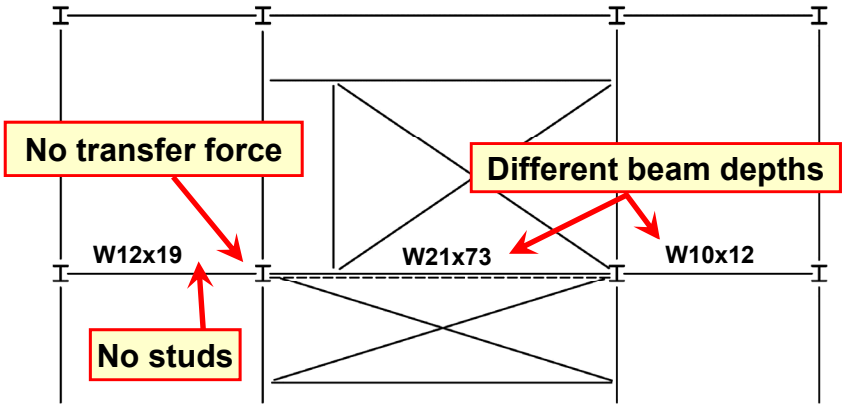
Getting the Load to the Lateral System



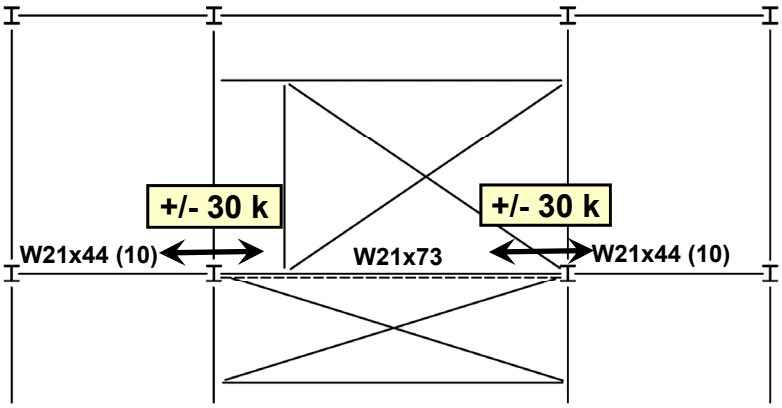
Getting the Load to the Lateral System



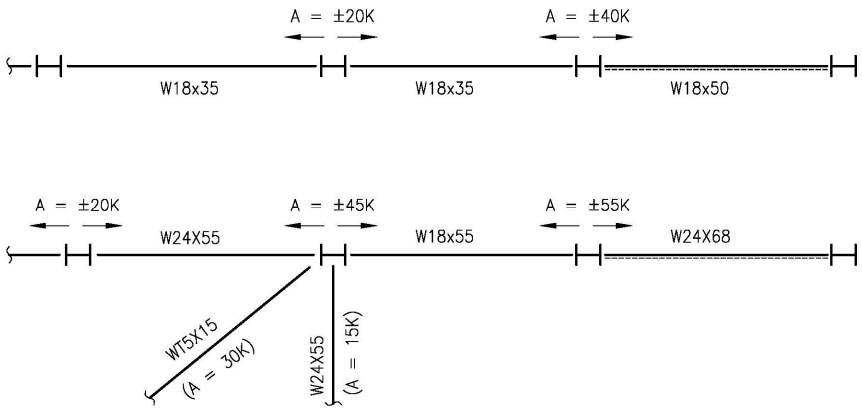
Getting the Load to the Lateral System



Getting the Load to the Lateral System

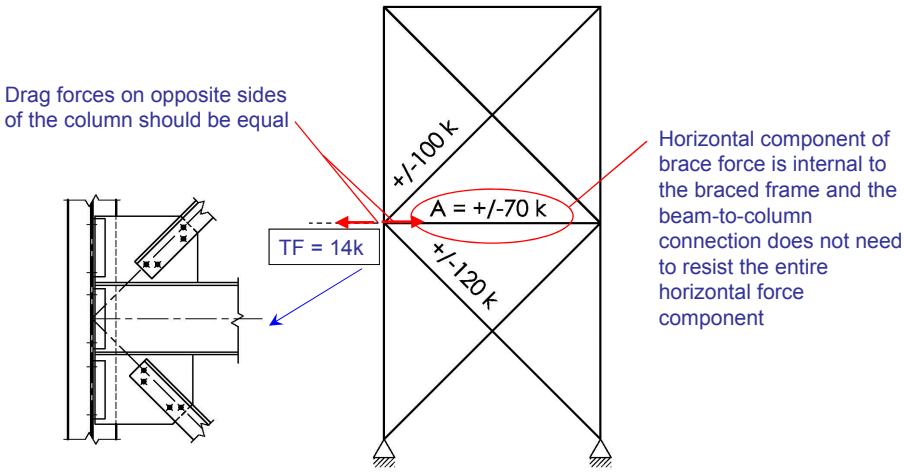


Getting the Load to the Lateral System



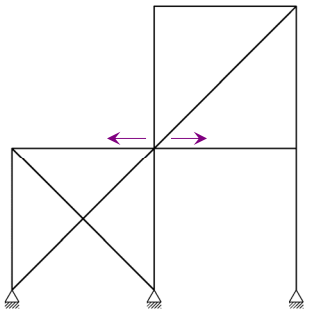
Load Path 41

Getting the Load to the Lateral System

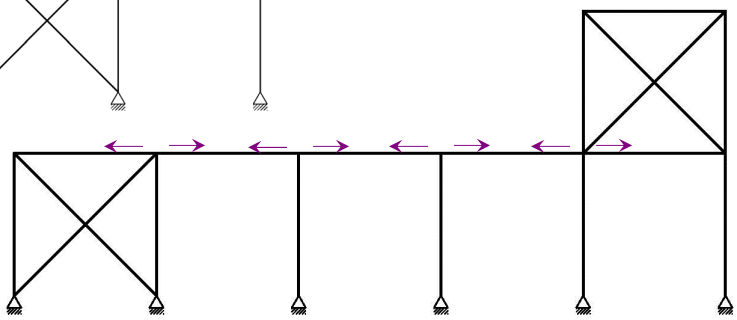


Load Path 42

Discontinuous Braced Bays



- Lateral force in a discontinuous bay needs to be transferred to the lateral system below



Load Path 43

Transfer Loads

Team Effort

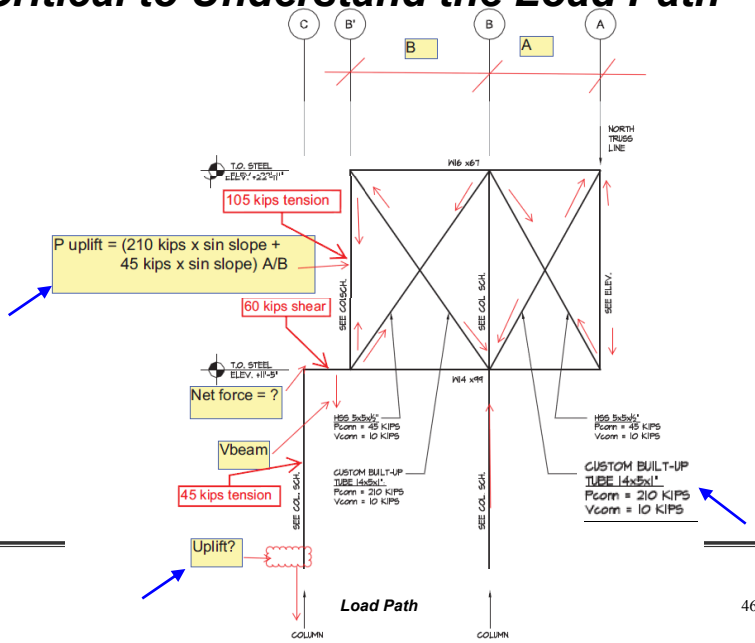
1. Dependant on diaphragm strength (special attention needed at roof deck)
2. Dependant on actual load combinations
3. Dependant on special project requirements
4. Need a complete load path

