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REINFORCEMENT
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DESIGN to AS 3600:2001 of SUSPENDED CONCRETE FLOORS REINFORCED with CLASS L MESH

1 SCOPE

This technical note addresses the design of suspended concrete floors reinforced with low-ductility Class L mesh in accordance with the current edition of the Concrete Structures Standard AS 3600:2001[1]. Changes to the Standard made in two amendments (1 & 2) that concern using Class L mesh as main reinforcement are fully accounted for.

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

Design for serviceability and ultimate strength are addressed. Important aspects of design not directly addressed in AS 3600 are clarified.

FIGURE 1 *Suspended Concrete Floor Construction using Class L Mesh*

2 BUILDING CODE OF AUSTRALIA (BCA)

The two complementary Australian Standards AS 3600:2001 *Concrete structures* and AS/NZS 4671:2001 *Steel reinforcing materials*[2] are both given legal status by being referenced in the current Building Code of Australia (BCA)[3]. Designs developed using these Standards comply with the Deemed-to-Satisfy Provisions of the BCA and accordingly fully satisfy its Performance Requirements.

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

3 AS/NZS 4671:2001

The standard grade of ribbed reinforcing mesh 500L referred to in AS/NZS 4671 has a nominal yield stress, f_{sy}, of 500 MPa and is designated as having low (L) ductility.

Its ductility is characterised by uniform strain, ε_{su}, and tensile-strength-to-yield-stress ratio, f_t/f_{sy}, for which compliance with Appendix A of AS/NZS 4671 must be demonstrated. Minimum lower characteristic values for Class L mesh are $\varepsilon_{suk} = 1.5\%$ and $(f_t/f_{sy})_k = 1.03$, on which the design rules in AS 3600 are based. Significantly higher values can be achieved in practice[4]. As well as confirming satisfactory mechanical properties, weld-shear strengths and geometric measurements must also be confirmed.

Cross-sectional areas of commonly-available Class L mesh sizes used in the construction of suspended concrete floors like that in **Figure 1** are given in **Table 1**, where A_{bl} and A_{bt} are the cross-sectional areas of the longitudinal and transverse bars, respectively, based on

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the minimum intensity of bars ignoring edge effects and lapping. For simplicity these values are normally used in design. However, in uniformly-stressed areas it may be more appropriate to use the larger average areas $\bar{A}_{bl}$ and $\bar{A}_{bt}$.

Table 1 *Cross-sectional Areas of Standard Australian Class L Meshes*

	Longitudinal bars		**Transverse bars**	
Mesh reference number(1),(2)	**Min. area A_{bl}** (mm^2/m)	**Av. area(3) $\bar{A}_{bl}$** (mm^2/m)	**Min. area A_{bt}** (mm^2/m)	**Av. area(3) $\bar{A}_{bt}$** (mm^2/m)
RL1218	1112	**1215**	227	**243**
RL1118	899	**982**	227	**243**
RL1018	709	**774**	227	**243**
RL918	581	**634**	227	**243**
RL818	454	**495**	227	**243**
RL718	358	**390**	227	**243**
SL81	454	**495**	454	**470**
SL102	354	**372**	354	**380**
SL92	290	**303**	290	**311**
SL82	227	**247**	227	**243**
SL72	179	**190**	179	**192**
SL62	141	**157**	141	**152**

Notes:

1. Reference number code: "R" = rectangular; "S" = square; "L" = low ductility; and *example 1:* "1218" = nominal 12 mm longit. bars @ 100 mm crs & nom. 8 mm transv. bars @ 200 mm crs or *example 2:* "102" = nominal 10 mm longit. and transv. bars @ 200 mm crs.
2. Standard mesh panel size is 6.0 m long x 2.4 m wide.
3. The increased average cross-sectional areas for lapped mesh panels are based on the tensile lap splicing rules in AS 3600:2001, as described in the text.

4 AS 3600:2001

The use of Class L mesh as main reinforcing steel in suspended concrete floors is permitted by the Australian Concrete Structures Standard AS 3600:2001.

