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Thomas Sputo

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Steel Deck Institute Standards for Composite Steel Floor Deck-Slabs

Thomas Sputo, Ph.D., P.E., S.E.[1]

Introduction

As an ANSI accredited standards developer, the Steel Deck Institute (SDI) has developed an updated and expanded version of its "Standard for Composite Steel Floor Deck-Slabs", ANSI/SDI C-2011 and a new standard, "Test Standard for Composite Steel Deck-Slabs", ANSI/SDI T-CD-2011. These two standards reflect the current state-of-the-art for the design and testing of composite steel deck-slabs where the steel deck provides the tensile reinforcement for the slab. Substantial changes in the ANSI/SDI-C-2011 Standard include increased information regarding the use of fibers for concrete crack control purposes and concrete serviceability, consideration of moving and concentrated loads, and use of updated shear bond provisions and "pre-qualified sections." The new ANSI/SDI-T-CD-2011 standard includes multiple methods for validating the flexural capacity of composite deck-slabs through. This paper will discuss the substantial changes from the earlier ANSI/SDI-C1.0-2006 Standard.

Scope

The ANSI/SDI C-2011 "Standard for Composite Steel Floor Deck-Slabs" governs the materials, design, and erection of composite concrete slabs utilizing cold formed steel deck functioning as a permanent form and as reinforcement for positive moment in floor and roof applications in buildings and similar structures. The standard covers the design of the complete deck-slab, not only the steel deck.

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[1] Technical Director, Steel Deck Institute, 10 SW 1st Avenue, Gainesville, FL 32601 (email: sputoeng@mindspring.com)

Strength of Deck and Concrete as a Composite Slab

The strength of the composite deck slab is permitted to be determined in one of four ways:

      a.   "Prequalified Section Method" as per Appendix 2.
      b.   "Shear Bond Method" as per Appendix 3.
      c.   Full scale performance testing as per SDI-T-CD.
      d.   Other methods approved by the building official.

Strength Determination of Composite Deck-Slab by Pre-qualified Section Method

This section provides methods for the calculation of strength of composite steel deck-slabs when the deck meets specified criteria for dimensional properties, specifically the web embossments. It is permitted to use this method with or without steel headed stud anchors (studs).
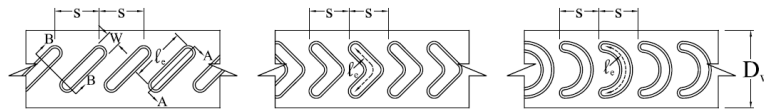
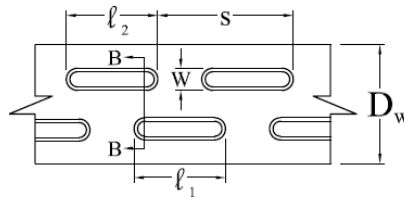

Figure 1 – Type 1 Embossments
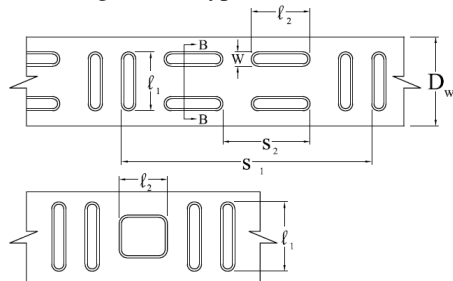

Figure 2 – Type 2 Embossments

Figure 3 – Type 3 Embossments

The resisting moment, M_{no}, of the composite section is determined using a strength coefficient (K) that is a percentage of the slab yield moment. The calculation of the strength coefficient is, based on a parametric study of embossments of previously tested deck-slabs. This method is an update to a similar method that was contained in ASCE 3-91 (ASCE 1991).

$$\Phi_s M_{no} \quad = \quad \Phi_s \, K \, M_y$$

Unless otherwise shown by testing, the upper limit of the nominal strength of the deck-slab is limited to the yield moment. If shown by testing or rational analysis, the upper limit of strength is permitted to not exceed the ultimate moment.

Strength Determination of Composite Deck-Slab by Shear Bond Method

This section provides methods for the calculation of strength of composite steel deck-slabs by the shear bond method. It is permitted to use this method with or without steel headed stud anchors (studs).

The bond between the concrete and the steel deck is experimentally determined using flexural testing, then the strength of the composite deck-slab is calculated from that bond stress. This method formed the basis for the ASCE 3-91 (ASCE 1991) Standard. The ANSI/SDI C-2011 Standard utilizes a more refined regression model for determining the bond stress that requires less testing. The shear bond equations contained within this Standard were developed by Seleim and Schuster (1985) and form the basis of the Canadian procedures for composite steel deck-slab design (CSSBI-S2-2008).

