TECHNICAL NOTE 6

October 2025

Steel Reinforcement Institute of Australia

DESIGN OF SUSPENDED CONCRETE SLABS REINFORCED WITH MESH TO AS 3600 (2018)

1 SCOPE

This Technical Note addresses the design of suspended concrete floors reinforced with Ductility Class L mesh in accordance with the 2018 edition of the Concrete Structures Standard AS 3600[1].

An example of a suspended reinforced concrete floor constructed using Ductility Class L mesh as a multi-purpose main and secondary reinforcement is shown in **Figure 1**.

While the main focus of this Technical Note is to address design for serviceability and ultimate strength, some aspects of designing with Ductility Class L mesh not directly covered in AS 3600 are also clarified.

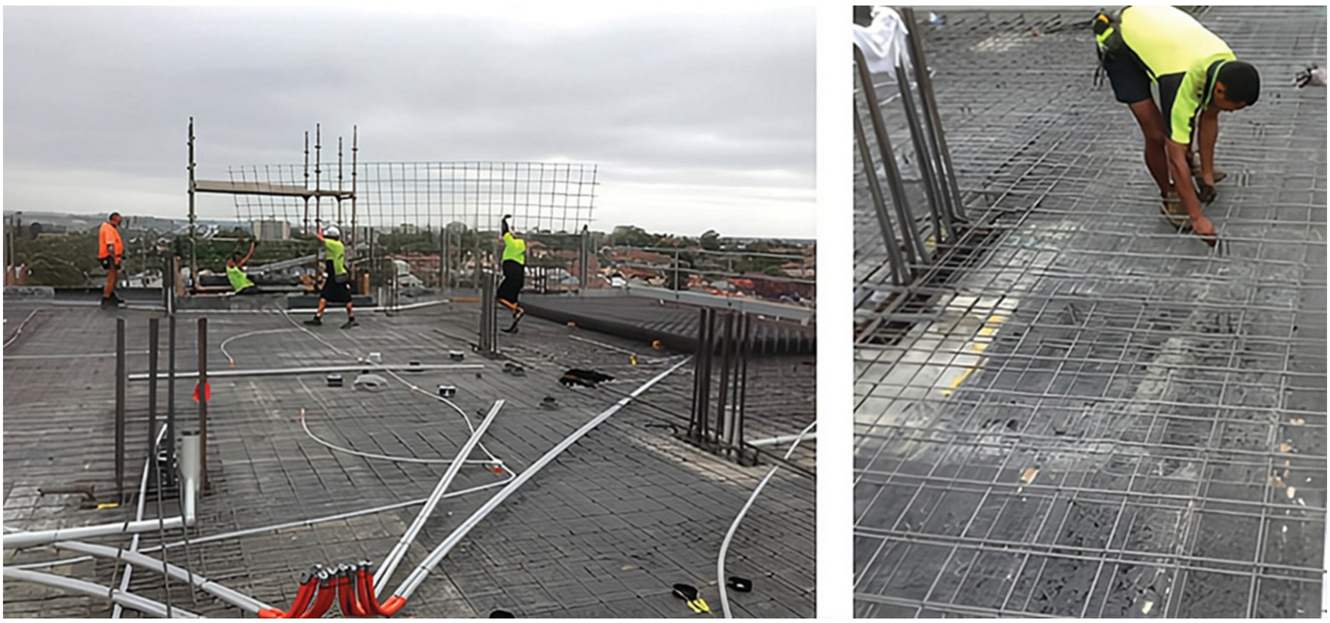


Figure 1 Suspended concrete floor construction using Ductility Class L mesh

2 NATIONAL CONSTRUCTION CODE (NCC)

The two complimentary Australian Standards AS 3600 (2018) Concrete structures and AS/NZS 4671 (2019) Steel for the reinforcement of concrete[2] are both given legal status by being referenced in the current National Construction Code of Australia (NCC)[3]. Designs developed using these Standards comply with the deemed-to-satisfy provisions of the NCC and accordingly fully satisfy its Performance Requirements.

These two Standards define the minimum properties, and design and construction requirements for Ductility Class L mesh as reinforcing steel in suspended concrete floors.

3 AS/NZS 4671 (2019)

The current grade of deformed (ribbed) reinforcing mesh, D500L, referred to in AS/NZS 4671, has a minimum yield stress, f_{sy}, of 500 MPa and is classified as having low (L) ductility, or being Ductility Class L reinforcement, as the bars undergo a cold-rolling (or strain hardening) process to achieve the minimum 500 MPa yield stress. Note that the yield stress of mesh can be up to 600 MPa in accordance with Clause 1.1.2(d) and the notes to Table 3.2.1 of AS 3600.

The ductility of mesh is characterised by uniform strain, ε_{su}, and tensile strength-to-yield-stress ratio f_t/f_{sy} for which compliance with Section 9 of AS/NZS 4671 must be demonstrated. Minimum lower characteristic values for Ductility Class L mesh are ε_{su} = 1.5% and $(f_t/f_{sy})_k$ = 1.03, meaning that the bars must elongate a minimum of 1.5% and gain a minimum of 3% strength after yielding of the bar. The design rules in AS 3600 are based on this minimum performance requirement being achieved by the reinforcement. Note that significantly higher values can be achieved in practice[4]. As well as satisfying minimum mechanical properties, weld-shear strengths and geometric measurements must also conform to the minimum requirements in AS/NZS 4671.

Cross-sectional areas of commonly available Ductility Class L mesh sizes used in the construction of suspended concrete floors similar to that shown in **Figure 1** are given in **Table 1**.

Table 1 Cross-sectional areas of standard Australian Ductility Class L meshes (from AS/NZS 4671)

Mesh type and reference number	Cross-sectional areas	
	Longitudinal bars mm²/m	Cross-bars mm²/m
RL1218	1112	227
RL1018	709	227
RL818	454	227
SL81	454	454
SL102	354	354
SL92	290	290
SL82	227	227
SL72	179	179
SL62	141	141

4 AS 3600 (2018)

The use of Ductility Class L mesh as main reinforcing steel in suspended concrete floors is permitted by AS 3600, but in recognition of the lower ductility and thus lower capacity for moment redistribution within the structure, the capacity reduction factor has been reduced to 0.65 in the following situations: axial force without bending, bending without axial tension or compression, and bending with axial tension (refer Table 2.2.2 of AS 3600).

Mesh may be used together with Ductility Class N reinforcement or prestressing tendons, but in these cases, AS 3600 recommends in Note 1 to Table 2.2.2, that Designers **should** adopt a maximum value for the capacity reduction factor of 0.65 for the total steel area when designing for strength in bending, with or without axial force.

Ductility Class L reinforcement is also used as main and secondary reinforcement in composite slabs incorporating profiled steel decking in the soffit. The design of composite slabs is covered in AS 2327[5] with similar principles applying.

The members of the suspended concrete floors may comprise beams or slabs, and the slabs may be one-way or two-way.

