Steel Joists, Joist Girders and Steel Deck

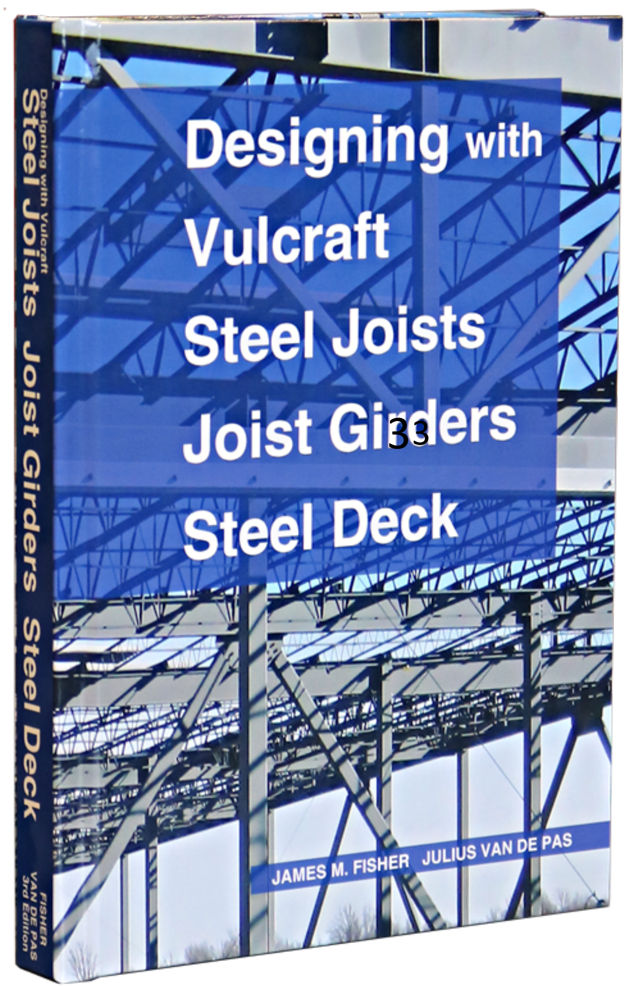
Diaphragm Design

Presented by NUCOR/Vulcraft
with contributions by the Steel Joist Institute

Topics

- Diaphragm Definitions
- Roof Deck Types
- Deck Connections
- Design Example
- Details

See Chapter 4, Section 4.2



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Definitions and Uses

- Each deck sheet is inter-connected by
  (side lap fasteners)

- The deck is attached to supporting members
  (support fasteners)

- The deck provides in-plane shear strength and stiffness
  (transfer in-plane forces)

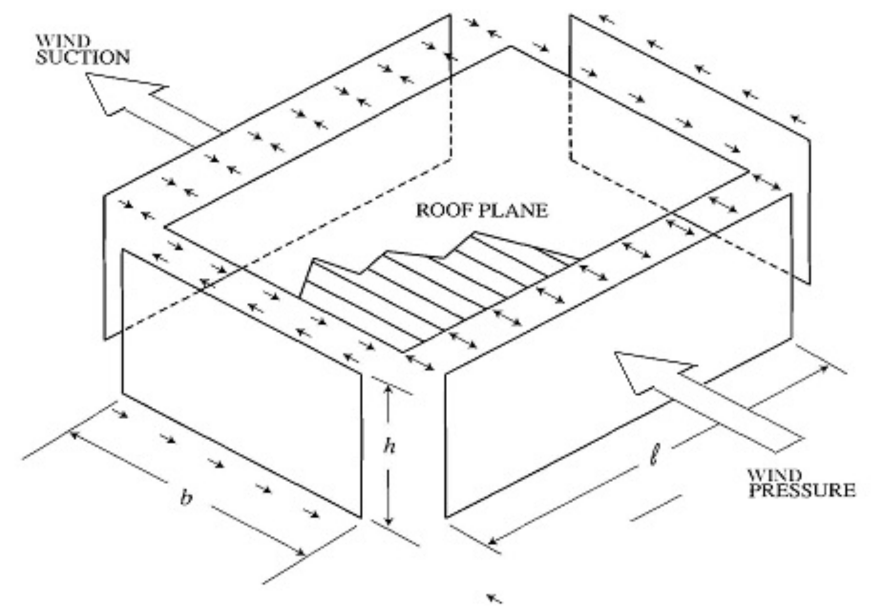
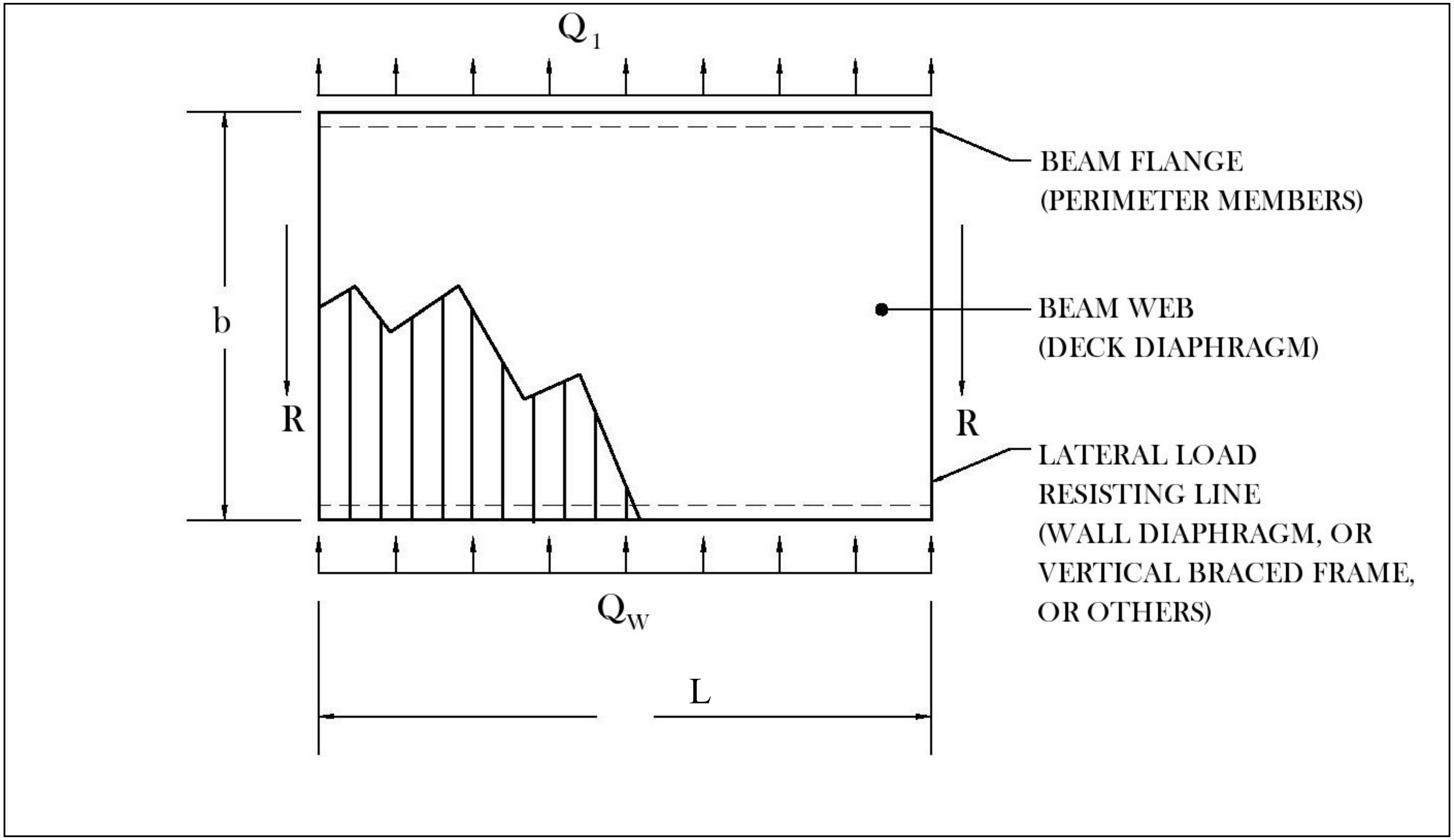
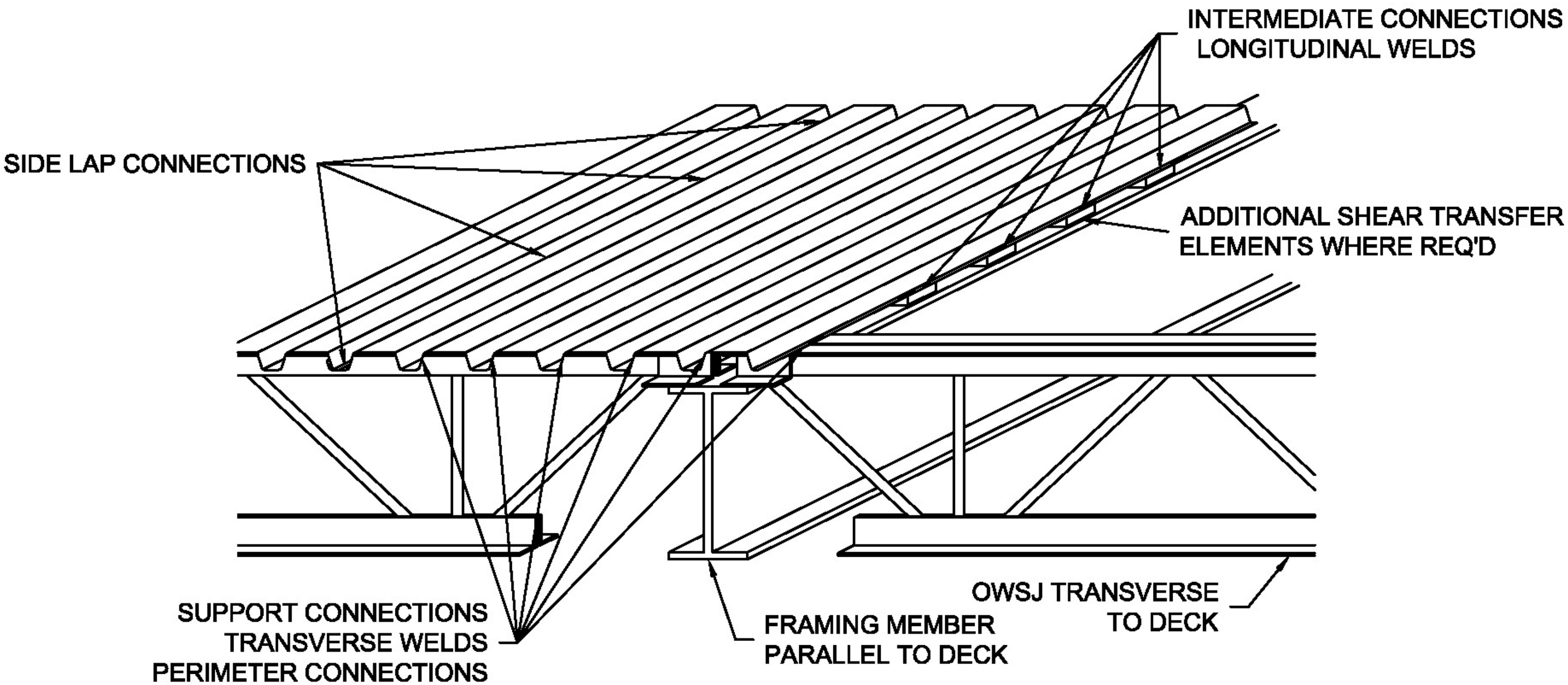


