



CSSBI S3-20179:

Criteria for the Design of Composite Slabs

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PREFACE

One of the objects of the CSSBI and its Members is the development of standards which promote safety, performance and good practice. This bulletin is intended to assist those involved in the testing of composite slabs by providing contemporary criteria for conducting the test program.

The material presented has been prepared for the general information of the reader. Neither the Canadian Sheet Steel Building Institute nor its Members warrant or assume liability for the suitability of the criteria for any general or particular application.

This publication replaces the previous edition dated October 2008.

1. GENERAL

This bulletin contains design criteria, based on limit states, for composite slabs made of a structural concrete placed permanently over composite steel deck. See CSSBI 12M *Standard for Composite Steel Deck* for information on the steel deck acting as a form during construction. See CSSBI S2 *Criteria for the Testing of Composite Slabs* for information concerning testing of composite slabs. The full capacity of the composite slab is not achieved until the concrete has attained its specified compressive strength.

2. LIMIT STATE OF STRENGTH

The strength of a composite slab is usually limited by one of the following resistance limit states: (a) shear-bond; (b) flexure of an under-reinforced section; (c) flexure of an over-reinforced section; (d) punching shear; and (e) concentrated loads.

3. LOADS AND SAFETY CRITERION

All factored resistances determined herein shall be equal to or greater than the effect of the factored loads, determined in accordance with the *National Building Code of Canada*.

4. RESISTANCE FACTORS

The following resistance factors shall apply:

Shear-bond	$N_v = 0.70$
Steel deck	$N_s = 0.90$
Concrete	$N_c = 0.65$

5. SHEAR-BOND RESISTANCE

The ultimate shear-bond resistance of a composite slab section shall be calculated using parameters determined from a testing program of full-scale slab specimens. The factored shear-bond resistance (V_r) of a composite slab shall be determined by the following expression:

$$V_r = N_v V_t \quad (1)$$

Where,

V_r = factored shear-bond resistance, N/m of slab width

V_t = tested shear-bond resistance, N/m of slab width

The basic equation used to determine the tested shear-bond resistance is one of the following:

$$V_t = bd[k_1 t / \ell' + k_2 / \ell' + k_3 t + k_4] \quad (2)$$

or,

$$V_t = bd[k_5 / \ell' + k_6] \quad (3)$$

Where,

b = unit slab width = 1000 mm

d = effective slab depth (distance from extreme concrete compression fibre to centroidal axis of full cross-section of steel deck), mm

ℓ' = shear span, mm; (see Section 6)

t = base steel design thickness, mm

$k_1, k_2, k_3,$ and k_4 are shear-bond coefficients obtained from a multi-linear regression analysis of test data from three or more deck thicknesses

k_5 and k_6 are shear-bond coefficients obtained from a linear regression analysis of test data for one individual deck thickness

Testing procedures used to determine the shear-bond coefficients are given in CSSBI S2 *Criteria for the Testing of Composite Slabs*.

6. SHEAR SPAN DETERMINATION

The shear span, ℓ' , shall be taken as:

- $L/4$ for a uniform load applied to the entire span;
- The distance between the applied load and the nearest support for two equal and symmetrically spaced loads; or,
- For other loading arrangements, including a combination of distributed and asymmetrical point loads, an assessment shall be made based upon test results. Alternatively, the shear span can be taken as the maximum moment divided by the greater vertical shear force adjacent to the supports for the span considered.

7. FLEXURAL RESISTANCE

Composite slabs subject to flexural failure are generally classified as under-reinforced or over-reinforced slabs depending on the compression depth ratio, (c/d) . Slabs with (c/d) less than the balanced condition ratio $(c/d)_b$ are considered under-reinforced, whereas slabs with (c/d) greater than or equal to $(c/d)_b$ are considered over-reinforced. The actual ratio is:

$$(c/d) = \frac{\phi_s A_s f_y}{\alpha_1 \phi_c f'_c d b \beta_1} \quad (4)$$

Whereas the ratio that denotes a balanced condition is:

$$(c/d)_b = \frac{71.1(h-d_d)}{(711 + f_y)d} \quad (5)$$

Where,

- A_s = area of steel deck, mm²/m of slab width
- b = unit width of compression face of composite slab (1000 mm)
- c = distance from extreme compression fibre to composite neutral axis, mm
- d = distance from extreme compression fibre to centroid of steel deck, mm
- d_d = overall depth of steel deck profile, mm
- f'_c = specified compressive strength of concrete, MPa
- f_y = Specified yield strength of steel deck, MPa
- h = nominal out-to-out depth of slab, mm
- $\nu_1 = 0.85 - 0.0015 f'_c \geq 0.67$
- $\beta_1 = 0.97 - 0.0025 f'_c \geq 0.67$

7.1 Under-reinforced Slabs $(c/d) < (c/d)_b$

The factored moment resistance, in positive bending, of an under-reinforced composite slab shall be taken as:

$$M_{ru} = N_s A_s f_y (d - a/2) \quad (6)$$

Where,

$$a = \frac{\phi_s A_s f_y}{\alpha_1 \phi_c f'_c b}$$

Equation (6) is valid only for composite slabs capable of developing the yield stress over the entire deck section. In some instances the strain compatibility of the slab cross-section or the ductility of the steel does not permit yielding over the entire deck section. Equation (6) does not account for steel reinforcement in addition to the steel deck and does not account for the case where a portion of the deck section lies on the compression side of the composite slab neutral axis. For those cases where equation (6) does not apply, the factored moment resistance shall be based on a detailed strain compatibility analysis.

7.2 Over reinforced Slabs $(c/d) \geq (c/d)_b$

The factored moment resistance, in positive bending, of an over-reinforced composite slab shall be determined by:

$$M_{ru} = \alpha_1 \phi_c f'_c b \beta_1 c (d - \beta_1 c/2) \quad (7)$$

Where,

$$c = d \left\{ \sqrt{\rho m + \left(\frac{\rho m}{2}\right)^2} - \frac{\rho m}{2} \right\}$$

$$\rho = \frac{A_s}{bd}; \quad m = \frac{\phi_s E_s \varepsilon_{cu}}{\alpha_1 \phi_c f'_c \beta_1}$$

$$E_s = 203000 \text{ MPa}; \quad \varepsilon_{cu} = 0.0035$$

Equation (7) is valid only for composite slabs where no part of the steel deck has yielded. If yielding of the steel deck does occur, M_{ro} may be determined by a detailed strain compatibility analysis and/or test.

7.3 Continuous Slabs

Where composite slabs are designed for continuity over supports, the factored moment resistance in negative bending shall be determined as in conventional reinforced concrete design in accordance with CSA-A23.3, *Design of Concrete Structures*. The contribution of the portion of the composite steel deck in compression may be neglected.

For positive bending it is permitted to use an equivalent isostatic span for the determination of the flexural resistance. The span shall be taken as:

- 0.8L for interior spans, and
- 0.9L for end spans.

8. TWO-WAY ACTION

In slabs requiring two-way action for load distribution, the flexural resistance in the direction transverse to the deck corrugations needs to be calculated. The following two cases apply for the determination of this resistance:

- Where no supplementary transverse reinforcement is provided, the flexural strength shall be taken as that of the plain concrete section above the corrugations. Any contribution from the steel deck is neglected.

b) Where supplementary transverse reinforcement is provided in the tension zone, equation (6) shall be used if the slab is under-reinforced. The area of steel, A_s , shall consist entirely of the supplementary reinforcement, and only the concrete section above the deck corrugations shall be considered effective, unless tests indicate conclusively that other assumptions are valid.

The effective width of the slab in the transverse direction shall be determined from tests of detailed analysis.