The following clauses within AS 3600 distinguish between the use of Ductility Class L and N steels as main reinforcement:

1. Clause 1.1.2 *Application* – it is noted that the Standard has been written using Ductility Class N reinforcing steels, and that Ductility Class L "*may be used as main or secondary reinforcement in the form of welded wire mesh, or as wire, bar and mesh in fitments, provided it is not used in any situation where the reinforcement is required to undergo large plastic deformation under strength limit state conditions.*" This excludes it from being taken into account using plastic analysis (Clause 6.7 of AS 3600), which is seldom used in practice anyway due to likely serviceability issues.
2. Table 2.2.2 – significantly lower capacity reduction factors are provided for Ductility Class L reinforcement. Note 1 to Table 2.2.2 recommends that where a combination of Ductility Class N and L bars are used, the maximum value of $\emptyset$ **should** be taken as 0.65.
3. Clause 2.2.4 dealing with strut-and-tie analysis requires that tie reinforcement must be provided by Ductility Class N reinforcement.
4. Clause 6.2 *Linear Elastic Analysis* – this analysis method cannot be used according to Clause 6.2.7.2(a), if Ductility Class L reinforcement is used. However, general structures incorporating Ductility Class L reinforcement may be designed using this Clause provided **moment redistribution is not included in the analysis**. Clause C6.2.1 of the Commentary background to AS 3600[6] states that, "*Notwithstanding the above, the Standard allows the use of Class L reinforcement as main tensile reinforcement if a linear elastic analysis is performed without assuming moment redistribution.*"

   Therefore, the ultimate design bending moments, M^* determined using linear elastic theory are designed for directly, and accordingly are not reduced or increased for moment redistribution as stated in Clause 6.2.7.1 of AS 3600.

   Moreover, beams and one-way slabs may be analysed elastically as individual elements, as may two-way slab systems, provided torsion is taken into account in this latter case. When using Ductility Class L reinforcement, Clause 6.10.2 has specific equations to calculate the negative and positive design moments when using Ductility Class L reinforcement, and Clause 6.10.3 requires that two-way slabs reinforced with Ductility Class L are continuously supported on walls (refer Clause 6.10.3.1(e)). Note that Clause 6.10.4 for two-way slab systems having multiple spans prohibits the use of Ductility Class L steel as main flexural reinforcement when using this simplified design method (refer Clause 6.10.4.1(i)).

5. Clause 6.7 *Plastic Methods of Analysis* – this method may only be used where Ductility Class N reinforcement is used throughout.
6. Clause 6.9.5 – Idealised frame method for structures incorporating two-way slab systems - can only be used provided Ductility Class L reinforcement is **not** used as the main flexural reinforcement.
7. Clause 6.10.2 *Simplified method for reinforced continuous beams and one-way slabs* - slightly different negative and positive design bending moments are calculated in Clauses 6.10.2.2 and 6.10.2.3 respectively when using Ductility Class L reinforcement. Note that the equations for Ductility Class L reinforcement (mesh) should also be used where Ductility Class N and L reinforcement is used together.
8. Clause 6.10.3 *Simplified method for reinforced two-way slabs supported on for sides* – slabs incorporating Ductility Class L reinforcement must be continuously supported on walls (or stiff beams) to limit moment redistribution, and a separate Table 6.10.3.2(B) is provided which gives the bending moment coefficients for Ductility Class L reinforcement, or used together with Ductility Class N reinforcement. Note that if the negative design bending moments at a continuous edge are unbalanced, they can only be redistributed if Ductility Class N reinforcement is the main flexural reinforcement.
9. Clause 6.10.4 *Simplified method for reinforced two-way slab systems having multiple spans* – the design method in this clause can currently only be used if Ductility Class L reinforcement is **not** used as the flexural reinforcement (refer Clause 6.10.4.1(i)).
10. Clause 17.2.1.1 *Reinforcement* – mesh to be used as main or secondary reinforcement may be Ductility Class L or Ductility Class N with a yield stress of up to 600 MPa. Also, "*Ductility Class L reinforcement shall not be substituted for Ductility Class N reinforcement unless the structure is redesigned*". This is due to the different capacity reduction factors and bending moment coefficients provided in AS 3600 that apply to Ductility Class N and L reinforcement.

5 Methods of Analysis for Serviceability and Strength Design of Beams and Slabs

Simplified Methods

The simplified methods in Clause 6.10.2 *Simplified Method for Reinforced Continuous Beams and One-Way Slabs* and Clause 6.10.3 *Simplified Method for Reinforced Two-Way Slabs Supported on Four Sides*, which both allow for the use of Ductility Class L reinforcement, are straightforward to apply and require no special clarification here. Their use will be illustrated in a worked example (refer **Section 15** and **Appendix A**).

Importantly, the uniformly-distributed design load, F_d, used with both of these methods is factored for strength or serviceability as appropriate. For example, for the typical case of a floor designed to support permanent (dead load) action, G, and imposed (live load) action, Q, under ambient temperature conditions: in accordance with AS/NZS 1170.0 (2002)[7], for strength $F_d = 1.2G + 1.5Q$; while for serviceability F_d can include different combinations of G, Q, live load factor ψ and creep and shrinkage factor k_{cs}, depending on the serviceability condition being considered, the method or sequence of construction, etc.

As another important point, Note 2 to Clause 8.6.1 of AS 3600, notes that "*Design bending moments at the serviceability limit state will normally be estimated using elastic analysis. Substantial errors may result where the actual in-service moments are likely to have redistributed significantly from the elastic distribution*". Thus, significant errors can result if serviceability bending moments, M^*_s and $M^*_{s.1}$, are calculated from strength design bending moments, M^*, if these latter values have been affected by moment redistribution assumed in their derivation.

General Linear Elastic Analysis

Scott and Whittle[8] confirm that normal practice when designing concrete buildings incorporating low or normal ductility reinforcing steel is to calculate design bending moment and shear force distributions using linear elastic analysis, and that this is endorsed by all the major international design Codes for both serviceability and ultimate load conditions, despite non-linear effects due to cracking, creep, shrinkage, temperature, etc. In accordance with Clause 6.2.4.2 of AS 3600, the stiffness of flexural members, columns and walls may be based on either (a) the dimensions of the uncracked (gross) cross-sections; or (b) for cracked sections, in accordance with Table 6.2.4. Scott and Whittle investigated using the uncracked concrete section (ignoring the reinforcement), *the uncracked gross section* (including the reinforcement using a modular ratio) or the *cracked transformed section* (ignoring concrete in tension). They explain that because the reinforcement area is unknown at the start of the design process, the uncracked concrete section is normally used, while the other approaches can involve significant iteration depending on how accurately the designer attempts to model the situation. They further explain that moment redistribution will arise at the serviceability and strength limit states due to these and other inaccuracies in the modelling. They recommend for normal design that the simplest *uncracked concrete section* approach be used, as per option (a) above in AS 3600.

