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Buckling of profiled steel diaphragms

Rao V. Nunna

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BUCKLING OF
PROFILED STEEL DIAPHRAGMS

By

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SECTION A

NOTATION

NOTATION

b	Vertical load span of deck (in).
D_x	Easley's (Ref. 1) bending stiffness per unit length of the diaphragm (lb-in^2/in), see Figure 2.
D_y	Easley's (Ref. 1) bending stiffness per unit length of the diaphragm (lb-in^2/in), see Figure 2.
D_{xy}	Easley's (Ref. 1) twisting stiffness per unit length of the diaphragm (lb-in^2/in) see Figure 2.
d	Steel deck corrugation pitch (in), see Figure 1.
E	Modulus of elasticity of diaphragm material.
F_{ut}	Tested tensile strength of steel deck (ksi).
F_y	Specified yield stress of steel deck (ksi).
F_{yt}	Tested yield stress of steel deck (ksi).
I, I_x	Gross (Full) Moment of Inertia of steel deck per foot of width (in^4/ft), see Figure 1.
I_y	Easley's (Ref. 1) Moment of Inertia of deck per width q (in^4), see Figure 2.
L_v, l_V	Vertical load span of steel deck (ft).
l	Vertical load span of deck (in).
N_{cr}	Buckling shear load per unit length (lbs/in).
n	Number of tests.
P_t	Maximum test load (lbs).

NOTATION

q	Deck corrugation pitch (in), see Figure 2.
q_D	Calculated allowable shear (ASD), per unit length of the diaphragm (lbs/ft).
S_n,S_{nb},S_{nc}	Calculated nominal shear strength (resistance) per unit length of the diaphragm, controlled by deck "out of plane buckling", (lbs/ft).
S_{nt}	Maximum tested nominal shear strength (resistance) per unit length of the diaphragm, controlled by deck "out of plane buckling", (lbs/ft).
s	Developed flute width per width d (in), see Figure 1. or Developed flute width per width q (in), see Figure 2.
t	Base steel thickness (exclusive of coatings) of steel deck (in).
μ	Poisson's ratio for steel = 0.30.
α	1, For U.S. customary units, 1826, For SI units.
Φ	Resistance factor.
Ω	Safety factor.

SECTION B

REPORT

REFERENCES

1. Buckling Formulas for Corrugated Metal Shear Diaphragms, by John T. Easley, Journal of the Structural Division, ASCE Volume 101, July 1975, pp. 1403-1417.

2. Strength and Stiffness of Corrugated Metal Shear Diaphragms, by John T. Easley, Journal of the Structural Division, ASCE Volume 103, January 1977, pp. 169-180.

3. TM 5-809-10 (Tri-Service Manual), Seismic Design for Buildings, Departments of the Army, Navy and Air Force, 1982.

4. Diaphragm Design Manual, Third Edition, No. DDM03, 2004.

5. 2009 International Building Code®, International Code Council.

6. AISI S100; North American Specification for the Design of Cold-Formed Steel Structural Members, 2007 Edition.

7. Acceptance Criteria for Steel Deck Roof and Floor Systems, AC43, ICC Evaluation Service, Inc., October 2010.

8. ASTM E455, Standard Method for Static Load Testing of Framed Floor or Roof Diaphragm Constructions for Buildings.

9. AISI S907-08, Test Standard for Cantilever Test Method for Cold-Formed Steel Diaphragms.

10. AISI S905-08, Test Methods for Mechanically Fastened Cold-Formed Steel Connections.

11. Standard Test Methods and Definitions for Mechanical Testing of Steel Products (ASTM A 370).

REPORT ON BUCKLING OF PROFILED STEEL DIAPHRAGMS

PURPOSE:

The purpose of this report is to check the validity of the widely used buckling* equations by the steel deck manufacturers, based on the historic diaphragm buckling test data and provide recommendations.

WIDELY USED DIAPHRAGM BUCKLING EQUATIONS:

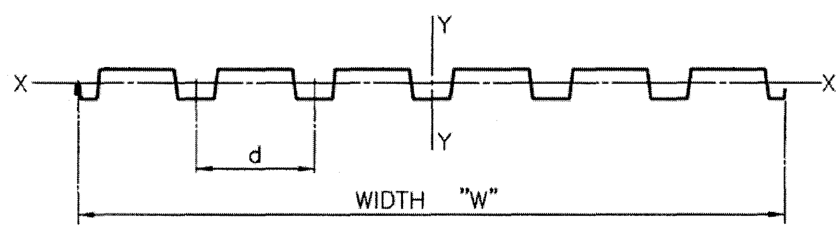

FIGURE 1 – TRI-SERVICE/SDI REFERENCE AXES

1) TM 5-809-10 (Tri-Service Manual; Ref. 3):

The following buckling equation is given in the Tri-Service Manual;

$$q_D \leq I_x \text{ x } 10^6/(2L_v^2) \qquad (5\text{-}9)$$

where,

q_D = Calculated allowable shear (ASD), per unit length of the diaphragm (lbs/ft).

I_x = Gross (Full) moment of inertia of steel deck about the horizontal neutral axis of the deck cross section per foot of width, see Figure 1 (in^4/ft).

L_v = Vertical load span of steel deck (ft).

This equation has been used for both single span and two or more span conditions.

The above equation was derived from the analysis of product manufacturer's propriety (non-public) full scale diaphragm testing data made available to initial Tri-Service Manual authors, "S. B. Barnes and Associates".

* The term "buckling" (out-of-plane buckling) is used to describe a system behavior at a strength limit state that is different from a fastener failure based strength limit state or a localized distortion / buckling based strength limit state.

