

Durability of Composite Decks Exposed to Surface Water

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Key Words

Composite decks; durability; cracks widths; cracking;

Introduction

Composite metal decking systems can be designed to satisfy durability requirements for a 50 year design life by ensuring that flexural crack widths, concrete strength and covers stay within the limits set in the Concrete Structures Standard NZS3101. This article illustrates the use of these code provisions by the way of two examples for the control of cracking due to direct flexure at internal slab supports.

Background

Control of crack widths in concrete structures through the provisions of suitable quantities of reinforcing steel is the primary means of controlling the ingress of moisture into the body of the concrete. If moisture is able to easily flow into and out of the concrete then the protective alkaline environment within the concrete that prevents corrosion occurring in the embedded reinforcing steel becomes neutralised. Composite metal slab systems should also be designed in the same way so as to protect the topping reinforcement as well as prevent unacceptable ingress of water from the upper surface to the decking below the concrete.

The New Zealand Concrete Structures Standard NZS 3101 sets limits on crack width in the context of its design for durability provisions (cl. 2.4.4.6).

Shrinkage control reinforcement in accordance with section 8.8.1 needs to be provided. In large floor plates the provision of structural control joints are also required.

For composite slabs the effect of propping during construction will increase flexural stress in negative reinforcing after props are removed and lead to larger crack widths compared to unpropped cases in which only the superimposed loads will affect tensile stress in the reinforcing.

For further discussion on the durability of metal deck slabs refer to HERA Design and Construction Bulletin 49 and 56.

Examples

Case 1: Unpropped Composite Deck

A slab is designed for a carpark. Durability is achieved by designing in accordance with NZS3101:2006. All notations are in accordance with NZS3101:2006 except as noted.

Slab thickness	$D_s = 135\text{mm}$
Average width of concrete rib	$b_r = 156\text{mm}$
Rib pitch	$P_r = 305\text{mm}$
Height of steel deck rib	$h_{rc} = 55\text{mm}$
Slab span	$L_d = 2.7\text{m}$
Live load	$Q = 2.5\text{kPa}$
Superimposed Dead Load	$SDL = 0.25\text{kPa}$

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Compressive strength of concrete	$f'_c = 25 \text{ MPa}$
Exposure Classification	B1
Minimum cover (table 3.6 NZS 3101)	40mm
Reinforcing mesh	664 Mesh

