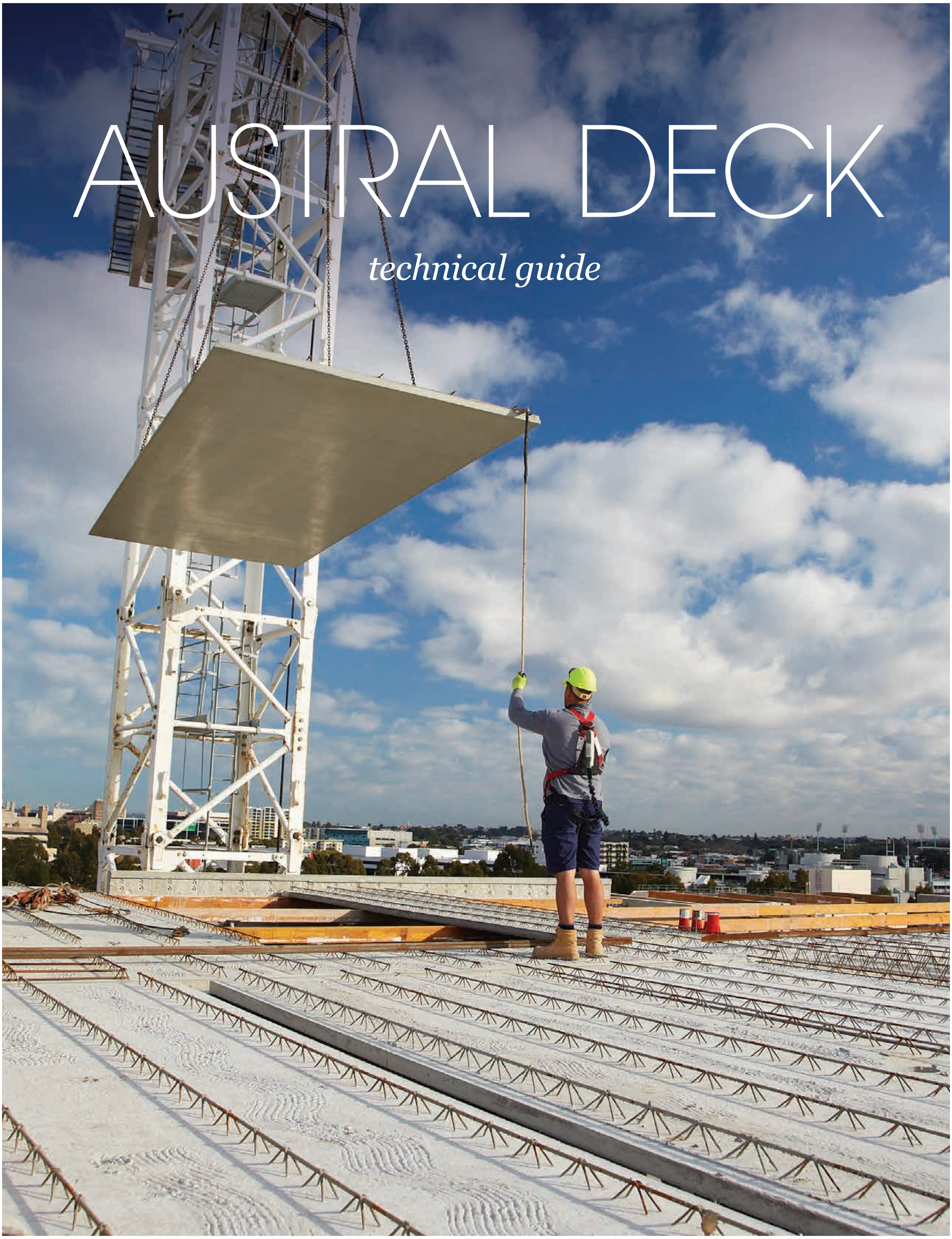
2017 / VERSION 1

AUSTRAL DECK

technical guide



australprecast®

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build faster, build smarter, build better

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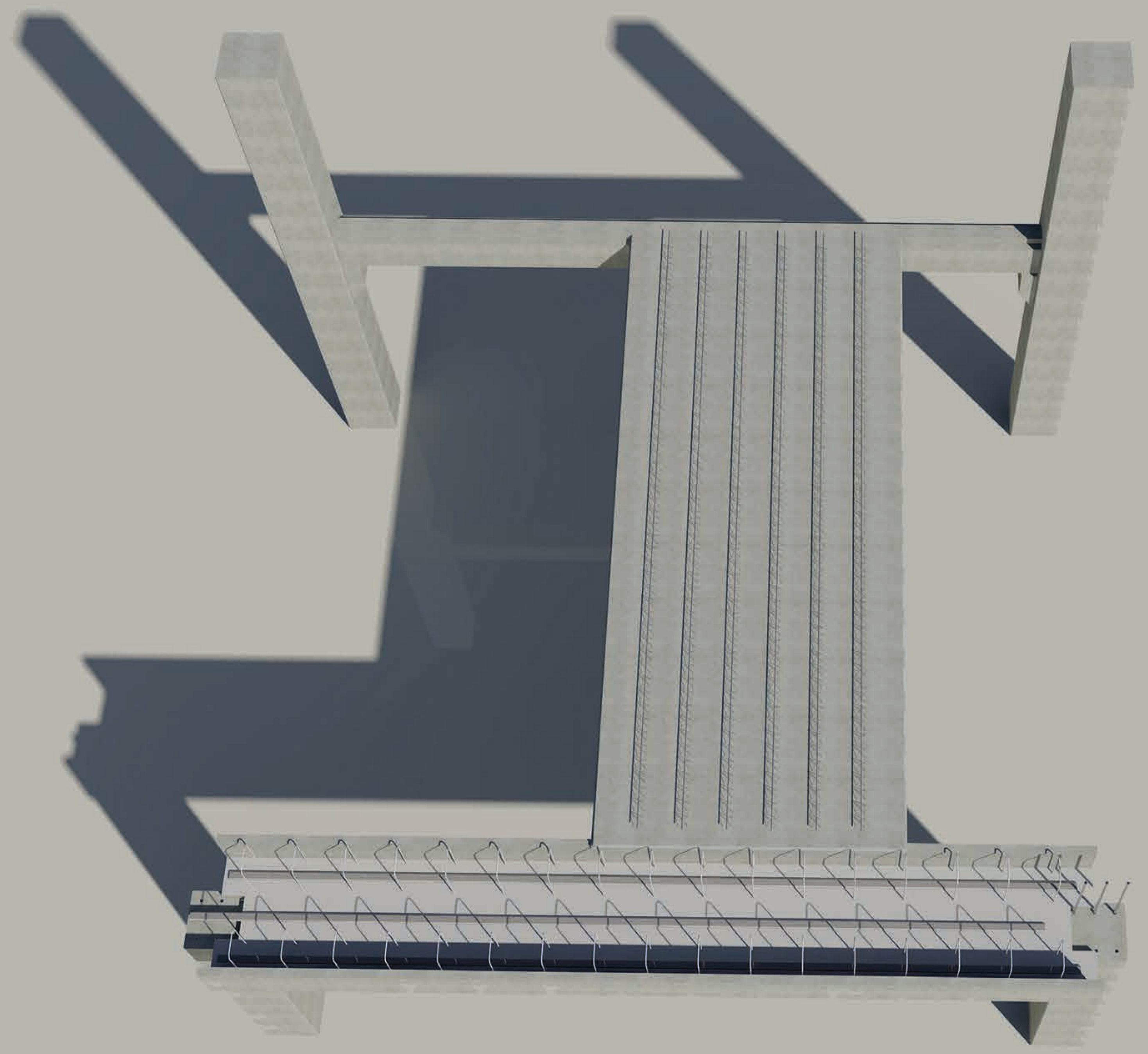


AUSTRAL DECK

design for construction, loading, permanent formwork, span capacity and final in service slab

The information contained in this document is provided as a general guide only and does not replace the need for the specification to be reviewed and checked by a qualified person in the field of concrete, energy, building construction, sound, design, services and/or fire.

This material has been prepared in the context of relevant Australian Standards, the National Construction Code (NCC) and the Building Code of Australia (BCA). Users should make themselves aware of any recent changes to these documents referred to therein and to local variations or requirements.

Austral Precast has dedicated engineering services available for project assistance. We are able to provide design support for engineers to determine the best way to specify and document Austral Deck.

Our technical experts can identify the most efficient panel geometry meeting project requirements, specifications and installation process.

Austral Precast offers fully detailed shop drawings as part of the Austral Deck supply.

It is the client's designer who is responsible to design and certify the concrete slab, the entire structure and certify the panel design for temporary propping and construction loads.

1. INTRODUCTION

Welcome to Austral Deck, an innovative, cost effective and time saving precast concrete flooring solution, designed to provide a one way and two-way spanning concrete floor slab and formwork solution in one.

Austral Deck combines features developed from many years of research, development and construction projects to provide a flexible solution that enables engineers, architects and builders to understand and use the solution as seamlessly as if they were designing a traditional concrete framed building.

The Guide aims to enable users to:

- Achieve a preliminary understanding of the Austral Deck solution, spans, costs and limitations
- Undertake designs and understand the theory behind their implementation
- Understand the way that Austral Deck is constructed, and plan accordingly.

1.1 Austral Deck – Overview

Austral Deck is based around a small number of key components, that combine to form a fully bonded, concrete slab.

The components combine the strengths, savings and benefits of precast concrete with the flexibility and simplicity of traditional in-situ formed, poured and finished floor slabs.

The solution can be broken down into the following key components (Figure 1):

1. A thin precast concrete "Austral Deck panel" providing a Class 2 bottom soffit finish whilst serving as formwork.
2. Reinforcement bar (rebar) and mesh cast into the Austral Deck panel, providing concrete spanning capability and contributes to slab reinforcement.
3. Triangular steel lattice girder "trusses" made from welded rebar, providing temporary stiffness for transport and installation. They provide permanent shear flow transfer capability.
4. Void formers, reducing the weight of the overall slab and increasing the efficiency of the concrete section.
5. On-site installation of top reinforcement and splice bars, providing easy access to cast in services whilst achieving rapid steel fixing time frames on site.
6. In-situ poured concrete topping.

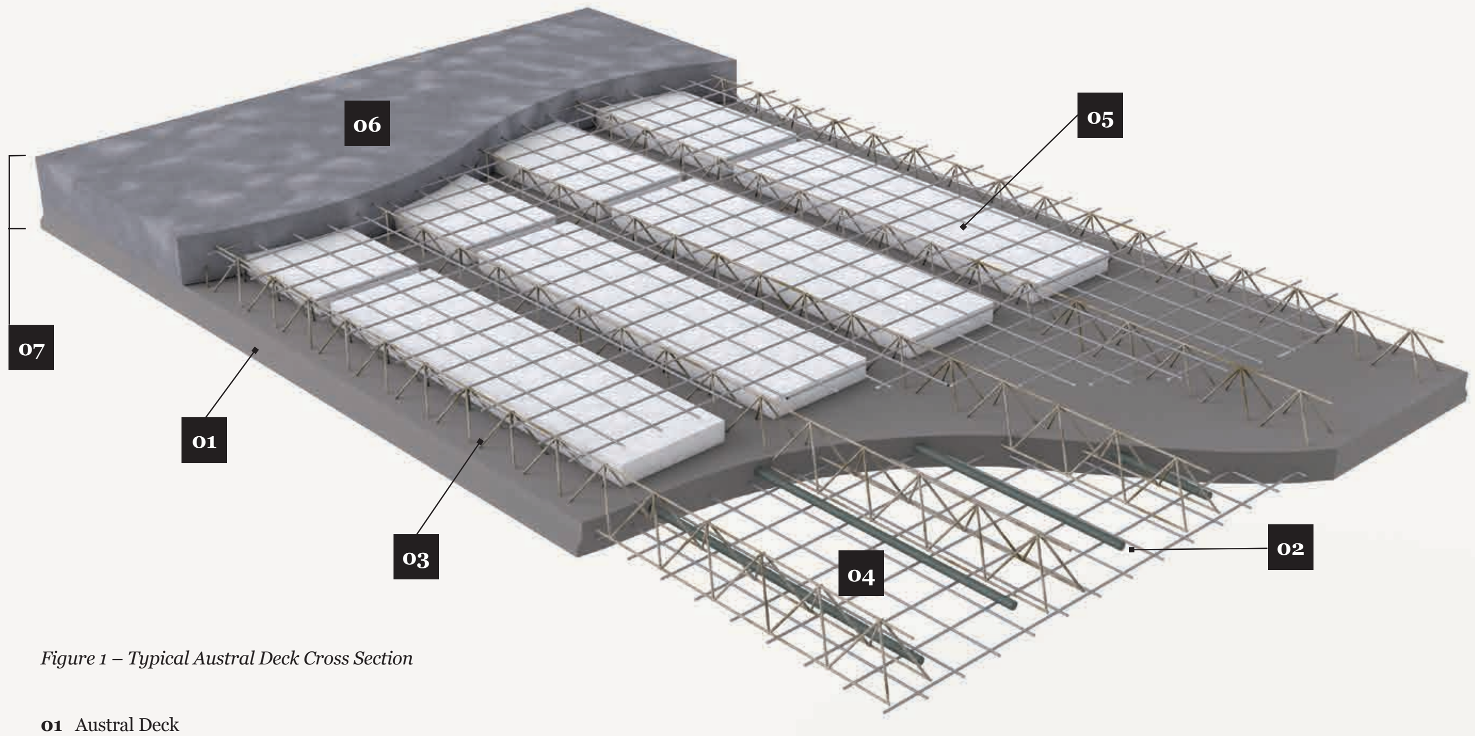


Figure 1 – Typical Austral Deck Cross Section

01 Austral Deck
02 Steel reinforcement if specified
03 Steel lattice girder
04 Steel mesh casted in the Austral Deck
05 Void formers
06 In-situ concrete topping
07 Slab thickness

1.2 Features and Benefits

Austral Deck is easy to design with and fast to install, saving time and money across the construction life cycle.

A flexible and adaptable formwork, Austral Deck integrates well with Austral Precast walling solutions, covering the entire structure including cantilevers and balconies.

A unique flooring solution

- An Austral Deck panel is part of a composite floor solution that provides rigid formwork that becomes part of the final structure. During construction the panel can stand construction loads and be used as a platform for workers and materials.
- An effective way to maintain the structural integrity of a monolithic slab.
- Composite platforms and shear connection panels can be constructed easily with partial or full-length gaps or pockets of concrete voids. The gaps will be located to accommodate structural beam configurations. This allows for the placement of the Austral Deck directly over precast, cast in-situ concrete or steel beams. Trusses and steel reinforcement can remain uninterrupted through these gaps for structural continuity. – Figure 2.
- This permanent formwork solution has been approved by many state road authorities, providing safer and more efficient construction of bridge superstructures.
- The quality of the form Class 2 finish on the under side of the Austral Deck floor can eliminate the need for a false ceiling, maximising floor to floor height.

