Steel Deck Diaphragm Innovations

New Provisions for
Composite Steel Deck Slabs, and

Best Practices for
Roof Deck Diaphragms

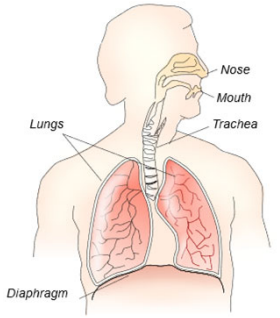
by Patrick Bodwell, P.E.
Vulcraft / Verco Group

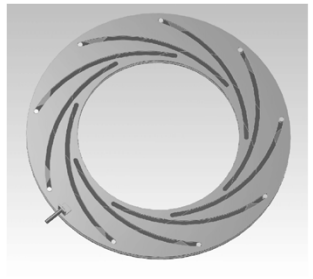


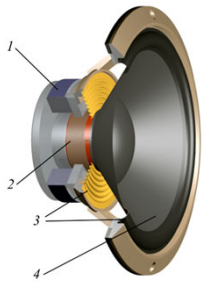
Diaphragm (noun) Di·a·phragm

Merriam Webster

1. a body partition of muscle and connective tissue specifically the partition separating the chest and abdominal cavities in mammals
2. a dividing membrane or thin partition especially in a tube
3. a more or less rigid partition in the body or shell of an invertebrate
   a transverse septum in a plant stem
4. a device that limits the aperture of a lens or optical system compare IRIS DIAPHRAGM
5. a thin flexible disk (as in a microphone or loudspeaker) that vibrates when struck by sound waves or that vibrates to generate sound waves
6. a molded cap usually of thin rubber fitted over the uterine cervix to act as a mechanical contraceptive barrier







Images from Wikipedia

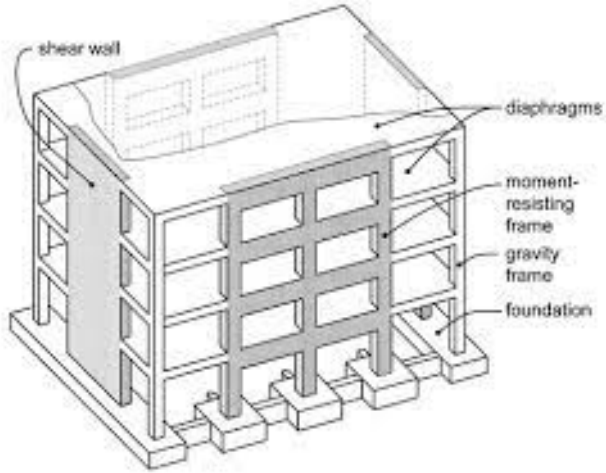
What is a structural diaphragm?

ChatGPT

A structural diaphragm refers to a horizontal, flat or arched component of a building or structure that provides horizontal support and stability.

It works similarly to the human diaphragm, by distributing loads and forces from the upper structure to the lower structure, preventing buckling and excessive deformation.

Structural diaphragms can be made of concrete, steel, wood, or a combination of materials, and can be found in roofs, floors, and decks in buildings.



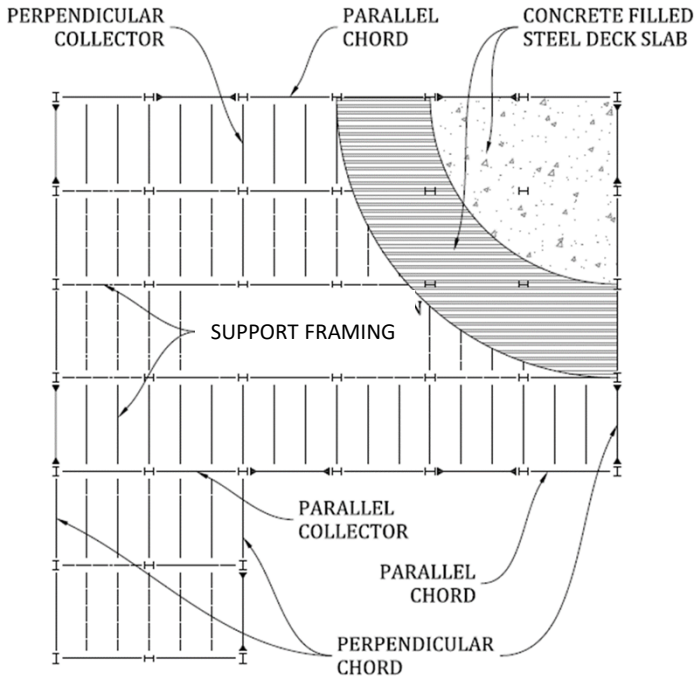
ASCE 7

§11.2 Definitions

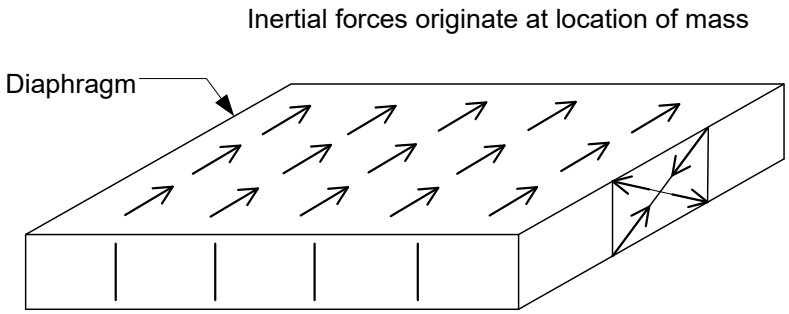
Diaphragm: Roof, floor, or other membrane or bracing system acting to transfer the lateral forces to the vertical resisting elements

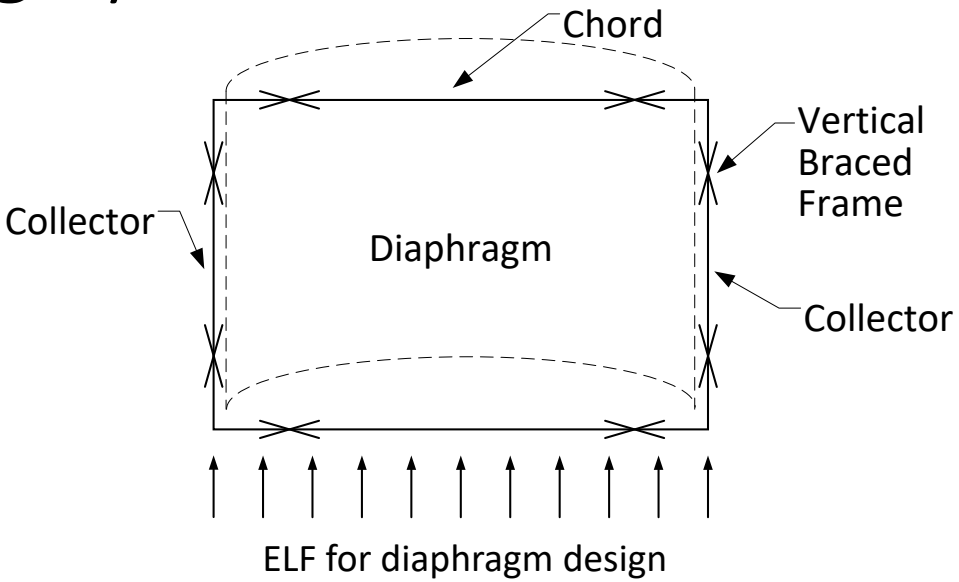
What does the diaphragm include?

- Stressed skin
- Chords around the perimeter
- Collectors, interior or perimeter
- Support framing for the stressed skin



Diaphragm – Horizontal Lateral Force Resisting System





<u>Diaphragm:</u>

- Transfers lateral loads to frames
- Critical part of lateral load path
- Concrete-filled steel deck (floor) diaphragm and bare steel deck (roof) diaphragm focus of SDII effort

Steel Deck Industry

SDI DDM / AISI S310

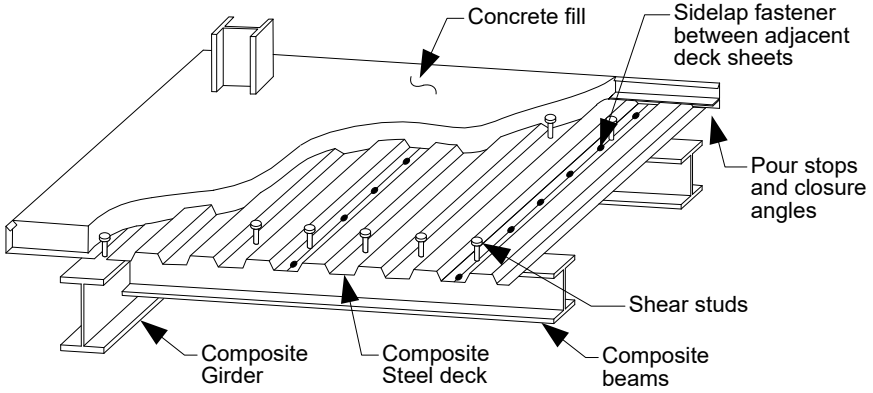
Industry Implied Definition of

Diaphragm: The steel deck (or deck-slab) shear strength and shear stiffness in consideration of the effect of deck connections to supports and side deck lap connections.

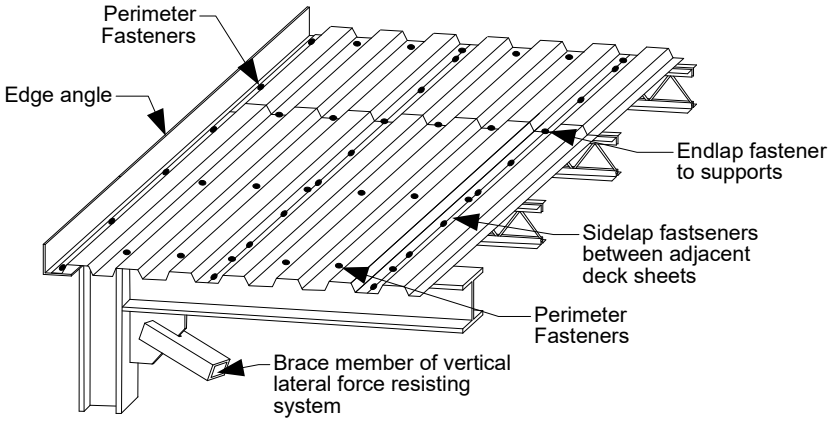
What definition of diaphragm will we use today?

Focus Today

- Performance of concrete filled steel deck diaphragms
- Design shear strength and stiffness of concrete filled diaphragms
- Performance of bare steel deck roof diaphragms
- Design of bare steel deck roof diaphragms
- Optimized steel deck roof structure details



Concrete-Filled Steel Deck



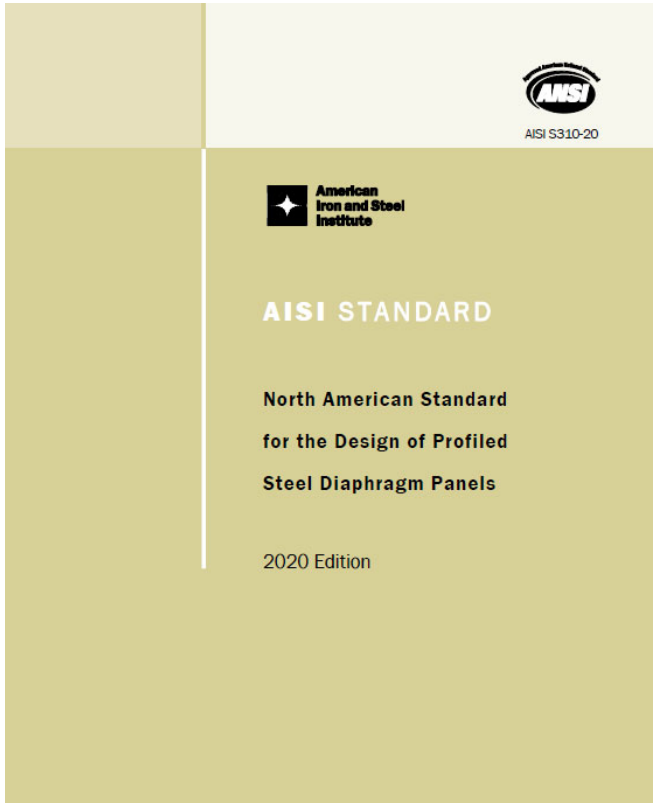
Bare Steel Deck

Objectives

✓Let's agree on the Definition of Diaphragm

- Structural Concrete fille Steel Deck Diaphragm Shear Strength & Shear Stiffness
- Bare (Roof) Steek Deck Diaphragm Shear Strength and Shear Stiffness
- Industrial Warehouse Roof Diaphragm Considerations
- Closing

Design Basis



IBC 2210. ….specifies AISI S100-16 w/s2-20
AISI S100-16 w/s2-20 section I2 specifies S310-20

AISI S310-20

NORTH AMERICAN STANDARD FOR THE DESIGN OF PROFILED STEEL DIAPHRAGM PANELS

A. GENERAL PROVISIONS

A1 Scope, Applicability, and Definitions

A1.1 Scope

This *Standard* applies to *diaphragms* and *wall diaphragms* that contain profiled steel *panels*, which include fluted *panels* or *deck*, and *cellular deck*.

Structural Concrete Filled Steel Deck Diaphragms

NEW Structural Concrete Methods in AISI S310-22



Out with the old, in with the new.... AISI S310-16 w/s2-20

AISI S310-16

Based on SDI Diaphragm Design Manual

Derived solution

- Bare steel deck
  +
- Connection contribution
  +
- Concrete fill contribution
  =
- Shear strength

AISI S310-16 w/s2-20

Based on full scale cyclic testing

Test based solution

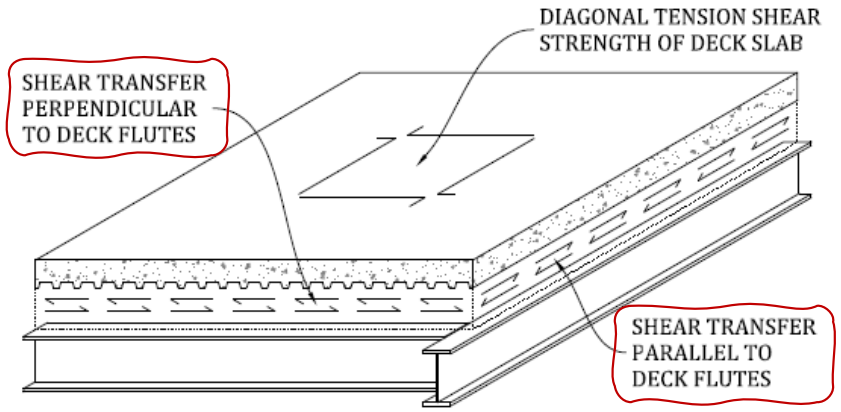
1. Diagonal Tension
   - Bare steel deck contribution
     +
   - Concrete contribution
     =
   - Shear strength
2. Connection design to transfer shear between the deck-slab and the diaphragm chord

Connection to Chord or Collector to the Concrete Filled Steel Deck

AISI S310-20

Nominal strength of the connections

$$S_{nf} = P_{nf} N_c$$



P_{nf} = Nominal shear strength of the connection

- Shear studs
- Arc spot welds
- Power actuated fasteners (Hilti / Pneutek fasteners)
- Screws

N_c = Average number of connections

Diagonal Tension Strength

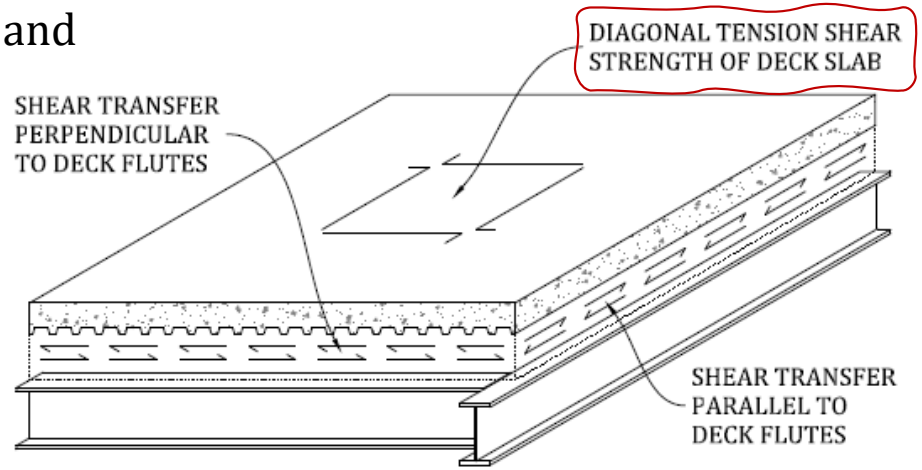
AISI S310-20

Nominal diagonal tension strength of the concrete and steel deck

$$S_{nt}=k_c\lambda_{LW}bt_e\sqrt{f'_c}$$

Equivalent transformed concrete thickness

$$t_e=t_a+n_{sc}t\frac{d}{s}$$



K_c = 3.2/1000 factor for structural concrete strength for U.S. Customary units

λ_{LW} = Factor for lightweight concrete

= 1.0 for NWC

= 0.75 for LWC

= 0.85 for SLC

b = 12 in/ft unit width

t_a = Average thickness of concrete

n_{sc} = E / E_c modular ratio

t = Steel deck thickness

d = Deck pitch

s = Developed flute width per pitch

f'_c = Concrete compressive strength

Future – Steel Reinforcing Contribution

AISI S310-xx

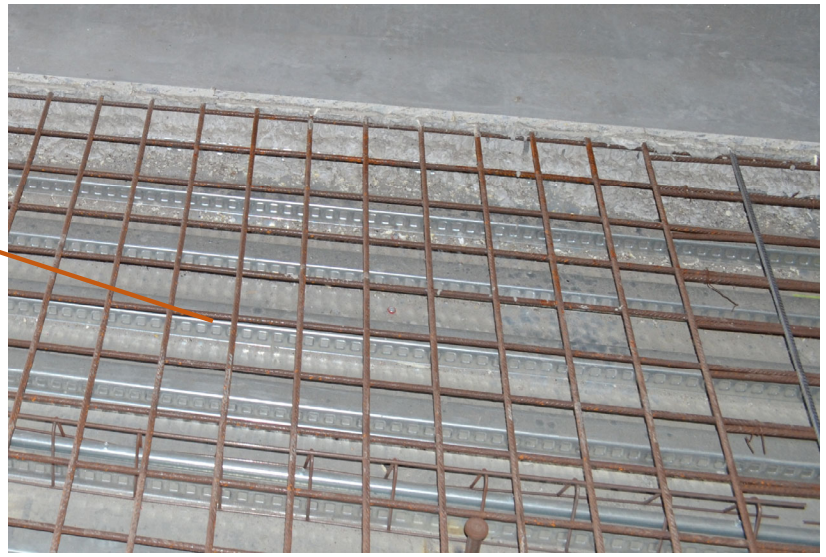
Coming in the next edition of AISI S310-xx (planned for 2024)

Nominal diagonal tension strength of the concrete and steel deck with steel reinforcing bars or welded wire fabric

$$S_{nt}=k_c\lambda_{LW}bt_e\sqrt{f'_c} + \underbrace{A_vF_{ys} \leq 0.0075bt_e\sqrt{f'_c}}$$