6 Deflection Control

Ductility Class L mesh is made from ribbed bars, and in combination with the cross-bars develops strong bond with the surrounding concrete. Its full cross-sectional area may be used when calculating the second moment of area of a cracked section, I_{cr}. Referring to **Table 1**, the cross-sectional areas of the longitudinal or cross-bars may be used for this purpose, taking into account the orientation of the mesh bars to calculate the reinforcement ratio, $\rho = A_s/bd$, when computing I_{cr} in the normal manner using elastic cracked-section theory.

7 Flexural Crack Control

The method for designing for flexural crack control included in AS 3600, as defined in Clauses 8.6.2 and 9.5.2 for beams and slabs, respectively, requires the tensile stresses in the main bars to be computed under serviceability conditions, and compared with maximum allowable values depending on the bar diameter (see Tables 8.6.2.2(A) and 9.5.2.1(A)), or spacing (see Tables 8.6.2.2(B) and 9.5.2.1(B)), which show that small diameter ribbed mesh bars can maintain crack control while sustaining high tensile stresses.

Useful general equations for calculating the necessary cracked section properties (which can also be used for deflection control design) can be found in References 9 and 10 for beams and slabs, respectively. Similar to deflection control design, the appropriate mesh areas for longitudinal and cross-bars given in **Table 1** may be used for this purpose.

8 Crack Control for Temperature and Shrinkage Effects

The full cross-sectional area of Ductility Class L mesh contributes towards controlling cracking in slabs due to temperature and shrinkage effects, as defined in Clause 9.5.3 of AS 3600. Again, the appropriate mesh area (refer Table 1) may be used for this purpose, in both the primary and secondary directions.

Often mesh is sized to control cracking due to temperature and shrinkage effects, particularly in the secondary direction of one-way slabs. The multifunctional mesh may then be supplemented with Ductility Class N bars to resist peak moments and vertical shear.

9 Design Strength in Bending

Theoretical and experimental studies have conclusively shown that Ductility Class L mesh has ample ductility to be able to reliably use ordinary simple plastic or rectangular stress block theory to compute the design bending strength, M^*, of beam or slab cross sections in peak moment regions[11]. Therefore, Clauses 8.1.2 to 8.1.4 of AS 3600 may be used directly in the normal manner for beam or slab cross sections incorporating a layer of Ductility Class L mesh as main reinforcement.

Note that the requirement to use a lower value of Ø = 0.65 when calculating the design strength in bending, M^*, of cross sections reinforced entirely with Ductility Class L mesh, or a combination of Ductility Class N and L reinforcement, is considered to be very conservative[11], as the real strength in bending of a plastic hinge can be expected to be at least twice the design strength in bending, while the method of analysis and load factors can significantly add further conservatism to the design.

10 Design Vertical Shear Strength

The full cross-sectional area of Ductility Class L mesh may be used to compute the reinforcement's contribution (V_{us}) to the ultimate shear strength, V_u, in accordance with Clause 8.2 of AS 3600.

11 Mixing Reinforcing Steels of Different Ductility Classes

Ductility Class N bars are frequently used in practice to supplement the limited cross-sectional area of Ductility Class L mesh in peak moment regions. It will be shown in the worked example (refer **Section 15** and **Appendix A**), that this can provide economical solutions to reduce the impact of the lower Ø factor for bending. That is, by sizing the mesh to control cracking due to temperature and shrinkage effects (for which the mesh is not penalised for its low ductility), and then using Ductility Class N bars lapped with the mesh to provide the necessary additional bending strength, the impact on the total amount of reinforcing steel for a project can be negligible.

Theoretical and experimental studies have confirmed that when the Ductility Class L bars of the mesh and the Ductility Class N bars are effectively in the same plane, they will achieve their full strengths. Therefore, the equivalent area of tensile reinforcement, A_{st}, when the two types of steel are mixed this way, simply equals A_{stN} + 0.77 A_{stL} for the calculation of design strength in bending, M^*, using f_{sy} = 500 MPa, where A_{stN} is the cross-sectional area of the Ductility Class N bars, and A_{stL} is the cross-sectional area of the Ductility Class L bars, for the same width. Using this approach, the capacity reduction factor, Ø = 0.85, combined with the 23% reduction in steel area for the Ductility Class L bars effectively applies a Ø factor of 0.65 to the Ductility Class L bars only, and not the total area of both Ductility Class N and L bars.

12 Fire Resistance

Concrete floors with Ductility Class L mesh as main reinforcement, possibly acting in conjunction with other reinforcement types, are normally simply designed for fire resistance by proportioning the floor members in accordance with Clauses 5.4 to 5.7 of AS 3600 to satisfy structural adequacy, integrity and insulation. No further consideration is usually required.

13 Tensile Lap Length

In accordance with Clause 13.2.3 of AS 3600, a lapped splice for mesh in tension shall be made so that the two edge bars of a mesh sheet overlap the two edge bars of the sheet being lapped, as shown in **Figure 2**. The edge bars may be the longitudinal or cross-bars of a mesh sheet. It should be noted that in accordance with AS/NZS 4671, all of the standard square meshes except SL81 have pairs of longitudinal edge side-lapping bars that are smaller in diameter than the main longitudinal bars, but the lapping detail in **Figure 2** still applies. This is because Clause 7.2.5 of AS/NZS 4671 requires each welded connection to resist a minimum shear force equal to half the yield stress of the bar multiplied by the bar area. That is, two welded connections will allow the bar to develop its full yield stress and therefore provide an adequate lapped splice length between mesh sheets.

The areas of laps should be considered when determining the effective depth of the main bars, and where critical (for example in peak moment regions over supports), lapping should be minimised whenever possible.

With bar reinforcement, it is usually laid in two orthogonal directions, with the bottom layer in the shortest span, which allows the designer to calculate the appropriate effective depths for bending and shear in each direction.

In the case of mesh reinforcement, it is recommended that designers establish the layout of the sheets and the direction of the bars of mesh prior to final design, and particular care is needed in thin slabs or slabs with metal deck formwork, as congestion can occur when a number of sheets are lapped. In the worst-case scenario, up to 8 sheets of mesh with 4 lapping in the bottom and 4 lapping in the top in each location. In these cases, sometimes short lengths of bar reinforcement are used for the laps rather than overlapping the mesh. Some mesh bars may also be cut out to reduce the buildup of lapped splices (refer Note 3 to **Figures A3** and **A4**). Techniques can also include offsetting lapped positions and alternating sheets as shown in **Figures A3** and **A4**. Also, where additional bar reinforcement is used, determine which layer it will be in for calculating covers.

Steel mesh is typically made with bars in each direction in nominal 6 m x 2.4 m sheets. Purpose made mesh is available but only for specific projects and typically large orders.

