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 designers of composite slabs by providing contemporary design criteria in a limit states format.

The material presented has been prepared for the general information of the reader. While the material is believed to be technically correct and in accordance with recognized practice at the time of publication it does not obviate the need to determine its suitability for a given situation. 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.

Acknowledgements

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CONTENTS

CRITERIA
for the
DESIGN
of
COMPOSITE SLABS

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. For design criteria where the composite steel deck acts as a form, ie., during construction, see Reference 1 and for information concerning criteria for the testing of composite slabs, see Reference 2. The full capacity of the composite slab is not achieved until the concrete has attained its specified compressive strength.

2. LIMIT STATES OF STRENGTH

The strength of a composite slab is usually limited by one of the following resistances: (a) shear-bond; (b) flexure of an underreinforced section; (c) flexure of an overreinforced section; and (d) punching shear with concentrated loads.

3. LOADS AND SAFETY CRITERION

3.1 Specified Loads

The following loads shall be considered in the design of composite slabs:

D dead loads, including the mass of the slab and all permanent materials of construction, partitions, and stationary equipment, multiplied by the acceleration due to gravity to convert mass (kg) to force (N);
L live loads, due to intended use and occupancy, snow, rain, etc., as applicable;
Q live load due to wind or earthquake;
T loads due to contraction or expansion caused by temperature changes.

3.2 Safety Criterion

All factored resistances determined herein shall be equal to or greater than the effect of the factored loads, determined in accordance with Clauses 3.2.1 through 3.3.4, which conform to the *National Building Code of Canada*[3].

3.3 Effect of factored loads

3.3.1 **General** The effect of the factored loads, in force units, is the structural effect due to the specified loads multiplied by load factors, α, defined in Clause 3.3.2, a load combination factor, ψ, defined in Clause 3.3.3, and an importance factor, γ, defined in Clause 3.3.4. The combination of factored loads shall be taken as

$$\alpha_D D + \gamma\psi(\alpha_L L + \alpha_Q Q + \alpha_T T) \qquad (1)$$

3.3.2 **Load factors (α)** The load factors, α, shall be taken as follows:

$\alpha_D = 1.25$, except when the dead load resists overturning, uplift, or reversal of load effect, then $\alpha_D = 0.85$
$\alpha_L = 1.50$
$\alpha_Q = 1.50$
$\alpha_T = 1.25$

3.3.3 **Load combination factor (ψ)** The load combination factor, ψ, shall be taken as follows:

(a) when only one of L, Q or T act, $\psi = 1.00$;
(b) when two of L, Q, or T act, $\psi = 0.70$;
(c) when all of L, Q, and T act, $\psi = 0.60$.

The most unfavourable effect shall be determined by considering L, Q, and T acting alone with $\psi = 1.00$; or in combination with $\psi = 0.70$ or 0.60.

3.3.4 **Importance factor (γ)** Unless otherwise specified, the importance factor, γ, shall be taken as follows:

(a) 1.00 for all buildings except as noted in item (b);
(b) not less than 0.80 for
  (i) farm buildings having low human occupancy, defined as having an occupant density not greater than one person per 40 m^2 during normal use; and
  (ii) buildings for which it can be shown that collapse is not likely to cause injury or other serious consequences.

4. RESISTANCE FACTORS

The following resistance factors shall apply:

Shear-bond	$\phi_v = 0.70$
Steel deck	$\phi_s = 0.90$
Concrete	$\phi_c = 0.60$

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:

$$V_r = \phi_v V_t \qquad (2)$$

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:

$$V_t = bd[k_1 t/\ell' + k_2/\ell' + k_3 t + k_4] \qquad (3)$$

or,

$$V_t = bd[k_5/\ell' + k_6] \qquad (4)$$

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; for uniform load, ℓ' is one quarter of the span

t = base steel nominal thickness, mm

k_1, k_2, k_3, and k_4 are shear-bond coefficients obtained from a multilinear regression analysis of test data from three or more deck thicknesses (see Reference 2)

k_5 and k_6 are shear-bond coefficients obtained from a linear regression analysis of test data for one individual deck thickness (see Reference 2).

Testing procedures used to determine the shear-bond coefficients are given in Reference 2.

6. FLEXURAL RESISTANCE

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

$$(c/d) = \frac{A_s F_y}{0.85 f'_c b d \beta_1} \qquad (5a)$$

whereas the ratio that denotes a balanced condition is:

$$(c/d)_b = \frac{609(h - d_d)}{(609 + F_y)d} \qquad (5b)$$

where

β_1 = 0.85 for concrete strengths $f'_c \leq 30$ MPa and is reduced continuously at a rate of 0.08 for each 10 MPa of concrete strenth in excess of 30 MPa, but β_1 shall not be less than 0.65.

h = nominal out-to-out depth of slab, mm

d_d = overall depth of steel deck profile, mm.

6.1 Underreinforced Slabs $(c/d)<(c/d)_b$

The factored moment resistance, in positive bending, of an underreinforced composite ab shall be taken as

$$M_{ru} = \phi_s A_s F_y (d - a/2) \qquad (6)$$

where

$$a = \frac{\phi_s A_s F_y}{0.85 \phi_c f'_c b}$$

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.