A flexible and adaptable formwork replacement

- Austral Deck imposes minimum restrictions on designers and builders. Custom made sizes and shapes can be manufactured to suit construction layout and design specifications.
- Austral Deck panels can cover the entire width of a structure, including the cantilever beyond the external support. Refer to Section 8, Typical Installation Details.
- The solution integrates well with concrete or steel framed structures. – Figure 2.
- Cast-in items such as ferrules, conduits and other service fixings and penetrations can be accommodated during the manufacture of Austral Deck.
- Balconies and edge forms can be cast within the Austral Deck panel. These can eliminate edge formwork and scaffold costs. Integrated edge forms allows for early installation of temporary or permanent balustrades.
- Safety rail post holes can be prefitted to the panels prior to installation, improving site safety.

Economic and fast to install

Austral Deck offers all the advantages of a precast concrete system;

- Reduction in formwork and propping compared to conventional formwork.
- To further increase efficiency on site, Austral Deck panels may be produced with void former blocks attached to the top of the precast. These formers reduce the volume of in-situ concrete topping volumes and reduce the overall mass of the floor structure by up to 30%.
- Construction trades can commence working on the structure immediately after installation. Service ducts and conduits can be installed and accommodated into the cast in-situ portion of the slab.
- Austral Deck can be lifted straight into position, reducing conventional installation time. An average of 10 Austral Deck panels (covering an area of 150m^2) can typically be installed per hour.
- The panels have a relatively thin layer of concrete, which makes it lighter to transport and install.
- Austral Deck has the properties to achieve fire resistance and energy efficiency provisions as specified in relvant standards and building code of practice. Refer to Section 7 in this guide "Fire and Thermal Resistance".

Figure 2 – Integration with steel framed structure.

1.3 Applications

Austral Deck has been designed to be as flexible as possible, and therefore ideally suited for a broad range of construction applications.

Some of the applications that Austral Deck is suited for are as follows:

- Multi-Level Residential Developments, including:
  - > Exposed flat soffits with quality concrete finish
  - > Upstands and balconies preformed and/or precast
  - > Irregular column grids
  - > Flexibility of loads, penetrations, ducts and set-downs
- Commercial Developments, including:
  - > Long span floor plates
  - > Flat slabs, reduce losses in ceiling space for tenant services and mechanical services reticulation
  - > High loaded areas such as compactus and storage zones
  - > Good interaction and connection with precast concrete lift and stair cores, shear walls and other features
  - > Cast-in fittings for curtain walling systems
- Parking and open-deck applications
  - > Fast construction times allow opening of carparks sooner, minimising loss of car bays and maximising economic benefits
  - > Light weight concrete spans allow for more efficient structures
  - > Ramps, aisles and traffic movement areas can easily be accommodated within the Austral Deck design
- Decks and platforms
  - > Traffic and pedestrian bridges
  - > Curved on and off ramp structures
  - > Rail platforms
  - > Marine jetties and platforms
- Roofs and lids
  - > Tunnel and shaft roof panels
  - > Culverts
  - > Tank lids

2. PROPERTIES OF AUSTRAL DECK

This chapter will detail the structural and geometric properties of Austral Deck.

Austral Deck has been designed to be completely flexible with regards to depths, sizes and layouts. The standard designs below allow for a streamlined detailing process, as many of the forms, trusses, chairs and jigs are already available in many of Austral Precast's factories around Australia.

2.1 *Standard Austral Deck Design Thicknesses, Span Table and Graph*

Table 1 shows various standard thicknesses of Austral Deck.

Code	Total Depth	Precast Panel	Topping	Void	Theoretical Weight Reduction*		Equivalent Stiffness (Strong Axis)		Equivalent Stiffness (Weak Axis)	
	mm	mm	mm	mm	mm	%	mm	%	mm	%
AD150	150	60	90	N/A	150	0.0%	150	100%	150	100%
AD175	175	60	115	N/A	175	0.0%	175	100%	175	100%
AD200	200	60	140	50	175	12.7%	199	98%	198	98%
AD225	225	60	165	100	174	22.6%	221	94%	220	93%
AD250	250	60	190	120	189	24.4%	244	93%	243	91%
AD275	275	60	215	145	201	26.8%	266	90%	264	89%
AD300	300	90	210	130	234	22.0%	294	95%	293	94%
AD350	350	90	260	160	269	23.2%	342	94%	341	93%
AD400	400	90	310	210	293	26.7%	387	90%	384	89%

Table 1 – Standard Austral Deck Design Thicknesses

There are several key assumptions inherent in the standard design table, which are detailed as follows.

- Generally, the panels are optimised to allow for 60mm or 90mm precast biscuit at the base and minimum 60mm cover to the top of the polystyrene void former.
- Weight reduction and equivalent stiffness factors are based on a typical plank, 2500 x 7800mm, with 18 void formers of size 550 x 1000 each.
- *Theoretical weight reduction ignores any additional void formers removed around columns and walls, penetrations, cast-in anchors, transfer beams or other features that require full thickness concrete.
- Stiffness equivalents are based on elastic section analysis of the concrete cross section only. Cracked or transformed section analysis should be carefully undertaken by the design engineer.

A standard 250mm thick slab has a 23% weight saving of the structure, with only 7.5% loss of stiffness

Table 2 shows span to depth ratios for residential application of Austral Deck.

Code	Total Depth mm	Precast Panel mm	Topping mm	Void Depth mm	Upper Span Limit *Single* mm	Upper Span Limit *Continuous* mm
AD150	150	60	90	N/A	3500	4500
AD175	175	60	115	N/A	4000	5200
AD200	200	60	140	50	4500	6000
AD225	225	60	165	100	5000	6500
AD250	250	60	190	120	5500	7300
AD275	275	60	215	145	6000	7750
AD300	300	90	210	130	6700	8500
AD350	350	90	260	160	7750	10200
AD400	400	90	310	210	8750	11500

Table 2 – Span to Depth ratios for residential application

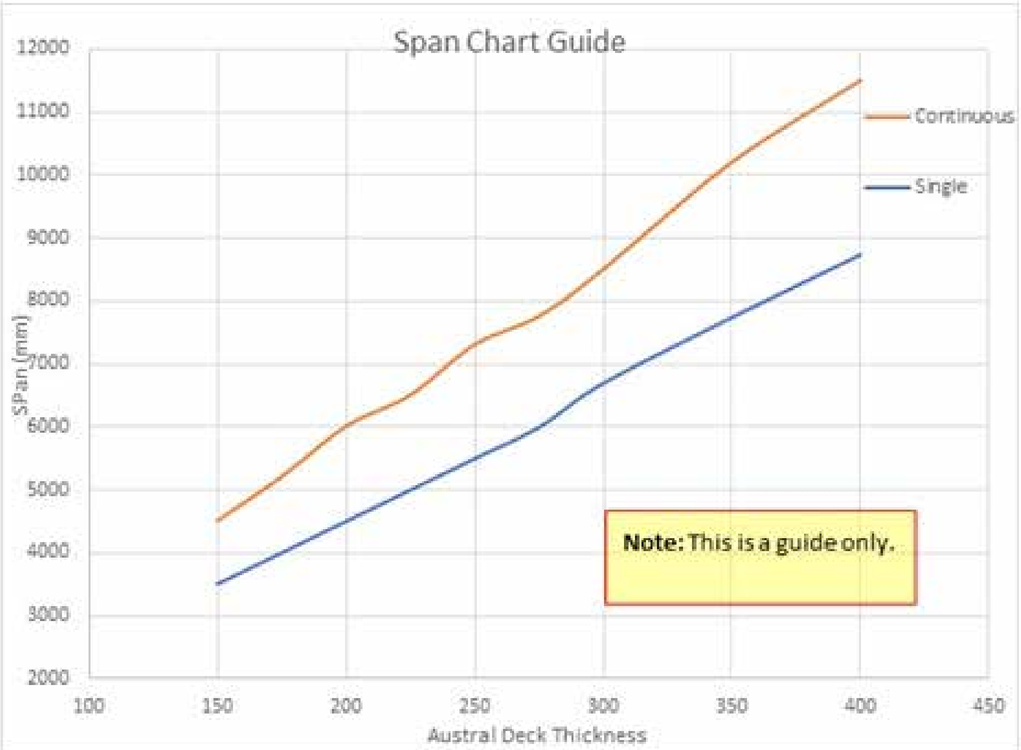


Chart 1 – Span chart guide

Typical Austral Deck dimensions and cross sections are shown in Figure 3.

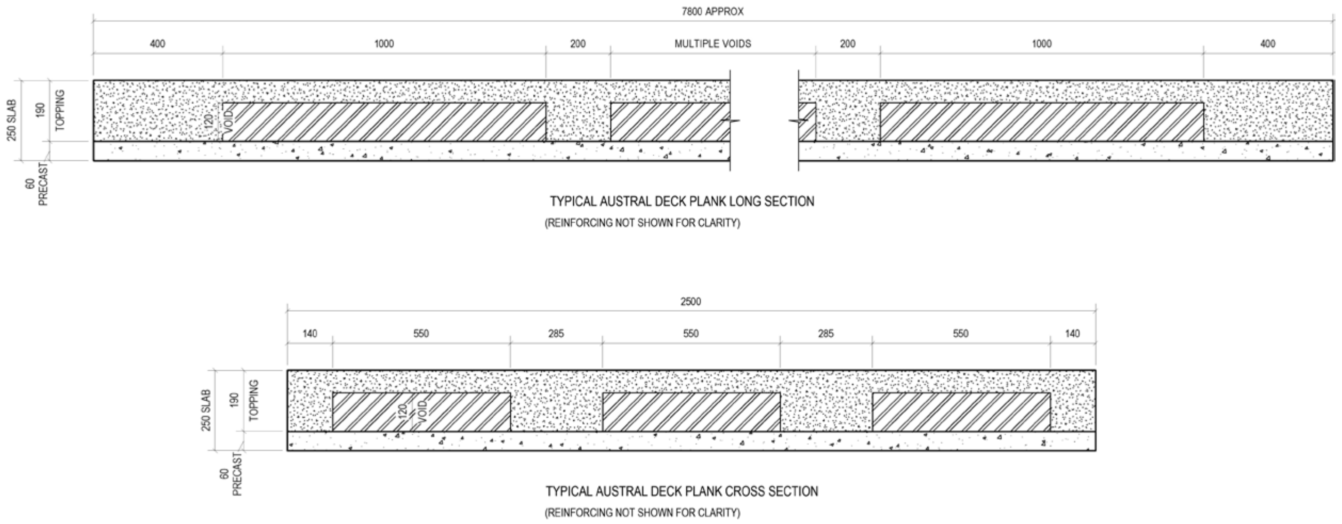


Figure 3 – Austral Deck Cross Sections

2.2 *Calculation of Austral Deck Weight Reduction*

The accurate calculation of the weight reduction is critical to the design of the structure.

Structural self-weight must be included for all calculations on slab performance. If the self-weight reduction due to the void formers is ignored then the slab will become needlessly conservative both for strength and serviceability calculations.

As a designer, one must also remember that for any concrete spanning element, serviceability (i.e. stiffness) effects are multiplied and amplified with the additional effects of creep and shrinkage. In some cases, this can cause significant over or under-estimation over the long term life of the project.

Self-weight has flow-on effects to the vertical and lateral supporting elements of the structure. Whilst the Austral Deck designer normally would only concern themselves with the design of the suspended slabs, any material change to the self-weight of the slabs will have flow-on effects, by increasing (or decreasing) the columns, foundations and transfer beams providing vertical support and cores and shear-walls providing lateral support.

Generally, over-estimating the self-weight of the structure would provide a conservative design, however for lateral elements, particularly for tall and slender buildings, the designer should also be careful as under-estimation of the building weight would put excessive tensile loads on the lateral support systems, by not providing enough tie-down force to counteract overturning effects.

Lastly, and possibly most importantly, if Austral Deck is adopted on a project after the preliminary and concept designs have already taken place, the designer should be careful not to increase the weight of the slabs, causing a flow-on increase in the costs of all the vertical and lateral elements above.

2.2.1 Basic Self-Weight Calculations

Calculate self-weight based on an average slab thickness and average reduction due to the voids.

For example, taking a typical 2.5m x 7.8m plank in a 250mm thick concrete slab, the concrete volume is:
$2.5 \times 7.8 \times 0.25 = 4.875\text{m}^3$

Over the plank area, there are 18 voids, in 6 rows x 3 columns. Each void is:
550mm x 1000mm x 120mm, or 0.066m^3 per void.

In total the concrete volume for the plank is therefore:
$2.5 \times 7.8 \times 0.25 - 18 \times (0.55 \times 1 \times 0.12) = 3.687\text{m}^3$

The total average reduction in the concrete slab is:

$$1 - \frac{3.687}{4.875} = 24.4\%$$

From a starting point of a 250mm slab, this is the weight equivalent of a 189mm slab.

2.2.2. Refinements to the Self-Weight

The basic self-weight calculations take into account the general proposed layout for a 2.5m x 7.8m plank, including 200mm solid sections longitudinally and 400mm solid plank ends.

However, there are many more areas where it may not be possible to achieve the maximum and most efficient void arrangement.

It is advised that there is a minimum of 500mm clearance around all load bearing elements and connections on a typical slab. That includes load bearing columns, walls and cores, as well as transfers, steps, folds and bathroom setdowns.

In some cases, it may not be feasible or practical to use void formers at all, usually once the slab depth narrows to under 175mm.

A typical layout of planks around a square column is shown below in Figure 4.

The figure shows a 600x600 square concrete column, with the precast planks stopping short of the column by 20mm all round.

There is minimum 500mm clearance to the column in one direction, and 675mm in the orthogonal direction. Note, 675mm allows the voids to remain in line and would not interfere with the reinforcement or rebar truss layout.

To calculate the effective or average self-weight for this example, an average should be taken over several column grids.

Note: the positioning of the 500mm clearance around columns and other load bearing elements is considered the minimum to allow for general detailing of the column-slab joint. It does not consider any punching shear perimeter, which may require a larger solid region around the column than depicted in Figure 4. Refer to Section 4.7 for further details on Punching Shear.

An example calculation is shown opposite in Section 2.2.3.

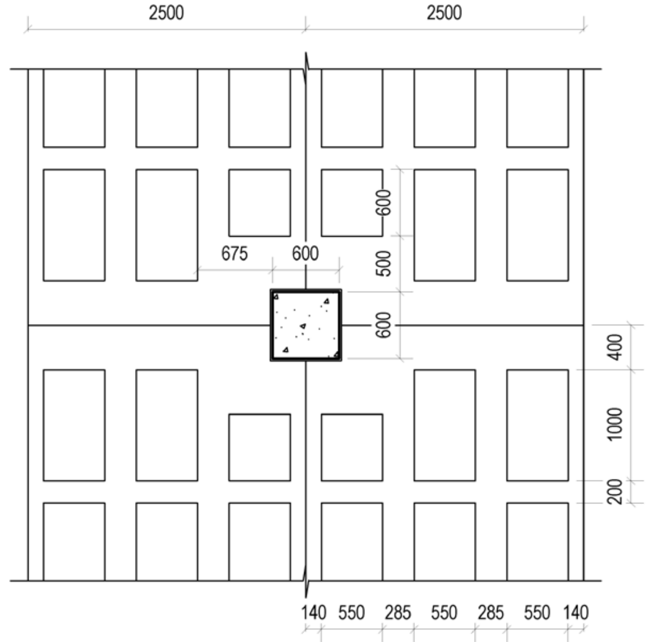


Figure 4 – Plan of Austral Deck Around Column

2.2.3. Multi-Span Weight Calculation Example

The basic self-weight calculations take into account the general proposed layout for a 2.5m x 7.8m plank, including 200mm solid sections longitudinally and 400mm solid plank ends.