It may be used in conjunction with normal ductility (Class N) reinforcing bars, or prestressing tendons. It is also widely used as main and secondary reinforcement in composite slabs incorporating profiled steel decking in the soffit, the design of which is not addressed in AS 3600, but similar principles apply.

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

With the move to 500 MPa as the primary standard strength grade for main reinforcing steel in the form of bars or mesh, the importance of steel ductility is now formally recognised in AS 3600. Therefore, as will be explained in more detail below, the following clauses in the Standard distinguish between the use of Class L and N steels as main reinforcement:

- *Clause 1.1.2 Application* – it is stated that Class L mesh "*shall not be used in any situation where the reinforcement is expected to undergo large deformation under strength limit state conditions*". This simply excludes it from being taken into account using plastic analysis (Clauses 7.9 and 7.10), which is seldom used in practice anyway due to likely serviceability issues.
- In a note to *Table 2.3 of Clause 2.3 Design for Strength*, reference is made to Clauses 7.2.1, 7.3.1 and 7.6.8.3 to use at least a 20% lower value of strength reduction factor, ϕ, when calculating the design strength in bending, ϕM_{uo}, of beam or slab cross-sections only reinforced with Class L mesh, ie, 0.8 x 0.8 = 0.64.
- *Clause 5.9 Prediction of Fire-Resistance Periods* – in a note to this clause which applies to conducting a rational method of fire analysis for assessing structural adequacy (which is not commonly done for concrete structures), it is pointed out that the effects of moment redistribution should be considered in a fire situation, particularly when Class L mesh is used as main reinforcement. Patrick[5] describes a 2-hour Standard Fire Test of a typical continuous slab incorporating only Class L ribbed mesh which behaved entirely satisfactorily without displaying any negative effects due to the low ductility of the steel. Extensive cracking due to the steel restraining thermal expansion contributed to the good behaviour observed.
- *Clause 7.2 Simplified Method for Reinforced Continuous Beams and One-Way Slabs* – slightly different design bending moment and design shear force terms are calculated, with the Class L terms derived assuming no moment redistribution using elastic analysis[6]. Obviously, the Class L mesh terms may also be used for slabs with Class N bars.
- *Clause 7.3 Simplified Method for Reinforced Two-Way Slabs Supported on Four Sides* – improved design moment coefficients were derived using linear elastic finite element analysis[6], which are directly applicable to slabs incorporating Class L mesh and/or Class N bars. Less moment redistribution assists with serviceability design. The slabs must be supported on walls (or stiff beams) to limit moment redistribution.

- *Clause 7.4 Simplified Method for Reinforced Two-Way Slab Systems having Multiple Spans* and *Clause 7.5 Idealized Frame Method for Structures incorporating Two-Way Slab Systems* – Class L mesh is excluded from being used as main reinforcing steel for either of these methods, until a similar study is undertaken like that by Patrick et al.[6] to determine what changes to the methods are needed to reduce the amount of moment redistribution currently assumed.
- Clause 7.6 Linear Elastic Analysis – general structures incorporating Class L mesh as main reinforcement may be designed using this clause provided moment redistribution is not included in the analysis.[(a)] 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. Patrick et al.[6] used elastic analysis in their simple numerical studies to develop the new design rules for Clauses 7.2 and 7.3. Their work illustrates how to correctly apply the principles of Clause 7.6.8.3 *Approval for Class L Reinforcement* when Class L mesh forms part or all of the main reinforcement of a typical reinforced-concrete floor comprising either beams or one-way slabs, or two-way slab systems.

  Clause 7.6.8.3 also requires "*the effects that relative foundation movements, variations in loading arrangements and accidental loadings*" to be assessed with regard to strength design of beams and slabs. Design engineers should consider whether or not these issues require any special consideration for their particular project, bearing in mind that they have normally been adequately catered for by using the lower ϕ value for design bending strength, ϕM_{uo}.
- *Clause 19.2.1.1 Reinforcement* – mesh to be used as main or secondary reinforcement may be Class L or Class N with a nominal yield stress of up to 500 MPa.

