The New SDI Diaphragm Design Manual

By Dong Li, P.E.

Expanding on its 1st and 2nd Editions, the Steel Deck Institute (SDI) published the 3rd edition of the Diaphragm Design Manual (DDM03) in 2004. This edition continues the design approaches presented in the previous editions, adapted to include both Allowable Stress Design (ASD) and Load and Resistance Factor Design (LRFD) methods and added several design examples to cover a wider variety of diaphragm applications.

DDM03 explains the method developed for calculating the design properties for diaphragms made with bare steel decks and concrete filled steel decks, provides examples on how to calculate the shear in a diaphragm, and demonstrates how to use the diaphragm load tables that have been developed as design aids.

Summary of Major Changes

DDM03 is modified for the ease of the user who is familiar either with LRFD or ASD, which represents a departure from the previous editions. The adoption of both design methods is reflected in the diaphragm design consideration, design examples and load tables. US customary and SI unit systems are used for calculations, some formulas are presented in unit-less format first, then in each unit system. Design verification and examples are added for combined shear and tension on fasteners. Nominal strength values are presented in the diaphragm load tables, and must be adjusted by resistance or safety factors before comparing with the loads calculated with the corresponding design approach.

Increased Application Range

Diaphragm design tables for decks up to and including 3 inches (76mm) deep are included in Appendix V in DDM03. It is indicated in an SDI published white paper *Deeper Steel Deck and Cellular Diaphragm*, that diaphragm values for the strength and stiffness of cellular decks and regular decks up to and including 7.5 inches (190mm) deep can be derived using the procedure illustrated in DDM03 for regular decks of 9/16 to 3 inches deep and 0.014 to 0.064 inches thick. Diaphragm values for steel deck attached to wood structural members may be calculated using approaches similar to those in DDM03. The Metal Construction Association published *A Primer on Diaphragm Design* that addresses these cases.

Use of ASD and LRFD Methods

With LRFD, factored nominal strength (or design strength) is the nominal strength of applicable limit state multiplied by the corresponding resistance factor (Φ). Required strength is the effect of applied factored loads. With ASD, allowable strength (or design strength) is the nominal strength of applicable limit state divided by the corresponding safety factor (Ω). Required strength is the effect of applied service loads. For both design methods, the design strength must be greater than the required strength. The applicable limit state that controls the diaphragm strength is typically the connector failure. Plate-like shear buckling (or panel buckling) can control for steel deck diaphragm having a shallow depth, relatively long span and closely spaced fasteners. Resistance and safety factors vary with the type of load (cyclic or quasi static), type of fastener (welds or screws) and limit state (connector failure or panel buckling). The selection of the resistance and safety factor is per *Table 2.1*, reproduced herein, which is based on the Supplement 2004 to the *North American Specification for the Design of Cold-Formed Steel Structural Members*, 2001 Edition.

Filled Diaphragm

Steel diaphragms may be reinforced by an overlay of insulating concrete, structural concrete, or by directly attaching flat panels used to produce a flat surface. Such devices eliminate the panel end warping and local corner buckling so to increase diaphragm strength and stiffness; they also present additional load paths for the shear forces that are developed in the diaphragm. It must be remembered that it may be necessary to increase the number or strength of perimeter connectors in order to develop the required diaphragm strength. The combination of steel deck and the covering material can lead to increased variability in strength. DDM03 Table 5.1 lists the resistance and safety factors for a filled diaphragm under different load cases. Intermediate side-lap fasteners in a concrete filled diaphragm add little to the diaphragm shear strength once the concrete is cured. Reasonable side-lap spacing is stipulated to limit the differential deflection between adjacent panels, which may result in concrete leakage.

The New SDI Diaphragm Design Manual

Table 2.1

Factors of Safety and Resistance Factors for Diaphragms

Load Type or Combinations Including	Connection Type[1]	Limit State			
		Connection Related		Panel Buckling[2]	
		USA and Mexico		USA and Mexico	
		Ω_d (ASD)	ϕ_d (LRFD)	Ω_d (ASD)	ϕ_d (LRFD)
Earthquake	Welds	3.00	0.55	2.00	0.80
	Screws	2.50	0.65		
Wind	Welds	2.35	0.70		
	Screws	2.35	0.70		
All Others	Welds	2.65	0.60		
	Screws	2.50	0.65		

Typical Diaphragm Load Table from Appendix V

COMPOSITE DECK
t = design thickness = 0.0358”
SUPPORT FASTENING: ⅝” puddle weld or equivalent
SIDE-LAP FASTENING: ⅝” puddle weld or 1 ½” long fillet weld

