Reinforced Concrete Buildings Series

Addendum No. 1

Minimising Crack Control Reinforcement

(Addendum to Design Booklets RCB-1.1(1) and RCB-2.1(1))

OneSteel Reinforcing

Guide to Reinforced Concrete Design

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Produced by the

Centre for Construction Technology and Research
University of Western Sydney

Contributors

Dr. Mark Patrick
Centre for Construction Technology and Research

Reviewed by

Prof. Russell Bridge
Centre for Construction Technology and Research

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Preface

This addendum is part of OneSteel Reinforcing's Guide to Reinforced Concrete Design that has been produced to promote the superiority of OneSteel Reinforcing's reinforcing steels, products and technical support services. The Guide covers important issues concerning the design and detailing of Reinforced Concrete Buildings, Residential Slabs and Footings, and Concrete Pavements. The use of 500PLUS® reinforcing steels is featured in the booklets. Special attention is given to showing how to get the most benefit from these new, superior high-strength steels.

The design booklets of the Reinforced Concrete Buildings Series have each been written to form two separate parts: Part 1- AS 3600 Design which provides insight into major new developments in AS 3600; and Part 2 – Advanced Design™ Using 500PLUS® which leads to significant economic advantages for specifiers of OneSteel reinforcing steel. These booklets are supported by 500PLUS® computer software that will prove to be indispensable to design engineers who use AS 3600.

Design booklet RCB-1.1(1) on the crack control of beams to AS 3600 was first published in February, 2000, then republished in August, 2000. Design booklet RCB-2.1(1) on the crack control of slabs to AS 3600 was published in August, 2000. Computer programs 500PLUS-BCC™ (Beam Crack Control) and 500PLUS-SCC™ (Slab Crack Control) were released at the same time as their respective design booklets. These programs perform cross-section analysis for strength and crack control, and the way they should be used has been illustrated in worked examples in the design booklets. The latest booklets and versions of the software are all available on OneSteel Reinforcing CD ROM 2: September 2000.

Recent attempts by others to apply the new design rules presented in RCB-1.1(1) and RCB-2.1(1) to actual design problems, having incorporated the rules into existing computer software for designing reinforced-concrete beams and slabs, have led to concern about the minimum amount of reinforcement required for crack control. This is primarily because it was incorrectly assumed that the minimum area of reinforcement, $A_{st.min}$, required by Clause 8.6.1 of AS 3600-2000, was needed at every location in a tensile zone of a member in a state of flexure. A new design rule is included in this addendum which clarifies that the minimum area $A_{st.min}$ is only required in critical tensile zones likely to be cracked in flexure under serviceability conditions. Checking that the tensile stresses in the reinforcement are not excessive under serviceability conditions is still required in all critical and non-critical tensile zones. Implementing the design procedure in computer software should now be unambiguous. Other important issues that will also assist designer engineers to minimise the amount of crack control reinforcement in beams and slabs – the theme of this addendum – are also covered. These new design recommendations are being considered for inclusion in the revision to AS 3600.

Computer programs 500PLUS-BCC™ (Version 1.2) and 500PLUS-SCC™ (Version 1.1) on OneSteel Reinforcing CD ROM 2 have both been updated to apply the new design rule presented in Section 2.2 of this addendum concerning critical and non-critical tensile zones. Computer program 500PLUS-BCC™ also details the longitudinal reinforcement by spreading it across the flange of a T-beam rather than concentrating it in the web, as described in Section 2.4. These improvements to design practice will greatly assist in minimising crack control reinforcement.

1. INTRODUCTION

New design rules proposed for inclusion in AS 3600-2000 for designing reinforced-concrete beams and slabs for crack control are presented in Section 5.3 of design booklets RCB-1.1(1) “Crack Control of Beams, Part 1: AS 3600 Design” [1] and RCB-2.1(1) “Crack Control of Slabs, Part 1: AS 3600 Design” [2].

Some important additional design rules are included in Section 2 of this addendum, which has been prepared to assist design engineers to minimise the amount of crack control reinforcement that they have to place in beams and slabs. These additional rules have also been recommended for inclusion in AS 3600-2000.

The implications of using several of these additional rules are examined in Section 3 with a worked example taken from each of the design booklets RCB-1.1(1) and RCB-2.1(1).

2. ADDITIONAL DESIGN RULES

2.1 Internal Areas of Buildings

The crack-control design provisions in AS 3600-2000 are intended to limit crack widths in reinforced-concrete beams and slabs to 0.3 mm under serviceability conditions. For members fully enclosed within a building except for a brief period of weather exposure during construction (exposure classification A1 in Table 4.3 of AS 3600), wet areas (bathrooms, etc.) excluded, wider cracks may occur without adversely affecting durability. Therefore, provided brittle finishes are not applied to the surfaces of these members or they are not exposed to view, then the design rules for crack control may be relaxed.

Specifically, at the discretion of the design engineer, it is recommended that for such internal areas of buildings:

- it is not necessary to comply with items (a), (c), (d) and (e) of Clause 8.6.1 in AS 3600-2000 (see pp. 36-37 of RCB-1.1(1)) for beams;
- it is not necessary to comply with item (c) of Clauses 9.4.1 (see p. 42 of RCB-2.1(1)) for slabs; and
- it is acceptable in slabs to use reinforcement that provides only a minor degree of control over cracking due to shrinkage and temperature effects in accordance with Clause 9.4.3 of AS 3600-2000.

2.2 Critical Tensile Zones for Flexural Crack Control Reinforcement

For economic reasons, it is important to minimise any additional reinforcement that results from using Clause 8.6.1 of AS 3600-2000 to control flexural cracking in reinforced-concrete beams and slabs.

Therefore, particularly for members otherwise governed by minimum strength in bending (Clause 8.1.4.1 or Clause 9.1.1 of AS 3600-2000 for beams or slabs, respectively), use of the following equation for the minimum area of tensile reinforcement, $A_{st.min}$, (Eq. 5.3(3) on p. 36 of RCB-1.1(1) or RCB-2.1(1)) needs to be clarified:

$$A_{st.min} = 3\, k_s\, A_{ct} / f_s \qquad \text{A1(1)}$$

where –

k_s = 0.6 for flexure;

A_{ct} = the area of concrete in the tensile zone assuming the section is uncracked;

f_s = the maximum tensile stress permitted in the reinforcement immediately after formation of a crack, which shall be the lesser of the yield strength of the reinforcement (f_{sy}) and the maximum steel stress given in Table 8.6.1(A) of AS 3600-2000 for the largest nominal diameter (d_b) of the bars in the section; and

the coefficient of 3 arises by having assumed a tensile strength of concrete, f_t, equal to 3.0 MPa.

Equation A1(1) is intended to ensure that multiple flexural cracks will form in peak moment areas. Its use should be restricted to *critical tensile zones* where the following inequality is satisfied (see Fig. A1(1)):

$$M^*_{s.1} \geq M_{crit} \qquad \text{A1(2)}$$

where –

$M^*_{s.1}$ = design bending moment at serviceability limit state, calculated with short-term load factor ψ_s=1.0; and

M_{crit} = critical moment for flexural cracking, the value of which can depend on the direction of bending (i.e. equals value of M^{+}_{crit} or M^{-}_{crit} for positive or negative bending, respectively), calculated assuming a flexural tensile strength of concrete equal to 3.0 MPa (see Eq. A1(3) below).