5 METHODS OF ANALYSIS FOR SERVICEABILITY AND STRENGTH DESIGN OF BEAMS AND SLABS

Simplified Methods

The simplified methods in *Clause 7.2 Simplified Method for Reinforced Continuous Beams and One-Way Slabs* and *Clause 7.3 Simplified Method for Reinforced Two-Way Slabs Supported on Four Sides* are elementary to apply and require no special explanation here. Their use will be illustrated below in a worked example.

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) action, G, and imposed (live) action, Q, under ambient temperature conditions: in accordance with AS/NZS 1170.0:2002[9], 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, in a note to Clause 8.6.1(d) of AS 3600, it is stated that 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. For this reason, the new rules for Class L mesh in Clauses 7.2 and 7.3 are normally more appropriate for serviceability design, irrespective of the ductility of the reinforcing steel.

General Linear Elastic Analysis

Scott and Whittle[10] 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 7.6.5 of AS 3600 where the general principles of linear elastic analysis are stated, an estimate of the flexural stiffness of each member may be based on either (i) the dimensions of the uncracked (gross) cross-sections; or (ii) other reasonable assumptions, which

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Note:

(a) It should be noted that continuous beams or slabs with Class L mesh main steel can exhibit large amounts of moment redistribution at all stages of loading, as shown conclusively in tests[7],[8]. Therefore, this requirement should not be misinterpreted to mean that significant amounts of moment redistribution cannot be relied upon to occur in floors with Class L mesh. It is only intended to mean that during design, 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.

better represent conditions at the limit state being considered. 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 (i) above in AS 3600.

6 DEFLECTION CONTROL

Class L mesh is made from ribbed bars, and in combination with the transverse 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 appropriate average mesh area $\bar{A}_{bl}$ or $\bar{A}_{bt}$ may be used for this purpose, taking into account the orientation of the mesh bars to calculate the reinforcement ratio, $p = \bar{A}_b/bd$, 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 with the move to 500 MPa reinforcing steels, as defined in Clauses 8.6.1 and 9.4.1 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 8.6.1(A) and 9.4.1(A), 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 [11], [12] for beams and slabs, respectively. Like for deflection control design, the appropriate average mesh area $\bar{A}_{bl}$ or $\bar{A}_{bt}$ may be used for this purpose.

8 CRACK CONTROL FOR TEMPERATURE AND SHRINKAGE EFFECTS

The full cross-sectional area of Class L mesh contributes towards controlling cracking in slabs due to temperature and shrinkage effects, as defined in Clause 9.4.3 of AS 3600. Again, the appropriate average mesh area $\bar{A}_{bl}$ or $\bar{A}_{bt}$ 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 Class N bars to resist peak moments & vertical shear.

9 DESIGN STRENGTH IN BENDING

Theoretical and experimental studies have conclusively shown that 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, ϕM_{uo}, of beam or slab cross-sections in peak moment regions[8]. Therefore, Clause 8.1.2 *Basic Principles* may be used directly in the normal manner for beam or slab cross-sections incorporating a layer of Class L mesh as main reinforcement.

The design bending moments, M*, determined using either of the simplified methods of Clauses 7.2 and 7.3, or general linear elastic analysis in accordance with Clause 7.6, are normally average peak values. Therefore, it is normally acceptable to use the appropriate average mesh area $\bar{A}_{bl}$ or $\bar{A}_{bt}$, taking into account the orientation of the mesh bars.

The requirements of Clauses 7.2.1, 7.3.1 and 7.6.8.3 to use a 20% lower value of $\phi = 0.64$ when calculating the design strength in bending, ϕM_{uo}, of cross-sections only reinforced with Class L mesh is considered to be very conservative indeed[8]; viz. 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 Class L mesh (using average mesh area $\bar{A}_{bl}$ or $\bar{A}_{bt}$) may be used to compute ultimate shear strength, V_{uc}, in accordance with Clause 8.2.7.1.

