SDI Webinar

Diaphragm Design with Steel Deck

Presented By:

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Basis of Presentation

Referred to as "DDM04" in Presentation

DIAPHRAGM DESIGN MANUAL

FOURTH EDITION

MAY 2015

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Available for Purchase at www.sdi.org

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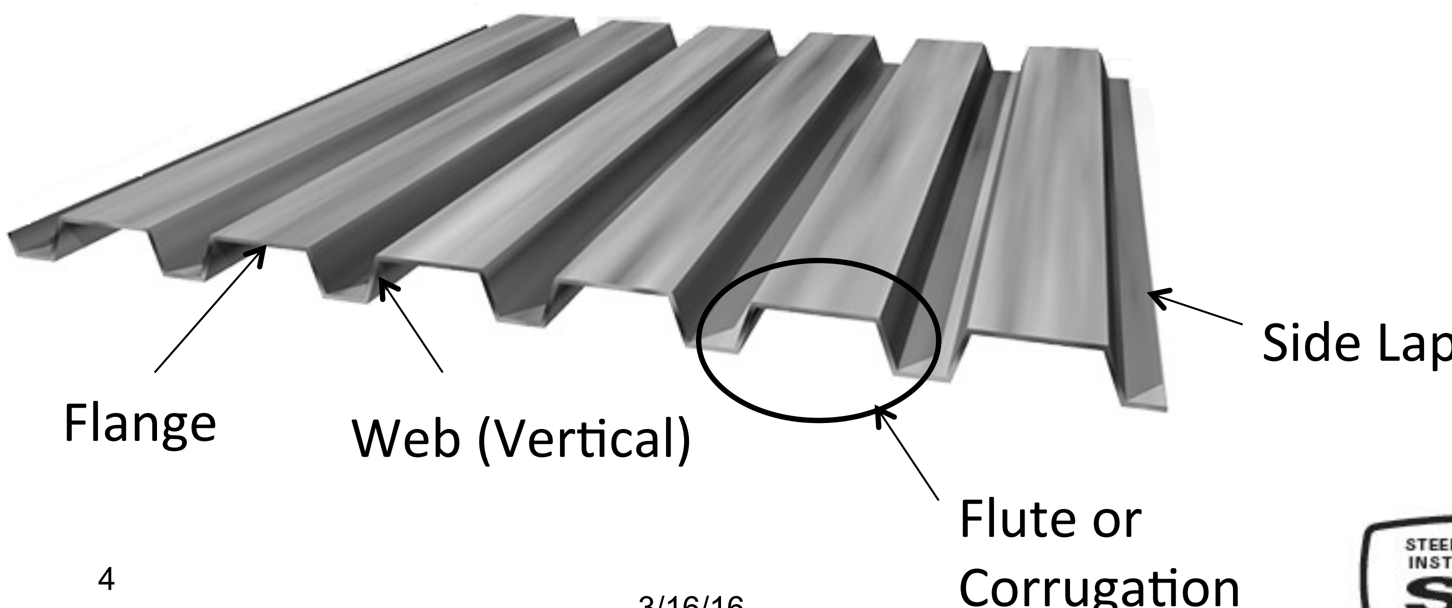
What is Steel Deck??

- Profiled Steel Sections Varying By Application
- Structural Building Component
- Shapes Use Geometry to Maximize Strength to Weight Efficiency



Manufactured via Roll Forming

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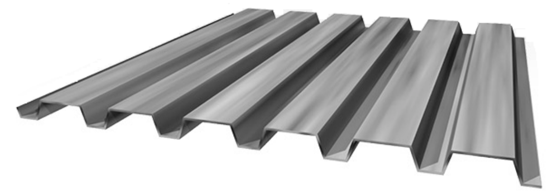
Types of Steel Deck



Roof Deck

- Structural Component Supporting Built Up Roof
- Not Used With Concrete

Composite Deck

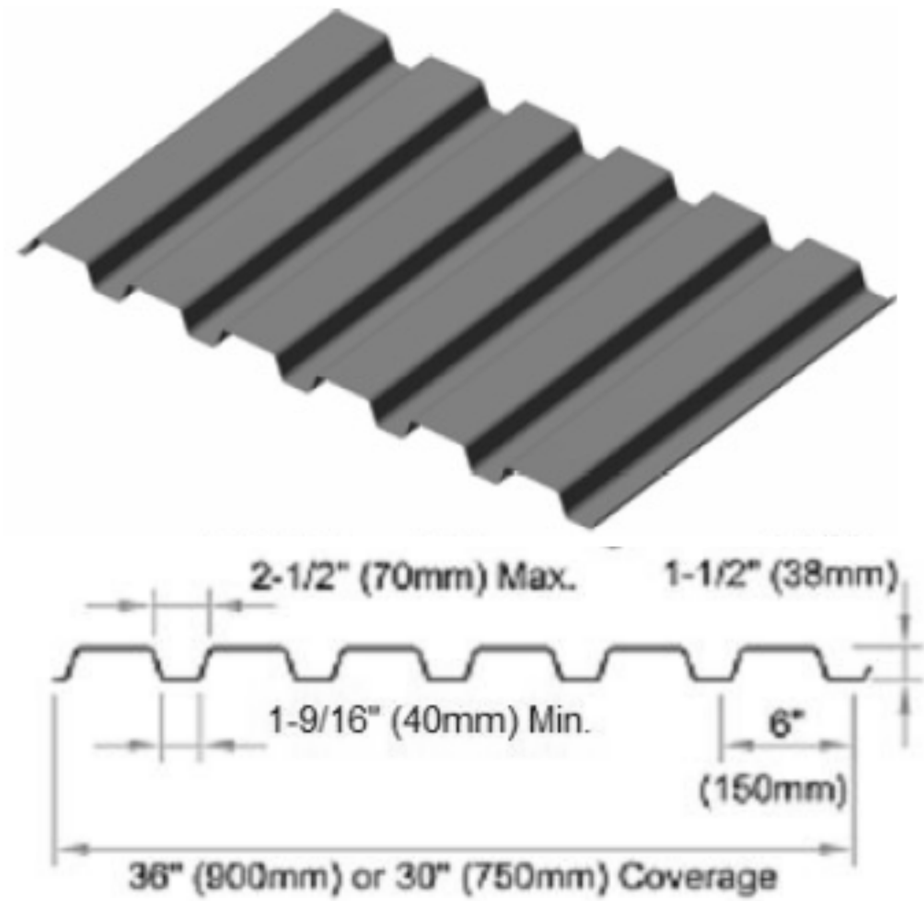
- *Working Platform + Stay In Place Form for Concrete*
- *Bonds with Concrete to Serve as Positive Reinforcement for Slab*

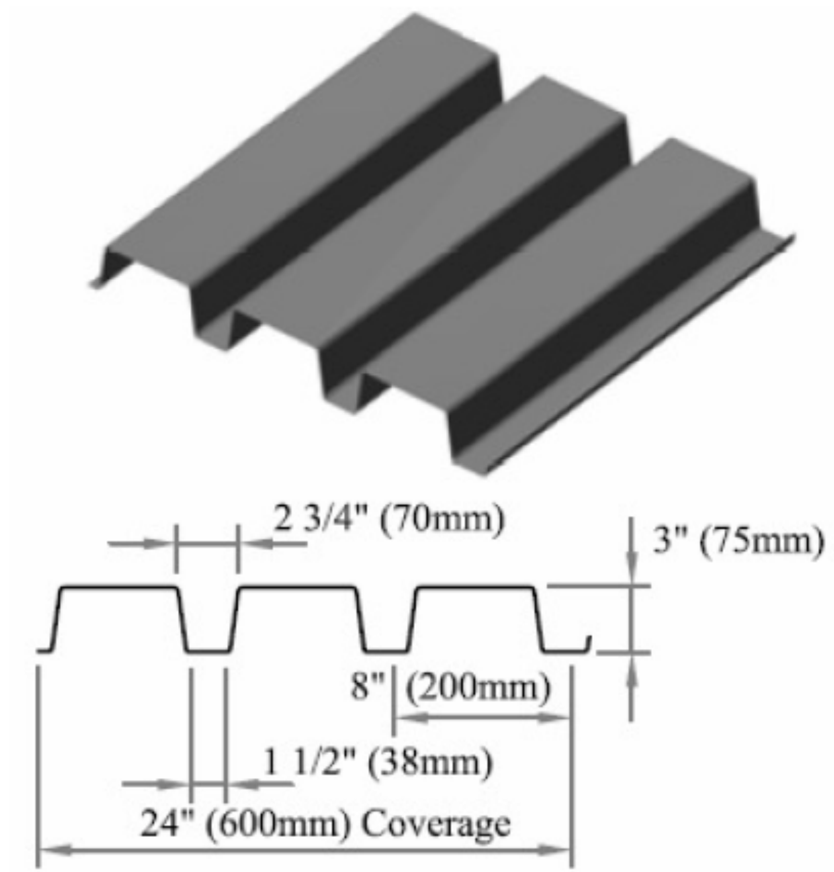
Non-Composite (Form) Deck

- *Working Platform + Stay In Place Form for Concrete*
- *Other Means of Slab Reinforcement Required*

Most Common Roof Decks

1 ½” and 3” Options



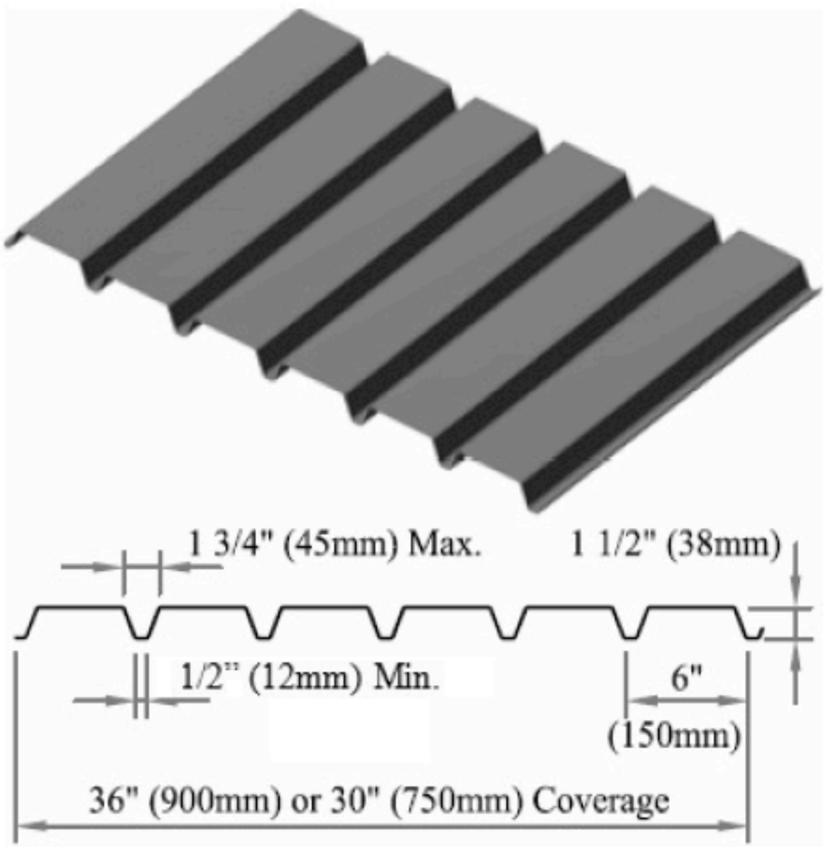


B Deck
[Wide Rib (WR) Deck]

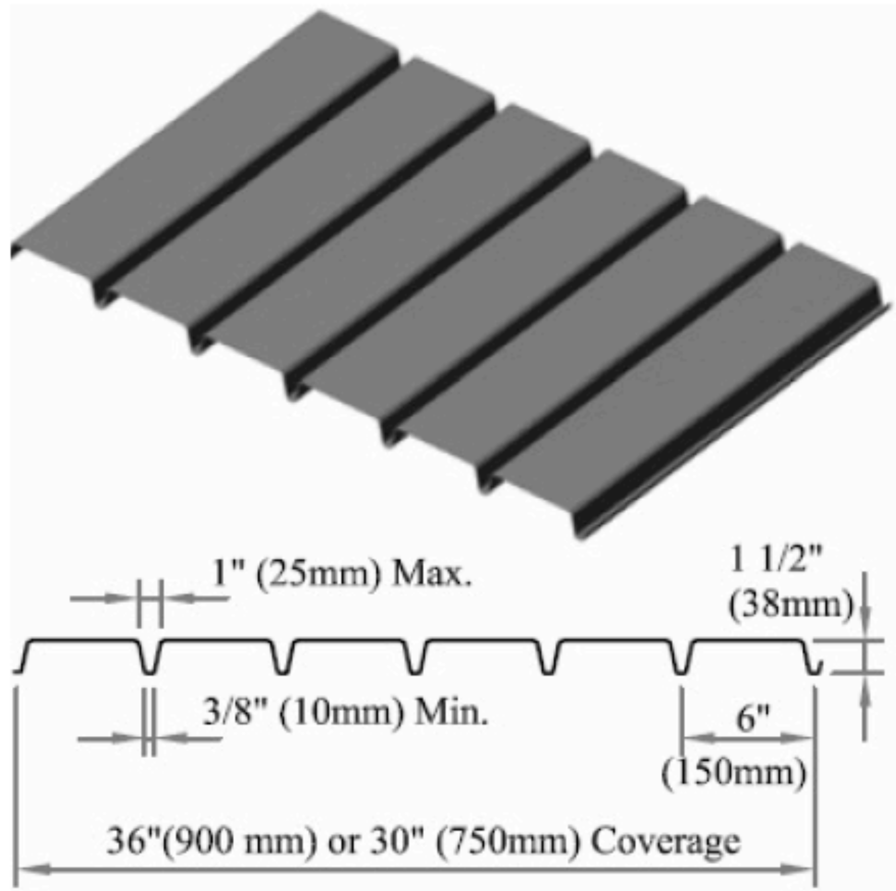
N Deck
[Deep Rib (DR) Deck]

Other Options for 1 ½" Deck

Narrower Low Ribs for Thin Insulation Scenarios



F Deck
[Intermediate Rib (IR) Deck]



A Deck
[Narrow Rib (NR) Deck]