A_v = Cross-sectional area of reinforcing per unit width

F_{ys} = Yield strength of reinforcing steel



Steel Fiber Reinforced Concrete Filled Steel Deck

Verco ESR-2018

Diagonal shear = concrete and deck + steel fiber

$S_n = S_c + S_f$

Concrete filled steel deck

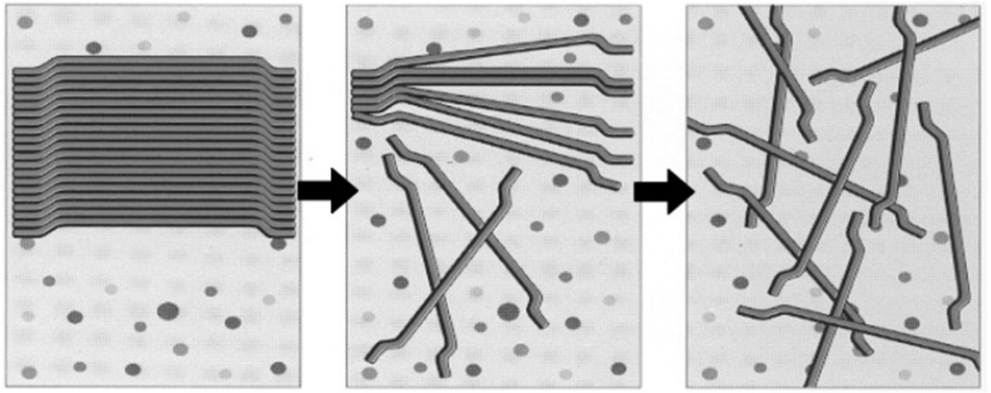
$$S_c = k_c \cdot \lambda \cdot b \cdot \left[\left(D_c + \frac{D_d}{2}\right) + t \cdot \left(\frac{E}{E_c}\right) \cdot \left(\frac{d}{s}\right)\right] \cdot \sqrt{f'_c}$$

$$S_c = k_c \lambda_{LW} b t_e \sqrt{f'_c}$$

Additive contribution of Bekaert Dramix steel fiber

$$S_f = 0.37 \cdot f_{150} \cdot \left(D_c + \frac{D_d}{2}\right)$$



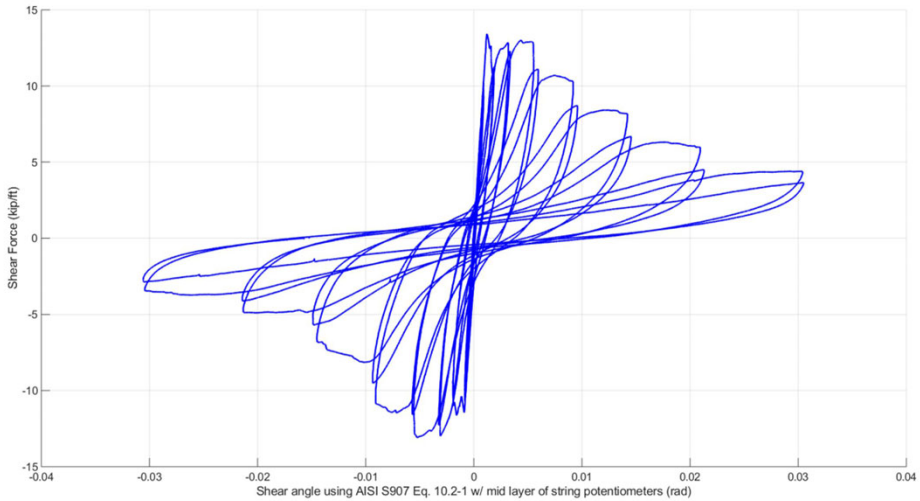


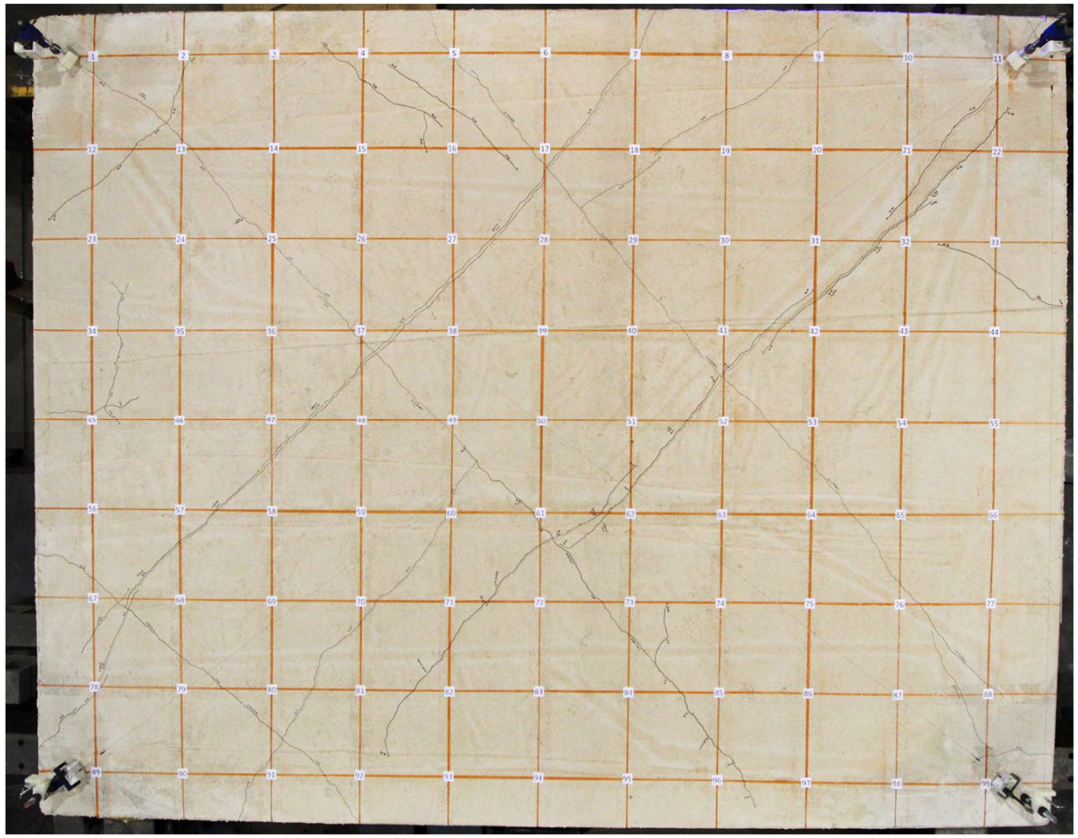
Glued Steel Fibers | Glue Dissolves in Concrete | Fibers-Dispersed in Concrete

Bekaert / Verco
Dramix FRC Cyclic Testing

Verco ESR-2018

- Reverse cyclic testing at Virginia Tech
- Resulting provisions in IAPMO ESR-2018 product approval report





Steel Fiber Contribution

Verco ESR-2018

Additive contribution of Bekaert Dramix steel fiber

$$S_f = 0.37 \cdot f_{150} \cdot \left(D_c + \frac{D_d}{2}\right)$$

D = Steel fiber dosage, pcy

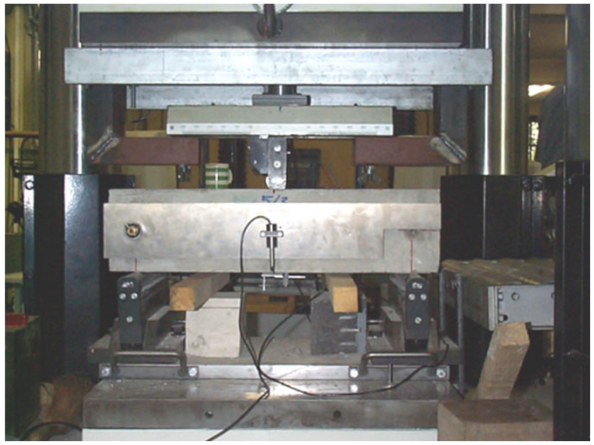
D_d = Depth of steel deck, in

F_{150} = Residual stress at L/150 (psi) derived from testing

$$f_{150} = C_1 \cdot \left(\frac{D}{\sqrt{f_c'}}\right)^2 + C_2 \cdot \left(\frac{D}{\sqrt{f_c'}}\right) \quad \text{for D} \geq 35 \text{ pcy}$$

Coefficient	f_{r1}	f_{r4}	f_{150}	$R^D_{T,150}$
C_1	-81	-127	-127	-30
C_2	537	507	507	105

Table 3.1 Dramix Coefficients from ER-2018



Design Shear Strength

AISI S310-20

Design shear strength is limited by the

Design strength of the shear transfer to chords or collectors

Diagonal tension design strength

$$\phi S_n = \min(\phi S_{nf}, \phi S_{nt})$$

ϕ = 0.8 for diagonal tension

ϕ = 0.55 for welded headed shear studs per AISC

ϕ = *Intended to be* the individual connection strength for arch spot welds, PAF, and screws per AISI

ϕ = 0.8 for diagonal tension with Dramix FRC per ER-2018

Example: 20 ga W3-36 with 6¼" 3000 psi LWC

AISI S310-20

Design Diagonal Tension strength of the concrete and steel deck in the field of the diaphragm

$S_{nt}=k_c\lambda_{LW}bt_e\sqrt{f'_c} = 0.0032 \cdot 0.75 \cdot 12 \cdot 5.14 \cdot \sqrt{3000} = 8.10$ kip/ft

$\phi S_{nt} = 0.8 \cdot 8.10$ kip/ft $=$ 6.49 kip/ft

Equivalent transformed concrete thickness

$t_e = t_a + n_{sc}t\frac{d}{s} = 4.75 + 14.1 \cdot 0.0359\frac{12}{15.7} = 5.14\ in$

K_c = 3.2/1000 = 0.0032

λ_{LW} = 0.75

b = 12 in/ft

t_a = 3.25 in + 3 in / 2 = 4.75 in

n_{sc} = E / E_c = 29500 ksi / 2085 ksi = 14.1

t = 0.359 in

d = 12 in

s = 15.7 in

f'_c = 3000psi

Example: 20 ga W3-36 with 6 ¼" 3000 psi LWC

AISI S310-20

Design Connection Strength to chords and collectors

¾ in. welded headed shear studs per AISC

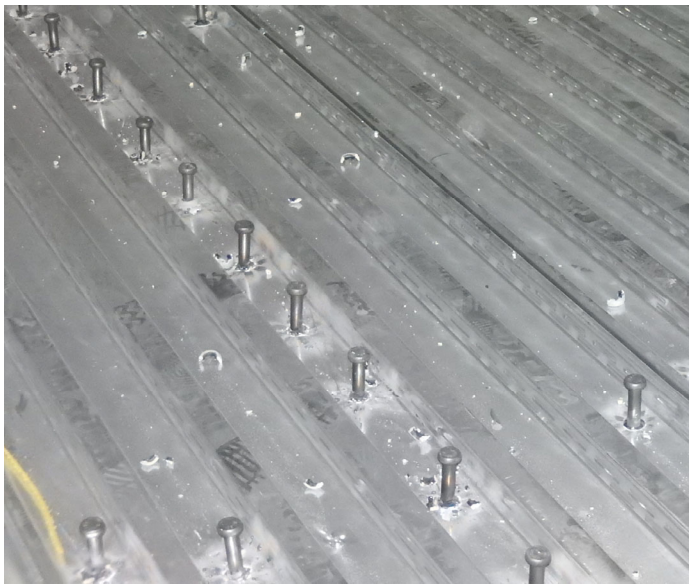
Assume 1 stud per rib in weak position (12 in. o.c.)

P_{nf} = 17.2 kip/stud

N_c = 1 stud/ft

$$S_{nf} = P_{nf} N_c = 17.2 \frac{kip}{stud} \cdot 1 \frac{stud}{ft} = 17.2\ k/ft$$

$$\phi S_{nf} = 0.55 \cdot 17.2 \frac{kip}{ft} \cdot 1 \frac{stud}{ft} = \underline{9.46\ kip/ft}$$



Therefore studs at 1 ft o.c. has more design shear transfer strength than the design diagonal shear strength of <u>6.49 kip/ft</u>

Example: 20 ga W3-36 with 6¼" 3000 psi LWC

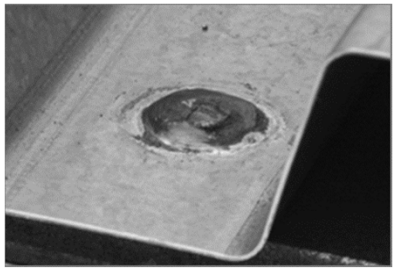
AISI S310-20 & Verco ESR-2018

¾ in. Arc Spot Welds per AISI 310-20

Assume 1 weld per rib (12 in. o.c.)

ϕP_{nf} = 1.9 kip/weld from AISI S100-20

N_c = 1 weld/ft



$$\phi S_{nf} = \phi P_{nf} N_c$$

$$\phi S_{nf} = 1.9 \frac{kip}{weld} \cdot 1 \frac{weld}{ft} = 1.9\ k/ft$$

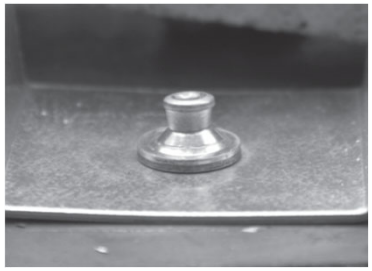
4 each ¾ in. Arc spot welds per rib to achieve the diagonal shear design strength of 6.49 kip/ft.

Hilti X-ENP19 PAF per ESR-2018

Assume 1 PAF per rib (12 in. o.c.)

ϕP_{nf} = 1.4 kip/PAF

N_c = 1 weld/PAF



$$\phi S_{nf} = \phi P_{nf} N_c$$

$$\phi S_{nf} = 1.4 \frac{kip}{PAF} \cdot 1 \frac{PAF}{ft} = 1.4\ k/ft$$

5 each X-ENP19 per rib to achieve the diagonal shear design strength of 6.49 kip/ft.

How Does This Compare To the Past?

AISI S310-17

Concrete deck strength was a hybrid of

1. Steel deck and connections to ALL supports, (roof deck analogy) combined with
2. Strength contribution of concrete fill
3. High resistance factor due to uncertainty of derivation $\phi = 0.5$

S310-17 Primary design equations:

$$S_n = \frac{\beta P_{nf}}{L} + kbd_c\sqrt{f'_c} \qquad \frac{\beta P_{nf}}{L} \le 0.25 S_n \qquad \beta = n_s\alpha_s + 2n_p\alpha_p^2 + 4\alpha_e^2$$

Where $\phi = 0.5$

Example: 20ga W3-36 with 6.25 in. of 3000psi LWC, with
10ft deck span, and
¾ in. arc spot welds in a 36/4 pattern with button punch at 24 in. o.c.

$\phi S_n =$ *2.34 kip/ft* < *6.03 kip/ft*

S310-17 *S310-20*

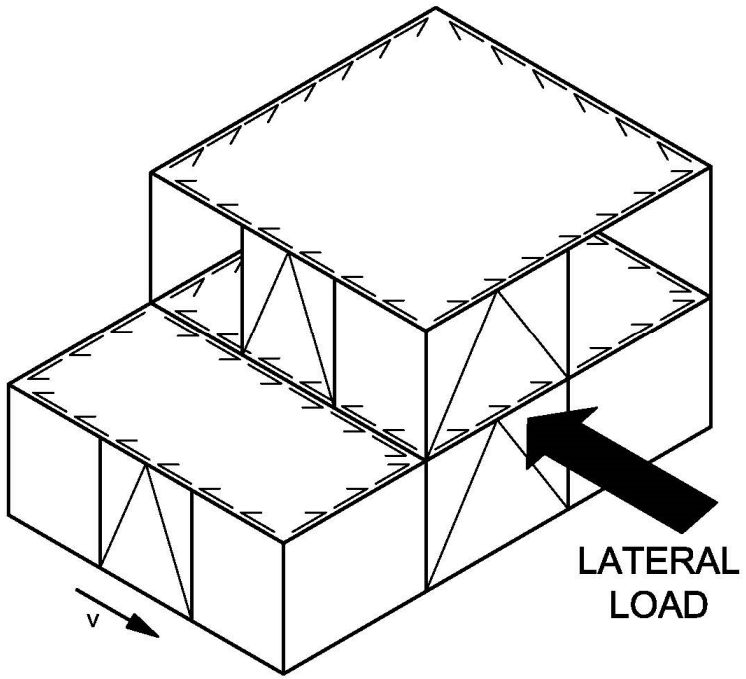
What About a 10 kip/ft Transfer Diaphragm?

What if you need more shear than the concrete and steel deck delivers?

1. Historic approach, design a reinforced concrete diaphragm above the steel deck following ACI.

   - or -

2. Use Verco composite steel deck with Dramix steel fiber reinforced concrete fill



Example: 20 ga 3W-36 with 6¼" 3000 psi LWC & Dramix FRC

Verco ESR-2018

$S_n = S_c + S_f$

From the previous example $S_c = 8.10$ kip/ft

Additive contribution of 35 pcy of Bekaert Dramix 4D 65/60 BG steel fiber

$$S_f = 0.37 \cdot f_{150} \cdot \left(D_c + \frac{D_d}{2}\right) = 0.37 \cdot 272 \cdot \left(3.25 + \frac{3}{2}\right) = 5.73\ kip/ft$$

$$f_{150} = C_1 \cdot \left(\frac{D}{\sqrt{f_c'}}\right)^2 + C_2 \cdot \left(\frac{D}{\sqrt{f_c'}}\right) = -127 \cdot \left(\frac{35}{\sqrt{3000}}\right)^2 + 507 \cdot \left(\frac{35}{\sqrt{3000}}\right) = 272\ psi$$

D_c = 3.25 in.

D_d = 3 in.

D = 35 pcy

C_1 = -127

C_2 = 507

$\phi S_n = \phi(S_c + S_f) = 0.8 \cdot (8.10 + 5.73) =$ **11.1 kip/ft**

with 66 pcy ϕS_n = 13.7 kip/ft

with the maximum slab depth of 9 in., f'$_c$ = 5000 psi NWC ϕS_n = 26.4 kip/ft

High Performance Composite Deck-Slab Diaphragm

Connections to Support Framing

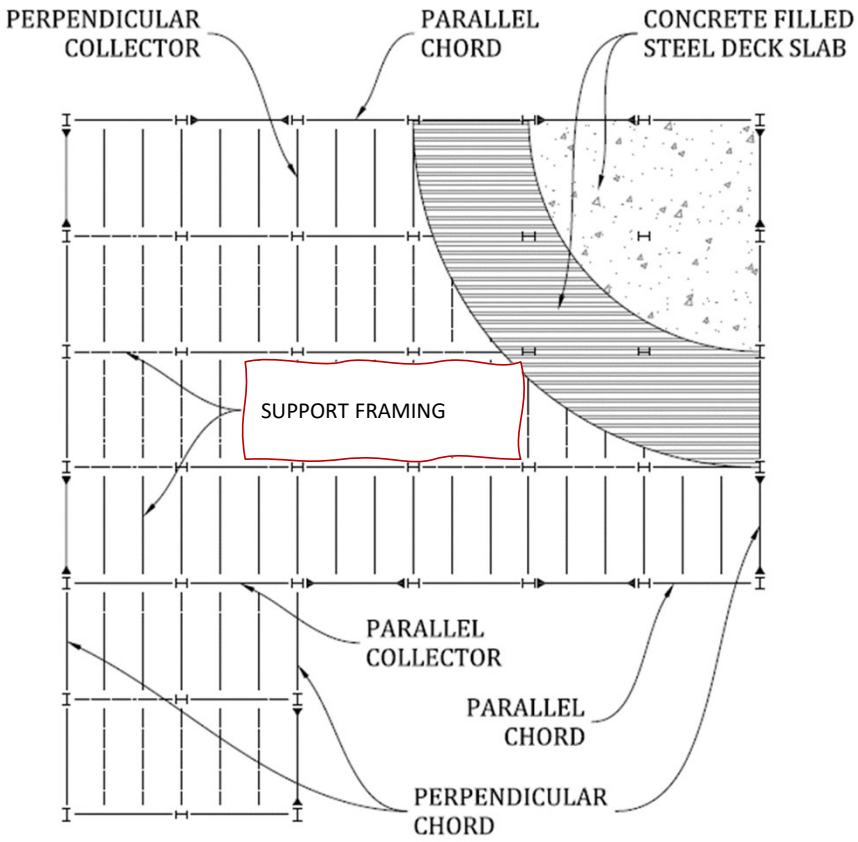
Key Observation:

Connections of the deck to the framing if this is NOT a chord of collector does not influence:

- Diagonal tension strength
- Shear transfer to chords or collectors

Where are the rules?

- SDI C-2017, NC-2017, &
- SD-2022

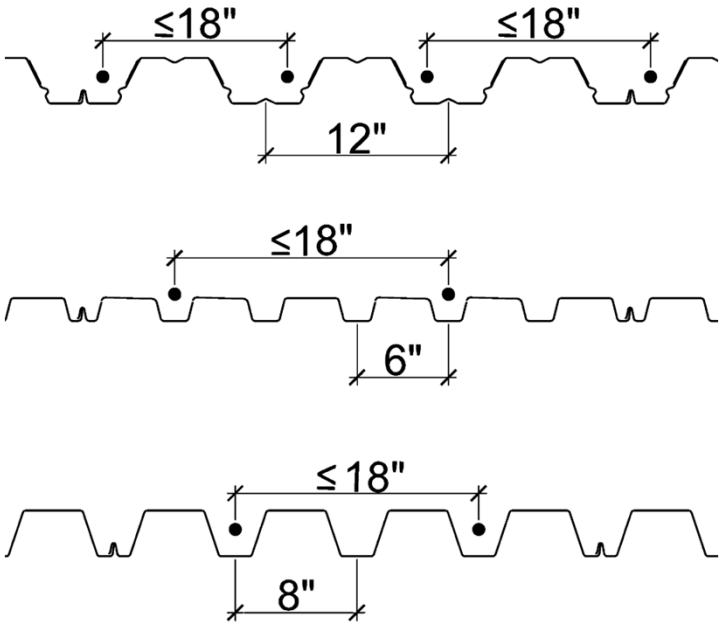


Nominal Connections

SDI SD-2022

ANSI/ SDI SD - 2022 Standard for Steel Deck

- Specifies minimum connections for steel deck to supporting members
  - Attachments may be, Welds, Welded Stud, Screws or PAFs
  - Maximum spacing of 18 in o.c. (except 12 in. o.c. for hurricane prone regions)
- Specifies minimum sidelap connections
  - Attachments may be, No. 10 (minimum) screws, Button punch or other punch system, or Welds
- Maximum spacing of 36 in. o.c. (except none required for deck span ≤ 5 ft)



Diaphragm Stiffness for Concrete Filled Steel Deck

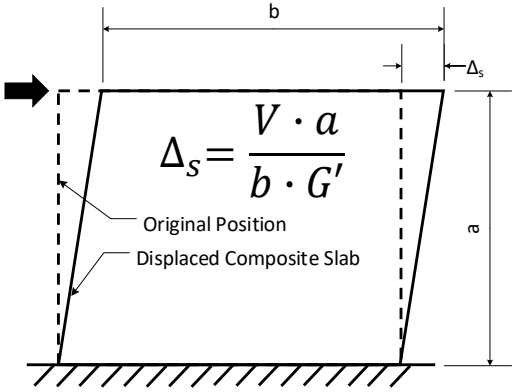
Sources of Diaphragm Deformation

$$\Delta_{tot} = \Delta_s + \Delta_b + \Delta_z$$

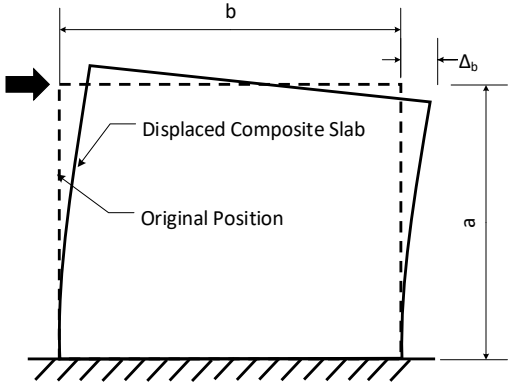
Shear deformations (function of shear stiffness, G')

Bending deformations

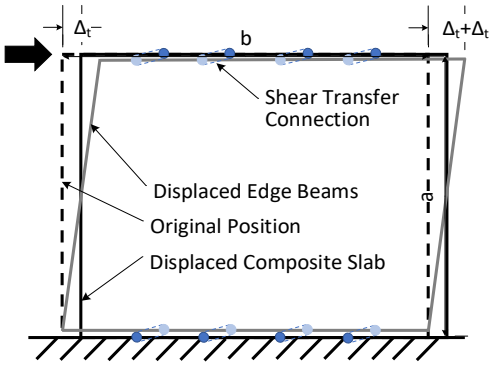
Deformations at shear transfer (studs)



Shear Deformations



Bending Deformations



Deformations at Shear Transfer

NEW Diaphragm Shear Stiffness

AISI S310-xx & Verco ESR-2018

G' = Diaphragm stiffness, kip/in.

$$G' = 4.8\left[\left(d_c + \frac{D_d}{2}\right) + t\left(\frac{E}{E_c}\right)\left(\frac{d}{s}\right)\right]\sqrt{f'_c} = 4.8 t_e \sqrt{f'_c}$$

Transformed thickness

$$t_e = t_a + n_{sc} t \frac{d}{s}$$

Average concrete depth

$$t_a = \left(d_c + \frac{D_d}{2}\right)$$

d_c = Structural concrete thickness above top of profiled panel, in.