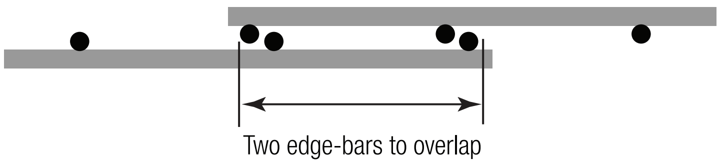


Figure 2 Lapped splice for mesh with alternating layers

14 Earthquake Resistance

Concrete structures in Australia should be designed for the earthquake actions specified in AS 1170.4[12], and Section 14 of AS 3600 contains the design requirements for earthquake actions depending on the assumed ductility of the structure. For non-ductile structural walls (μ = 1), non-structural walls (μ = 1, 2 or 3) and ordinary moment-resisting frames (μ = 2), Ductility Class L reinforcement in the form of mesh can be used as flexural reinforcement, and as fitments in the form of rod, bar or mesh. For the more ductile limited and moderately ductile structural walls (μ = 2 or 3), and intermediate moment-resisting frames (μ = 3), Clause 14.5.1 of AS 3600 requires that "*only Ductility Class N steel or prestressing tendons are used as flexural reinforcement*." Note that Ductility Class L can still be used for fitments and non-flexural reinforcement such as shrinkage and temperature reinforcement.

15 Worked Example

The rectangular two-way slab worked example provided in Reference 10 incorporating Grade 500 Ductility Class N bars, has been redesigned using Ductility Class L mesh as the principal type of reinforcement **Figure A1**. The new design satisfies all of the requirements of AS 3600 (2018). As noted above it is recommended that the layout of mesh and bars be determined so that the effective depths of the reinforcement can be calculated before starting final design. Refer to **Figures A3** and **A4** showing proposed layout.

Note that the slab is supported on all four sides by walls, which satisfies the requirement of Clause 6.10.3.1(e) of AS 3600 for the use of Ductility Class L reinforcement, and the bending moment coefficients from Table 6.10.3.2(B) which apply to Ductility Class L reinforcement (as they assume no moment redistribution occurs – see Clause 6.10.3.2(a)(ii)), have been used to calculate the design bending moments.

In particular, it is shown in the worked example (the detailed design criteria and calculations of which are given in **Appendix A**), that:

- As noted above, the design bending moments for serviceability, M^*_s, can be determined directly using the design rules in Cluse 6.10.3 of AS 3600, thus avoiding having to use some other method for calculating these action effects (noting that finite element analysis was used in Reference 10);
- The Ductility Class L mesh is multi-functional, in particular controlling cracking due to shrinkage and temperature effects under conditions of full restraint, and also serving as main flexural reinforcement under ambient and elevated temperature (fire) conditions;
- Only a minor amount of extra reinforcing steel is required as a consequence of the low ductility of the Ductility Class L mesh compared with Ductility Class N bars;
- The Ductility Class L mesh is augmented by Ductility Class N bars in peak moment regions over the supports, effectively negating the impact of the lower value of $Ø$ = 0.65 for the Ductility Class L mesh; and
- Ductility Class L mesh is fully effective at controlling vertical deflections, and providing for vertical shear strength, particularly in the vicinity of the supporting walls where the maximum shear forces occur.

16 References

1. Standards Australia, AS 3600 *Concrete structures*, 2018.
2. Standards Australia and Standards New Zealand, AS/NZS 4671 *Steel for the reinforcement of concrete*, 2019.
3. Australian Building Codes Board, *National Construction Code*, 2022.
4. Fenwick J.M., Pritchard R.W. and Turner M.D., *Long-Term Quality of Steel Reinforcement and Strand – Implications for concrete Design*, CIA Concrete '05 Conference Proceedings, 2005.
5. Standards Australia and Standards New Zealand, AS/NZS 2327 *Composite structures – Composite steel-concrete construction in buildings*, 2017.
6. Standards Australia, AS 3600:2018 Sup 1:2022 *Concrete structures – Commentary (Supplement 1 to AS 3600:2018)*, 2022.
7. Standards Australia and Standards New Zealand, AS/NZS 1170.0 *Structural design actions, Part 0: General principles*, 2002.
8. Scott R.H. and Whittle R.T., *Moment Redistribution Effects in Beams*, Magazine of Concrete Research, Vol. 57 No. 1, pp. 9-20, Feb 2005.
9. OneSteel Reinforcing, *Crack Control of Beams, Part 1: AS 3600 Design*, Design Booklet RCB-1.1(1), 2nd Edition, Guide to Reinforced Concrete Design, August 2000.
10. OneSteel Reinforcing, *Crack Control of Slabs, Part 1: AS 3600 Design*, Design Booklet RCB-2.1(1), 1st Edition, Guide to Reinforced Concrete Design, August 2000.

11. Patrick M. and Keith J., *New Developments in the Testing, Design and Construction of Concrete Structures incorporating Class L Reinforcing Mesh*, Steel Reinforcement Institute of Australia, (www.sria.com.au), June 2008.

12. Standards Australia, AS 1170.4 *Structural design actions, Part 4: Earthquake actions in Australia*, 2024.

Appendix A – Ductility Class L Mesh Worked Example (Design to AS 3600:2018)

The interior slab shown in **Figure A1** is to be reinforced with Ductility Class L mesh for strength, deflection and crack control.

Note that the design for deflection control is beyond the scope of the worked example and for brevity, not all of the calculations for flexural crack control will be shown.

The low-ductility mesh will be supplemented as required with Ductility Class N bars wherever any additional steel is required for bending strength. When this is done, as already shown, the simple effective area of Ductility Class N bar $A_{st} = A_{stN} + 0.77\ A_{stL}$ will be calculated, for which $\varnothing = 0.85$ when computing $\varnothing M_{uo}$. This is a more general approach to use when Ductility Class L mesh is mixed with Ductility Class N bars, and is equivalent to applying $\varnothing = 0.65$ (ie 0.77 x 0.85) for the Ductility Class L mesh.

Note that if using this approach, where the reduced capacity reduction factor of 0.65 is effectively only applied to the Ductility Class L mesh, the bending moment coefficients are derived from Table 6.10.3.2(B) of AS 3600, which takes into account that moment redistribution does not occur.

The slab is to be cast on 200 mm thick concrete walls that run continuously along each of its sides, thereby satisfying the requirements for use of the simplified method of Clause 6.10.3, which allows the use of Ductility Class L reinforcement in Clause 6.10.3.1(e).

Cogged Ductility Class N bars will be positioned in the outer face of each wall to lap with the top slab mesh reinforcement **Figure A2**. Further, it will be assumed that these bars will have sufficient strength to tie the slab edges down, preventing any uplift or relative rotation with respect to the walls, and thus the edges of the slab are assumed to be continuous in terms of the design bending moments and shears. The exact details of these cranked bars are not presented as they are not important to the worked example.

The slab will be assumed to be ‘fully’ restrained in its horizontal plane by the walls. It follows that the slab will also have to be designed for crack control due to shrinkage and temperature effects in accordance with Clauses 9.5.3.2 *Reinforcement in the primary direction* and 9.5.3.4 *Reinforcement in the secondary direction in restrained slabs* of AS 3600. A moderate degree of control over cracking will be deemed sufficient for the interior slab.