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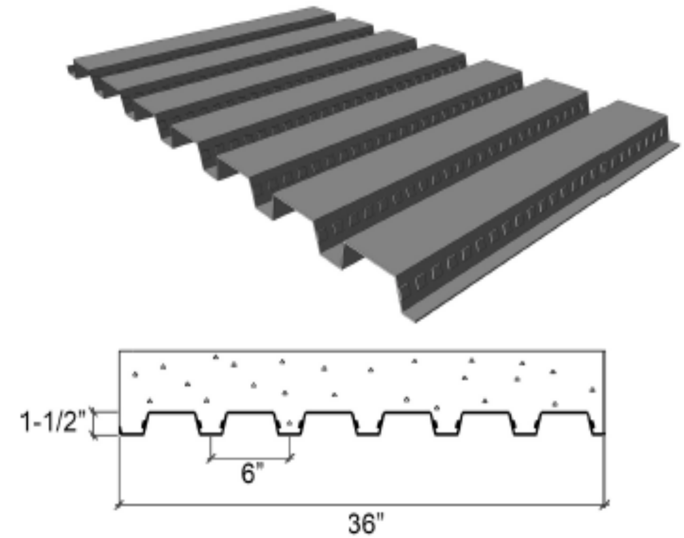
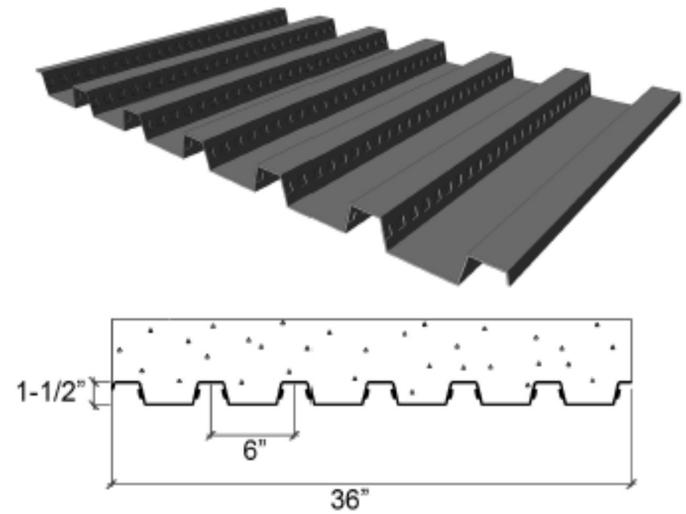
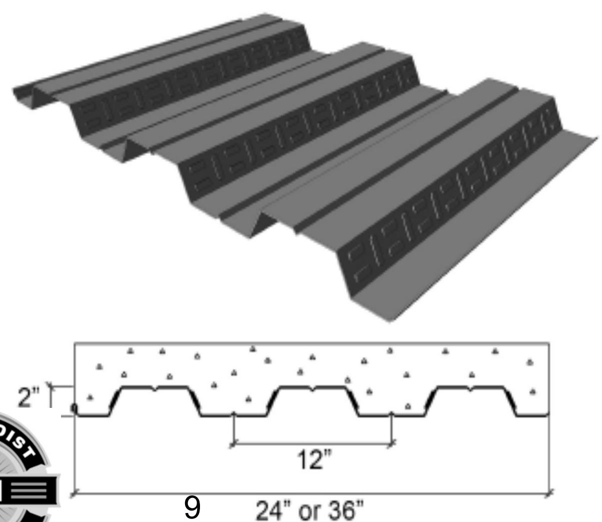
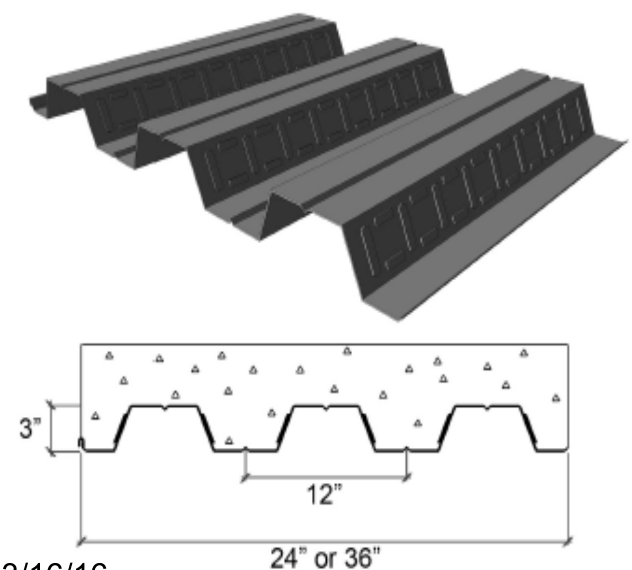
Most Common Composite Decks

1 ½", 2" and 3" Options



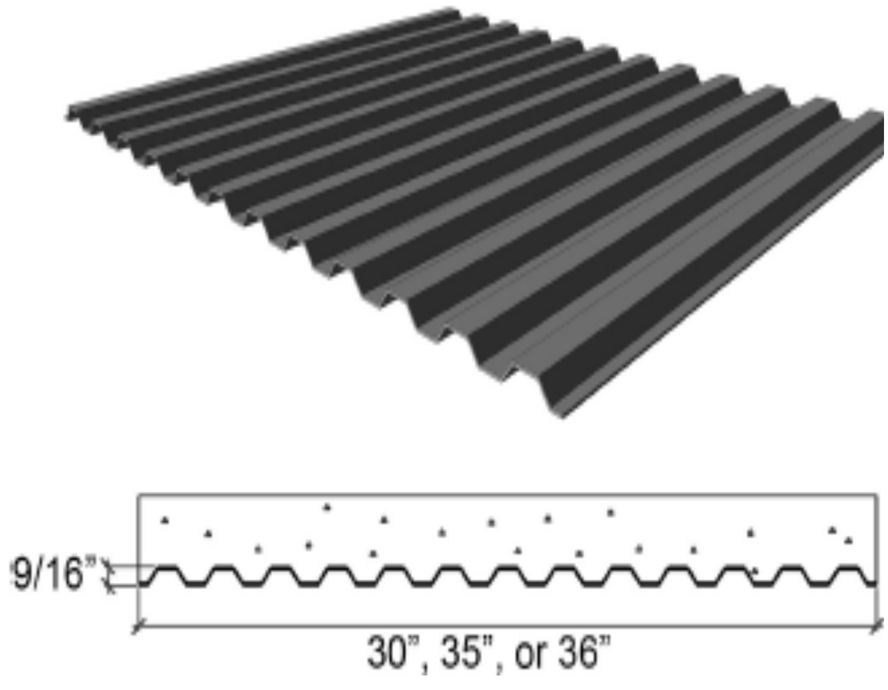


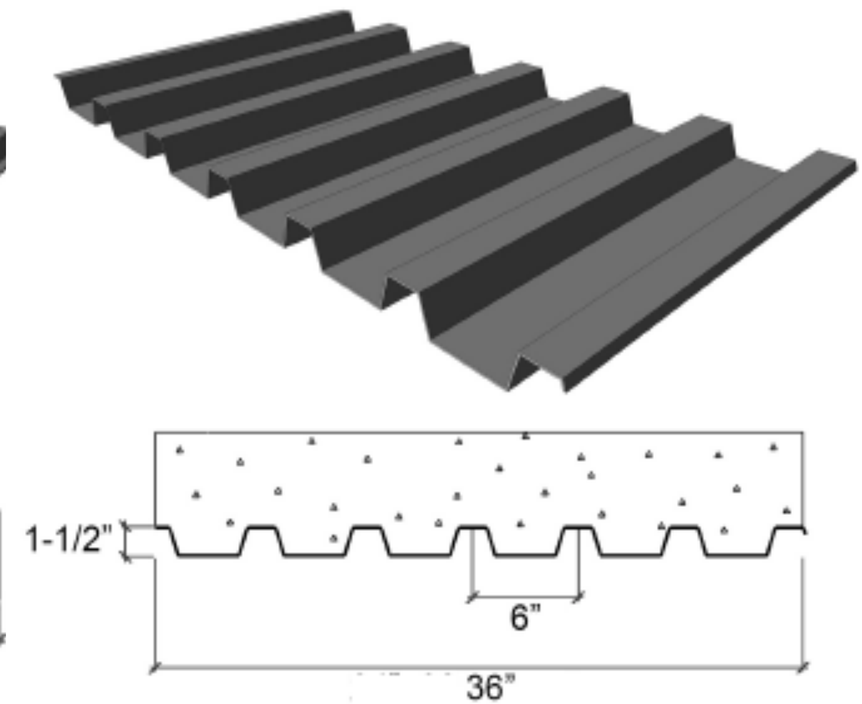




Most Common Form Decks

9/16" and 1 ½" Options





9/16" Non-Composite Deck

1 ½" Inverted Non-Composite Deck

Steel Properties

AISI S100 Sections A2.1 and A2.2

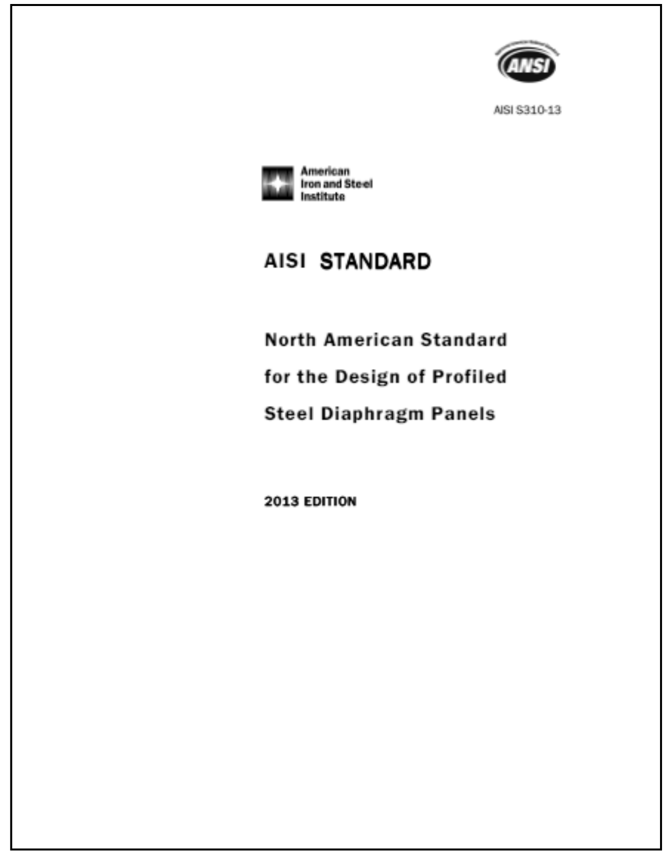
ASTM A1008 – Cold Rolled Steel

ASTM A653 – Galvanized Steel (ASTM A924 – Zinc Coating)

Deck Type	Typical Gages	F_y min	F_u min
Roof	22 - 16	33 ksi	45 ksi
Composite	22 - 16	40 ksi	52 ksi
Form	26 - 20	60 ksi	62 ksi
Form	22 - 16	33 ksi	45 ksi

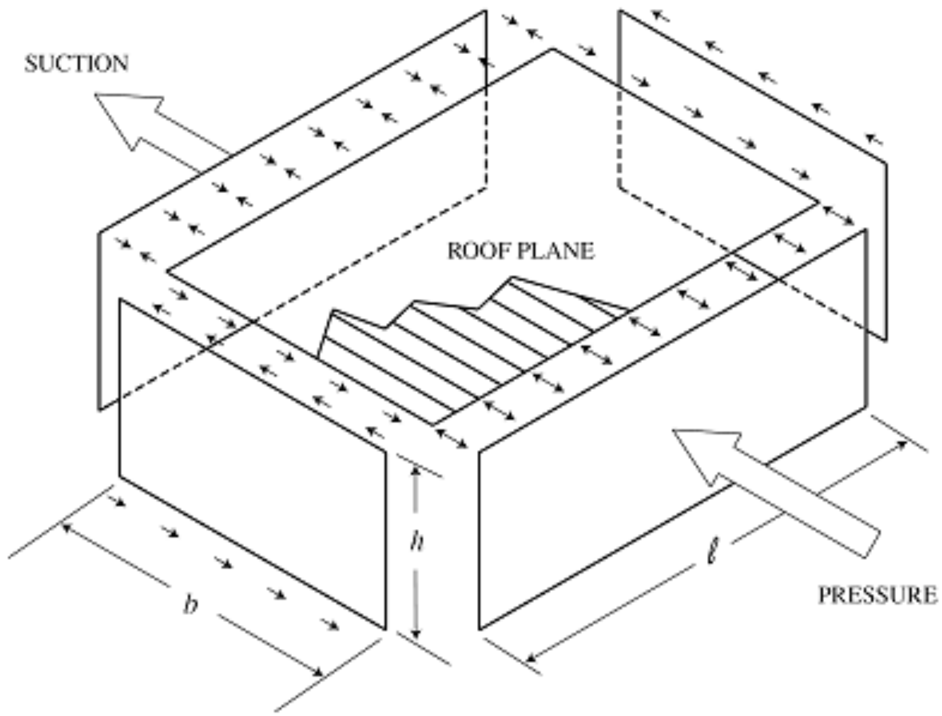
Other Steel Strengths Available

Design References



What is a Shear Diaphragm?

Building Components Work Together to Resist Horizontal Force



Example Shows Force Applied to Long Wall and Roof Acting as a Diaphragm

What is a Shear Diaphragm?

Roof Deck Acts as a Short Deep Beam

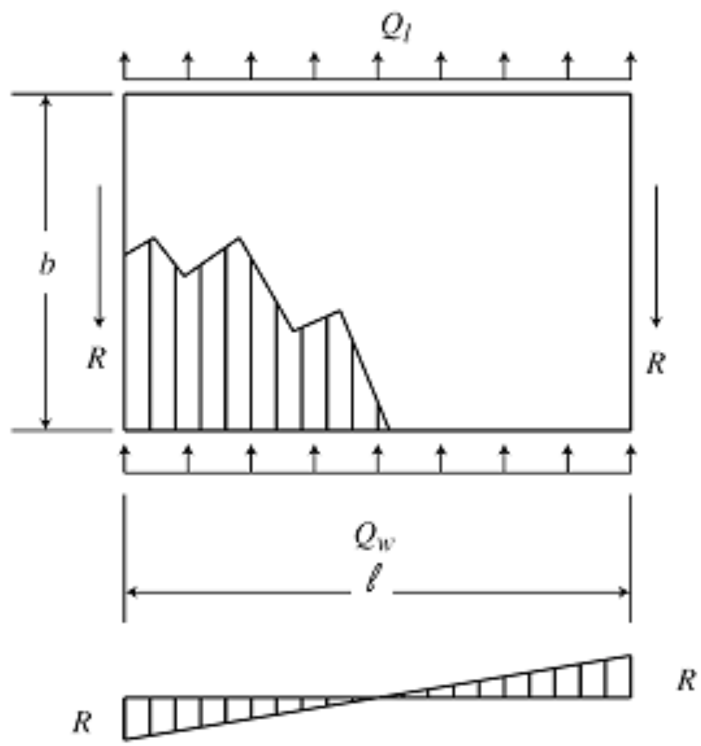
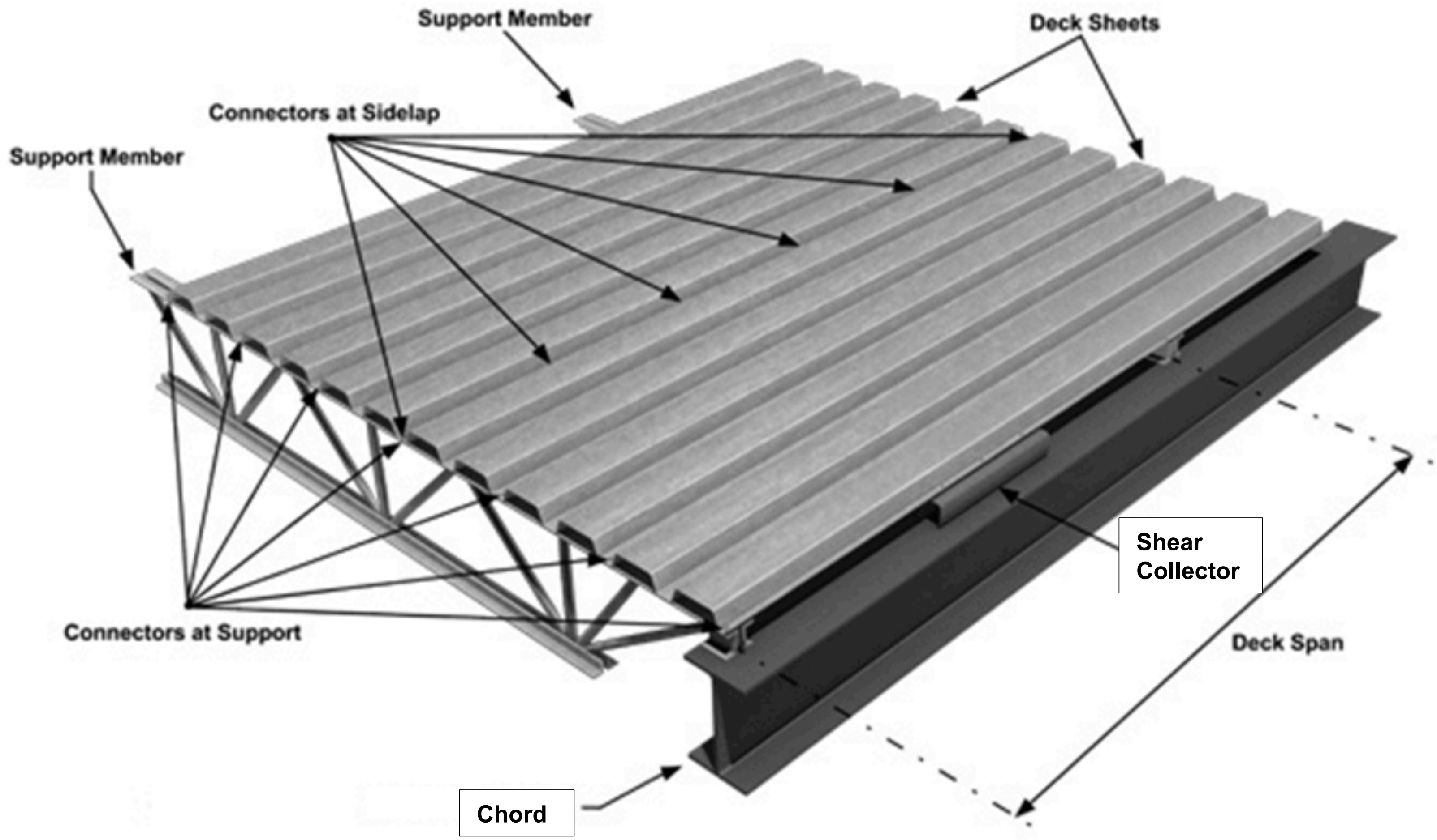