6.2 **Overreinforced Slabs $(c/d)>(c/d)_b$**

The factored moment resistance, in positive bending, of an overreinforced composite slab shall be determined by

$$M_{ro} = k\,\phi_c f'_c\, bc\,(d - \bar{k}c) \qquad (7)$$

where

$$c = d\left\{\left[\rho m + \left(\frac{\rho m}{2}\right)^2\right]^{1/2} - \frac{\rho m}{2}\right\}$$

$$\rho = \frac{A_s}{bd}; \qquad m = \frac{\phi_s E_s \varepsilon_{cu}}{k\phi_c f'_c};$$

$$E_s = 203\,000 \text{ MPa}; \qquad \varepsilon_{cu} = 0.003$$

k = 0.723 for concrete strengths, $f'_c \leq 30$ MPa, and is reduced continuously at a rate of 0.068 for each 10 MPa of concrete strength in excess of 30 MPa, but k shall not be less than 0.553.

$\bar{k}$ = 0.425 for concrete strengths, $f'_c \leq 30$ MPa, and is reduced continuously at a rate of 0.04 for each 10 MPa of concrete strength in excess of 30 MPa, but $\bar{k}$ shall not be less than 0.325.

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.

6.3 **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 CAN3-A23.3, *Design of Concrete Structures for Buildings*[4]. The contribution of the portion of the composite steel deck in compression may be neglected.

7. 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:

(a) Where no supplementary transverse reinforcement is provided, the flexural strength shall be taken as that of the plain concrete section above the deck 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. The area of steel, A_s, shall consiste entirely of the supplementary reinforcement, and only the 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 or detailed analysis.

8. 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 shall be determined as follows:

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

where

V_{pr} = factored punching shear resistance, N

h_c = thickness of concrete cover above steel deck, mm

b_o = perimeter of critical section, 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.

9. DEFLECTION CRITERIA

9.1 **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_d, 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.

9.2 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 9.1. Maximum permissible computed deflections are listed in Table 1. Additional 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.

Table 1 (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	span/180(2)
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(4) occuring 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(3)
Roof or floor construction supporting or attached to nonstructural elements not likely to be damaged by large deflections		span/240(5)

(1) *Table 1 is a duplicate of table 9-2 of CAN3-A23.3-M84[4] except for minor editing of footnotes.*
(2) *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.*
(3) *Limit may be exceeded if adequate measures are taken to prevent damage to supported or attached elements.*
(4) *Long-time deflections are determined in accordance with Clause 9.2 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.*
(5) *But not greater than the tolerance provided for nonstructural elements.*

10. NBC CONCENTRATED LOAD CRITERIA

The *National Building Code of Canada*[3] requires that floors be designed for a specified concentrated live load acting on an area of 750 by 750 mm. With a composite slab system, there will be some lateral distribution of 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 centre 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.

11. 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
$80 \leq h_c \leq 150$	$(3h_c - 180)$
$150 \leq h_c$	$1.8h_c$

NOTE: 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.

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 temperatures 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 stresses.

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 Reference 4.

REFERENCES

[1] Standard for Composite Steel Deck, Canadian Sheet Steel Building Institute, Willowdale, Ontario, 1984, Revised 1988.

[2] Criteria for the Testing ofComposite Slabs, Canadian Sheet Steel Building Institute, Willowdale, Ontario, 1984, Revised 1988.

[3] National Building Code of Canada, National Research Council of Canada, Ottawa, 1985.

[4] CAN3-A23.3-M84, Design of Concrete Structures for Buildings, Canadian Standards Association, Rexdale, Ontario, 1984.

[5] Specification for the Design and Construction of Composite Slabs, ASCE Standard 3-84, American Society of Civil Engineers, New York, 1984.

NOTE: Reference 5 is currently the most authoritative U.S.A. document which contains similar information as in References 1 and 2 and this document. Reference 5 also contains a commentary providing detailed explanations of the major specification items.

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_o	perimiter 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
D	specified dead load
E_c	modulus of elasticity of concrete, MPa (see Clause 8.5.1 of Reference 4)
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	$(I_c + I_u)/2$
I_u	moment of inertia of composite section based on uncracked section and equivalent area of concrete, mm^4/m of slab width
k	0.723 for concrete strengths, $f'_c \leq 30$ MPa, and is reduced continuously at a rate of 0.068 for each 10 MPa of concrete strength in exces of 30 MPa, but k shall not be less than 0.553.
$\bar{k}$	0.425 for concrete strengths, $f'_c \leq 30$ MPa, and is reduced continuously at a rate of 0.04 for each 10 MPa of concrete strength in excess of 30 MPa, but $\bar{k}$ shall not be less than 0.325.
k_1, k_2	are shear-bond coefficients obtained from a multilinear regression analysis of test data from three
k_3, k_4	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	specified live load due to intended use and occupancy
M_{ro}	factored moment resistance of overreinforced composite slab, N.m/m of slab width
M_{ru}	factored moment resistance of underreinforced composite slab, N.m/m of slab width
Q	specified live load due to wind or earthquake, whichever produces the more unfavourable effect
t	base steel nominal thickness, mm
T	specified cumulative effects of temperature, creep, shrinkage, and differential settlement
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
α_D	load factor on dead load
α_L	load factor on live load
α_Q	load factor on wind or earthquake load
α_T	load factor on T-load
β_1	0.85 for concrete strengths $f'_c \leq 30$ MPa, and is reduced continuously at a rate of 0.08 for each 10 MPa of concrete strength in excess of 30 MPa, but β_1 shall not be less than 0.65.
β_c	ratio of long to short side of concentrated load or reaction area
γ	importance factor
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
ϕ_s	resistance factor for steel deck
ϕ_v	resistance factor for shear-bond
ψ	load combination factor