2) SDI DDM03 (Ref. 4):

The following buckling equation is given in DDM03:

$$S_{nb} = (36\beta E/l^2)(I^3\, t^3\, (d/s)/12)^{0.25} \qquad \text{(Eq. 2.3-1)}$$

where,

E = Modulus of elasticity of steel (ksi) = 29,500 ksi
d = Steel deck corrugation pitch (in), see Figure 1
I = Panel moment of inertia, per inch of width (in^4/in), see Figure 1
l = Panel length (in)
s = Developed flute width per width d (in) (see Figure 1), s = 2(a + b) + c (see Figure 3)
t = Base steel thickness (exclusive of coatings) of steel deck (in)
β = Panel buckling factor = 1.75

Eq. 2.3-1 above, is modified for multi span condition in DDM03 and is shown below,

$$S_{nb} = (3250/l_v^2)(I^3\, t^3\, (d/s))^{0.25} \qquad \text{(Eq. 2.3-3)}$$

where,

d = Steel deck corrugation pitch (in), see Figure 1
I = Gross (Full) moment of inertia of steel deck about the horizontal neutral axis of the deck cross section per foot of width, see Figure 1 (in^4/ft).
l_v = Load span of steel deck (Purlin or Joist spacing) (ft).
s = Developed flute width per width d (in) (see Figure 1), s = 2(a + b) + c (see Figure 3)
t = Base steel thickness (exclusive of coatings) of steel deck (in)

The equation "(Eq. 2.3-1)" above is a modified equation given by Easley (Ref. 1), which is shown on the next page.

EASLEY'S BUCKLING EQUATIONS

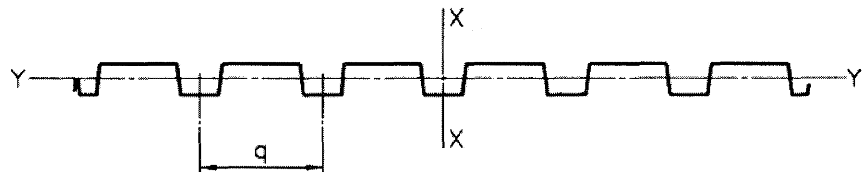

FIGURE 2 – EASLEY REFERENCE AXES

The following buckling equation is given by Easley (Ref. 1) for simply supported diaphragms.

$$N_{cr} = 36((D_x)^{0.25} (D_y)^{0.75})/b^2 \tag{7}$$

$$D_x = E\, t^3 q/(12\, s) \tag{19}$$

$$D_y = E\, I_y/q \tag{20}$$

Equation (7) was generalized as shown below:

$$N_{cr} = 36\beta((D_x)^{0.25} (D_y)^{0.75})/b^2 \tag{22}$$

$1 \leq \beta \leq 1.90$, β is diaphragm end restraint coefficient

where,

b = Length of diaphragm parallel to corrugations (in)
E = Modulus of elasticity of diaphragm material (psi)
I_y = Moment of inertia one repeating corrugation cross section (in4), see Figure 2
N_{cr} = Buckling shear load per unit length (lbs/in)
q = Deck corrugation pitch (in), see Figure 2
s = Developed flute width per width q (in) (see Figure 2), $s = 2(a + b) + c$ (see Figure 3)
t = Base metal thickness (exclusive of coatings) of deck (in)

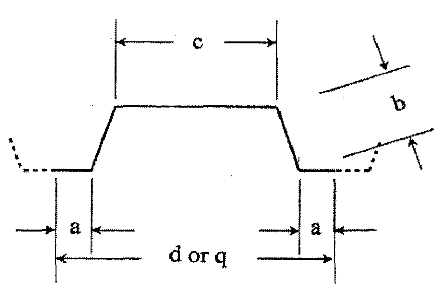

FIGURE 3 – STEEL DECK CORRUGATION DIMENSIONS

HISTORIC DIAPHRAGM BUCKLING TEST DATA:

AISI Subcommittee 33-Diaphragm Design was formed to develop S310 North American Standard for the Design of Profiled Steel Diaphragms. From Subcommittee 33, "Buckling Task Group" was formed, and its member's names and their affiliation are shown below in "Acknowledgements".

The diaphragm buckling test data was provided by the members of "Buckling Task Group", and these tests were based on either ASTM E455 Standard (Ref. 8, cantilever or simple span setup) or AISI S907 (Ref. 9) Test Standard (cantilever set up). The test data consisted of 28 full scale diaphragm tests, where the failure mode was deck "out of plane buckling", and localized failure at the fasteners did not occur first.

The above test data included the following significant variables:

1. Deck nominal depths: 1 test - 5/8", 26 tests – 1-1/2" and 1 test 2"

2. Deck gages: 29, 22, 20, 18 and 16.

3. Number of spans: 22 tests single span, 4 tests two span, 1 test a combination of two span & single span and 1 test four span.

4. Deck span length: 6'-0" minimum to 16'-0" maximum.

5. Decks with end lap: 14 tests with end lap (Tests 5, 7 thru 15 and 25 thru 28).

ANALYSES:

The test data was evaluated in three spreadsheets. The tests were evaluated in accordance with the performance procedure specified in Section F1 of AISI S100-2007 (Ref. 6) with the following revisions per proposed AISI S310, December 2010 draft, except β_0 used is for structural members (Ref. 6):

$C_\Phi = 1.6$ (LRFD), 1.5 (LSD); $P_m = 1/n \sum(S^i_{nt}/S^i_{nc})$, i = 1 to n

$\beta_0 = 2.5$ for structural members LRFD; 3.0 for structural members LSD

$V_Q = 0.25$ for LRFD and LSD

The summary evaluations are shown below.