Figure 1.2 – Roof Diaphragm

- Maximum Shear (S = R/b) at Ends
- Shear Varies Across Building – See Shear Diagram

A Closer Look at Roof Deck Diaphragm



Floor Deck Diaphragm

Before Concrete Placement…

Bare Deck Can Be Used to
Resist Horizontal Forces
During Construction

After Slab is Cured…

Concrete Does the Majority of the
Work in Resisting Much Higher
Forces than Deck Alone

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Diaphragm Table from DDM04

1.5(WR, IR, NR)20
Design thickness = 0.0358 in.
Support fastening: 5/8 in. arc spot welds or equivalent
Side-lap fastening: #10 screws

F_u= 45 ksi
F_y= 33 ksi
F_{xx}= 60 ksi

Loading	ϕ_{df}	Ω_{df}
Seismic	0.55	3.00
Wind	0.70	2.35
Other	0.60	2.65

No Change

Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 4	4.5	5	5.5	6	6.5	7	7.5	8	K_1 1/ft
36/9	0	1670	1485	1330							0.357
	1	1785	1605	1440	1300	1185					0.299
	2	1895	1710	1550	1400	1275	1170	1080	1005	935	0.258
	3	2000	1810	1650	1505	1370	1260	1160	1075	1005	0.226
	4	2105	1910	1745	1600	1465	1345	1240	1150	1075	0.202
	5	2205	2005	1835	1685	1555	1430	1320	1225	1145	0.182
	6	2300	2095	1920	1770	1640	1515	1400	1300	1215	0.166
36/7	0	1035	915	820							0.535
	1	1170	1040	930	840	765					0.415
	2	1290	1160	1040	940	860	790	730	680	630	0.340
	3	1410	1270	1150	1045	950	875	810	750	700	0.287
	4	1525	1375	1250	1145	1045	960	890	825	770	0.249
	5	1635	1475	1345	1235	1140	1045	970	900	840	0.219
	6	1740	1575	1440	1320	1220	1135	1050	975	910	0.196
36/4	0	725	640	570							0.802
	1	835	755	680	615	560					0.561
	2	935	850	780	715	655	600	555	515	480	0.431
	3	1035	940	865	800	740	685	635	585	550	0.350
	4	1120	1025	945	875	815	760	710	660	615	0.294
	5	1200	1105	1025	950	885	830	775	730	685	0.254
	6	1275	1180	1095	1020	950	895	840	790	750	0.224

Nominal

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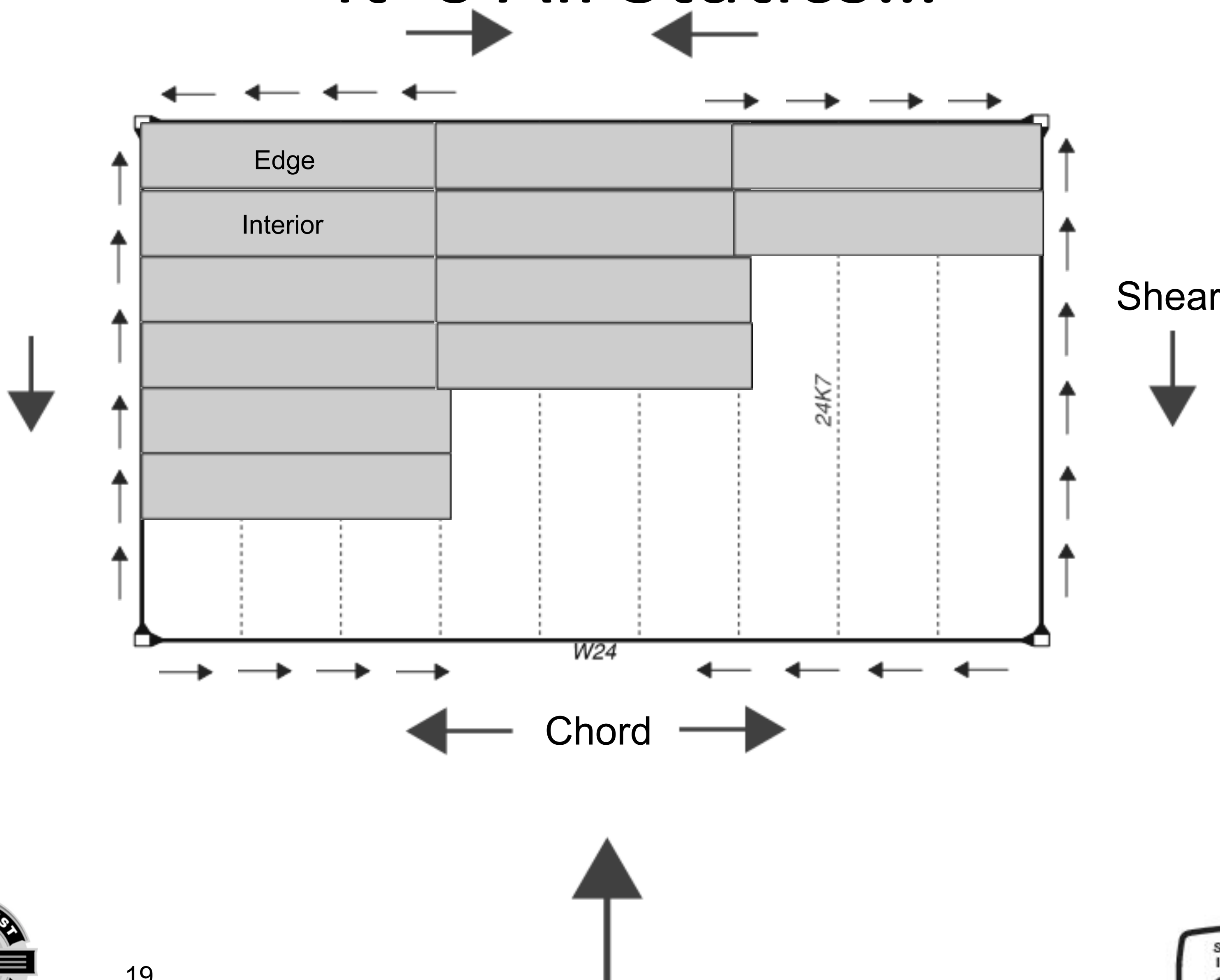
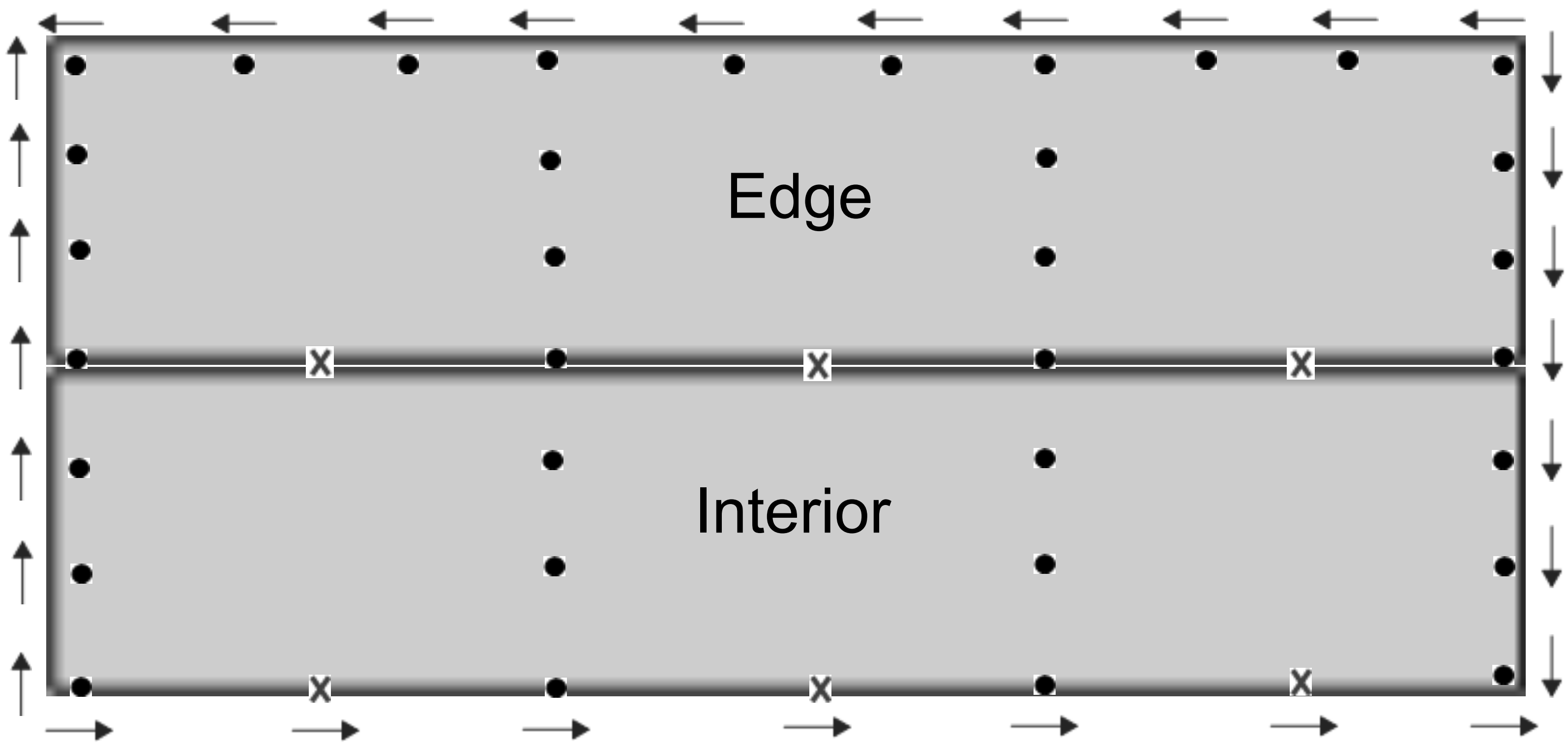
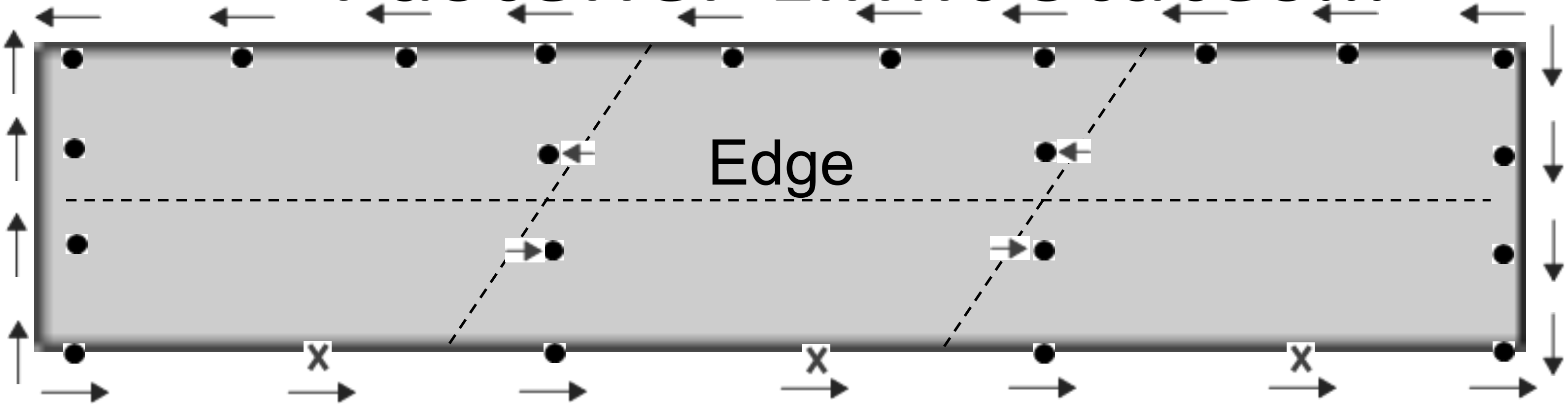
It’s All Statics...

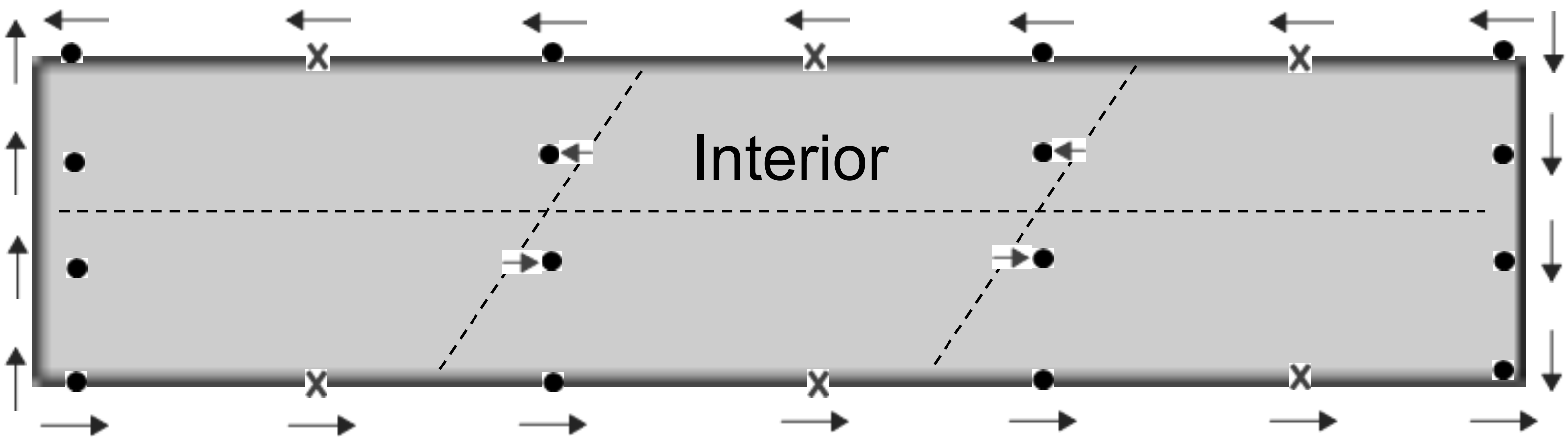


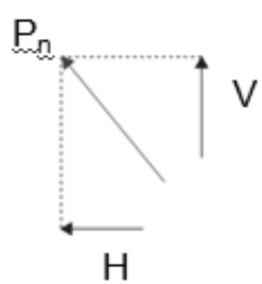
It's All Statics…



Fastener Limit States…

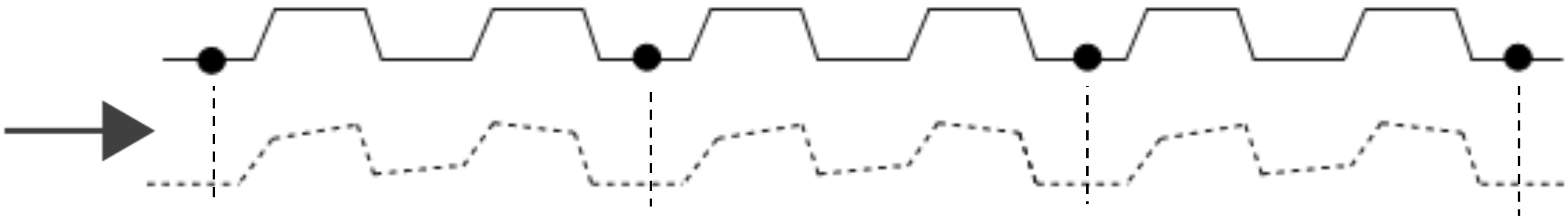






S_{ne} = Sum of Horizontal Forces
S_{ni} = Sum of Moments
S_{nc} = Corner Fastener

Deck Limit State



S_{nb} - Will shear buckling ever control??