Outside of the critical tensile zones (in the non-critical tensile zones), it is still necessary to limit the tensile stresses in the reinforcement under the action of M^{*}_{s} and $M^{*}_{s.1}$ as required by Clause 8.6.1. This is necessary in order to control flexural crack widths. The maximum tensile stresses must be limited in the normal manner such that $f_{scr} \leq f_{s.max}$ and $f_{scr.1} \leq 0.8 f_{sy}$, where f_{scr} and $f_{scr.1}$ are calculated assuming a cracked section, for M^{*}_{s} and $M^{*}_{s.1}$, respectively. When applying this requirement: design bending moment, M^{*}_{s}, is calculated at the serviceability limit state with a value for the short-term load factor, ψ_s, taken from AS 1170.1; $f_{s.max}$ is the maximum tensile stress permitted in the reinforcement based on either Table 8.6.1(A)[1] or Table 8.6.1(B) of AS 3600-2000; and f_{sy}=500 MPa for 500PLUS® Rebar or OneMesh500™.

Note: Cracking can occur in non-critical tensile zones due to shrinkage and other effects. Therefore, even in these zones the concrete is assumed to have cracked when calculating steel tensile stresses f_{scr} and $f_{scr.1}$.

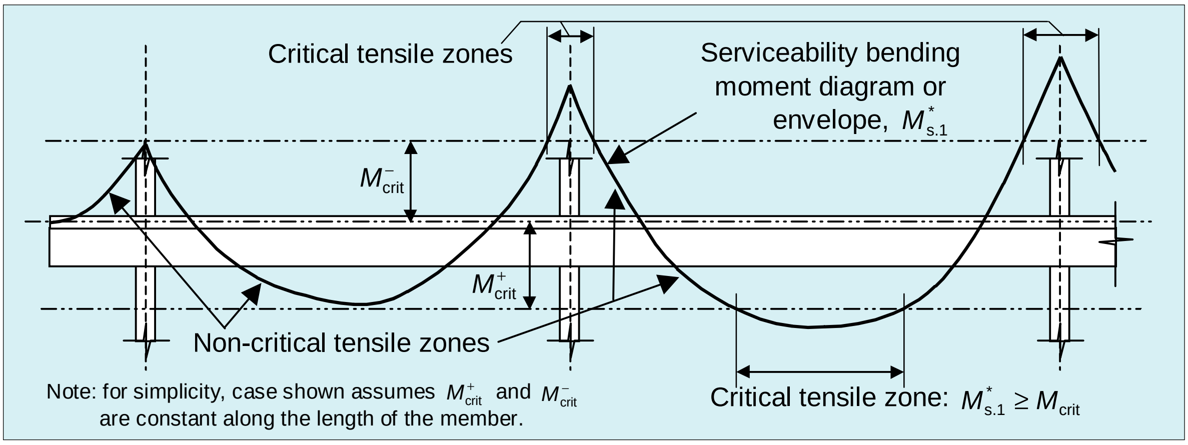


Fig. A1(1) Critical and Non-Critical Tensile Zones for Flexural Crack Control

The reinforcement must be suitably anchored on each side of any cross-section where it is required to control cracking, at least such that it will develop a tensile stress equal to the larger of $f_{s.max}$ and $f_{scr.1}$ calculated at the cross-section of concern. This can affect where the reinforcement may be terminated, and is an additional requirement to consider when anchoring the tensile steel.

Assuming a flexural tensile strength of concrete equal to 3.0 MPa (consistent with Eq. A1(1)), the critical moment, M_{crit}, (kNm) can simply be calculated as:

$$M_{crit} = 3.0 Z \times 10^{-6} \qquad \text{A1(3)}$$

where –

Z = section modulus of the uncracked section (mm^3), referred to the extreme fibre at which flexural cracking occurs, which can be directly calculated using equations given in design booklets RCB-1.1(1) and RCB-2.1(1) for I_{uncr}, the uncracked second moment of area.

[1] It is recommended in RCB-2.1(1) (see pages 22 and 38 therein) that the values of maximum steel stress in Table 8.6.1(A) should be reduced for slabs with an overall depth, D_s, not exceeding 300 mm and with bar diameters, d_b, less than 20 mm.

2.3 Crack Control of Slabs for Shrinkage and Temperature Effects

As well as providing sufficient reinforcement to control flexural cracking of slabs according to Clause 8.6.1 and the new additional rule in Section 2.2, cracking due to shrinkage and temperature effects must be controlled. For this purpose, slabs must also be designed in accordance with Clause 9.4.3 of AS 3600-2000. This clause requires the influence of flexural action, the degree of restraint against in-plane movements and the exposure classification all to be taken into account when detailing reinforcement for this purpose in the primary or secondary directions of a slab. The area of reinforcement required must be fully anchored on both sides of any transverse cross-section where a crack could form.

For restrained slabs with exposure classification A1 or A2, designing for a minor degree of control over cracking is not considered acceptable for slabs with critical or non-critical tensile zones designed for flexural crack control in accordance with Clause 8.6.1. Therefore, restrained slabs with exposure classification A1 or A2 must be designed for either a moderate or strong degree of control over cracking as defined in AS 3600.

2.4 Placement of Longitudinal Tensile Reinforcement Across Top-Flange of T-Beams

Common practice has been to concentrate the area of longitudinal tensile reinforcement, A_{st}, required for bending strength in the support regions of continuous T-beams, within the region of the beam web (see Fig. A1(2)(a)). Additional longitudinal reinforcement is then required in the flange of the beam for crack control. In addition, the bars concentrated in the web may need to be placed in two layers in the top face, which can increase congestion, but also reduces the effective depth of the tensile reinforcement thus reducing its efficiency. Therefore, the total area of longitudinal tensile reinforcement can be considerably in excess of A_{st} if bars are arranged in this manner.