1. First spreadsheet (sheet B-7) provides S_n (nominal shear strength), as a modified Tri-Service Manual (Ref. 3) buckling equation, and shown below as equation 1.

$$S_n = 480 \times I_x \times t \times F_y / Lv^2 \qquad \text{(Eq. 1)}$$

Average of all tests R_m = 1.006; Correlation Coefficient = 0.950;
Φ = 0.73 (LRFD); Φ = 0.57 (LSD); Ω = 2.20 (ASD)

2. Second spreadsheet (sheet B-8) provides S_n (nominal shear strength), as a modified Easley's (Ref. 1) buckling equation, and shown below as equation 2.

$$S_n = 5760 \times D_y \times t \times F_y / (E \times Lv^2) \quad \text{(Eq. 2)}$$

Average of all tests R_m = 1.006; Correlation Coefficient = 0.950;
Φ = 0.73 (LRFD); Φ = 0.57 (LSD); Ω = 2.20 (ASD)

3. Third spreadsheet (sheet B-9) provides a comparison of various buckling equations and how they fit the diaphragm buckling test data are shown below.

a) Repeat of above Eq.1 and Eq. 2 (Best Fit), which gave the same results are given in first and second spreadsheets respectively.

b) SDI DDM03, Eq. 2.3-3 (Multi span) & AISI S310 (December 2010 draft), Eq. D2.1-1 (Multi Span) is shown below:

$$S_{nb} = [3250/(\alpha\ Lv^2)]\ [I^3t^3d/s]^{1/4}$$

Average of all tests R_m = 2.432; Correlation Coefficient = 0.910;
Φ (LRFD) = 1.71; Φ (LSD) = 1.33; Ω = 0.94

c) AISI S310 (December 2010 draft) Eq. D2.1-2 :

$$S_{nb} = [8480/(\alpha\ Lv^2)]\ [I^3t^3d/s]^{1/4}$$

Average of all tests R_m = 0.932; Correlation Coefficient = 0.910;
Φ (LRFD) = 0.66; Φ (LSD) = 0.51; Ω = 2.44

d) TSM 5-809-10 (1982) Eq. 5-9 (ASD) x Ω (Ω = 2);

Average of all tests R_m = 0.904; Correlation Coefficient = 0.876;
Φ (LRFD) = 0.61; Φ (LSD) = 0.47; Ω = 2.63

e) Proposed AISI S310 (July 2011 draft), Eq. D2.1-1;

$$S_{nb} = [7890/(\alpha\ Lv^2)]\ [I^3 t^3 d/s]^{1/4} \qquad \text{(Eq. 3)}$$

Average of all tests $R_m = 1.002$; Correlation Coefficient = 0.910;
Φ (LRFD) = 0.70; Φ (LSD) = 0.55; $\Omega = 2.27$

CONCLUSIONS:

Comparison of various buckling equations is shown on page B-10. Based on the available diaphragm buckling data it is recommended to use any of the following buckling equations.

Modified Tri-Service Manual buckling equation (Eq. 1) or Modified Easley's buckling equation (Eq. 2) or Proposed AISI S310 (July 2011 draft), Eq. D2.1-1 (Eq. 3)

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In addition to the author, the "Buckling Task Group" consisted of :

Patrick Bodwell	ASC Steel Deck
William Gould	Hilti, Inc.
Keith Cullum	Verco Decking, Inc.
Jeffrey Martin	Verco Decking, Inc.
Dave Boltz	Wheeling Corrugating Company

The "Buckling Task Group" would also like to thank John Mattingly for his guidance and assistance in the completion of this report.

Respectfully submitted,
S. B. Barnes Associates
CONSULTING STRUCTURAL ENGINEERS

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Diaphragm Shear Buckling - Modified TRI-Services Equation (All Tests)