Load Path 44

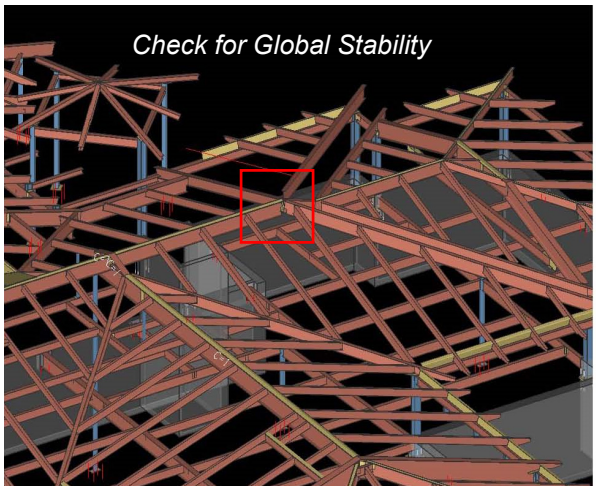
Connections

- Connections are critical for complete load path
- A continuous load path is as strong as its weakest link
- Fine line between load path and equilibrium for connections

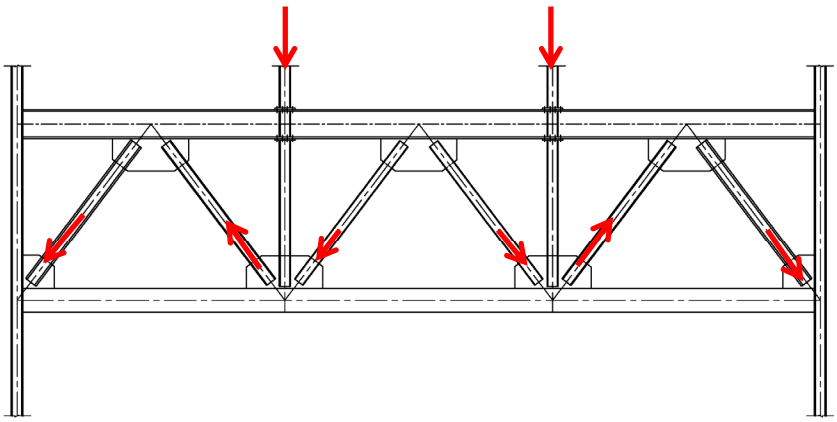
Critical to Understand the Load Path



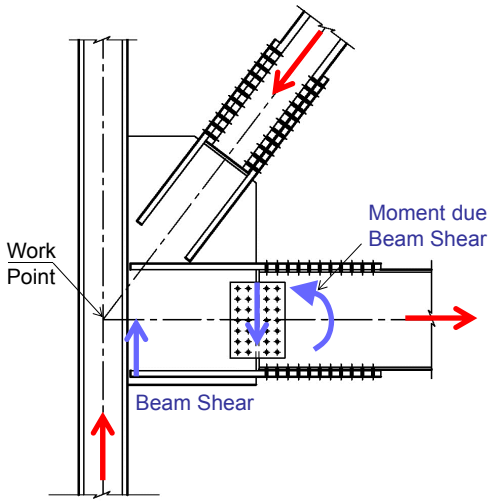
Ridge Connections



Connections - Trusses

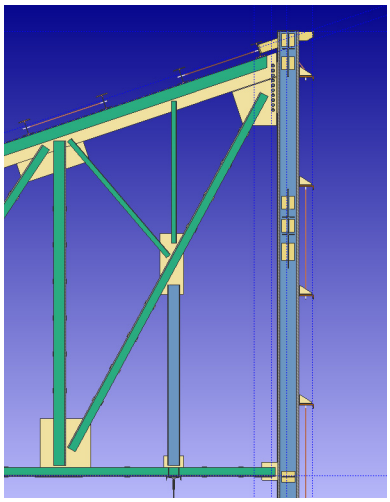


Connections - Trusses

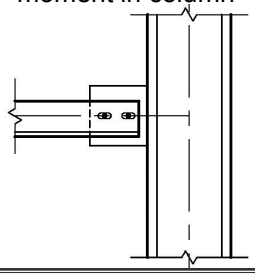


- Consider work points when designing connections.
- Connections should not induce moments on supporting members

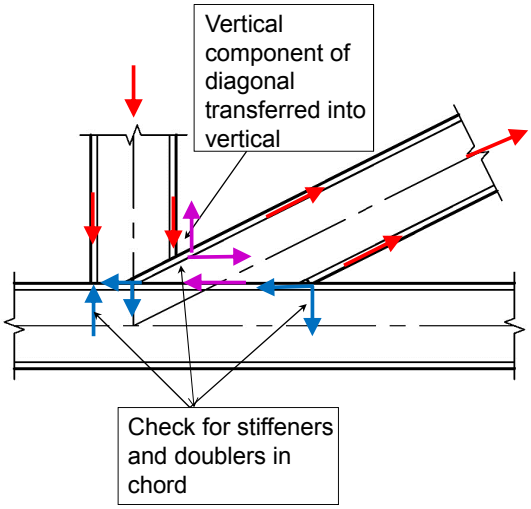
Connections - Trusses



- Truss End Connections
- Slot at one chord connection to allow for movement due to truss rotation
- Alternately, consider some moment in column



Connections - Trusses



- Welded Truss – understand load path
- Joint must be in equilibrium
- Check for stiffeners and doublers at relevant sections
- Pick a load path and stick with it
- See Blodgett

Connections - Trusses

- Welded Truss – understand load path
- Joint must be in equilibrium
- Check for stiffeners and doublers at relevant sections
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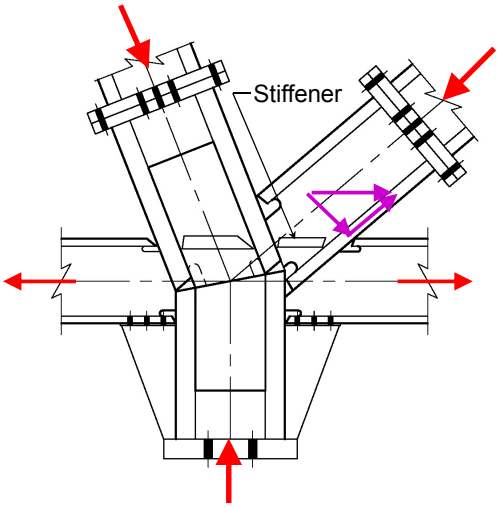
Connections - Trusses

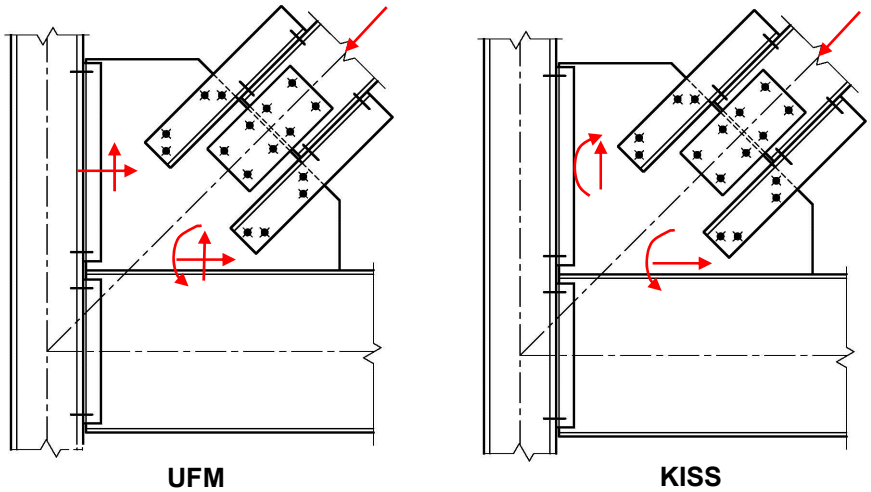


- Welded Truss – understand load path
- Stiffener added to transfer load across joint and avoid stiffeners and doublers in right diagonal