FIG 1.1-1 DIAPHRAGM COMPONENTS

Diaphragm Analogous to a Deep Girder with Deck as Web

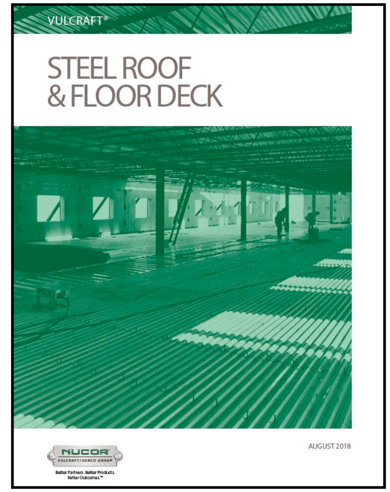


Typical Connections



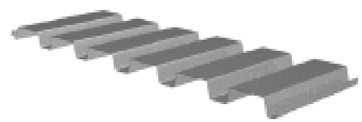
Roof Decks

Reference Vulcraft catalog (Nucor, 2018a)
www.vulcraft.com

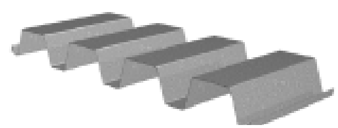


ROOF DECKS

1.5B ROOF DECKS
COVER WIDTHS: 30”, 36”
GAGES: 24, 22, 20, 19, 18, 16



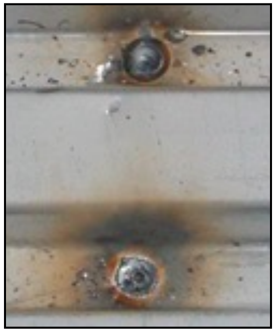
32” WIDE 3N ROOF DECKS
COVER WIDTH: 32”
GAGES: 22, 20, 19, 18, 16



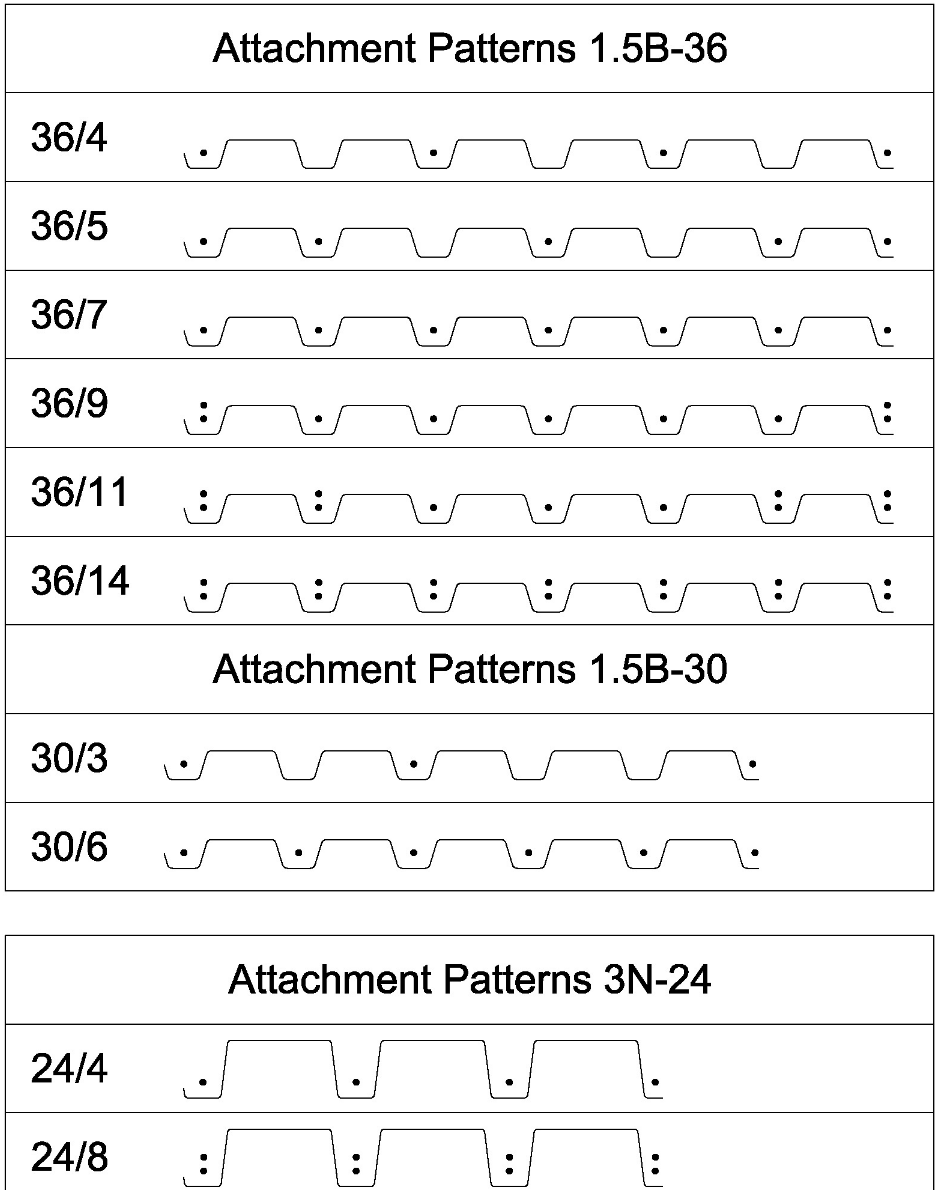
Use 1.5B, 22 or 20 gage deck is very common