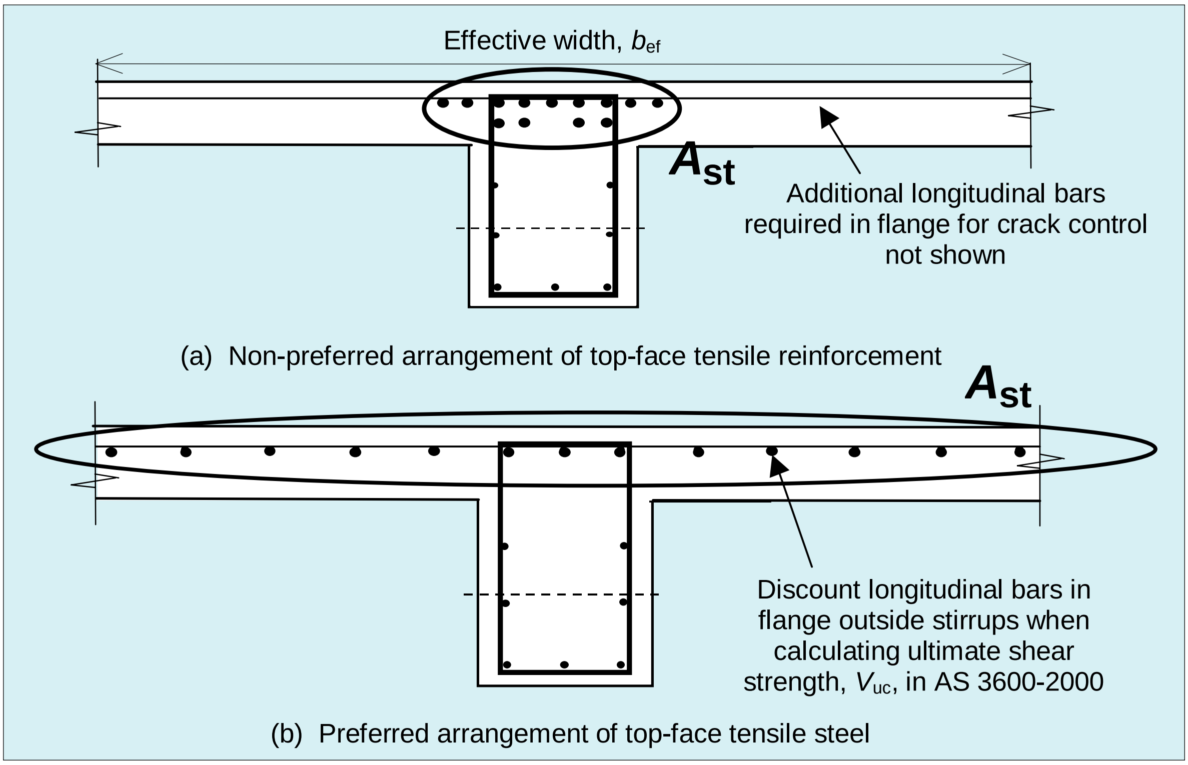


Fig. A1(2) Alternate Ways of Arranging Top-Face Longitudinal Tensile Reinforcement in a Reinforced-Concrete T-Beam

A more effective way of arranging the bars is to distribute them approximately uniformly across the effective width, b_{ef}, of the beam (see Fig. A1(2)(b)). Then it is possible that the area of longitudinal tensile reinforcement, A_{st}, required for bending strength will also be sufficient for flexural crack control (see Example 1 in Section 7.2 of RCB-1.1(1)). However, many of the bars spread across the flange will fall outside the stirrups. It is conservative to ignore the presence of this reinforcement when calculating the component of ultimate shear strength, V_{uc}, which arises excluding shear reinforcement, in accordance with Clause 8.2.7.1 of AS 3600-2000. Some additional vertical shear reinforcement may be required in support regions, which is not normally of any economic significance compared with the savings that result from the reduced amount of longitudinal steel.

2.5 Methods of Analysis

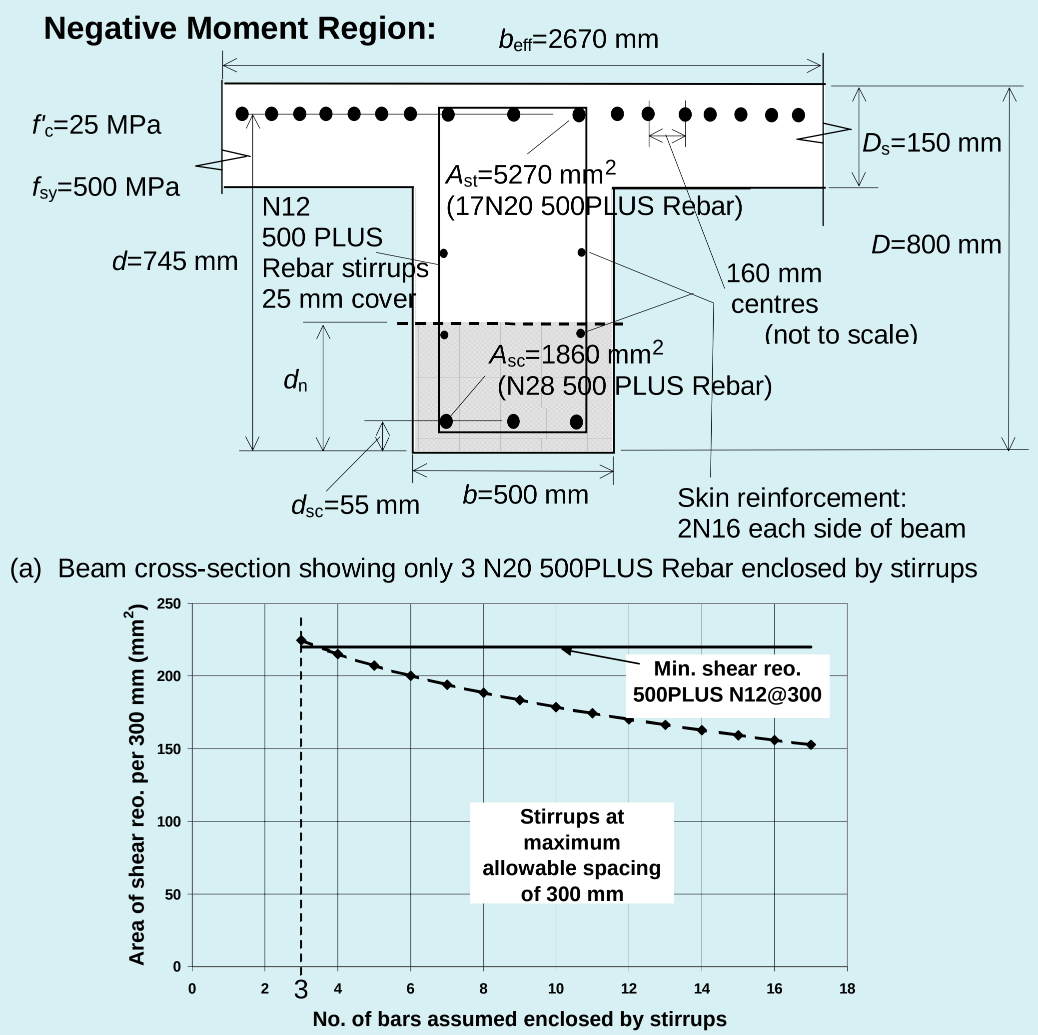
Some of the methods of analysis in Section 7 of AS 3600-2000 are based on strength considerations only, and should be used with care if designing for crack control. Two examples of these are the "Simplified Method for Reinforced Two-Way Slabs Supported on Four Sides" (Clause 7.3), and "Plastic Methods of Analysis for Slabs" (Clause 7.9). These methods usually result in lower negative design bending moments, M^{*-}, and higher positive design bending moments, M^{*+}, for the strength limit state than would be obtained using elastic analysis.

The value of the degree of moment redistribution, η, is unknown to the designer, so the serviceability design bending moments cannot be estimated accurately from the strength design bending moments. Moreover, the serviceability negative design bending moments, M_s^{*-} and $M_{s.1}^{*-}$, calculated using elastic analysis, can even exceed M^{*-}. Therefore, yielding of the reinforcement under service loads can occur, leading to uncontrolled cracking, unless the reinforcement is distributed more in accordance with elastic analysis (see Example 2 in Section 7.3 of RCB-2.1(1)). This can lead to significant amounts of additional top steel being placed in support regions although not required for strength [3]. The overall efficiency of the design is accordingly reduced, putting into question whether these methods of analysis should be used when crack control is important. Less reinforcement may be required overall by using elastic analysis to calculate the design action effects for both the strength and serviceability limit states.

3. WORKED EXAMPLES IN DESIGN BOOKLETS

3.1 Design Booklet RCB-1.1(1) – Crack Control of Beams

Example 1 in Section 7.2 of RCB-1.1(1) addresses the design of a two-span continuous T-beam for bending strength and flexural crack control. Vertical shear design is not discussed. Originally, the negative moment region was detailed with 12Y28 bars (A_{st}=7440 mm^2, f_{sy}=400 MPa) arranged in a similar fashion to the bars in Fig. A1(2)(a). The beam was redesigned using 500PLUS® Rebar. The most efficient design was determined as being 17N20 bars (A_{st}=5270 mm^2, f_{sy}=500 MPa), representing a 29% saving in cross-sectional area of tension steel. This large reduction in steel area was due to a combination of factors, viz.: the increase in design yield strength from 400 to 500 MPa; an increase in effective depth with only one rather than two layers of bars in each face; and the use of the smaller diameter bars in the top face, which provide adequate crack control under higher serviceability tensile stresses. The details recommended for the negative moment region of the beam are shown in Fig. A1(3)(a).