11 MIXING REINFORCING STEELS OF DIFFERENT DUCTILITY CLASSES

Class N bars are frequently used in practice to supplement the limited cross-sectional area of Class L mesh in peak moment regions. It will be shown in the worked example that this can provide economical solutions to lessen the impact of the reduced ϕ value for bending. That is, by sizing the mesh to control cracking due to temperature and shrinkage effects (when the mesh is not penalised for its low ductility), and then using 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 Class L bars of the mesh and the Class N bars are effectively in the same plane, they will achieve their full strengths. Therefore, the equivalent area of tensile reinforcement, A_{stN}, when the two types of steel are mixed this way, simply equals $A_{Nb} + 0.8 \ \overline{A}_b$ for the calculation of design strength in bending, ϕM_{uo} using f_{sy} = 500 MPa, where A_{Nb} is the cross-sectional area of the Class N bars, and $\overline{A}_b$ is the cross-sectional area of the Class L bars, for the same width. Using this approach, $\phi = 0.8$.

12 FIRE RESISTANCE

Concrete floors with Class L mesh 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 Clause 5.3.4(a) of AS 3600 to satisfy thermal insulation and structural integrity. No further consideration is usually required.

13 TENSILE LAP LENGTH

In accordance with Clause 13.2.2 of AS 3600, a lapped splice for mesh in tension shall be made so that the two edge bars of a mesh panel overlap the two edge bars of the panel being lapped, as shown in **Figure 2**, for nominally identical panels. The edge bars may be longitudinal or transverse bars of a mesh panel. 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.

For the purpose of determining the values of average cross-sectional mesh areas $\overline{A}_{bl}$ and $\overline{A}_{bt}$ in **Table 1**, the clear distance between the corresponding transverse bars of the overlapped mesh panels was assumed to equal 30 mm.

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

FIGURE 2 *Lapped Splice for Mesh*

14 EARTHQUAKE RESISTANCE

In accordance with Appendix A of AS 3600, concrete structures in design categories defined therein not required to be specifically designed or detailed for resistance to earthquake loads, shall be regarded as ductile provided they are designed, detailed and constructed in accordance with the Standard. This includes concrete structures incorporating Class L mesh as main reinforcement. Also, many concrete structures with Class L mesh are adequately laterally braced to prevent sway. Concrete structures in Australia should also now be designed for the earthquake actions specified in AS 1170.4:2007[13].

15 WORKED EXAMPLE

A rectangular two-way slab incorporating Grade 500 Class N bars, from Reference[12], which was designed in accordance with AS 3600 prior to the development of the improved simplified design rules in Clause 7.3 of AS 3600:2001, has been redesigned using Class L mesh as the principal type of reinforcement. The new design satisfies all of the latest requirements of AS 3600:2001.

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

- as explained above, the design bending moments for serviceability, M^*_s, can now be determined directly using the new design rules, thus avoiding having to use some other method for calculating these action effects (noting that finite element analysis was used in Reference[12]);
- the 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 steel under ambient and elevated temperature (fire) conditions;

- an inconsequential extra amount of reinforcing steel is required as a consequence of the low ductility of the Class L mesh compared with Class N bars;
- the Class L mesh is augmented by Class N bars in peak moment regions over the supports, effectively negating the impact of the lower value of $\phi = 0.64$ for Class L steel; and
- Class L mesh is fully effective at controlling vertical deflections, and providing for vertical shear strength, particularly in the vicinity of the supporting walls were shear forces are maximum.

16 REFERENCES

[1] Standards Australia *Concrete structures* AS 3600:2001, incorporating Amendments 1 (May 2001) & 2 (October 2004).

[2] Standards Australia & Standards New Zealand *Steel reinforcing materials* AS/NZS 4671:2001 incorporating Amendment 1 (June 2003).

[3] Australian Building Codes Board *Building Code of Australia* Vols 1 & 2, 2007.

[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] Patrick M. *Safe Design of Slabs incorporating Class L Mesh – Latest Design Advice about AS 3600* Concrete in Australia, Volume 31 No. 4 December 2005-February 2006, pp 23-27 (abridged version – full version at ***www.sria.com.au***).

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[7] Keith J., Patrick M. and Marsden W. *Advances in the Design and Construction of Concrete Structures incorporating Class L Reinforcing Mesh supported by Australian Test Data, and Future Research Directions* CIA Concrete '07 Conference Proceedings, 2007.