The example shown in Figure 5 shows a slab of 2 x 2 grid bays of 7.5m x 7.8m each.

The 250mm slab has 9 columns each of 600 x 600.

Using a typical case where the slab beneath a column is included in the slab volumes the total volume of this slab is:

$15 \times 15.6 \times 0.25 = 58.5\text{m}^3$

Excluding the void free areas around the columns the normal reduction of 24.4% equates to a total volume of 44.2m^3.

However there are a number of smaller 600x550 voids around the columns. The total void volume:

$[16 \times 0.4 \times 0.55 + (12 \times 18 - 16) \times 1 \times 0.55] \times 0.12 = 13.62\text{m}^2$

$$\textit{Volume Reduction} = \frac{13.62}{58.5} = 23.2\%$$

If the slab were to have setdowns, walls and folds, as is likely for a residential apartment complex, the volume reduction may well reduce to 20% or beyond.

2.2.4. Calculations Using Software

It is possible to use 3D modelling software to calculate rough slab volumes and therefore self-weights, including Tekla, Autodesk Revit or Bentley Microstation.

When using any modelling software, the designer and draftsperson should always have in mind the additional complexity of modelling voids, and take care not to use any volume outputs without hand checking the results.

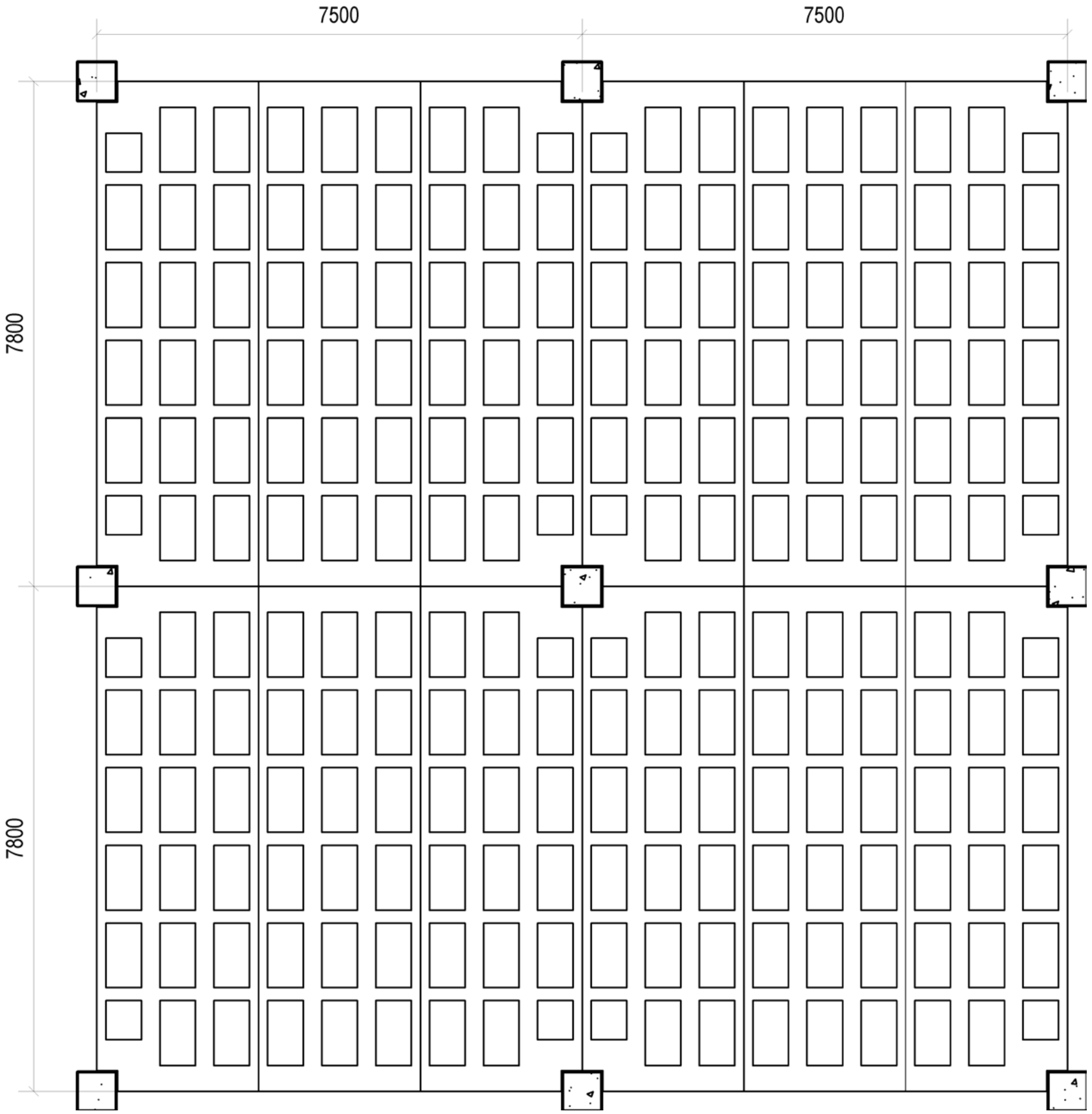


Figure 5 – Typical Multiple Span Austral Deck Layout

Note: Refer to 2.1 about Theoretical Weight Reduction. Some voids might be required to be removed to place the splice bars.

2.3 Calculation of Austral Deck Stiffness

The elastic stiffness of a suspended slab (or any structural element) is solely dependent on two properties;

- Material properties, E, the Young's Modulus
- Geometric properties, I, the Second Moment of Inertia

The effective, transformed stiffness of a suspended slab depends on a number of non-linear and behavioural properties of the concrete material and layout within the structure, including;

- Extent of cracking, influenced by reinforcement ratio, concrete material and horizontal prestress as per AS3600 sections 8.5.3 and 9.3
- Load duration (ψ factors) and Dead to Live Load ratios
- Creep, influenced by environmental conditions, concrete strength and hypothetical slab thickness as per AS3600 section 3.1.8
- Shrinkage, influenced by environmental conditions, concrete strength and hypothetical slab thickness as per AS3600 section 3.1.7

Generally in the case of Austral Deck slabs, the calculation of stiffness is no different, however the designer should also take the precast concrete panel joints into consideration. For example, stiffness across panel joints every 2.5m on a 10m span may well be reduced by 10%, as indicated in section 2.3.3.

In general, we ignore any changes to the Young's Modulus of the section, as the concrete is usually a relatively standard strength mix, with well-known properties. Concrete specification is discussed further in this document.

The geometric stiffness depends on the layout and position of the void forms and for fully transformed sections, the location of the reinforcement.

For computer modelling purposes, the voids are considered using a traditional elastic modulus calculation.

For the example in Section 2.2.3 the stiffness of a plank is calculated below:

2.3.1. Calculation of the Neutral Axis – Elastic Section

The neutral axis of the cross section is found as follows:

$$Q = \sum y \cdot dA$$

$$= \frac{(2.5 \times 0.25m) \times 0.125 - 3 \times (0.55 \times 0.12) \times 0.120}{(2.5 \times 0.25m) - 3 \times (0.55 \times 0.12)}$$

$$= 127.3mm$$

2.3.2. Calculation of the Moment of Inertia

The Moment of Inertia of the cross section is found using the parallel axis theorem as follows, assuming an elastic, uncracked section.

$$Ixx = \sum y^2 \cdot dA$$

$$= \frac{bd^3}{12} + Ay^2 \text{ (Concrete minus voids)}$$

$$= \frac{2.5 \times 0.25^3}{12} + 2.5 \times 0.25\,(0.125-0.1273)^2 - 3\left(\frac{0.55 \times 0.12^3}{12}\right)$$

$$- 3\,(0.55 \times 0.12)\,(0.12 - 0.1273)^2$$

$$= 3010 \times 10^6 \; mm^4$$

Without void formers, the Moment of Inertia of the equivalent section would be:

$$Ixx = \frac{2.5 \times 0.25^3}{12} = 3255 \times 10^6 \; mm^4$$

The reduced stiffness in this case is only:

$$\frac{3010}{3255} = 92.47\%$$

In other words, for a standard 250mm thick slab, there is a 23-24% weight saving of the structure, with only 7.5% loss of stiffness.

2.3.3. *Calculation of Elastic Stiffness Allowing for Joints*

The calculation of a reduction of stiffness based on the precast concrete joints can be estimated based on simple linear elastic calculations, but a detailed finite element model may be more useful.

For example, Figure 6 below are two spans, approximating a 280mm thick, 1000mm wide concrete slab spanning 10m. The lower span has three joints at 2500mm centres, where the slab thickness is reduced by 60mm.

The joints are set to be 20mm wide and the slab in the joint is raised such that the top of slab remains constant (i.e. elastic neutral axis is raised by 30mm).

The deflection for the model below has increased by between 1% and 2% overall at the midspan.

It should be noted that the below case is for a solid, elastic section only, and does not include effects for voids, transformed sections, creep, shrinkage etc. Only the impact of the panel joints are modelled.

Whilst the joint location may seem trivial, the over impact on deflection may be critical, and the location of joints should be positioned where possible to produce minimal impact on the slab, such as the one-quarter to one-third points of the slab where a point of inflection exists.

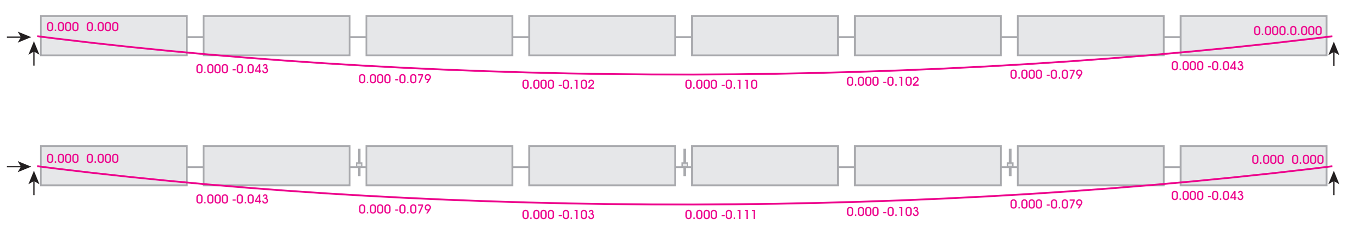


Figure 6 – Elastic Analysis of Panel Joints

3. MODELLING AUSTRAL DECK

3.1 Design Principles

This chapter primarily discusses the use of computer modelling software to analyse and design Austral Deck in a variety of project settings. The chapter mostly uses examples and specific settings from RAM Concept, by Bentley Systems, however the general principles can be applied to any internally recognised software package, including SAFE/ETabs (by Computers and Structures Inc), RAPT (by PCDC), Slabs (by Inducta), Strand7, SAP2000, DIANA and other Finite Element Analysis packages.

In general, the design of the Austral Deck consists of two design stages

1st Stage : Design as formwork

Must be designed for

- Lifting during manufacturing
- Transport
- Lifting during installation
- Construction loads during use as formwork

2nd Stage: Final in-use slab design

- Must be designed for strength and serviceability for in-service situation as per conventional reinforcement concrete suspended slab

3.2 General Modelling

The concept and general properties of Austral Deck can be analysed and designed using regular methods, concepts and codes that would normally be employed to design a reinforced concrete suspended slab.

In general, the designer needs to take account of the following properties and changes:

- Structural mass – changing the concrete material properties to account for void formers.
- Structural stiffness – changing the slab shape properties to account for void formers.
- One vs Two-way spanning – changing the shape properties to account for non-isotropic properties of the precast joints and void former shapes.

3.2.1. *Outputs from Modelling*

Just like an ordinary suspended concrete slab, Austral Deck can be modelled using 1-D (strip run), 2-D (area plan) or 3-D (full building) software.

The designer can use the normal software outputs such as load run-downs, bending moments and deflections to design and design-check the suspended slab.

Some software has also been specifically developed to output detailed designs, including strip-run analysis, reinforcement design and detailing and even bar bending schedules. Any output related to the reinforcement and strip analysis of Austral Deck should be carefully checked, as some of the detailing requirements are different to a normal suspended reinforced concrete slab.

3.2.2. *Code Compliance*

Austral Deck has been designed such that it is code compliant with all of the standard design and construction codes that exist around the world. These include:

- AS3600-2009 – Concrete Structures
- AS3610-1-2010 – Form Work for Concrete
- Eurocode 2 – 1992-1-1 - Design of Concrete Structures (Europe)
- BS8110 – Structural Use of Concrete (United Kingdom, now superseded by Eurocode 2)
- ACI318 - Building Code Requirements for Structural Concrete (Nth America)
- NZS-3101 – Concrete Structures Standard (New Zealand)

The designer should make themselves familiar with the particular code requirements for analysis, design and detailing for the region that is most relevant to the project.

In addition, the designer should also make themselves familiar with additional code requirements for materials and testing of reinforcement, concrete, formwork, temporary works and propping that is relevant to the project location.

3.3 Using Ram Concept

RAM Concept (by Bentley Systems) is a two-way analysis package, using Finite Element Analysis (FEA) to determine loads and actions for a suspended concrete slab. It can be customised and can be used to design, check and detail concrete slabs, including Austral Deck slabs.

RAM Concept can undertake analyses and code compliant detailing for a variety of country specific concrete standards.

Only relatively minor adjustments are required to enable RAM Concept to be compatible with Austral Deck, which are detailed below. It is important to note, however that there are many other options in RAM Concept that the Austral Deck designer can be used to adjust or "tweak" the analysis or design. Designers should always familiarise themselves with the limitations of the software and undertake sensitivity/ variance analysis runs to ascertain the magnitude of impact on any of these options.

Note: The following examples are based on current menus and screenshots from RAM Concept CONNECT Edition, v6.00.01.006 x64. Other versions may have slightly different menu configurations.