D_d = Depth of panel, in.

t = Base steel thickness of top profiled panel in cellular deck, in.

E = Modulus of elasticity of steel, ksi

E_c = Modulus of elasticity of concrete in accordance with ACI 318, ksi

d = Panel corrugation pitch, in.

s = Developed flute width per pitch, in.

f'_c = Specified structural concrete compressive strength, psi

Current Diaphragm Shear Stiffness

AISI S310-20

G' = Diaphragm stiffness, kip/in.

$$G' = \frac{Et}{2(1+\mu)\frac{s}{d} + C} + K_3$$

Concrete Stiffness

$$k_3 = 3.5 d_c (f_c')^{0.7}$$

Slip constant considering slippage at side-lap connections and distortion at support connections

$$C = \left(\frac{Et}{w}\right)\left(\frac{2L}{2\alpha_3 + n_p\alpha_4 + 2n_s\frac{S_f}{S_f}}\right)S_f$$

Connection Group Effect

$$\alpha_n = \frac{\sum x_n}{w}$$

L = deck sheet length, ft
n_p = number of intermediate beams
μ = 0.3 Poisson's ratio for steel
d = Panel corrugation pitch
s = Developed flute width per pitch
E = Modulus of elasticity of steel, ksi
t = Base steel thickness of fluted deck
d_c = Structural concrete thickness above top of deck, in.
x_n = Distance from panel center line to an exterior support structural connection in an edge panel
w = Panel cover width at the edge panel
S_f = Structural support connection flexibility, in./kip
S_s = Side-lap connection flexibility, in./kip

Connection Group Effect, β

AISI S310-20

β Factor defining connection contribution and interaction to diaphragm shear strength per unit length

$$\beta = n_s \alpha_s + 2 n_p \alpha_p^2 + 4 \alpha_e^2$$

This is a roof deck connection group effect equation

α_n^2 is analogous to section modulus of connection group

$$\alpha_n^2 = \left(\frac{1}{w^2}\right) \sum x_n^2$$

α_s Ratio of the connection strength to the support to the sidelap connection strength

$$\alpha_s = \frac{P_{ns}}{P_{nf}}$$

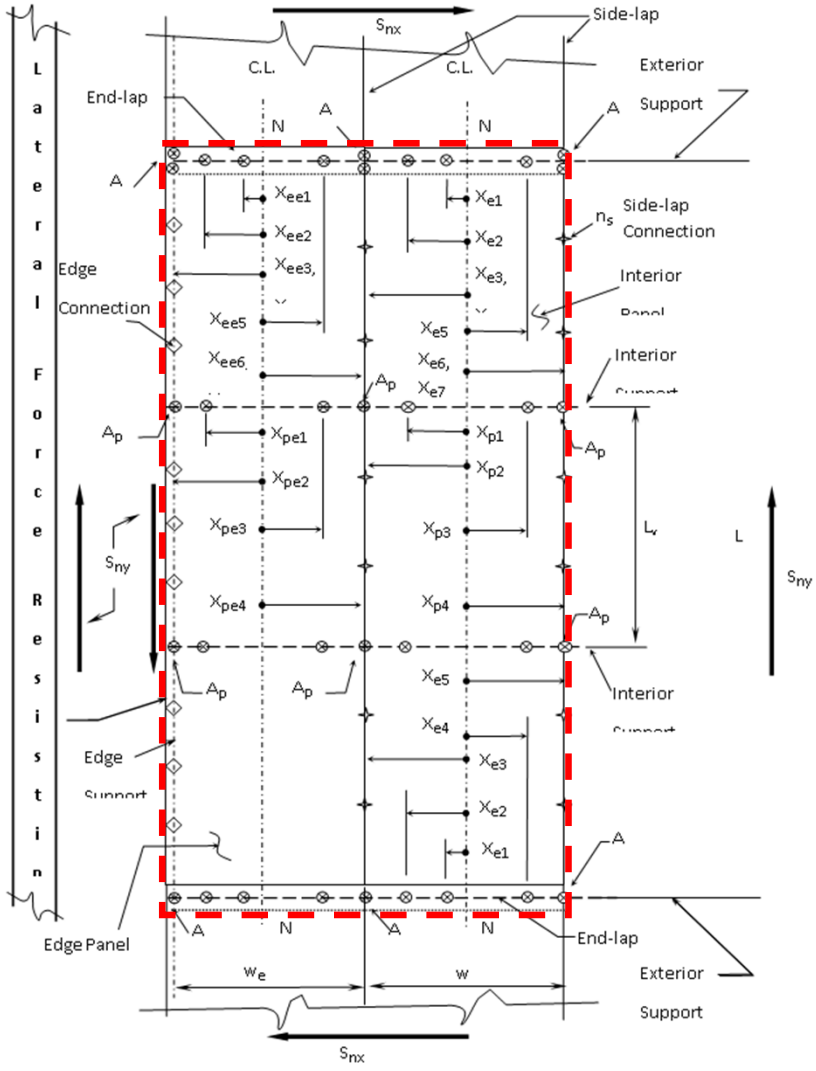


Figure D1-1 Schematic Illustration of Section D1 Parameters

Example: 20 ga W3-36 with 6¼" 3000 psi LWC

AISI S310-20

$$G' = \frac{Et}{2(1+\mu)\frac{s}{d}+C} + K_3 = \frac{29500 \cdot 0.0359}{2(1+0.3)\frac{15.7}{12}+0.255} + 3090 = 3379\ kip/in$$

$$K_3 = 3.5 \cdot 3.25 \cdot (3000)^{0.7} = 3090$$

$$C = \left(\frac{Et}{w}\right)\left(\frac{2L}{2\alpha_3 + n_p\alpha_4 + 2n_s\frac{S_f}{S_f}}\right)S_f$$

$$= \left(\frac{29500 \cdot 0.0359}{36}\right)\left(\frac{2 \cdot 30}{2 \cdot 0.8 + 2 \cdot 0.8 + 2 \cdot 33\frac{0.0061}{0.0093}}\right) \cdot 0.0061 = 0.255$$

$$\alpha_n = \frac{\sum x_n}{w} = \ \alpha_3 = \alpha_3 = \frac{4.6 + 7.4 + 16.8}{36} = 0.80$$

Min. attachment per SDI SD-2022

- Minimum ¾ in. arc spot welds at 12 in. o.c. (36/3 pattern) to field supports
- Button punch side laps at 36 in. o.c.

Deck sheet of 30 ft

L = 30 ft
n_p = 2
μ = 0.3
d = 12 in.
s = 15.7 in.
E = 29500 kai
t = 0.0359 in.
d_c = 3.25 in.
x_n = 4.6 in., 7.4 in., 16.8 in.
w = 36 in.
S_f = in./kip
S_s = in./kip

Example: 20 ga W3-36 with 6¼" 3000 psi LWC

AISI S310-xx & Verco ESR-2018

G' = Diaphragm stiffness

$G' = 4.8 \cdot 5.14 \cdot \sqrt{3000} = 1351\ kip/in$

Transformed thickness (from shear strength example)

$t_e = 5.14\ in$

Average concrete depth (from shear strength example)

$t_a = 4.75\ in$

G' = *1351 kip/in* < *3379 kip/ft*

S310-xx or ESR-2018 *S310-20*

In general, anything in the range of 1000 kip/in is rigid and does not impact the load distribution to VLFRS.

d_c = Structural concrete thickness above top of profiled panel, in.

D_d = Depth of panel, in.

t = Base steel thickness of top profiled panel in cellular deck, in.

E = Modulus of elasticity of steel, ksi

E_c = Modulus of elasticity of concrete in accordance with ACI 318, ksi

d = Panel corrugation pitch, in.

s = Developed flute width per pitch, in.

f'_c = Specified structural concrete compressive strength, psi

Objectives

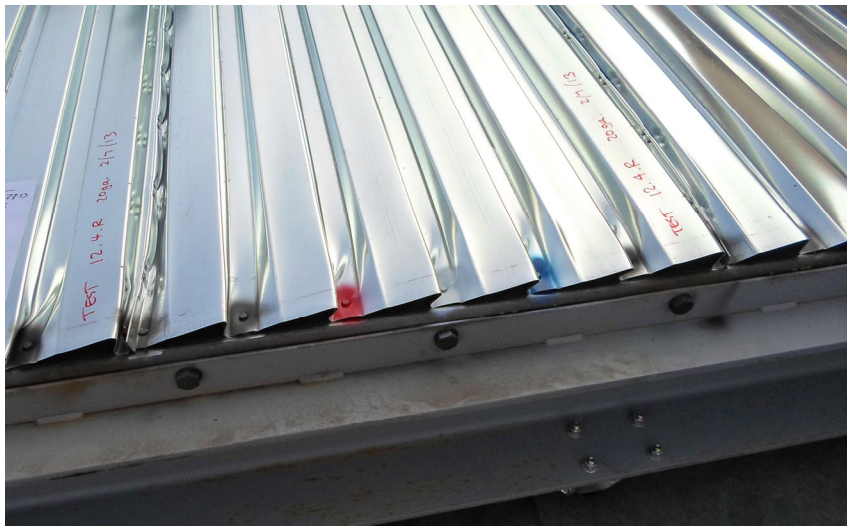
- ✓Let's agree on the Definition of Diaphragm
- ✓Structural Concrete fille Steel Deck Diaphragm Shear Strength & Shear Stiffness
- Bare (Roof) Steek Deck Diaphragm Shear Strength and Shear Stiffness
- Industrial Warehouse Roof Diaphragm Considerations
- Closing

Bare (Roof) Steel Deck Diaphragms

NEW limit states in AISI S310-20 affecting high shear diaphragms

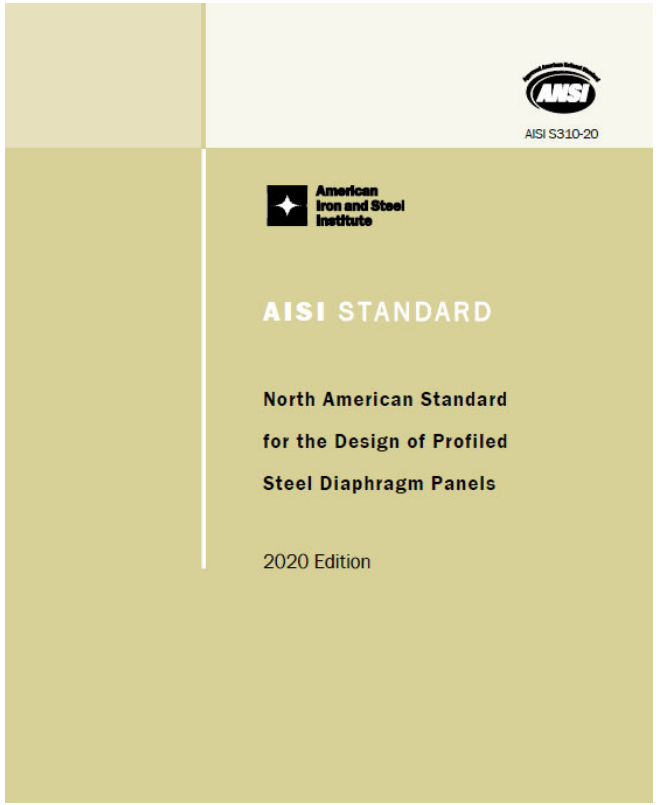
Connection Perpendicular Panel Limit





Local Web Buckling Panel Limit

Design Basis



IBC 2210. ….specifies AISI S100-16 w/s2-20
AISI S100-16 w/s2-20 section I2 specifies S310-20

AISI S310-20

NORTH AMERICAN STANDARD FOR THE DESIGN OF PROFILED STEEL DIAPHRAGM PANELS

A. GENERAL PROVISIONS

A1 Scope, Applicability, and Definitions

A1.1 Scope

This *Standard* applies to *diaphragms* and *wall diaphragms* that contain profiled steel *panels*, which include fluted *panels* or *deck*, and *cellular deck*.

Steel Deck Shear Strength

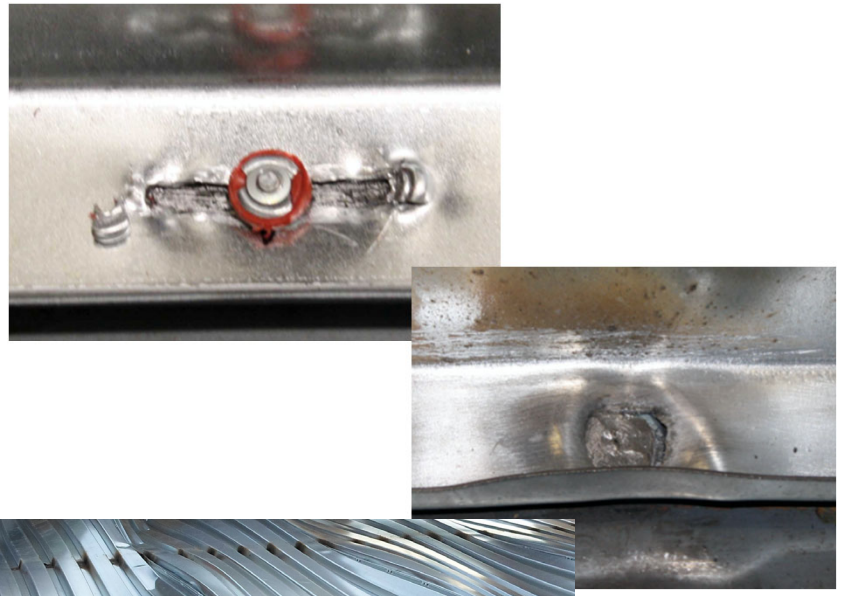
AISI S310-20

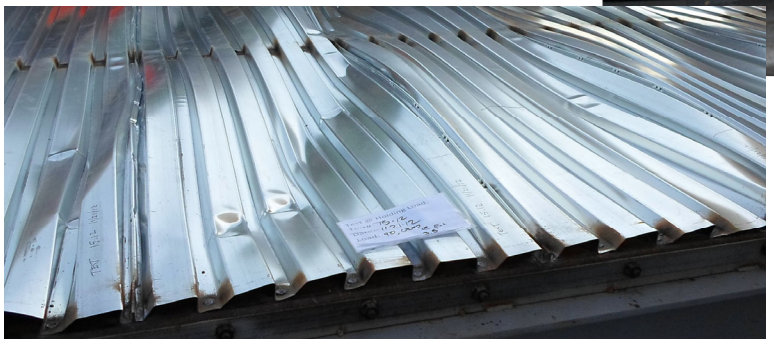
Strength of deck controlled by connections to supports

- General connection group effect limits
- Corner connection limit
- Parallel edge connection limits
- ***NEW*** Connection limit across the end of the sheets

Strength of deck controlled by stability (buckling)

- Plate like buckling in the field of the deck between support limit
- ***NEW*** web stability of deck at sheet ends due to shear rollover limit





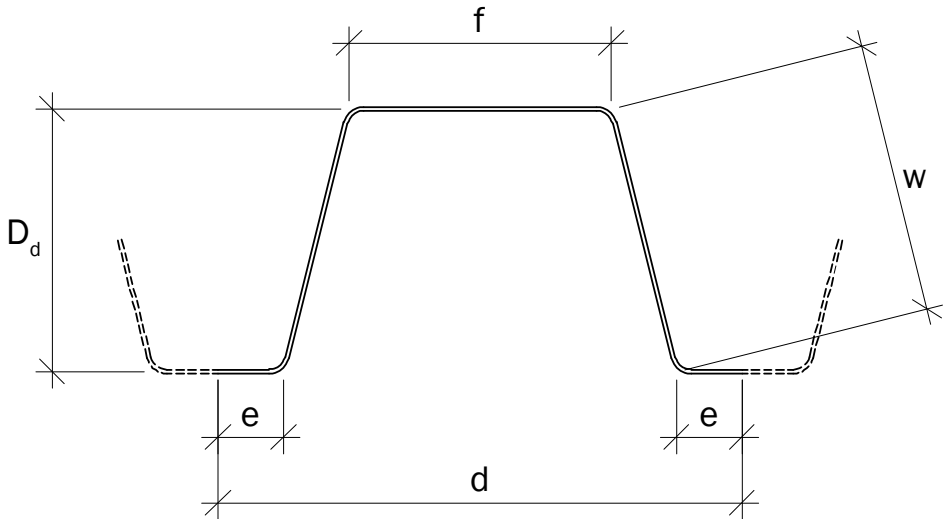
Geometry of Roof Deck Panel

AISI S310-20

Developmental flute width per pitch, “stretch out”

$$s = 2(e + w) + f$$

d = pitch



Connection Group Effect, β

AISI S310-20

β Factor defining connection contribution and interaction to diaphragm shear strength per unit length

$$\beta = n_s \alpha_s + 2 n_p \alpha_p^2 + 4 \alpha_e^2$$

α_n^2 is analogous to section modulus of connection group

$$\alpha_n^2 = \left(\frac{1}{w^2}\right) \sum x_n^2$$

α_s Ratio of the connection strength to the support to the sidelap connection strength

$$\alpha_s = \frac{P_{ns}}{P_{nf}}$$

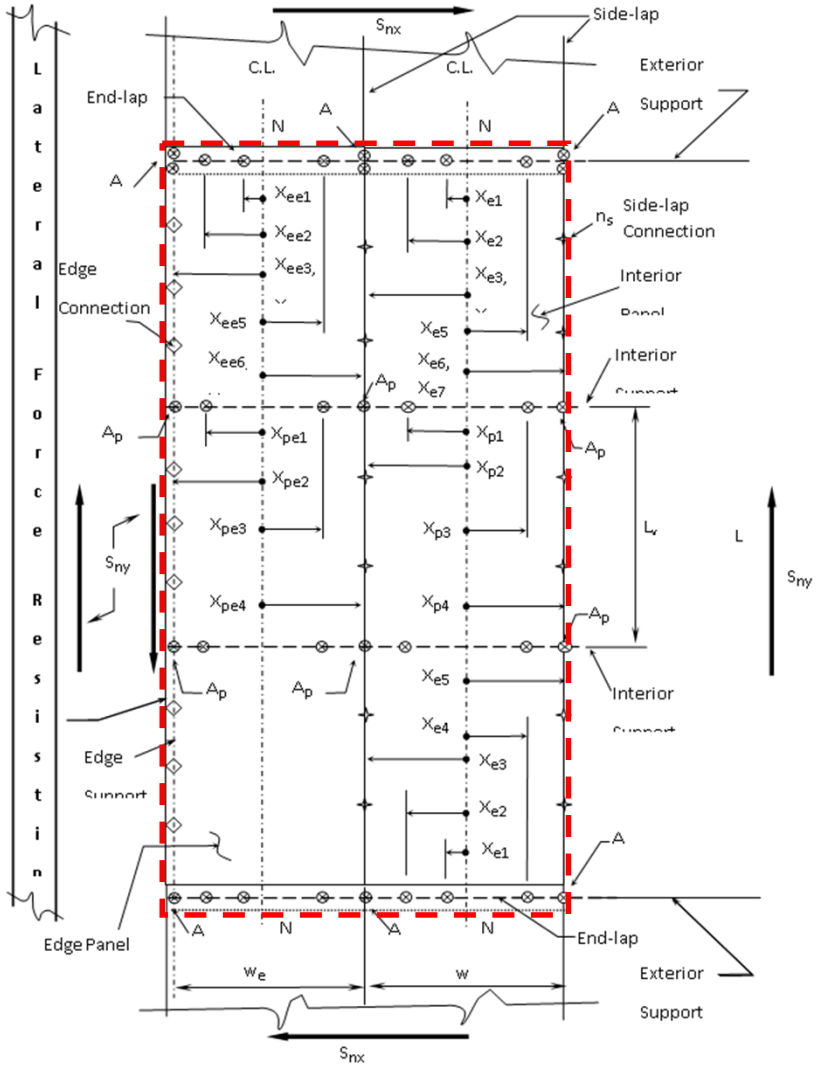
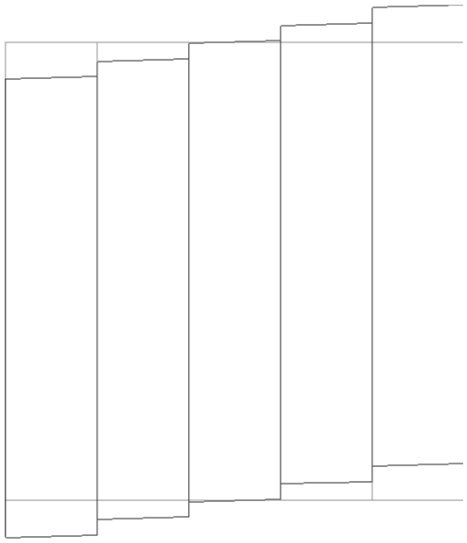