Connections - Trusses

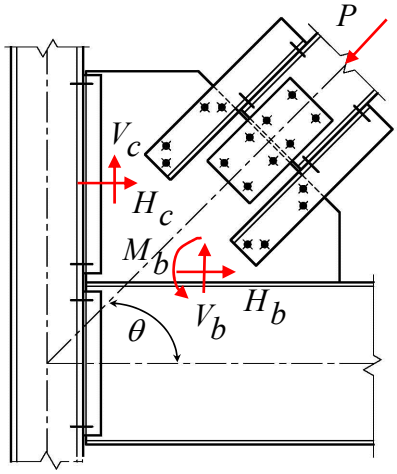
Connections - Trusses

Connections-Bracing



UFM KISS

Connections-Bracing UFM



UFM

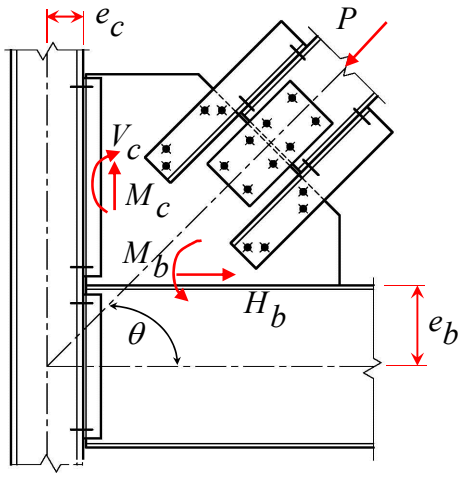
$$V_b = \frac{e_b}{r} P - \Delta V_b$$

$$H_b = \frac{\alpha}{r} P$$

$$M_b = \frac{e_b}{r} P(\alpha - \alpha') + \Delta V_b \alpha'$$

$$V_c = \frac{\beta}{r} P + \Delta V_b \qquad H_c = \frac{e_c}{r} P$$

Connections-Bracing KISS



KISS

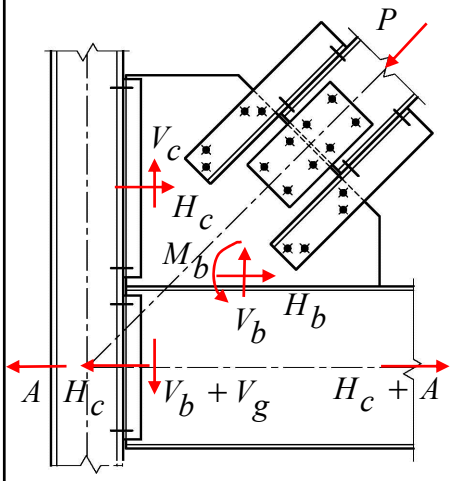
$$H_b = P\cos(\theta)$$

$$M_b = H_b(e_b)$$

$$V_c = P\sin(\theta)$$

$$M_c = V_c(e_c)$$

Connections-Bracing UFM

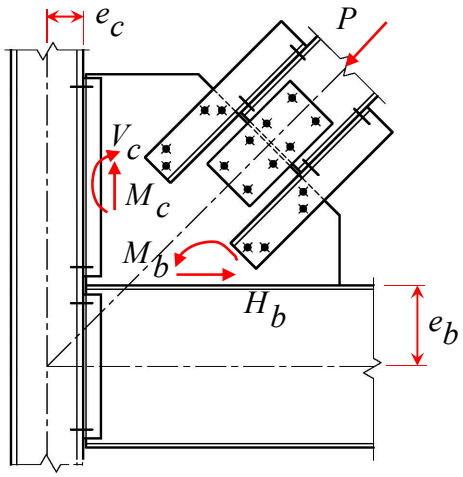


UFM

- *Hc* from gusset-to-column to column-to-beam
- *Vb* from gusset-to-beam to beam-to-column
- Add gravity to *Vb*
- Consider transfer forces and *Hc*
- Allows for force redistribution

Load Path 59

Connections-Bracing KISS



KISS

- No *Hc*
- No *Vb*
- Does not impact beam-to-column connection
- **Need to consider moment at column**

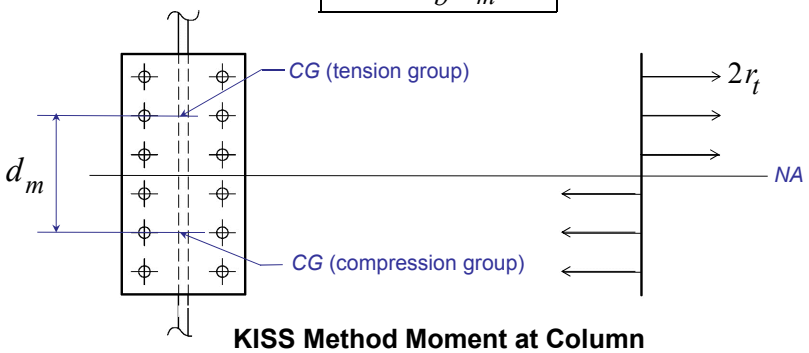
Load Path 60

Connections-Bracing KISS

BOLT TENSION

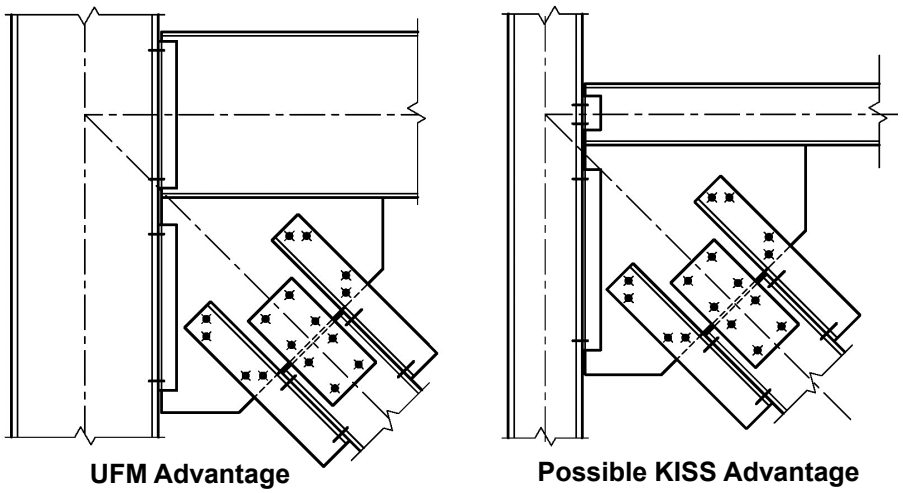
$$r_t = \frac{M_c}{n'_b \, d_m}$$

- See Manual Fig. 7-7



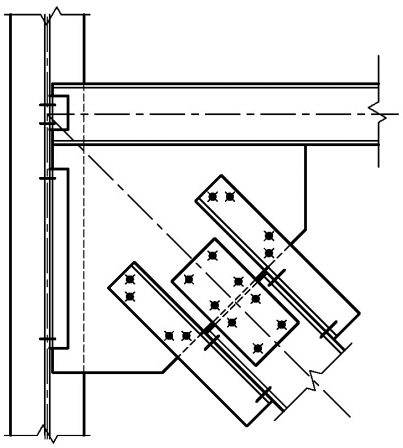
KISS Method Moment at Column

Connections-Bracing



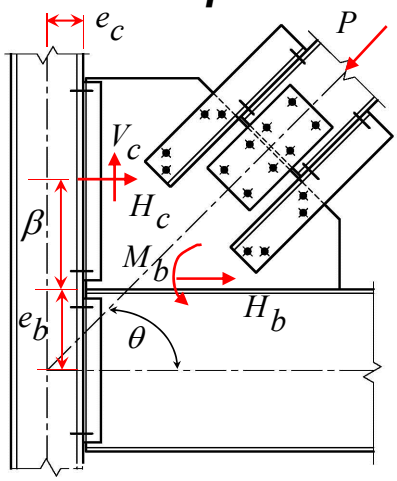
UFM Advantage **Possible KISS Advantage**