3.3.1. Adjustment for Structural Weight

On creating a new "Elevated Slab" model, the designer should select the "Materials" screen from the navigation menu, Figure 7:

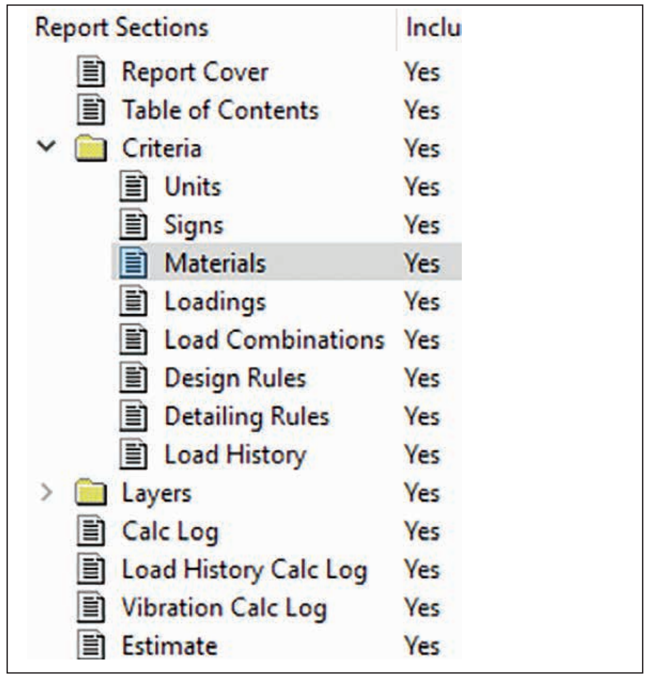


Figure 7 – RAM Concept Menu

From the Materials screen, the designer should select a concrete strength most likely to be used – generally this would be 32MPa or 40MPa (N32 or N40) grade concrete.

Select "Add Concrete Mix" and name it to appropriately reflect the Austral Deck mix, e.g.: "50 MPa (Austral Deck).

Copy the concrete mix properties, ensuring that the strength and stiffness properties remain the same as the ordinary concrete mix (refer to Table 3).

Reduce the concrete Density by a factor calculated/estimated to be the slab average, allowing for weight reductions from void formers.

For example, for a rectangular, regular carpark slab in Figure 4 the maximum density might be 24.4%, but the average reduction might be 20%. Conservatively, the designer may even use 17% as an initial assumption.

For this case, the density would be:

$2400\ kg/m^3 \times (1-0.17) = 1992\ kg/m^3$

Note: the design density of normal concrete is specified by AS3600-2009, Section 3.1.3 as 2400kg/m3. In practice, the actual density of concrete changes with the concrete and aggregate specifications, quantity of reinforcement and other properties.

The designer should also take care to check if the density properties are used in calculation for any other structural properties that might impact the results of the analysis.

In the case of RAM Concept, it is possible to specify a separate Density property from Density For Loads calculation. It is highly recommended that the designer run the analysis for both options and check if any differences in the results are significant to the calculations.

It is also important that the concrete strength and stiffness characteristics, such as f'_{ci}, f'_c, E_{ci} and E_c remain the same as the traditional concrete mix – these will be altered later.

MIX NAME	Density (kg/m^3)	Density For Loads (kg/m^3)	f'_{ci} (N/mm^2)	f'_c (N/mm^2)	f'_{cui} (N/mm^2)	f'_{cu} (N/mm^2)	Poisson's Ratio	Ec Calc	User E_{ci} (N/mm^2)	User E_c (N/mm^2)
20 MPa	2400	Density	15	20	18.75	25	0.2	Code	21000	25000
25 MPa	2400	Density	20	25	25	30	0.2	Code	25000	27000
32 MPa	2400	Density	20	32	25	40	0.2	Code	25000	31000
40 MPa	2400	Density	20	40	25	50	0.2	Code	25000	34000
50 MPa	2400	Density	20	50	25	60	0.2	Code	25000	38000
65 MPa	2400	Density	20	65	25	80	0.2	Code	25000	43000
32 MPa (Austral Deck)	2400	Density	20	32	25	40	0.2	Code	25000	31000

Table 3 – RAM Concept Concrete Mix Properties

3.3.2. Average Slab Thickness

Designers should also take care when calculating the average density for highly variable slabs, such as residential slabs with bathroom and wet-area setdowns, balconies and closely spaced load bearing elements.

Each of these items would alter the average slab thickness and density reduction.

The designer should always err on the conservative side of judgement when calculating average weight reductions. For the example shown in Figure 2 3, a residential slab may have a reduction of 10-12%, with an equivalent density of 2112 – 2160kg/m³.

For large floor areas, it is also possible to add multiple slab types with multiple densities, as per Table 4.

MIX NAME	Density (kg/m^3)	Density For Loads (kg/m^3)	f'_{ci} (N/mm^2)	f'_c (N/mm^2)
25 MPa	2400	Density	15	20
32 MPa	2400	Density	20	25
40 MPa	2400	Density	20	32
40 MPa	2400	Density	20	40
50 MPa	2400	Density	20	50
65 MPa	2400	Density	20	65
40 MPa Austral Deck Bathroom Setdown	2400	Density	20	32

Table 4 – Reduced Austral Deck densities for regular and bathroom slab areas

3.3.3. Reduced Concrete Stiffness

Different software packages have the ability to directly influence concrete stiffness either globally or locally in certain areas of the slab.

Structural stiffness is proportional to both material (Young's Modulus E) and geometric stiffness (Moment of Inertia I).

The material stiffness values were unmodified in the material settings above, as the concrete material is not actually changing when using Austral Deck.

RAM Concept can modify geometric stiffness by altering the slab thickness or directly with modification coefficients.

It is the designer's prerogative as to which option is modified, but one should always remember the flow-on effects of each option. For instance, reducing the slab thickness in RAM Concept would directly reduce the structural self-weight, and dramatically reduce the capacity calculations for Bending Moment, Beam Shear and Punching Shear.

It is recommended to reduce only the bending stiffness coefficients as per Figure 8. For RAM Concept, the coefficients are found in the Slab Properties of the Mesh Input window.

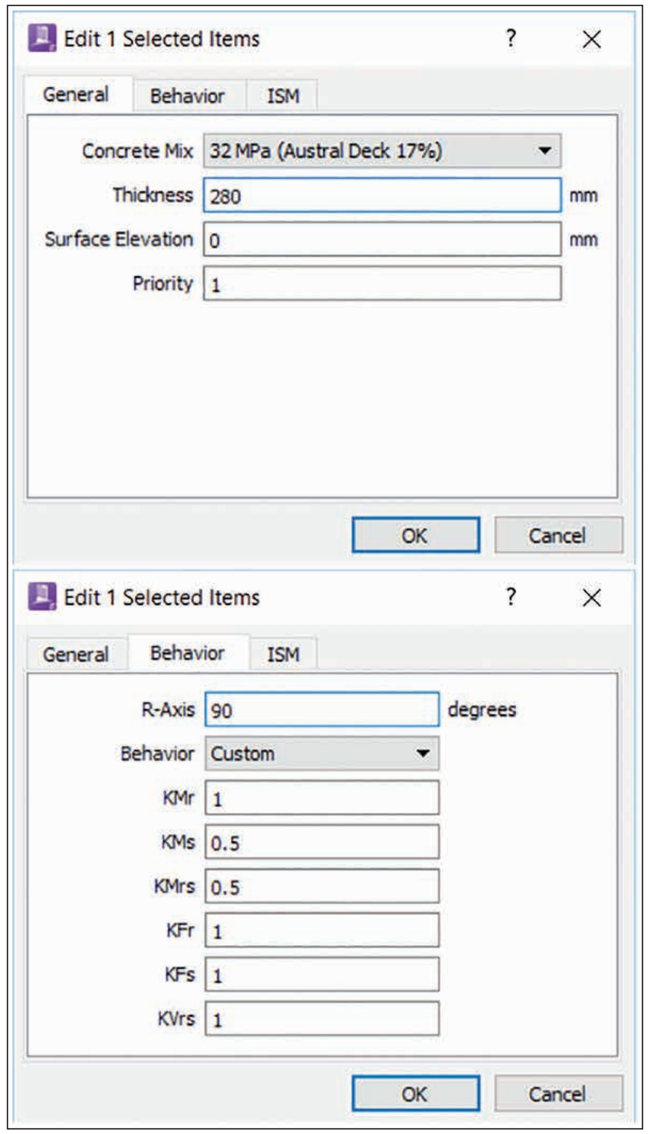


Figure 8 – Slab properties showing Austral Deck concrete mix and custom reduced stiffness

3.3.4. Isotropic vs Orthotropic Stiffness

When modelling a suspended slab in a finite element software environment, it is often possible to adjust the individual stiffness coefficients separately.

In the case of RAM Concept, Figure 7 shows the 6 degrees of slab movement, as follows:

- KMr Bending stiffness about primary direction (about R axis)
- KMs Bending stiffness about secondary directory (about S axis)
- KMrs Torsional stiffness
- KFr In-plane axial/membrane stiffness in primary direction
- KFs In-plane axial/membrane stiffness in secondary direction
- KVrs In-plane shear stiffness

Where custom coefficients are used, the orientation of the R-axis is critical.

For Austral Deck slabs, it is good practice to orientate the R-axis in the direction of the Austral Deck plank. Whilst Austral Deck has been designed to be a two-way suspended slab system, the planks, voids and joints interact such that the direction of the deck is considered the stronger and stiffer direction.

For RAM Concept, if all coefficients are 1, the slab is perfectly isotropic, or two-way spanning. Whereas, for an idealised one-way slab, RAM Concept defaults to

KMr = 0.001 and KMrs = 0.5.

3.2.5. Austral Deck and Orthotropic Stiffness

In an ideal design, Austral Deck is considered to be almost isotropic. As Table 1 indicates, the difference between strong and weak axis reductions is subtle. In the case of AD250 the difference is 93% compared to 91%.

In practice, for longer Austral Deck spans, plank dimensions may be 8-9m x 2.5m. This results in 3-4 times more plank joints in the secondary direction than the primary direction.

For properly (and ideally) laid out slab plans, the cumulative impact of the joints may reduce stiffness (and increase deflection) by as much as 5% over larger spans. This also has the effect of redistributing primary and secondary direction moments which will alter the reinforcement design and placement.

3.3.6. Orthotropic Stiffness and Australia Code Compliance

It is imperative that any variation to the slab stiffness takes into account both the actual, real-world differences in the structural properties of the slab, but also the limitations imposed by any relevant design codes and standards.

For instance, Australian Standards AS3600-2009 describes methods for structural analysis in Section 6. In particular, Section 6.9 describes the use of Idealised Frames, whereby positive and negative moments in both primary and secondary axes are apportioned to column and middle strips.

RAM Concept enables the designer to split the suspended slab into various design strips. If design strips are set up automatically, RAM Concept will default to using "Code Slab" layout rules, which generally apportion the strips in accordance with AS3600, Section 6.1.

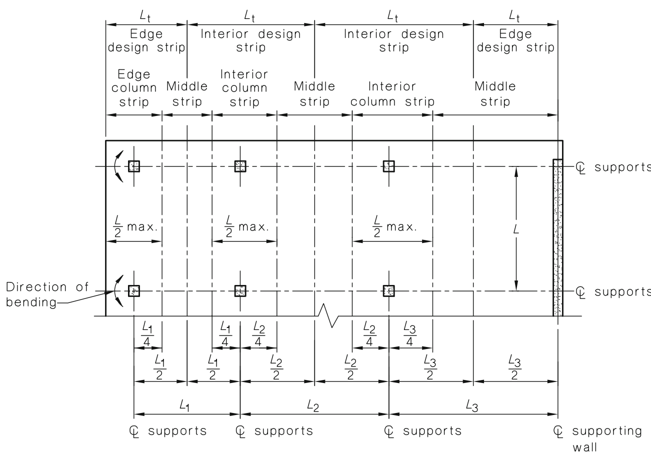


Figure 9 – Design column and interior strips as defined by AS3600-2009 Section 6.1.

For Austral Deck designs, the use of primary and secondary stiffness modifiers will significantly influence the apportionment of load and therefore bending moment into the column and middle strips.

The designer should take care to ensure that the moment redistribution does not exceed the limits of redistribution that is allowed by the code. For instance, AS3600-2009 Table 6.9.5.3 limits the moment distribution as follows in Table 5:

Distribution of Bending Moments to the Column Strip

Bending Moment Under Consideration	Strength Limit State	Servicability Limit State
Negative moment in an interior support	0.60 to 1.00	0.75
Negative moment in an exterior support with spandrel beam	0.75 to 1.00	0.75
Negative moment in an exterior support without spandrel beam	0.75 to 1.00	1.0
Negative moment in an interior support	0.50 to 0.70	0.6

Table 5 – Design strip distribution from AS3600-2009 Table 6.9.5.3

3.3.7. Austral Deck and RAM Concept Design Strips

RAM Concept uses Design Strips to integrate design actions such as bending moments, shears and support reactions and create a one-dimensional span. The design or span is then split into several regular cross sections which are analysed.

Reinforcement quantities (in mm²) are determined for the design load envelopes over the design cross section. Finally, the software takes all the design sections along a particular span and applies code compliant detailing rules to lay out the reinforcement.

3.3.8. RAM Concept and AS3600-2009 Implementation

The designer should be aware of the various inclusions and exclusions that RAM Concept applies and ensure that adequate hand-checks are performed to make sure there is no areas of the slab that are excluded from the run.

For instance, RAM Concept does not apply all the various requirements from AS3600-2009, or applies its own interpretations of some of the various design requirements. This is detailed in the RAM Concept manual.

Some of the design limitations that RAM Concept applies are pertinent to Austral Deck designs, as follows:

Initial Service Load Case

RAM Concept does not take into account the differential age between the precast plank and topping portion of Austral Deck.

Concrete modulus

RAM Concept uses the formula for Ec and Eci as specified by the equations in AS3600-2009 Section 3.1.2, not the values specified by Table 3.1.2.

f'_{cm} values used in the equations, however, are taken from Table 3.1.2. in AS3600.

Low Ductility Rebar

RAM Concept does not apply the low ductility (Class L) rules that were updated as part of Amendment #2 of AS3600-2009. This is particularly relevant for the mesh reinforcement placed within the precast section of Austral Deck.

Minimum Reinforcement

RAM Concept uses AS3600-2009 Section 8.1.6 and Section 9.4.3.2 for minimum reinforcement in span directions. Section 9.1.1 is implemented via Section 8.1.6.1 for spanning reinforcement. This may result in different reinforcement quantities in Austral Deck planks.

Crack Control

AS3600-2009 Section 9.4.1(c) and (d) are ignored when the slab environment is specified as "protected", which is the typical setting for internal slabs. This may be unconservative for Austral Deck slabs and should be checked manually.

Axial Forces

Axial forces are sometimes taken into account, depending on the design strip settings, however for "T", "L", or "Z" beams, Austral Deck designers should take care that the design strips/sections include the entire beam flange area, otherwise significant out-of-balance axial forces will be applied into the plank zones of the Austral Deck slab.

Reinforcement depth

Austral Deck designers should carefully specify the design location and actual location of the Layer 2 reinforcement, i.e. the bars placed on the bottom of the in-situ slab, sitting directly on the bottom of the precast plank. In some cases, these bars may not be properly included as bottom face reinforcement.

3.3.9. Austral Deck and RAM Concept Deflection Analysis

Accurate prediction of slab deflections can be a difficult task and is dependent on both analysis and design parameters including:

- Loading and load history estimates over short term (days) and long term (years)
- Estimation of slab cracking and effective/transformed slab section properties
- Tension and compression reinforcement ratios
- Interaction between cracked concrete slabs and reinforcement
- Estimation of creep and shrinkage properties
- Estimation of short and long term concrete strength and stiffness (as design compared to as-constructed)
- Estimation of concrete rates of strength gain over 24 hours, 30 days and 30 years.
- Slab age at de-propping and loading

RAM Concept provides load history calculations which are then reconciled to the cracked section analysis in orthogonal directions. (Figure 10).