[8] 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.

[9] Standards Australia & Standards New Zealand *Structural design actions, Part 0: General principles* AS/NZS 1170.0:2002, incorporating Amendments 1 (Jan. 2003) & 2 (Nov. 2003).

[10] Scott R.H. and Whittle R.T. *Moment Redistribution Effects in Beams* Magazine of Concrete Research, Vol. 57 No. 1, Feb 2005, pp. 9-20.

[11] 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.

[12] 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.

[13] Standards Australia *Structural design actions, Part 4: Earthquake actions in Australia* AS 1170.4:2007.

[14] Standards Australia & Standards New Zealand *Structural design actions, Part 1: Permanent, imposed and other actions* AS/NZS 1170.1:2002.

APPENDIX A – CLASS L MESH WORKED EXAMPLE (DESIGN TO AS 3600:2001)

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

Design for deflection control is beyond the scope of the worked example. For brevity, neither will all of the calculations for flexural crack control be shown.

The low-ductility mesh will be supplemented as required with Class N bars wherever any additional steel is required for bending strength. When this is done, as already shown, the simple effective area of N bar $A_{stN} = A_{Nb} + 0.8\ \overline{A}_b$ will be calculated, for which $\phi = 0.8$ when computing ϕM_{uo}. This is a more general approach to use when Class L mesh is mixed with Class N bars, and is equivalent to applying $\phi = 0.64$ for the mesh steel.

The slab is to be cast on 200 mm thick concrete walls that run continuously along each of its sides. Cranked Class N bars will be positioned in the outer face of each wall to lap with the slab mesh reinforcement. 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. 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 9.4.3.2 *Reinforcement in the primary direction* and 9.4.3.4 *Reinforcement in the secondary direction in restrained slabs* of AS 3600. Moderate degree of control over cracking will be deemed sufficient for the interior slab.

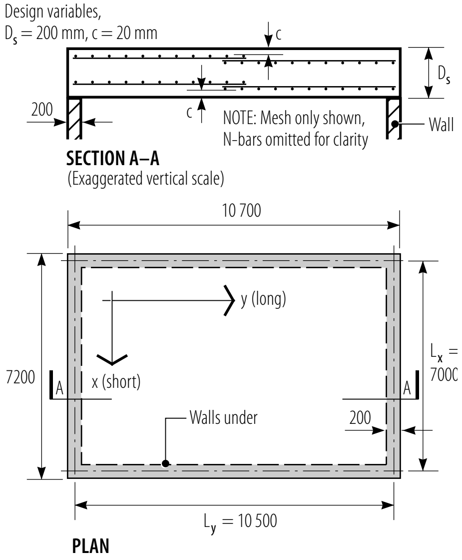


FIGURE A1 *Rectangular Two-Way Slab Supported on Four Sides*[12]

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 1170.1[14]*, $\psi_s = 1.0$ and $\psi_l = 0.6$ for storage areas.)*

Concrete density, ρ_c = 2450 kg/m^3
Allowance for reinforcing steel, ρ_s = 50 kg/m^3

Additional design variables 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 steel grade, f_{sy} = 500 MPa
Main steel 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)

Minimum reinforcement effective depths:

(a) Top or bottom x-direction steel *(extends in 7200 mm direction in **Figure A1**)*:

- SL102 mesh, d_{xb} = 153 mm *(ie = 200 - 20 - 12 - 10 - 10/2)*
- N12 bar, d_{xNb} = 174 mm *(ie = 200 - 20 - 12/2)*

(b) Top or bottom y-direction steel *(extends in 10 700 mm direction in **Figure A1**)*:

- SL102 mesh, d_{yb} = 163 mm *(ie = 200 - 20 - 12 - 10/2)*
- N12 bar, d_{yNb} = 162 mm *(ie = 200 - 20 - 12 - 12/2)*