Connections-Bracing



UFM Special Case II = KISS at Column Webs

UFM – Special Case II to Column Flange



UFM Special Case II

$$V_c = P \sin \Theta$$

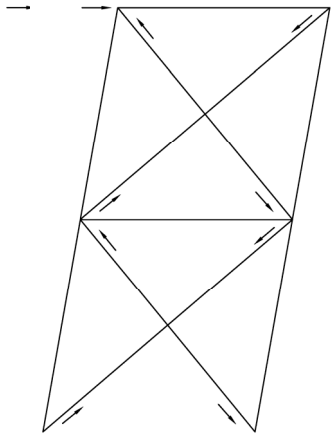
$$H_c = V_c \frac{e_c}{(e_b + \beta)}$$

$$H_b = P \cos \Theta - H_c$$

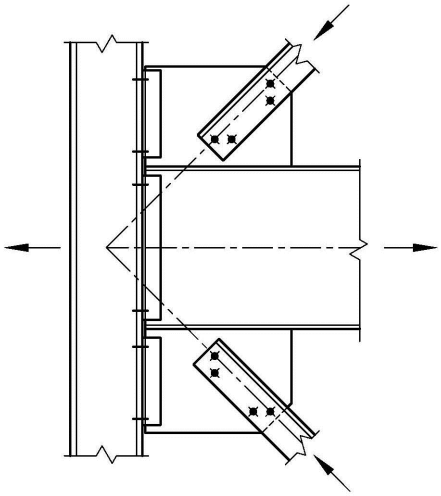
$$M_b = H_b(e_b)$$

$$V_b = 0$$

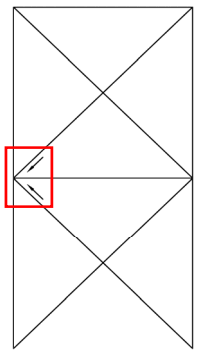
Vertical Bracing



Vertical Bracing

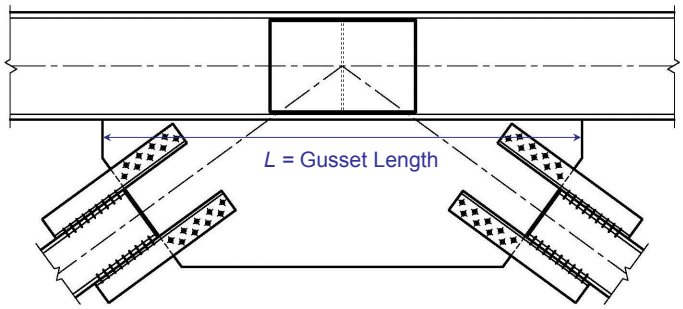


- Indicate if both top and bottom braces in compression



Brace to Beam Centers

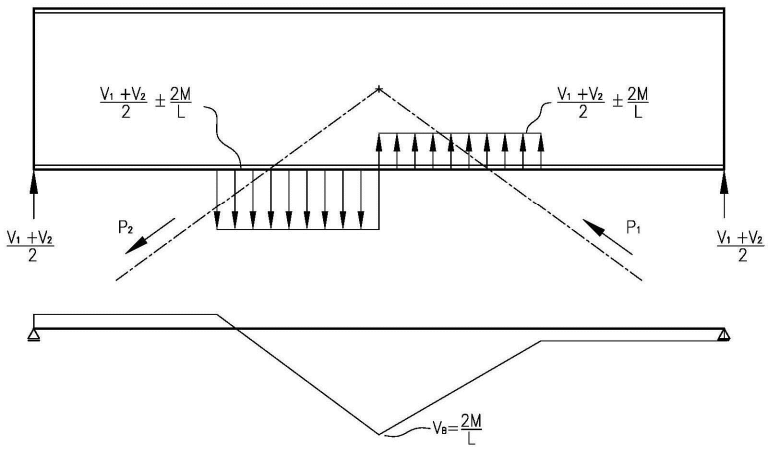
- Check for doublers – example (bottom brace only)