Connections

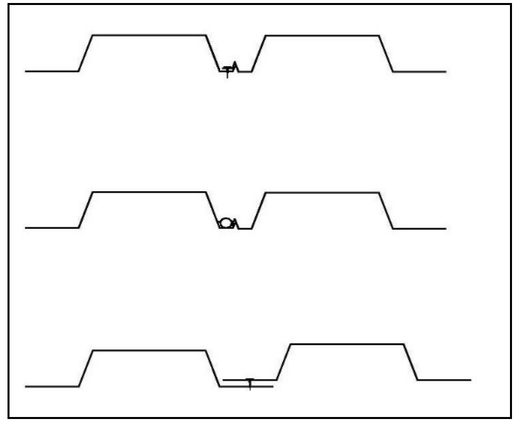
- Support Fasteners
  - Arc spot weld / Weld with washer (for t <= 0.028 in.)
  - Screw (self-drilling & self-tapping)
  - Power-driven fasteners
- Side-lap fasteners
  - PunchLok II
  - Weld (not recommended for t <= 0.028 in.)
  - Screw
  - Button punch (stabilize panels, small strength)



Support Fastening Patterns



Side-Lap Fastening



Number of fasteners per span in the load tables

Diaphragm Design Procedure

- Determination of forces
- Selection of deck type and fastening
  - Steel Deck Institute (SDI)
  - ICC-ES reports
  - IAPMO reports
  - Vulcraft catalog (Nucor, 2018a)
- Evaluation of deflections
- Analysis of chord forces
- Force transfer details

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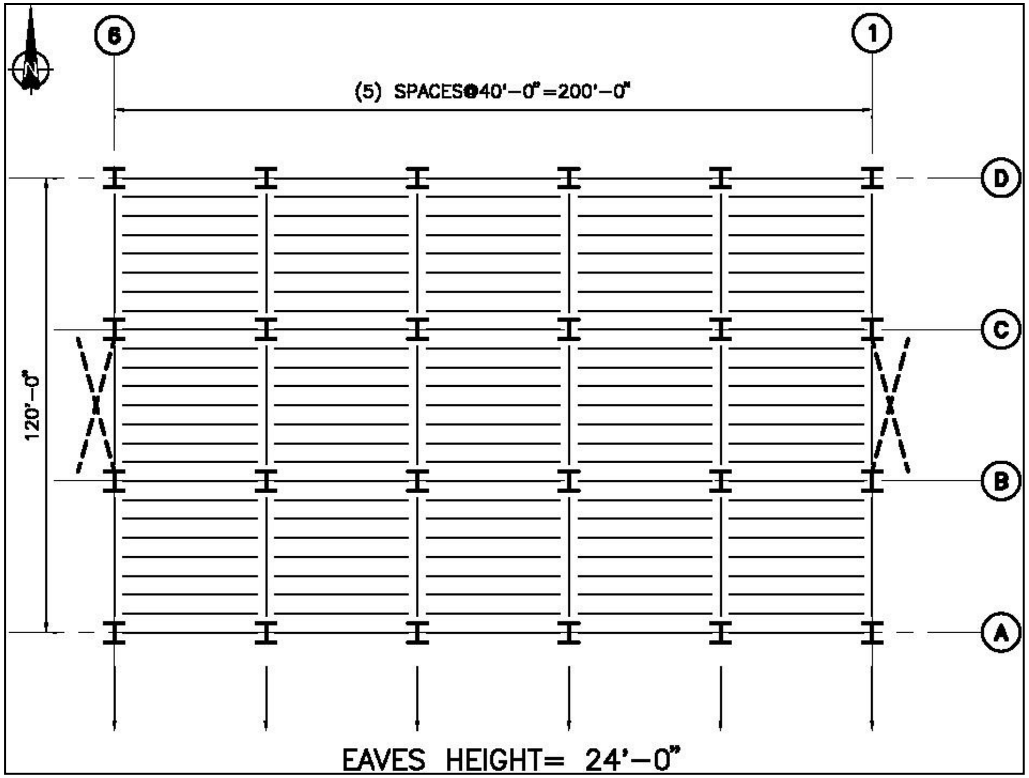
Example: Roof Diaphragm



DESIGN DATA
(service loads)

Dead Load	26 psf
Live Load	20 psf
Wind Load	20 psf
Uplift	30 psf

22K7 joists
1.5B22 deck
(t = 0.0295 in.)

The building is constructed using a metal wall system and is located in a warm climate where snow load is negligible.

Diaphragm Design

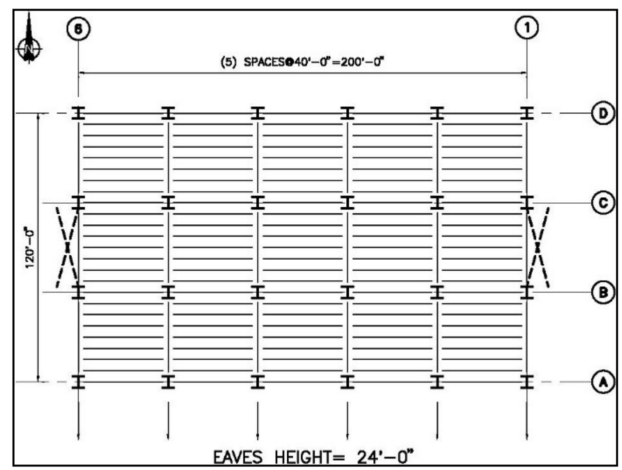
Determine shear at each wall

The shear force at each end wall equals the wind pressure times one-half of the building height and one-half of the length of the wind loaded wall.

Lines 1 and 6:

$$V_1 = V_6 = (\text{Wind Pressure})\left(\frac{\text{Bldg. Ht.}}{2}\right)\left(\frac{\text{Windward Wall Length}}{2}\right)$$

$$= \frac{(20\ \text{psf})\left(\frac{24\ \text{ft}}{2}\right)\left(\frac{200\ \text{ft}}{2}\right)}{1000\ \text{lb/kip}} = 24.0\ \text{kips}$$



Line A and D:

$$V_A = V_D = \frac{(20\ \text{psf})\left(\frac{24\ \text{ft}}{2}\right)\left(\frac{120\ \text{ft}}{2}\right)}{1000\ \text{lb/kip}} = 14.4\ \text{kips}$$

Diaphragm Design (continued)

Determine maximum linear diaphragm shear

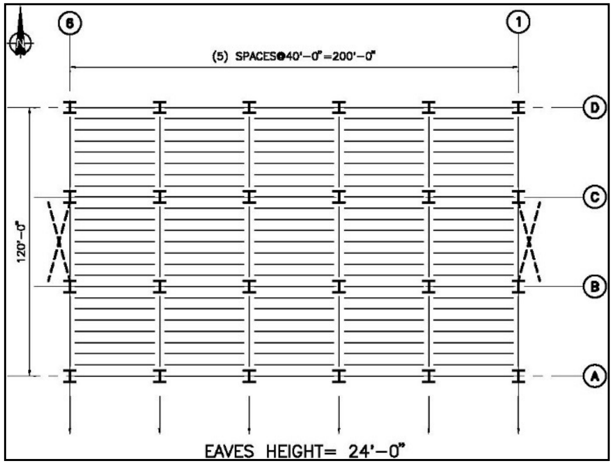
The linear diaphragm shear equals the wall shear divided by the wall length.