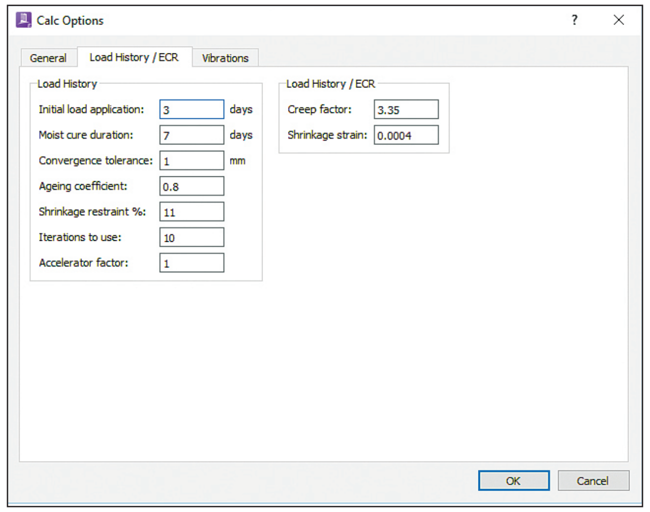


Figure 10 – RAM Concept load history options

It is important for the designer of Austral Deck to take into account some particular deflection characteristics which may influence the deflection calculation, as follows:

- The RAM Concept creep and shrinkage models are derived from ACI report 209R-92. There is significant literature online for this deflection model, however it is important to note that the ACI model assumes the initial loading time is 7 days, whereas AS3600 assumes initial loading is 28 days. Designers should either use the ACI model and specify the actual time of loading, or use the AS3600-2009 final creep factors from Table 3.1.8.3, and then multiply by 1.326, which is (k3-7days / k3-28days).
- Designers should also note that the creep factor includes elastic strain + creep strain.
- Shrinkage Restraint plays an important role in deflection. Online guidance from RAM Concept is as follows:
  - 0% - unrestrained or very lightly restrained slabs (flexible columns only, single stiff element)
  - 10% - normally restrained slabs (more than one stiff element, some flexibility)
  - 20% - completely restrained slabs (basement walls around entire perimeter, etc. causing a high degree of restraint)
- Generally, shrinkage restraint for Austral Deck should be set between 10 and 15% depending on the level of conservatism required for deflection calculations.
- Whilst designers usually ignore the live load reduction factors settings in RAM Concept, it is important to set live loads to their correct load case (Reducible, Unreducible, Storage, Parking, Roof). RAM Concept uses these cases to determine short and long term combination factors in accordance with AS1170.0 Table 4.1. These are then used for the load history. For example, setting residential loading to "unreducible" would apply ψL=0.6 and ψS=1, rather than ψL=0.4 and ψS=0.7. This would obviously increase the deflection over the long term.
- RAM Concept defaults to using 5000 days (132/3 years) for long term deflection, but AS3600 conventions suggest 30 years, or 10950 days.

3.3.10. Example – Austral Deck Load History Settings

Table 6 is a set of load history settings that might be typical of a residential slab (average 250mm thick, 32MPa, coastal environment).

Variation in these settings, combined with an abundance of localised environmental effects will give rise to differences in real-world experiences of deflection. It is highly recommended that conservative values are chosen, and that the designer undertake sensitivity analyses with different values to check that the slab design is sufficiently conservative.

Setting	Value	Comments
Live Load	1.5kPa (reducible)	As per AS1170.1, to ensure short and long term factors are correct
Load History –Sustained	10950 days	Equal to 30 years for total long term
Initial Load Application	7 days	As per RAM Concept Recommendations
Shrinkage Restraint	15%	For example, a residential slab, precast concrete party walls and a sheer core, but free to shrink on the edges
Creep Factor	3.8	Design creep factor from AS3600-2009 using: $F'_c + 32$, $t_h = 250$, t = 10950, $k^2 = 1.127$, $k^3 = 1.463$ $\varphi^*_{cc} = 2.8$, Design creep = $1 + \varphi^*_{cc}$
Shrinkage Strain	0.000462	From AS3600-2009, using basic shrinkage ε*ccsd,b = 1000με, based on aggregate supply from "elsewhere'

Table 6 – Typical load history settings for a residential Austral Deck slab

3.4 Austral Deck Design Strip Layout in RAM Concept

This section discusses some of the modelling options available to Austral Deck designers using RAM Concept.

The layouts are only suggested for various designs, and could easily be reconfigured to suit the Austral Deck designer's own preferences.

3.4.1. Example Design

The example design used in this section has been chosen to demonstrate some design strip layout options, and does not represent a real-world model.

To ensure the terminology of RAM Concept remains consistent, we will refer to the slab axes as Latitude, running horizontally to the page, and Longitude, running vertically to the page.

The slab contains 3 spans of 8m, 6.5m and 8m respectively in the Latitude direction, and 2 spans of 6.5m in the Longitude direction. (Figre 11–12)

The overall floor is 250mm thick Austral Deck, with 40mm bathroom set-downs. There are 200mm wide, 1000mm deep upstand beams on two sides of the model.

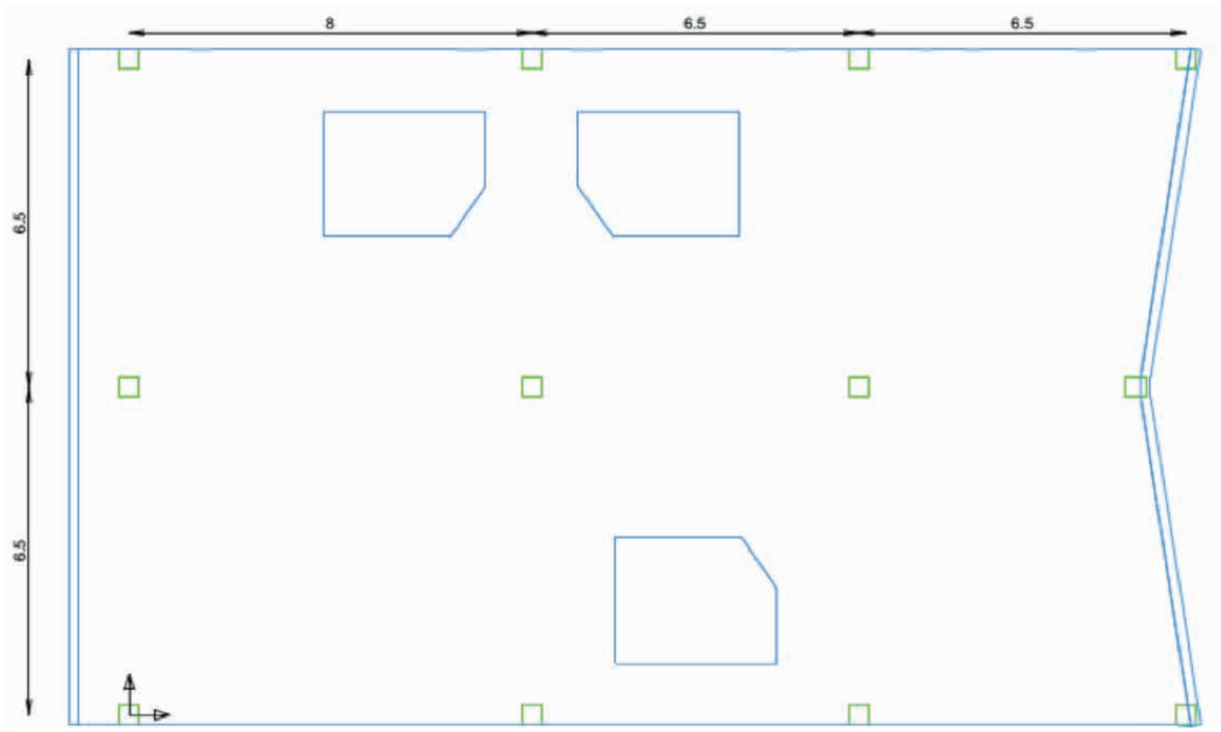


Figure 11 – RAM Concept strip layout example

Figure 12 – RAM Concept strip layout - 3D render

3.4.2. Flat Plate

Flat plate slabs can be modelled as individual strips or as individual Austral Deck planks.

In this case the 250mm Austral Deck slab was modelled with a 17% reduction allowance for voids, but the bathrooms were modelled with 11% reduction, using 210mm thick slabs, roughly based on the reduction factors from Table 1.

RAM Concept priority numbers were used (higher priority numbers are meshed in preference to lower numbers), as follows:

- Upstand beams, full density, priority 5, meshed as slab elements
- Bathroom areas, latitude orientation, priority 3
- General primary spans, longitude orientation, priority 2
- General secondary spans, latitude orientation, priority 1.

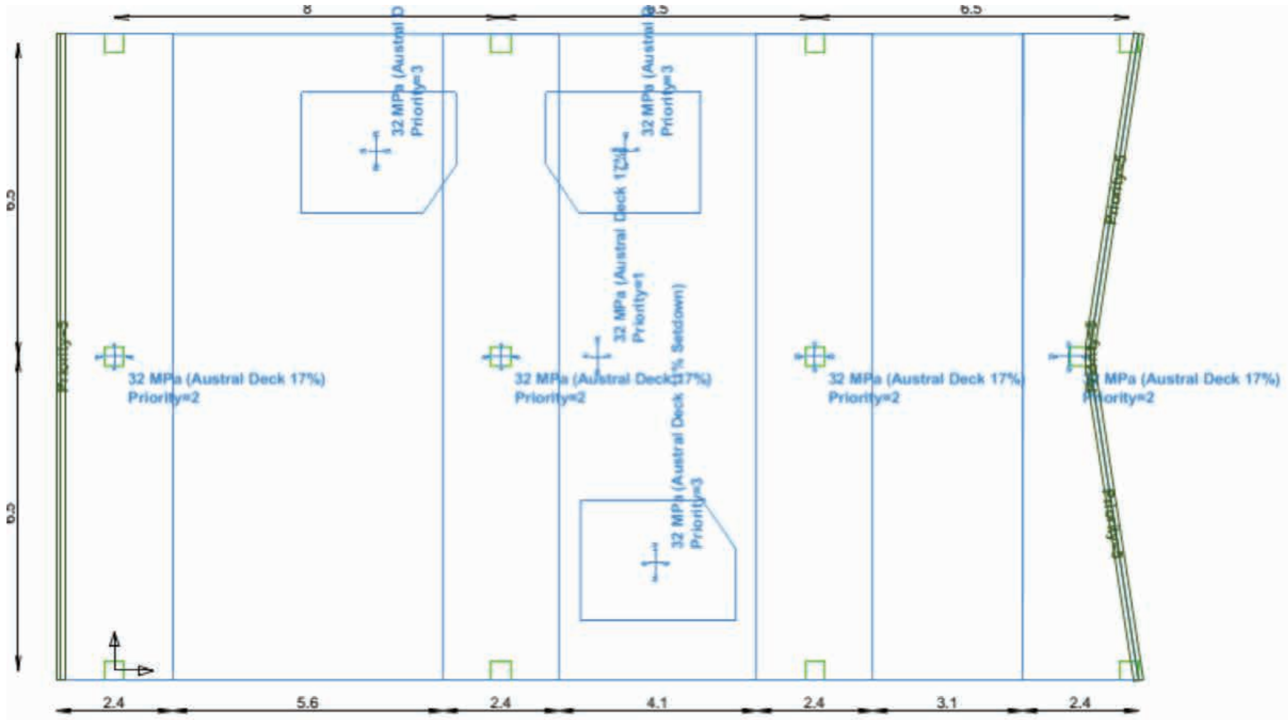


Figure 13 – Example model showing mesh area layouts

Figure 13 presents a reasonable mesh for Austral Deck, however does not provide a very cost effective plank layout, as seen in Figure 14. There are eight primary Austral Deck planks and 18 secondary planks, which are quite short.

Figure 15 removes one of the primary planks and extends the secondary planks, reducing the total plank count to 18, saving eight planks in total.

The Austral Deck designer must consider that extra planks require extra propping, transport and lifting requirements, and increase the number of joints visible in the soffit of the slab.