9. PUNCHING SHEAR RESISTANCE

The critical surface for calculating punching shear shall be perpendicular to the plane of the slab and located outside of the periphery of the concentrated load or reaction area but not further than $0.50h_c$ from the periphery of the concentrated load or reaction area. Figure A1 of Appendix A illustrates this loading condition. The factored punching shear resistance, V_{pr} , shall be determined as follows:

$$V_{pr} = (1+2/\beta_c)0.2\phi_c\lambda\sqrt{f'_c}b_o h_c \quad (8)$$

Where,

- b_o = perimeter of critical section, mm
- h_c = thickness of concrete cover above steel deck, mm
- β_c = ratio of long to short side of concentrated load or reaction area
- λ = 1.00 for normal density structural concrete
= 0.85 for semi-low density structural concrete
= 0.75 for low density structural concrete.

In lieu of equation (8), the punching shear resistance may be determined from tests.

10. DEFLECTION CRITERIA

10.1 Flexural Properties for Deflection Calculations

Composite flexural section properties needed to determine vertical deflections of composite slabs shall be computed in accordance with conventional elastic theory applied to reinforced concrete, transforming steel areas to equivalent areas of concrete. The following assumptions permit derivation of the necessary relationships:

- (i) Plane sections remain plane after bending;
- (ii) Stresses are proportional to strain in both concrete and steel at specified loads;
- (iii) The entire steel cross section is utilized except as reduced by holes;
- (iv) The moment of inertia used in deflection calculations, I_g , shall be taken as the average of the cracked, I_c , and uncracked sections, I_u , using the design depth of the slab. Formulae for flexural section properties and moments of inertia are given in Appendix B.

10.2 Deflection Limitations

Consideration needs to be given to both immediate and long-time loading. Computed maximum deflections shall be based on the assumptions of Clause 10.1. Maximum permissible computed deflections are listed in Table 1. **Additional Total immediate plus long term** deflection caused by creep shall be calculated by multiplying the immediate deflection due to the sustained load by the following

factor:

- (2.0) for load duration of 3 months
- (2.2) for load duration of 6 months
- (2.4) for load duration of 1 year
- (3.0) for load duration of 5 years or more.

Table 1: Maximum Permissible Computed Deflections

Type of Member	Deflection to be considered	Deflection Limitation
Flat roofs not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to specified live load, L, or snow load, S	Span/180 ⁽¹⁾
Floors not supporting or attached to nonstructural elements likely to be damaged by large deflections	Immediate deflection due to specified live load, L	Span/360
Roof or floor construction supporting or attached to nonstructural elements likely to be damaged by large deflections	That part of the total deflection ⁽³⁾ occurring after attachment of nonstructural elements (sum of the long-time deflection due to all sustained loads and the immediate deflection due to any additional live load)	Span/480 ⁽²⁾
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		Span/240 ⁽⁴⁾
	Span/240 ⁽⁵⁾	

- (1) Limit not intended to safeguard against ponding. Ponding should be checked by suitable calculations of deflection, including added deflections due to ponded water, and considering long-time effects of all sustained loads, and reliability of provisions for drainage.
- (2) Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.
- (3) Long-time deflections are determined in accordance with CSA-A23.3 and may be reduced by the amount of deflection calculated to occur before the attachment of nonstructural elements. This amount shall be determined on the basis of accepted engineering data relating to time-deflection characteristics of composite slab systems similar to those being considered.
- (4) But not greater than the tolerance provided to nonstructural elements.

11. CONCENTRATED LOADS

The *National Building Code of Canada* requires that floors be designed for a specified concentrated live load acting on an area of 750 by 750mm. With a composite slab system, there will be some lateral distribution of a concentrated load due to the steel deck acting as slab reinforcement. The exact extent to which a concentrated load is distributed depends on a number of factors; however, it can be assumed that the load is distributed down to the center of gravity of the steel deck. This will give a resulting load distribution area of $(750+2d)$ by $(750+2d)$ mm. Figure A2 of Appendix A illustrates this loading condition.

Concentrated loads can be laterally distributed perpendicular to the deck ribs over an effective width, b_e . The distribution over the effective width shall be uniform.