Test No.	Gage	Deck Type	Measured Thickness	Full Moment of Inertia	Panel Corrugation Pitch	Developed Flute Width	Yield	Tensile	Deck Span	Number of Spans	Stiffnesses per unit length			Maximium Test Load	Maximum Uniform Test Shear	Calculated Nominal shear	S_{nt}/S_{nc}
			t	Ix	d	s	F_y	F_u	Lv		Dx	Dy	Dxy	P_t^*	S_{nt}	S_{nc}	R_i
			(in)	(in^4/ft)	(in)	(in)	ksi	ksi	ft		(in-lb)	(in-lb)	(in-lb)	lbs	(lbs/ft)	(lbs/ft)	
1	22	1-1/2"	0.0300	0.1925	6.00	8.34233	53767	67233	10.00	2	47.74	473229	141.98	30572	1274	1490	0.855
2	20	1-1/2"	0.0360	0.2312	6.00	8.34233	52433	65967	10.00	2	82.49	568367	245.34	45447	1894	2095	0.904
3	18	1-1/2"	0.0470	0.3026	6.00	8.34233	56467	69033	10.00	2	183.57	743892	545.96	72479	3020	3855	0.783
4	22	1-1/2"	0.0290	0.1861	6.00	8.34233	55700	68233	10.00	2	43.12	457496	128.25	44487	1854	1443	1.285
5	20	1-1/2"	0.0336	0.2158	6.00	8.34233	42960	61820	6.67	2+1	67.07	530582	199.47	58853	3270	3361	0.973
6	29	5/8"	0.0132	0.0220	9.00	9.59000	115000	118000	6.00	4	5.31	54083	9.27	5270	293	445	0.658
7	16	1-1/2"	0.0570	0.3632	6.00	8.34233	54025	67737	10.00	1+1	327.44	892867	973.84	84813	4712	5369	0.878
8	22	1-1/2"	0.0287	0.1842	6.00	8.34233	45210	56960	8.00	1+1	41.80	452825	124.31	28910	1606	1793	0.896
9	20	1-1/2"	0.0345	0.2216	6.00	8.34233	48500	58260	10.00	1+1	72.60	544767	215.93	41300	2294	1780	1.289
10	16	1-1/2"	0.0562	0.3581	6.00	8.34233	45490	56390	10.00	1+1	313.84	880329	933.41	74340	4130	4394	0.940
11	20	1-1/2"	0.0360	0.2370	6.00	7.99680	67320	75740	10.00	1+1	86.06	582625	235.18	56483	2824	2757	1.024
12	22	1-1/2"	0.0317	0.2090	6.00	7.99680	50210	69900	10.00	1+1	58.76	513792	160.57	32426	1621	1597	1.015
13	22	1-1/2"	0.0310	0.2040	6.00	7.99680	53890	72550	8.00	1+1	54.95	501500	150.17	53122	3320	2556	1.299
14	22	1-1/2"	0.0310	0.2090	6.00	7.99680	51670	70100	10.00	1+1	54.95	513792	150.17	48354	2418	1607	1.505
15	22	1-1/2"	0.0310	0.2090	6.00	7.99680	49790	68960	10.00	1+1	54.95	513792	150.17	31642	1582	1548	1.022
16	22	1-1/2"	0.0285	0.1829	6.00	8.16228	49500	54900	8.00	1+1	41.83	449629	119.10	27000	1682	1935	0.869
17	22	1-1/2"	0.0290	0.1861	6.00	8.16228	48800	55900	8.00	1+1	44.07	457496	125.48	31000	1932	1975	0.978
18	18	1-1/2"	0.0470	0.3026	6.00	8.16228	42700	60800	8.00	1+1	187.62	743892	534.17	64200	4076	4555	0.895
19	18	1-1/2"	0.0470	0.3026	6.00	8.16228	42700	60800	8.00	1+1	187.62	743892	534.17	71640	4549	4555	0.999
20	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	71500	4540	6138	0.740
21	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	70400	4470	6138	0.728
22	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	93200	5918	6138	0.964
23	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	90000	5714	6138	0.931
24	16	2"	0.0559	0.6571	12.00	14.58428	46210	56191	16.00	1	353.32	1615273	802.91	63550	3531	3182	1.110
25	22	1-1/2"	0.0281	0.18035	6.00	8.34233	46820	63660	8.00	1+1	39.23	443360	116.68	37925	2107	1780	1.184
26	20	1-1/2"	0.0338	0.21711	6.00	8.34233	44220	61560	10.00	1+1	68.27	533729	203.05	35363	1965	1558	1.262
27	16	1-1/2"	0.0560	0.35679	6.00	8.34233	57280	65930	10.00	1+1	310.51	877109	923.48	78470	4359	5493	0.793
28	22	1-1/2"	0.0282	0.18099	6.00	8.34233	47060	65530	8.00	1+1	39.65	444934	117.93	45100	2506	1801	1.391

$$Snc = 480 \times \beta \times (I_x)^{n2} \times t^{n1} \times (Fy)^{n4} / (Lv)^{n3}$$

Equation proposed by:
Rao Nunna, S.E.
S. B. Barnes Associates

Poisson's ratio for steel μ = 0.30

Modulus of elsticity of steel (psi) E = 29500000

Panel Buckling factor β = 1.000

Power of Fy Correction n4 = 1

Average, R_m =		1.006	
Power of Span Correction	n3 =	2	
Correlation Coeff =		0.950	
	Method	AISI	
Power of Thickness Correction	n1 =	1	
Power of Ix Correction	n2 =	1	
Standard Deviation of S_{nt}/S_{nc}	σ =	0.213	
Number of Tests	n =	28	
= n-1	m =	27	
Calibration Coefficient	C_Φ =	1.6	(LRFD)
		1.5	(LSD)
Material Factor	M_m =	1.10	
Fabrication Factor	F_m =	1.00	
Average of S_{nt}/S_{nc} P_m =		1.00	
Coefficient of Variation for Material	V_m =	0.10	
Coefficient of Variation for Fabrication	V_F =	0.05	
Number of Samples Factor	C_p =	1.12	
Coefficient of Variation for Test Resulte	V_p =	0.211	
Coefficient of Variation for Load Effect	V_Q =	0.25	
Cumulative Coefficient of Variation	V_R =	0.35	

Resistance factor for connections for LRFD with a target reliability index of 2.5 Φ = 0.73 (LRFD)
Resistance factor for connections for LSD with a target reliability index of 3.0 Φ = 0.57 (LSD)

Factor of safety Ω = 2.20 (ASD)

Diaphragm Shear Buckling - Modified Easley's Equation (All Tests)