Figure D1-1 Schematic Illustration of Section D1 Parameters

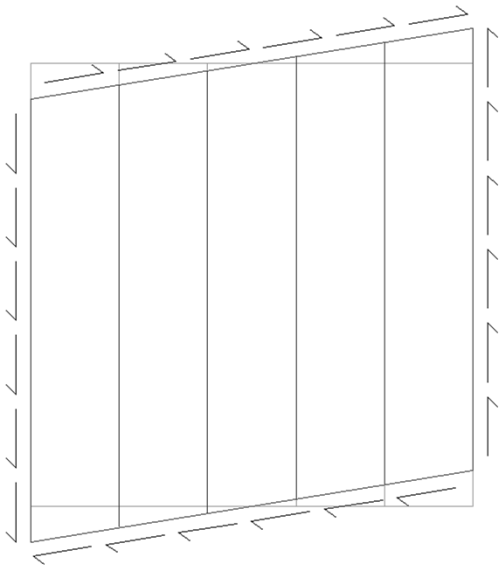
Verco / Vulcraft / Hilti Contribution to AISI

AISI S310-20

- Limit state for high-shear roof deck diaphragms
- Derived from diaphragm tests performed by
  - Verco
  - Wheeling (acquired by Vulcraft)
  - Hilti
- Identified the impact of Weak vs Strong sidelaps



AISI S310 / SDI
Panels slide at sidelaps

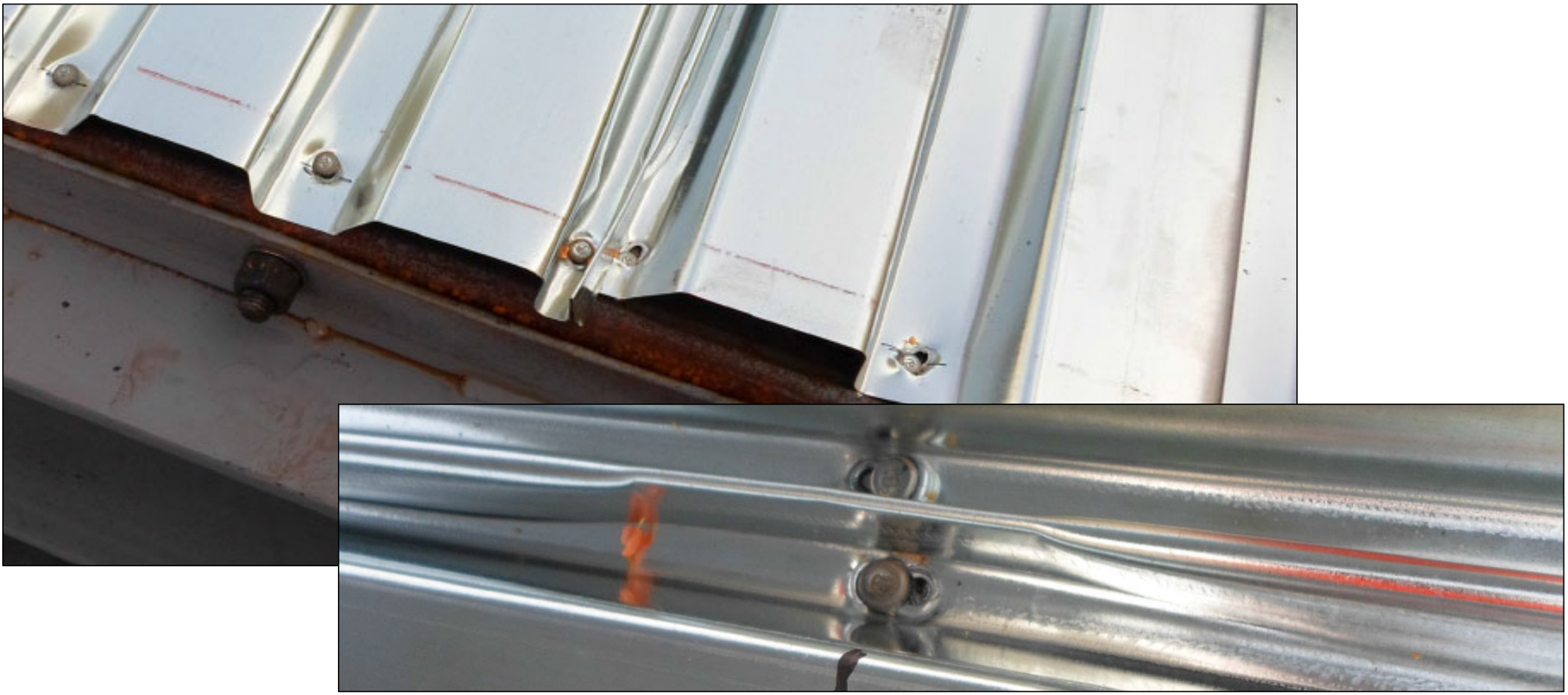


Perpendicular Shear and Web Crippling
Panels do not slide at sidelaps

Strong Sidelap



Weak Sidelap



Connection at Interior Panel Limit

AISI S310-20

Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by connections at interior panels or edge panels.

$$S_{ni} = [2A(\lambda - 1) + \beta] \frac{P_{nf}}{L}$$

Weak Sidelap Behavior

This is essentially the sum of the moments of the connection strength about the centerline of the panel divided by the length



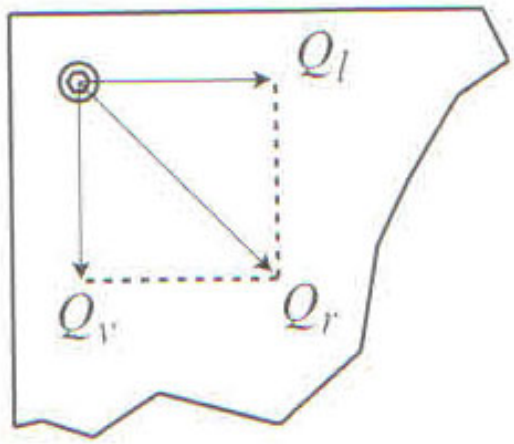
Connection at Panel Corner Limit

AISI S310-20

Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by connections at interior panels or edge panels.

$$S_{nc} = \left(\frac{N^2 \beta^2}{L^2 N^2 + \beta^2} \right)^{0.5} P_{nf}$$

Weak Sidelap Behavior



This limits the strength to not overload the connection in the corners of the deck sheet

Connection Parallel Panel Limit

AISI S310-20

Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by connections along the edge parallel to the panel span in an edge panel and located at a diaphragm reaction line

$$S_{ne}=\frac{(2\alpha_1+n_p\alpha_2)P_{nf}+n_eP_{nfs}}{L}$$

Weak Sidelap Behavior

This address the deck parallel edge attached to a chord or collector which are a support connector compared to the sidelap connection on the other parallel edge of the sheet.

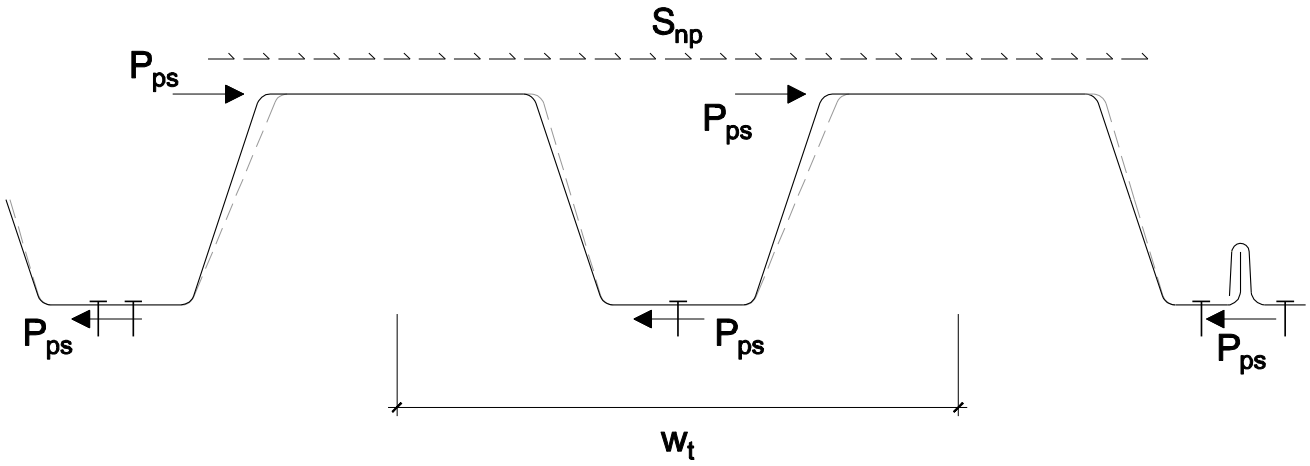
NEW Connection Perpendicular Panel Limit

AISI S310-20

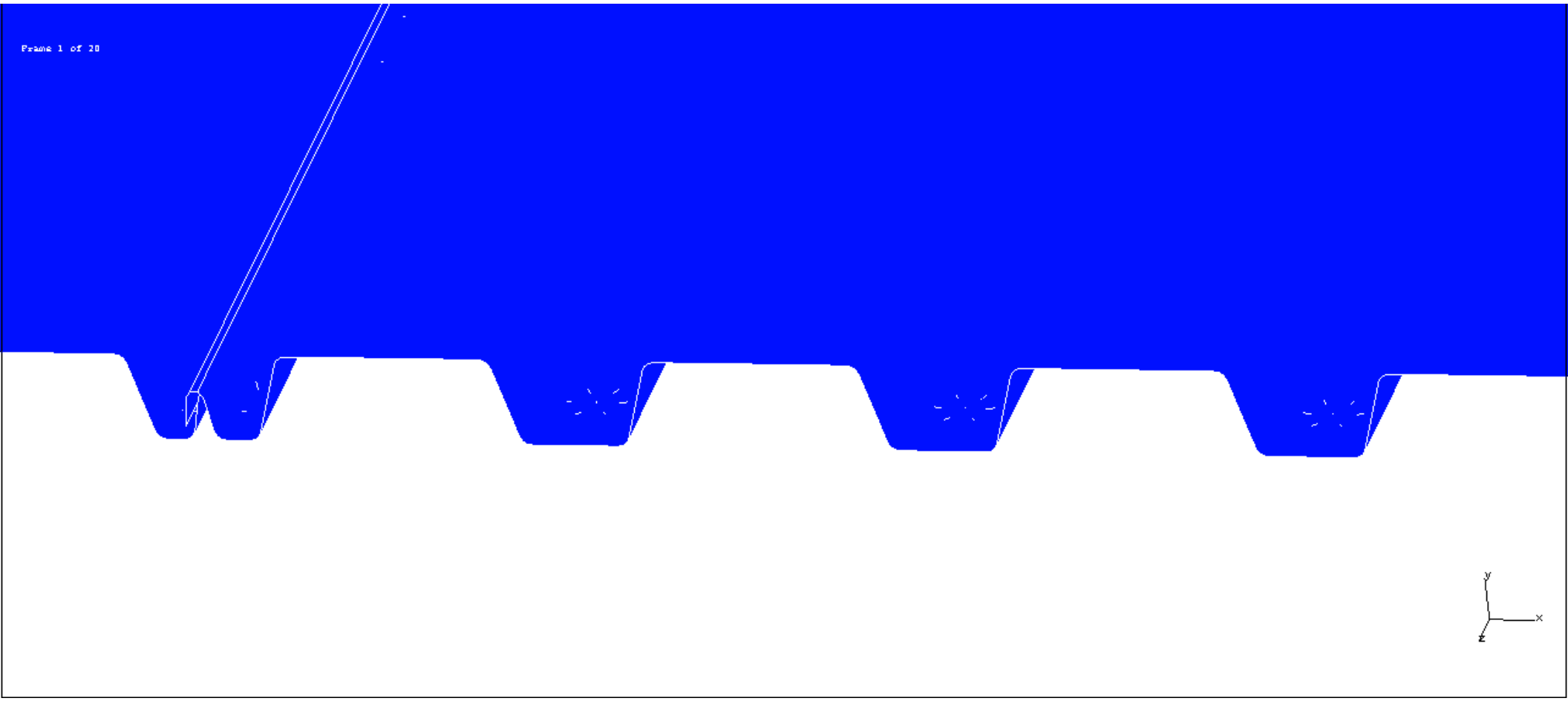
Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by connections along the ends of interior panels or edge panels and into exterior supports

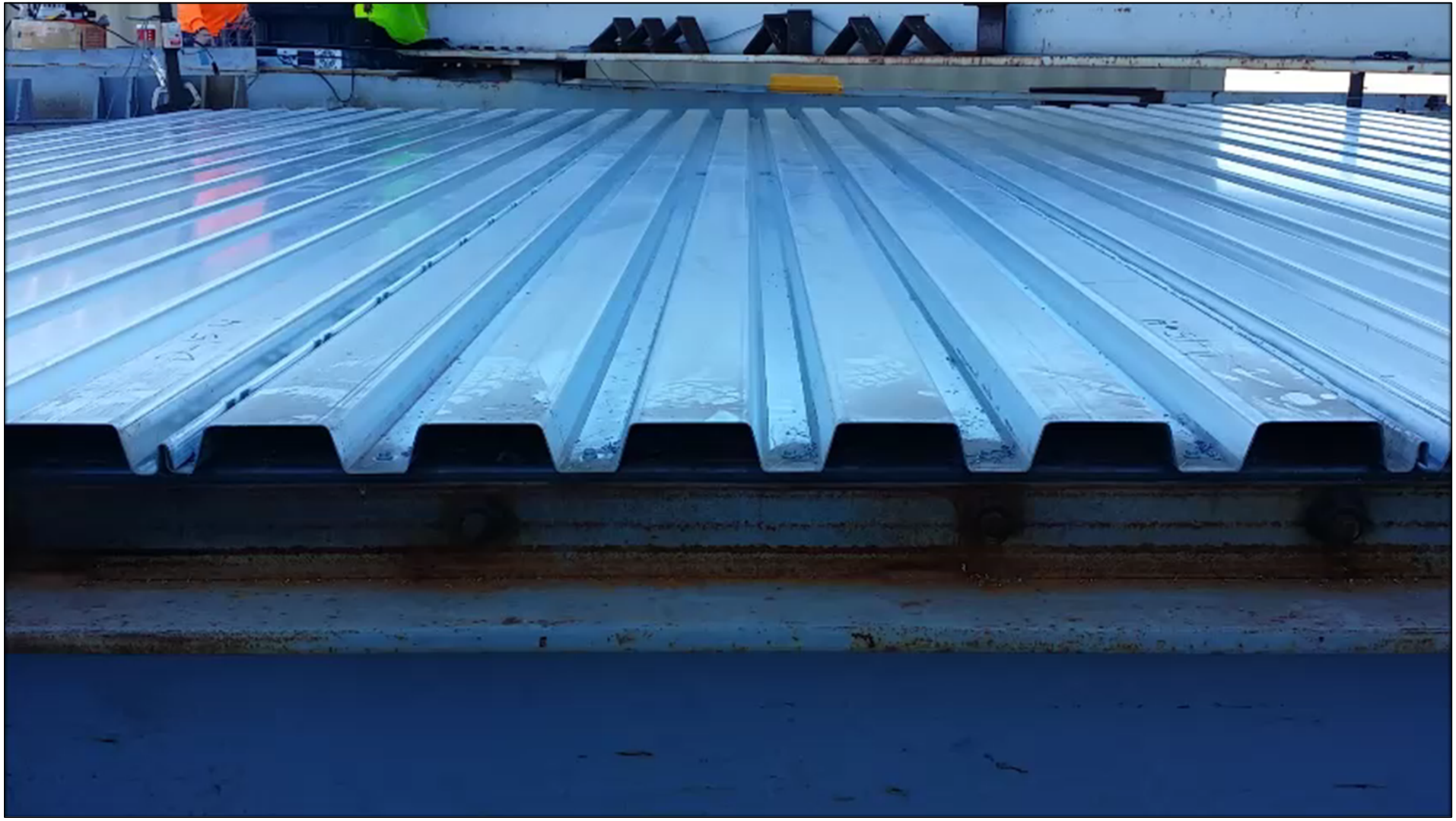
$$S_{np} = n_d P_{nf} \frac{1}{w_t}$$

This is essentially the perpendicular limit like the parallel limit



PERPENDICULAR SHEAR FAILURE MODE


Frame 1 of 20
Y
X
Z



Panel Out-of-Plane Buckling

AISI S310-20

Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by panel out-of-plane buckling

$$S_{no} = \frac{7890}{\alpha L_v^2}\left(\frac{I_{xg}^3 t^3 d}{s}\right)^{0.25}$$



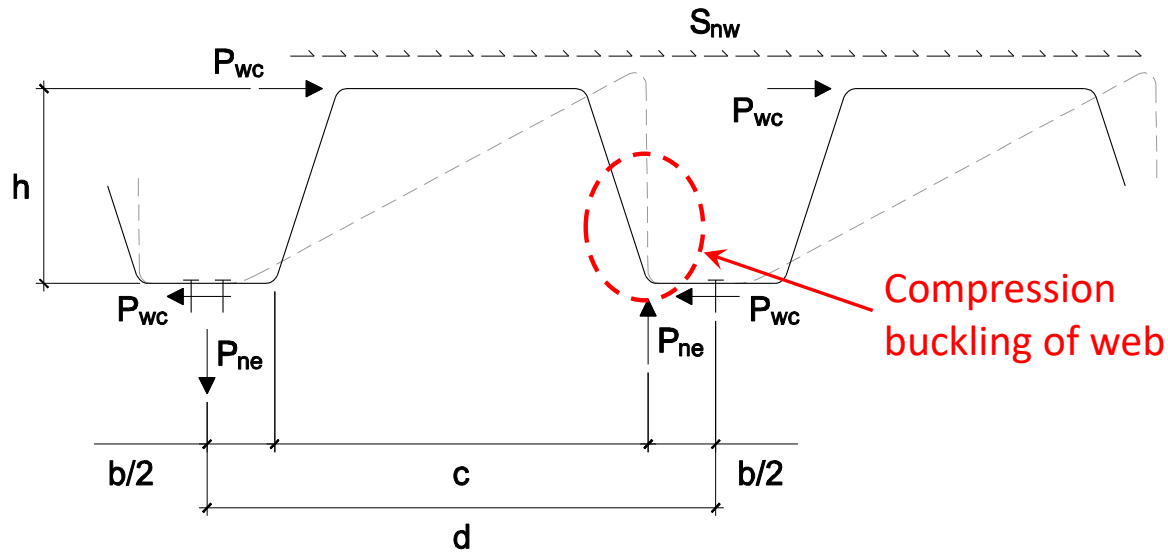
NEW Local Web Buckling Panel Limit

AISI S310-20

Nominal shear strength [resistance] per unit length of diaphragm or wall diaphragm controlled by panel local web buckling over exterior support

$$Sn_{\ell}=P_{nw}\left(\frac{d-e}{D_d}\right)\left(\frac{1}{d}\right)$$

For those who have used the Verco web-based diaphragm tool you need to put in bearing width.



WEB CRIPPLING FAILURE MODE



New Limit States Impact on Diaphragm Shear Strength

AISI S310-20 & Verco ESR-2018

Hilti X-HSN24 PAF Connections to Supports
36 / 9 / 4 Perpendicular Connection Pattern to Supports
PunchLok II Connection (VSC2) Sidelap

A572 GR50 Support Member or Equivalent
0.188 ≤ Support Thickness (in.) ≤ 0.375
in. Minimum Deck End Bearing Length

NEW Local Web Buckling or Connection End Shear Plateau

Traditional Plate Like Buckling Limit State Plateau

LRFD Design Seismic Diaphragm Shear Strength ΦSn (plf)

Sidelap Connection Spacing (in.)	Span 4'-0"	5'-0"	6'-0"	7'-0"	8'-0"	9'-0"	10'-0"	11'-0"	12'-0"
4	2520	2520	2520	2520	2496	1972	1597	1320	1109
6	2520	2520	2520	2520	2496	1972	1597	1320	1109
8	2520	2520	2520	2520	2496	1972	1597	1320	1109
12	2240	2161	2106	2066	2034	1972	1597	1320	1109
18	1946	1918	1665	1685	1699	1544	1570	1320	1109
24	1594	1637	1405	1465	1305	1365	1244	1299	1109
36	1594	1318	1117	1227	1080	953	1062	966	885

Objectives

- ✓Let's agree on the Definition of Diaphragm
- ✓Structural Concrete fille Steel Deck Diaphragm Shear Strength & Shear Stiffness
- ✓Bare (Roof) Steek Deck Diaphragm Shear Strength and Shear Stiffness
- Industrial Warehouse Roof Diaphragm Considerations
- Closing

Industrial Warehouse Roof Structure Design Considerations

- ✓Maximize material usage (trim the fat)
- ✓Fewer pieces & Connections
- ✓Fewer interior braced frame or moment frames
- ✓Eliminate expansion joints
- ✓Eliminate unneeded elements



Construction Efficiency and Economic Considerations

Lower cost and faster erection

- Maximize material usage (trim the fat)
- Fewer pieces
- Less connections
- Fewer interior braced frame or moment frames
- Eliminate thermal expansion joints
- Eliminate unnecessary steel elements

This is not hard when implemented at the beginning of the design

Design to Accommodate Panelized Erection

Safe & Fast….