Lines 1 and 6:

$$S_1 = S_6 = \frac{(24.0\ \text{kips})(1000\ \text{lb/kip})}{120\ \text{ft}} = 200\ \text{plf}$$

Line A and D:

$$S_A = S_D = \frac{(14.4\ \text{kips})(1000\ \text{lb/kip})}{200\ \text{ft}} = 72.0\ \text{plf}$$



Diaphragm Design (continued)

Try fastening pattern:

Steel deck:	1.5B22 (0.0295 in. thickness)
Support fasteners:	5/8 in. puddle weld, 36/4 pattern
Side-laps:	(1) #10 Tek screw side-lap connection per span
Deck support:	Joists spaced at 5 ft center-to-center

Load and execute Vulcraft 2018 IBC Diaphragm Tool (Nucor, 2018b) Vulcraft Tools

Vulcraft /Verco Diaphragm Design Tool 2018 IBC

22 ga 1.5B-36 Grade 50 Roof Deck

Diaphragm Shear & Wind Uplift Interaction

with MWFRS Allowable Net Wind Uplift (ASD) of 30 psf

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5/8" Visible Dia. Arc Spot Weld Connections to Supports
36 / 7 / 4 Perpendicular Connection Pattern to Supports
#10 Screw Sidelap Connections

A572 GR50 Support Member or Equivalent
0.25 ≤ Support Thickness (in.)
2 in. Minimum Deck End Bearing Length

ASD Allowable Combined Wind Uplift & Diphragm Shear Strength Sn/Ω (plf) Generic 3 Span Condition

Sidelap Connections per Span	Span								
	5'-0"	5'-0"	5'-0"	5'-0"	5'-0"	5'-0"	5'-0"	5'-0"	5'-0"
1	339	339	339	339	339	339	339	339	339
2	395	395	395	395	395	395	395	395	395
3	451	451	451	451	451	451	451	451	451
4	505	505	505	505	505	505	505	505	505
5	553	553	553	553	553	553	553	553	553
6	600	600	600	600	600	600	600	600	600
7	645	645	645	645	645	645	645	645	645

200 plf ≤ 339 plf **O.K.**

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Check Diaphragm Chord Forces

Diaphragm chord force calculation

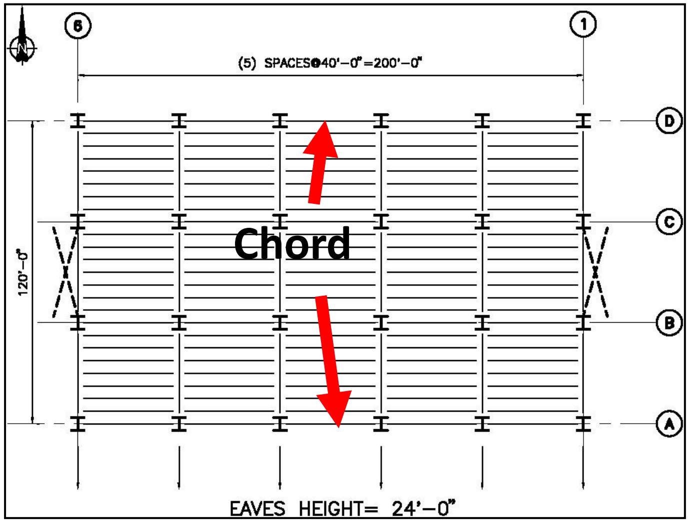
Considering the edge joists to resist the diaphragm chord force,

$$M_{A\&D} = \frac{wL^2}{8} = \frac{(20.0\ \text{psf})\left(\frac{24\ \text{ft}}{2}\right)(200\ \text{ft})^2}{8(1000\ \text{lb/kip})} = 1200\ \text{kip-ft}$$

$$P_{chord} = \frac{M_{A\&D}}{\text{Diaphragm depth}}$$

The edge member should be continuous.

$$= \frac{1200\ \text{kip-ft}}{120\ \text{ft}} = 10\ \text{kips}$$



Check Diaphragm Chord Forces (continued)

Diaphragm chord force calculation

The diaphragm chord force is combined with forces due to dead and live loads. The edge joist top chord is designed for the combined force

$$P_{chord} + P_{chord(D+L)}$$

where

$$M_{D+L} = \frac{w_{(D+L)} L_{joist}^{2}}{8} = \frac{(46.0 \text{ psf})(2.50 \text{ ft})(40 \text{ ft})^2}{8(1000 \text{ lb/kip})} = 23.0 \text{ kip-ft}$$

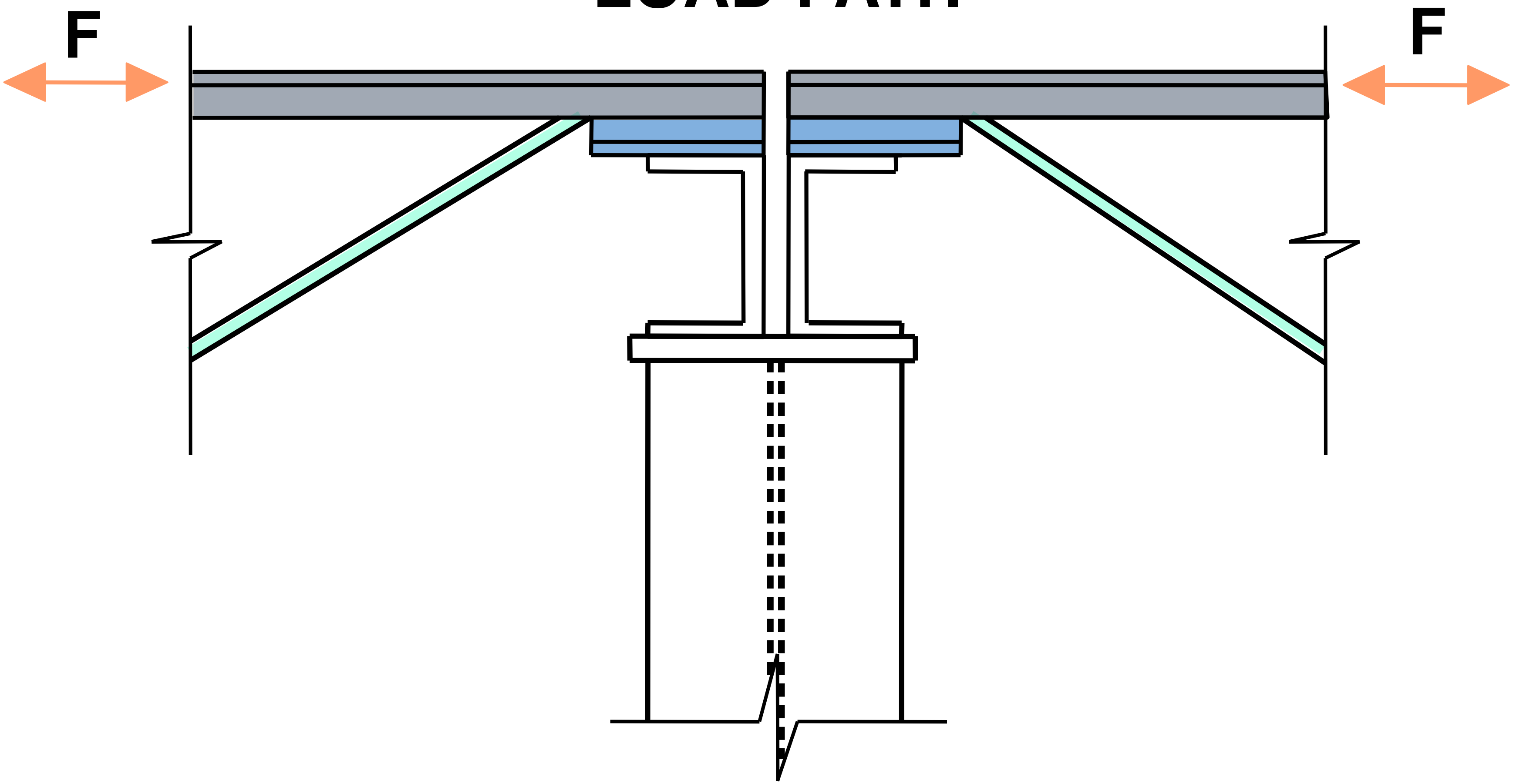
$$P_{chord(D+L)} = \frac{M_{(D+L)}}{\text{Joist chord centroid distance}} = \frac{23.0 \text{ kip-ft}}{1.75 \text{ ft}} = 13.1 \text{ kips}$$

$$P_{chord} + P_{chord(D+L)} = 10.0 \text{ kips} + 13.1 \text{ kips} = 23.1 \text{ kips}$$