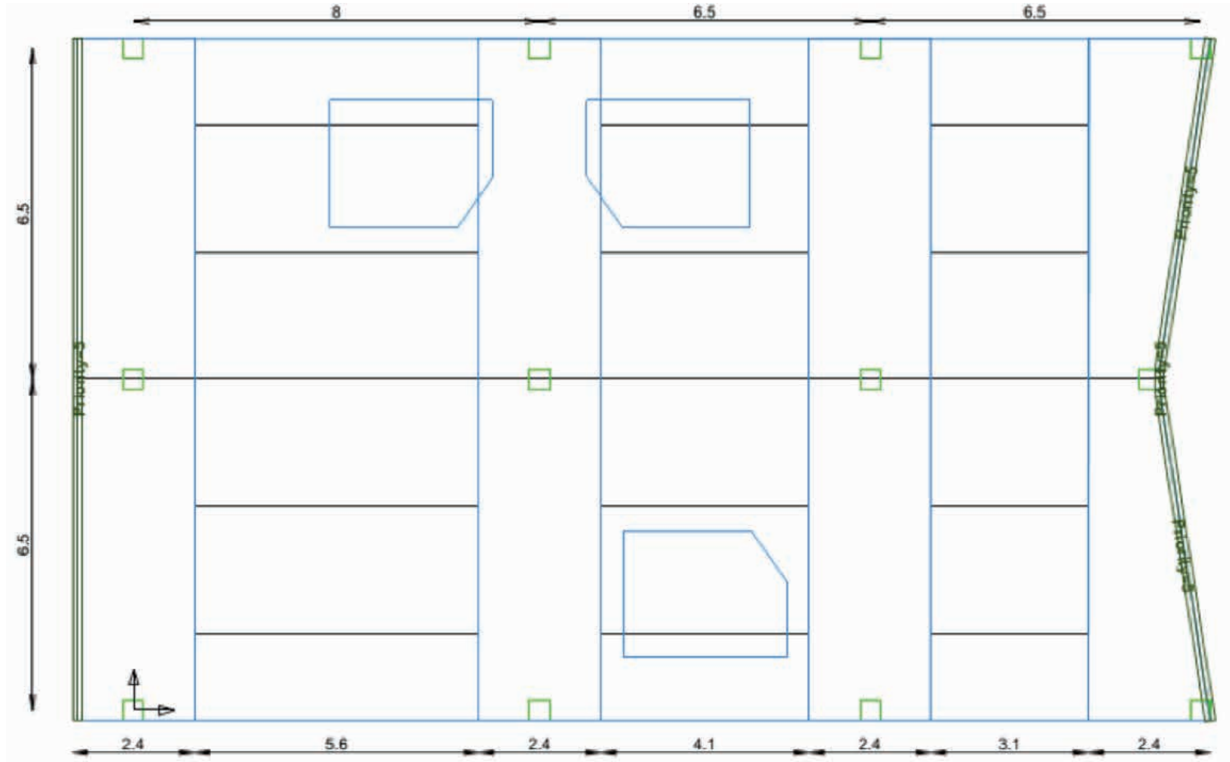


Figure 14 – Example plank layout #1

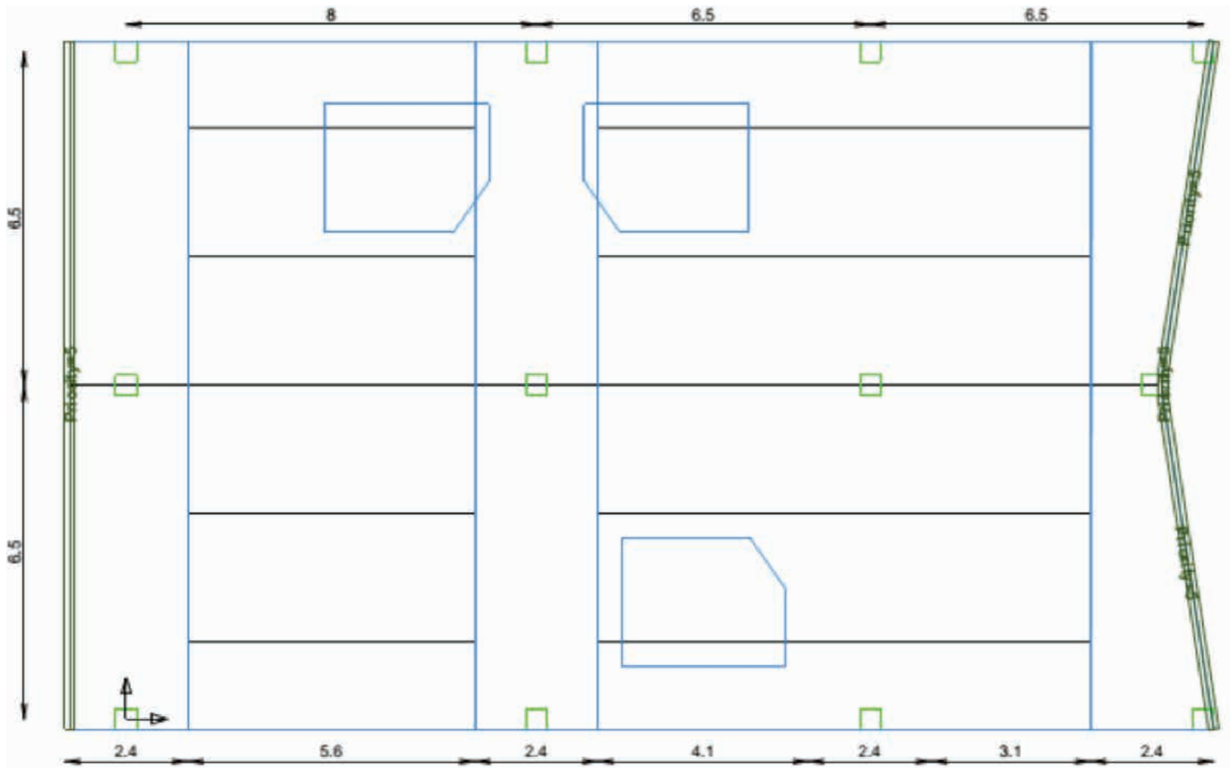


Figure 15 – Example plank layout #2

The design strip layouts in Figure 15 follow the plank layouts at left for latitude and longitude strips. They are all designed as “slab rectangle” strips, with the exception of the upstand beams.

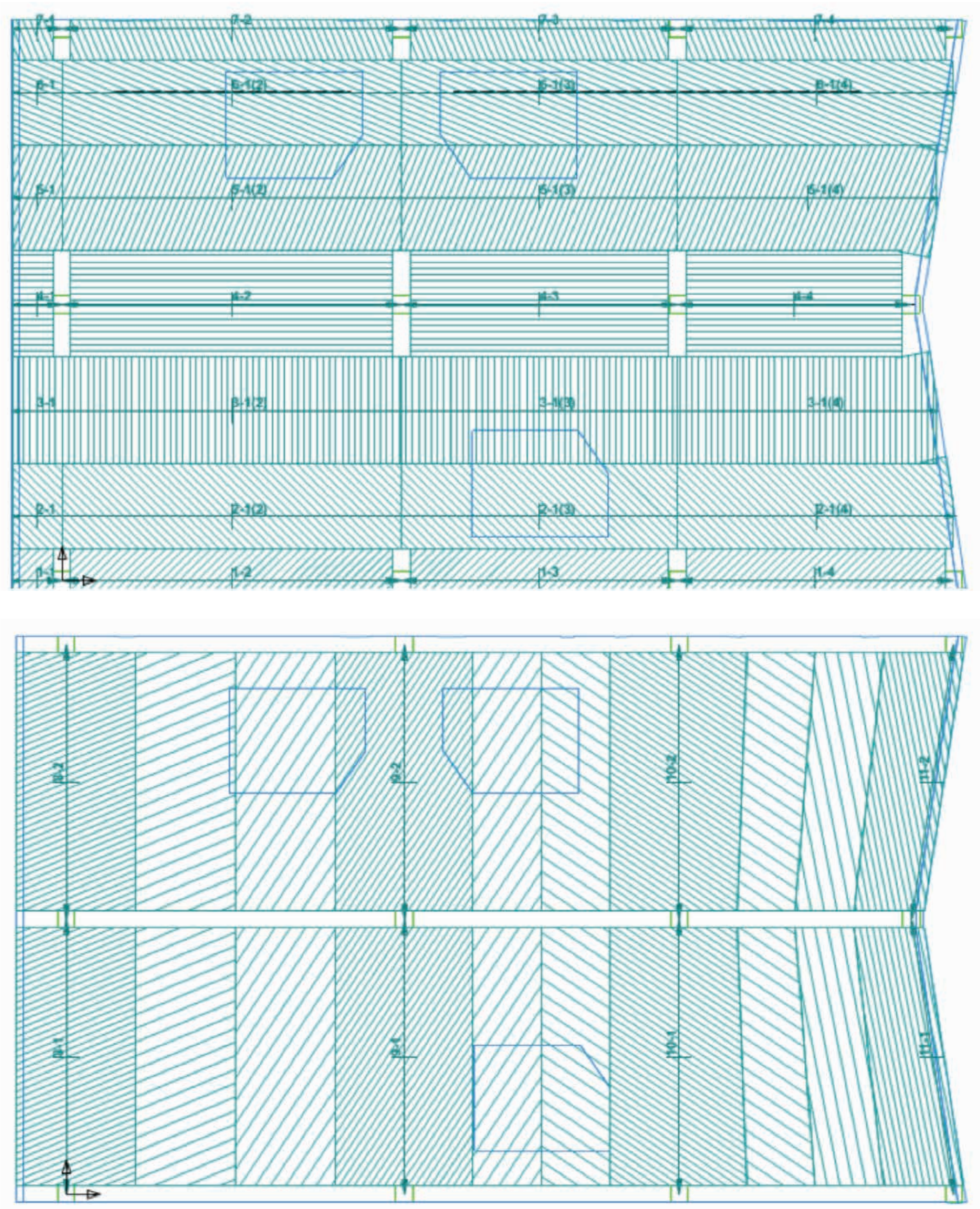


Figure 16 – Latitude and longitude design strips

Some of the other characteristics of the strips in Figures 16 and 17 are:

- All latitude strips have their reinforcement covers set to minimum – i.e. the designed reinforcement allows for bottom bars to be located in the plank. The designer should note, however, that the planks in the latitude direction stop short by the width of the column planks spanning in the longitude direction. Bottom layer reinforcement at this point would not be in the critical section, but needs to be checked nonetheless. Further detailing rules for these circumstances are shown in Section 4.
- Latitude strips have been set to roughly 2.4m wide, mirroring the plank layout, however the strips are shifted such that they are centred on the columns lines. This means that the edge designs (span 1-1 to 1-4 and 7-1 to 7-4) would actually be “half-strips”. The designer could either bear this in mind when detailing the reinforcement on structural drawings, or could adjust the strip boundaries manually to exactly mirror the plank layout.
- Longitude strips follow the traditional Column Strip/Middle Strip layout as specified by AS3600. These strips would be stiffer as they are generally shorter spans and as such the designer should take advantage of AS3600 detailing guidelines for positioning of rebar within the effect compression width of the column strips. Further details are shown in Section 4.
- Longitude strips for the upstand planks are set as “Inverted L” beams, however the designer should consider using manual design sections to ensure the top dimension is cut off to 200mm above the slab surface level. This enables Austral Deck to provide the upstand plank with a short hob and the remainder of the upstand as a precast wall element.

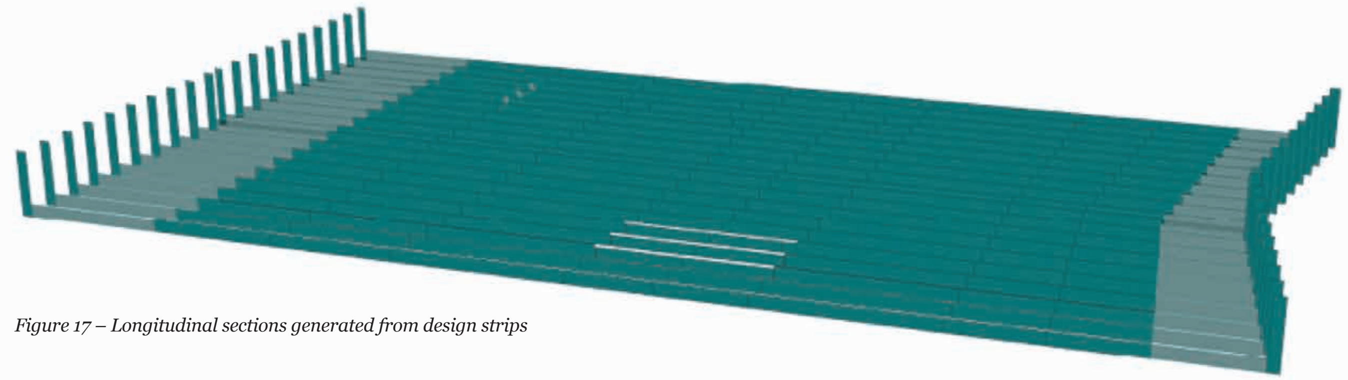


Figure 17 – Longitudinal sections generated from design strips

3.4.3. Banded Slab

A banded slab (Figure 18 & 19) represents a more specific use of Austral Deck, most likely to be found in carparks, commercial buildings or transfer floors.

The deeper bands effectively configure the slab into a series of one-way spanning beams and one-way spanning slabs. If the spans between the beams are sufficiently long, Austral Deck provide an ideal design to limit formwork and propping and speed up construction cycles.

The deeper bands (usually in the order of two times to three times the slab depth) are still sufficiently wide to enable flexural capacity in their transverse direction, however there would not usually be any voids present in the bands. The bands, therefore, are specified with normal, rather than reduced density, concrete materials.

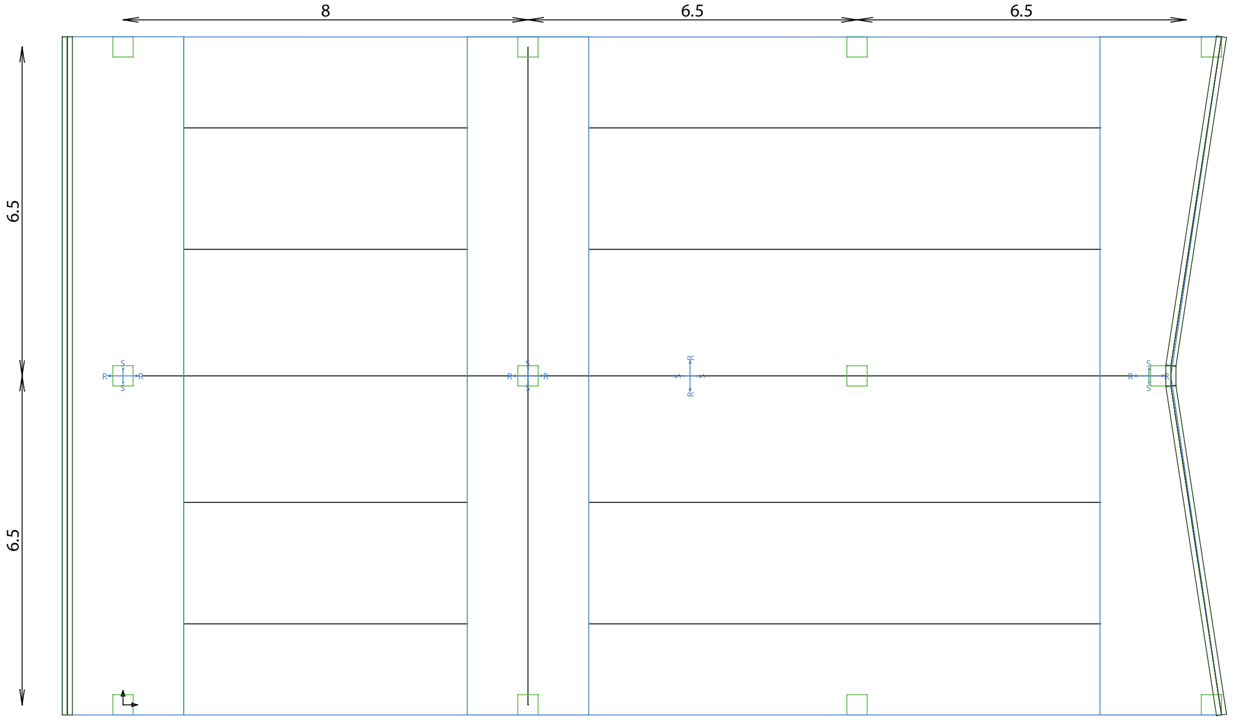


Figure 18 – Banded slab layout

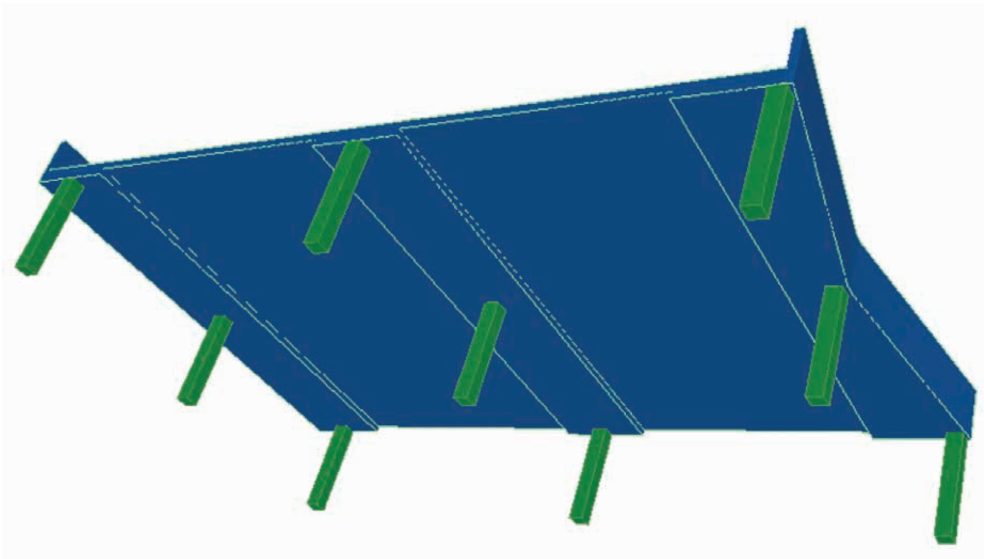


Figure 19 – Banded slab 3D render (viewed from below)

The design strips in Figure 20, particularly in the longitudinal direction are not altered in layout, however designating the strips as "beam" adjusts the effective strip width, in accordance with AS3600-2009 Section 8.8.