- Consistent 8 ft joist spacing
- Use PunchLok II sidelap attachment (or DeltaGrip)
- Attach deck with PAF's (Hilti nails or Pneutek pins)

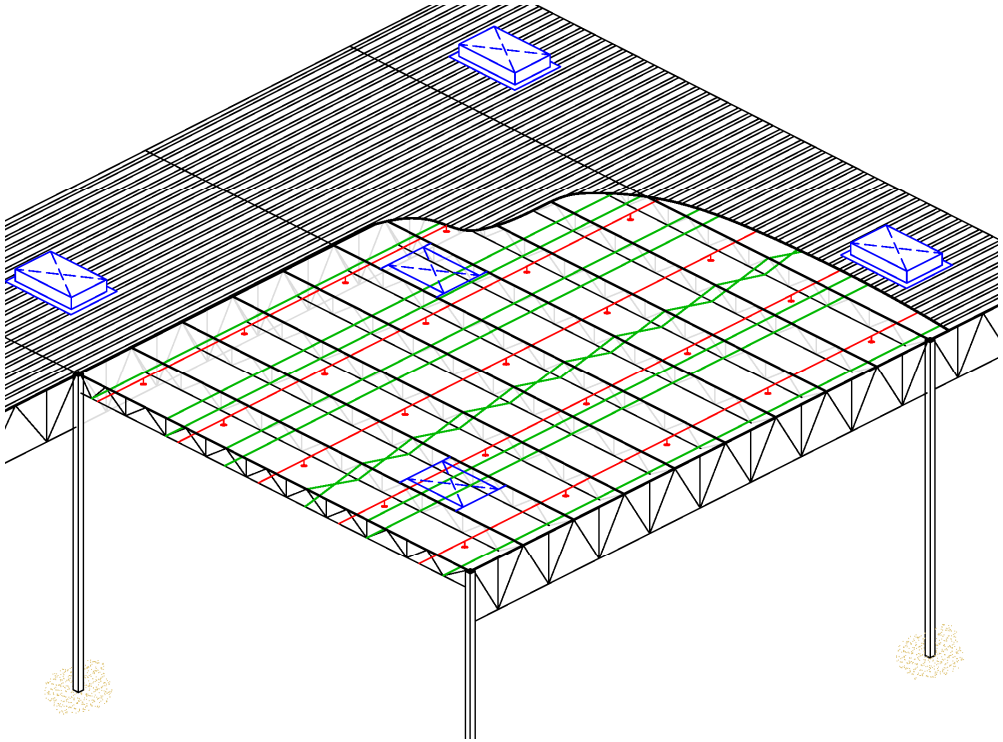


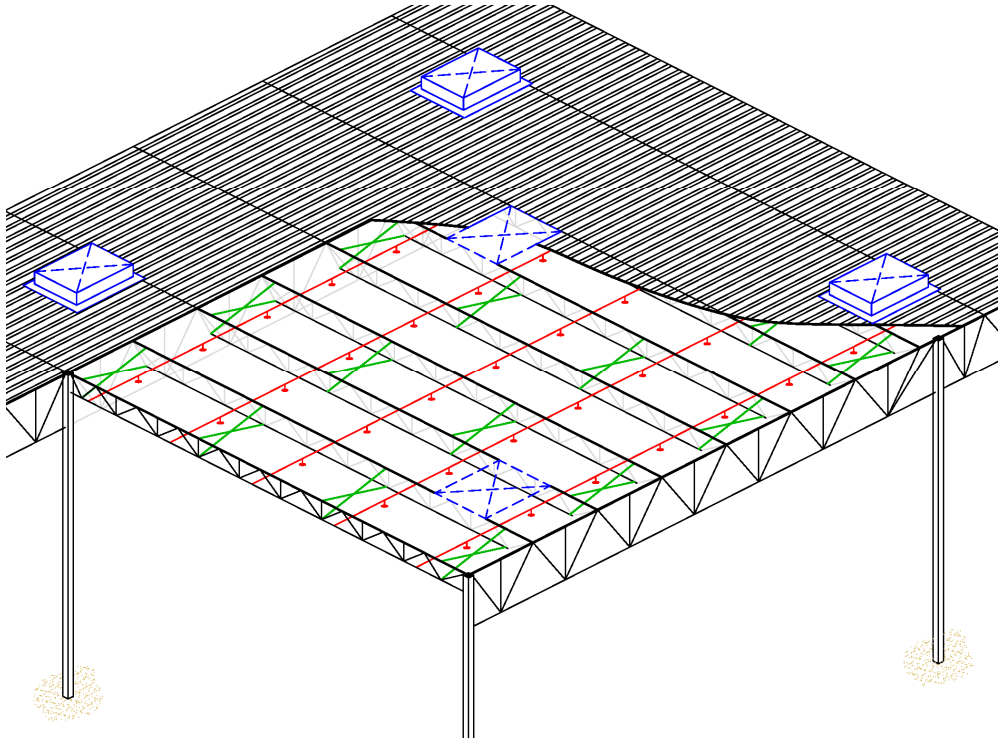


- Eliminate skylight frames
- Eliminate time to install wall blocking between joists
- Minimize deck weight (use minimum deck gage)

Fewer Pieces, Fewer Connections, & Eliminate Skylight Frames

Joists & Deck





Traditional → Optimized

Maximize Deck Span

Verco ESR-2018

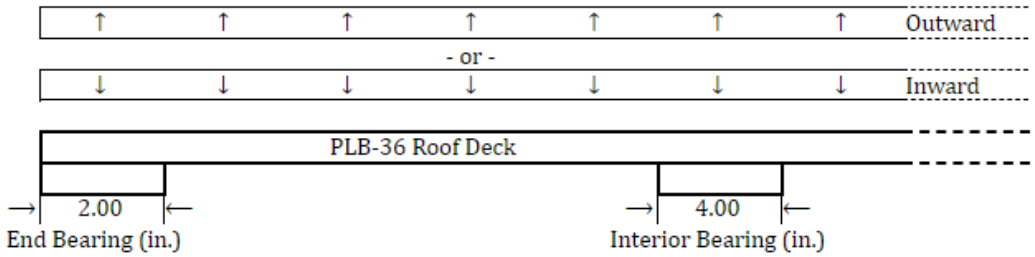
22 Gage PLB™-36 Grade 50

Uniform Allowable Load Table, ASD (psf)

For End Lapped Deck

36/7/ 4 Connection Pattern to Supports with Hilti X-HSN 24 PAF

Support Member A572 GR50
$0.125 \le t_2$ (in.) ≤ 0.375



Inward Uniform Allowable Load Table, ASD (psf)

Span	Span	5'-0"	5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"
1	Wn/Ω	140	116	98	83	72	62	55	49
	L/180	124	94	72	57	45	37	30	25
2	Wn/Ω	148	122	103	88	76	66	58	52
	L/180	-	-	-	-	-	-	-	-
3	Wn/Ω	184	152	128	110	95	83	73	64
	L/180	-	-	-	-	92	75	62	52

Uniform Roof Live Load

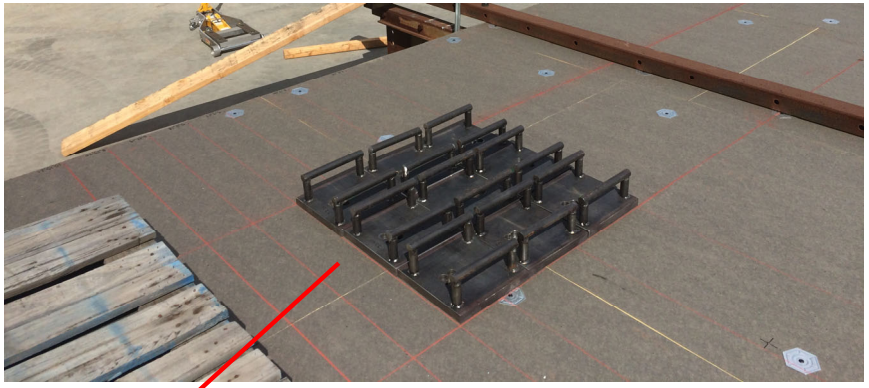
≥ 20 psf

≤ L/180 deflection for roofs not supporting ceilings

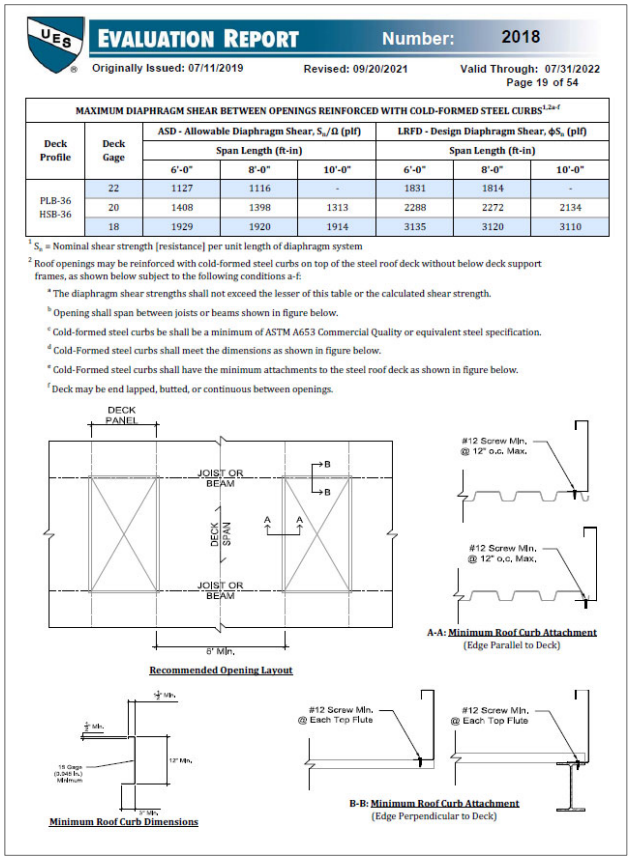
Maximize Deck Span

AISI S100 & Verco ESR-2018

IBC Concentrated Roof Live Load
300 lb.
distributed over
2½ ft x 2½ ft







EVALUATION REPORT Number: 2018

Originally Issued: 07/11/2019 Revised: 09/20/2021 Valid Through: 07/31/2022

MAXIMUM DIAPHRAGM SHEAR BETWEEN OPENINGS REINFORCED WITH COLD-FORMED STEEL CURBS[1,2,a-f]

Deck Profile	Deck Gage	ASD - Allowable Diaphragm Shear, S_n/Ω (plf)			LRFD - Design Diaphragm Shear, ϕS_n (plf)		
		Span Length (ft-in)			Span Length (ft-in)		
		6'-0"	8'-0"	10'-0"	6'-0"	8'-0"	10'-0"
PLB-36 HSB-36	22	1127	1116	-	1831	1814	-
	20	1408	1398	1313	2288	2272	2134
	18	1929	1920	1914	3135	3120	3110

[1] S_n = Nominal shear strength [resistance] per unit length of diaphragm system

[2] Roof openings may be reinforced with cold-formed steel curbs on top of the steel roof deck without below deck support frames, as shown below subject to the following conditions a-f:

[a] The diaphragm shear strengths shall not exceed the lesser of this table or the calculated shear strength.

[b] Opening shall span between joists or beams shown in figure below.

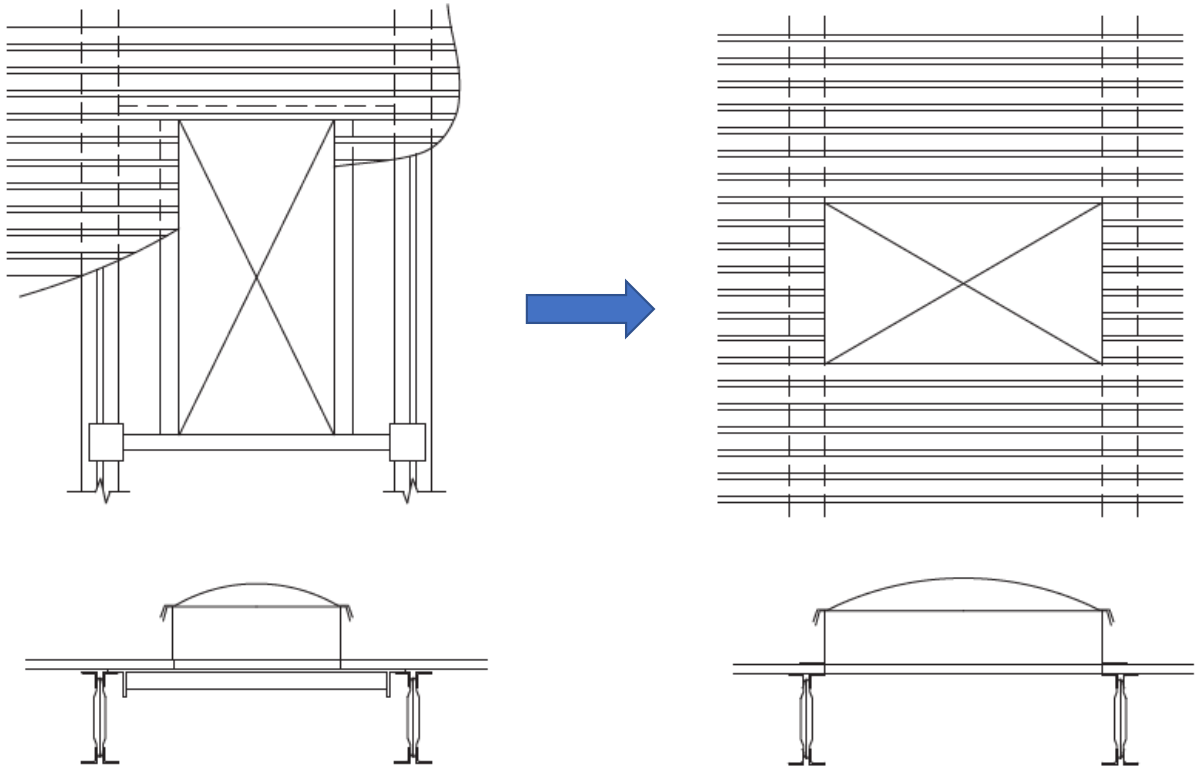
[c] Cold-formed steel curbs be shall be a minimum of ASTM A653 Commercial Quality or equivalent steel specification.

[d] Cold-Formed steel curbs shall meet the dimensions as shown in figure below.

[e] Cold-Formed steel curbs shall have the minimum attachments to the steel roof deck as shown in figure below.

[f] Deck may be end lapped, butted, or continuous between openings.

Eliminate Skylight Opening Frames



Traditional

Optimized



- Eliminate the cost of below deck structural opening frames
- Works with 8ft standard joist spacing

Shear Transfer Around “Unreinforced” Skylight Opening

Verco ESR-2018



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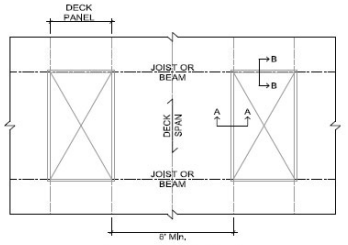
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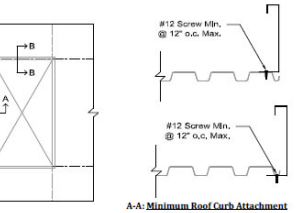
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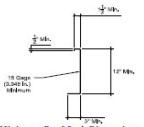
[f] Deck may be end lapped, butted, or continuous between openings.



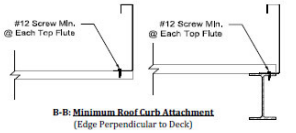
Recommended Opening Layout



A-A: Minimum Roof Curb Attachment
(Edge Parallel to Deck)



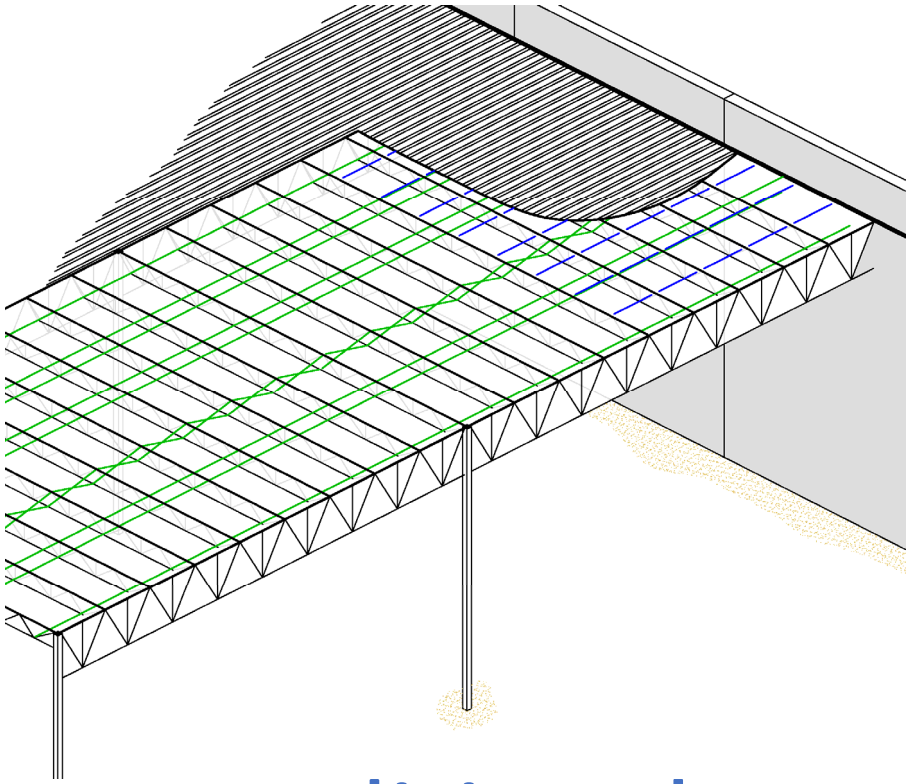
Minimum Roof Curb Dimensions

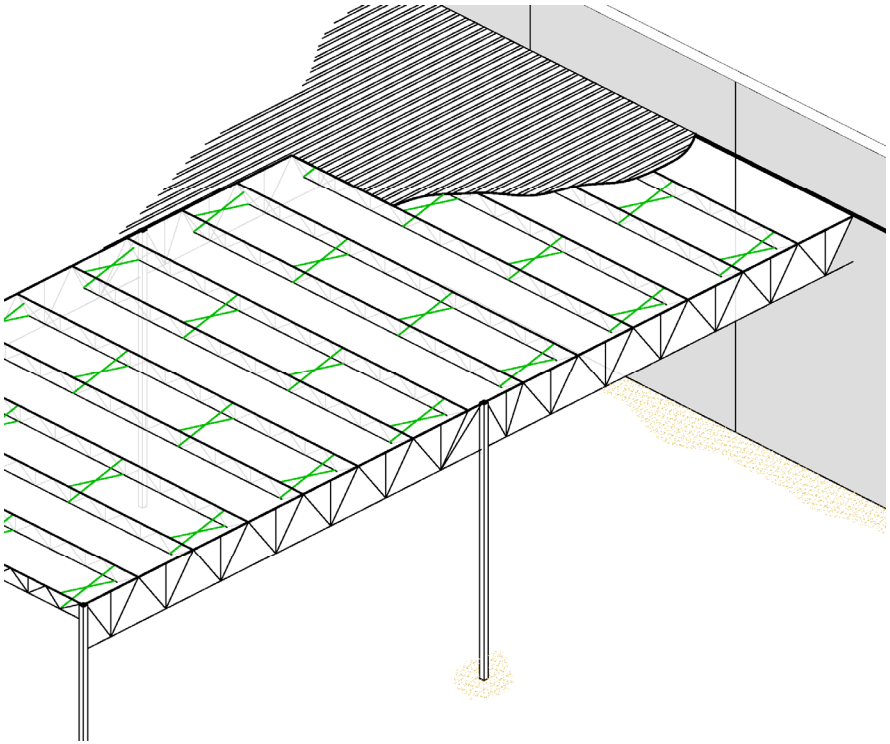


B-B: Minimum Roof Curb Attachment
(Edge Perpendicular to Deck)