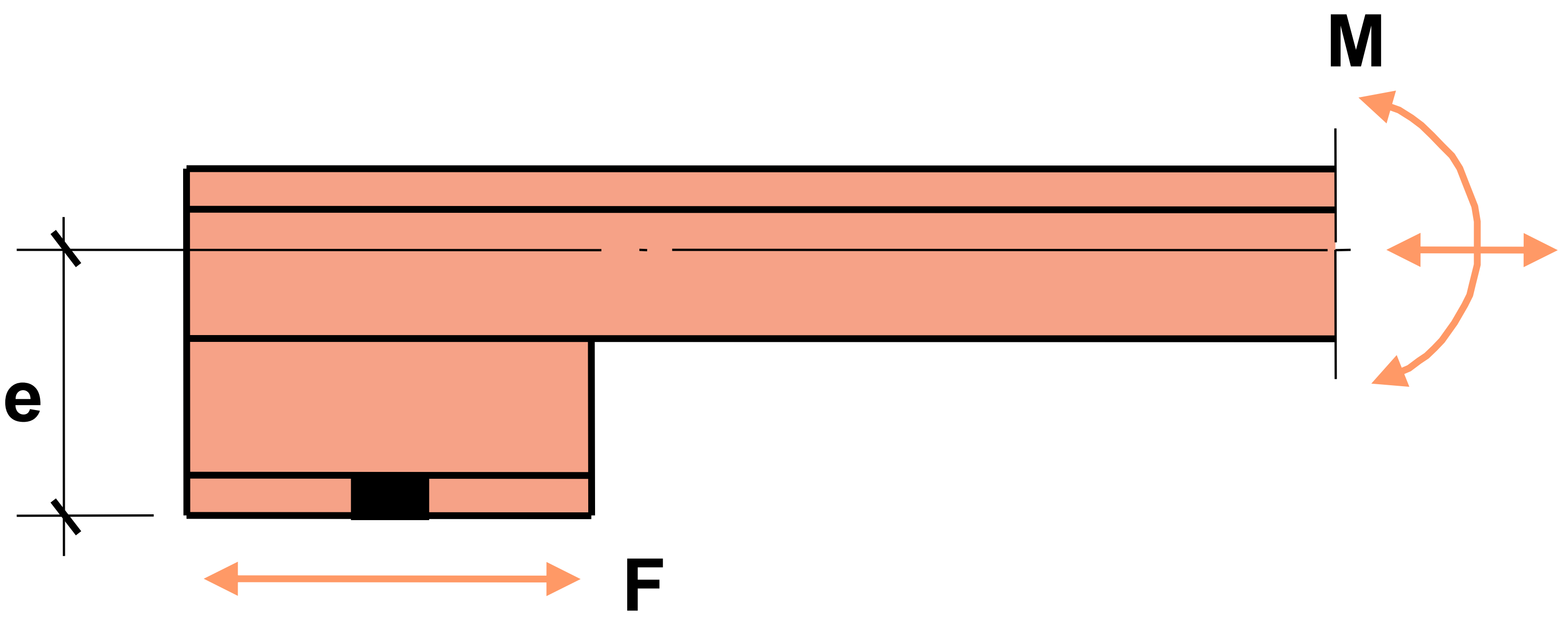
Specify the minimum chord force equal to 23.1 kips.