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 7.3 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 7000 and 10 500 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:

$$\begin{aligned} G_s &= D_s(\rho_c + \rho_s)\,g \\ &= 0.2\,(2.45 + 0.05)\,9.81 \\ &= 4.9 \text{ kPa} \end{aligned}$$

$$G_{sup} = 1.5 \text{ kPa}$$

$$\begin{aligned} G &= G_s + G_{sup} \\ &= 6.4 \text{ kPa} \end{aligned}$$

$$Q = 5.0 \text{ kPa}$$

$$\begin{aligned} F_d &= 1.2\,G + 1.5\,Q \\ &= 1.2 \text{ x } 6.4 + 1.5 \text{ x } 5.0 \\ &= 15.2 \text{ kPa} \end{aligned}$$

In accordance with Clause 7.3.2 of AS 3600, the positive and negative design bending moments are calculated as follows, using $\beta_x = 0.036$ and $\alpha_x = 2.03$, and $\beta_y = 0.020$ and $\alpha_y = 2.69$, for $L_y/L_x = 1.5$ from Table 7.3.2(B) for four edges continuous:

$$\begin{aligned} M^{*+}_{x} &= \beta_x F_d L^2{}_x \\ &= 0.036 \text{ x } 15.2 \text{ x } 7.0^2 \\ &= 26.8 \text{ kNm/m} \end{aligned}$$

$$\begin{aligned} M^{*-}_{x} &= -\alpha_x M^{*+}_{x} \\ &= -2.03 \text{ x } 26.8 \\ &= -54.4 \text{ kNm/m} \end{aligned}$$

$$\begin{aligned} M^{*+}_{y} &= \beta_y F_d L^2{}_x \\ &= 0.020 \text{ x } 15.2 \text{ x } 7.0^2 \\ &= 14.9 \text{ kNm/m} \end{aligned}$$

$$\begin{aligned} M^{*-}_{y} &= -\alpha_y M^{*+}_{y} \\ &= -2.69 \text{ x } 14.9 \\ &= -40.1 \text{ kNm/m} \end{aligned}$$

It can be shown that the negative design bending moments are much larger than would be determined using Table 7.3.2(A), which is based on yield-line theory with significant amounts of moment redistribution assumed[12].

The average design bending moments M^*_x and M^*_y are to be applied over central regions of the slab equal in width to $0.75\,L_y$ and $0.75\,L_x$, respectively, in accordance with Clause 7.3.2 of AS 3600.

Minimum flexural reinforcement ($p = A_{st}/bd = 0.002$ in accordance with Clause 9.1.1(b) of AS 3600) is required in both faces of the slab in all edge regions.

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

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

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

It follows that for serviceability design:

$$M^{*+}_{xs} = M^{*+}_{xs.1} = 0.74 \text{ x } 26.8 = 19.8 \text{ kNm/m}$$

$$M^{*-}_{xs} = M^{*-}_{xs.1} = 0.74 \text{ x } -54.4 = -40.3 \text{ kNm/m}$$

$$M^{*+}_{ys} = M^{*+}_{ys.1} = 0.74 \text{ x } 14.9 = 11.0 \text{ kNm/m}$$

$$M^{*-}_{ys} = M^{*-}_{ys.1} = 0.74 \text{ x } -40.1 = -29.7 \text{ kNm/m}$$

Design vertical shear forces can simply be calculated in accordance with Clause 7.3.4, but for brevity the values have been omitted here, noting that it is a non-critical check.

Reinforcement Details

The reinforcement in the bottom and top faces of the slab is shown detailed in **Figures A2 and A3**, respectively, with the following brief explanation.

(a) In accordance with Clause 9.4.1 of AS 3600, the maximum bar spacing equals min. (300 mm, $2D_s = 400$mm) = 300 mm.

(b) In accordance with Clause 9.1.1, minimum tensile reinforcement for minimum bending strength in the x-direction equals 0.002 × 1000 × 174 = 348 mm^2/m = SL102 or N12@300.

(c) Similarly, minimum tensile reinforcement for minimum bending strength in the y-direction equals 0.002 × 1000 × 163 = 326 mm^2/m = SL102 or N12@300.