Back to the Table…

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36/4	0	725	640	570
	1	835	755	680
	2	935	850	775
	3	1030	940	865
	4	1115	1025	945
	5	1195	1100	1020
	6	1270	1175	1090

S_{ne} = Edge Shear = 1160 plf

S_{ni} = Interior Shear = 680 plf

S_{nc} = Corner Shear = 689 plf

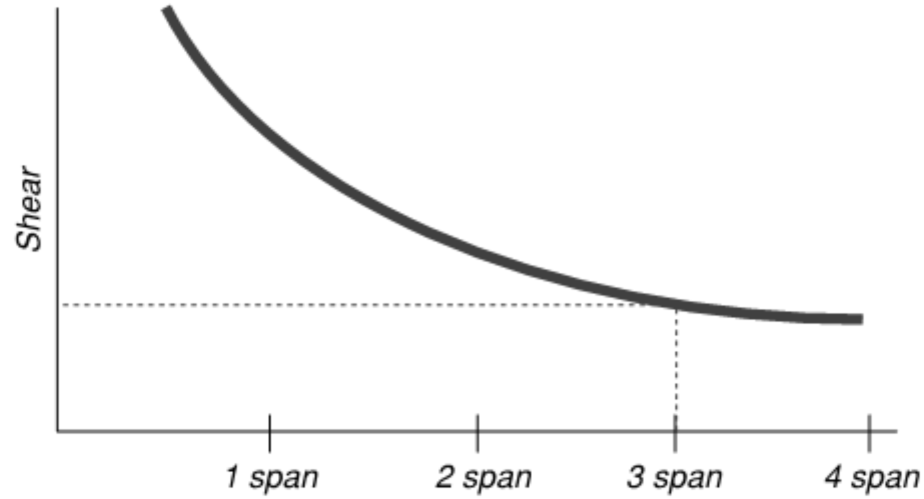
S_{nb} = Buckling Shear = 7465 plf

Deck Profile	I in^4/ft	Nominal Shear Due to Panel Buckling, S_{nb}, plf[2]								
		Span, ft								
		4	4.5	5	5.5	6	6.5	7	7.5	8
NR	0.138	8467	6690	5419	4478	3763	3206	2765	2408	2117
IR	0.151	9177	7251	5873	4854	4079	3475	2997	2610	2294
WR	0.210	11665	9216	7465	6170	5184	4417	3809	3318	2916

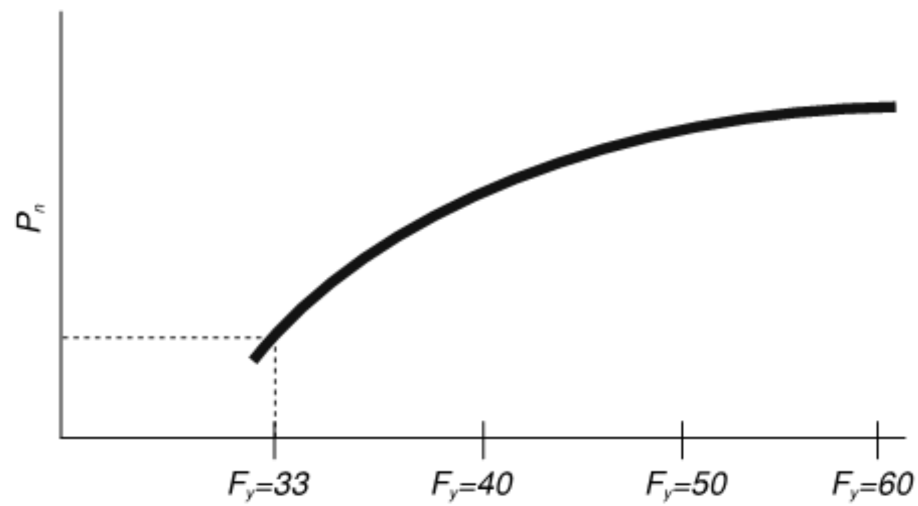
Understanding how shear limit states and how shear tables are developed results in more efficient design, faster erection, and the confidence to address alternates and field concerns.

DDM04 Tables Have Fixed Parameters…

3 Span Sheets



Minimum Yield Strengths



Effect of Varying Parameters

36/4	0	725	640	570
	1	835	755	680
	2	935	850	775
	3	1030	940	865
	4	1115	1025	945
	5	1195	1100	1020
	6	1270	1175	1090

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S_{ne} = Edge Shear = 1160 plf

S_{ni} = Interior Shear = 680 plf

S_{nc} = Corner Shear = 689 plf

S_{nb} = Buckling Shear = 7492 plf

	S_{ne}	S_{ni}	S_{nc}	S_{nb}
3 span, F_y=33 ksi, 20 gage	1160	680	689	7492
3 span, F_y=50 ksi, 20 gage	1676	989	996	7492
2 span, F_y=50 ksi, 22 gage	1314	772	793	5476
2 span, F_y=60 ksi, 22 gage	1371	810	831	5476

Ω and ϕ Factors

No Change from DDM03 to DDM04!!!

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Table 2.4 Resistance and Safety Factors

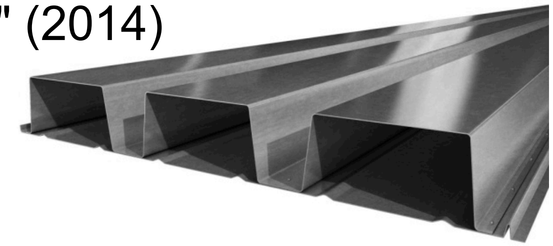
Load Type or Combination Including	Connection Type	Limit State					
		Connection Related			Panel Buckling		
		Ω_d (ASD)	Φ_d (LRFD)	Φ_d (LSD)	Ω_d (ASD)	Φ_d (LRFD)	Φ_d (LSD)
Earthquake	Welds	3.00	0.55	0.50	2.00	0.80	0.75
	Screws	2.50	0.65	0.60			
Wind	Welds	2.35	0.70	0.65			
	Screws	2.35	0.70	0.65			
All Others	Welds	2.65	0.60	0.55			
	Screws	2.50	0.65	0.60			

Note: Resistance factors for Limit State Design (LSD) are applicable to Canada and are included for completeness. LSD is not otherwise covered in this Manual.

Additional Applications Referenced

Diaphragm with Skewed Walls

SDI White Paper "Diaphragm Analysis with Skew Walls" (2014)

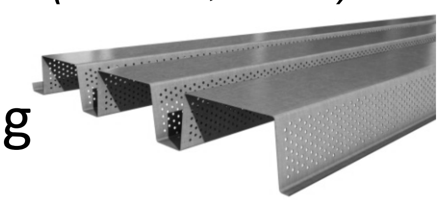


Deep Deck and Cellular Diaphragms

SDI White Paper, "Deeper Steel Deck and Cellular Diaphragms" (Luttrell, 2005)

Perforated Deck Diaphragms

SDI White Paper, " Perforated Metal Deck Diaphragm Design" (Luttrell, 2011)



Steel Deck Diaphragms on Cold-Formed Steel Framing

Follow Principles in AISI S310, Examples on AISI Website

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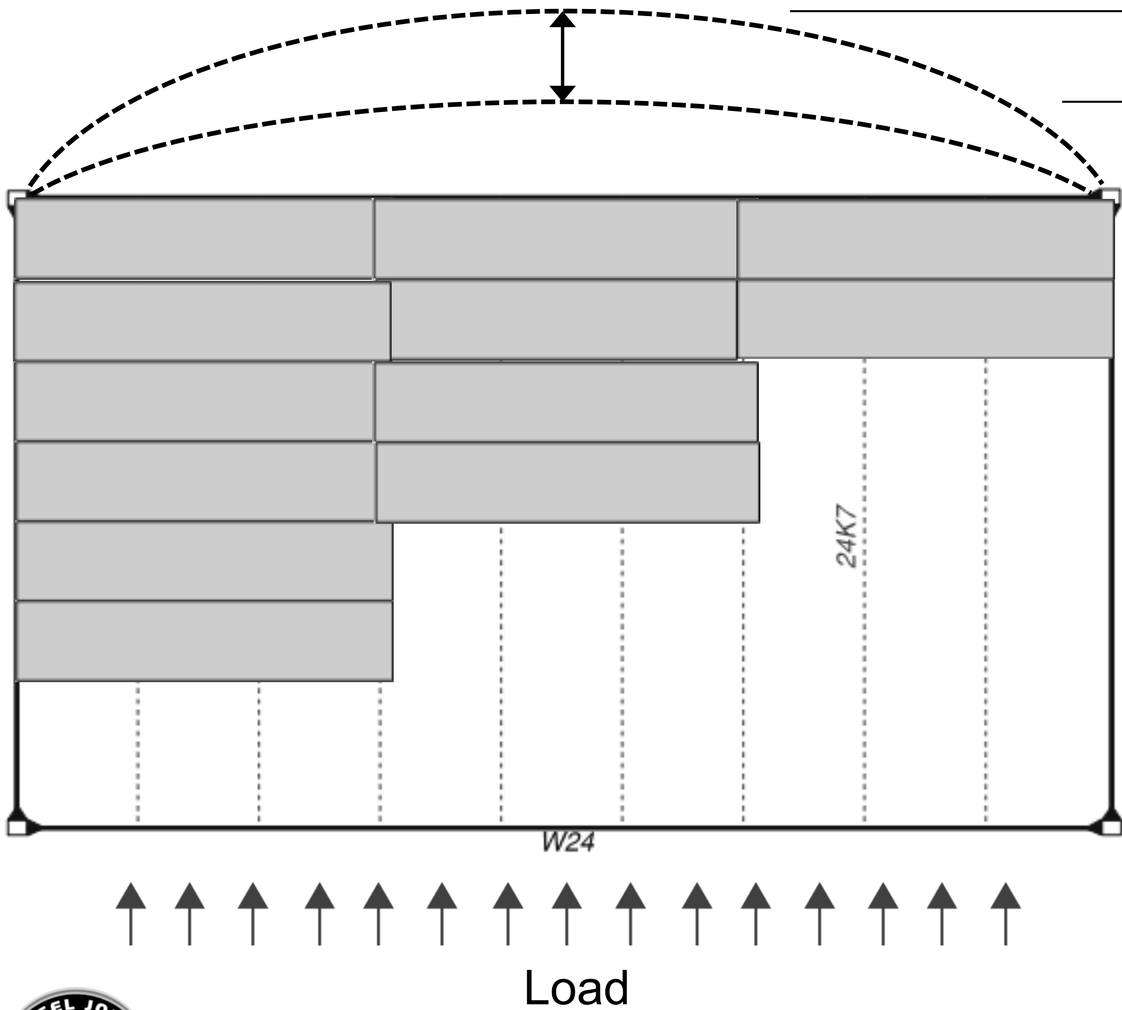
Stiffness ? *Deflection ?*



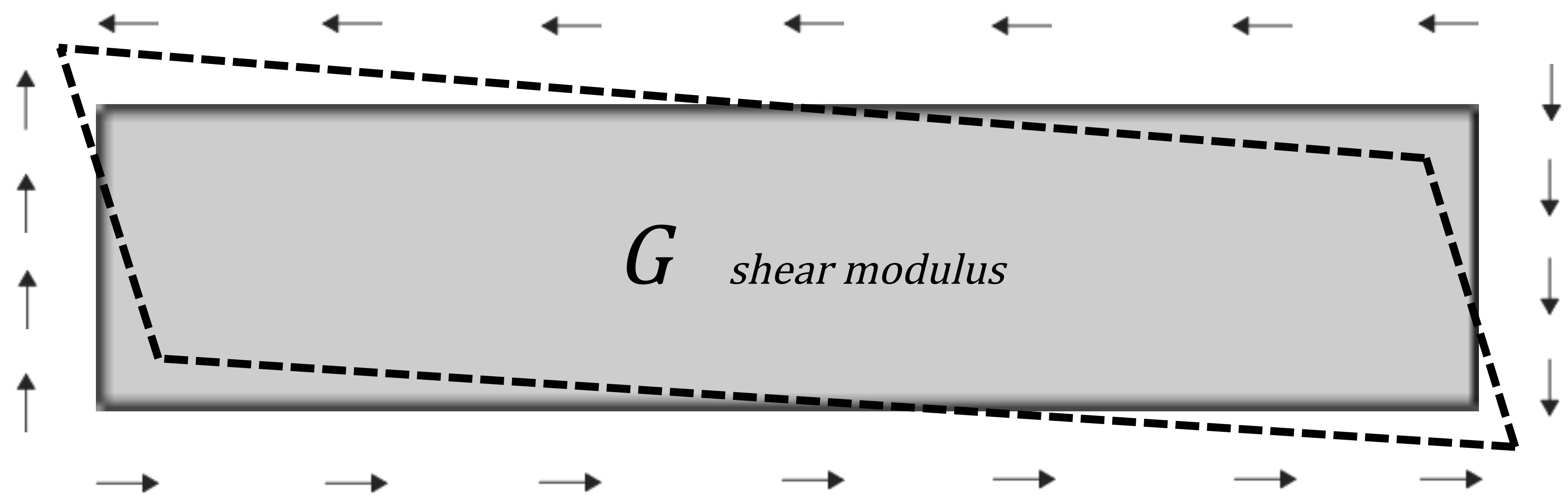
$\mathbf{D}_s = wL^2/8bG'$

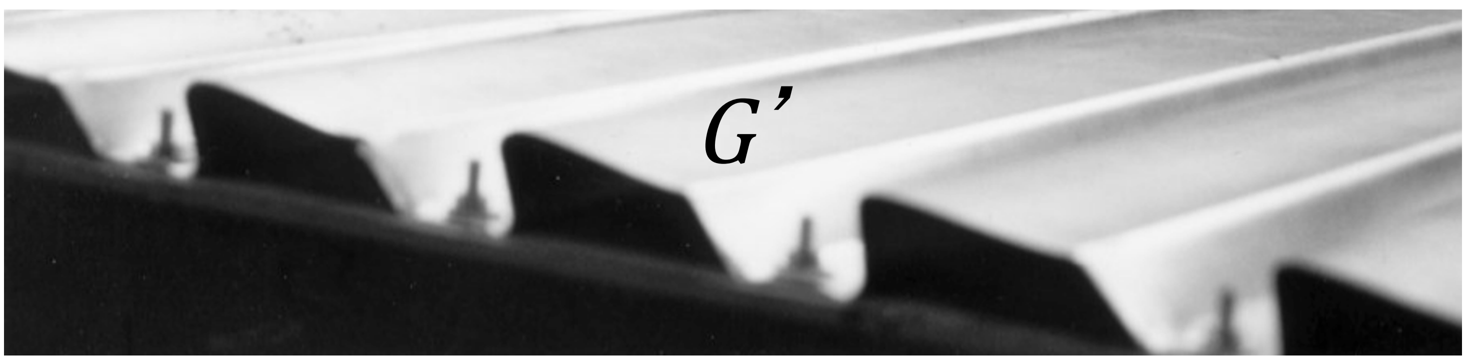
$\mathbf{D}_b = 5wL^4/384EI$

$\mathbf{D}_t = \mathbf{D}_b + \mathbf{D}_s$

Shear deformation, $\mathbf{D}_s$, depends on a modified shear modulus, G'