Design Criteria

For simplicity, construction loads that occur after the falsework has been removed will not be considered critical, and the slab will only be designed for the long-term in-service condition. The design loads for strength and serviceability design can be calculated using the following information:

Superimposed dead load, G_{sup} = 1.5 kPa

Live load, Q = 5.0 kPa (*storage area*)

(Note: in accordance with AS/NZS 1170.0[7], ψ_s = 1.0 and ψ_l = 0.6 for storage areas.)

Concrete density, ρ_c = 2450 kg/m^3

Allowance for reinforcing steel, ρ_s = 50 kg/m^3

Additional design parameters are as follows:

Overall depth of slab, D_s = 200 mm (see **Figure A1**)

Minimum concrete cover, c = 20 mm (see **Figure A1**)

Concrete strength grade, f'_c= 32 MPa

Main reinforcement yield stress, f_{sy}= 500 MPa

Main reinforcement ductility classes = L (mesh) and N (bars)

Exposure classification = A1 (interior)

Deflection limits = L/250 long-term, total deflection
= L/500 long-term, incremental deflection

Fire rating (FRL) = 2 hours (120/120/120)

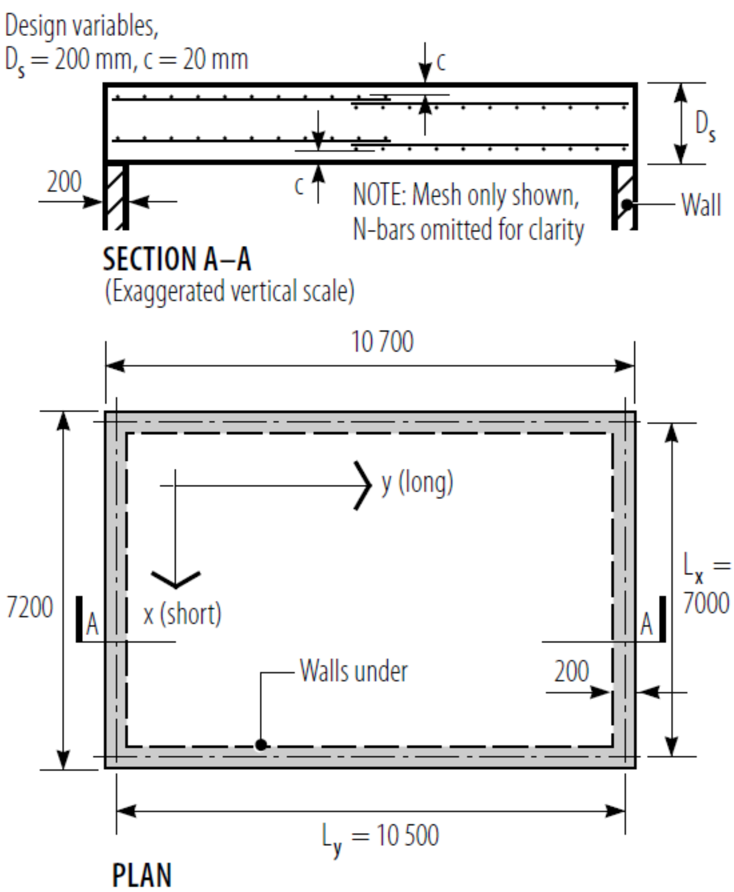


Figure A1 Rectangular two-way slab supported on four sides[10]
(note the position of the lap on section A–A may be varied to suit sheet sizes and minimise wastage)

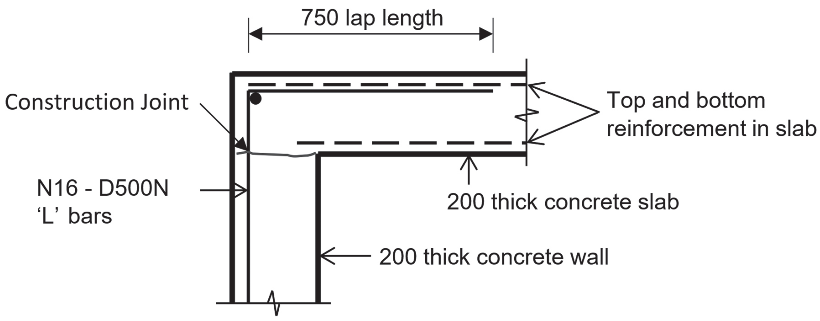


Figure A2 N16 - D500N 'L' bars to restrain all slab edges to provide continuity at edges (from Reference 10)

Design Action Effects (Bending)

The slab can be readily designed using the simplified method for reinforced two-way slabs supported on four sides given in Clause 6.10.3 of AS 3600.

The values of the effective spans, L_x (short) and L_y (long), are shown in **Figure A1** and have been calculated according to the definition of effective span, L_{ef}, in Clause 1.7 of AS 3600 as L_x= 7000 and L_y = 10500 mm, respectively. Therefore, L_y/L_x = 1.5.

For the strength limit state, the uniformly-distributed design load per unit area, F_d, is calculated as follows:

$$G_s = D_s(\rho_c + \rho_s)g$$
$$= 0.2(2.45 + 0.05)9.81$$
$$= 4.9 \text{ kPa}$$
$$G_{sup} = 1.5 \text{ kPa}$$
$$G = G_s + G_{sup}$$
$$= 6.4 \text{ kPa}$$
$$Q = 5.0 \text{ kPa}$$
$$F_d = 1.2G + 1.5Q$$
$$= 1.2\times6.4 + 1.5\times5.0$$
$$= 15.2 \text{ kPa}$$

In accordance with Clause 6.10.3.2 of AS 3600, the positive and negative design bending moments are calculated as follows, using β_x = 0.036 and α_x = 2.03, and β_y = 0.020 and α_y = 2.69, for L_y/L_x = 1.5 from Table 6.10.3.2(B) for four edges continuous:

$$M_x^{*+} = \beta_x F_d L_x^2$$
$$= 0.036\times15.2\times7.0^2$$
$$= 26.8 \text{ kNm/m}$$
$$M_x^{*-} = -\alpha_x M_x^{*+}$$
$$= -2.03\times26.8$$
$$= -54.4 \text{ kNm/m}$$
$$M_y^{*+} = \beta_y F_d L_x^2$$
$$= 0.020\times15.2\times7.0^2$$
$$= 14.9 \text{ kNm/m}$$
$$M_y^{*-} = -\alpha_y M_y^{*+}$$
$$= -2.69\times14.9$$
$$= -40.1 \text{ kNm/m}$$

It can be shown that the negative design bending moments are much larger than would be determined using Table 6.10.3.2(A), which is based on yield line theory with significant amounts of moment redistribution assumed[10].