Diaphragm Chord Force Transfer

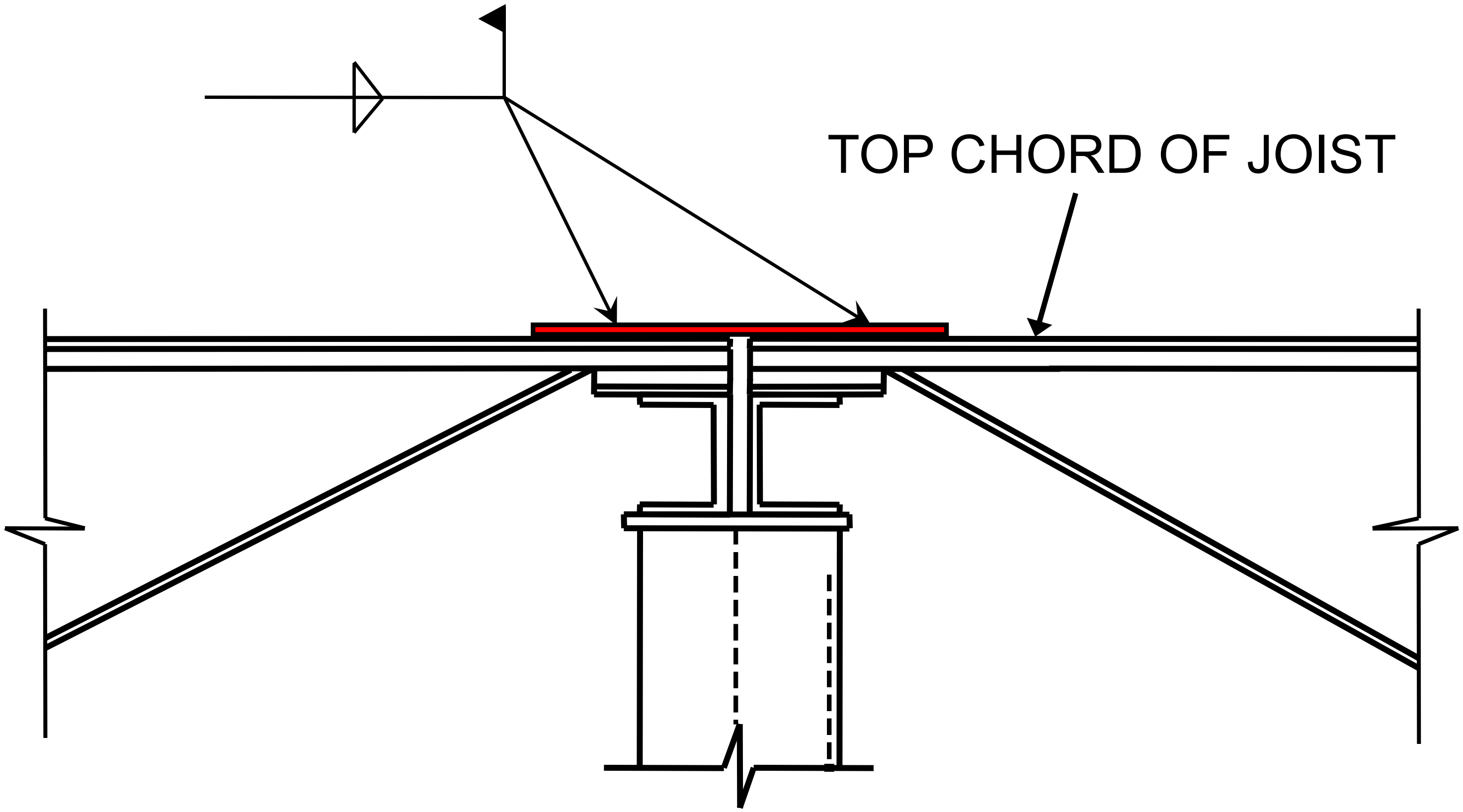
LOAD PATH



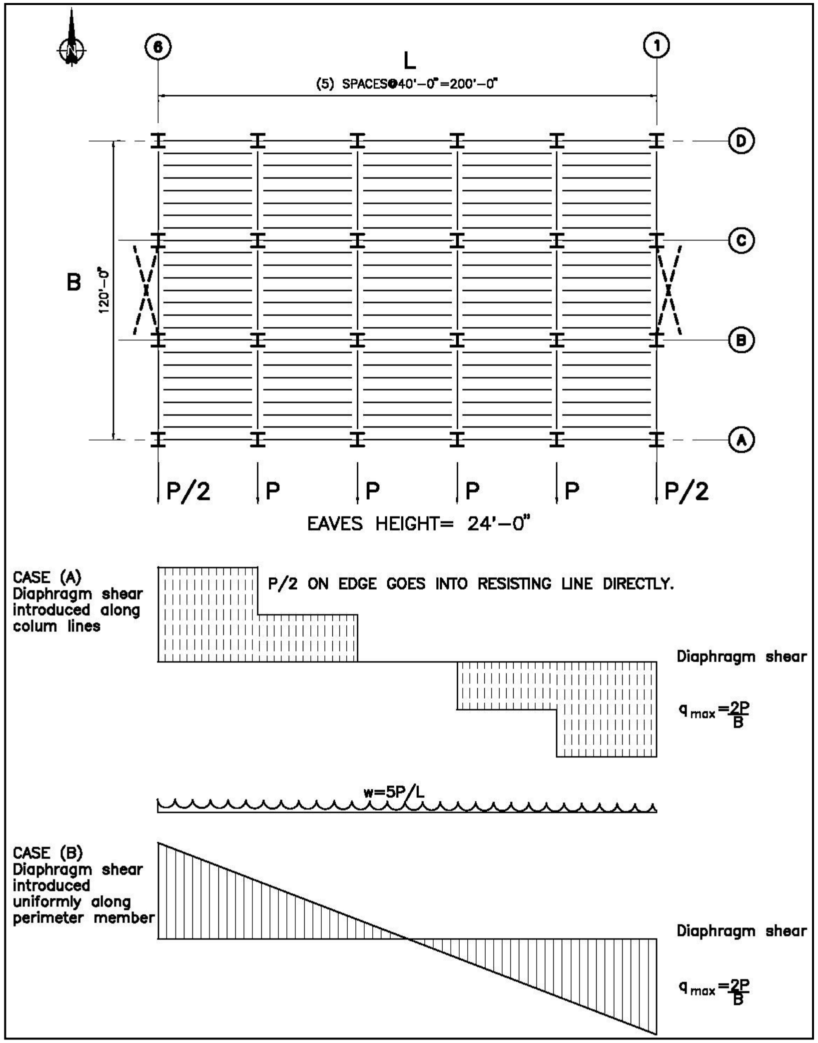
Joist Chord Bending



Joist Tie Plate (For Load Path)



Connections for Shear Transfer



At lines where exterior horizontal loads are introduced into the diaphragm, a sufficient number of fasteners should be provided to transfer the load from structure up to the diaphragm.

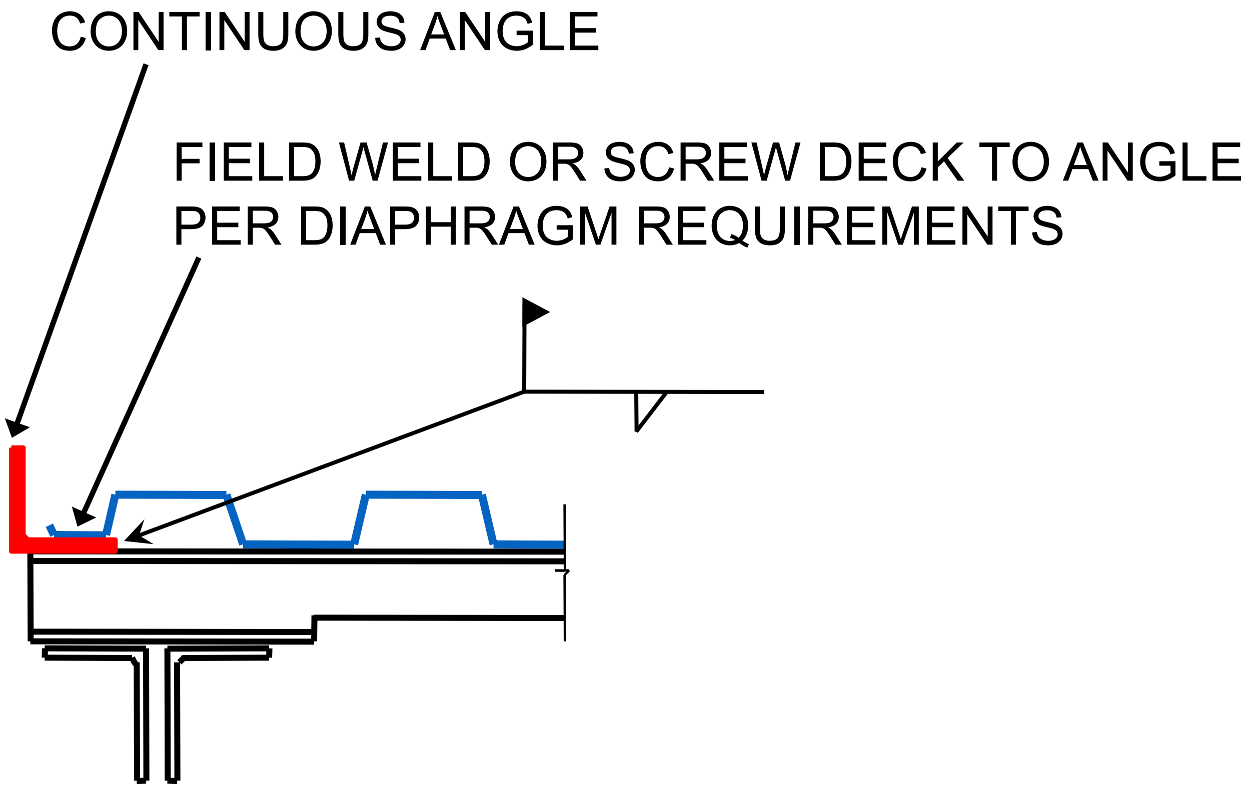
Shear collectors may be used.