Eliminate Unneeded Wall Blocking, Use the Steel Deck

AISI S100 & Verco ESR-2018

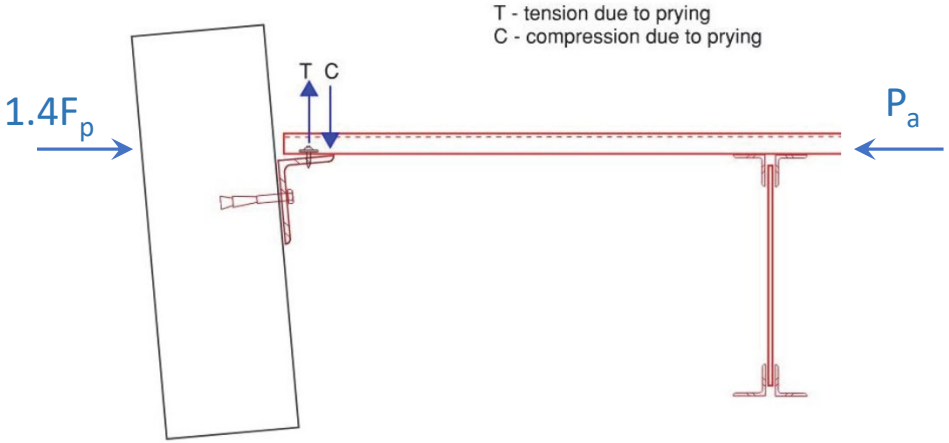


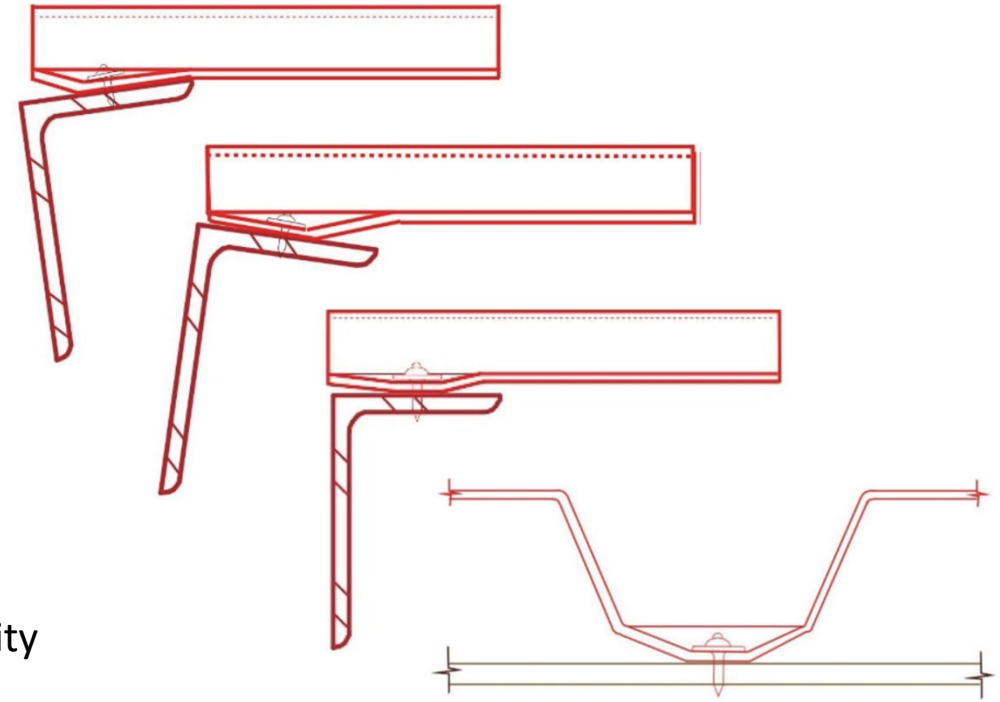


Traditional → Optimized

Wall Anchorage with Steel Deck
Axial & Bending Strength

AISI S100-22 & Verco ESR-2018

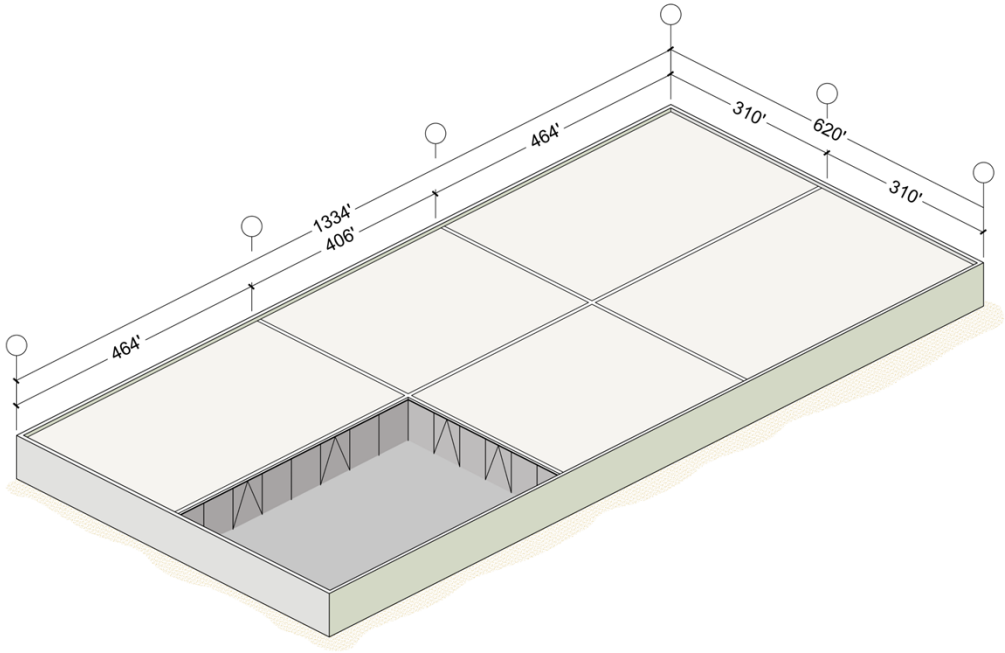


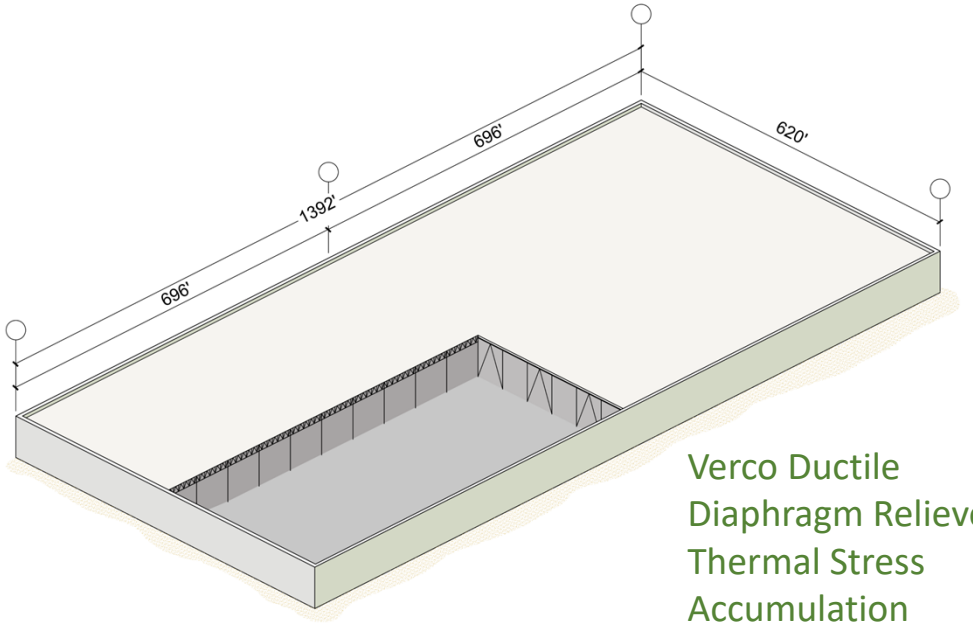


- Combined Axial and Bending Strength AISI S100-20 Ch H.
- Connection Combined Shear & Tension for prying action AISI S100-20 Ch. J.
- Verco ESR-2018 for connection tension flexibility to estimate tension force due to prying action

Eliminate Expansion Joints, and Reduce Interior braced Frames

Verco ESR-2018





Verco Ductile Diaphragm Relieves Thermal Stress Accumulation

- Traditional design,
  Expansion Joints very 300ft to 450ft

✓ More Desirable with Fewer Obstructions
✓ Reduce or eliminate costly frame lines

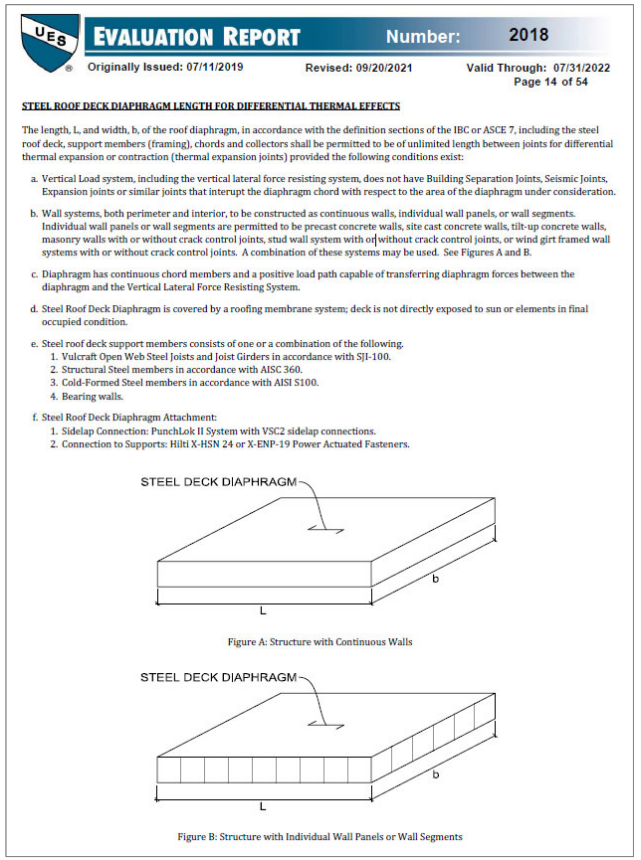
Traditional → Optimized

Eliminate Expansion Joints with Unlimited Length Diaphragm

Verco ESR-2018

Steel Roof Deck Diaphragm Length for Differential Thermal Effects

- Utilizes Ductility of the Verco PunchLok II system with Hilti Power Actuated Fasteners (PAF)
- Diaphragm must have continuous chords with positive connections to walls transferring diaphragm forces to the walls
- Ideal for use with concrete shear walls
- Expansion joint is required in the deck where the structure has expansion joints or building separations



EVALUATION REPORT Number: 2018

Originally Issued: 07/11/2019 Revised: 09/20/2021 Valid Through: 07/31/2022

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STEEL ROOF DECK DIAPHRAGM LENGTH FOR DIFFERENTIAL THERMAL EFFECTS

The length, L, and width, b, of the roof diaphragm, in accordance with the definition sections of the IBC or ASCE 7, including the steel roof deck, support members (framing), chords and collectors shall be permitted to be of unlimited length between joints for differential thermal expansion or contraction (thermal expansion joints) provided the following conditions exist:

a. Vertical Load system, including the vertical lateral force resisting system, does not have Building Separation Joints, Seismic Joints, Expansion joints or similar joints that interupt the diaphragm chord with respect to the area of the diaphragm under consideration.

b. Wall systems, both perimeter and interior, to be constructed as continuous walls, individual wall panels, or wall segments. Individual wall panels or wall segments are permitted to be precast concrete walls, site cast concrete walls, tilt-up concrete walls, masonry walls with or without crack control joints, stud wall system with or without crack control joints, or wind girt framed wall systems with or without crack control joints. A combination of these systems may be used. See Figures A and B.

c. Diaphragm has continuous chord members and a positive load path capable of transferring diaphragm forces between the diaphragm and the Vertical Lateral Force Resisting System.

d. Steel Roof Deck Diaphragm is covered by a roofing membrane system; deck is not directly exposed to sun or elements in final occupied condition.

e. Steel roof deck support members consists of one or a combination of the following.
   1. Vulcraft Open Web Steel Joists and Joist Girders in accordance with SJI-100.
   2. Structural Steel members in accordance with AISC 360.
   3. Cold-Formed Steel members in accordance with AISI S100.
   4. Bearing walls.

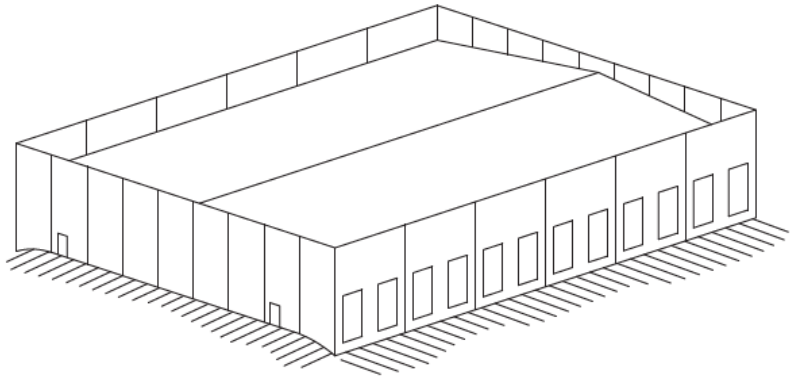
f. Steel Roof Deck Diaphragm Attachment:
   1. Sidelap Connection: PunchLok II System with VSC2 sidelap connections.
   2. Connection to Supports: Hilti X-HSN 24 or X-ENP-19 Power Actuated Fasteners.

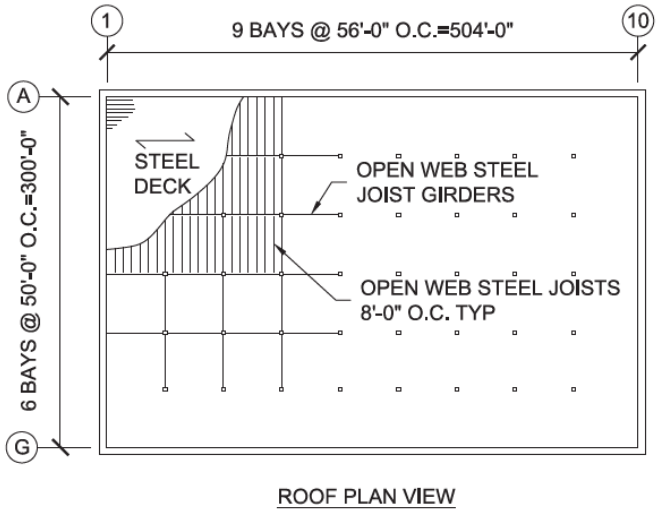
Figure A: Structure with Continuous Walls

Figure B: Structure with Individual Wall Panels or Wall Segments

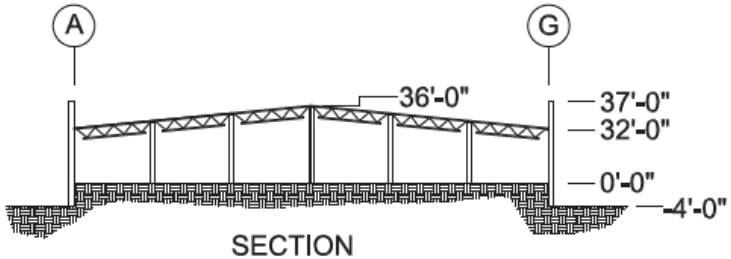
Example: 300 ft x 500 ft Warehouse

Verco Roof Structure Design Guide





ROOF PLAN VIEW



SECTION

Ontario, CA

SDC = D

S_{DS} = 1.0

Intermediate Precast Shear Walls

Steel Joist and Deck Roof Structure



Roof Diaphragm Shear Demand

Base Shear	$V = C_s W = 0.25W$
Diaphragm Force	$F_{px} = 0.25W$
Diaphragm Force	$F_{px} = 0.25w_{N\text{-}S}$

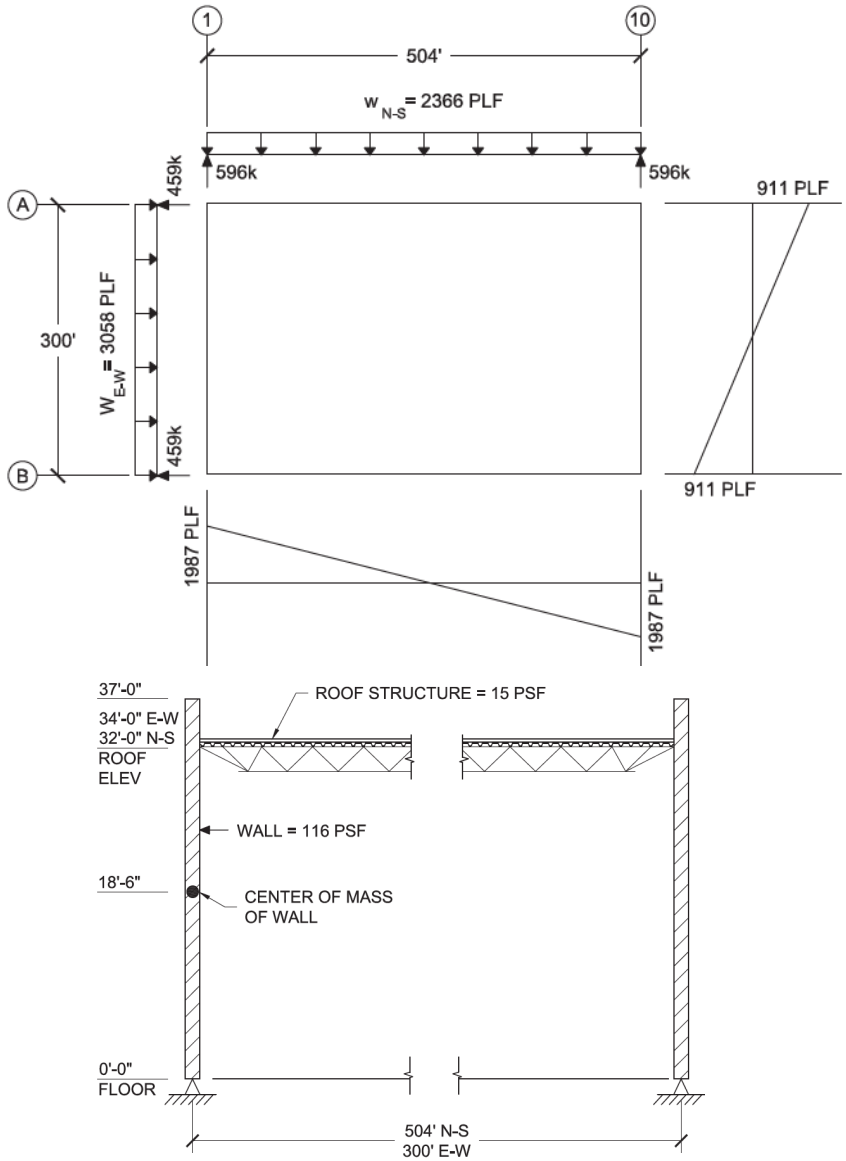
North-South Shear Force

$F_{px} = 0.25[15\ psf(300\ ft)$

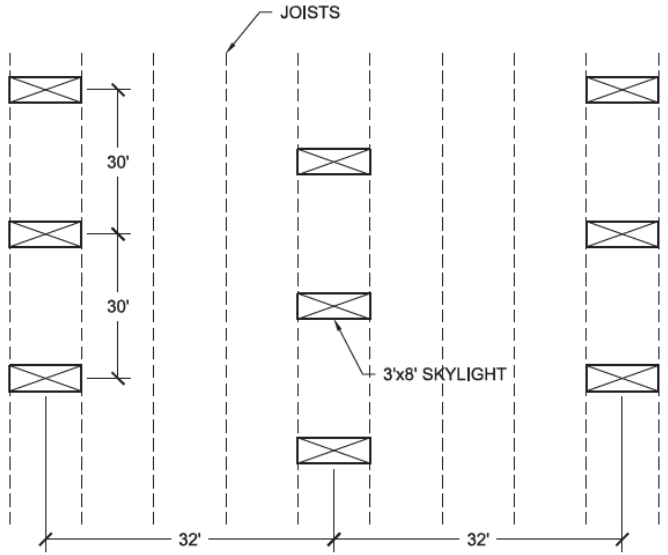
$+2[116\ psf(37\ ft)(37\ ft/2)(1/32\ ft)]] = 2366\ plf$