For single span bending:

$$b_e = b_m + 2(1 - x/L)x \leq 2700h_c/h \text{ (mm)}$$

For shear:

$$b_e = b_m + (1 - x/L)x \leq 2700h_c/h \text{ (mm)}$$

$$b_m = b_2 + 2h_c$$

Where,

- b_e = effective width of concentrated load, perpendicular to the deck ribs (mm)
- b_2 = width of bearing perpendicular to deck ribs (mm)
- h = overall thickness of composite slab, mm
- h_c = thickness of concrete cover above top of steel deck, mm
- x = distance from centre of concentrated load to nearest support (mm)
- L = deck span length (mm)

USER NOTE: The NBC also requires that floors be designed for a concentrated load on an area of 120 by 120mm for vehicle loads not exceeding 9 000 kg gross weight. Composite steel deck is not recommended as the only concrete reinforcement for use in applications where the floor is loaded with moving concentrated loads associated with lift trucks (forklift) or similar heavy wheeled traffic. Loading from lift trucks includes not only moving gravity loads, but also includes the vertical impact loading and in-plane loading from starting, stopping and turning. The repetitive nature of the loading, including impact, fatigue and in-plane effects can be detrimental to the slab-deck performance. The design should only use the steel deck as a stay-in-place form.

12. REPEATED OR VIBRATORY LOADING

Where repeated or vibratory loading is a factor, adequate test data to substantiate the suitability of the composite slab involved is necessary.

12. SHRINKAGE AND CRACK CONTROL REINFORCEMENT

Composite slabs shall have minimum shrinkage and temperature reinforcement in accordance with Table 2 unless a greater amount is required by the specified fire resistance rating.

Where designed for continuity over structural supports, composite slabs shall have negative moment reinforcement as required in conventional reinforced concrete. When the composite slab is not designed for continuity over structural supports, the effects of cracking of the concrete shall be considered and adequate crack control measures shall be taken where necessary.

Table 2: Minimum Shrinkage and Temperature Reinforcement

Concrete Cover $h_c = (h - d_d)$ (mm)	Minimum Area of Reinforcement Required (mm ² /m of slab width)
$h_c \leq 80$	60
$80 \leq h_c \leq 150$	$(3h_c - 180)$
$150 \leq h_c$	$1.8h_c$

Notes:

- (1) Shrinkage and temperature reinforcement alone is not intended to resist negative bending moments. Additional reinforcement must be provided as required by a structural design if negative bending is to be resisted.
- (2) The recommended minimum temperature and shrinkage reinforcement, usually in the form of welded wire mesh, if properly placed and if good concreting practices such as low water/cement ratio, low slump and proper curing are followed, will often be sufficient to cause the shrinkage and temperature stresses to be relieved in small local cracks rather than accumulating over greater distances. It is recommended that the mesh be placed approximately 25 mm below the top surface of the concrete, particularly in areas of negative moments, such as over supports where bending stresses in the top portion of the concrete add to the shrinkage.
- (3) For applications where a higher degree of crack control is required, the designer should refer to recognized standards of concrete practice and design such as CSA-A23.3.