The adjustment also removes the upstands on the edges from the concrete section calculations, in favour of the downstand band. Note that the stiffening effect of the upstands, including bending moment distribution is still taken into account.

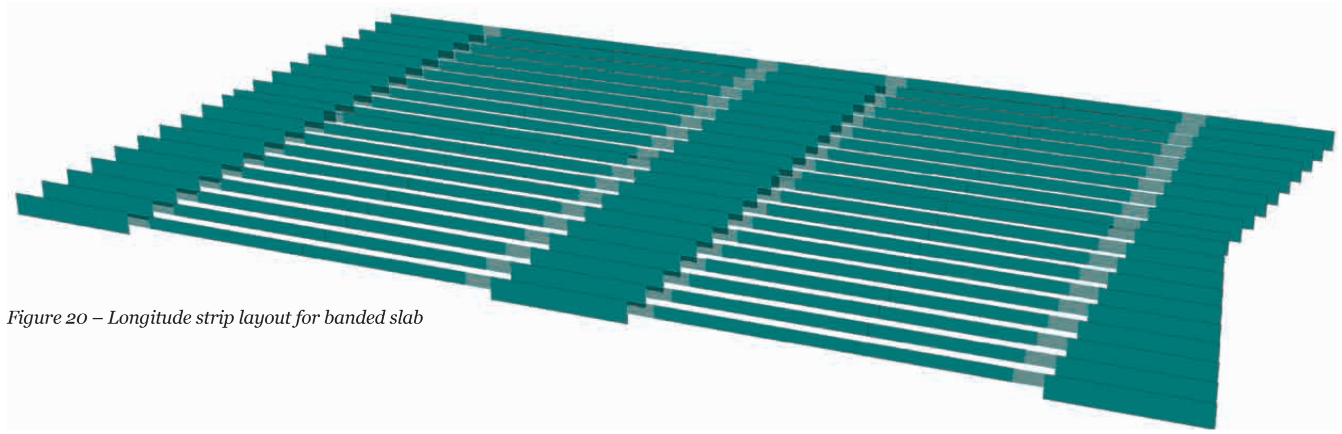


Figure 20 – Longitude strip layout for banded slab

When properly reinforced and detailed, the above design produces a deflection profile as follows:

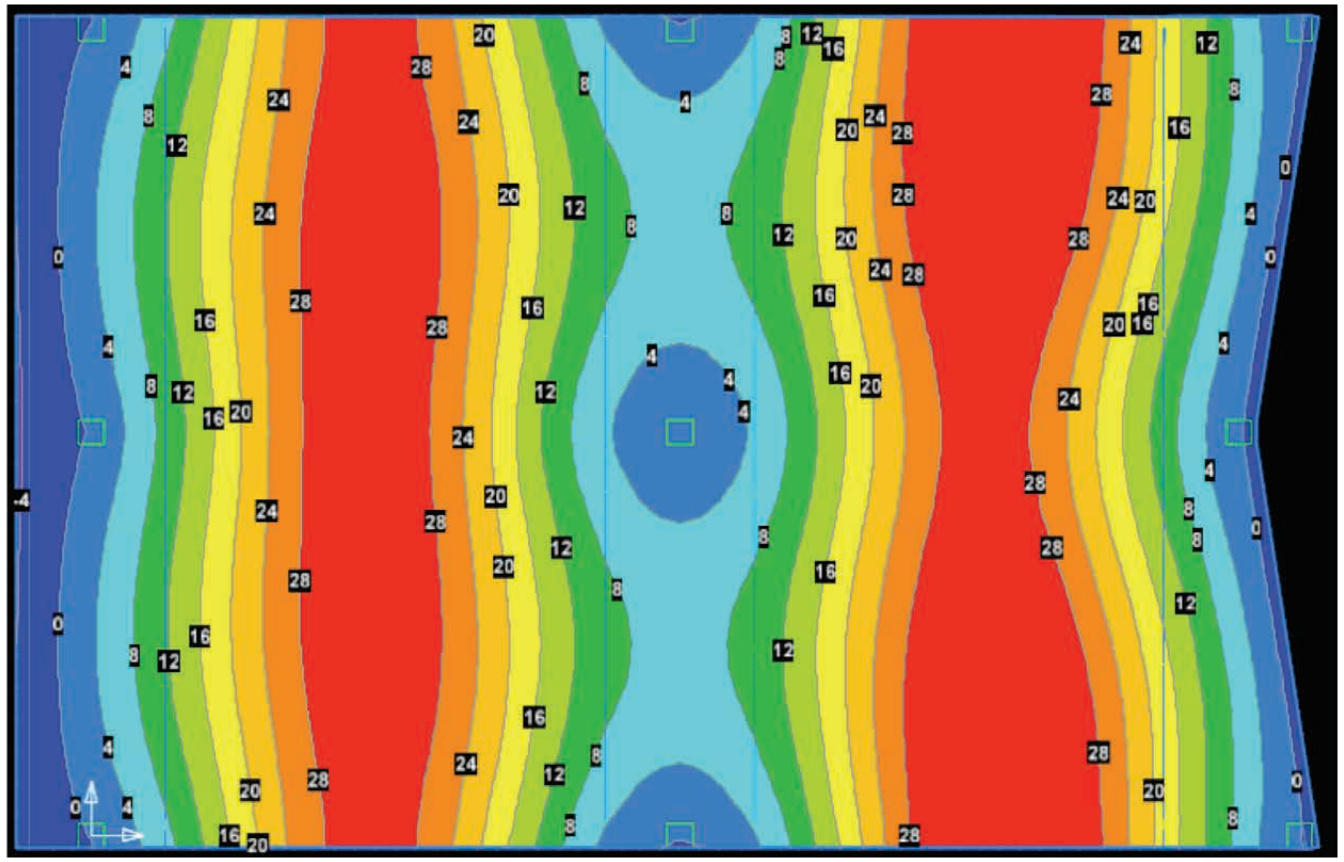


Figure 21 – Banded slab deflection profile

The maximum slab deflection in this case is 32-35mm, which is Span/295 for a 10m span. This is considered reasonable as far as span-to-deflection ratios, but generally would be considered 5-10mm too large in absolute deflection terms.

4. AUSTRAL DECK AND AS3600 DETAILING REQUIREMENTS

The following chapter discusses some of the more specific requirements of AS3600-2009, Concrete Structures. The standard has specific design and detailing requirements that all designers are required to check as part of the normal design process.

This chapter will discuss those requirements, and how they impact the design of Austral Deck slabs.

4.1 Concrete Cover

4.1.1. Code Requirements

The cover requirements for Austral Deck slabs are the same as for any normal reinforced concrete element, with one exception.

Minimum cover to the base (soffit) and sides of the Austral Deck precast plank can be taken from AS3600-2009, Table 8 in this guide, rather than Table 4.10.3.2. This is justified as the Austral Deck planks are cast on rigid steel casting beds, off-site in a precast concrete factory. It is assumed (and should always be checked by the design engineer), that the precast factory will employ rigorous quality control and checking procedures.

The minimum cover requirements for environmental conditions, as detailed in AS3600-2009 Table 4.8.1 and Table 4.8.2 should always be adhered to, for Austral Deck slabs close to or in contact with the ground, especially in aggressive soils.

Careful reinforcement laying directions should be followed for the general mesh, especially with the standard 60mm Austral Deck biscuit thickness. These are represented in Figure 22.

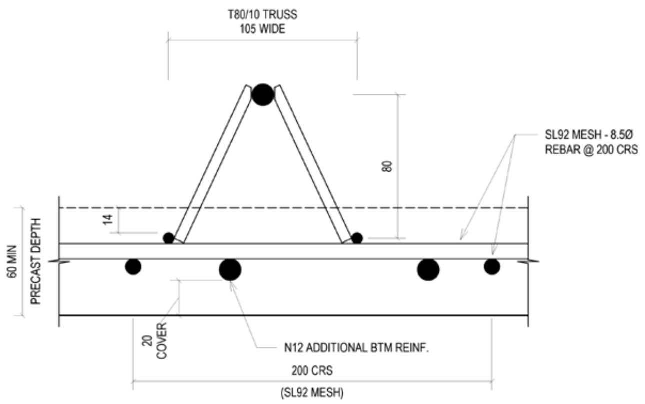


Figure 22 – Cover requirements for Austral Deck planks

The Austral Deck designer should also check the exposure and durability requirements for the Austral Deck planks, especially for the soffits of external elements such as balconies.

Table 4.3 of AS3600-2009, (Table 7) in this guide, details the exposure classification for various concrete elements. Section 4 of the Standard indicates the most common elements that would be used for Austral Deck planks.

Surfaces of members in above ground exterior environments in areas that are:	
(a) Inland (>50 km from coastline) environment being:	
(i) Non-industrial and arid climatic zone	A1
(ii) Non-industrial and temperate climatic zone	A2
(iii) Non-industrial and tropical climatic zone	B1
(iv) Industrial and any climatic zone	B1
(b) Near-coastal (1 km to 50 km from coastline), any climatic zone	B1
(b) Coastal and any climatic zone	B2

Table 7 – Extract from AS3600-2009, Table 4.3 - Concrete Exposure Classification

Required cover where repetitive proceedures and intense compaction or self-compacting concrete are used in rigid formwork

Exposure classification	Required cover, mm				
	Characteristic strength (f'_c)				
	20 MPa	25 MPa	32 MPa	40 MPa	≥50 MPa
A1	20	20	20	20	20
A2	(45)	30	20	20	20
B1	–	(45)	30	25	20
B2	–	–	(50)	35	25
C1	–	–	–	(60)	45
C2	–	–	–	–	60

Table 8 – Extract from AS3600-2009 Table 4.10.3.3 - Concrete Cover

Referencing the above tables from AS3600-2009, Austral Deck projects in tropical climatic zones, or any Austral Deck planks located externally and within 50km of the coast would be defined as B1. These require minimum 25mm cover for 40MPa concrete in accordance with AS3600. Note: tropical zones are also defined in AS3600, and generally refer to areas North of 20°S in Western Australia and Northern Territory, North of 23° in Queensland.

4.2 Ductility Requirements in Flexural Reinforcement

Ductility requirements are one of the fundamental concerns of well designed, conservative concrete structures in accordance with Australian (and most international) codes and standards.

The general ductility principle requires structures that have been loaded beyond the point of failure to deflect significantly without collapse, so as to provide sufficient warning to their occupants to evacuate.

AS3600-2009 specifically addresses some ductility concerns. The changes to the code should be carefully considered in all Austral Deck designs.

AS3600-2009 section 1.1.2 requires:

Reinforcing steel of Ductility Class L in accordance with AS/NZS 4671—

(i) may be used as main or secondary reinforcement in the form of welded wire mesh, or as wire, bar and mesh in fitments; but

(ii) shall not be used in any situation where the reinforcement is required to undergo large plastic deformation under strength limit state conditions.

Generally, throughout the code, the use of low ductility reinforcement, such as SL and RL grade meshes is expressly forbidden. However, Section 6 of AS3600-2009 provides design guidance as to the use of "L" grade reinforcement. Essentially, positive design moments are increased by up to 10%, (for example wL2/16 becomes wL2/14), and moment redistribution is not allowed.

Austral Deck uses a combination of low ductility (L) and normal ductility (N) reinforcement for the primary positive (mid-span) bending moments, and normal ductility reinforcement for the negative bending moments, over supports.

It is the Austral Deck designer's responsibility to determine the ratio of L to N ductility. One suggestion is to provide sufficient N grade reinforcement to comply with ultimate loads under "fire" or "earthquake" load conditions. This is typically W* = DL + 0.3 x LL in accordance with AS1170.0.

4.3 Reinforcement Laying Sequence

Whilst the reinforcement laying sequence will primarily be defined by the plank span direction, the sequence of the top reinforcement layers are somewhat more flexible.

Reinforcement is usually referred to as Layers 1 through 5, or B1/T1, depending on the normal naming conventions of the Austral Deck designer. These are detailed in Figure 23:

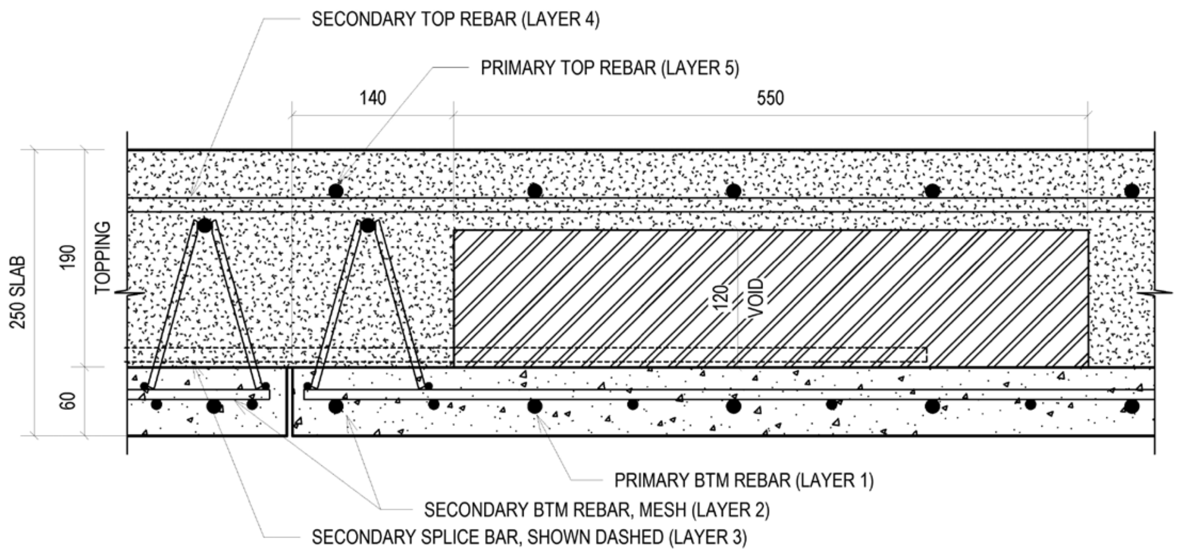


Figure 23 – Reinforcement bar laying sequence

For Austral Deck slabs, layers 1 and 2 are cast into the precast concrete plank. Splice bars on layer 3, along with any additional secondary reinforcement is placed on the surface of the plank once the Austral Deck has been positioned on site.