(a) Beam cross-section showing only 3 N20 500PLUS Rebar enclosed by stirrups

(b) Effect of varying number of bars enclosed by stirrups in peak negative moment region

Fig. A1(3) Vertical Shear Design of Negative Moment Region for Beam in Example 1, Section 7.2 of RCB-1.1(1)

The negative moment region of the beam incorporating the N20 500PLUS® Rebar has been designed for vertical shear in accordance with AS 3600-2000. The results, shown in Fig. A1(3)(b), indicate that minimum shear reinforcement (N12@300) is still all that is required over the middle support region, even with only three bars enclosed by the stirrups and conservatively ignoring the other fourteen bars when calculating V_{uc}.

3.2 Design Booklet RCB-2.1(1) – Crack Control of Slabs

Example 2 in Section 7.3 of RCB-2.1(1) addresses the design of a rectangular slab for strength and crack control. The reinforcement was detailed according to the calculations presented in Part 5 of the example. It has been possible to reduce the amount of steel in the bottom of the slab by applying the additional design rule presented in Section 2.2 of this addendum, which had not been formulated at the time RCB-2.1(1) was first written. Therefore, the calculations and reinforcement layout drawings in Part 5 are revamped below, as are the drawings of the BAMTEC® reinforcing carpets [4], which are represented in Part 6.

[The following text and figures supersede the corresponding text and figures on pp. 61-67 of RCB-2.1(1).]

Part 5 – Detailing requirements for the reinforcement

The reinforcement in the bottom and top faces of the slab is shown detailed in Figs 7.13 and 7.14, respectively, with the following brief explanation. It should be noted that all the N10 500PLUS® Rebar chosen will be placed in BAMTEC® reinforcing carpets, the final details of which are given in Part 6. This system gives the designer freedom to optimise the design, without being overly concerned about bar spacings and numbers.

(a) In accordance with Clause 9.1.1 of AS 3600-2000, minimum tension reinforcement for bending strength in the (shorter) x-direction equals $0.002\times1000\times175=350$ mm^2/m = N10@230 mm.

(b) Similarly, minimum tension reinforcement for bending strength in the (longer) y-direction equals $0.002\times1000\times165=330$ mm^2/m = N10@240 mm.

(c) In accordance with Clause 9.4.1 of AS 3600-2000, the maximum bar spacing equals min.(300 mm, $2D_s$=400 mm)=300 mm, which both items (a) and (b) satisfy.

(d) In accordance with Clause 9.4.3.2 of AS 3600-2000, for control of cracking due to shrinkage and temperature effects, the minimum area of reinforcement required in the x-direction equals the larger of that required for strength, i.e. $0.002bd$ as above in item (a), and 0.75 times that required by Clause 9.4.3.4, i.e. $0.75\times0.0035\times1000\times200=525$ mm^2/m for exposure classification A1, which requires N10@300 mm in each face if placed equally. It follows that the requirement for minimum bending strength, i.e. N10@230 mm, would then control in that face if applicable.

(e) In accordance with Clause 9.4.3.2 of AS 3600-2000, for control of cracking due to shrinkage and temperature effects, the minimum area of reinforcement required in the y-direction also equals the larger of that required for strength, i.e. $0.002bd$ as above in item (b), and 0.75 times that required by Clause 9.4.3.4, i.e. $0.75\times0.0035\times1000\times200=525$ mm^2/m, which requires N10@300 mm in each face if placed equally. It follows that the requirement for minimum bending strength, i.e. N10@240 mm, would then control in that face if applicable. For simplicity, this will be increased to N10@230 to make it the same as the minimum reinforcement in the x-direction.

(f) The width of the central region in the x-direction equals $0.75L_y=0.75\times10500=7875$ mm. According to the superseded version of 500PLUS-SCC™ (Version 1.0)[2] and Fig. 7.8, this central region must be reinforced in the bottom face with N10@143. However,

[2] As stated in the Preface, Version 1.1 of program 500PLUS-SCC™ supplied on OneSteel Reinforcing CD ROM 2 identifies whether a tensile zone is critical or non-critical according to the inequality Eq. A1(2). Therefore, running this later version of the software avoids having to perform the additional calculations shown in this part of the example.

$M^{*+}_{xs.1} = 19.7$ kNm/m $< M^{+}_{crit} = 20$ kNm/m (calculated using Eq. A1(3) and, for simplicity, ignoring the presence of any reinforcement, which is a conservative assumption). Therefore, in accordance with Eq. A1(2) this is not a critical tensile zone, and it is not necessary to provide minimum reinforcement in accordance with Eq. A1(1). The area of tensile steel needed for bending strength (with $M^{*+}_{x} = 26.6$ kNm/m) is determined as N10@206 (from separate bending strength calculations or running 500PLUS-SCC™, Version 1.1), which can be rounded to N10@200. A check on the serviceability stresses in the steel will be made at this stage. Using Eq. 4.1(1) in RCB-1.1(1), f_{scr}=$f_{scr.1}$=294 MPa (cf. elastic theory gives f_{scr}=$f_{scr.1}$=298 MPa), while from Tables 8.6.1(A) & (B), $f_{s.max}$=320 MPa so crack widths are satisfactory and yielding is avoided (i.e. $f_{scr.1} \leq 400$ MPa) using N10@200. Because this is only a little more than the minimum steel required for bending strength, it will not be curtailed along the span. The width of this central band of reinforcement can be calculated as int.(7875/200)×200=39×200=7800 mm, with 40 bars required. To the sides of this central band, N10@230 are required, which equates to int.((10700-7840)/2/230)=6 bars, but this will be reduced to 5 bars, leaving the bar out over the concrete wall so that it doesn't clash with the vertical bars. A separate bar can be added in the side face of the slab to make up for this.

(g) The width of the central region in the y-direction equals 0.75L_x=0.75×7000=5250 mm. Again, according to the superseded version of 500PLUS-SCC™ (Version 1.0) and Fig. 7.11, this central region must be reinforced in the bottom face with N10@143. However, $M^{*+}_{ys.1} = 8.9$ kNm/m $< M^{+}_{crit} = 20$ kNm/m (calculated using Eq. A1(3) and for simplicity ignoring the presence of any reinforcement). Therefore, in accordance with Eq. A1(2) this is not a critical tensile zone, and it is not necessary to provide minimum reinforcement in accordance with Eq. A1(1). It follows from item (e), that the area of tensile steel that will be provided for minimum bending strength (with $M^{*+}_{y} = 12.0$ kNm/m) equals N10@230, and a check of the steel serviceability stresses f_{scr} and $f_{scr.1}$ using elastic theory shows that they both equal 164 MPa so are satisfactory. Steel at this intensity will be placed over the entire width of the panel to also serve as shrinkage and temperature reinforcement.

(h) The detailing of the tensile reinforcement should comply with Clause 9.1.3 of AS 3600. Therefore, for simplicity all the bottom bars will extend past the internal face of the walls. Because this reinforcement also serves as shrinkage and temperature reinforcement, it must be suitably lapped with L-bars (see item (l) below). The amount of extension will be minimal, and will equal 50 mm so as not to clash with any vertical reinforcement in the concrete walls. The clear spans in the x- and y-directions are L_{nx}=6800 mm and L_{ny}=10300 mm, whereby the overall lengths of the bars will equal L_{nx}+100 mm=6900 mm and L_{ny}+100 mm=10400 mm.