NOTATIONS

A_s	area of steel deck, mm ² /m of slab width
b	unit width of compression face of composite slab (1000 mm) b_2 Width of bearing perpendicular to deck ribs, mm
b_e	Effective width of concentrated load, perpendicular to the deck ribs, mm
b_o	perimeter of critical section, mm
c	distance from extreme compression fibre to composite neutral axis, mm
d	distance from extreme compression fibre to centroid of steel deck, mm
d_d	overall depth of steel deck profile, mm
E_c	modulus of elasticity of concrete, MPa (see CSA-A23.3)
E_s	modulus of elasticity of steel deck, (203 000 MPa)
f'_c	specified compressive strength of concrete, MPa
f_y	Specified yield strength of steel deck, MPa
h	overall thickness of composite slab, mm
h_c	thickness of concrete cover above top of steel deck, mm
I_c	moment of inertia of composite section based on cracked section and equivalent area of concrete, mm ⁴ /m of slab width
I_d	moment of inertia used for deflection calculations = $(I_c + I_u)/2$
I_u	moment of inertia of composite section based on uncracked section and equivalent area of concrete, mm ⁴ /m slab width
k_1, k_2, k_3, k_4	are shear-bond coefficients obtained from a multi-linear regression analysis of test data from three or more deck thicknesses
k_5, k_6	are shear-bond coefficients obtained from a linear regression analysis of test data for one individual deck thickness
l'	shear span of composite slab, mm
L	span of composite slab measured from centre of supports, mm
M_{ro}	factored moment resistance of over-reinforced composite slab, N.m/m of slab width
M_{ru}	factored moment resistance of under-reinforced composite slab, N.m/m of slab width
t	base steel design thickness, mm
V_r	factored shear-bond resistance, N/m of slab width
V_t	tested shear-bond resistance, N/m of slab width
V_{pr}	factored punching shear resistance, N
x	Distance from centre of concentrated load to nearest support, mm
ν_1	$0.85 - 0.0015 \geq 0.67$
β_1	$0.97 - 0.0025 \geq 0.67$
β_c	ratio of long to short side of concentrated load or reaction area
λ	1.00 for normal density structural concrete 0.85 for semi-low density structural concrete 0.75 for low density structural concrete.
ϕ_c	resistance factor for concrete = 0.65
ϕ_s	resistance factor for steel deck = 0.90
ϕ_v	resistance factor for shear-bond = 0.70

APPENDIX A: FIGURES

Figure A1: Critical Punching Shear Section

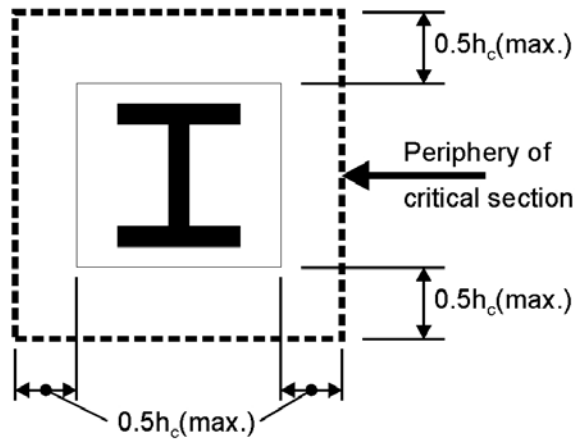


Figure A2: NBC Concentrated Load Condition

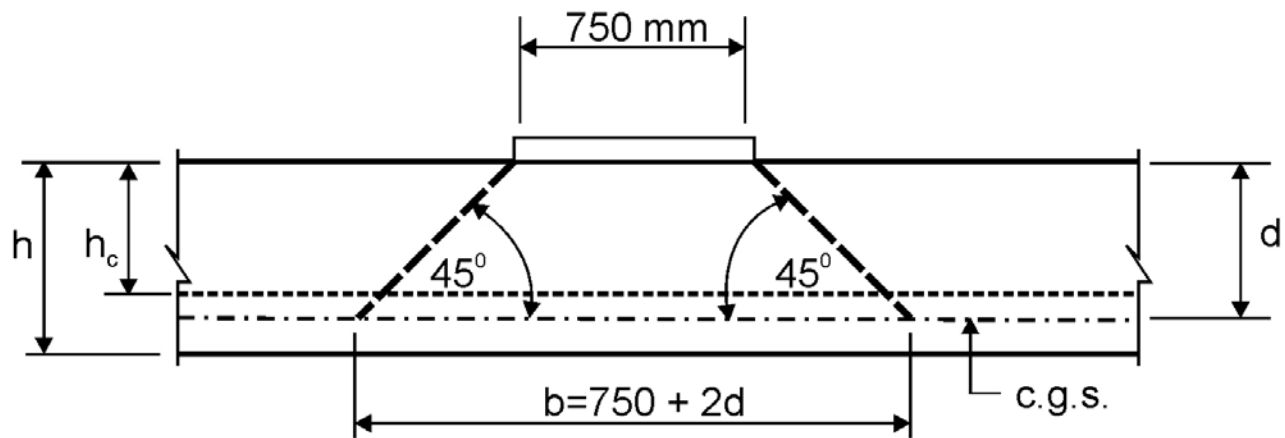
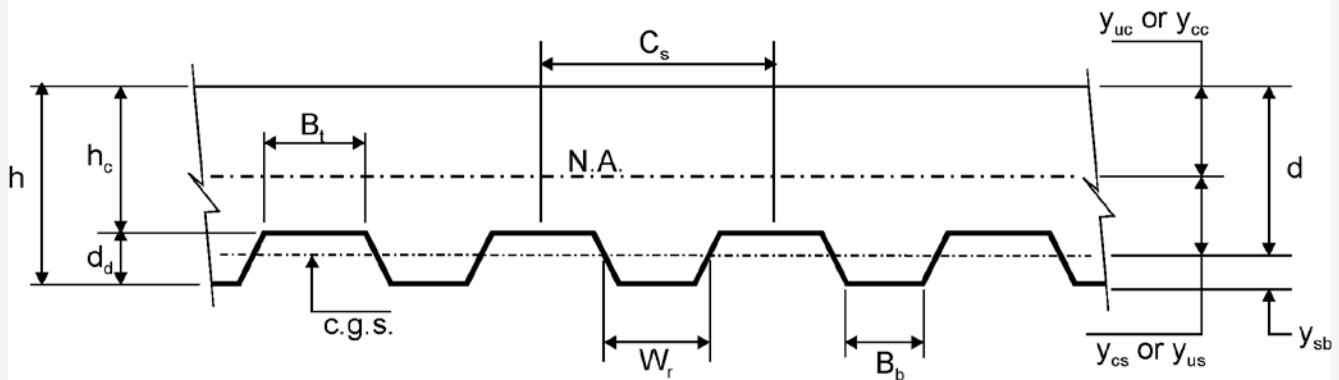