Shear Transfer Grid Lines 1 and 6

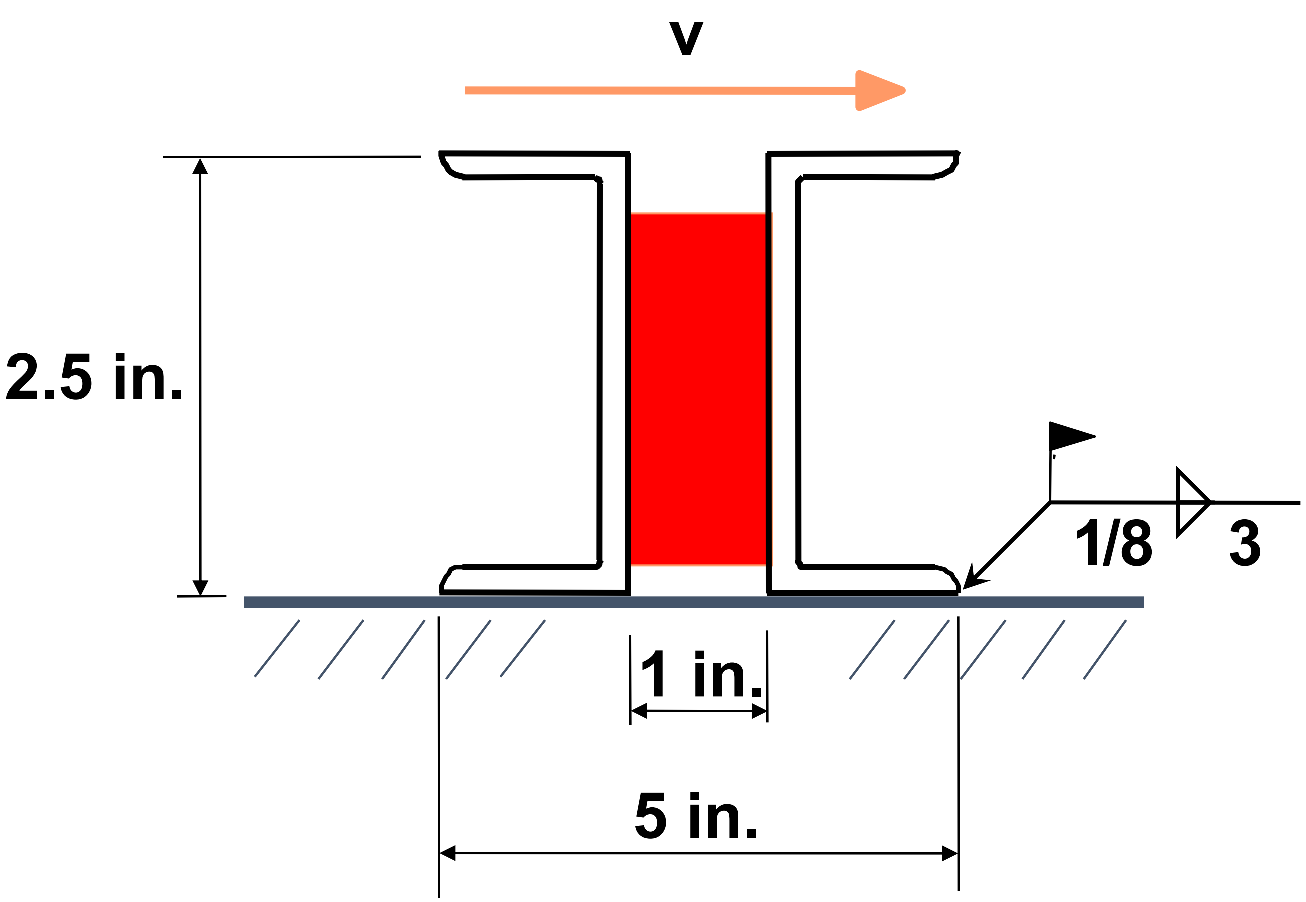
Topics:

- Deck support angles
- Joist seat rollover
- Shear collectors

Deck Support Angle



Joist Seat Rollover Strength

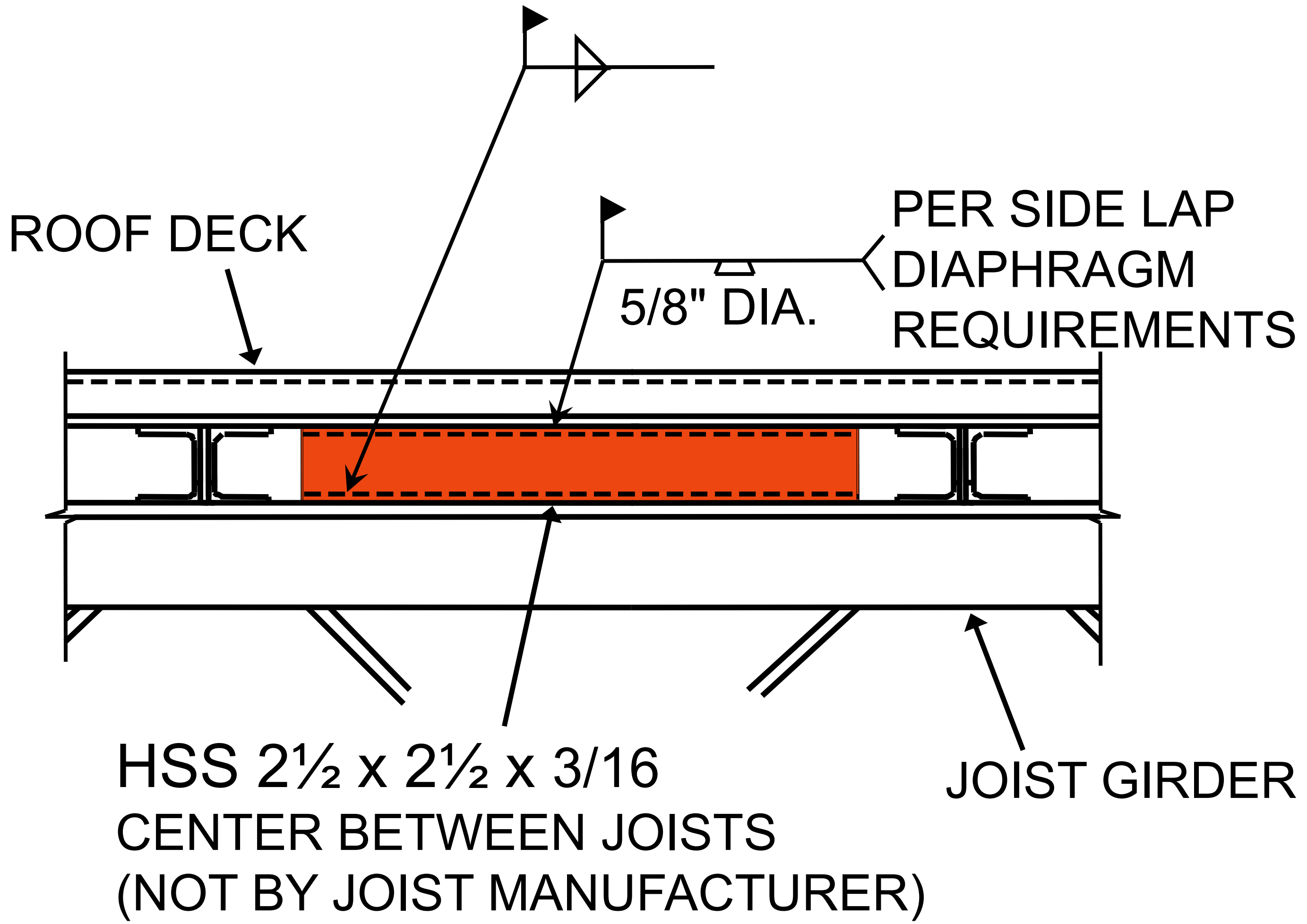


Maximum Roll over Strength = 1.82 kips (ASD), 2.64 kips (LRFD)
(Fisher and Van de Pas, 2019)