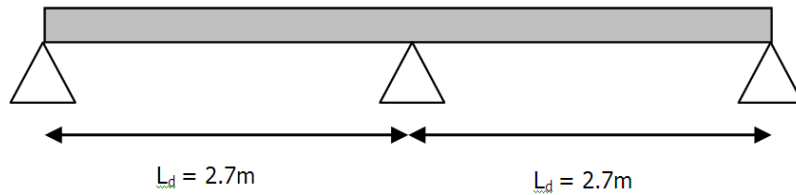


Figure 1: Span arrangement

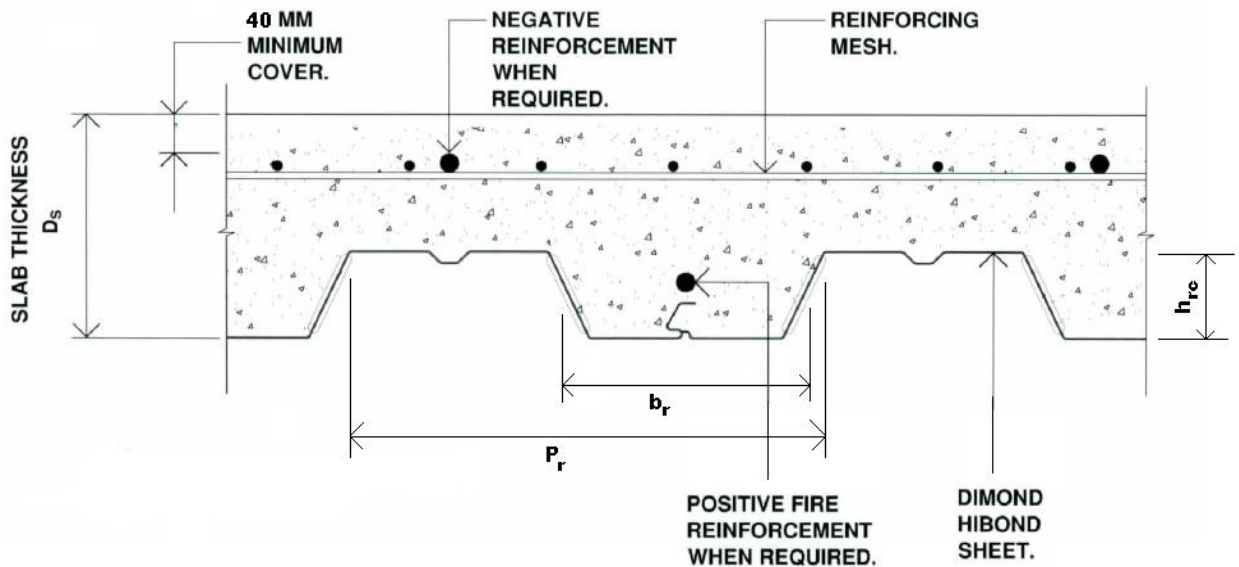


Figure 2: Slab details (Modified from Dimond Manual)

Minimum area of top reinforcement for shrinkage transverse to ribs

$$\frac{A_s}{A_c} \geq \frac{0.7}{f_y} \text{ but equal to or greater than } 0.0014$$

cl 8.8.1 NZS3101

A_s = reinforcement area

A_c = concrete area

$$= 55 \times (156 \times 1000/305) + (135-55) \times 1000$$

$$= 108,131 \text{ mm}^2/\text{m}$$

$$\therefore A_s \geq \frac{0.7}{500} \times 108,131 = 151 \text{ mm}^2/\text{m}$$

664 Mesh has cross sectional area of 188 mm²/m **OK!**

Negative moment at internal support

Consider worst case for negative moment is at internal support of a double span floor slab

$$M^* = \frac{W_u L_d^2}{9}$$

cl C6.7.2(a) NZS3101

As deck slab is unpropped consider serviceability live load only

$$W_u = \text{SDL} + \phi_s Q = 0.25 + 0.7 \times 2.5 = 2.0 \text{ kPa}$$

$$\therefore M^* = \frac{2.0 \times 2.7^2}{9} = 1.62 \text{ kNm}$$

Assessment of surface crack widths at internal support

Design surface crack width is assessed in accordance with clause 2.4.4.6 NZS3101

$$w = 2.0\beta' \frac{f_s}{E_s} g_s$$

where $\frac{f_s}{E_s}$ is the strain at the level of the reinforcement, determined by standard flexural theory for transformed elastic sections

β' is a coefficient given by

$$\beta' = \frac{y - kd}{d - kd}$$

where

kd is the depth of the neutral axis

g_s is the distance from the centre of the nearest reinforcing bar to the surface of the concrete at the point where the crack width is being calculated

y is the distance from the extreme compression fibre to the fibre being considered

(1) First step is to determine depth of neutral axis

Calculate effective width of slab acting in compression (the metal decking is neglected in compression).