ϕ (EQ): 0.55 Ω (EQ): 3.00 ϕ (FILLED, EQ): 0.50 Ω (FILLED, EQ): 3.25
ϕ (WIND): 0.70 Ω (WIND): 2.35 ϕ (FILLED, WIND): 0.50 Ω (FILLED, WIND): 3.25
ϕ (OTHER): 0.60 Ω (OTHER): 2.65 ϕ (FILLED, OTHER): 0.50 Ω (FILLED, OTHER): 3.25

TYPE OF FILL	FASTENER LAYOUT	SIDE-LAP CONN./ SPAN	NOMINAL SHEAR STRENGTH, PLF — SPAN, FT										K1
			4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0	
1 ½” X 6” NO FILL (BARE DECK)	36/4	0	725	575	470	395	340	300	270	245	225	205	0.803
		1	1020	850	730								0.394
		2	1250	1070	930	820	730	645					0.261
		3	1425	1250	1105	985	885	800	730	670	615 *		0.195
		4	1560	1395	1250	1125	1020	930	855	790 *	730 *	680 *	0.156
		5	1660	1510	1375	1250	1145	1050	970 *	895 *	835 *	780 *	0.130
		6	1735	1600	1475	1355	1250	1155*	1070 *	1000 *	930 *	875 *	0.111
		8	1840	1735	1630	1525	1425*	1335*	1250 *	1175 *	1105 *	1040 *	0.086
2” x 12” NO FILL (BARE DECK)	36/4	0	715	560	455	385	335	300	270	245	225	205	0.803
		1	1020	850	715								0.394
		2	1250	1070	930	820	725	645					0.261
		3	1425	1250	1105	985	885	800	730	670	615 *		0.195
		4	1560	1395	1250	1125	1020	930	855	790 *	730 *	680 *	0.156
		5	1660	1510	1375	1250	1145	1050	970 *	895 *	835 *	780 *	0.130
		6	1735	1600	1475	1355	1250	1155 *	1070 *	1000 *	930 *	875 *	0.111
		8	1840	1735	1630	1525	1425*	1335 *	1250 *	1175 *	1105 *	1040 *	0.086
3” X 12” NO FILL (BARE DECK)	36/4	0	680	535	445	385	335	300	270	245	225	205	0.803
		1	1020	850	705								0.394
		2	1250	1070	930	820	725	645					0.261
		3	1425	1250	1105	985	885	800	730	670	615 *		0.195
		4	1560	1395	1250	1125	1020	930	855	790 *	730 *	680 *	0.156
		5	1660	1510	1375	1250	1145	1050	970 *	895 *	835 *	780 *	0.130
		6	1735	1600	1475	1355	1250	1155 *	1070 *	1000 *	930 *	875 *	0.111
		8	1840	1735	1630	1525	1425 *	1335 *	1250 *	1175 *	1105 *	1040 *	0.086
2 ½” NW CONC. (ABOVE DECK)	36/4	0	5680	5525	5420	5345	5290	5250	5215	5185	5160	5140	0.803
		1	6070	5835	5680								0.394
		2	6460	6150	5940	5795	5685	5595					0.261
		3	6855	6465	6205	6020	5880	5770	5685	5615	5555		0.195
		4	7245	6775	6465	6240	6075	5945	5840	5755	5685	5625	0.156
		5	7635	7090	6725	6465	6270	6120	5995	5900	5815	5745	0.130
		6	8030	7405	6985	6690	6465	6290	6155	6040	5945	5865	0.111
		8	8810	8030	7510	7135	6860	6640	6465	6325	6205	6105	0.086
2 ½” LW CONC. (ABOVE DECK)	36/4	0	4015	3860	3755	3685	3630	3585	3550	3520	3500	3480	0.803
		1	4405	4175	4020								0.394
		2	4800	4485	4280	4130	4020	3935					0.261
		3	5190	4800	4540	4355	4215	4105	4020	3950	3890		0.195
		4	5580	5115	4800	4580	4410	4280	4175	4090	4020	3960	0.156
		5	5970	5425	5060	4800	4605	4455	4335	4235	4150	4080	0.130
		6	6365	5740	5325	5025	4800	4630	4490	4375	4280	4200	0.111
		8	7145	6365	5845	5475	5195	4975	4805	4660	4545	4440	0.086

* NOMINAL SHEAR SHOWN ABOVE MAY BE LIMITED BY SHEAR BUCKLING. SEE TABLE BELOW.
THE SHADED VALUES DO NOT COMPLY WITH THE MINIMUM SPACING REQUIREMENTS FOR SIDE-LAP CONNECTIONS AND SHALL NOT BE USED EXCEPT WITH PROPERLY SPACED SIDE-LAP CONNECTIONS.
WHEN FILLED DIAPHRAGMS ARE USED, IT MAY BE NECESSARY TO INCREASE THE NUMBER, OR STRENGTH, OF THE PERIMETER CONNECTIONS TO DEVELOP THE VALUES SHOWN IN THE TABLE. CHECK SECTION 5.4.
REFER TO THE O SIDE-LAP CONNECTION ROWS FOR DESIGN SHEAR OF DIAPHRAGMS WITH BUTTON PUNCHED SIDE-LAPS.