APPENDIX A

Figures

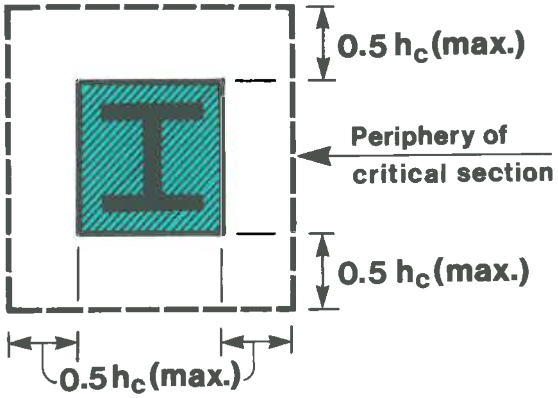

Figure A1: Critical Punching Shear Section

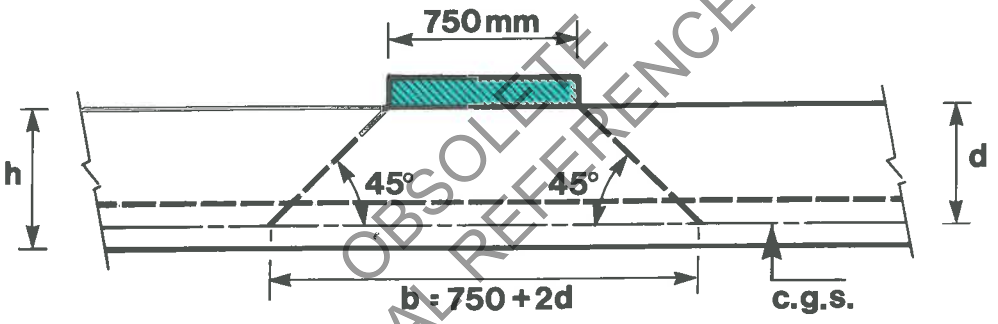

Figure A2: NBC Concentrated Load Condition[3]

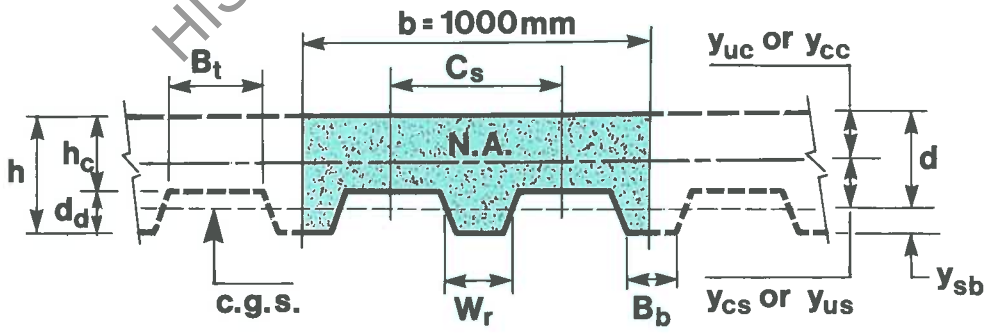

Figure A3: Composite Section

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, $y_{cc} \leq h_c$,

$$y_{cc} = d\{[2\rho n + (\rho n)^2]^{1/2} - \rho n\} \qquad \text{(B1)}$$

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 CAN3-A23.3-M84, Clause 8.5.1)[4]

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

The cracked moment of inertia is:

$$I_c = \frac{b}{3}(y_{cc})^3 + nA_c(y_{cs})^2 + nI_s \qquad \text{(B2)}$$

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

$$y_{uc} = \frac{0.5b(h_c)^2 + nA_s d + W_r d_d(h - 0.5d_d)\,\dfrac{b}{C_s}}{bh_c + nA_s + W_r d_d\,\dfrac{b}{C_s}} \qquad \text{(B3)}$$

where

C_s = cell spacing

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

The uncracked moment of inertia is:

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

where

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

B.4 Moment of Inertia for Design

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

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The Canadian Sheet Steel Building Institute, the national association of the structural sheet steel industry, promotes the use of sheet steel in building construction through engineered design and standards of quality and performance. Activities focus on sheet steel building products and steel building systems for commercial, industrial and institutional applications and similar products and systems for farm applications.

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