(i) A fundamental requirement when detailing the negative reinforcement in the top face is that its curtailment should be based on the distribution of elastic bending moments. The finite element analysis shows that the contraflexure band is approximately 1400 mm out from the boundary of the slab, which is a little over 0.2L_{nx}. Since Clause 9.1.3.1 of AS 3600 must also be satisfied, which requires a hypothetical envelope of bending moments to be considered, it is clear that the deemed-to-comply arrangement of the top steel shown in Fig. 9.1.3.2 of AS 3600 will be satisfactory. Therefore, and for simplicity, the top-face reinforcement in both the x- and y-directions will be continued approximately 0.3L_{nx}=2040 mm past the inside face of the concrete walls. This can be achieved by using N10 bars 2200 mm long around the perimeter of the slab in the top face.

(j) Again, the width of the central region in the x-direction equals 0.75L_y=0.75×10500=7875 mm. The regions near the walls must be reinforced in the top face with N10@91 (see Fig. 7.9), which can be rounded to N10@90. Because negative bending will not occur over the mid-span area of the central region, minimum reinforcement for bending strength is not needed. However, it follows from item (d) that the minimum reinforcement for shrinkage and temperature equals 525 mm^2/m, being the total provided in both faces. A simplification will be made to assist with efficient bar placement. Namely, N10@270, 7100 mm long bars will extend across the entire width of the slab, with 2N10@90, 2200 mm long bars placed between each adjacent pair of long bars. Therefore, the minimum total area of shrinkage and temperature reinforcement equals N10@270 (top) + N10@200 (bottom) = 696 > 525 mm^2/m. The width of this central band of reinforcement can be calculated as int.(7875/90)×90=87×90=7830 mm, with 88 bars required (starting and finishing with a long bar). To the sides of this central band, N10@230 are required, which equates to int.((10700-7830)/2/230)=6 bars, but this will be reduced to 5 bars, leaving the bar out over the concrete wall so that it doesn't clash with the vertical bars. A separate corner bar can be added to make up for this bar.

(k) Again, the width of the central region in the y-direction equals $0.75L_x$=0.75×7000=5250 mm. This must be reinforced in the top face with N10@121 (see Fig. 7.12), which can be rounded to N10@115, since according to item (e) minimum transverse top-face reinforcement equals N10@230 when minimum strength is required. The width of this central band of reinforcement can be calculated as int.(5250/115)×115=45×115=5175 mm, with 46 bars required. To the sides of this central band, N10@230 are required, which equates to int.((7200-5180)/2/230)=4 bars, but this will be reduced to 3 bars, leaving the bar out over the concrete wall so that it doesn't clash with the vertical bars. A separate corner bar can be added to make up for this bar.

(l) The L-bars that lap with the N10 top and bottom-face bars can be detailed as follows. Firstly, in order to limit their number, N16 bars will be used, which can be bent on site if necessary. They are placed along the entire length of the long side, and in the central region of the short side (see Fig. 7.15). They would be positioned immediately after the two bottom reinforcing carpets are rolled into place. The top carpets can then be rolled out on top of the L-shaped bars. Running 500PLUS-SCC™ shows that N16 bars at 170 mm and 230 mm centres along the long and short sides, respectively, will provide sufficient strength and control flexural cracking. This is also ample steel to control cracking due to in-plane restraint to shrinkage and temperature effects around the boundaries of the slab, viz. N16@230=870 mm^2/m > 525 mm^2/m.

(m) No torsional reinforcement is required in the slab since all the corners are interior.

(n) The vertical shear strength of the slab has been checked separately, and is satisfactory without requiring additional reinforcement.

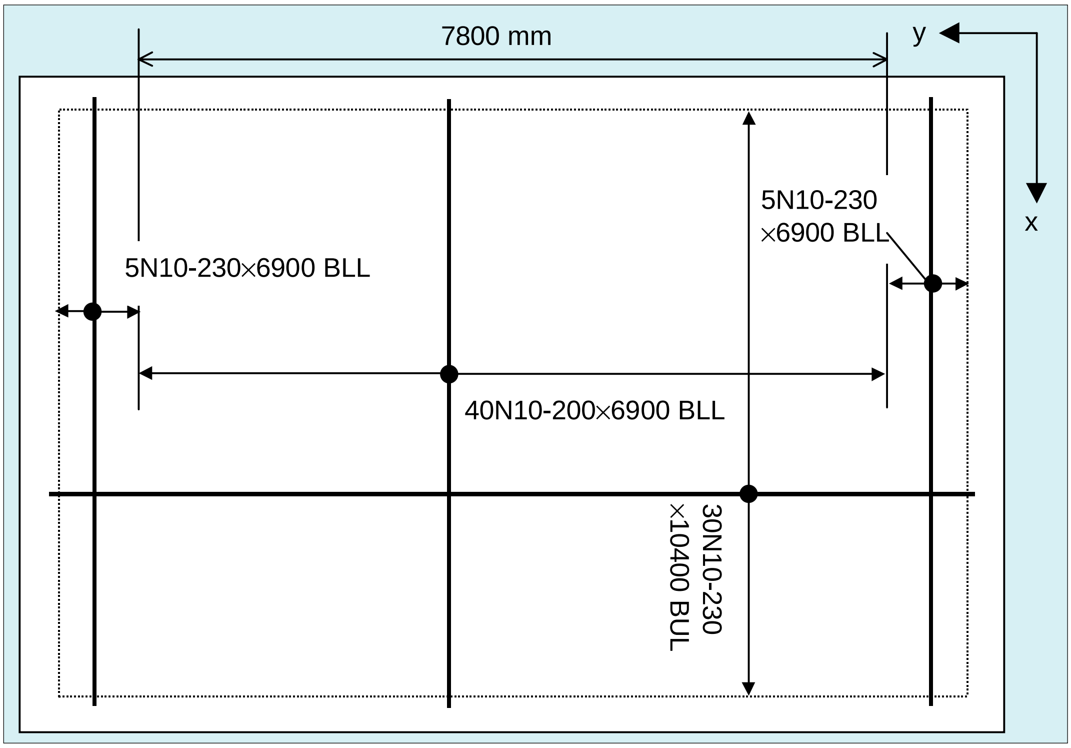


Figure 7.13 Example 2 – Bottom Reinforcement (d_b=10 mm)

(Note: BLL= bottom lower layer, BUL= bottom upper layer)