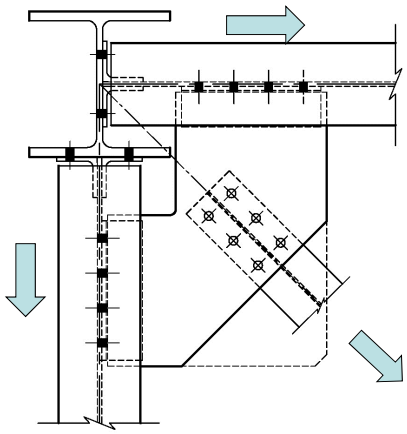
Brace to Beam Centers

- Check for doublers

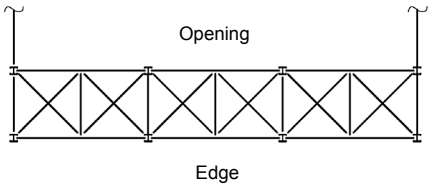
$P_1 \neq P_2$



Horizontal Bracing

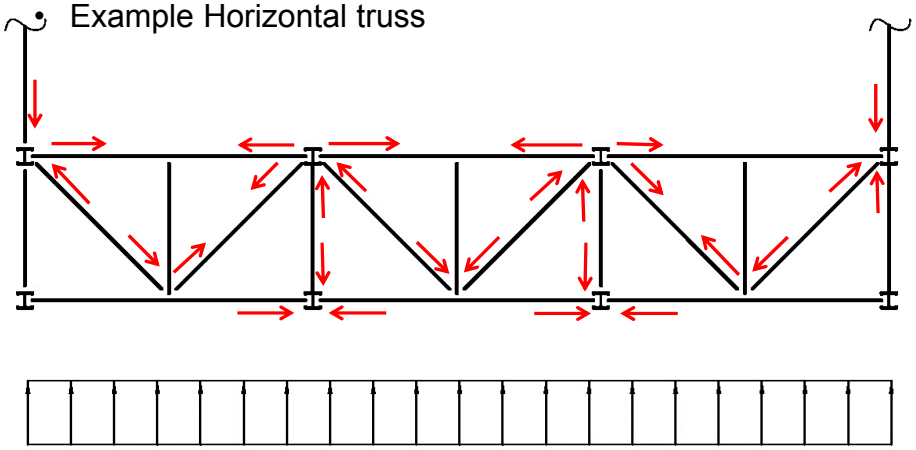


- Can use horizontal gussets to transfer loads

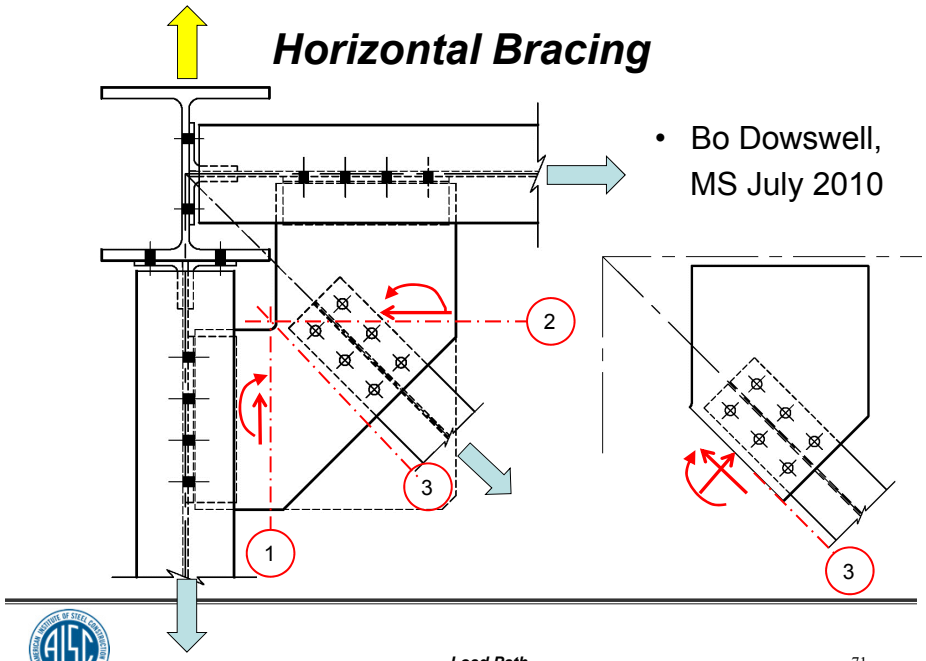


Horizontal Bracing

- Example Horizontal truss



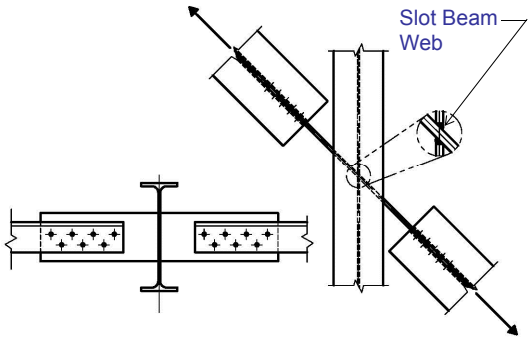
Horizontal Bracing



- Bo Dowswell, MS July 2010

Load Path 71

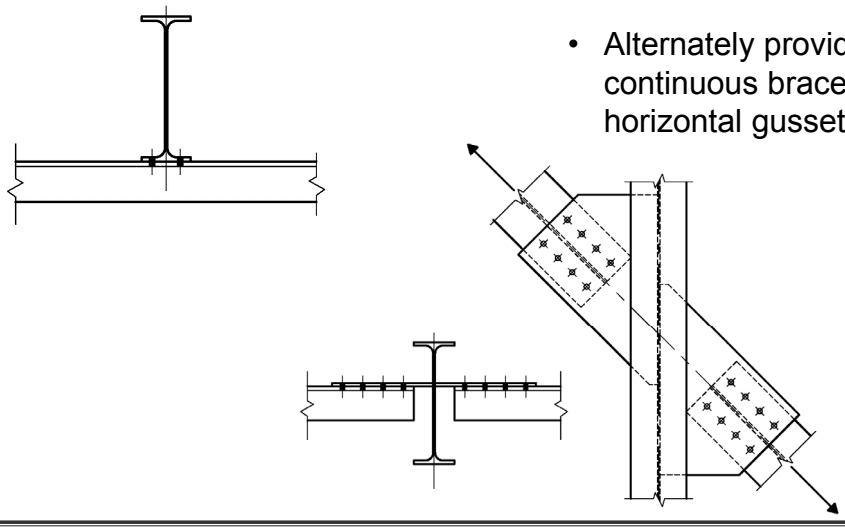
Horizontal Bracing



- Can slot beams for horizontal bracing connections to allow for a direct transfer of forces