Test No.	Gage	Deck Type	Measured Thickness	Full Moment of Inertia	Panel Corrugation Pitch	Developed Flute Width	Yield	Tensile	Deck Span	Number of Spans	Stiffnesses per unit length			Maximium Test Load	Maximum Uniform Test Shear	Calculated Nominal shear	S_{nt}/S_{nc}
			t	Ix	d	s	F_y	F_u	Lv		Dx	Dy	Dxy	P_t^*	S_{nt}	S_{nc}	R_i
			(in)	(in^4/ft)	(in)	(in)	ksi	ksi	ft		(in-lb)	(in-lb)	(in-lb)	lbs	(lbs/ft)	(lbs/ft)	
1	22	1-1/2"	0.0300	0.1925	6.00	8.34233	53767	67233	10.00	2	47.74	473229	141.98	30572	1274	1490	0.855
2	20	1-1/2"	0.0360	0.2312	6.00	8.34233	52433	65967	10.00	2	82.49	568367	245.34	45447	1894	2095	0.904
3	18	1-1/2"	0.0470	0.3026	6.00	8.34233	56467	69033	10.00	2	183.57	743892	545.96	72479	3020	3855	0.783
4	22	1-1/2"	0.0290	0.1861	6.00	8.34233	55700	68233	10.00	2	43.12	457496	128.25	44487	1854	1443	1.285
5	20	1-1/2"	0.0336	0.2158	6.00	8.34233	42960	61820	6.67	2+1	67.07	530582	199.47	58853	3270	3361	0.973
6	29	5/8"	0.0132	0.0220	9.00	9.59000	115000	118000	6.00	4	5.31	54083	9.27	5270	293	445	0.658
7	16	1-1/2"	0.0570	0.3632	6.00	8.34233	54025	67737	10.00	1+1	327.44	892867	973.84	84813	4712	5369	0.878
8	22	1-1/2"	0.0287	0.1842	6.00	8.34233	45210	56960	8.00	1+1	41.80	452825	124.31	28910	1606	1793	0.896
9	20	1-1/2"	0.0345	0.2216	6.00	8.34233	48500	58260	10.00	1+1	72.60	544767	215.93	41300	2294	1780	1.289
10	16	1-1/2"	0.0562	0.3581	6.00	8.34233	45490	56390	10.00	1+1	313.84	880329	933.41	74340	4130	4394	0.940
11	20	1-1/2"	0.0360	0.2370	6.00	7.99680	67320	75740	10.00	1+1	86.06	582625	235.18	56483	2824	2757	1.024
12	22	1-1/2"	0.0317	0.2090	6.00	7.99680	50210	69900	10.00	1+1	58.76	513792	160.57	32426	1621	1597	1.015
13	22	1-1/2"	0.0310	0.2040	6.00	7.99680	53890	72550	8.00	1+1	54.95	501500	150.17	53122	3320	2556	1.299
14	22	1-1/2"	0.0310	0.2090	6.00	7.99680	51670	70100	10.00	1+1	54.95	513792	150.17	48354	2418	1607	1.505
15	22	1-1/2"	0.0310	0.2090	6.00	7.99680	49790	68960	10.00	1+1	54.95	513792	150.17	31642	1582	1548	1.022
16	22	1-1/2"	0.0285	0.1829	6.00	8.16228	49500	54900	8.00	1+1	41.83	449629	119.10	27000	1682	1935	0.869
17	22	1-1/2"	0.0290	0.1861	6.00	8.16228	48800	55900	8.00	1+1	44.07	457496	125.48	31000	1932	1975	0.978
18	18	1-1/2"	0.0470	0.3026	6.00	8.16228	42700	60800	8.00	1+1	187.62	743892	534.17	64200	4076	4555	0.895
19	18	1-1/2"	0.0470	0.3026	6.00	8.16228	42700	60800	8.00	1+1	187.62	743892	534.17	71640	4549	4555	0.999
20	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	71500	4540	6138	0.740
21	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	70400	4470	6138	0.728
22	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	93200	5918	6138	0.964
23	16	1-1/2"	0.0590	0.3759	6.00	8.16228	36900	49700	8.00	1+1	371.14	924088	1056.68	90000	5714	6138	0.931
24	16	2"	0.0559	0.6571	12.00	14.58428	46210	56191	16.00	1	353.32	1615273	802.91	63550	3531	3182	1.110
25	22	1-1/2"	0.0281	0.18035	6.00	8.34233	46820	63660	8.00	1+1	39.23	443360	116.68	37925	2107	1780	1.184
26	20	1-1/2"	0.0338	0.21711	6.00	8.34233	44220	61560	10.00	1+1	68.27	533729	203.05	35363	1965	1558	1.262
27	16	1-1/2"	0.0560	0.35679	6.00	8.34233	57280	65930	10.00	1+1	310.51	877109	923.48	78470	4359	5493	0.793
28	22	1-1/2"	0.0282	0.18099	6.00	8.34233	47060	65530	8.00	1+1	39.65	444934	117.93	45100	2506	1801	1.391

Average, R_m = 1.006

Power of Span Correction n3 = 2

Correlation Coeff = 0.950

$$Snc = 5760 \times \beta \times (Dy)^{n2} \times t^{n1} \times (Fy)^{n4} / (E \times (Lv)^{n3})$$

Equation proposed by:
Rao Nunna, S.E.
S. B. Barnes Associates

		Method AISI	
Power of Thickness Correction	n1 =	1	
Power of Ix Correction	n2 =	1	
Standard Deviation of S_{nt}/S_{nc}	σ =	0.213	
Number of Tests	n =	28	
= n-1	m =	27	
Calibration Coefficient	C_Φ =	1.6	(LRFD)
		1.5	(LSD)
Material Factor	M_m =	1.10	
Fabrication Factor	F_m =	1.00	
Average of S_{nt}/S_{nc}	P_m =	1.00	
Coefficient of Variation for Material	V_m =	0.10	
Coefficient of Variation for Fabrication	V_F =	0.05	
Number of Samples Factor	C_p =	1.12	
Coefficient of Variation for Test Resulte	V_p =	0.211	
Coefficient of Variation for Load Effect	V_Q =	0.25	
Cumulative Coefficient of Variation	V_R =	0.35	

Poisson's ratio for steel μ = 0.30

Modulus of elsticity of steel (psi) E = 29500000

Panel Buckling factor β = 1.000

Power of Fy Correction n4 = 1

Resistance factor for connections for LRFD with a target reliability index of 2.5 Φ = 0.73 (LRFD)