(d) In accordance with Clause 9.4.3.2, for control of cracking due to shrinkage and temperature effects, the minimum area of reinforcement required in the x- and y-directions equals the larger of that required for minimum bending strength, ie 0.002 bd as per above in items (b) or (c) in each face, and 0.75 times that required by Clause 9.4.3.4 as total steel in both faces, ie 0.75 × 0.0035 × 1000 × 200 = 525 mm^2/m for exposure classification A1, which equals 263 mm^2/m in each face.

It follows that the requirement for minimum bending strength demands more steel, ie SL102 or N12@300 governs.

(e) The width of the central region in the x-direction equals $0.75 L_y = 0.75 \times 10500 = 7875$ mm. This can be reinforced in the bottom face with SL102 + N12@600 to satisfy $\phi M_{uo} \geq 26.8$ kNm/m with min. d = 153 mm, and the additional bars extend over 4.0 metres, with the SL102 acting alone in the bottom face near the walls.

(f) The width of the central region in the y-direction equals $0.75 L_x = 0.75 \times 7000 = 5250$ mm. This can be reinforced in the bottom face with SL102 to satisfy $\phi M_{uo} \geq 14.9$ kNm/m with minimum d = 163 mm.

(g) The detailing of the tensile reinforcement should comply with Clause 9.1.3 of AS 3600. Therefore, the meshes extend onto the walls without clashing with the vertical bars, noting that six SL102 panels are fitted with their longitudinal bars in the direction of the y-axis. The side of the mesh panels facing up alternates between adjacent panels (see **Figures A2 and A3** and the associated notes), with the transverse and longitudinal bars of adjacent panels on opposite sides, in order to maximise the effective depths of the top and bottom steel layers.

(h) To satisfy the deemed-to-comply arrangement of the top steel shown in Fig. 9.1.3.2 of AS 3600, the top face reinforcement in both the x- and y-directions has been continued at least $0.3L_{nx} = 2040$ mm past the inside face of the concrete walls into the span. This is achieved using SL102 + N12@200 around the perimeter of the slab in the top face, which satisfies $\phi M_{uo} \geq 54.4$ kNm/m with mean $\bar{d}_x = 166$ mm and ≥ 40.1 kNm/m with mean $\bar{d}_y = 162$ mm.

For example, in the x-direction:

$$\begin{aligned} A_{stN} &= A_{Nb} + 0.8\ \bar{A}_b \\ &= 110/0.2 + 0.8 \text{ x } 380 \\ &= 854 \text{ mm}^2/\text{m} \end{aligned}$$

$$\begin{aligned} \bar{d}_x &= \frac{A_{Nb} d_{xNb} + 0.8\ \bar{A}_b d_{xb}}{A_{Nb} + 0.8\ \bar{A}_b} \\ &= \frac{550 \text{ x } 174 + 0.8 \text{ x } 380 \text{ x } 153}{550 + 0.8 \text{ x } 380} \\ &= 166 \text{ mm} \end{aligned}$$