Stiffness ? *Deflection ?*





Stiffness ? *Deflection ?*

$$G'_{S310} = \left(\frac{E\,t}{2[1+\mu]\frac{s}{d} + \gamma_c D_n + \frac{E\,t\,S_f}{w}\left[\frac{2\,L}{2\alpha_3 + n_p\alpha_4 + 2n_s\frac{S_f}{S_s}}\right]} \right) \mathrm{K}$$

Does this look overly complicated? Yes, until we recognize for any given deck, the shape, fastener pattern, modulus of elasticity and Poisson's ratio are fixed. The only variables are :

Panel length, L

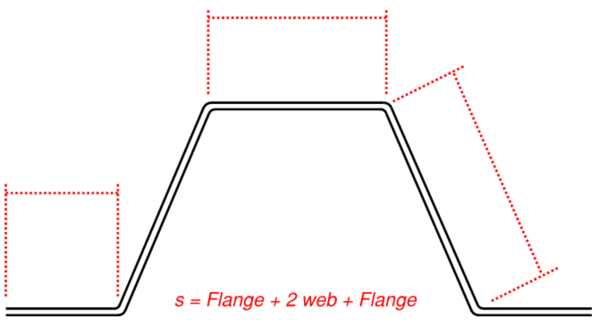
Panel thickness, t

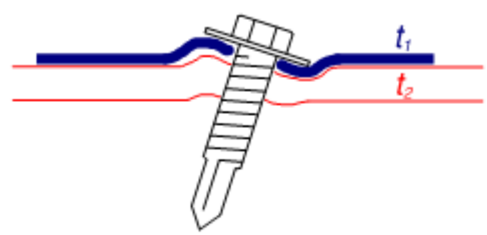
Fastener stiffness, S_f S_s

Stiffness ? *Deflection ?*

$$G'_{DDM03} = \left(\frac{K_2}{K_4 + \frac{0.3\, D_{xx}}{L_v} + 3\, K_1\, L_v} \right)$$

$$G'_{DDM04} = \left(\frac{K_2}{K_4 + \frac{0.3\, D_{xx}}{L_v} + 3\, K_1\, L_v} \right)$$





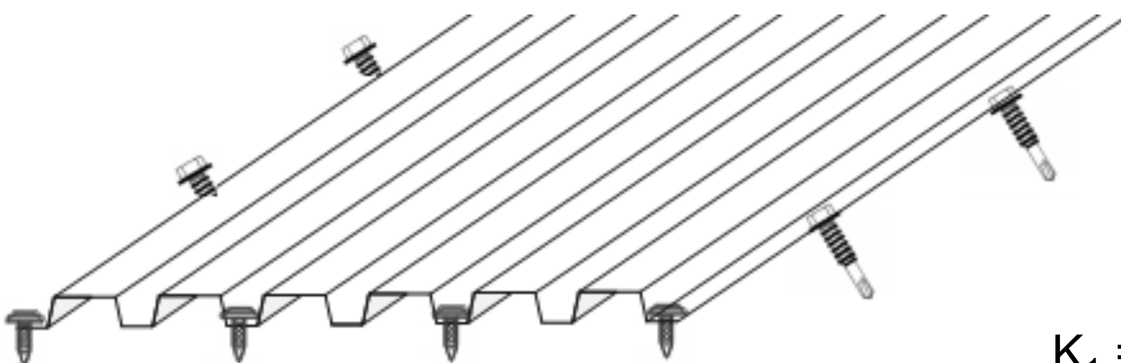
K_4, D_{xx}, K_1 revised in DDM04

1.5(WR, IR, NR)20
Design thickness = 0.0358 in.
Support fastening: 5/8 in. arc spot welds or equivalent
Side-lap fastening: #10 screws

F_u= 45 ksi
F_y= 33 ksi
F_{xx}= 60 ksi

Loading	ϕ_{df}	Ω_{df}
Seismic	0.55	3.00
Wind	0.70	2.35
Other	0.60	2.65

Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 4	4.5	5	5.5	6	6.5	7	7.5	8	K_1 1/ft
36/4	0	725	640	570							0.802
	1	835	755	680	615	560					0.561
	2	935	850	780	715	655	600	555	515	480	0.431
	3	1035	940	865	800	740	685	635	585	550	0.350
	4	1120	1025	945	875	815	760	710	660	615	0.294
	5	1200	1105	1025	950	885	830	775	730	685	0.254
	6	1275	1180	1095	1020	950	895	840	790	750	0.224



$K_1 = f$ (fasteners) = 0.561

Table 9-1 Value of K_2

Gage	Thickness		K_2	
	in.	mm.	kip/in.	kN/mm
26	0.0179	0.45	528	91
24	0.0239	0.60	705	122
22	0.0295	0.75	870	152
20	0.0358	0.91	1056	185
18	0.0474	1.20	1398	244
16	0.0598	1.52	1764	309

Table 9-3 Value of K_4

Deck Profile	K_4
1.5 NR roof deck	3.62
1.5 IR roof deck	3.45
1.5 WR roof deck	3.55
3 DR roof deck	4.18
9/16" x 2.5" form deck	3.20
1.5" x 6" composite deck	3.55
2" x 12" composite deck	3.14
3" x 12" composite deck	3.54

$K_2 = Et = 1056$

$K_4 = f\,(\text{shape}) = 3.55$

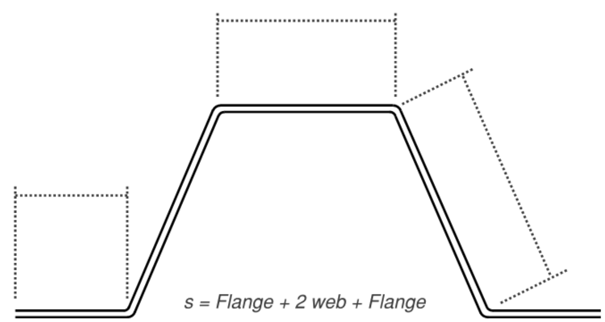


Table 9-6 Deck Warping Factors

Deck Type	Deck Profile	Fastener Pattern	α	Σ(x/w)²	N 1/ft	s/d	A	Warping Constant, D_{xx}, ft					
Typical Fastener Patterns								D26	D24	D22	D20	D18	D16
1.5" Roof Deck	WR	36/9	3.000	1.278	2.333	1.365	2	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/7	2.000	0.778	2.000	1.365	1	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/5	1.667	0.722	1.333	1.365	1	--	--	607	454	298	210
	IR					1.325				637	477	313	221
	NR					1.393				857	641	421	297
	WR	36/4	1.333	0.556	1.000	1.365	1	--	--	860	643	422	298
	IR					1.325				863	645	424	299
	NR					1.393				1126	842	553	390
	WR	30/6	1.800	0.700	2.000	1.365	1	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	30/4	1.600	0.680	1.200	1.365	1	--	--	1102	824	541	382
	IR					1.325				1090	815	535	377
	NR					1.393				1410	1054	692	488

$D_{20} = 643$

Stiffness ? *Deflection ?*

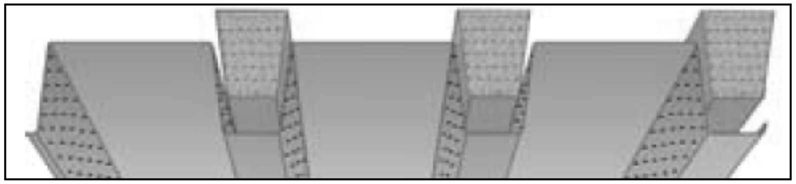
$$G'_{DDM04} = \left(\frac{K_2}{K_4 + \frac{0.3\, D_{xx}}{L_v} + 3\, K_1\, L_v} \right)$$

$$G' = \left(\frac{1056}{3.55 + \frac{0.3\,(643)}{5\, ft} + 3(0.561)\, 5ft} \right)$$

$$G' = 20.89\ kips/in$$

$$F = \frac{1000}{G'} = 48\ in/lbf$$

$G' < 14.3$	*Flexible*
$14.3 < G' < 100$	*Semi-Flexible*
$100 < G' < 1000$	*Semi-Rigid*
$G' > 1000$	*Rigid*



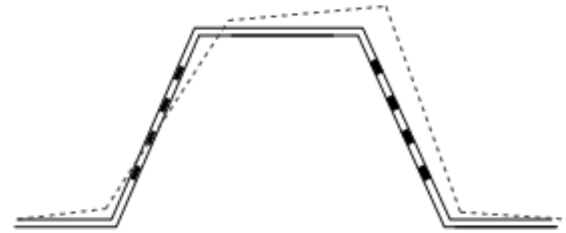


Table 9-6 Deck Warping Factors

Typical Fastener Patterns													
Deck Type	Deck Profile	Fastener Pattern	α	$\Sigma(x/w)^2$	N 1/ft	s/d	A	Warping Constant, D_{xx}, ft					
								D26	D24	D22	D20	D18	D16
1.5" Roof Deck	WR	36/9	3.000	1.278	2.333	1.365	2	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/7	2.000	0.778	2.000	1.365	1	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/5	1.667	0.722	1.333	1.365	1	--	--	607	454	298	210
	IR					1.325				637	477	313	221
	NR					1.393				857	641	421	297
	WR	36/4	1.333	0.556	1.000	1.365	1	--	--	860	643	422	298
	IR					1.325				863	645	424	299
	NR					1.393				1126	842	553	390

With perforations in the web, warping increases but only fractionally.

$D_{20accoutical}$ = 645. $\mathbf{D}_s$ changes < 1%

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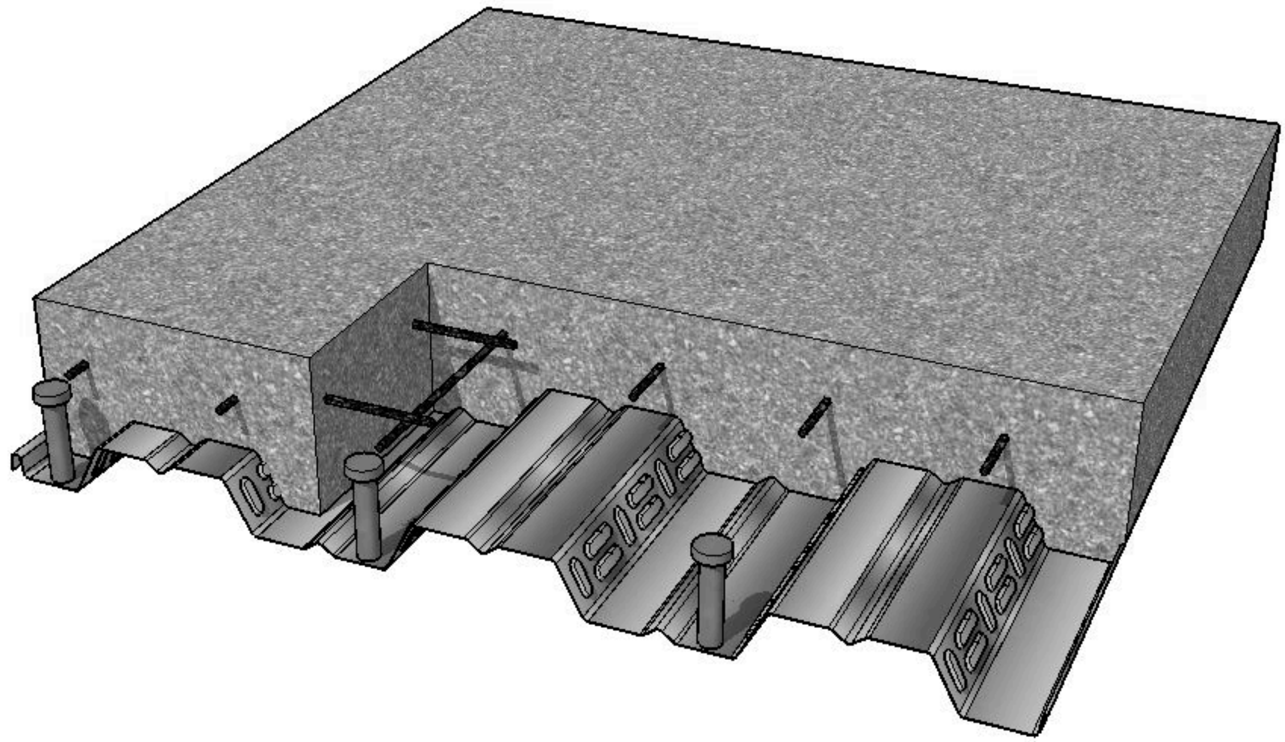
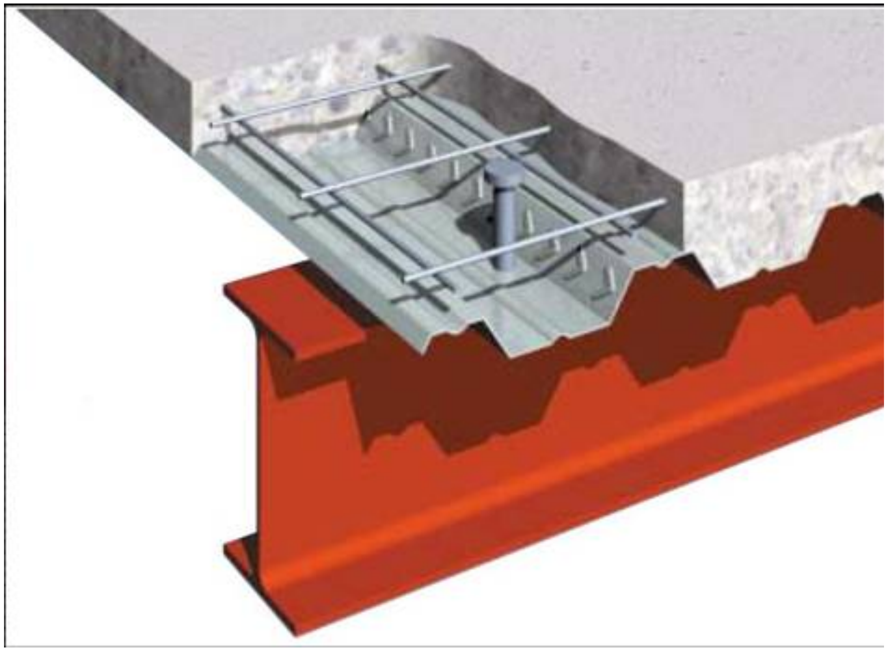
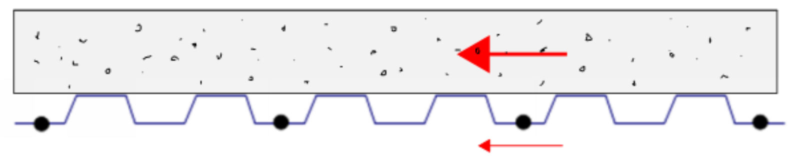
Filled Diaphragms



Welded Wire Fabric Shown For Temperature and Shrinkage
Not Required for Diaphragm Design