At the serviceability limit state, for flexural crack control design:

$$\begin{aligned} F_{d.ef} &= G + \psi_s Q \\ &= 6.4 + 1.0 \times 5.0 \\ &= 11.4 \text{ kPa} \end{aligned}$$

Since ψ_s = 1.0, $M^*_s = M^*_{s.1}$, while from above F_d = 15.2 kPa, and therefore in the absence of moment redistribution, $M^*_s = M^*_{s.1}$ both equal $F_{d.ef}/F_d$ = 11.4/15.5 = 0.74 times M^*.

It follows that for serviceability design:

$$\begin{aligned} M^{*+}_{xs} &= M^{*+}_{xs.1} = 0.74 \times 26.8 = 19.8 \text{ kNm/m} \\ M^{*-}_{xs} &= M^{*-}_{xs.1} = 0.74 \times -54.4 = -40.3 \text{ kNm/m} \\ M^{*+}_{ys} &= M^{*+}_{ys.1} = 0.74 \times 14.9 = 11.0 \text{ kNm/m} \\ M^{*-}_{ys} &= M^{*-}_{ys.1} = 0.74 \times -40.3 = -29.7 \text{ kNm/m} \end{aligned}$$

These moments can be used to calculate the stress in the reinforcement in order to control cracking in accordance with Clause 9.5 of AS 3600, to ensure the limits in Tables 9.5.2.1(A) and (B) are not exceeded. For this worked example, being an interior slab, only Clause 9.5.1(a) requiring the minimum area of flexural reinforcement to conform with Clause 9.1.1, and Clause 9.5.1(b) limiting the maximum spacing of the flexural reinforcement, need to be satisfied for crack control. For all other situations, the stress in the reinforcement must also be checked, or the actual crack width calculated.

Design vertical shear forces can simply be calculated in accordance with Clause 6.10.3.4, but for brevity the values have been omitted here, noting that it is a non-critical check.

Reinforcement Details

Note that all the following calculations are based on a metre wide strip.

The reinforcement in the bottom and top faces of the slab is shown detailed in **Figures A3** and **A4**, respectively, with the following brief explanation.

(a) In accordance with Clause 9.5.1(b) of AS 3600, the maximum bar spacing equals the minimum of 300 mm or $2D_s$ (2 x 200 = 400mm). Therefore, maximum = 300 mm.

(b) The average design bending moments M_x^* and M_y^* are to be applied over a central region of the slab equal in width to 0.75 L_y and 0.75 L_x, respectively, in accordance with Clause 6.10.3.2(a) of AS 3600. Outside this region, Clause 6.10.3.2 of AS 3600 states that the minimum tensile strength requirement will be deemed to be met by conforming with Clause 9.1.1, regardless of the Ductility Class.

In addition, the effective depths have been correctly calculated depending on the layers and orientation of the mesh. Sometimes, designers rationalise the effective depths to the minimum depth due to a lack of control on site as to how the reinforcement is placed, and use that value, which will lead to an overdesign of about 2%.

According to Clause 9.1.1 of AS 3600, the minimum flexural reinforcement required in both faces of the slab in all edge regions is such that:

$A_{st}/bd \geq 0.19(D/d)^2 f'_{ct.f}/f_{sy}$ where $f'_{ct.f} = 0.6\sqrt{f'_c}$ from Clause 3.1.1.3 of AS 3600

$\geq 0.19(200/160)^2 \times 0.6\sqrt{32}/500$ (assuming $d = 0.8D$)

≥ 0.0020

This gives the following minimum area of flexural reinforcement:

$A_{st} = 0.0020 \times 1000 \times 160 = 320 \text{mm}^2\text{/m}$

To satisfy this, provide SL102 mesh with an area of 354 mm²/m top and bottom throughout and supplement with N12 bars where required to satisfy design moment capacities.

(c) Minimum reinforcement effective depths for both mesh and N12 bars, assuming that no additional N12 bars will be required in the y-direction, and in the x-direction, any additional N12 bars are placed closest to the concrete surface.

(i) Top or bottom x-direction steel (*extends in 7,200 mm direction in **Figure A1***):
- SL102 mesh, $d_{xb} = 154$ mm min. (*ie = 200 – 20 – 12 – 9.5 – 9.5/2*)
- N12 bar, $d_{xNb} = 174$ mm (*ie = 200 – 20 – 12/2*)

(ii) Top or bottom y-direction steel (*extends in 10,700 mm direction in **Figure A1***):
- SL102 mesh, $d_{yb} = 154$ mm min. (same as x-direction)
- N12 bar, $d_{yNb} = 162$ mm (*ie = 200 – 20 – 12 – 12/2*)

Check minimum tensile strength reinforcement in x-direction (Clause 9.1.1(b) of AS 3600)

$A_{st} \geq 1000 \times 154 \times 0.19 \times (200/154)^2 \times 0.6\sqrt{32}/500$

$\geq 335 \text{ mm}^2\text{/m}$

Similarly, minimum tensile strength reinforcement in y-direction will be the same, as $d = 154$ is a minimum value.

Therefore, SL102 mesh is satisfactory

(d) In accordance with Clause 9.5.3.2, for control of cracking due to shrinkage and temperature effects in interior (exposure classification A1) restrained slabs with a moderate degree of crack control, the minimum area of reinforcement required in the x- and y-directions equals the larger of that required for minimum bending strength, ie 335 mm²/m as per above in items (b) or (c) in each face, and 0.75 times that required by Clause 9.5.3.4(a)(ii) as total reinforcement in both faces as follows:

$A_{st} = 0.75 \times (3.5 - 2.5\sigma_{cp})bD \times 10^{-3} = 0.75 \times 3.5 \times 1000 \times 200 \times 10^{-3} = 525 \text{ mm}^2$

This 525 mm²/m for exposure classification A1, which equals 263 mm²/m in each face of the slab is satisfied by the SL102 mesh.

It follows that the 335 mm²/m requirement for minimum bending strength governs the amount of reinforcement required, ie SL102 (or N12 at 300) governs.

Note that in accordance with Clause 9.5.3.4 of AS 3600, for a moderate degree of crack control, the maximum spacing of the distribution bars is the lesser of $2.0D_s$ or 300 mm. Using mesh with bar spacing of 200 mm satisfies this requirement.