Load Path 72

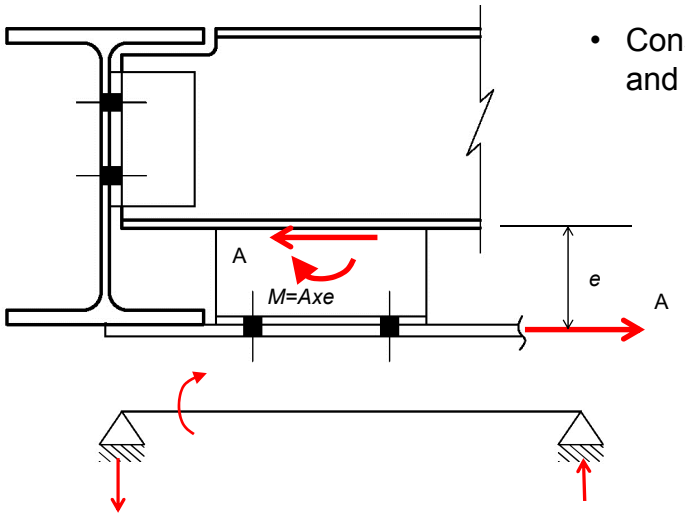
Horizontal Bracing



- Alternately provide a continuous brace or horizontal gussets

Load Path 73

Horizontal Bracing

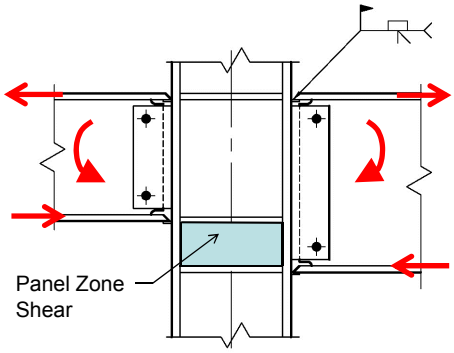


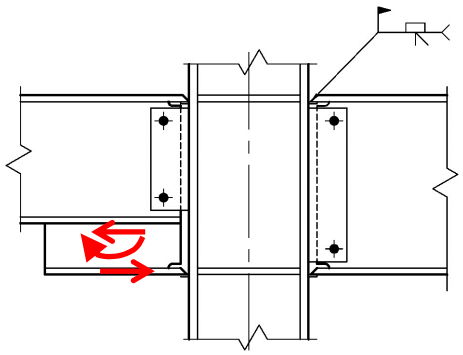
- Consider load path and equilibrium

Load Path 74

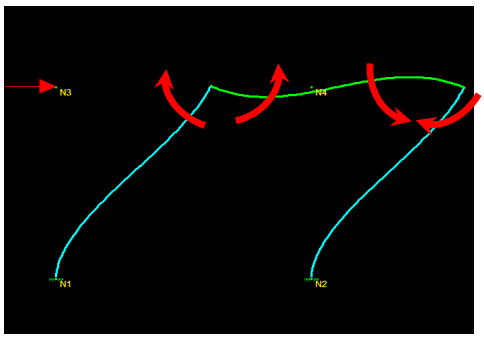
Moment Connections

- Consider load path and equilibrium

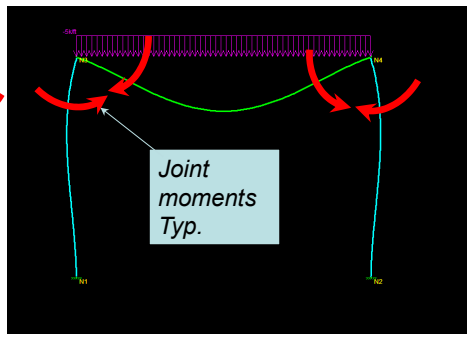




Deflected Shape

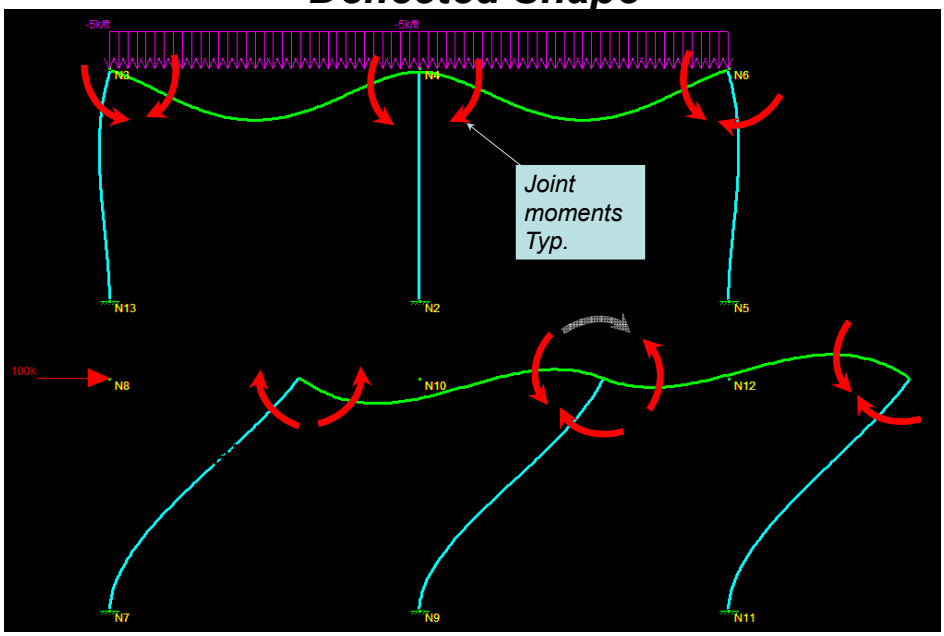


Lateral

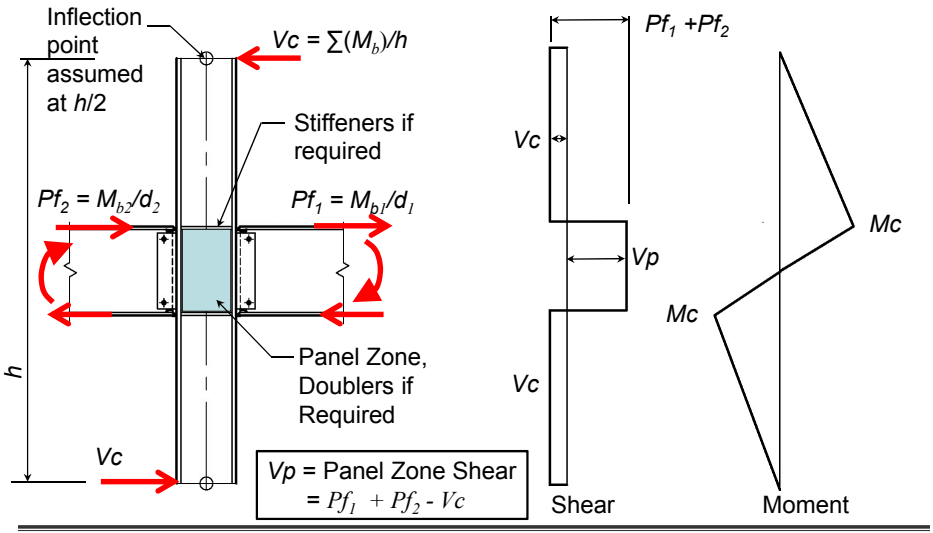


Gravity

Deflected Shape

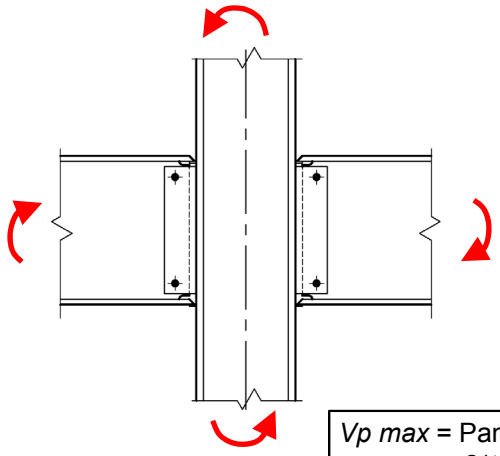


Moment Connections – Lateral FBD



Load Path 78

Moment Connections – Doublers

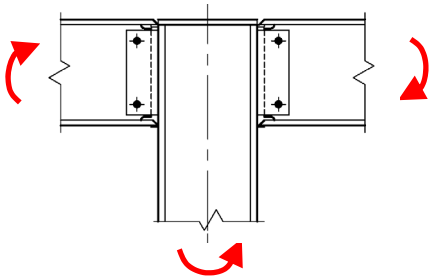


- $\sum M = 0$
  $\therefore \sum(M_b) \le \sum(\phi M_c)$
- Sum of beam moments can not exceed sum of column moment strengths

Vp max = Panel Zone Shear
= $2(\phi Mc)/d_b - 2(\phi Mc)/h$

Moment Connections – Doublers

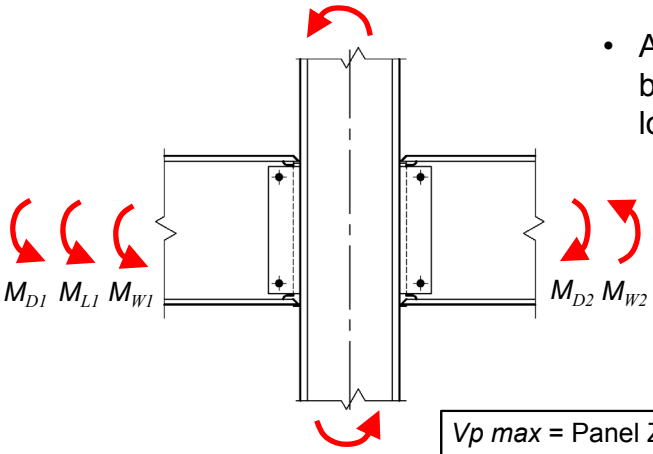
Top of Column



- $\sum M = 0$
  $\therefore \sum(M_b) \le \phi M_c$
- At top for column, sum of beam moments can not exceed column moment strengths

Vc max = Panel Zone Shear
= $\phi Mc/d_b$

Moment Connections – Doublers

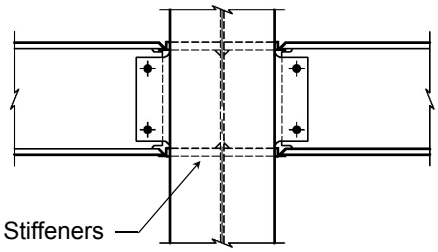


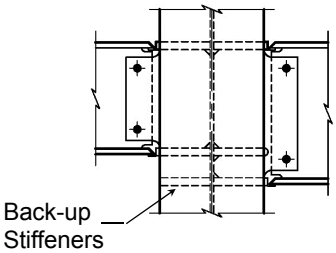
- Add dead load on both sides and live load on one side

Vp max = Panel Zone Shear
= $2(\phi Mc)/d_b - 2(\phi Mc)/h$

Load Path 81

Connections – Moments to Column Webs

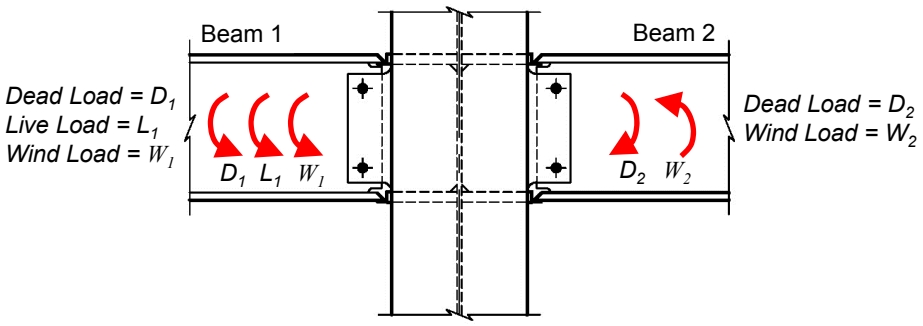




- Doublers not required
- Size Stiffeners and Stiffener welds
- Can be 1-sided or 2-sided

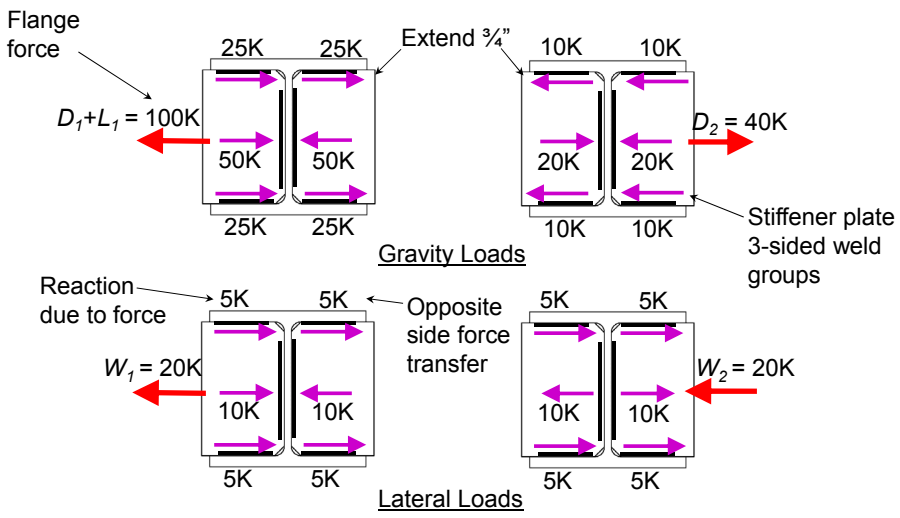
Load Path 82

Connections – Stiffener Load Path



83

Connections – Stiffener Load Path



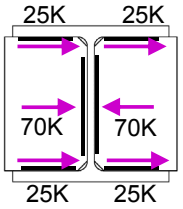
*All welds in the group are to be the same size