Shear along lines 1 & 10

$v_{N\text{-}S} = 2366\ plf\ (504\ ft) / (2\ (300\ ft)) = 1987\ plf$



Skylight Influence

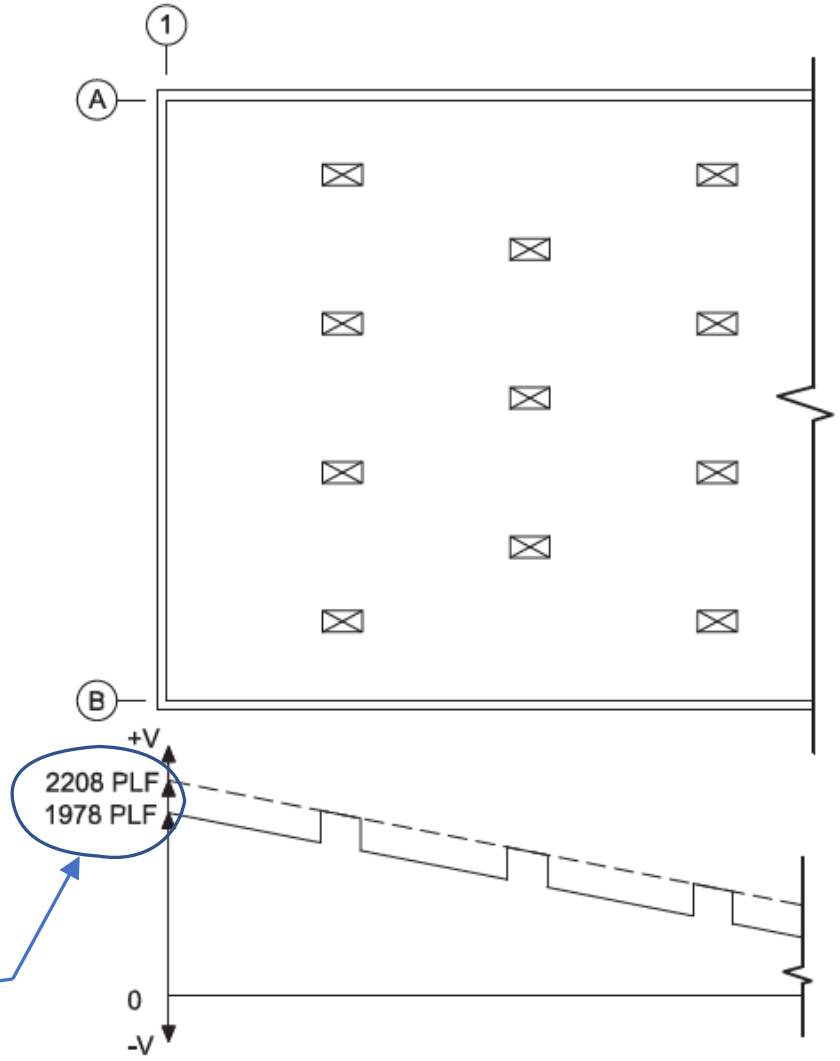


Effective diaphragm depth percentage

Reduction$_{N\text{-}S}$ = [(30 ft – 3 ft) / 30 ft] x 100 = 90%

Increased diaphragm unit shear for skylight openings

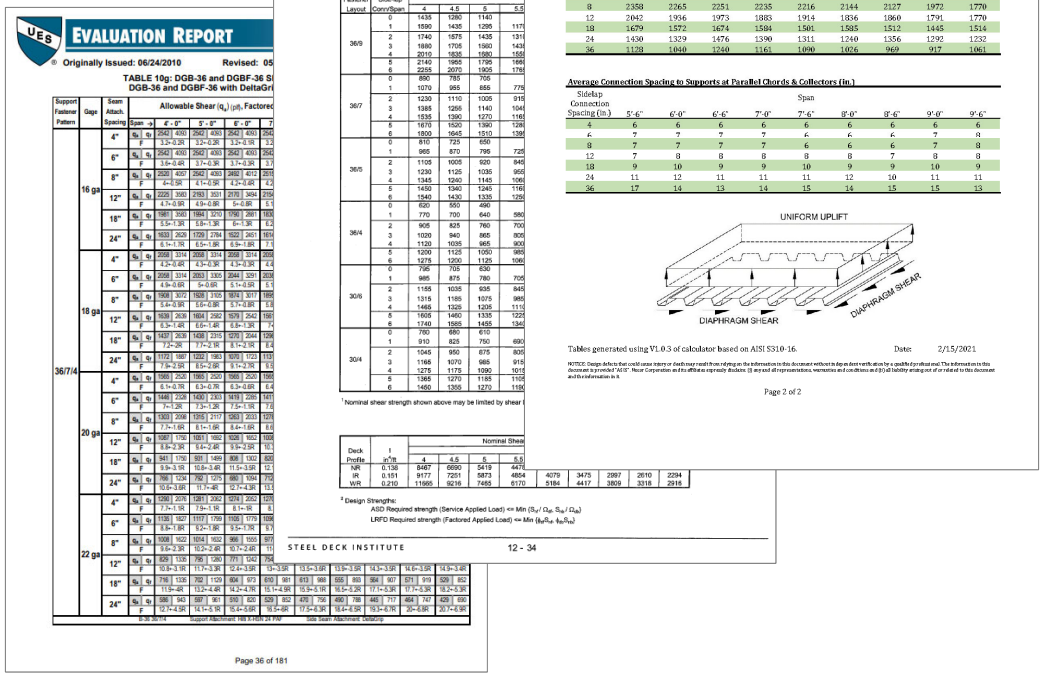
$V_{N\text{-}S}$ = 1987 plf (1/0.90) = 2208 plf LRFD



Roof Deck Shear Strength and Shear Stiffness

- Direct calculation following AISI S310-20
- SDI Diaphragm Design Manual Tables (based on AISI S310-16)
- Product Approval Reports
- Literature
- Web Based Design Solution
  - ➢**Verco** supported by ESR-2018
    - *Hilti*
    - *Simpson*

Verco ESR-2018



EVALUATION REPORT

Originally Issued: 06/24/2010 Revised: 05

TABLE 10g: DGB-36 and DGBF-36 S
DGB-36 and DGBF-36 with DeltaGr

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ROOF DECK

1.5(WR, IR, NR)20
Design thickness = 0.0358 in.
Support fastening: Hilti ENP2K, X-EDN19, X-EDNK22
Side-lap fastening: Buildex, Elco, Hilti, or Simpson S
0.125 in. through 0.375 in. Support Steel

Nominal shear strength shown above may be limited by shear

Design Strengths:
ASD Required strength (Service Applied Load) <= Min
LRFD Required strength (Factored Applied Load) <= Min

STEEL DECK INSTITUTE 12 - 34

20 ga PLB™-36 Grade 50 Roof Deck
Diaphragm Shear & Wind Uplift Interaction
For Both Ends Lapped Deck
with MWFRS Design Net Wind Uplift (LRFD) of 20.9 psf

Hilti X-HSN24 PAF Connections to Supports
36 / 7 / 4 Perpendicular Connection Pattern to Supports
PunchLok II Connection (VSC2) Sidelap Connections

A572 GR50 Support Member or Equivalent
0.125 ≤ Support Thickness (in.) ≤ 0.375
2 in. Minimum Deck End Bearing Length

LRFD Design Combined Wind Uplift & Diphragm Shear Strength ΦSn (plf) Generic 3 Span Condition

Sidelap Connection Spacing (in.)	Span 5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"
4	2441	2401	2361	2321	2281	2241	2201	1972	1770
6	2441	2401	2361	2321	2281	2241	2201	1972	1770
8	2358	2265	2251	2235	2216	2144	2127	1972	1770
12	2042	1936	1973	1883	1914	1836	1860	1791	1770
18	1679	1572	1674	1594	1501	1585	1512	1445	1514
24	1430	1329	1476	1390	1311	1240	1356	1292	1232
36	1128	1040	1240	1161	1090	1026	969	917	1061

Average Connection Spacing to Supports at Parallel Chords & Collectors (in.)

Sidelap Connection Spacing (in.)	Span 5'-6"	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"
4	6	6	6	6	6	6	6	6	6
6	7	7	7	7	6	6	6	7	8
8	7	7	7	7	6	6	6	7	8
12	7	8	8	8	8	8	7	8	8
18	9	10	9	9	10	9	9	10	9
24	11	12	11	11	11	12	10	11	11
36	17	14	13	14	15	14	15	15	13

UNIFORM UPLIFT
DIAPHRAGM SHEAR
DIAPHRAGM SHEAR

Tables generated using V1.0.3 of calculator based on AISI S310-16. Date: 2/15/2021

Page 2 of 2

Diaphragm Design and Attachment Zones

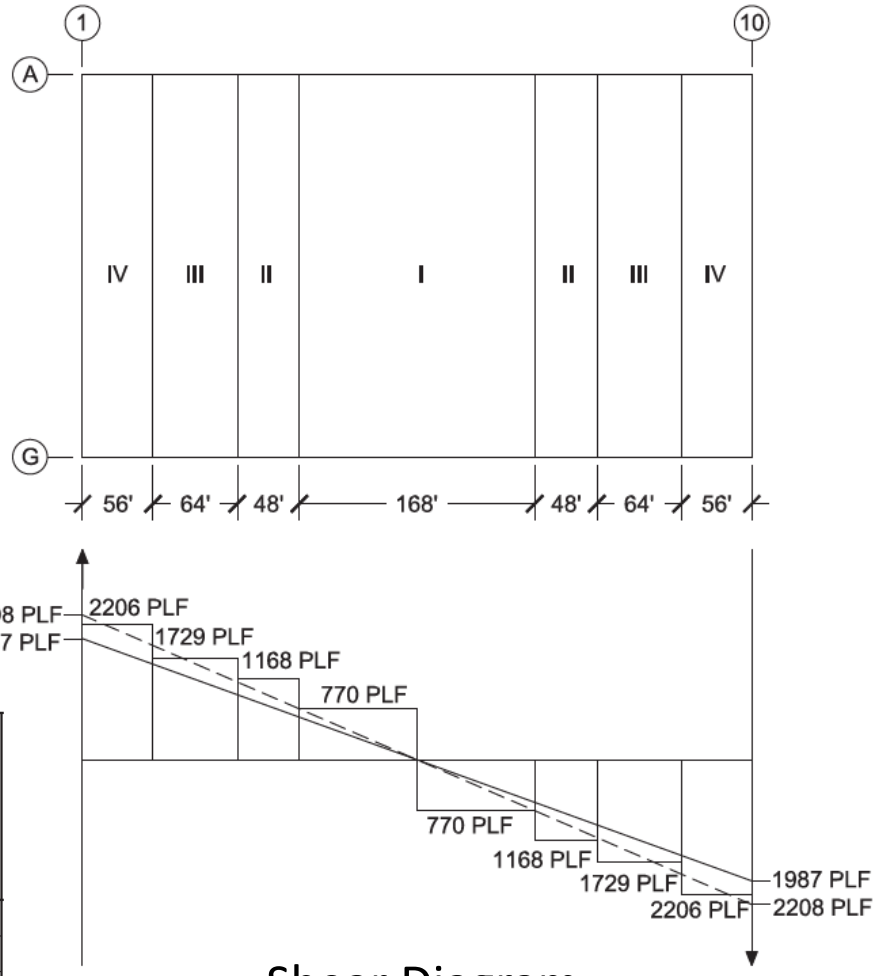
Optimize Deck

- Minimize Gage
- Minimize Fasteners to Supports
- Use Maximum Sidelap Spacing

Shear Diagram Schedule

ASC DeltaGrip is Similar

Zone	PLB Gage	Span (ft)	Fastener to Supports			Sidelap Connection VSC2 (in o.c.)	Required Shear LRFD		Design Shear Strength ϕV_n (plf)
			Pattern	Type	Parallel chords and collectors (in o.c.)		With Skylight (plf)	Without Skylight (plf)	
IV	20	8	36/7/4	X-HSN 24	7	8	2208	1988	2206
III	22	8	36/7/4	X-HSN 24	8	8	1717	1546	1729
II	22	8	36/7/4	X-HSN 24	12	12	1157	1041	1168
I	22	8	36/4	X-HSN 24	16	24	736	662	770



Shear Diagram

Diaphragm Deflection Mechanics

The change in shear deflection between two points along the diaphragm span can be determined by calculating the area under the $\frac{V}{G'b}$ diagram between those points.

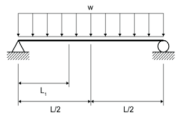
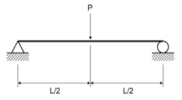
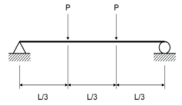
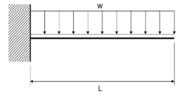
For a uniform load on a simple beam

$$\Delta_w = \frac{q_{ave} L_1}{G'}$$

Where b is the depth of the diaphragm or web of the beam

DIAPHRAGM SHEAR DEFLECTION EQUATIONS

Diaphragm shear deflection may be determined by the following equations:

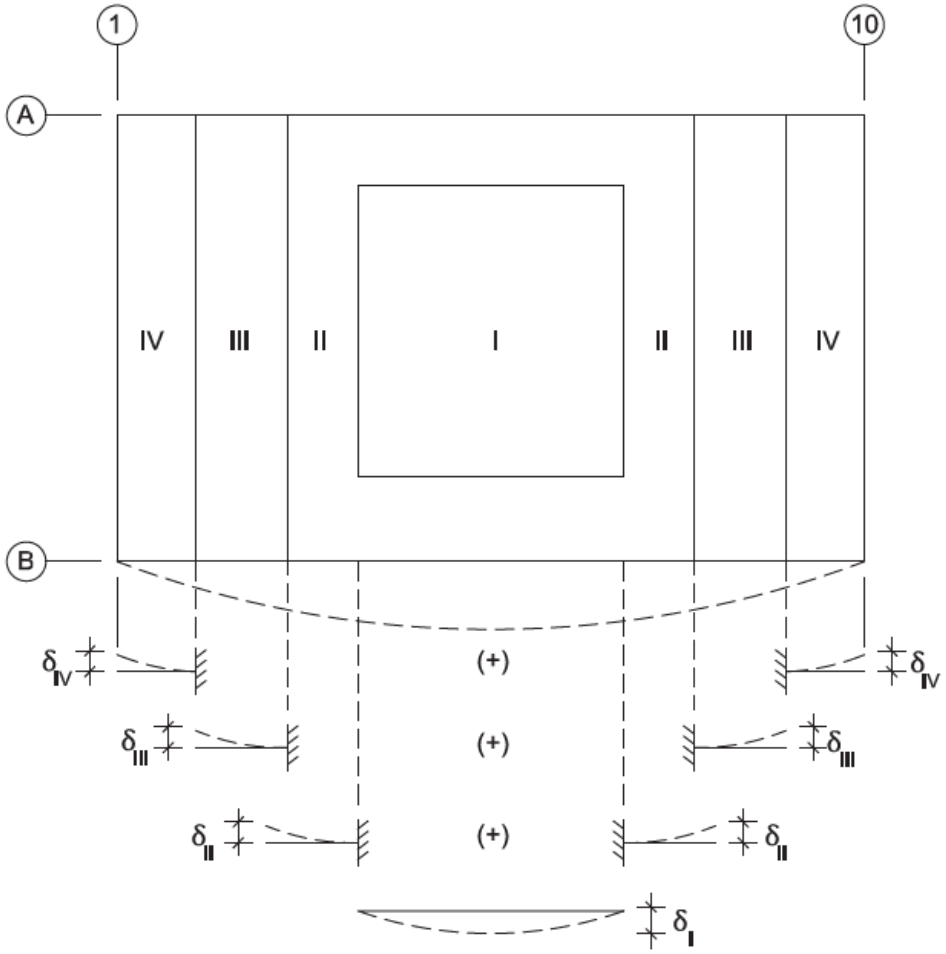
Type of Loading	Loading Condition	Shear Deflection	Diagrams
Simple Span Diaphragm, Deflection at L_1	Uniform Load, w	$\Delta_w = \frac{q_{ave} L_1}{G'}$	
Simple Span Diaphragm, Deflection at center	Uniform Load, w	$\Delta_w = \frac{wL^2}{8bG'}$	
Simple Span Diaphragm, Deflection at center	Point Load, P	$\Delta_w = \frac{PL}{4bG'}$	
Simple Span Diaphragm, Deflection at 1/3 points	Point Load, P	$\Delta_w = \frac{PL}{3bG'}$	
Cantilever Diaphragm, Deflection at Free End	Uniform Load, w	$\Delta_w = \frac{WL^2}{2bG'}$	
Cantilever Diaphragm, Deflection at Free End	Point Load, P	$\Delta_w = \frac{PL}{bG'}$	

Where:
- Δ_w = Diaphragm shear web deflection (in)
- q_{ave} = Average diaphragm shear (lbs/ft)
- L_1 = Distance between vertical resisting element (such as shear wall) and the point at which deflection is to be calculated (ft)
- G' = Diaphragm shear stiffness factor (kips/in)
- b = Depth of diaphragm (ft)
- L = Diaphragm Length (ft)
- P = Concentrated load (lbs)
- w = Uniform load (lbs/ft)

Diaphragm Deflection

- Design level deflection
- The simple beam is broken into left and right halves
- Deflection is summed for each zone stiffness

Zone	v_{left} plf	v_{right} plf	$v_{i\ ave}$ plf	L_i ft	G' kip/in	$0.5(v_{i\ ave}L_i)/(1000G')$ in
I	1987	1545	1766	56	191	0.26
II	1545	1041	1293	64	150	0.28
III	1041	662	852	48	117	0.17
IV	662	0	331	84	96	0.14
IV	662	0	331	84	96	0.14
III	1041	662	852	48	117	0.17
II	1545	1041	1293	64	150	0.28
I	1987	1545	1766	56	191	0.26
Total Elastic Strength Level Shear Deflection, δ_v						1.71



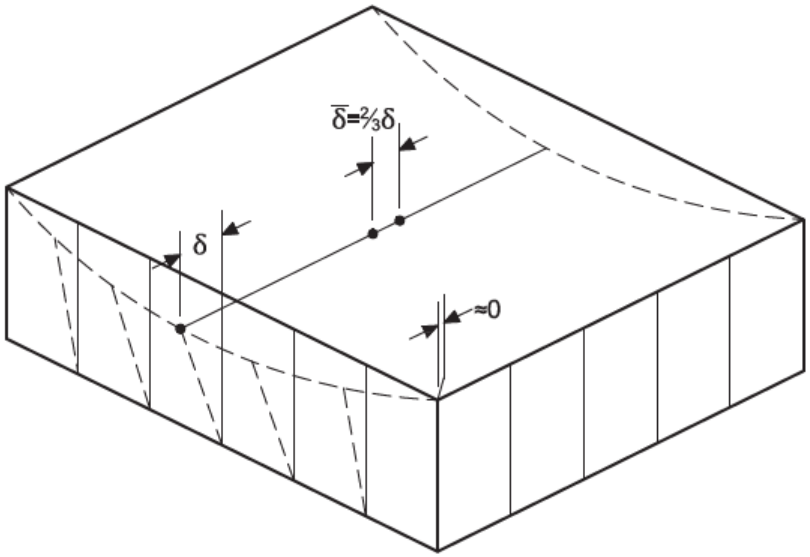
Diaphragm Stability Check

Stability Coefficient Equation

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \leq 0.10$$ ASCE 7 eq 12.8-16

Amplified Deflection

$$\delta_x = \frac{C_d \delta_{xe}}{I_e} = \frac{4.0 \cdot 1.71}{1.0} = 6.84\ in$$ ASCE 7 eq 12.8-15



Average Diaphragm Deflection

$$\Delta = \frac{2}{3}\delta_x = \frac{2}{3}6.84 = 4.56\ in$$

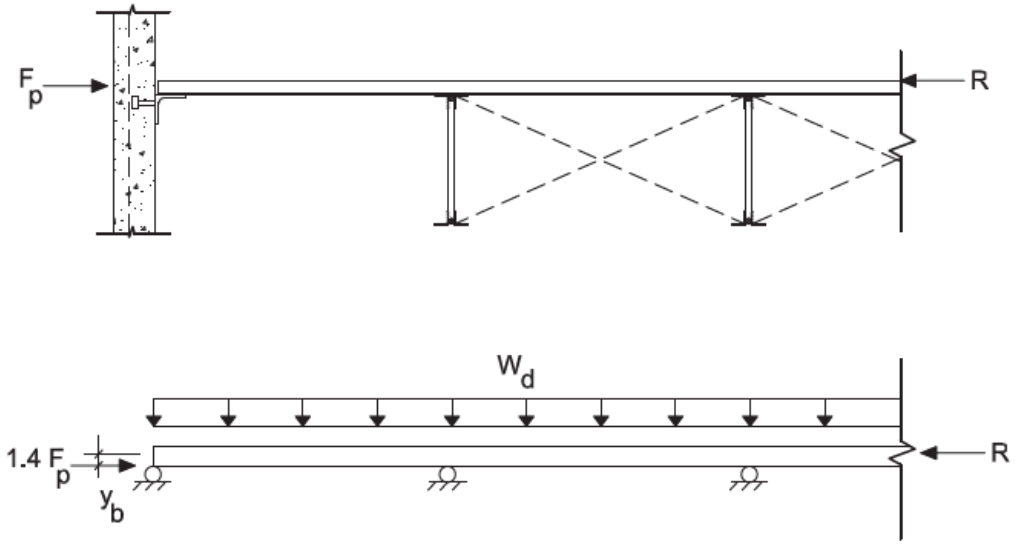
Stability Check

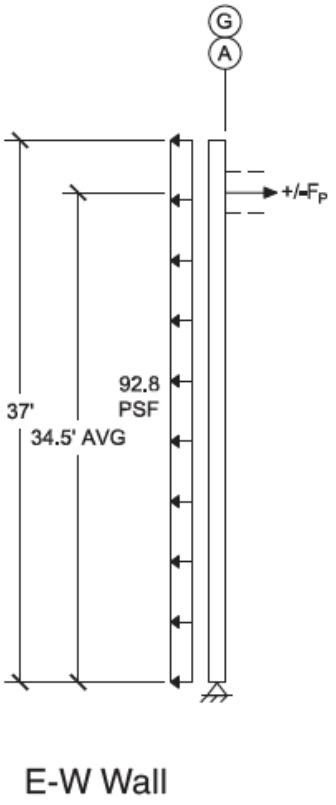
$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} = \frac{4470kip \cdot 4.56in \cdot 1.0}{1192kip \cdot 384in \cdot 4.0} = 0.01 \leq 0.10$$ Acceptable