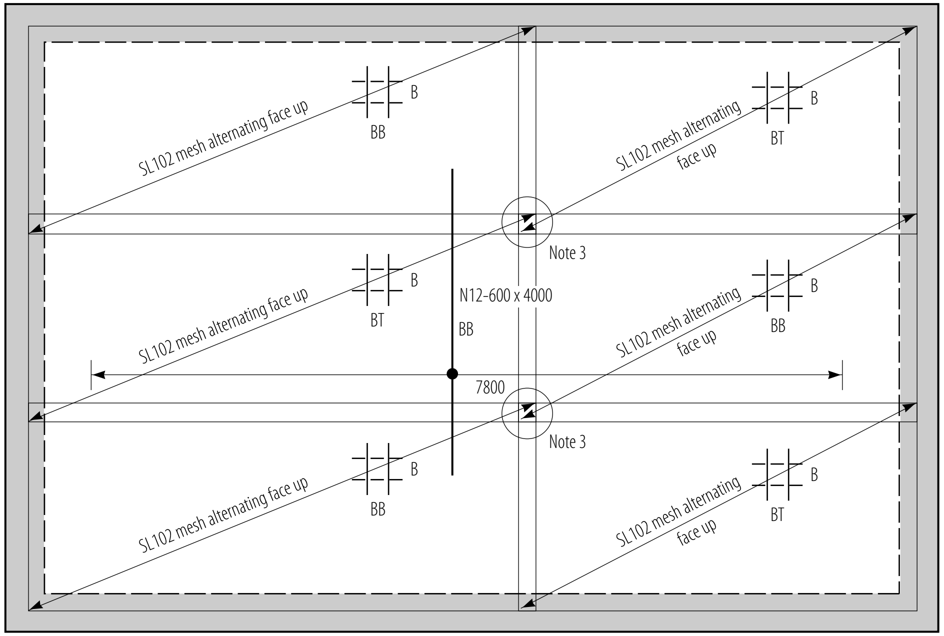
$$\begin{aligned} \phi M_{uo} &= \phi f_{sy} A_{stN}\ \bar{d}_x (1 - 0.6 \frac{A_{stN} f_{sy}}{b\ \bar{d}_x f'_c}) \\ &= 0.8 \text{ x } 500 \text{ x } 854 \text{ x } 166 [1 - 0.6 \frac{854 \text{ x } 500}{1000 \text{ x } 166 \text{ x } 32}] \text{ x } 10^{-6} \\ &= 54.0 \text{ kNm/m} \\ &\approx 54.4 \text{ kNm/m} \quad \text{say OK} \end{aligned}$$

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

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

(k) Separate calculations, like in Reference[12] using cracked section properties, show that the tensile stresses in the mesh and N bars under the action of the serviceability design bending moments calculated above, do not exceed the maximum allowable values permitted for flexural crack control in Clause 9.4.1.

(l) Design for fire resistance is readily satisfied by the soffit concrete cover being at least 15 mm for a continuous slab, in accordance with Table 5.5.3(A) of AS 3600:2001.



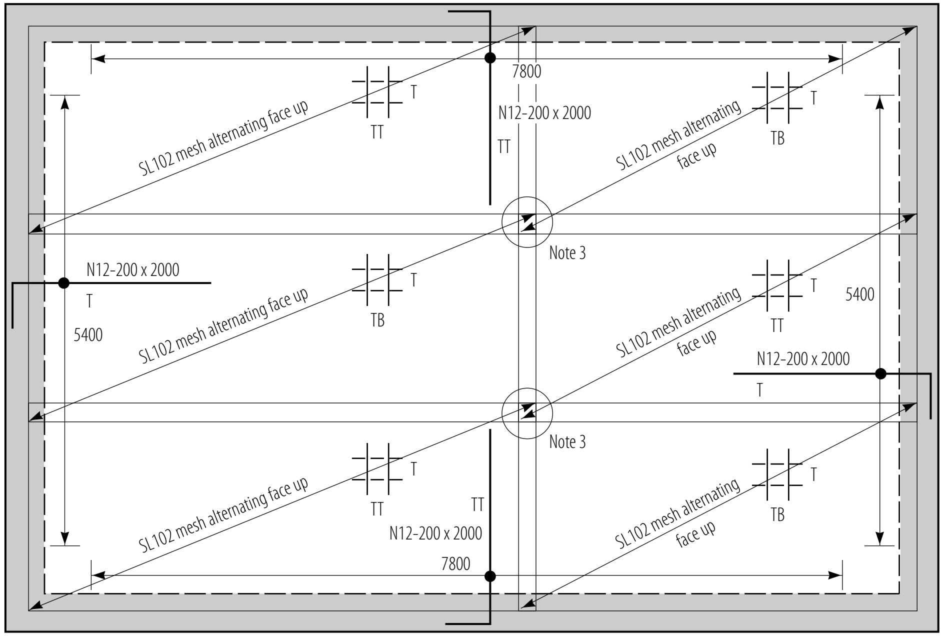
NOTES:

1 Code for bar levels of alternating mesh panels and N-bars:
BB = bottom-bottom (ie first or lowest level)
B = bottom (ie second or middle level)
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 At 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 A2 *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 level)
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 At 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 *Top Reinforcement for Rectangular Two-Way Slab Supported on Four Sides*