$$b = b_r \times \frac{1000}{P_r}$$

$$b = 156 \times \frac{1000}{305} = 511 \text{ mm/m}$$

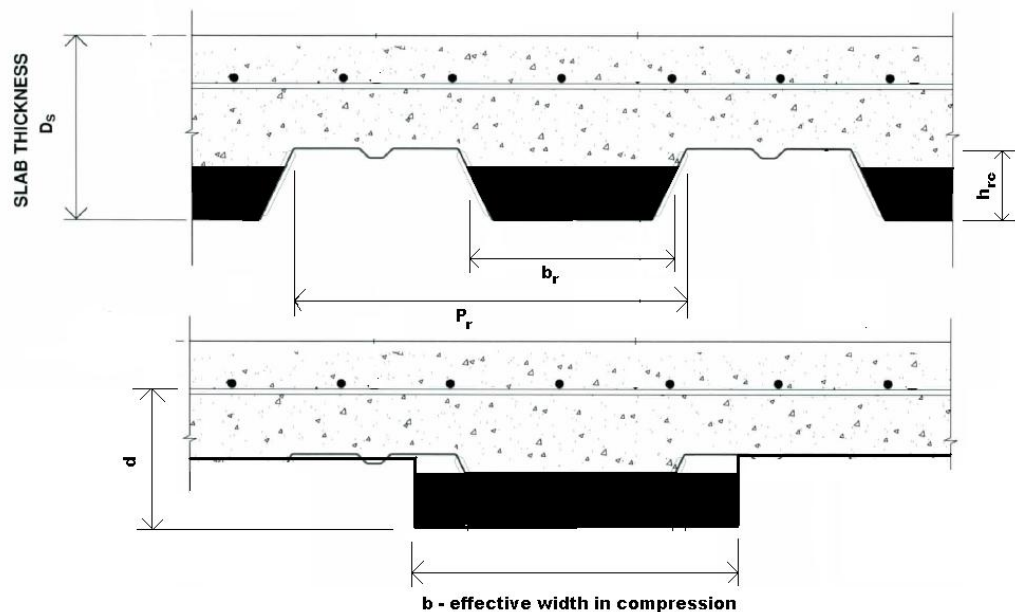


Figure 3: Effective width of slab acting in compression

Calculate effective depth

$$\begin{aligned} \text{Mesh depth} &= 40 + 6 + 6/2 \\ &= 49\text{mm} \\ \\ \text{Effective depth - } d &= D_s - \text{mesh depth} \\ &= 135 - 49 \\ &= 86 \text{ mm} \end{aligned}$$

$$E_c = 3320\sqrt{f'_c} + 6900 = 23,500\text{MPa} \quad \text{cl 5.2.3 NZS3101}$$

$$E_s = 200,000\text{MPa} \quad \text{cl 5.3.4 NZS3101}$$

$$n = \frac{E_s}{E_c}$$

$$n = \frac{200,000}{23,500} = 8.51$$

$$\rho = \frac{A_s}{bd}$$

$$\rho = \frac{188}{511 \times 86} = 0.0043$$

$$\rho n = 0.0043 \times 8.51 = 0.0364$$

$$k = \sqrt{(n^2) + 2\rho n} - \rho n = 0.236$$

$$kd = 0.236 \times 86 = 20.3\text{mm}$$

(2) Determine stress in top reinforcing mesh

$$j = 1 - \frac{k}{3} = 1 - \frac{0.236}{3} = 0.921$$

$$f_s = \frac{M}{A_s j d} = \frac{1.62\text{kNm}}{188\text{mm}^2 \times 0.921 \times 86} = 109\text{MPa} < 0.6f_y \text{ for mesh}$$

(3) Determine β'

$$\beta' = \frac{y - kd}{d - kd} = \frac{135 - 20.3}{86 - 20.3} = 1.75$$

(4) Determine crack width

$$w = 2.0\beta' \frac{f_s}{E_s} g_s \quad \text{cl 2.4.4.6 NZS3101}$$

$$w = 2.0 \times 1.75 \times \frac{109}{200,000} \times 43 = 0.08\text{mm}$$

From table C2.1 NZS3101 recommended maximum surface width of cracks at the serviceability limit state is 0.3mm **OK!**

Also for unpropped construction check the spacing of reinforcement in accordance with cl2.4.4.4.

Case 2: Propped Composite Deck

A slab is designed for a carpark. Durability is achieved by designing in accordance with NZS3101:2006

Slab thickness	$D_s = 150\text{mm}$
Average width of concrete rib	$b_r = 156\text{mm}$
Rib pitch	$P_r = 305\text{mm}$
Height of steel deck rib	$h_{rc} = 55\text{mm}$
Slab span	$L_d = 5\text{m}$

Compressive strength of concrete	$f'_c = 25 \text{ MPa}$
Carpark live load	$Q = 2.5 \text{ kPa}$
Superimposed Dead Load	$\text{SDL} = 0.25 \text{ kPa}$
Slab weight (incl ponding etc)	$G = 3.22 \text{ kPa}$
Exposure Classification	B1
Minimum cover (table 3.6 NZS 3101)	40mm
Reinforcing mesh	664 Mesh
Additional negative reinforcement over supports	HD10@200c/c