Figure A3: Composite Section



APPENDIX B: SECTION PROPERTIES OF COMPOSITE SLABS**B.1 General**

Using conventional elastic theory and the stated assumptions of Clause 8.1, section properties for computing vertical deflections of composite slabs are derived in accordance with Figure A3.

B.2 Moment of Inertia of Cracked Section

When y_{cc} is equal to or less than the concrete thickness, h_c , above the top of the steel deck, that is $y_{cc} \leq h_c$,

$$y_{cc} = d\{\sqrt{2\rho n + (\rho n)^2} - \rho n\} \quad (\text{B1})$$

Where,

$$d = h - y_{sb}$$

$$\rho = A_s/bd$$

A_s = area of gross steel deck section

n = modular ratio, E_s/E_c (for E_c , see CSA-A23.3-04)

If $y_{cc} > h_c$, use $y_{cc} = h_c$.

The cracked moment of inertia (equivalent steel) is:

$$I_c = \frac{b}{3n} (y_{cc})^3 + A_s (y_{cs})^2 + I_s \quad (\text{B2})$$

Where,

$$y_{cs} = d - y_{cc}$$

I_s = moment of inertia of gross steel deck section.

B.3 Moment of Inertia of Uncracked Section

The neutral axis of the uncracked section is determined by

$$y_{uc} = \frac{\frac{0.5b(h_c)^2}{n} + A_s d + \frac{W_r b d_d}{n C_s} (h - 0.5d_d)}{\frac{bh_c}{n} + A_s + \frac{W_r b d_d}{n C_s}} \quad (\text{B3})$$

Where,

C_s = cell spacing

W_r = average rib width = $0.5(C_s - B_t + B_b)$

B_t and B_b are illustrated in Figure A3

The uncracked moment of inertia (equivalent steel) is:

$$I_u = \frac{b(h_c)^3}{12n} + \frac{bh_c}{n} (y_{uc} - 0.5h_c)^2 + \frac{W_r b d_d}{n C_s} \left[\frac{(d_d)^2}{12} + (h - y_{uc} - 0.5d_d)^2 \right] + I_s + A_s (y_{us})^2 \quad (\text{B4})$$

Where,

$$y_{us} = d - y_{uc}$$

B.4 Moment of Inertia for Design

$$I_d = \frac{I_c + I_u}{2} \quad (\text{B5})$$