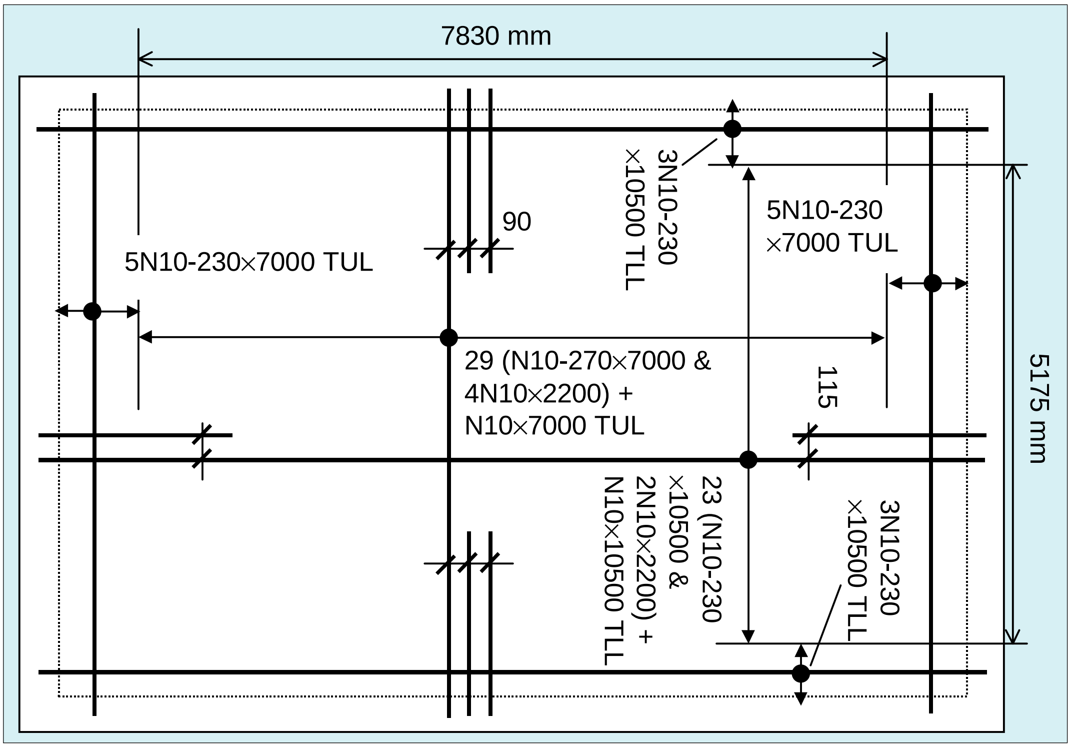


Figure 7.14 Example 2 – Top Reinforcement (d_b=10 mm)

(Note: TLL= top lower layer, TUL= top upper layer)

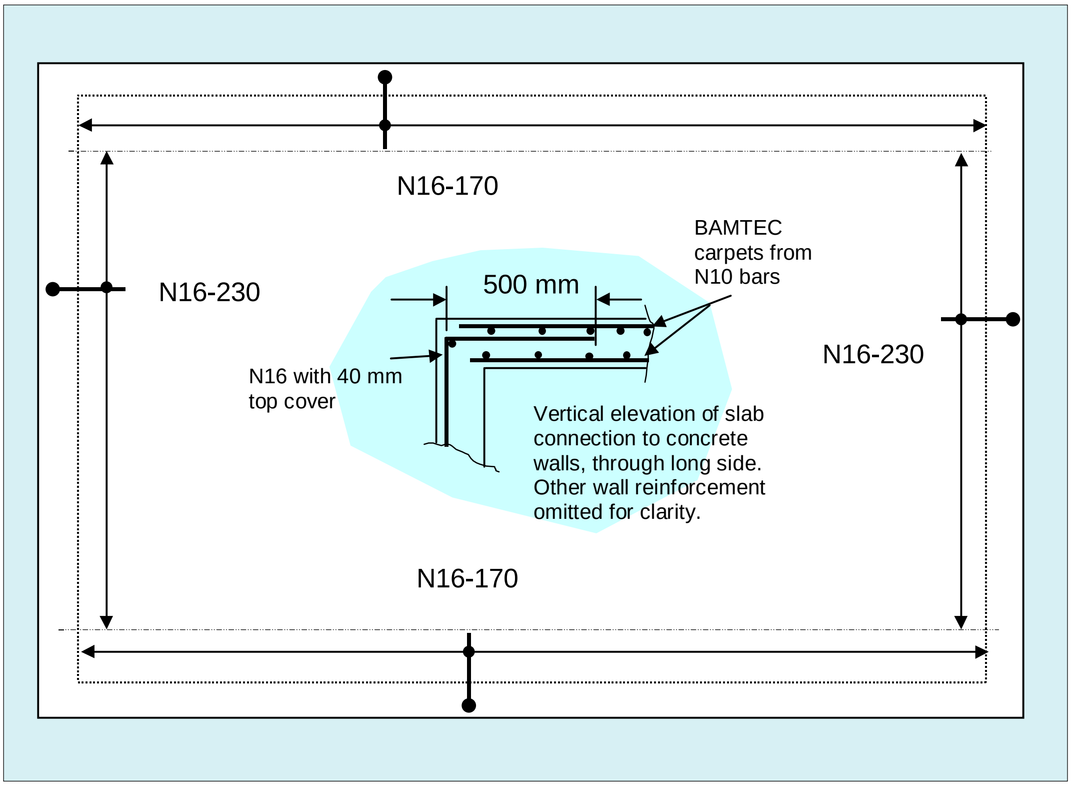


Figure 7.15 Example 2 – L-shaped Splice Bars Around Slab Perimeter (d_b=16 mm)

Part 6 – BAMTEC® reinforcing carpets

BAMTEC® reinforcing carpets are manufactured from 500PLUS® Rebar, Class N reinforcement. The bars are welded in the factory to regularly spaced, thin steel straps that are used to hold the bars in place in the carpet. The carpets are first rolled up for transport to site, lifted into position by crane, and then simply and rapidly rolled out in successive layers that are normally orthogonal to each other. Strip bar chairs are used to support and separate the carpets as necessary.

To conclude this example, the reinforcement in Figs 7.13 and 7.14 has been detailed to form BAMTEC® reinforcing carpets. They are laid according to the details shown in Figs 7.16 to 7.19. It was mentioned in Part 3 of this example that the results of the finite element analysis could have been applied more accurately, which would have lead to savings in reinforcement. Software is being developed to support the use of the BAMTEC® system, which will allow this type of saving to be readily gained. This will enhance the benefits to be had from using BAMTEC® reinforcing carpets. Further information about this system can be obtained from OneSteel Reinforcing or found at www.reinforcing.com. A brochure [4] can be found on OneSteel Reinforcing CD ROM2.