(e) The width of the central region in the y-direction equals 0.75 L_x = 0.75 × 7000 = 5250 mm. Check that this can be reinforced in the bottom face with SL102 to satisfy $ØM_{uo}$ ≥14.9 kNm/m with minimum d = 154 mm. $bdf'_c A_{stL} f_{sy} A_{stL}$

$$ØM_{uo} = Øf_{sy} A_{stL} d(1 - 0.6 \frac{A_{stL} f_{sy}}{bdf'_c})$$

$$= 0.65 \times 500 \times 354 \times 154 \times (1 - 0.6 \frac{354 \times 500}{1000 \times 154 \times 32}) \times 10^{-6}$$

= 17.3 kNm

> 14.9 kNm, therefore satisfactory

(f) The width of the central region in the x-direction equals 0.75 L_y = 0.75 × 10500 = 7875 mm. To satisfy $ØM_{uo}$ ≥ 26.8 kNm/m, based on the capacity in the y-direction, try adding N12 at 600 centres to the mesh, extending over 4.0 metres, with the SL102 acting alone in the bottom face near the walls as follows:

In the x-direction, the equivalent area of Ductility Class N steel is:

$$A_{stN} = A_{Nb} + 0.77\, A_{Lb}$$

= 110 / 0.6 + 0.77 × 354

= 456 mm²/m

The mean effective depth of both bars and mesh in the x-direction is:

$$d_m = \frac{A_{Nb}\, d_{xNb} + 0.77 A_{Lb}\, d_{xLb}}{A_{Nb} + 0.77 A_{Lb}}$$

$$= \frac{(113/0.6) \times 174 + 0.77 \times 354 \times 154}{(113/0.6) + 0.77 \times 354}$$

= 162mm

Ultimate positive moment capacity in x-direction is:

$$ØM_{uo} = Øf_{sy} A_{stN} d_{av.}(1 - 0.6 \frac{A_{stN} f_{sy}}{bd_{av.} f'_c})$$

$$= 0.85 \times 500 \times 456 \times 162 \times (1 - 0.6 \frac{456 \times 500}{1000 \times 162 \times 32}) \times 10^{-6}$$

= 30.6 kNm

> 26.8 kNm, therefore satisfactory

(g) The deemed-to-comply arrangement of the top steel shown in Figure 9.1.3.2 of AS 3600, requires a minimum of 50% of the top face reinforcement in both the x and y directions to be continued at least $0.3L_{nx}$ = 0.3 x 6800 = 2040 mm past the inside face of the concrete walls into the span. Allowing for the wall thickness, make any additional 'L' bars required to achieve the negative moment capacity, 2200 mm long. To satisfy $ØM_{uo} \geq 54.4$ kNm/m, based on the capacity of the mesh alone (refer (e) above), try adding N12 at 200 mm centres to the top mesh.

Calculate the ultimate negative moment capacity in x-direction.

The mean effective depth of both top bars and mesh in the x-direction is:

$$d_m = \frac{A_{Nb}\,d_{xNb} + 0.77A_{Lb}\,d_{xLb}}{A_{Nb} + 0.77A_{Lb}}$$

$$= \frac{(113/0.2)\times174 + 0.77 \times 354 \times 154}{(113/0.2) + 0.77 \times 354}$$

= 167mm

Equivalent reinforcement area

$$A_{stN} = A_{Nb} + 0.77\,A_{Lb} = 113 / 0.2 + 0.77 \times 354$$

= 838 mm²/m

Ultimate negative moment capacity in x-direction is:

$$ØM_{uo} = Øf_{sy}\,A_{stN}\,d_m(1 - 0.6\,\frac{A_{stN}\,f_{sy}}{bd_m\,f'_c})$$

$$= 0.85 \times 500 \times 838 \times 167 \times (1 - 0.6\,\frac{838 \times 500}{1000 \times 167 \times 32})\times10^{-6}$$

= 56.7 kNm

> 54.4 kNm, therefore satisfactory

Calculate the ultimate negative moment capacity in y-direction.

In the y-direction, as the maximum negative moment is only 40.1 kNm/m, try adding N12 bars at 400 mm centres to top mesh.

The mean effective depth of both top bars and mesh in the y-direction is:

$$d_m = \frac{A_{Nb}\,d_{xNb} + 0.77A_{Lb}\,d_{xLb}}{A_{Nb} + 0.77A_{Lb}}$$

$$= \frac{(113/0.4)\times162 + 0.77 \times 354 \times 154}{(113/0.4) + 0.77 \times 354}$$

= 158mm

Equivalent reinforcement area

$A_{stN} = A_{Nb} + 0.77\,A_{Lb} = 113 / 0.4 + 0.77 \times 354$

$= 555\ mm^2/m$

Ultimate negative moment capacity in y-direction is:

$$ØM_{uo} = Øf_{sy}\,A_{stN}\,d_m(1 - 0.6\,\frac{A_{stN}\,f_{sy}}{bd_m\,f'_c})$$

$$= 0.85 \times 500 \times 555 \times 158 \times (1 - 0.6\,\frac{555 \times 500}{1000 \times 158 \times 32}) \times 10^{-6}$$

$= 36.0$ kNm

$<$ 40.1 kNm, therefore try N12 at 300mm centres

The new mean effective depth of both top bars and mesh in the y-direction is:

$$d_m = \frac{A_{Nb}\,d_{xNb} + 0.77 A_{Lb}\,d_{xLb}}{A_{Nb} + 0.77 A_{Lb}}$$

$$= \frac{(113/0.3) \times 162 + 0.77 \times 354 \times 154}{(113/0.3) + 0.77 \times 354}$$

$= 159$mm

Equivalent reinforcement area with N12 at 300 mm centres is:

$A_{stN} = A_{Nb} + 0.77\,A_{Lb} = 113 / 0.3 + 0.77 \times 354$

$= 649\ mm^2/m$

Ultimate negative moment capacity in y-direction is with N12 at 300 mm centres:

$$ØM_{uo} = Øf_{sy}\,A_{stN}\,d_m(1 - 0.6\,\frac{A_{stN}\,f_{sy}}{bd_m\,f'_c})$$

$$= 0.85 \times 500 \times 649 \times 159 \times (1 - 0.6\,\frac{649 \times 500}{1000 \times 159 \times 32}) \times 10^{-6}$$