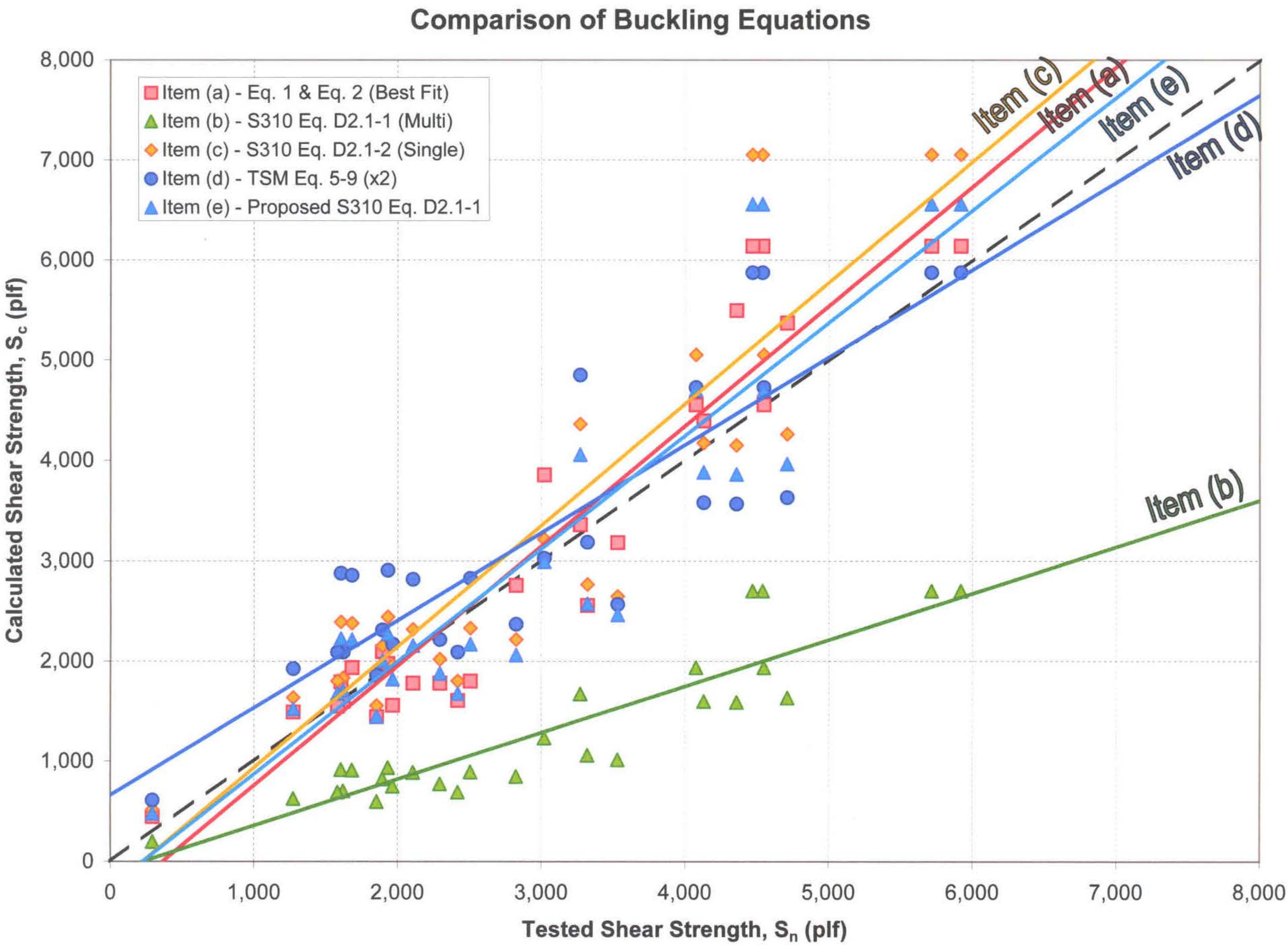
Resistance factor for connections for LSD with a target reliability index of 3.0 Φ = 0.57 (LSD)

Factor of safety Ω = 2.20 (ASD)

Diaphragm Shear Buckling - Comparison of Various Buckling Equations (All Tests)