84

Connections – Stiffener Load Path

Total **Flange Weld**
$D_1+L_1-D_2+W_1+W_2$

Web Weld
$(D_1+L_1)/2+(D_2+L_2)/2+(W_1-W_2)/2$

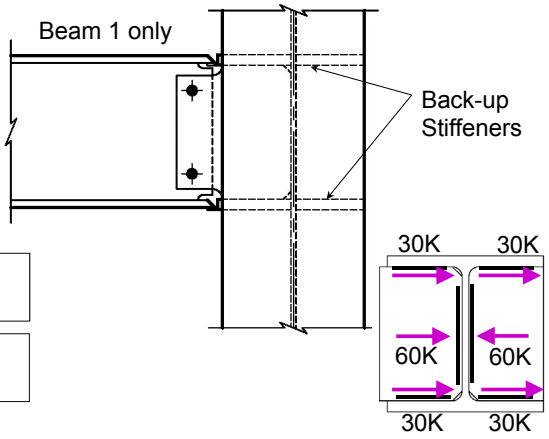


Also check $D_1+L_1+W_1$ for total weld 1-side of column

85

Connections – Stiffener Load Path

Dead Load = D_1
Live Load = L_1
Wind Load = W_1



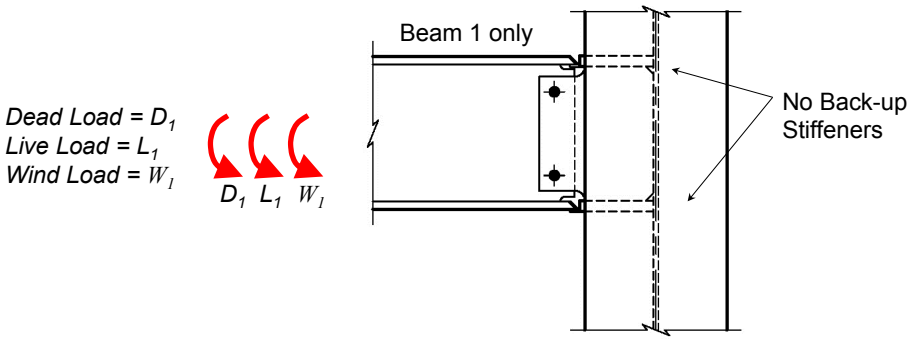
Total **Flange Weld**
$D_1+L_1+W_1$

Web Weld
$(D_1+L_1+W_1)/2$

**All welds in the group are to be the same size*

86

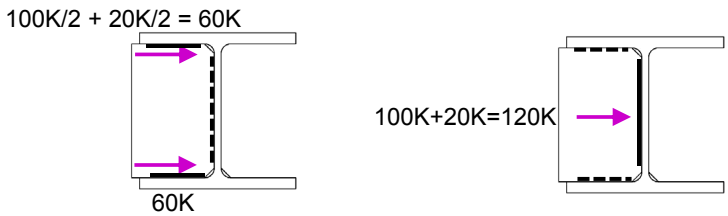
Connections – Stiffener Load Path



87

Connections – Stiffener Load Path

*No Back-up Stiffener Flanges Resist Load	*No Back-up Stiffener Web Resist Load
Total **Flange Weld** $D_1+L_1+W_1$	Total **Flange Weld** -
Web Weld -	**Web Weld** $D_1+L_1+W_1$



*See AISC Design Guide 13

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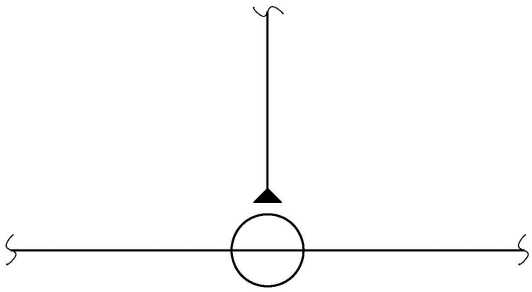
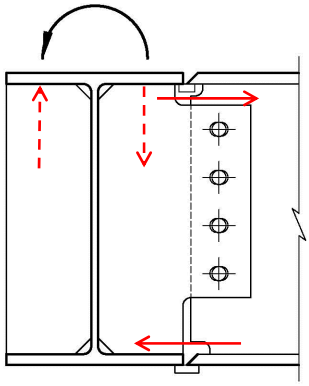
Davits

Davits

- Moments at base
- Moments typically in any direction

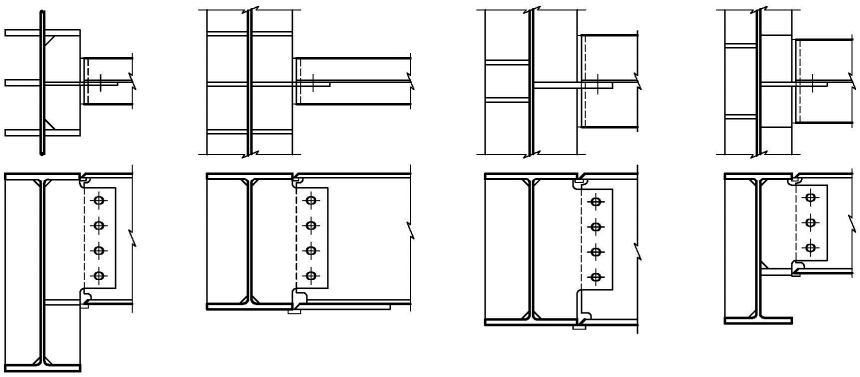


Davit Support Beam FBD

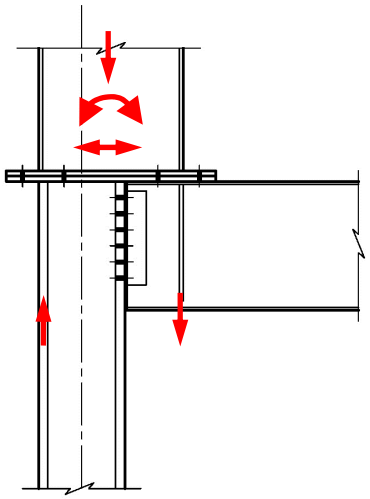


- Perpendicular beam typically resists the moment applied about the davit support beam's longitudinal axis
- Typically requires 2, 3, or 4 stiffeners

Davits - Alternate Framing Examples

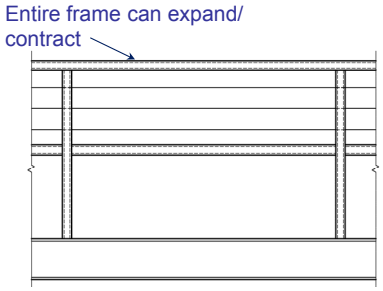


Davits - Alternate Framing Examples

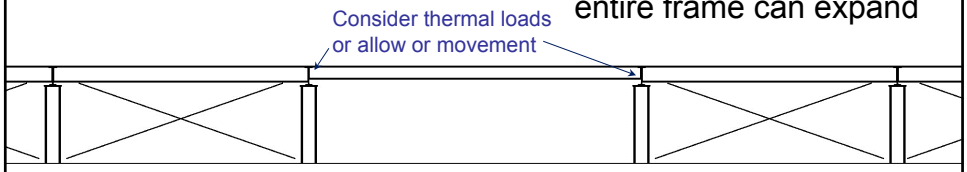


- Can transfer load to support through flexure

Thermal Expansion

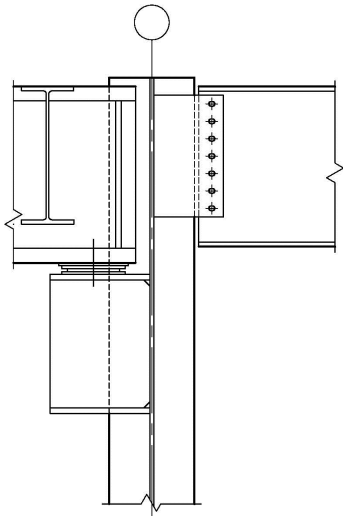


- Allow for movement
- Alternately, resist restraining forces
- Less of a concern if entire frame can expand



Exterior Frames

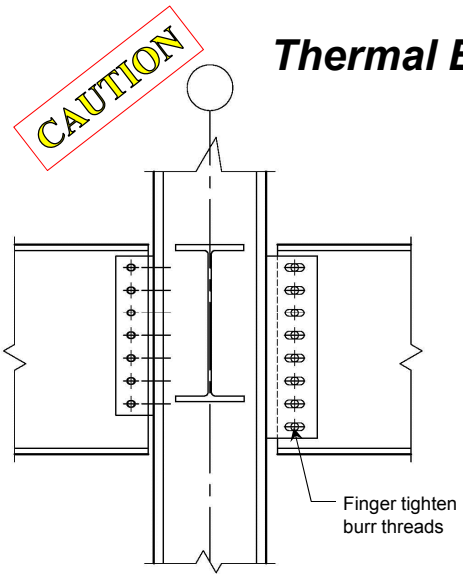
Thermal Expansion



- Can use single column with slide bearing connection
- Consider appropriate eccentricity in supporting member