Shear Strength



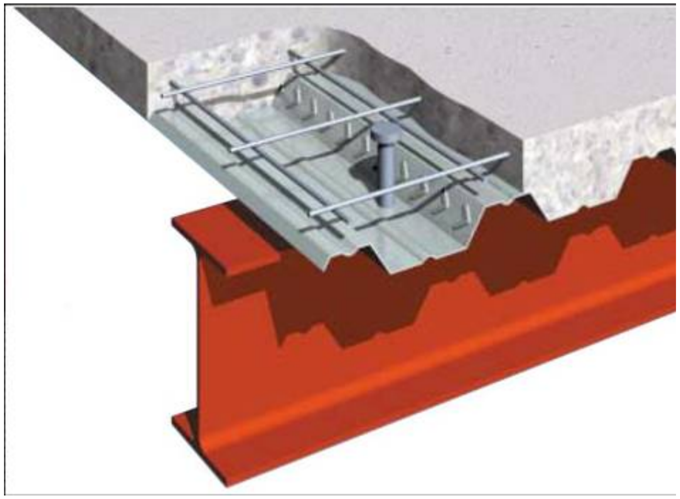


$$S_n = \frac{\beta Q_f}{L} + kbd_c\sqrt{f'_c}$$

Shear Strength = Strength of Deck + Strength of Concrete

Deck Strength Contribution Limited to 25% of Total Shear Capacity

Structural Concrete



$$S_n = \frac{\beta Q_f}{L} + kbd_c\sqrt{f'_c}$$

$$k = \frac{w^{1.5}}{585(10^3)}$$

$w_{min} > 110\ pcf$

$b = 12"$

$2" < d_c < 6"$

$f'c > 2500\ psi$

Insulating Fill

$k = 0.0013\ without\ insulating\ board$

$k = 0.0064\ with\ insulating\ board$

$w_{min} > 30\ pcf$

$b = 12"$

$d_c > 2"\ (tables\ use\ 2\ ^1/_2\ ")$

$f'c > 125\ psi$

Design thickness = 0.0358 in.
Support fastening: 5/8 in. arc spot welds
Side-lap fastening: Buildex, Elco, Hilti, or Simpson Strong-Tie #10 screws

F_u = 52 ksi
F_y = 40 ksi
F_{xx} = 60 ksi

Bare Deck Diaphragm			Filled Diaphragm		
Loading	ϕ_{df}	Ω_{df}	Loading	ϕ_{df}	Ω_{df}
Seismic	0.55	3.00	Seismic	0.50	3.25
Wind	0.70	2.35	Wind	0.50	3.25
Other	0.60	2.65	Other	0.50	3.25

Type of Fill	Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 4	5	6	7	8	9	10	11	12	K_1 1/ft
2-1/2" NW Conc. (Above Deck)	36/4	0	5795	5615								0.802
		1	5990	5770	5625							0.561
		2	6180	5925	5755	5630	5540	5470				0.431
		3	6370	6080	5880	5740	5635	5555	5490	5435	5390	0.350
		4	6535	6230	6010	5850	5735	5640	5565	5505	5455	0.294
		5	6535	6385	6140	5960	5830	5725	5645	5575	5520	0.254
		6	6535	6535	6265	6070	5925	5810	5720	5645	5585	0.224
		8	6535	6535	6525	6290	6120	5985	5875	5785	5710	0.180
2-1/2" LW Conc. (Above Deck)	36/4	0	4355	4175								0.802
		1	4550	4330	4185							0.561
		2	4615	4485	4315	4190	4100	4030				0.431
		3	4615	4615	4440	4300	4195	4115	4050	3995	3950	0.350
		4	4615	4615	4570	4410	4295	4200	4125	4065	4015	0.294
		5	4615	4615	4615	4520	4390	4285	4205	4135	4080	0.254
		6	4615	4615	4615	4615	4485	4370	4280	4205	4145	0.224
		8	4615	4615	4615	4615	4615	4540	4435	4345	4270	0.180

Why are tables based upon 2 ½" of topping?

Ω and ϕ Factors

No Change from DDM03 to DDM04!!!

Table 2.1 - Filled Diaphragm Resistance and Safety Factors

Φ (LRFD)	Ω (ASD)	Diaphragm Condition
0.50	3.25	For filled diaphragms subjected to **earthquake** loads, or subjected to load combinations which include earthquake loads.
0.50	3.25	For filled diaphragms subjected to **wind** loads, or subjected to load combinations which include wind loads.
0.50	3.25	For filled diaphragms subjected to load combinations not involving wind or earthquake loads.

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Shear Stiffness

Bare deck

$$G' = \left(\frac{K_2}{K_4 + \frac{0.3\, D_{xx}}{L_v} + 3\, K_1\, L_v} \right)$$

Filled deck

$$G' = \left(\frac{K_2}{K_4 + \frac{0.3\, D_{xx}}{L_v} + 3\, K_1\, L_v} \right) + K_3$$

$D_{xx} = 0$

Deck contribution

Concrete contribution

$K_3 = 3.5\ d_c\ f'c^{0.7}$

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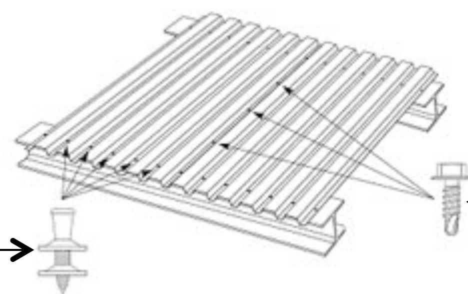
Fasteners

✓ During construction they secure the sheets from sliding

✓ Critical for horizontal (diaphragm) shear loads and/or uplift



Supports

- Welds
- Screws
- Pins (Powder Actuated or Pneumatic)

Side Laps

- Welds
- Screws
- Button Punches

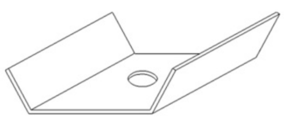
Arc Spot Welds (Puddle Welds)

Sheet Steel Welding AWS D1.3

Typical Welding Electrodes

E60xx Minimum (E6022 Common)

Per SDI No More Than 1/16" Gap Between Deck and Support



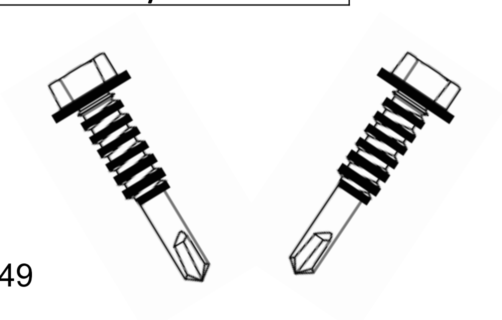
Weld Washers Only For Gages Less than 22 (Not Including 22 gage)

Mechanical Fasteners

Screws

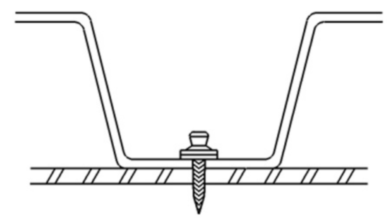
- Typical for Attachment to Light Gage Framing
- Also Used for Steel Joist or Beam Supports Especially with Fastener Manufacturer Tools
- Draw Deck Down to Supports
- No Fire Watch
- #10, #12, #14, ¼" Diameters (#12 Most Common)
- Drill Points No. 3 thru 5
- Performance Based on Specific Manufacturer

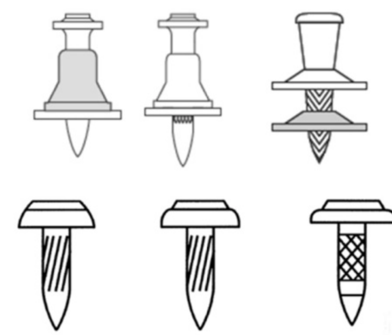
Drill Point	Max Total Material Thickness
3	5/32"
4	5/16"
5	1/2"



Pins

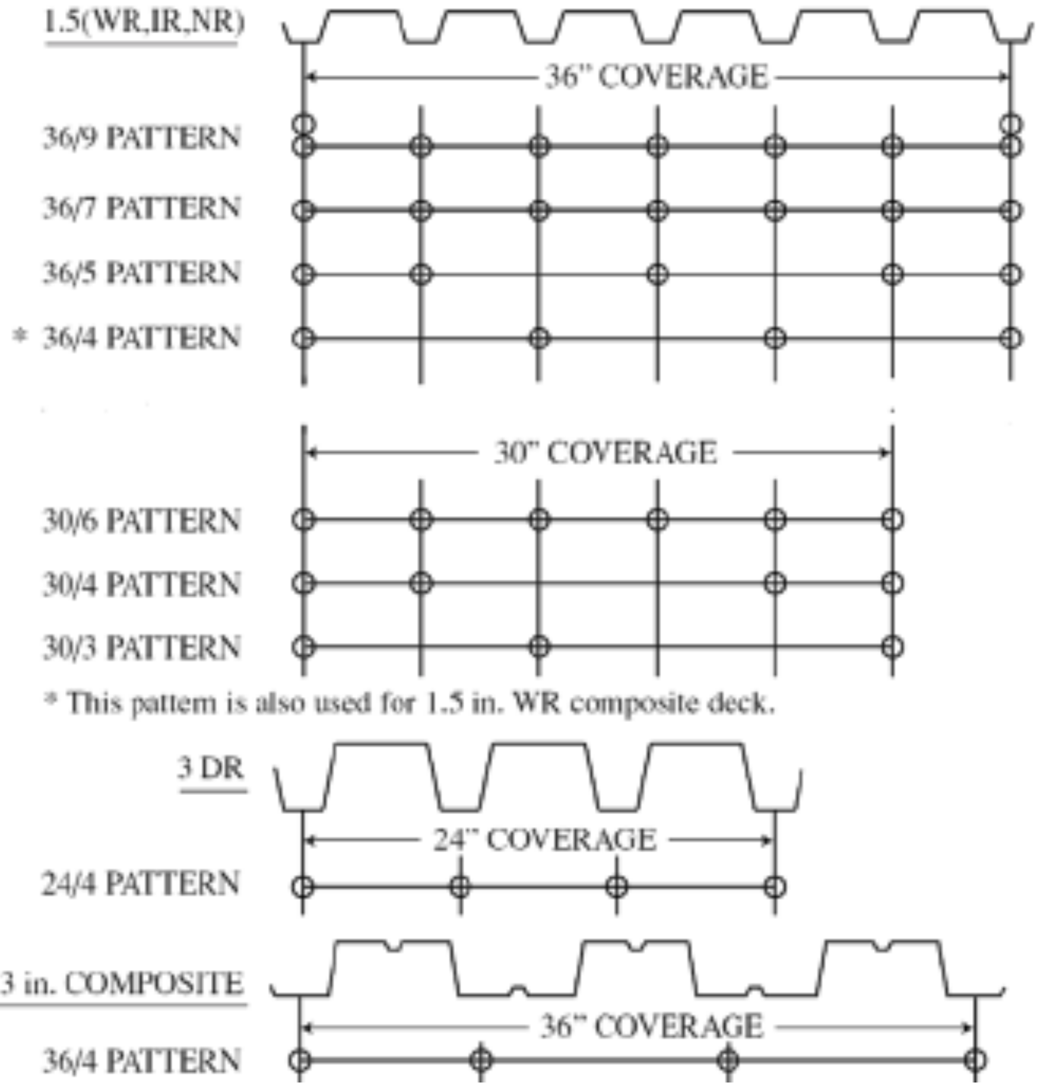
- Powder Actuated or Pneumatic
- Quick Installation
- No Fire Watch
- Performance Based on Specific Manufacturer





Attachment Patterns

(Deck Panel Coverage (inches) / # Fasteners Per Sheet at Each Support)



Side Lap Fasteners

Welds

- Arc Spot or Fillet
- Difficult to Make for Lighter Gages
- Not Recommended for 22 Gage or Thinner

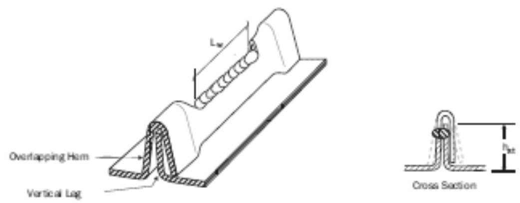


Figure 3.4 – Top Seam Weld - Vertical Leg and Overlapping Hem Joint

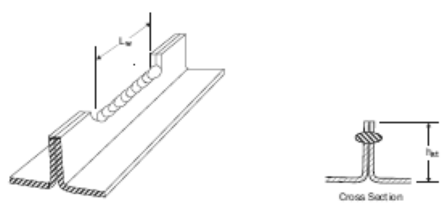


Figure 3.5 – Top Seam Weld - Back-to-Back Vertical Leg Joint

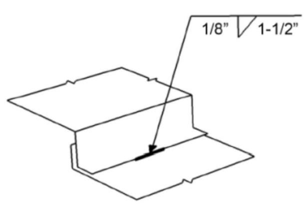


Figure 3.6 – Sidelap Fillet Weld

Screws

- Easy Installation if Horizontal Runout Exists
- Visible from Underside

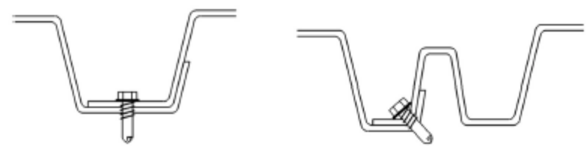
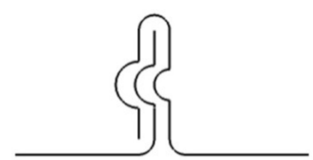


Figure 3.9 – Screw Sidelap Connections

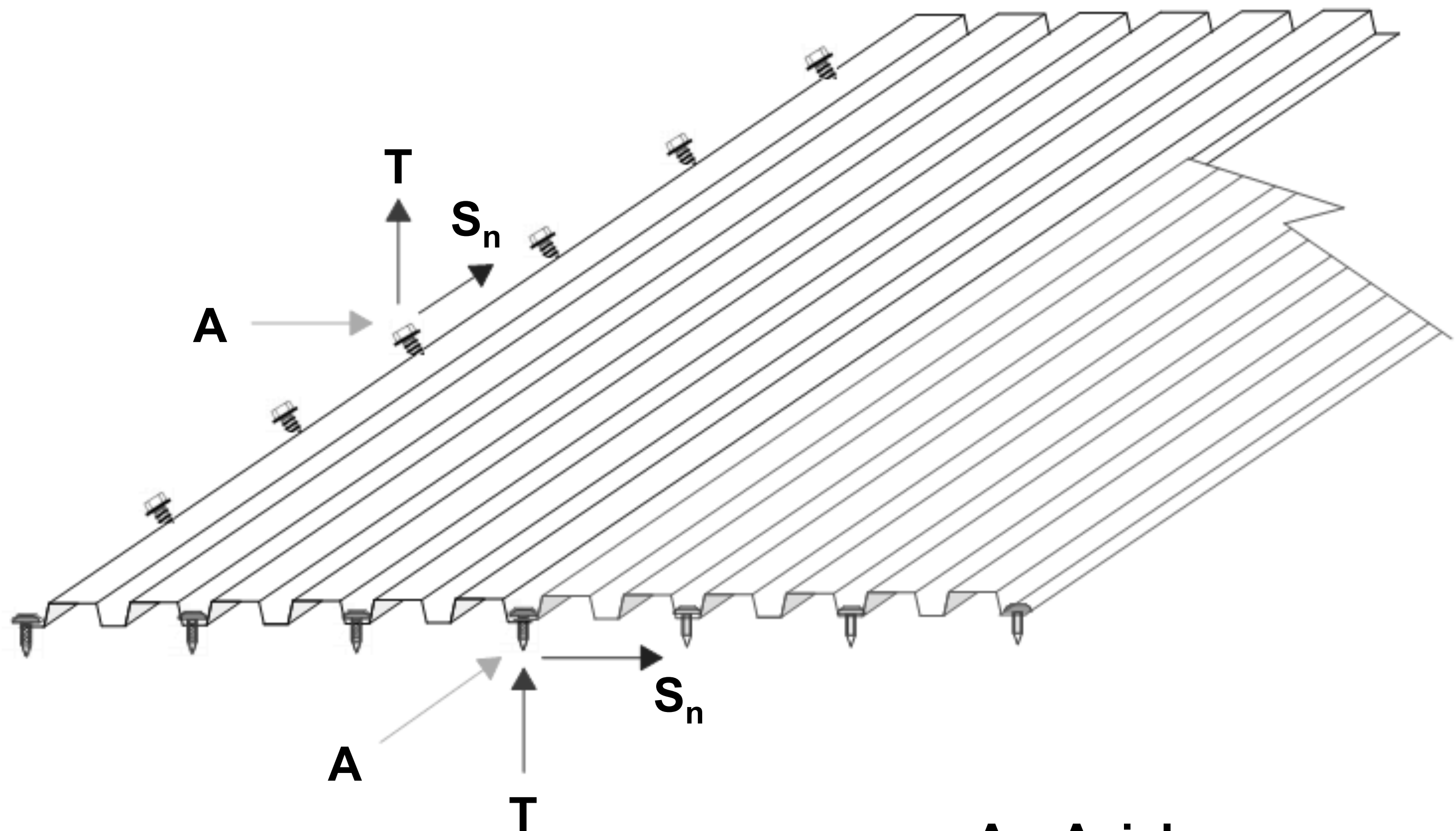
Button Punches

- Must Have Interlocking Side Lap

East Coast - Standard Button Punch
West Coast - Proprietary Systems that Crimp and Pierce Interlock
- Tested to Achieve High Shears
- Special Installation Tools by Manufacturer