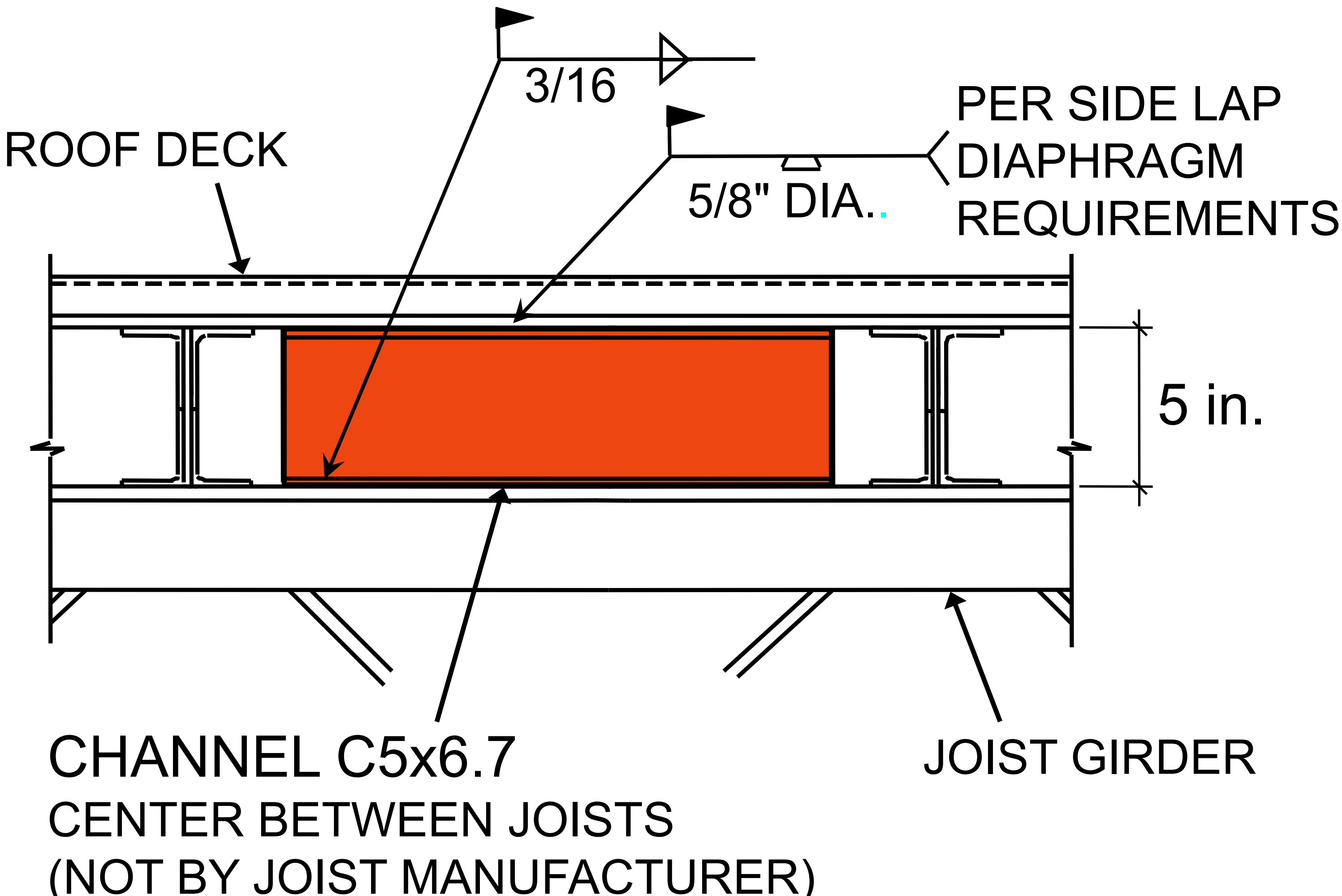
Deck Support Angle and Joist Seat Rollover

Shear Collector for K-Series Joist

Use if joist seat rollover force is not adequate



Shear Collector for LH-Series Joist



Deck Support Angle and Joist Seat Rollover

Calculate the rollover force on the joist

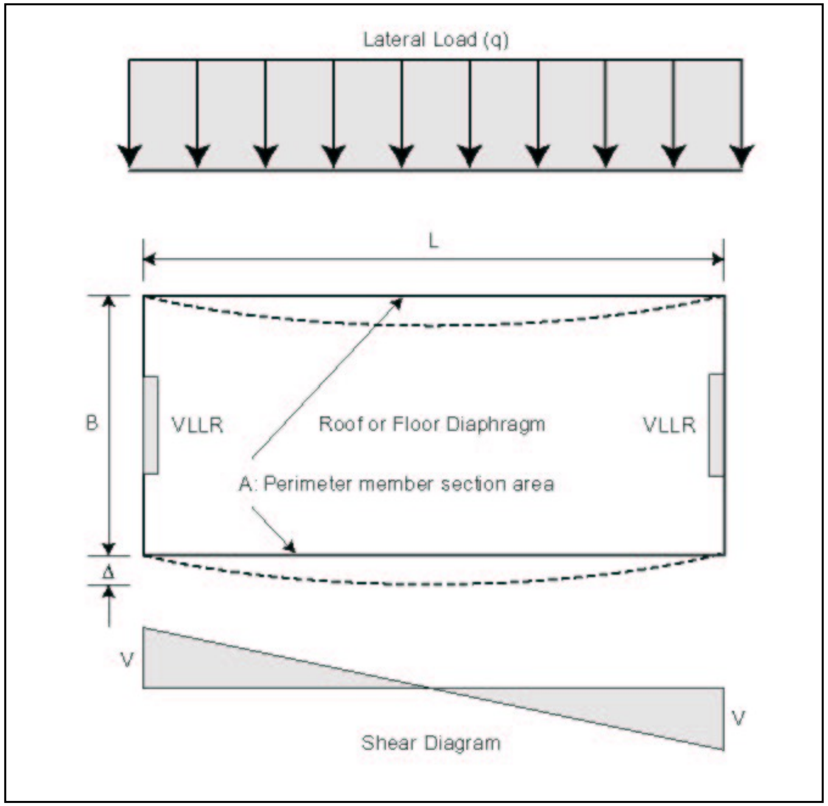
The shear per foot at gridlines 1 and 6 is 200 plf (see slide 13)

With joists spaced at 5 ft center-to-center, the rollover force on the joist seat is

$$F_{rollover} = \frac{(200 \text{ plf})(5 \text{ ft})}{1000 \text{ lb/kip}} = 1.00 \text{ kips}$$

1.00 kips ≤ 1.82 kips
Shear collectors are not required.

Diaphragm Stiffness (deflection calculation)



$$\Delta = \frac{5qL^4}{384EI} + \frac{qL^2}{8BG'}$$

1st part: area of the edge members determine moment of inertia

2nd part: deck type and attachment pattern determine value G'

Diaphragm Deflection

Calculate the diaphragm deflection

Using the wind load from slide 11,

$$q = (20.0 \text{ psf})\left(\frac{24.0 \text{ ft}}{2}\right) = 240 \text{ plf}$$

The length of the building normal to the wind pressure, L, is 200 ft.
The width of the building parallel to the wind pressure, B, is 120 ft.

$$I = 2(A_{chord})\left(\frac{B}{2}\right)^2 = 2\left(0.773 \text{ in.}^2\right)\left[\frac{(120 \text{ ft})(12 \text{ in./ft})}{2}\right]^2$$

$$= 801{,}000 \text{ in.}^4$$

where

$$A_{chord} \approx \frac{\text{Chord Force}}{0.60F_y} = \frac{23.2 \text{ kips}}{0.60(50 \text{ ksi})} = 0.773 \text{ in.}^2$$

From the Vulcraft IBC 2018 diaphragm tool, *G'* = 54 kips/in.

Diaphragm Deflection (continued)

Calculate the diaphragm deflection

$$\Delta = \frac{5qL^4}{384EI} + \frac{qL^2}{8BG'}$$

$$= \frac{5(0.240 \text{ klf})(200 \text{ ft})^4 \left(1728 \text{ in.}^3/\text{ft}^3\right)}{384(29{,}000 \text{ ksi})\left(801{,}000 \text{ in.}^4\right)} + \frac{(0.240 \text{ klf})(200 \text{ ft})^2}{8(120 \text{ ft})(54 \text{ kips/in.})}$$

$$= 0.372 \text{ in.} + 0.185 \text{ in.} = 0.557 \text{ in.}$$

From AISC Design Guide 3 (West *et al*., 2003), the serviceability criteria for deflection considering a metal wall system is

$$\Delta_{max} = \frac{H}{100} = \frac{(24 \text{ ft})(12 \text{ in./ft})}{100} = 2.88 \text{ in.}$$

Since 0.557 in. < 2.88 in., the diaphragm meets deflection criteria.

Conclusion to Steel Deck Diaphragms

- How diaphragm works
  - Deep girder with deck as web
- Fasteners and attachment patterns
  - control strength and stiffness
- Design methods and limit states
  - ASD and LRFD
- Diaphragm stiffness
  - Part bending plus part shear

References

Fisher, J.M. and Van de Pas, J.P. (2019), *Designing with Vulcraft Steel Joists, Joist Girders and Steel Deck*, 3rd Ed., Nucor, Vulcraft/Verco Group, Nucor Corporation, Charlotte, NC.

Nucor (2018a), *Steel Roof & Floor Deck*, Nucor, Vulcraft/Verco Group, Nucor Corporation, Charlotte, NC.

Nucor (2018b), *2018 IBC Deck Diaphragm Design Tool*, Nucor, Vulcraft/Verco Group, Nucor Corporation, Charlotte, NC.

West, M.A., Fisher, J.M. and Griffis, L.G. (2003), *Serviceability Design Considerations for Steel Buildings*, Steel Design Guide 3, 2nd Ed., American Institute of Steel Construction, Chicago, IL.

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