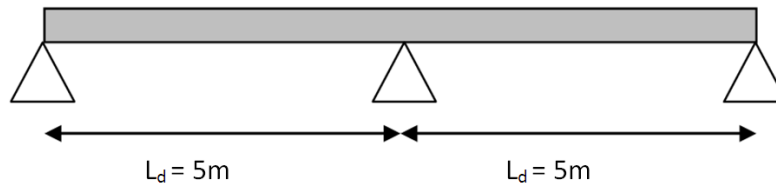


Figure 4: Span

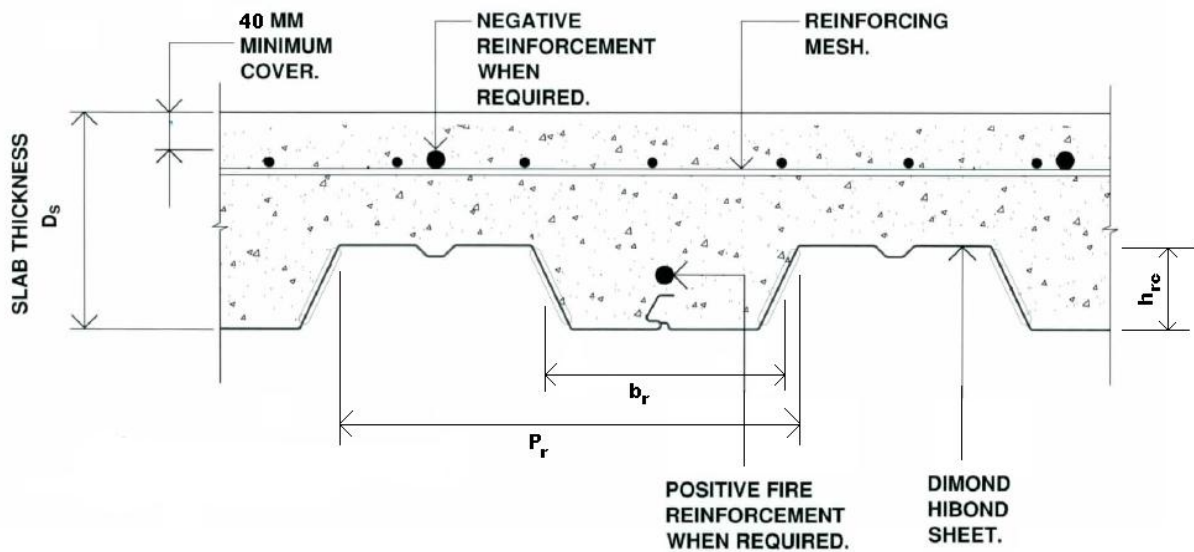


Figure 5: Slab details (Modified from Dimond Manual)

Minimum area of top reinforcement for shrinkage transverse to ribs

$$\frac{A_s}{A_c} \geq \frac{0.7}{f_y} \text{ but equal to or greater than } 0.0014$$

cl 8.8.1 NZS3101

A_s = reinforcement area

A_c = concrete area

$$= 55 \times (156 \times 1000/305) + (150-55) \times 1000$$

$$= 123,131 \text{ mm}^2/\text{m}$$

$$\therefore A_s \geq \frac{0.7}{500} \times 123,131 = 172 \text{ mm}^2/\text{m}$$

664 Mesh has cross sectional area of 188 mm²/m **OK!**

Negative moment at internal support

Consider the worst case for negative moment as internal support of a double span floor slab.

The simplified analysis approach used in NZS3101 C6.7.2 is used to determine negative moment.

$$M^* = \frac{W_u L_d^2}{9}$$

cl C6.7.2(a) NZS3101

As deck slab is propped during construction consider serviceability dead and live load

$$W_u = G + \text{SDL} + \varphi_s Q = 3.22 + 0.25 + 0.7 \times 2.5 = 5.22 \text{ kPa}$$

$$\therefore M^* = \frac{5.22 \times 5^2}{9} = 14.5 \text{ kNm}$$

Assessment of surface crack widths at internal support

Design surface crack width is assessed in accordance with clause 2.4.4.6 NZS3101

(1) First step is to determine depth of neutral axis

Calculate effective width of slab acting in compression (the metal decking is neglected in compression).

$$\begin{aligned} b &= b_r \times \frac{1000}{P_r} \\ &= 156 \times \frac{1000}{305} \\ &= 511 \text{ mm/m} \end{aligned}$$