When three or more different deck thicknesses are tested, the following equation shall apply:

Vt   =   bd [k1t/l'+ k2/l'+ k3t + k4]

Where:
Vt	=	tested shear bond resistance, pounds/foot (N/m) of slab width
b	=	unit slab width = 12 inches (1000 mm)
d	=	effective slab depth, measured from top of slab to the gross section neutral axis of the deck unit, in (mm)
l'	=	shear span, in (mm)
t	=	base metal thickness, in (mm)
k1, k2, k3, k4	=	shear bond coefficients obtained from multi-linear

regression analysis of test data from three or more deck thicknesses tested.

When one or two deck thicknesses are tested, the following equation shall apply:

Vt   =   bd [k5/l' + k6]

Where:
k5, k6 =   shear bond coefficients obtained from a linear regression analysis of the test data for each individual deck thickness tested.

It is conservatively permitted to use the provisions for one or two deck thicknesses for three or more deck thicknesses.

Linear Regression for Three or More Deck Thicknesses

The coefficients k_1 through k_4 must be evaluated for each product type only, regardless of the variation in deck thickness and slab depth, by using a multilinear regression analysis. Experimental data are needed for the multilinear regression analysis. The number of tests depends mainly on the level of accuracy required of the computed ultimate shear bond values. In order to obtain a level of accuracy of +- 15% between computed and experimental ultimate shear bond values, Saliem and Schuster (1985) recommend using a minimum of eight data points (experiments) representing three or more different deck thicknesses for a single product type (deck profile).

Example:

For a single product type, the following tested results were obtained.

Test	t (deck) in	Y_b (deck depth) in	h (slab) in	l' in	Slab Width in	Failure Load #/in	Slab Weight #/in	V_t #/in
A	0.0299	0.8709	3.50	39.37	35.43	139.13	22.20	80.67
B	0.0299	0.8709	6.85	11.81	35.43	1002.45	48.51	525.48
C	0.0358	0.8744	3.50	39.37	35.43	141.11	22.20	81.66
D	0.0358	0.8744	6.81	11.81	35.43	987.78	48.10	517.94
E	0.0480	0.8815	3.50	39.37	35.43	234.24	22.20	128.22
F	0.0480	0.8815	6.97	11.81	35.43	1332.93	49.34	691.13
G	0.0598	0.8886	3.54	39.37	35.43	293.51	22.48	157.99
H	0.0598	0.8886	6.85	11.81	35.43	1409.41	48.51	728.96

Where:
Y_b =   Location of the centroid of the deck profile cross section, referenced from the bottom of the deck.

h = Overall thickness of the slab, measured from the bottom of the deck to the top of the concrete.

l' = Shear span.

d = $h - Y_b$

Failure Load = The tested failure load, reported in pounds per inch of deck width.

V_t = The tested end shear, calculated as the Failure Load minus the Slab Weight, reported in pounds per inch of deck width.

The data is rearranged as follows to allow for the multilinear regression analysis.

Test	b	d	Vt/(bd)	t/L'	1/L'	t
	in	in	y	x1	x2	x3
A	12.00	2.63	2.55	0.000760	0.025400	0.0299
B	12.00	5.98	7.32	0.002533	0.084667	0.0299
C	12.00	2.63	2.59	0.000910	0.025400	0.0358
D	12.00	5.94	7.27	0.003033	0.084667	0.0358
E	12.00	2.62	4.07	0.001220	0.025400	0.0480
F	12.00	6.09	9.46	0.004067	0.084667	0.0480
G	12.00	2.65	4.96	0.001520	0.025400	0.0598
H	12.00	5.96	10.19	0.005067	0.084667	0.0598

A multilinear regression analysis is performed using a commercial spreadsheet software package, resulting in the following constants:

k1	351.9604482
k2	69.38377236
k3	78.33614666
k4	-2.006928773

Standard Error of Y Estimate	0.384424064
R Squared	0.990340056
Number of Observations	8
Degrees of Freedom	4

Therefore the predicted shear bond equation can be written as follows:

$$Vu = \frac{P_u}{2} = bd\left[351.960\frac{t}{l'} + 69.384\frac{1}{l'} + 78.336t + (-2.007)\right]$$

Calculating the predicted value of shear, and comparing it to the tested value results in the following:

Test	V from Prediction Equation	Theory/Test
A	74.78	0.927
B	509.68	0.970
C	90.95	1.114
D	551.51	1.065
E	124.22	0.969
F	661.89	0.958
G	158.59	1.004
H	739.65	1.015

It can be seen that the maximum deviation from the tested results is 11.4%, which is less than 15%. Therefore the values of the constants need not be reduced.

Linear Regression for One or Two Deck Thicknesses

The coefficients k_5 and k_6 must be evaluated for each product type only, regardless of the variation in deck thickness and slab depth, by using a linear regression analysis. In order to obtain a level of accuracy of +- 15% between computed and experimental ultimate shear bond values, Saliem and Schuster (1985) recommend using a minimum of four data points (experiments) representing one or two different deck thicknesses for a single product type (deck profile).