Wall Anchorage

AISI S100 & Verco ESR-2018

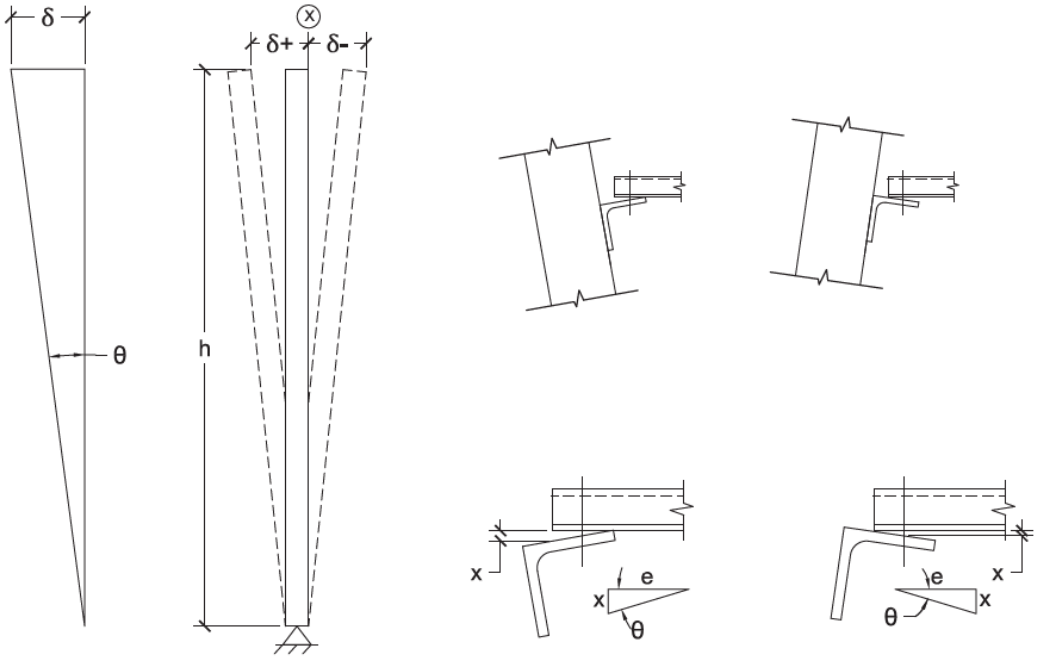
- Steel deck may provide wall anchorage
- Steel deck may also be used as continuous ties, or
- Steel deck in combination with a sub-diaphragm, and girder ties



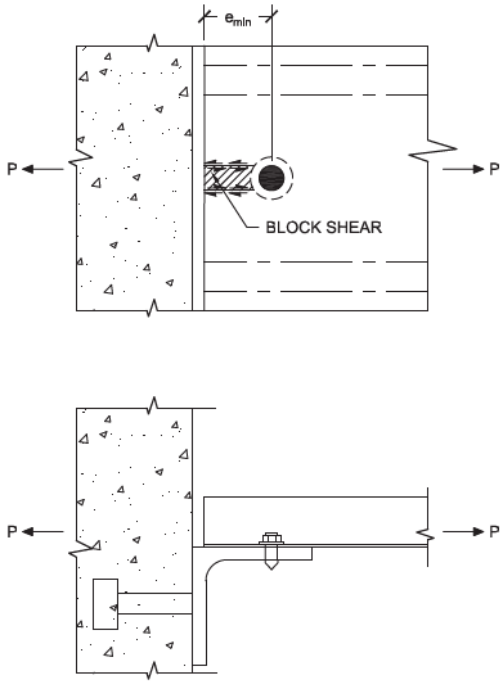


E-W Wall

Prying Action and Rupture



- Prying action tension force estimated based on connection tension flexibility testing



- Shear rupture by calculation or testing in accordance with AISI S100-20

Wall Anchorage Made Easy

- AISI S100-20 Cold-formed steel axial and bending calculations are challenging
- Verco web-based design tools
  - AISI S100 Combined axial and bending
  - AISI S100 or ESR-2018 for connection strength
  - ESR-2018 for connection tension flexibility
  - Aids in prying action analysis
- Detailed calculation output is a road map demonstrating how to do this for any steel profiled panel

Verco ESR-2018

Wall Anchorage & Continuous Tie Design - Summary

20 gage PLB™-36 Grade 50 with 8' - 0" Deck Span

Project: Roof Structure Design Guide
Description:

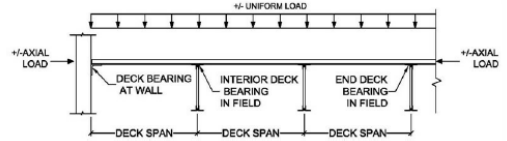
Job No. Roof Structure Design
Engineer: Roof Structure Design

Connections to Support (Ledger/Chord) at WALL	*Connections in FIELD of Diaphragm*
Hilti X-HSN24 PAF	Hilti X-HSN24 PAF
36 / 7 Perpendicular Connection Pattern	36 / 7 / 4 Perpendicular Connection Pattern
0.528 in Steel Deck Minimum End Distance	0.528 in Steel Deck Minimum End Distance
A572 GR50 Support Member or Equivalent	A529 GR50 Support Member or Equivalent
0.313 in ≤ Support Thickness ≤ 0.375 in	0.125 in ≤ Support Thickness ≤ 0.375 in
0.50 in Support Member Minimum Edge Distance	0.50 in Support Member Minimum Edge Distance
3.00 in Steel Deck Bearing on Support at Wall	5.00 in Steel Deck Bearing on Supports in Field of Diaphragm
	2.00 in Steel Deck Sheet End Bearing on Support in the Field
0.01in Connection Prying Action for Seismic at Wall	1.06 in Minimum Steel Deck End Lap Length
0.00 in Connection Prying Action for Wind at Wall	

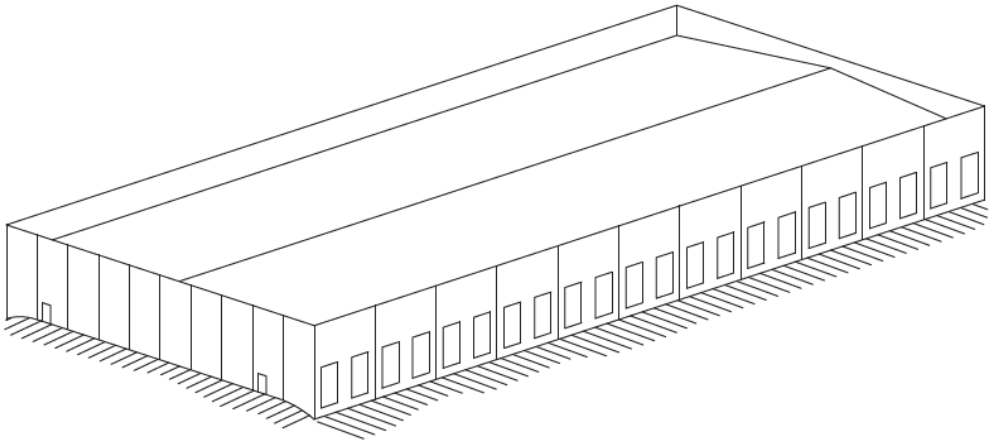
Summary of Calculations in accordance with ASCE 7-16, AISI S100-16, and ER-2018

1-Span	Steel Deck Axial and Bending Check	0.71	≤1.0 Pass		
	Connection Strength Check	0.99	≤1.0 Pass at wall	0.95	≤1.0 Pass in field
	Web Crippling Check	0.07	≤1.0 Pass at wall	0.08	≤1.0 Pass in field
2-Span	Steel Deck Axial and Bending Check	0.60	≤1.0 Pass		
	Connection Strength Check	1.00	≤1.0 Pass at wall	0.97	≤1.0 Pass in field
	Web Crippling Check	0.05	≤1.0 Pass at wall	0.12	≤1.0 Pass in field
3-Span	Steel Deck Axial and Bending Check	0.62	≤1.0 Pass		
	Connection Strength Check	1.00	≤1.0 Pass at wall	0.96	≤1.0 Pass in field
	Web Crippling Check	0.06	≤1.0 Pass at wall	0.10	≤1.0 Pass in field

Vertical Loads		*Horizontal Loads and Factors*	
Dead Load for Inward Wind Combo, D_i (psf)	7.3	Wall Inward Wind Anchorage Load, W_i (plf)	423
Dead Load for Wind Uplift Combo, D_o (psf)	5.3	Wall Outward Wind Anchorage Load, W_o (plf)	342
Live Load, L (psf)	0.0	Notional Load for Wall Anchorage, ±N (plf)	124
Roof Live Load, L_r (psf)	20.0	Seismic Wall Anchorage Load, ±F (plf)	1985
Rain Load, R (psf)	0.0	Seismic Parameter, SDS	1.00
Snow Load, S (psf)	0.0	Seismic Design Category	C, D, E or
Inward Wind, W_i (psf)	0.0	Wall Construction	Concrete or Masonry
Wind Uplift on Steel Deck , W_o (psf)	25.3	Steel Element of Structural Wall Anchorage System Increase (ASCE 7 Section 12.11.2.2.2)	1.4
Wind Uplift for Connections, W_o (psf)	25.3		

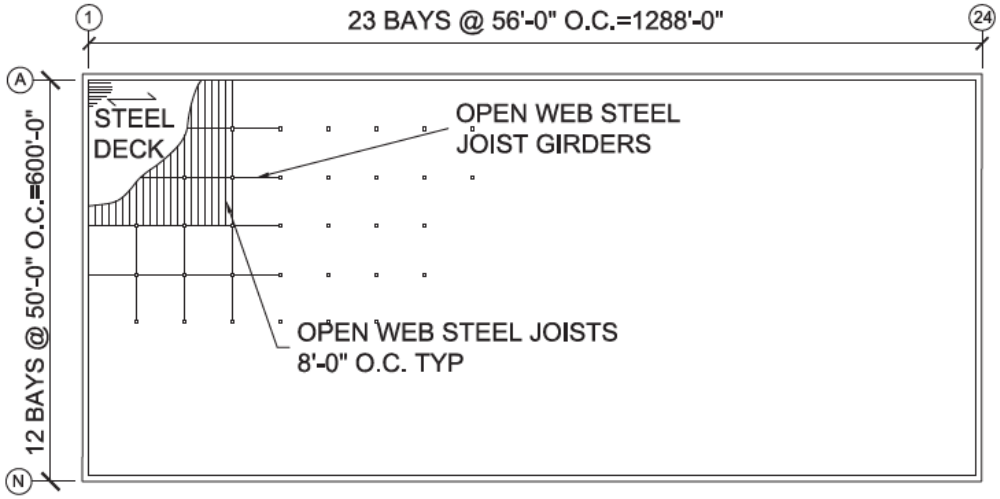


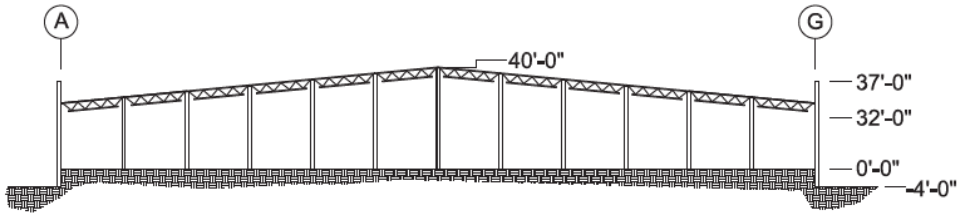
Example: 600 ft x 1288 ft Warehouse



- Ontario, CA
- SDC = D
- SDS = 1.0
- Intermediate Precast Shear Walls
- Steel Joist and Deck Roof Structure

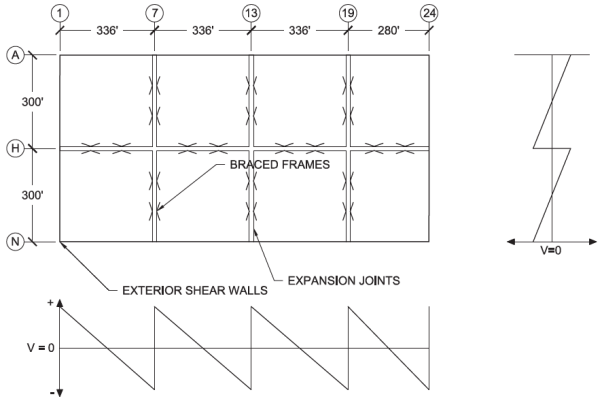
Verco Roof Structure Design Guide

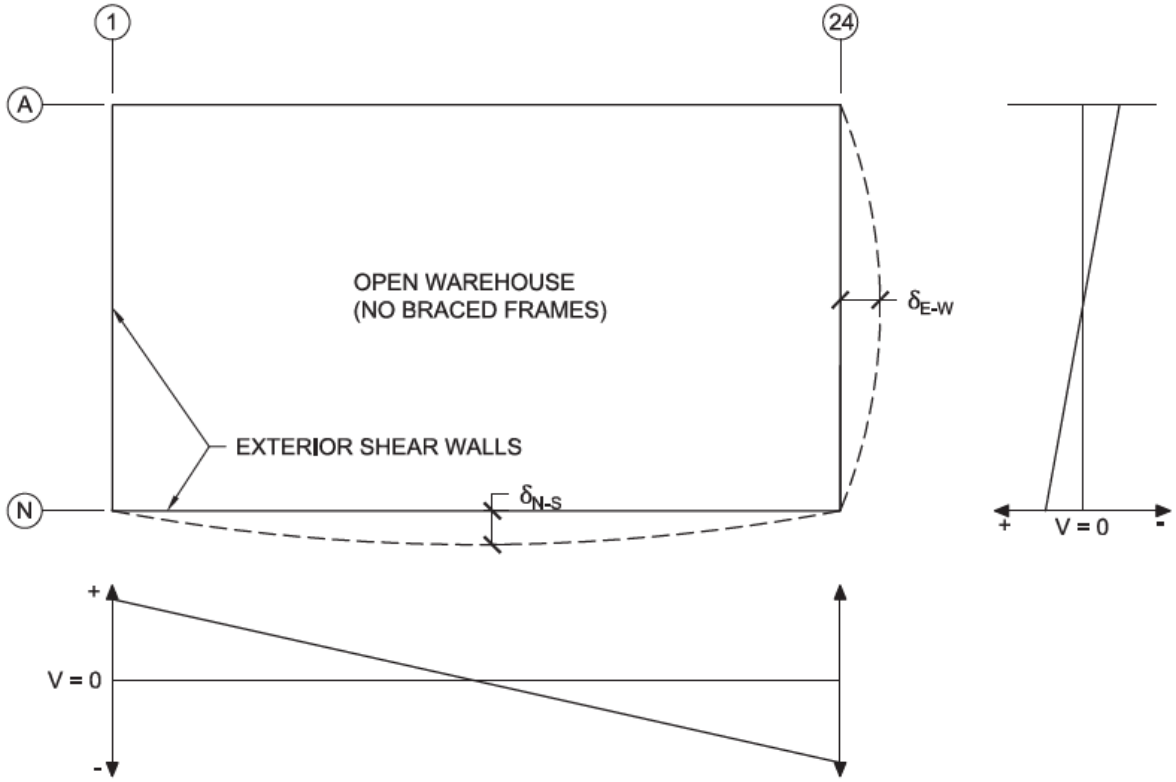




Large Roof Structure without Thermal Expansion Joints

Verco Roof Structure Design Guide





- Traditional, expansion joints every 300 ft to 450 ft
- Ductile PunchLok II system with Hilti PAF may eliminate all expansion joints

Diaphragm Design and Attachment Zones

Verco Roof Structure Design Guide

- Optimize Deck
- Minimize Gage
- Minimize Fasteners to Supports
- Use Maximum Sidelap Spacing

Zone	PLB Gage	Span (ft)	Fastener to Supports			Sidelap connection VSC2 (in o.c.)	Required Shear LRFD (plf)	Design Shear Strength ϕV_n (plf)
			Pattern	Pin	Parallel chords and collectors (in o.c.)			
VI	18	8	36/14/4	X-HSN 24	6	8	3742	3820
V	18	8	36/7/4	X-HSN 24	7	8	3045	3090
IV	20	8	36/7/4	X-HSN 24	7	8	2162	2206
III	22	8	36/7/4	X-HSN 24	8	8	1697	1729
II	22	36/7/4	36/7/4	X-HSN 24	12	18	1139	1168
I	22	36/4	36/4	X-HSN 24	16	24	767	770

Heavier 18 gage deck is required for the high shear

Diaphragm Deflection, and Stability Check

Verco Roof Structure Design Guide

- Large diaphragm, large deflection

Zone	v_{left} (lb/ft)	v_{right} (lb/ft)	$v_{i\ ave}$ (lb/ft)	L_i (ft)	G' (kip/in)	$0.5(v_{i\ ave}L_i)/(1000G')$ (in)
VI	3742	3045	3393	120	279	0.73
V	3045	2162	2603	152	274	0.72
IV	2162	1697	1929	80	191	0.40
III	1697	1139	1418	96	150	0.45
II	1139	767	953	64	117	0.26
I	767	0	383	132	96	0.26
I	0	767	383	132	96	0.26
II	767	1139	953	64	117	0.26
III	1139	1697	1418	96	150	0.45
IV	1697	2162	1929	80	191	0.40
V	2162	3045	2603	152	274	0.72
VI	3045	3742	3393	120	279	0.73
Total Elastic Strength Level Shear Deflection, δ_v						5.67

- Stability Check

$$\theta = \frac{P_x \Delta I_e}{V_x h_{sx} C_d} \leq 0.10$$

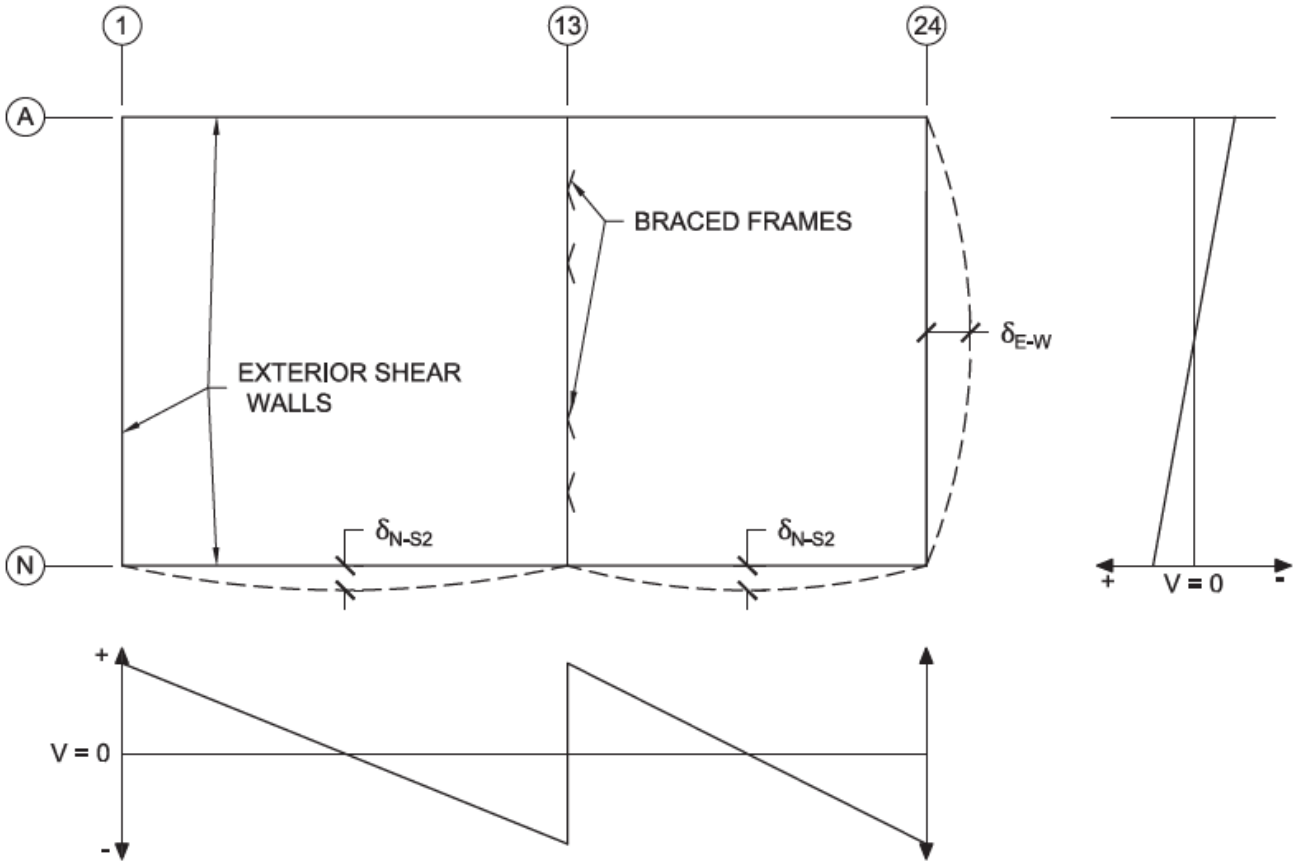
$$\theta = \frac{17867kip \cdot 15.1in \cdot 1.0}{4492kip \cdot 384in \cdot 4.0} = 0.04 \leq 0.10$$

Acceptable

To Big for Comfort?

Verco Roof Structure Design Guide

- Add an interior braced frame without an expansion joint
- Keep in mind a braced frame line is a costly add
- Partially offset by a small savings in 18 ga deck



Mega Unlimited Length Steel Deck Roof Structures



E. Central Ave., Fresno, CA
670,000 sf
1250 ft x 590 ft

S. Harlan Rd., Lathrop, CA
518,000 sf
1248 ft x 430 ft



Objectives

- ✓Let's agree on the Definition of Diaphragm
- ✓Structural Concrete filled Steel Deck Diaphragm Shear Strength & Shear Stiffness
- ✓Bare (Roof) Steek Deck Diaphragm Shear Strength and Shear Stiffness
- ✓Industrial Warehouse Roof Diaphragm Considerations
- Closing

Closing Comments

Your thoughts?....