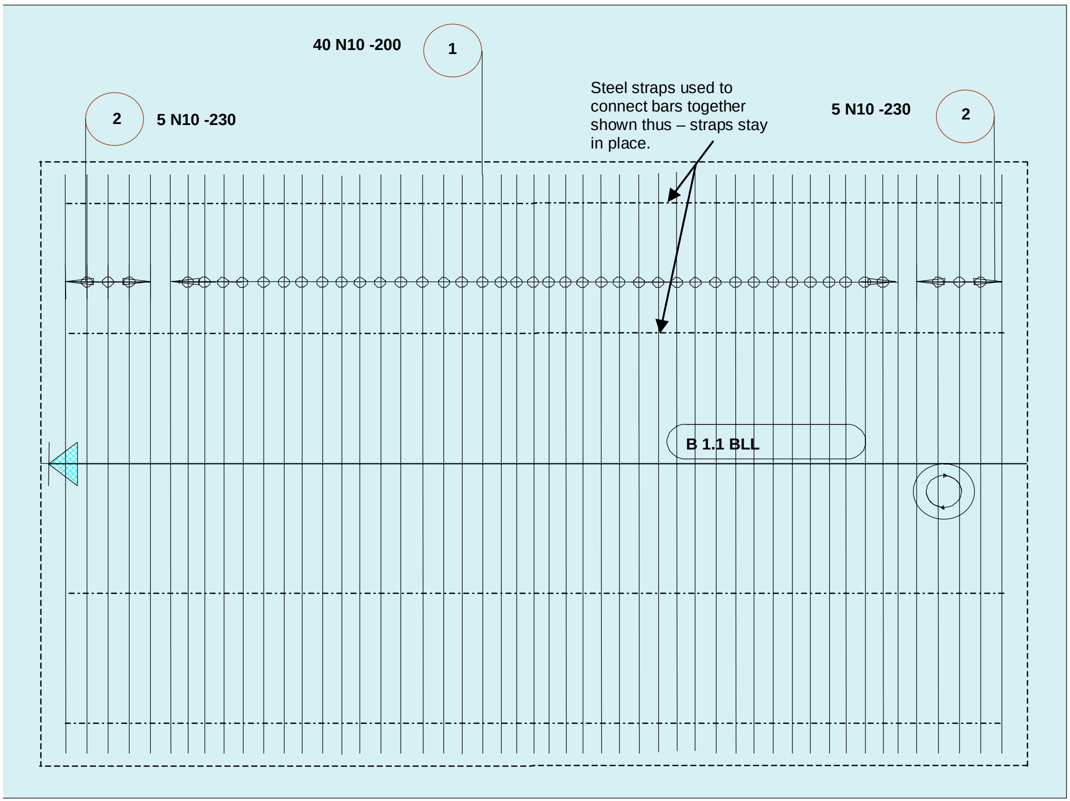


Figure 7.16 Example 2 – BAMTEC® Carpet (Laid 1st – BLL)

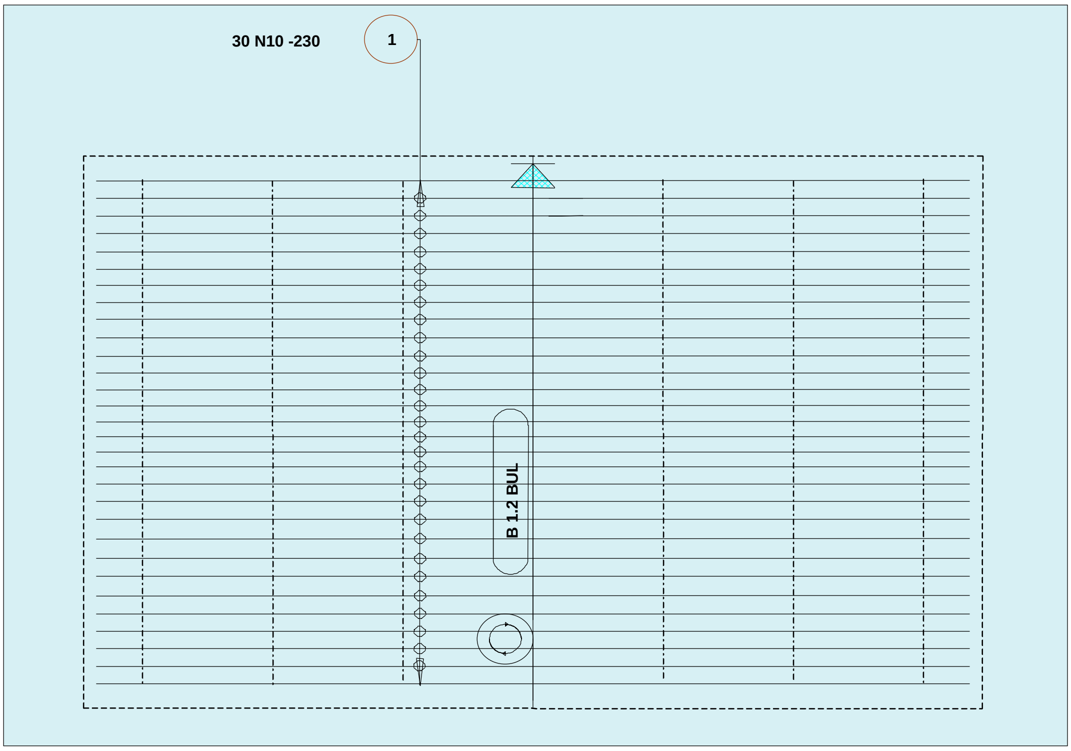


Figure 7.17 Example 2 – BAMTEC® Carpet (Laid 2nd – BUL)

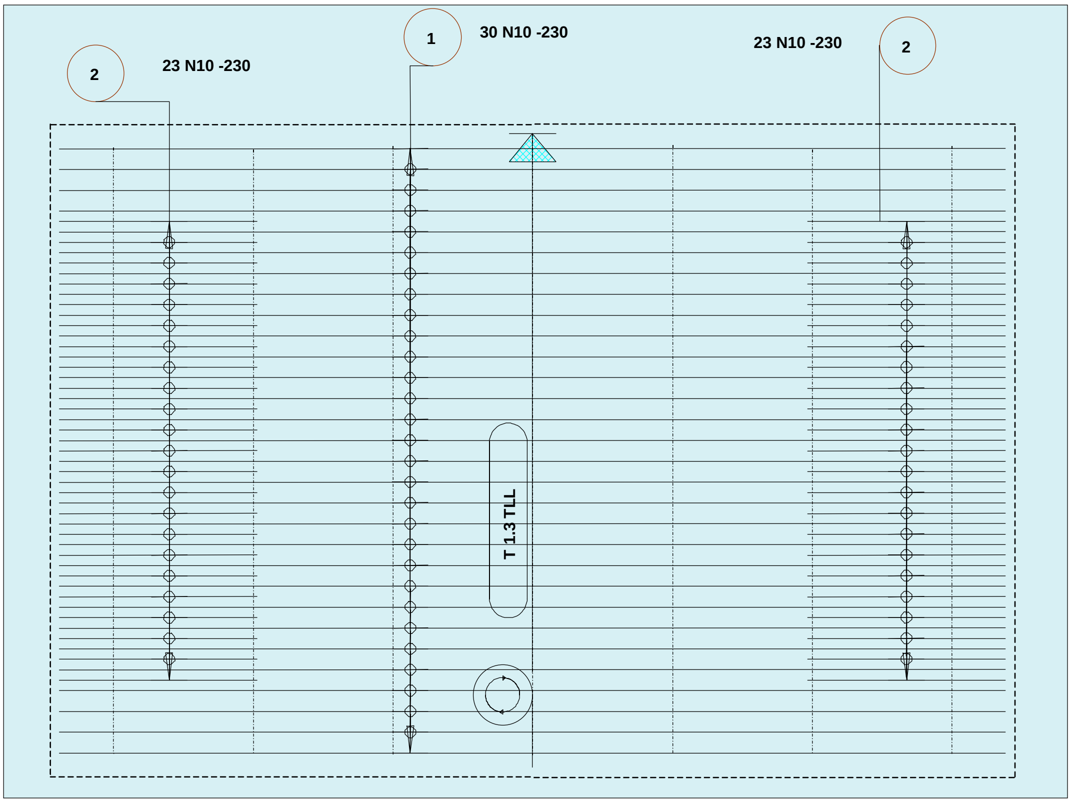


Figure 7.18 Example 2 – BAMTEC® Carpet (Laid 3rd – TLL)