Load Path 95

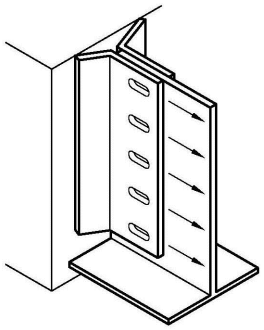
Thermal Expansion



- If possible, avoid connections with slotted holes to accommodate slip
- Slots need to be long enough to accommodate slip – both directions
- Bolt threads should be eXcluded from the shear plane.
- Bolts should not be over tensioned. Do not over weld

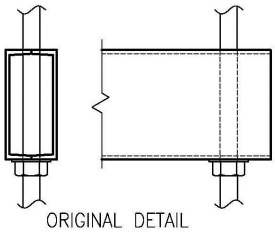
Load Path 96

Thermal Expansion



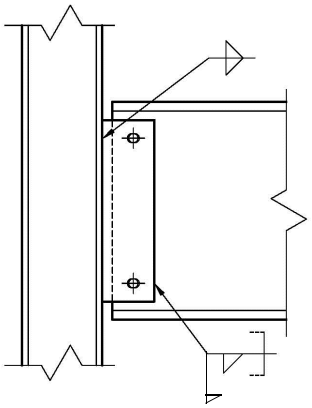
- David L. Lawrence Convention Center collapse in February 2007 blamed on expansion joint failure
- Welded/Bolted Double-Angles should not be used at expansion joints
- Axial load induces moment through the throat of the fillet weld

Framing



- Hyatt collapse was in part due to revised continuous member

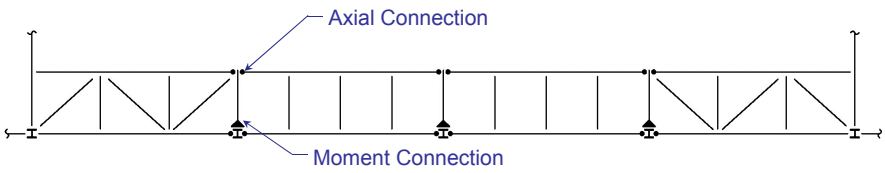
Simple Connections



- Beam end connections need to allow for end rotation of simply supported beams (see AISC Spec J1.2)
- Avoid welded-welded shear plate connections

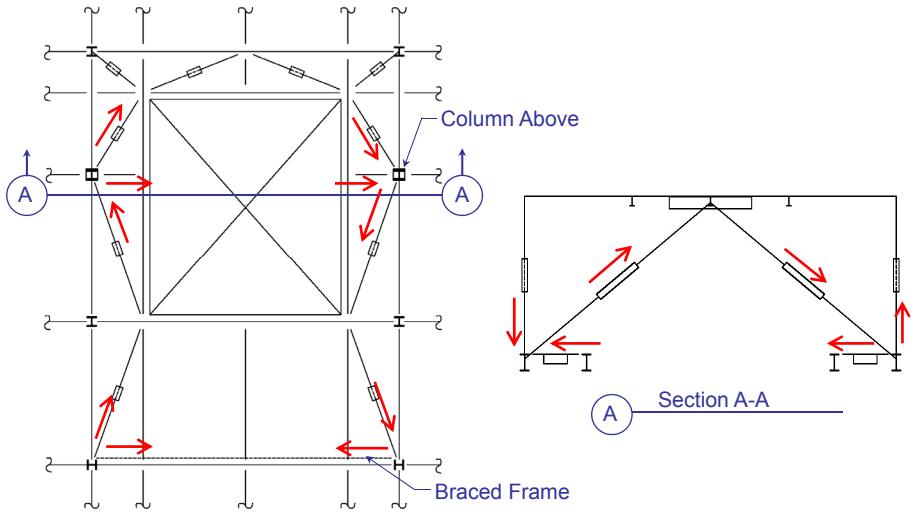
Good Load Path - Lateral

- Axial connection used to transfer chord forces
- Horizontal bracing used to reinforce diaphragm



Plan View

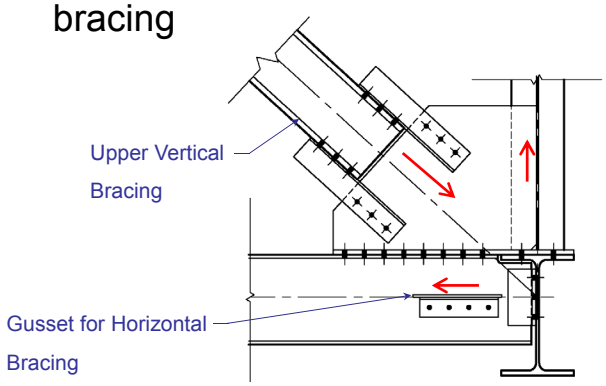
Good Load Path - Lateral



Load Path 101

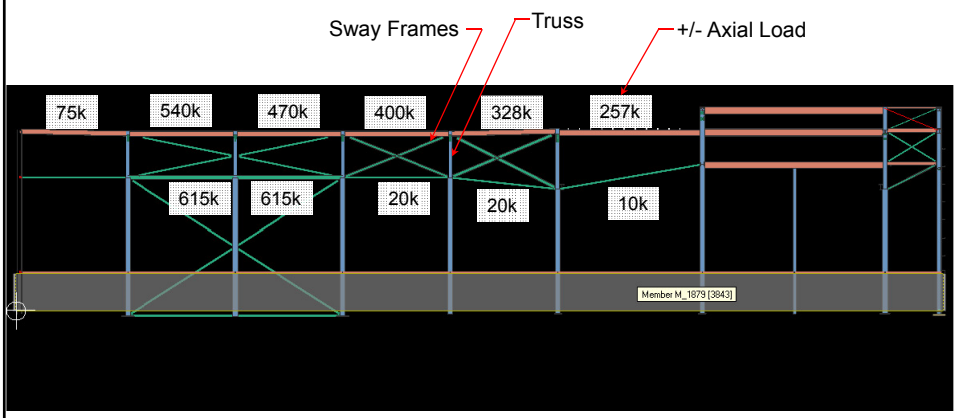
Good Load Path - Lateral

- Continuous load path from upper vertical bracing to horizontal bracing to lower vertical bracing



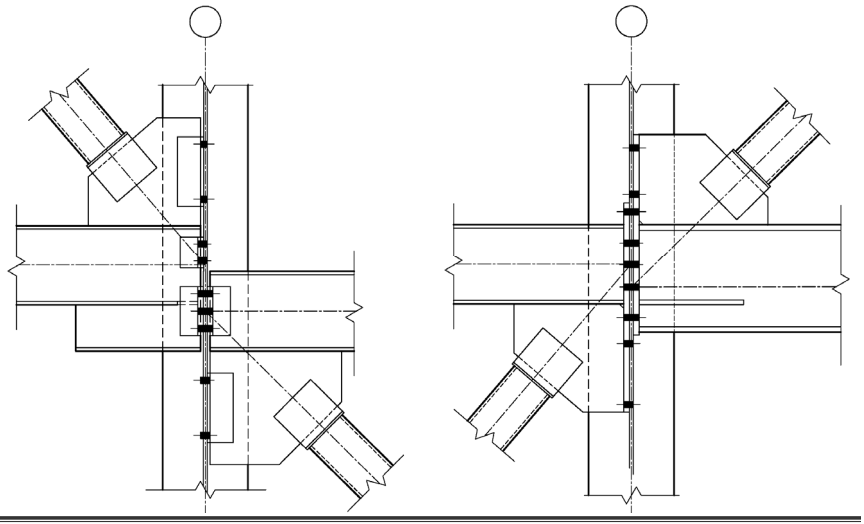
Load Path 102

Good Load Path - Bracing



Load Path 103

Good Load Path – Transfer Force



Load Path 104

Load Path

By: Carol Drucker, SE, PE, P.Eng

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  Username: Your Attendee ID (found on your reg. receipt)
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