Test No.	Gage	Deck Type	Number of Spans	Maximum Uniform Test Shear S_{nt} (lbs/ft)	(a) Eq.1 & Eq. 2 (Best Fit) S_{nc} (lbs/ft)	S_{nt}/S_{nc} R_i	(b) SDI DDM03 Eq. 2.3 3 (Multi Span) & AISI S310 (December 2010, draft) Eq. D2.1-1 (Multi Span)	S_{nt}/S_{nc} R_i	(c)AISI S310 (December 2010, draft) Eq. D2.1-2 (Single Span)	S_{nt}/S_{nc} R_i	(d) TSM 5-809-10 (1982) Eq. 5-9 (x2 for Nominal Strength)	S_{nt}/S_{nc} R_i	(e) Proposed AISI S310 Eq. D2.1-1 (July 2011, draft) Single Span and Multiple Span	S_{nt}/S_{nc} R_i
1	22	1-1/2"	2	1274	1490	0.855	627	2.03	1636	0.78	1925	0.66	1522	0.84
2	20	1-1/2"	2	1894	2095	0.904	825	2.30	2152	0.88	2312	0.82	2002	0.95
3	18	1-1/2"	2	3020	3855	0.783	1233	2.45	3216	0.94	3026	1.00	2992	1.01
4	22	1-1/2"	2	1854	1443	1.285	596	3.11	1555	1.19	1861	1.00	1447	1.28
5	20	1-1/2"	2+1	3270	3361	0.973	1672	1.96	4362	0.75	4851	0.67	4059	0.81
6	29	5/8"	4	293	445	0.658	198	1.48	516	0.57	611	0.48	480	0.61
7	16	1-1/2"	1+1	4712	5369	0.878	1633	2.88	4262	1.11	3632	1.30	3966	1.19
8	22	1-1/2"	1+1	1606	1793	0.896	917	1.75	2392	0.67	2878	0.56	2226	0.72
9	20	1-1/2"	1+1	2294	1780	1.289	774	2.96	2019	1.14	2216	1.04	1879	1.22
10	16	1-1/2"	1+1	4130	4394	0.940	1599	2.58	4173	0.99	3581	1.15	3882	1.06
11	20	1-1/2"	1+1	2824	2757	1.024	849	3.33	2216	1.27	2370	1.19	2061	1.37
12	22	1-1/2"	1+1	1621	1597	1.015	702	2.31	1833	0.88	2090	0.78	1705	0.95
13	22	1-1/2"	1+1	3320	2556	1.299	1060	3.13	2765	1.20	3188	1.04	2573	1.29
14	22	1-1/2"	1+1	2418	1607	1.505	691	3.50	1802	1.34	2090	1.16	1677	1.44
15	22	1-1/2"	1+1	1582	1548	1.022	691	2.29	1802	0.88	2090	0.76	1677	0.94
16	22	1-1/2"	1+1	1682	1935	0.869	912	1.84	2380	0.71	2858	0.59	2215	0.76
17	22	1-1/2"	1+1	1932	1975	0.978	936	2.06	2443	0.79	2908	0.66	2273	0.85
18	18	1-1/2"	1+1	4076	4555	0.895	1936	2.10	5053	0.81	4728	0.86	4701	0.87
19	18	1-1/2"	1+1	4549	4555	0.999	1936	2.35	5053	0.90	4728	0.96	4701	0.97
20	16	1-1/2"	1+1	4540	6138	0.740	2702	1.68	7051	0.64	5873	0.77	6560	0.69
21	16	1-1/2"	1+1	4470	6138	0.728	2702	1.65	7051	0.63	5873	0.76	6560	0.68
22	16	1-1/2"	1+1	5918	6138	0.964	2702	2.19	7051	0.84	5873	1.01	6560	0.90
23	16	1-1/2"	1+1	5714	6138	0.931	2702	2.11	7051	0.81	5873	0.97	6560	0.87
24	16	2"	1	3531	3182	1.110	1014	3.48	2647	1.33	2567	1.38	2463	1.43
25	22	1-1/2"	1+1	2107	1780	1.184	888	2.37	2318	0.91	2818	0.75	2156	0.98
26	20	1-1/2"	1+1	1965	1558	1.262	750	2.62	1958	1.00	2171	0.91	1822	1.08
27	16	1-1/2"	1+1	4359	5493	0.793	1591	2.74	4150	1.05	3568	1.22	3861	1.13
28	22	1-1/2"	1+1	2506	1801	1.391	893	2.81	2330	1.08	2828	0.89	2168	1.16

		(a)		(b)	(c)	(d)	(e)
Average, R_m =		1.006		2.432	0.932	0.904	1.002
Power of Span Correction	n3 =	2					
Correlation Coeff =		0.950		0.910	0.910	0.876	0.910
		AISI					
Power of Thickness Correction	n1 =	1		1	1	1	1
Power of Dy Correction	n2 =	1		1	1	1	1
Standard Deviation of S_{nt}/S_{nc}	σ =	0.213		0.561	0.215	0.231	0.231
Number of Tests	n =	28		28	28	28	28
= n-1	m =	27		27	27	27	27
Calibration Coefficient	C_Φ =	1.6	(LRFD)	1.6	1.6	1.6	1.6
		1.5	(LSD)	1.5	1.5	1.5	1.5
Material Factor	M_m =	1.10		1.10	1.10	1.10	1.10
Fabrication Factor	F_m =	1.00		1.00	1.00	1.00	1.00
Average of S_{nt}/S_{nc}	P_m =	1.01		2.43	0.93	0.90	1.00
Coefficient of Variation for Material	V_m =	0.10		0.10	0.10	0.10	0.10
Coefficient of Variation for Fabrication	V_F =	0.05		0.05	0.05	0.05	0.05
Number of Samples Factor	C_p =	1.12		1.12	1.12	1.12	1.12
Coefficient of Variation for Test Resulte	V_p =	0.211		0.231	0.231	0.255	0.231
Coefficient of Variation for Load Effect	V_Q =	0.25		0.25	0.25	0.25	0.25
Cumulative Coefficient of Variation	V_R =	0.35		0.37	0.37	0.38	0.37
2.5	Φ =	0.73	(LRFD)	1.71	0.66	0.61	0.70
3.0	Φ =	0.61	(LSD)	1.33	0.51	0.47	0.55
Factor of safety	Ω =	2.19	(ASD)	0.94	2.44	2.63	2.27


Comparison of Buckling Equations
Item (a) - Eq. 1 & Eq. 2 (Best Fit)
Item (b) - S310 Eq. D2.1-1 (Multi)
Item (c) - S310 Eq. D2.1-2 (Single)
Item (d) - TSM Eq. 5-9 (x2)
Item (e) - Proposed S310 Eq. D2.1-1
Item (c)
Item (a)
Item (e)
Item (d)
Item (b)
Calculated Shear Strength, S_c (plf)
Tested Shear Strength, S_n (plf)
8,000
7,000
6,000
5,000
4,000
3,000
2,000
1,000
0
1,000
2,000
3,000
4,000
5,000
6,000
7,000
8,000