Fastener Loads



A = Axial
S_n = Shear
T = Tension

Fastener Loads

Significant Changes from DDM03 to DDM04…

Differences Between DDM03 and AISI S100

DDM04 Now Uses AISI S310 (S100) Equations

AISI S310 Allows Alternates so DDM03 Listed as Alternate Equations

Arc Spot Weld Strength

Weld Shear

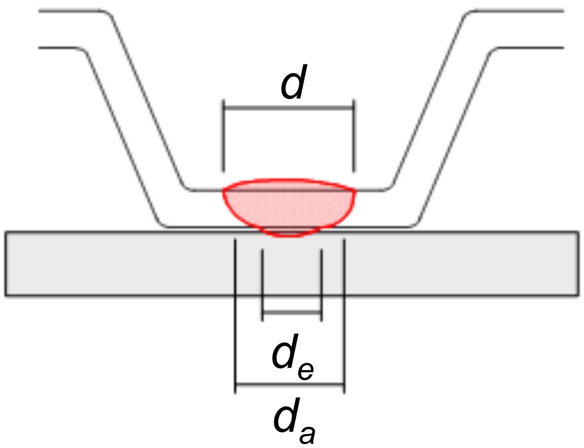
$$P_{nf} = \frac{\pi {d_e}^2}{4} 0.75\, F_{xx}$$

$$P_{nf} = 2.2\, t\, d_a\, F_u$$

$$P_{nf} = 0.28 \left[1 + 5.59 \frac{\sqrt{E/F_u}}{d_a/t} \right] t\, d_a\, F_u$$

$$P_{nf} = 1.40\, t\, d_a\, F_u$$

$$P_{nf} = 99(1.33\, d_o + 0.5\, F_{xx}\, t)$$



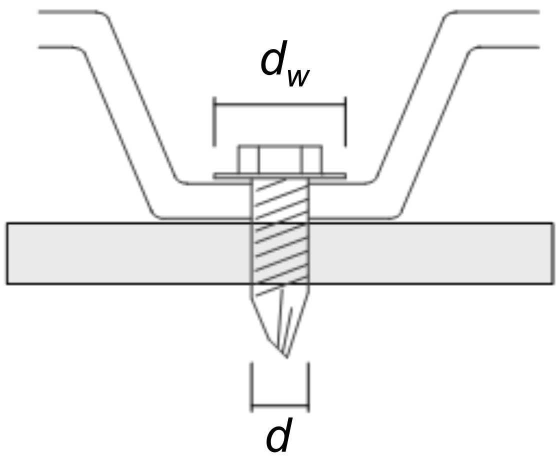
Weld Tension

$$P_{nt} = \frac{\pi {d_e}^2}{4} F_{xx}$$

$$P_{nt} = 0.8 \left(F_u / F_y \right)^2 t\, d_a\, F_u$$

Screw Strength

Screw Shear



Screw Tension

$$P_{nf} = 4.2\,(t_2{}^3\,d)^{0.5}\;F_{u2}$$

$$P_{nf} = 2.7\;t_1\,d\,F_{u1}$$

$$P_{nf} = 2.7\;t_2\,d\,F_{u2}$$

$$P_{not} = 0.85\;t_c\,d\,F_{u2}$$

$$P_{nov} = 1.5\;t_1\,d_w\,F_{u1}$$

Side Lap Fastener Strength

D1.2.1 Arc Spot Welds

AISI S100 E2.2.2.2 Shear Strength [Resistance] for Sheet-to-Sheet Connections

The *nominal shear strength* [*resistance*] for each weld between two sheets of equal *thickness* shall be determined in accordance with AISI S100 Eq. E2.2.2.2-1.

$$P_{ns} = 1.65td_aF_u \quad \text{(AISI S100 } Eq. \text{ E2.2.2.2-1)}$$

where

P_{ns} = *Nominal shear strength* [*resistance*] of sheet-to-sheet *connection*

D1.2.5 Side-Lap Screw Connections

The *side-lap connection nominal shear strength* [*resistance*], P_{ns}, per screw shall be determined in accordance with Section D1.1.2.

User Note:
In AISI S100 Eq. E4.3.1-1 through AISI S100 Eq. E4.3.1-5, t_2 is the fluted *deck* or *panel thickness* not in contact with the screw head.

D1.2.6 Non-Piercing Button Punch Side-Lap Connections

For fluted *panel* or *deck* less than or equal to 3 in. (76.2 mm) in depth, the *nominal shear strength* [*resistance*], P_{ns}, of a non-piercing button punch *side-lap connection* shall be:

P_{ns} = 0.10 kips (0.45 kN)

For *fluted panel* or *deck* greater than 3 in. (76.2 mm) in depth or *cellular deck* as described in Section D1.5, the *nominal shear strength* [*resistance*], P_{ns}, of a non-piercing button punch *side-lap connection* shall be ignored, i.e.:

P_{ns} = 0.00 kips (0.00 kN)

Shear-Tension Interaction (ASD)

$$\left(\frac{P_{nf}}{P_n}\right)^{1.5} + \left(\frac{\Omega_t T_f}{P_{nt}}\right)^{1.5} = 1$$

Arc Spot Welds
Ω_t = 2.5

$$\left(\frac{P_{nf}}{\Omega_d\, P_n}\right) + \left(\frac{0.71T}{P_{nov}}\right) = \frac{1.1}{\Omega}$$

Screws (Pull-Over)
Ω_d = 2.35
Ω = 2.35

$$\left(\frac{P_{nf}}{\Omega_d\, P_n}\right) + \left(\frac{T}{P_{not}}\right) = \frac{1.15}{\Omega}$$

Screws (Pull-Out)
Ω_d = 2.35
Ω = 2.55

$$\left(\frac{P_{nf}}{P_n}\right) + \left(\frac{\Omega_t T}{P_{nts}}\right) = 1.3$$

Screws (Tensile Breaking Strength)
Ω_t = 3.0

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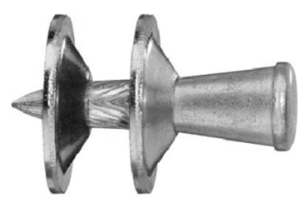
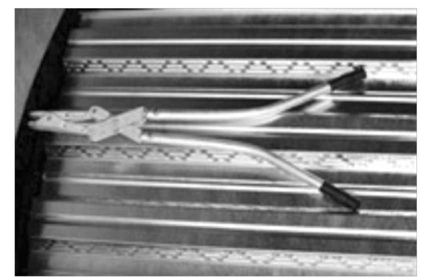
Alternate Fasteners

Values from DDM03 Still Applicable as Alternate Fasteners Permitted by AISI S310 (D1.1.3)…



- Arc Spot Welds
- Button Punches (Generic)
- Elco (Stanley)
- Hilti
- ITW Buildex
- Pneutek
- Simpson Strong Tie
- Triangle Fastener Corp



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SYMBOLS

SYMBOL	DEFINITION
a	Diaphragm width perpendicular to panel span direction - may be taken as equal to joist length for finding G' or S_s
b	Diaphragm dimension, or
b	Panel unit width, 12 inches for US unit or 1000 mm for SI unit
C	Slip relaxation constant
d	External diameter of arc-spot weld, or
d	Corrugation pitch
D, D_n, D_m	Panel warping constants, or
D	Panel depth
E	Modulus of Elasticity, 29500 ksi
F_y	Panel yield strength
F_u	Panel ultimate strength
F_{xx}	Electrode strength
G	Elastic modulus in shear
G'	Diaphragm shear stiffness
I	Panel moment of inertia per unit width
K_1	Slip relaxation constant
L	Panel length
L_v	Purlin or joist spacing
M_e, M_p	Resisting shear couples at panel ends and purlins
n_e	Number of intermediate sheet-to-structure connections per panel length and between purlins at the diaphragm edge
n_p	Number of purlins in length ℓ excluding those at ends and end laps
n_s	Number of intermediate side-lap connections in length ℓ per panel side-lap
n_{sh}	The number of panels in the width a
N	The average number of connectors per unit width along panel ends
P	Required allowable diaphragm strength for ASD
P_n	Nominal diaphragm strength
P_{nf}	Nominal shear strength (resistance) of a support connection
P_{ns}	Nominal shear strength (resistance) of a side-lap connection

SYMBOL	DEFINITION
P_u	Required factored diaphragm strength for LRFD
Q	Fastener required allowable shear strength
Q_f	Fastener strength, panel-to-frame
Q_s	Fastener strength, panel-to-panel
q_W, q_L, q_E	Line loads at diaphragm edges
R_W, R_L, R_W	Diaphragm reactions
S	Required allowable linear diaphragm shear for ASD
S_f	Fastener flexibility factors, panel-to-frame
S_s	Fastener flexibility factors, panel-to-panel
S_n	Nominal linear diaphragm shear
S_u	Required factored linear diaphragm shear for LRFD
s	Developed width of corrugation per pitch d
T	Fastener required allowable tensile strength
T_n	Fastener nominal tensile strength
T_{nov}	Fastener nominal pull over strength
T_u	Fastener required factored tensile strength
t	Base sheet metal thickness
w	Panel width, or
w, w_c	Concrete weight
x_e	Distance from panel centerline to fastener at end support
x_p	Distance from panel centerline to fastener at purlins
α_1, α_2	Fastener weighing factors
β	Fastener pattern factor, or
β	Panel buckling factor
γ	Shear strains
Δ	Total shear displacement = $\Delta_s + \Delta_c + \Delta_e + \Delta_m$
Φ, Φ_u	Resistance factor
ρ	Purlin effect on warping
ν	Poisson's Ratio
τ	Shear stress
Ω, Ω_u	Safety factor

References

Over 40 References Utilized

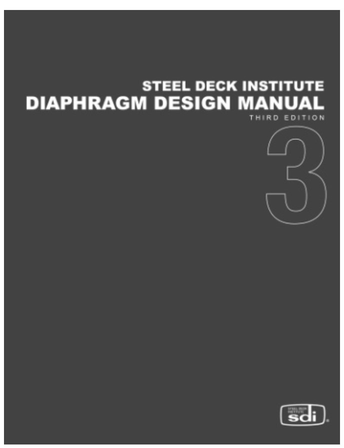
American Iron and Steel Institute

STEEL DECK INSTITUTE sdi

AMERICAN INSTITUTE OF STEEL CONSTRUCTION AISC FOUNDED 1921

ASCE

AWS



STEEL DECK INSTITUTE sdi

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Lots of Information…

- Typical Fastener Layouts
- Stiffness Equations and Values
- Default Deck Thickness and Strength Values
- Moment of Inertia Values
- Shear Stud Strength
- Fastener Strength and Flexibility Values

K Values for Stiffness

Table 9-1 Value of K_2

Gage	Thickness		K_2	
	in.	mm.	kip/in.	kN/mm
26	0.0179	0.45	528	91
24	0.0239	0.60	705	122
22	0.0295	0.75	870	152
20	0.0358	0.91	1056	185
18	0.0474	1.20	1398	244
16	0.0598	1.52	1764	309

Table 9-2 Value of K_3

Concrete Type	f'c		K_3	
	psi	MPa	kip/in.	kN/mm
Insulating concrete	125	0.86	260	46
Structural concrete	3000	21	2380	430

Table 9-3 Value of K_4

Deck Profile	K_4
1.5 NR roof deck	3.62
1.5 IR roof deck	3.45
1.5 WR roof deck	3.55
3 DR roof deck	4.18
9/16" x 2.5" form deck	3.20
1.5" x 6" composite deck	3.55
2" x 12" composite deck	3.14
3" x 12" composite deck	3.54

Pages 9-4 thru 9-5

WARPING CONSTANTS

Table 9-6 Deck Warping Factors

Typical Fastener Patterns								Warping Constant, D_{xx}, ft					
Deck Type	Deck Profile	Fastener Pattern	α	$\Sigma(x/w)^2$	N 1/ft	s/d	A	D26	D24	D22	D20	D18	D16
1.5" Roof Deck	WR	36/9	3.000	1.278	2.333	1.365	2	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/7	2.000	0.778	2.000	1.365	1	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	36/5	1.667	0.722	1.333	1.365	1	--	--	607	454	298	210
	IR					1.325				637	477	313	221
	NR					1.393				857	641	421	297
	WR	36/4	1.333	0.556	1.000	1.365	1	--	--	860	643	422	298
	IR					1.325				863	645	424	299
	NR					1.393				1126	842	553	390
	WR	30/6	1.800	0.700	2.000	1.365	1	--	--	103	77	51	36
	IR					1.325				186	139	92	65
	NR					1.393				318	238	156	110
	WR	30/4	1.600	0.680	1.200	1.365	1	--	--	1102	824	541	382
	IR					1.325				1090	815	535	377
	NR					1.393				1410	1054	692	488
3" Roof Deck	DR	24/4	1.333	0.556	1.500	1.608	1	--	--	603	451	296	209
9/16" Form Deck	2.5" Pitch	35/8	2.286	0.857	2.400	1.232	1	97	63	46	--	--	--
		35/7	2.143	0.847	2.057			143	93	68			
		35/6	1.714	0.674	1.714			190	124	90			
		35/5	1.571	0.663	1.371			277	181	131			
		30/7	2.000	0.778	2.400	1.232	1	97	63	46	--	--	--
		30/5	1.500	0.625	1.600			205	134	97			
		30/4	1.333	0.556	1.200			331	216	156			
1.5" Comp. Deck	6" Pitch	36/4	1.333	0.556	1.000	1.365	1	--	--	860	643	422	298
2" Comp. Deck	12" Pitch	36/4	1.333	0.556	1.000	1.206	1	--	--	139	104	68	48
		24/3	1.000	0.500	1.000	1.206							
3" Comp. Deck	12" Pitch	36/4	1.333	0.556	1.000	1.360	1	--	--	271	203	133	94
		24/3	1.000	0.500	1.000	1.360							

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Proprietary Fasteners

(Tabular Data for Alternate Fasteners)

- Buildex, Elco, Hilti, Simpson, or Triangle #12 or #14 Screws
- Hilti ENP-19L15, ENP2K, X-HSN24, etc Pins
- Pneutek SDK61, SDK63, K64, K66 Series Pins
- Buildex BX-12, BX-14 Pins
- Simpson Strong Tie XL Screws