$= 42.2$ kNm

$\geq$ 40.1 kNm, therefore N12 at 300mm centres satisfactory

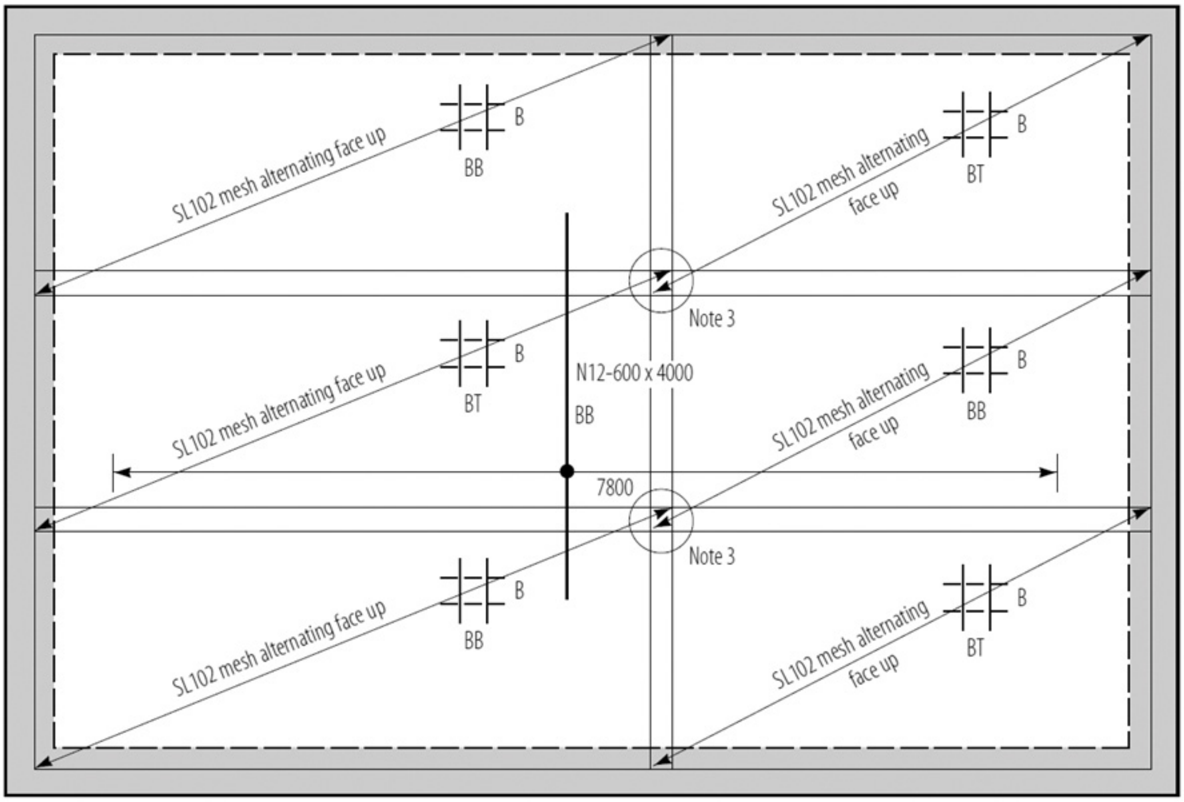
(h) No additional corner torsional reinforcement is required in the slab since all the corners are interior.

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

(j) A fire resistance period of 120 minutes for structural adequacy is readily satisfied by the soffit concrete cover being at least 20 mm for a continuous slab, in accordance with Table 5.5.2(B) of AS 3600. Fire resistance period for insulation is also satisfied as the 200 mm thickness exceeds the minimum 120 mm required in Table 5.5.1 of AS 3600 for insulation. The requirement for integrity is satisfied as both structural adequacy and insulation are satisfied.

While calculations are not shown here, the 'L' bars from the walls will be N16 at 200 mm centres along the long edge and N16 at 300 mm centres along the short walls to achieve the required negative moment capacities.

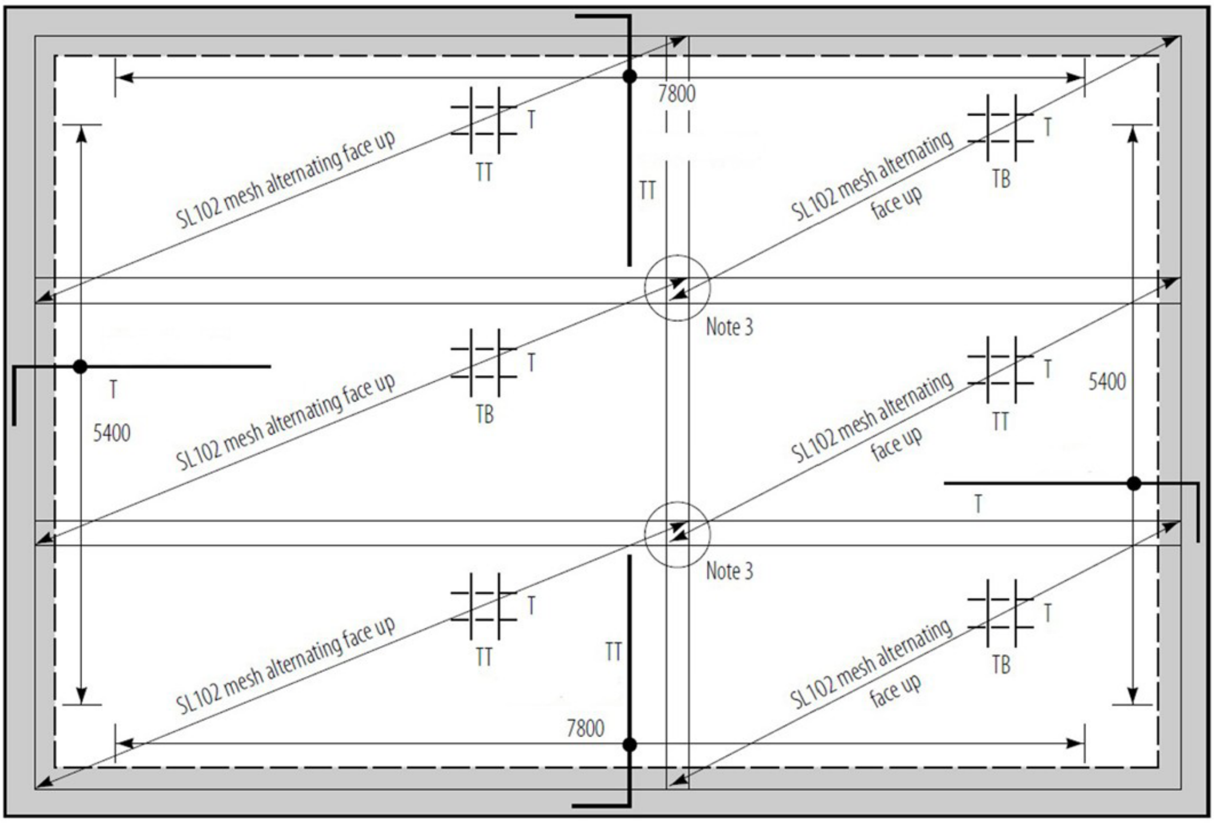
For constructability, the 'L' bars from the walls will be cogged 750 mm (basic lap length for an N16 bar) into the top of the slab and lapped spliced with the required 'L' bars in the top of the slab, which will have a standard cog at the wall end. Lap top mesh 750 mm with cogged bars from the walls as well.



Notes:

1. Code for bar levels of alternating mesh sheets and N-bars:
   BB = bottom-bottom (ie first or lowest level)
   B = bottom (ie second or middle layer)
   BT = bottom-top (ie third or highest level)
2. All mesh laps to be in accordance with **Figure 2** (ie two edge bars to be overlapped).
3. All overlapping corners where four layers of mesh occur, two of these layers may be cut off on site to reduce overall depth of steel at these locations.

Figure A3 Bottom reinforcement for rectangular two-way slab supported on four sides



Notes:

1. Code for bar levels of alternating mesh panels and N-bars:
   TB = top-bottom (ie first or lowest level)
   T = top (ie second or middle layer)
   TT = top-top (ie third or highest level)
2. All mesh laps to be in accordance with Figure 2 (ie two edge bars to be overlapped).
3. All overlapping corners where four layers of mesh occur, two of these layers may be cut off on site to reduce overall depth of steel at these locations.
4. Lap top mesh 750 mm with N16 bars from walls (refer **Figure A2**)

Figure A4 Top reinforcement for rectangular two-way slab supported on four sides