Example:

For a single product type, the following tested results were obtained.

Test	t (deck) in	Yb (deck depth) in	H (slab) in	L' in	Slab Width in	Failure Load #/in	Slab Weight #/in	Vt #/in
A	0.0299	0.8709	3.50	39.37	35.43	139.13	22.20	80.67
B	0.0299	0.8709	6.85	11.81	35.43	1002.45	48.51	525.48
C	0.0358	0.8744	3.50	39.37	35.43	141.11	22.20	81.66
D	0.0358	0.8744	6.81	11.81	35.43	987.78	48.10	517.94

The data is rearranged as follows to allow for the linear regression analysis.

Test	b	d	Vt/(bd)	1/L'
	in	in	y	X1
A	12.00	2.63	2.553015	0.025400
B	12.00	5.98	7.323349	0.084667
C	12.00	2.63	2.587762	0.025400
D	12.00	5.94	7.270402	0.084667

A linear regression analysis is performed using a commercial spreadsheet software package, resulting in the following constants:

k5	79.74949549
k6	0.544751597

Standard Error of Y Estimate	0.031664862
R Squared	0.999910243
Number of Observations	4
Degrees of Freedom	2

Therefore the predicted shear bond equation can be written as follows:

$$Vu = \frac{P_u}{2} = bd\left[79.749\frac{1}{l'} + 0.544\right]$$

Calculating the predicted value of shear, and comparing it to the tested value results in the following:

Test	V from Prediction Equation	Theory/Test
A	81.22	1.007
B	523.58	0.996
C	81.11	0.993
D	519.82	1.004

It can be seen that the maximum deviation from the tested results is 0.7%, which is less than 15%. Therefore the values of the constants need not be reduced.

Strength Determination from Full Scale Performance Testing as per ANSI/SDI-T-CD

It is permitted to determine the strength of a deck-slab directly through the use of full scale performance testing.
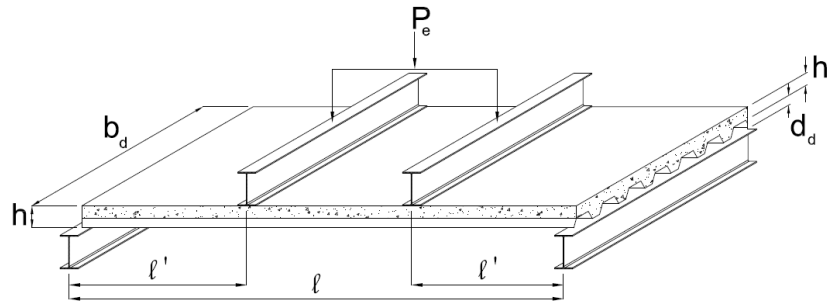

Figure 4 – Deck-slab testing

Strength Determination of Composite Deck-Slab by Other Methods Approved by the Building Official

Determination of strength of the deck-slab using other methods, including compliance with legacy standards, the application of ultimate strength method per the SDI Composite Deck Design Handbook (SDI 1997) or the development of new rational methods may be permitted by the building official.

Concentrated Loads

Information regarding concentrated loads that was contained in the SDI Composite Deck Design Handbook (SDI 1997) was added to the Standard, along with additional information regarding design for moving loads.
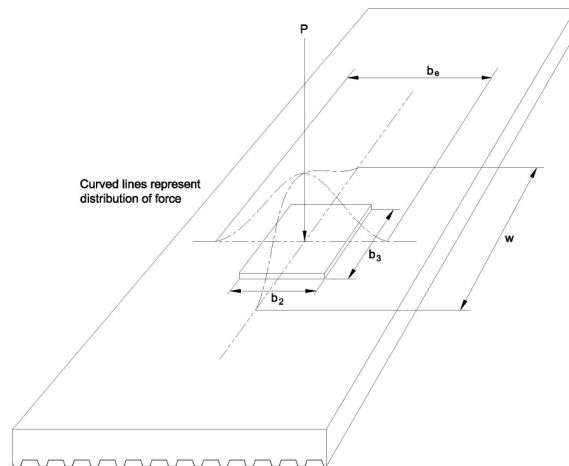
Figure 5 – Concentrated Load

The following commentary is contained in the Standard:

Composite floor deck is not recommended as the only concrete reinforcement for use in applications where the floor is loaded with repeated lift truck (forklift) or similar heavy wheeled traffic. (Lift trucks are defined as small power operated vehicles that have devices for lifting and moving product. The definition of lift trucks does not include manually operated "pallet jacks.") Loading from lift trucks includes not only moving gravity loads, but also includes vertical impact loading and in-plane loading effects from starting, stopping, and turning. The repetitive nature of this loading, including impact, fatigue, and in-plane effects can be more detrimental to the slab-deck performance than the gravity loads. Suspended floor slabs subjected to lift truck traffic have special design requirements to ensure the fatigue stress in the reinforcement is low to keep the cracks sufficiently tight and serviceable to minimize crack spalling due to the hard wheel traffic. The design should only use the steel deck as a stay-in-place form. Structural concrete design recommendations contained in ACI 215R and AASHTO-LRFD are suggested for guidance in the design of these slabs. Due consideration for the stiffness of the supporting framing should be given by the designer.