SECTION C

HISTORIC DIAPHRAGM BUCKLING TEST DATA

HISTORIC DIAPHRAGM BUCKLING TEST DATA

Test No.	Deck Type	Support Fastening[1]	End Lap	Side Lap[2]	Deck Gage (Measured Thickness)	Full Moment of Inertia I_x (in^4/ft)	s developed flute width (in)	d Panel corrugation pitch (in)	Fy (psi)	Fu (psi)	Deck Span	Number of Spans	Ultimate Load	Test Frame (Length x Width)	Ultimate Load (lbs/ft)
1	1-1/2"	36/7	none	6" o.c.	22(0.0300)	0.1925	8.34233	6.00	53767	67233	10'-0"	2	30572	20'x24'	1274
2	1-1/2"	36/9	none	6" o.c.	20(0.0360)	0.2312	8.34233	6.00	52433	65967	10'-0"	2	45447	20'x24'	1894
3	1-1/2"	36/9	none	3" o.c.	18(0.0470)	0.3026	8.34233	6.00	56467	69033	10'-0"	2	72479	20'x24'	3020
4	1-1/2"	36/9	none	3" o.c.	22(0.029)	0.1861	8.34233	6.00	55700	68233	10'-0"	2	44487	20'x24'	1854
5	1-1/2"	36/7	2"	9 per span	20(0.0336)	0.21583	8.34233	6.00	42,960	61,820	6'-8"	2 + 1	58853	20'x18'	3270
6	5/8"	36/4	none	24" o.c.	29(0.0132)	0.0220	9.590	9.00	115000	118000	6'-0"	4	5270	24'x18'	293
7	1-1/2"	36/7	2"	19 per span	16(0.0570)	0.3632	8.34233	6.00	54,025	67737	10'-0"	1 + 1	84813	20' x 18'	4712
8	1-1/2"	36/7	2"	7 per span	22(0.0287)	0.1842	8.34233	6.00	45,210	56,960	8'-0"	1 + 1	28910	16'x18'	1606
9	1-1/2"	36/7	2"	9 per span	20(0.0345)	0.2216	8.34233	6.00	48,500	58,260	10'-0"	1 + 1	41300	20'x18'	2294
10	1-1/2"	36/7	2"	9 per span	16(0.0562)	0.3581	8.34233	6.00	45,490	56,390	10'-0"	1 + 1	74340	20'x18'	4130
11	1-1/2"	36/7	4"	24" o.c.	20(0.0360)	0.237	7.9968	6.00	67,320	75,740	10'-0"	1 + 1	56483	20'x21'	2824
12	1-1/2"	36/4	4"	24" o.c.	22(0.0317)	0.209	7.9968	6.00	50,210	69,900	10'-0"	1 + 1	32426	20'x21'	1621
13	1-1/2"	36/7	4"	12" o.c.	22(0.0310)	0.204	7.9968	6.00	53,890	72,550	8'-0"	1 + 1	53122	16'x18'	3320
14	1-1/2"	36/7	4"	12" o.c.	22(0.0310)	0.209	7.9968	6.00	51,670	70,100	10'-0"	1 + 1	48354	20'x21'	2418
15	1-1/2"	36/7	4"	24" o.c.	22(0.0310)	0.209	7.9968	6.00	49,790	68,960	10'-0"	1 + 1	31642	20'x21'	1582
16	1-1/2"	36/7	none	24" o.c.	22(0.0285)	0.1829	8.16228	6.00	49,500	54,900	8'-0"	1 + 1	27000	16.30'x16.05'	1682
17	1-1/2"	36/7	none	12" o.c.	22(0.0290)	0.1861	8.16228	6.00	48,800	55,900	8'-0"	1 + 1	31000	16.30'x16.05'	1932
18	1-1/2"	36/7	none	24" o.c.	18(0.0470)	0.3026	8.16228	6.00	42,700	60,800	8'-0"	1 + 1	64200	16.00'x15.75'	4076
19	1-1/2"	36/7	none	12" o.c.	18(0.0470)	0.3026	8.16228	6.00	42,700	60,800	8'-0"	1 + 1	71640	16.00'x15.75'	4549
20	1-1/2"	36/7	none	24" o.c.	16(0.0590)	0.3759	8.16228	6.00	36,900	49,700	8'-0"	1 + 1	71500	16.00'x15.75'	4540
21	1-1/2"	36/7	none	24" o.c.	16(0.0590)	0.3759	8.16228	6.00	36,900	49,700	8'-0"	1 + 1	70400	16.00'x15.75'	4470
22	1-1/2"	36/7	none	12" o.c.	16(0.0590)	0.3759	8.16228	6.00	36,900	49,700	8'-0"	1 + 1	93200	16.00'x15.75'	5918
23	1-1/2"	36/7	none	12" o.c.	16(0.0590)	0.3759	8.16228	6.00	36,900	49,700	8'-0"	1 + 1	90000	16.00'x15.75'	5714
24	2"	36/4	none	15 per span	16(0.0559)	0.65706	14.58428	12.00	46,210	56191	16'-0"	1	63550	16' x 18'	3531
25	1-1/2"	36/7	2"	8 per span	22(0.0281)	0.18035	8.34233	6.00	46,820	63,660	8'-0"	1 + 1	37925	16'x18'	2107
26	1-1/2"	36/7	2"	4 per span	20(0.0338)	0.21711	8.34233	6.00	44,220	61,560	10'-0"	1 + 1	35363	20'x18'	1965
27	1-1/2"	36/7	2"	4 per span	16(0.0560)	0.35679	8.34233	6.00	57,280	65,930	10'-0"	1 + 1	78470	20'x18'	4359
28	1-1/2"	36/7	2"	8 per span	22(0.0282)	0.18099	8.34233	6.00	47,060	65,530	8'-0"	1 + 1	45100	16'x18'	2506

Notes:
1. Arc Spot Welds or PAF or Bolts or Screws.
2. Top Seam Welds or Fillet Welds or Button Punch or Screws or Proprietary fastening