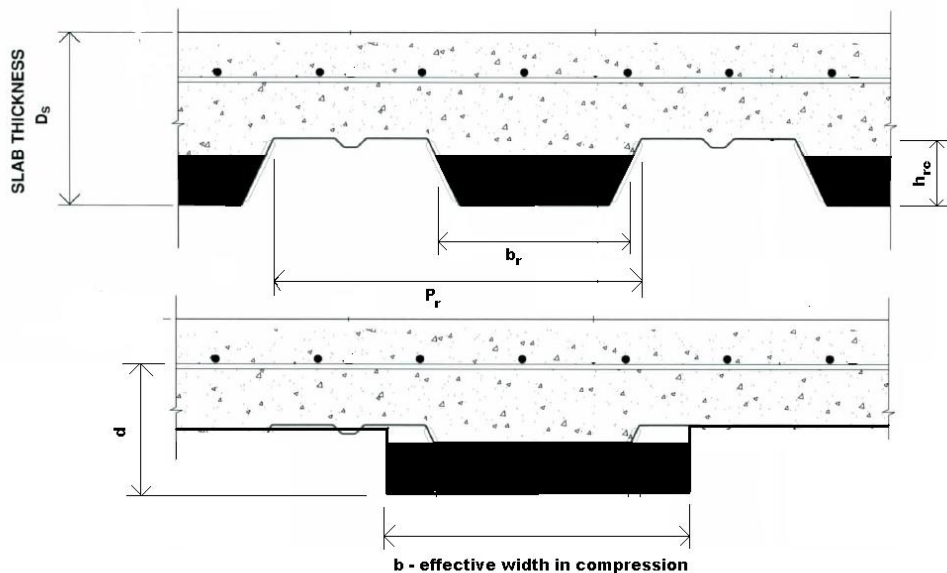


Figure 6: Effective width of slab acting in compression

Calculate effective depth

$$\begin{aligned} \text{Area bars} &= \frac{\pi 10^2}{4} \times \frac{1000}{200} \\ &= 393 \text{ mm}^2/\text{m} \\ \text{Area mesh} &= 188 \text{ mm}^2/\text{m} \\ \text{Total area} &= 581 \text{ mm}^2/\text{m} \\ \text{Bar depth} &= 40 + 10/2 \\ &= 45 \text{ mm} \\ \text{Mesh depth} &= 40 + 10 + 6 + 6/2 \\ &= 59 \text{ mm} \end{aligned}$$

Equivalent depth of reinforcing from top concrete surface

$$= \frac{393 \times 45 + 188 \times 59}{581}$$

$$= 49.5 \text{ mm}$$

Effective depth - d = D_s – equivalent depth of reinforcing from top concrete surface

$$= 150 - 49.5$$

$$= 100.5 \text{ mm}$$

$$E_c = 3320\sqrt{f'_c} + 6900 = 23,500 \text{ MPa}$$

cl 5.2.3 NZS3101

$$E_s = 200,000 \text{ MPa}$$

cl 5.3.4 NZS3101

$$n = \frac{E_s}{E_c}$$

$$n = \frac{200,000}{23,500} = 8.51$$

$$\rho = \frac{A_s}{bd}$$

$$\rho = \frac{588}{511 \times 100.5} = 0.0114$$

$$\rho n = 0.0114 \times 8.51 = 0.097$$

$$k = \sqrt{(n^2) + 2\rho n} - \rho n = 0.354$$

$$kd = 0.354 \times 100.5 = 35.6 \text{ mm}$$

(2) Determine stress in the top reinforcing

$$j = 1 - \frac{k}{3} = 1 - \frac{0.354}{3} = 0.882$$

$$f_s = \frac{M}{A_s j d} = \frac{14.5 \text{ kNm}}{588 \text{ mm}^2 \times 0.882 \times 100.5} = 278 \text{ MPa} < 0.6f_y \text{ for wire mesh and } 0.85f_y \text{ for rebar}$$

(3) Determine β'

$$\beta' = \frac{y - kd}{d - kd} = \frac{150 - 35.6}{100.5 - 35.6} = 1.76$$

(4) Determine crack width

$$w = 2.0\beta' \frac{f_s}{E_s} g_s$$

cl 2.4.4.6 NZS3101

$$\therefore w = 2.0 \times 1.76 \times \frac{278}{200,000} \times 45 = 0.22 \text{ mm}$$

From table C2.1 NZS3101 recommended maximum surface width of cracks at the serviceability limit state is 0.3mm **OK!**

For propped construction also check the spacing of reinforcement in accordance with cl 2.4.4.4 NZS3101

References

Standards New Zealand, NZS3101: Part 1: 2006 Concrete Structures Standard Part 1 – The Design of Concrete Structures, Wellington, 2006

Standards New Zealand, NZS3101: Part 2: 2006 Concrete Structures Standard Part 2 – Commentary on the Design of Concrete Structures, Wellington, 2006