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Examples

Examples

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Example #7 – Roof Design

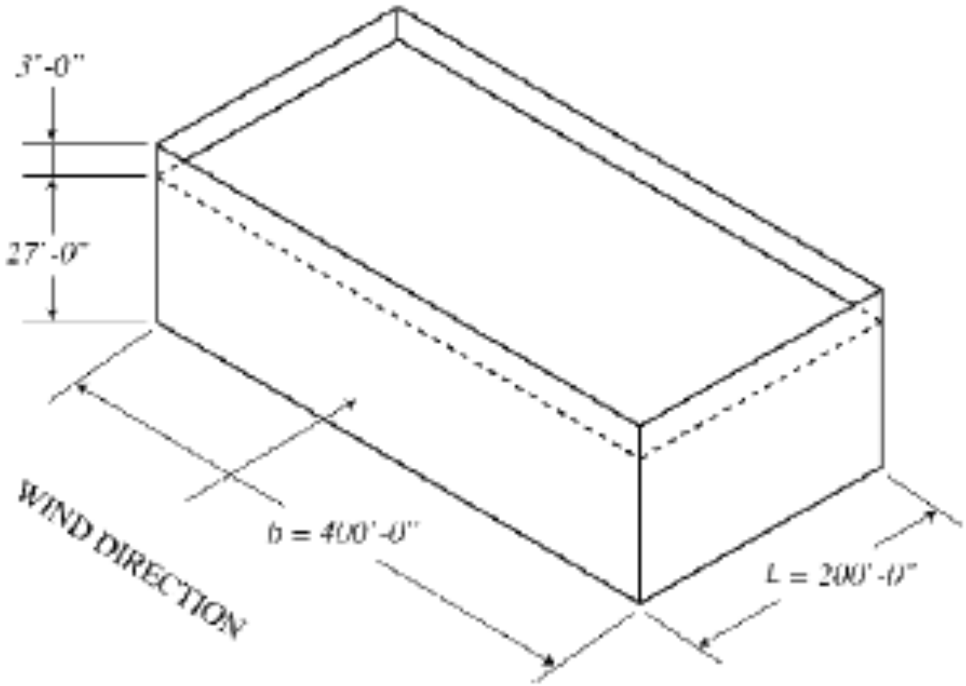


Figure 7.1

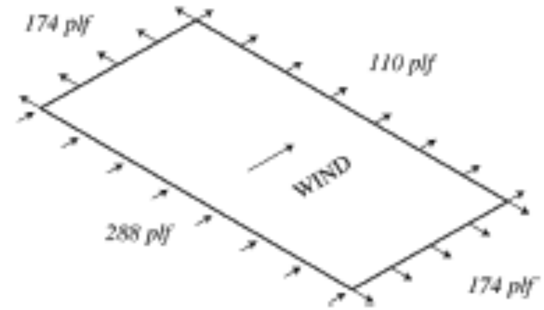


Figure 7.2 – Internal Suction

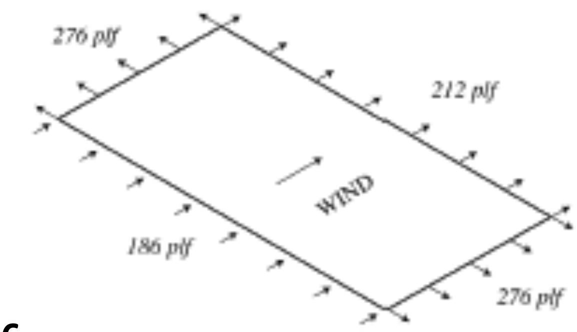


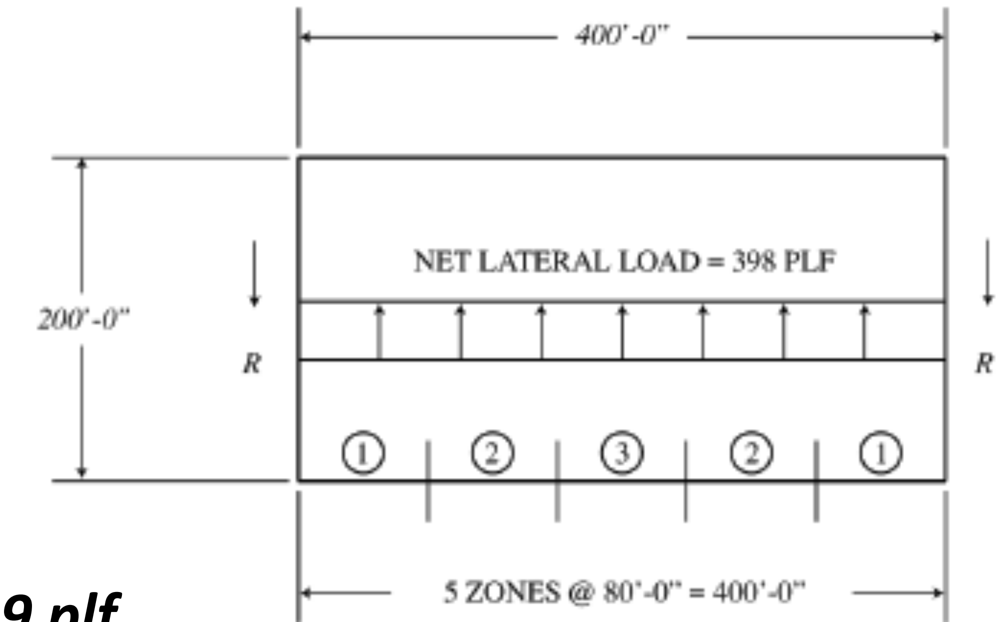
Figure 7.3 – Internal Pressure

Total Diaphragm = 288 + 110 plf = 398 plf

Reaction to End Wall = 398 plf x 400 ft / 2 = 79.6 kips

Look at Creating Diaphragm Zones to Optimize Design…

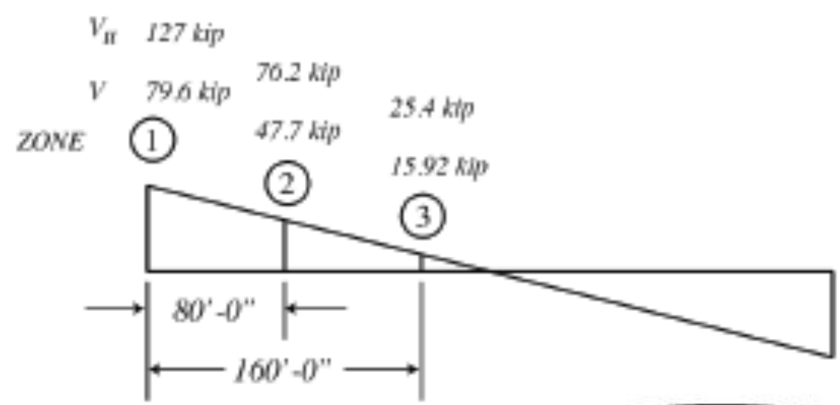
Choose 3 Symmetric Zones at 80' Each



Zone 1 = ***398 plf***

Zone 2 = 47.7 kips / 200 ft = ***239 plf***

Zone 3 = 15.9 kips / 200 ft = ***80 plf***



Try 22 Gage Wide Rib (B) Deck
Support Spacing = 5’-0” o.c.

Shear (S_n)

1.5(WR, IR, NR)22
Design thickness = 0.0295 in.
Support fastening: 5/8 in. arc spot welds or equivalent
Side-lap fastening: #10 screws

F_u = 45 ksi
F_y = 33 ksi
F_{xx} = 60 ksi

Loading	ϕ_{df}	Ω_{df}
Seismic	0.55	3.00
Wind	0.70	2.35
Other	0.60	2.65

Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 3	3.5	4	4.5	5	5.5	6	6.5	7	K_1 1/ft
36/9	0	1775	1560	1390	1230	1100					0.324
	1	1875	1650	1475	1325	1180	1065	970			0.272
	2	1970	1740	1560	1405	1265	1140	1040	955	880	0.234
	3	2060	1830	1640	1480	1350	1220	1110	1015	940	0.206
	4	2145	1910	1715	1555	1420	1295	1180	1080	1000	0.183
	5	2230	1990	1795	1630	1490	1370	1250	1145	1060	0.165
	6	2310	2070	1870	1700	1555	1430	1320	1210	1115	0.151
36/7	0	1135	985	855	755	675					0.486
	1	1250	1090	960	850	760	685	625			0.377
	2	1360	1190	1055	940	845	765	695	640	590	0.308
	3	1465	1285	1145	1030	925	840	765	705	650	0.261
	4	1565	1380	1230	1110	1005	915	835	765	710	0.226
	5	1665	1470	1315	1185	1080	990	905	830	770	0.199
	6	1755	1560	1395	1265	1150	1055	975	895	830	0.178
36/5	0	1005	880	785	700	625					0.583
	1	1100	975	870	785	710	640	585			0.433
	2	1195	1060	950	860	785	715	655	600	555	0.345
	3	1275	1140	1030	935	855	785	720	665	615	0.286
	4	1355	1215	1100	1005	920	845	785	725	670	0.245
	5	1425	1290	1170	1070	980	905	840	785	730	0.214
	6	1490	1355	1235	1130	1045	965	895	835	785	0.190
36/4	0	770	675	600	530	470					0.728
	1	865	765	685	620	555	500	455			0.509
	2	950	850	765	690	635	575	525	480	445	0.391
	3	1025	925	835	760	700	645	595	545	500	0.318
	4	1095	995	905	825	760	705	655	610	560	0.267
	5	1155	1055	965	890	820	760	705	660	620	0.231
	6	1210	1110	1025	945	875	815	760	710	665	0.203

Zone 1 = 398 plf

$$\frac{1265\,plf}{2.35} = 538\,plf$$

Zone 2 = 239 plf

$$\frac{710\,plf}{2.35} = 302\,plf$$

Zone 3 = 80 plf

$$\frac{470\,plf}{2.35} = 200\,plf$$

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Verify Panel Buckling Does Not Control

	ϕ_{db}	Ω_{db}
Buckling	0.80	2.00

Deck Profile	I in^4/ft	Nominal Shear Due to Panel Buckling, S_{nb}, plf[2] Span, ft: 3	3.5	4	4.5	5	5.5	6	6.5	7
NR	0.114	11246	8263	6326	4998	4049	3346	2812	2396	2066
IR	0.125	12191	8956	6857	5418	4389	3627	3048	2597	2239
WR	0.173	15500	11388	8719	6889	5580	4612	3875	3302	2847

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$$S_{nb} = \frac{5580\,plf}{2.00} = 2790\,plf$$

Buckling Strength Much Higher Than Fastener Controlled Limits

Stiffness (G')

Table 9-1 Value of K_2

Gage	Thickness		K_2	
	in.	mm.	kip/in.	kN/mm
26	0.0179	0.45	528	91
24	0.0239	0.60	705	122
22	0.0295	0.75	870	152
20	0.0358	0.91	1056	185
18	0.0474	1.20	1398	244
16	0.0598	1.52	1764	309

Table 9-3 Value of K_4

Deck Profile	K_4
1.5 NR roof deck	3.62
1.5 IR roof deck	3.45
1.5 WR roof deck	3.55
3 DR roof deck	4.18
9/16" x 2.5" form deck	3.20
1.5" x 6" composite deck	3.55
2" x 12" composite deck	3.14
3" x 12" composite deck	3.54

D_{xx} Values From Table 9-6

36/9 Pattern = 103

36/5 Pattern = 607

36/4 Pattern = 860

$$G' = \frac{K_2}{K_4 + \frac{0.3D_{xx}}{L_v} + 3K_1L_v}$$

Zone 1

G' = 65.7 kips/inch

Zone 2

G' = 18.7 kips/inch

Zone 3

G' = 13.2 kips/inch

Pages 9-4 thru 9-6

Deflection

See Example 5 For Determination of Deflection Equations Using Shear Area…

$$\Delta_1 = \frac{(79.6 + 47.76)\text{kips}}{2(200\text{feet})}\frac{80\text{feet}}{G'}$$

Δ_1 = 0.388 inches

$$\Delta_2 = \Delta_1 + \frac{(47.76 + 15.92)\text{kips}}{2(200\text{feet})}\frac{80\text{feet}}{G'}$$

Δ_2 = 1.069 inches

$$\Delta_3 = \Delta_2 + \frac{(15.92)\text{kips}}{2(200\text{feet})}\frac{40\text{feet}}{G'}$$

Δ_3 = 1.109 inches

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1.5(WR, IR, NR)20

Design thickness = 0.0358 in.

Support fastening: 3/4" arc spot welds or equivalent

Side-lap fastening: 5/8" arc spot welds or equivalent

F_u=	45 ksi
F_y=	33 ksi
F_{xx}=	60 ksi

Loading	ϕ_{df}	Ω_{df}
Seismic	0.55	3.00
Wind	0.70	2.35
Other	0.60	2.65

Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 4	4.5	5	5.5	6	6.5	7	7.5	8	K_1 1/ft
36/9	0	2025	1805	1610							0.357
	1	2335	2110	1925	1740	1585					0.244
	2	2630	2385	2180	2010	1845	1695	1565	1455	1355	0.186
	3	2900	2645	2425	2240	2075	1935	1790	1665	1550	0.150
	4	3145	2885	2655	2460	2285	2135	2000	1870	1745	0.126
	5	3375	3105	2870	2665	2485	2325	2180	2055	1940	0.108
	6	3580	3310	3075	2865	2675	2505	2360	2225	2100	0.095
36/7	0	1255	1110	990							0.535
	1	1615	1450	1305	1180	1080					0.317
	2	1935	1745	1590	1455	1340	1230	1140	1060	990	0.225
	3	2230	2025	1850	1700	1575	1465	1365	1270	1185	0.174
	4	2500	2280	2095	1930	1790	1670	1560	1465	1380	0.142
	5	2745	2520	2320	2150	2000	1870	1750	1645	1555	0.120
	6	2965	2735	2535	2355	2195	2055	1930	1820	1720	0.104

	ϕ_{db}	Ω_{db}
Buckling	0.80	2.00

Deck Profile	I in^4/ft	Nominal Shear Due to Panel Buckling, S_{nb}, plf[2] Span, ft 4	4.5	5	5.5	6	6.5	7	7.5	8
NR	0.138	8467	6690	5419	4478	3763	3206	2765	2408	2117
IR	0.151	9177	7251	5873	4854	4079	3475	2997	2610	2294
WR	0.210	11665	9216	7465	6170	5184	4417	3809	3318	2916

[2] Design Strengths:

ASD Required strength (Service Applied Load) <= Min $\{S_{nf} / \Omega_{df}, S_{nb} / \Omega_{db}\}$

LRFD Required strength (Factored Applied Load) <= Min $\{\phi_{df} S_{nf}, \phi_{db} S_{nb}\}$

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Pages 12-10

1.5(WR, IR, NR)20
Design thickness = 0.0358 in.
Support fastening: Buildex, Elco, Hilti, or Simpson Strong-Tie #12 screws
Side-lap fastening: Buildex, Elco, Hilti, or Simpson Strong-Tie #10 screws

F_u= 45 ksi
F_y= 33 ksi

Loading	ϕ_{df}	Ω_{df}
Seismic	0.65	2.50
Wind	0.70	2.35
Other	0.65	2.50

Fastener Layout	Side-lap Conn/Span	Nominal Shear Strength, S_{nf}, plf[1,2] Span, ft. 4	4.5	5	5.5	6	6.5	7	7.5	8	K_1 1/ft
36/9	0	985	875	785							0.403
	1	1140	1030	935	845	770					0.331
	2	1280	1165	1065	980	900	825	765	710	660	0.281
	3	1415	1290	1185	1090	1010	945	875	810	755	0.244
	4	1535	1405	1295	1200	1115	1040	975	915	855	0.216
	5	1645	1515	1400	1300	1215	1135	1065	1005	945	0.193
	6	1745	1615	1500	1395	1305	1225	1150	1085	1025	0.175
36/7	0	610	540	480							0.605
	1	785	705	635	575	525					0.456
	2	945	850	775	710	655	600	555	515	480	0.366
	3	1090	985	900	830	770	715	665	620	580	0.306
	4	1220	1115	1020	945	875	815	760	715	675	0.263
	5	1340	1230	1135	1050	975	910	855	805	760	0.230
	6	1445	1335	1235	1150	1075	1005	945	890	840	0.205

	ϕ_{db}	Ω_{db}
Buckling	0.80	2.00

Deck Profile	I in^4/ft	Nominal Shear Due to Panel Buckling, S_{nb}, plf[2] Span, ft 4	4.5	5	5.5	6	6.5	7	7.5	8
NR	0.138	8467	6690	5419	4478	3763	3206	2765	2408	2117
IR	0.151	9177	7251	5873	4854	4079	3475	2997	2610	2294
WR	0.210	11665	9216	7465	6170	5184	4417	3809	3318	2916

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Questions???