Composite floor deck has successfully been used in applications that are loaded by occasional "scissor lift" use, and in warehouses with industrial racks without lift truck traffic and in areas serviced by "pallet jacks." Proper analysis and design for moving and point loads must be performed.

Deck-Slab Reinforcement for Temperature and Shrinkage

The following provisions for control of non-structural cracking in the concrete caused by temperature and shrinkage effects is contained in the Standard, giving the option to use continuous steel reinforcement or steel or synthetic fibers.

> Reinforcement for crack control purposes other than to resist stresses from quantifiable structural loadings shall be permitted to be provided by one of the following methods:
>
> 1. Welded wire reinforcement or reinforcing bars with a minimum area of 0.00075 times the area of the concrete above the deck (per foot or meter of width), but not be less than the area provided by 6 x 6 – W1.4 x W1.4 (152 x 152 – MW9 x MW9) welded wire reinforcement.
> 2. Concrete specified in accordance with ASTM C1116, Type I, containing steel fibers meeting the criteria of ASTM A820, Type I , Type II, or Type V, at a dosage rate determined by the fiber manufacturer for the application, but not less than 25 lb/cu yd (14.8 kg/cu meter).
> 3. Concrete specified in accordance with ASTM C1116, Type III, containing macrosynthetic fibers meeting the criteria of ASTM D7508 at a dosage rate determined by the fiber manufacturer for the application, but not less than 4 lb./cu yd (2.4 kg/m3).

The following commentary is contained in the Standard:

Concrete floor slabs employing Portland cement will start to experience a reduction in volume as soon as they are placed. Where shrinkage is restrained, cracking will occur in the floor. The use of the appropriate types and amount of reinforcement for shrinkage and temperature movement control is intended to result in a larger number of small cracks in lieu of a fewer number of larger cracks. Even with the best floor design and proper construction, it is unrealistic to expect crack free floors. Every owner should be advised by both the designer and contractor that it is normal to expect some amount of cracking and that such occurrence does not necessarily reflect adversely on either the adequacy of the floor's design or quality of the construction.

Cracking can be reduced when the causes are understood and preventative steps are taken in the design phase. The major factors that the designer can control concerning shrinkage and cracking include cement type, aggregate type and gradation, water content, water/cement ratio, and reinforcement.

Most measures that can be taken to reduce concrete shrinkage will also reduce the cracking tendency. Drying shrinkage can be reduced by using less water in the mixture and the largest practical maximum-size aggregate. A lower water content can be achieved by using a well-graded aggregate and lower initial temperature of the concrete. Designers are referred to ACI 302.1R and ACI 224.1 for additional information.

Although cracking is inevitable, properly placed reinforcement used in adequate amounts will reduce the width of individual cracks. By distributing the shrinkage strains, the cracks are distributed so that a larger number of narrow cracks occur instead of a few wide cracks. Additional consideration by the designer may be required to further limit the size and frequency of cracks. Additional provisions for crack control are frequently required where concrete is intended to be exposed, floors that will be subjected to wheel traffic, and floors which will receive an inflexible floor covering material (such as tile).

Modifications to fiber dosages will vary depending upon the specific fiber manufacturers' recommendations. As a general rule, reduced crack widths can be achieved by increasing the amount of steel reinforcement or by increasing the fiber dosage and/or minimizing the shrinkage potential of the concrete.

Because composite deck-slabs are typically designed as a series of simple spans, flexural cracks may form over supports. Flexural cracking of the concrete in negative moment regions of the slab (over beams and girders) is not typically objectionable unless the floor is to be left exposed or covered with inflexible floor coverings. Flexural cracking and crack widths can be minimized by one or more of the following: 1.) by paying strict attention to preventing overloads at deck midspan during construction, as this is a common source of flexural cracks; 2.) utilizing a stiffer steel deck; 3.) reducing the slab span. If flexural cracks must be strictly controlled, consideration should be given to designing the composite deck-slab for negative moments over supports (both beams and girders) and providing appropriate reinforcing steel at these supports.

Conclusion

The Steel Deck Institute "Standard for Composite Steel Floor Deck-Slabs" and "Test Standard for Composite Steel Deck-Slabs" provide the most current information regarding the design and testing of composite steel deck-slabs.

References

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