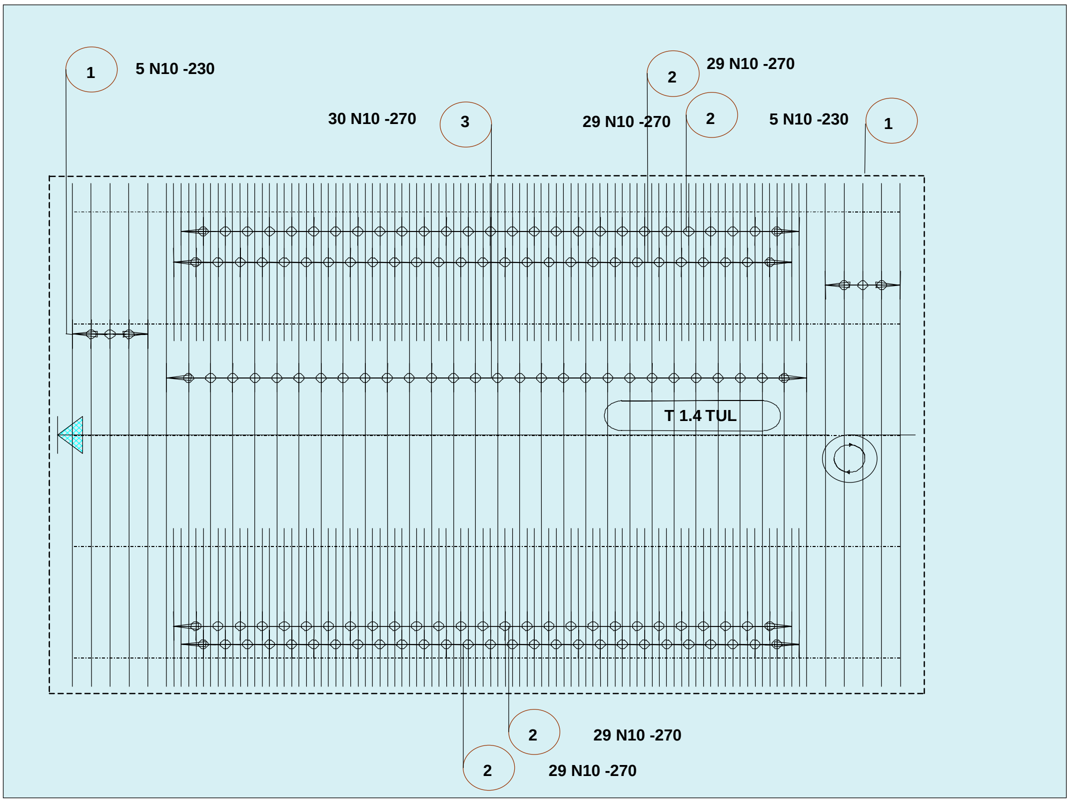


Figure 7.19 Example 2 – BAMTEC® Carpet (Laid 4th – TUL)

4. REFERENCES

1. OneSteel Reinforcing, *Crack Control of Beams, Part 1: AS 3600 Design*, 2nd Edition, Guide to Reinforced Concrete Design, August 2000.[3]
2. OneSteel Reinforcing, *Crack Control of Slabs, Part 1: AS 3600 Design*, 1st Edition, Guide to Reinforced Concrete Design, August 2000.[3]
3. Park, R. and Gamble, W.L., *Reinforced Concrete Slabs*, 2nd Edition, John Wiley & Sons, 2000.
4. OneSteel Reinforcing, *BAMTEC® Concrete Slab Reinforcement System*, August 2000.[3]

[3] Available on OneSteel Reinforcing CD ROM 2: September 2000.

APPENDIX A

REFERENCED AUSTRALIAN STANDARDS

REFERENCE NO.	TITLE
AS 1170.1-1989	Minimum Design Loads on Structures (known as the SAA Loading Code), Part 1: Dead and Live Loads and Load Combinations
AS 3600/Amdt 1/1996-08-05	Amendment No. 1 to AS 3600-1994 Concrete Structures, August, 1996
AS 3600 Supp1-1994	Concrete Structures – Commentary
AS 3600/Amdt 1/1996-12-05	Amendment No. 1 to AS 3600-1994 Concrete Structures – Commentary, December, 1996
DR 99193 CP	Combined Postal Ballot/Draft for Public Comment Australian Standard, Amendment 2 to AS 3600-1994 Concrete Structures, Issued 1 May, 1999
AS 3600-2000[4]	Concrete Structures (including Amendments Nos 1 & 2)

[4] This Standard is yet to be published.

APPENDIX B

NOTATION

The notation used in this booklet has been taken from AS 3600-1994, RCB-1.1(1) and RCB-2.1(1) when appropriate.

Latin Letters

A_{ct}	cross-sectional area of concrete in the tensile zone assuming the section is uncracked
A_{sc}	cross-sectional area of compression steel
A_{st}	cross-sectional area of tension steel
$A_{st.min}$	minimum area of reinforcement permitted in a critical tensile zone (see Eq. A1(1) herein and Eq. 5.3(3) in RCB-1.1(1) and RCB-2.1(1))
b	slab width
b_{eff}	beam flange effective width calculated in accordance with Clause 8.8.2 of AS 3600-1994
d	effective depth of reinforcement at a section in bending
d_b	nominal diameter of reinforcing bar
d_n	depth of elastic neutral axis below compressive face at a cracked section
d_{sc}	depth of centroid of compression reinforcement below compression face
D	overall depth of beam
D_s	overall depth of slab
f'_c	characteristic compressive cylinder strength of concrete at 28 days
f_s	maximum tensile stress permitted in the reinforcement immediately after the formation of a crack
$f_{s.max}$	maximum tensile stress permitted in the reinforcement based on both Table 8.6.1(A) and Table 8.6.1(B) of AS 3600-2000 for crack control design
f_{scr}	tensile stress in reinforcement at a cracked section
$f_{scr.1}$	tensile stress in reinforcement at a cracked section, calculated with ψ_s=1.0
f_{sy}	yield strength of steel reinforcement
f_t	tensile strength of concrete (mean value in Eurocode 2), assumed to equal 3.0 MPa
I_{uncr}	second moment of area of an uncracked section
k_s	a coefficient that takes into account the shape of the stress distribution within the section immediately prior to cracking, as well as the effect of non-uniform self-equilibrating stresses
L_{nx}	shorter clear span of a slab supported on four sides
L_x	shorter effective span of a slab supported on four sides
L_{ny}	longer clear span of a slab supported on four sides
L_y	longer effective span of a slab supported on four sides
M_{crit}	critical moment for flexural cracking
M^{*+}_{crit}	critical positive moment for flexural cracking
M^{*-}_{crit}	critical negative moment for flexural cracking

M^*	design bending moment at strength limit state
M^{*-}	negative design bending moment at strength limit state
M^{*+}	positive design bending moment at strength limit state
M_x^{*+}	positive design bending moment at mid-span, at strength limit state, in x-direction
M_y^{*+}	positive design bending moment at mid-span, at strength limit state, in y-direction
$M_{xs.1}^{*+}$	positive design bending moment at mid-span, at serviceability limit state, in x-direction, calculated with ψ_s=1.0
$M_{ys.1}^{*+}$	positive design bending moment at mid-span, at serviceability limit state, in y-direction, calculated with ψ_s=1.0
M_s^*	design bending moment at serviceability limit state
M_s^{*-}	negative design bending moment at serviceability limit state
$M_{s.1}^*$	design bending moment at serviceability limit state, calculated with ψ_s=1.0
$M_{s.1}^{*-}$	negative design bending moment at serviceability limit state, calculated with ψ_s=1.0
V_{uc}	ultimate shear strength excluding shear reinforcement (see Clause 8.2.7 of AS 3600)
Z	section modulus of uncracked section, referred to the extreme fibre at which flexural cracking occurs (see Eq. A1(3))

Greek Letters

η	degree of moment redistribution
ψ_s	short-term load factor (see AS 1170.1)