ϕ (BUCKLING): 0.80 Ω (BUCKLING): 2.00

TYPE OF DECK NO FILL	FASTENER LAYOUT	I in^4/ft	NOMINAL SHEAR DUE TO PANEL BUCKLING (S_n), PLF/SPAN. FT									
			4.0	5.0	6.0	7.0	8.0	9.0	10.0	11.0	12.0	13.0
1 ½” x 6”	36/4	0.212	4755	3040	2110	1550	1185	935	760	625	525	450
2” x 12”	24/3 & 36/4	0.420	8320	5325	3695	2715	2080	1640	1330	1100	925	785
3” x 12”	24/3 & 36/4	0.993	15395	9855	6840	5025	3850	3040	2460	2035	1710	1455

NOTE: ASD Required Strength (Service Applied Load) <= Minimum [Nominal Shear Strength/Ω (EQ or WIND), Nominal Buckling Strrength S_n/Ω (Buckling)]
LRFD Required Strength (Factored Applied Load) <= Minimum [ϕ (EQ or WIND) x Nominal Shear Strength, ϕ (Buckling x Nominal Buckling Strength S_n]

continued on next page

More Fasteners Options Available

New to DDM03, Section 4 presents the nominal shear resistance for power driven fasteners, in addition to arc spot welds and screws. The power driven fastener strength is provided for Buildex BX-14 or BX-12; Hilti ENP2 and ENPH2, ENP2K, X-EDN19, X-EDNK22; Pneutek SDK61-series, SDK63 series, K64-series. The addition of Appendix VI allows the inclusion of the new Hilti fastener X ENP-19 L15. Appendix IV and VI have the nominal shear strength and flexibility listed for these fasteners. The nominal resistance for both weld and screw shear connectors is calculated according to equations that were previously presented in the second edition of DDM.

Diaphragm Load Tables in Nominal Values with Φ and Ω

DDM03 Appendix V&VI present the load tables for the nominal values for roof, composite and form deck for common design thicknesses having specific combination of support and side-lap fastening. The upper part of the sheet shows the type of deck, fastening method, resistance and safety factors for different load cases. The limiting nominal shear strength is listed for the different fastener failure modes. The shaded values do not comply with the minimum spacing requirement for the side-lap connections and shall not be used except with properly spaced side-lap connections. Also tabulated is the nominal shear strength based on panel buckling as well as the appropriate resistance and safety factors associated with such failure.

Fasteners in Tension and Shear-Tension Interaction

Generally as a result of wind uplift pressure, roof diaphragm fasteners are subjected to tension. DDM03 Section 4 addresses the nominal tensile strength of arc-spot weld, screw and some power driven fasteners. Different resistance and safety factors are applied to the tension strength in Section 4.9.4. Appendix IV presents tables for the nominal tensile strength for commonly used fasteners. Research at West Virginia University has concluded that there is an interaction between shear force and tension force on the diaphragm fasteners. DDM03 provides a solution for shear-tension interaction for arc-spot weld, screw, Hilti power driven fastener and Pneutek fastener. Example 7 in Appendix III demonstrates the design check for shear-tension interaction, and Example 7A shows how the diaphragm shear is affected when tension is introduced. As an example, the following is the shear-tension interaction equation for arc-spot welds.

The interaction between shear and tension for arc-spot welds is described by:

Typical Interaction Equation

LRFD: $$\left(\frac{Q_u}{\phi Q_f}\right)^{1.5} + \left(\frac{T_u}{\phi_u T_n}\right)^{1.5} \leq 1$$

if $\left(\frac{T_u}{\phi_u T_n}\right)^{1.5} \leq 0.15$, no interaction check is required

ASD: $$\left(\frac{\Omega Q}{Q_f}\right)^{1.5} + \left(\frac{\Omega_u T}{T_n}\right)^{1.5} \leq 1.0$$

if $\left(\frac{\Omega_u T}{T_n}\right)^{1.5} \leq 0.15$, no interaction check is required

Conclusion

Modifications and enhancements in the DDM03 were made to meet the designer's needs using either ASD or LRFD design methods. DDM03 can be implemented for any consistent set of units, for example either Imperial or SI units. For more information regarding DDM03 and the design of cold-formed steel deck, see **www.sdi.org**.▪

*Dong Li, P.E., is an engineer of Cold-Formed Products for Canam Steel Corporation at Point of Rocks, Maryland. She can be reached at **dong.li@canam.ws**.*