These bars are usually threaded through gaps in the trusses.

Finally, layers 4 and 5, are placed and tied in the top layer in the same manner as a typical in-situ poured concrete slab.

4.4 Detailing of Span Direction Reinforcement

Primary reinforcement detailing in accordance with AS3600 is specified in section 9.1.3.1 for suspended slabs. This includes, among others, the following key requirements:

- Requirement for anchorage of positive (bottom) flexural reinforcement at end supports – generally at least 50% of the total flexural reinforcement, anchored to at least the larger 12 bar diameters or D, the slab thickness.
- Requirement of at least 25% of the positive (bottom) flexural reinforcement to extend past the near face of an internal, continuous support point, typically to full anchorage of 25 bar diameters.

4.4.1 End Supports

For Austral Deck planks supported by a precast concrete wall, the first requirement can be met by the following:

1. Provide screw-in ferrules, rip-boxes or other proprietary reinforcement equivalent to at least 50% of the flexural reinforcement.
2. Provide a full lap of ferrules with the bottom reinforcement, as per AS3600 Section 13.2, to a minimum length of Lsy.t.lap

For planks supported by masonry or brickwork, this can be achieved by providing cogs on the primary bottom reinforcement, as the cogs will provide 50% anchoring in accordance with AS3600 Section 13.1.2.6

4.4.2 Internal Supports

At internal columns or walls, at least one quarter of the flexural bottom reinforcement should be extended past the face of the support. This will require additional splice bars to be added to the Austral Deck once it has been installed on site. Refer to Section 4.6 in this guide for notes on calculation of splice bars.

Figure 24 below shows a typical splice bar detail at an internal column location. Note that only 25% of the flexural bars are required to be spliced.

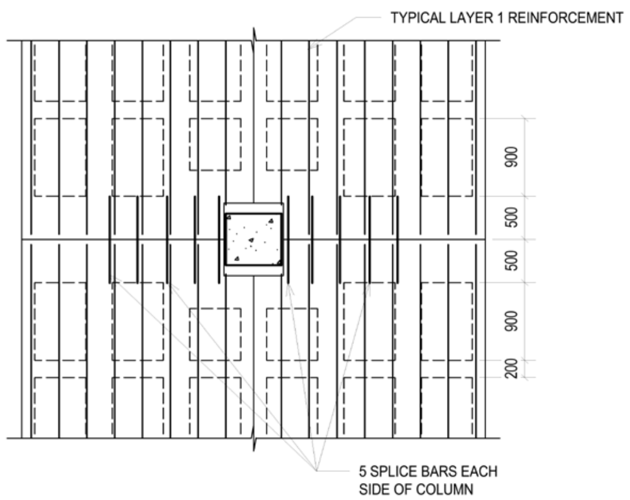


Figure 24 – Typical internal support splice bar locations

4.4.3 Negative Reinforcement

Standard detailing rules remain applicable for the conventionally laid, negative or top layers of reinforcement.

One critical such rule is AS3600-2009, Section 9.1.2, Reinforcement and tendon distribution in two-way flat slabs.

In two-way flat slabs, at least 25% of the total of the design negative moment in a column-strip and adjacent half middle-strips shall be resisted by reinforcement or tendons or both, located in a cross-section of slab centred on the column and of a width equal to twice the overall depth of the slab or drop panel plus the width of the column

Given that the majority of Austral Deck slabs are two-way, with generally flat soffits, the above requirement will most likely apply.

4.5 Detailing of Cross Direction Reinforcement

If the Austral Deck designer reduces the stiffness of a two-way slab to 50% or less, then it is likely that the secondary direction reinforcement requirement will be almost entirely met by the cross rods of the mesh cast into the precast plank. Typically, for SL92* mesh, this is 287mm2/m, or the equivalent of N12 rebar at 400mm centres.

The designer will need to be mindful of ductility requirements (refer to section 4.2).

The number of splice bars required for the cross direction reinforcement would then be calculated as a proportion of the cross direction reinforcement. For instance, if 180mm^2/m reinforcement is required and 287mm^2/m is provided, then splice bars the equivalent of N12 at 600mm centres would be required, providing 183mm^2/m. This is equivalent to splicing every third rod from SL92* (8.55mm bars).

** The common mesh size used for manufacturing Austral Deck is SL72.*

4.6 Calculation of Splice Bars

The calculation of splice bar quantity and length is required to be carefully determined for Austral Deck slabs, as traditional “lapped splices” are not usually applicable. (Figure 25)

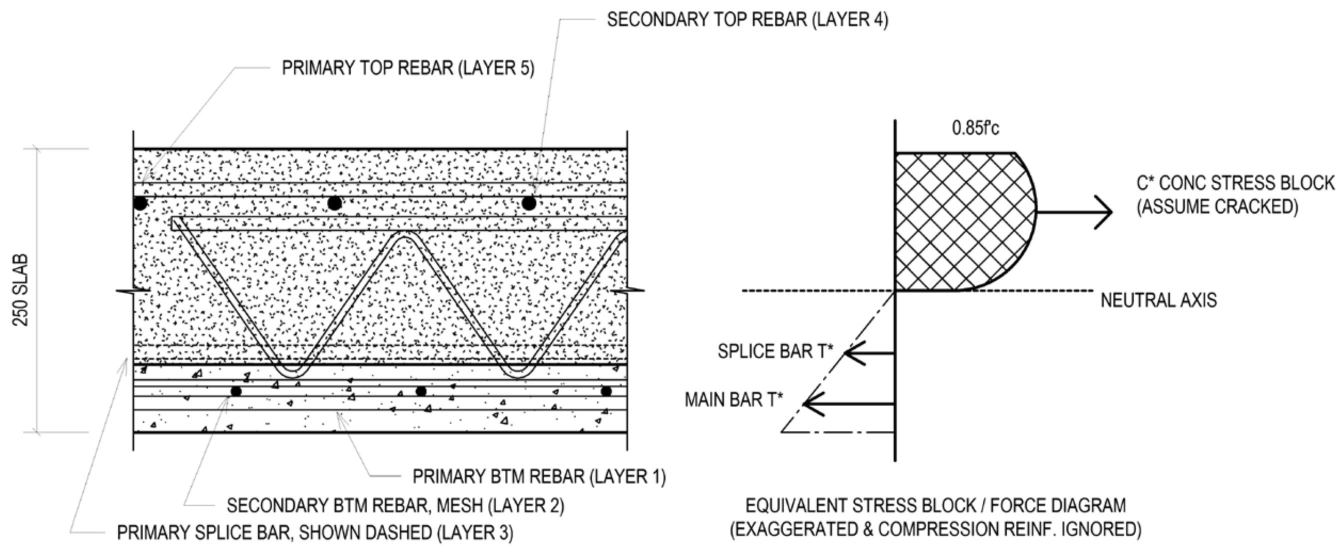


Figure 25 – Splice bar calculation of forces

4.7 Punching Shear

4.7.1 General Design Issues

Punching shear for Austral Deck slabs needs to be carefully designed and checked, especially with larger, flat-plate type slab designs.

In Australia, it is generally accepted design practice to either use AS3600 Section 9.2 or to use the Eurocode EN 1992-1-1 Section 6.4.4

Both of the above design methods have significant bodies of research behind them, and are not compared specifically in this manual.

In general, Australian Standard AS3600 treats punching shear using closed reinforcement ties laid in a torsional design strip across the column. The detailing requires the ties to be placed over a quarter-span in each direction to adjacent columns.

The Eurocode (and the old British Standard 8110) models a series of concentric shear planes or rings progressing outwards from the column in question. Vertical shear reinforcement is placed in a cruciform or radial pattern outwards from the column until the punching shear perimeter is sufficient large enough to carry the load. The reinforcing is usually in the form of individual hooks or “S” shape rebar, or proprietary studs tack-welded on to light bars such as Ancon Studrail.

4.7.2 Punching Shear Reinforcement and Austral Deck

For Austral Deck slabs, it is usually simpler to use the Eurocode to both check and design for punching shear, and the use of shear studs rather than closed ligatures is certainly easier for installation.

Where required, the punching shear studs can be installed into the precast biscuit in the factory to a precisely laid out position, and generally do not interfere with the trusses or bottom reinforcing.

It is critically important that all void formers are removed from the punching shear perimeter, however wide that may be. This in turn will impact the total slab weight and may require recalculation of run-down loads to columns and foundations, all of which should be taken into account by the Austral Deck designer.

4.7.3 Basic Punching Shear Checks

Prior to undertaking detailed checks and design, it is often useful to determine a basic punching shear capacity around the columns. For this purpose either Australian or European codes can be used.

The Austral Deck designer should establish the capacity of the topping component of the Austral Deck, excluding the precast biscuit. This is considered the absolute minimum capacity as it ignores up to 60mm (or 90mm) of the concrete depth.

For instance, a 500x500 concrete column supporting a 275mm thick N40 Austral Deck slab has the following capacity in accordance with AS3600.

$$\varnothing V_{uo} = \varnothing u d_{om} (f_{cv} + 0.3\sigma_{cp})$$

$$f_{cv} = 0.17\left(1 + \frac{2}{\beta_h}\right)\sqrt{f'_c} \leq 0.34\sqrt{f'_c}$$

$\sigma_{cp} = 0$ *(slab is not tensioned)*

$\beta_h = 1$ *(square column aspect ratio)*

$f_{cv} = 0.34\sqrt{40} = 2.15MPa$

$$d_{om} = 179mm \left(275mm - 30\ cover - \frac{12mm}{2} - 60mm\ planket\right)$$

$u = 4 \times (500 + d_{om}) = 4 \times (679) = 2716mm$

$\varnothing V_{uo} = 0.7 \times 2716 \times 179 \times 2.15 = 731.7kN$

For a 275mm Austral Deck slab, carrying residential loads (1kPa SDL and 1.5kPa LL) with self-weight of 5.85kPa (based on 15% void ratio), the total ultimate slab weight is 1.2 (5.85 + 1) + 1.5 (1.5) = 10.47kPa.

The designer can then deduce that the column tributary load area is approximately 731.7/10.47 = 69.9m² that could be carried by the topping portion of the slab alone with no punching reinforcing.

If using AS3600 section 9.2.4, there are further reductions due to the torsional moments across the column, approximately equal to $\frac{uM_v^*}{8V^* ad_{om}}$ which need to be considered.

4.7.4 Punching Shear Using Rebar Trusses

It is possible to consider the full depth of the Austral Deck slab for punching shear, using the rebar trusses as shear ties. Generally, the design for this should be undertaken using the Eurocode provisions, and would require careful checking.

Usually, however, the spacing of the trusses and lack of truss continuity over column supports precludes their inclusion in the punching shear calculations.

4.7.5 Alternatives for Punching Shear

If punching shear becomes too great to be able to be supported by the topping slab alone, and shear ties/studs are impractical, it may also be possible to pour a localised “mushroom head” (Figure 26) around the column, where the precast slab is cut back roughly 100mm and the entire depth of concrete is used.

For instance, taking the previous example, if d_{om} were increased by 60mm to 239mm, then the shear perimeter *u* becomes 4(500 + 239) = 2956mm. Punching shear capacity is increased by approximately 45%

$\varnothing V_{uo} = 0.7 \times 2956 \times 239 \times 2.15 = 1063kN$

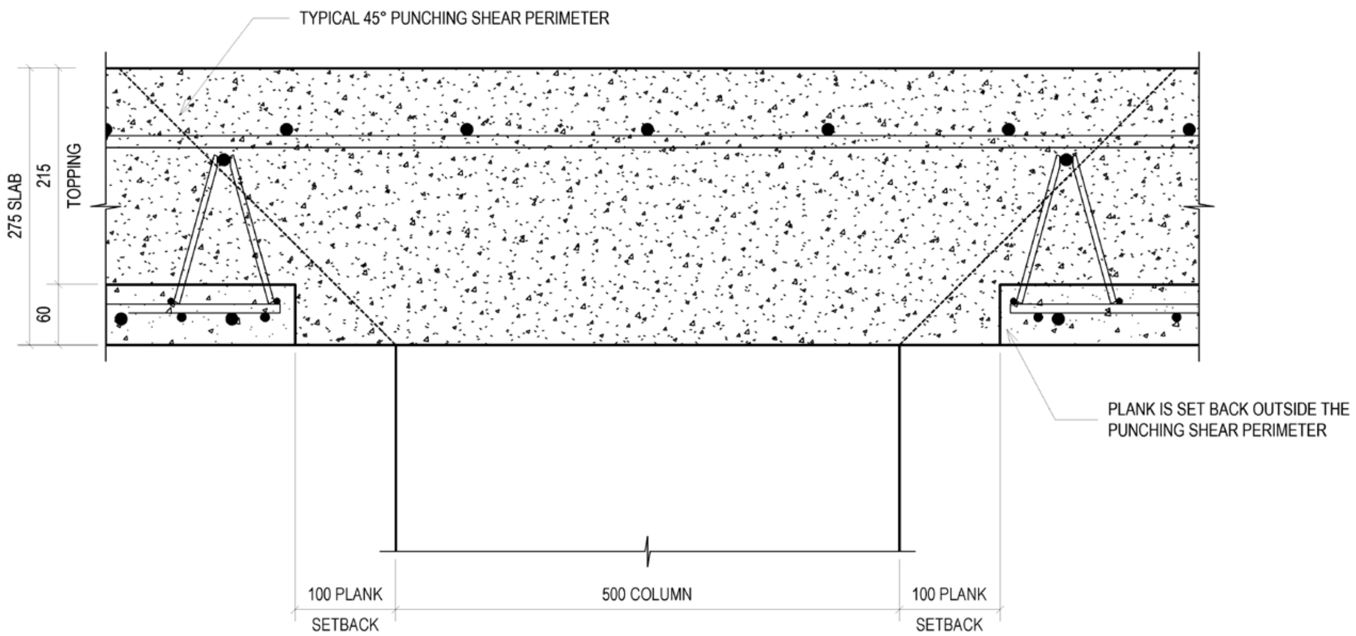


Figure 26 – Punching Shear Setback

4.8 Longitudinal Shear

In zones of high transverse loads, longitudinal shear can become significant for any composite structure, including Austral Deck.

In the case of Austral Deck, the shear can be resisted by the friction interface between the in-situ topping slab and the precast biscuit or by the rebar trusses, or both.

Calculation of the longitudinal shear follows the formula for Shear Flow:

$$q = \frac{V^* Q}{I}$$

Where: q is the longitudinal shear, or shear flow, in kN/mm

V* is the transverse shear force (kN)

Q is the first moment of area at the shear interface (mm³)

I is the moment of inertia above the natural axis (mm⁴)

For instance, taking the example from Section 4.7.3. where the total load on the slab is 10.47kPa, and we assume a single span of 7.5m and tributary width of 6m.

$$V^* = \frac{wL}{2} = 10.47 \times 6 \times \frac{7.5}{2} = 235.5kN$$

$$I_{xx} = \frac{BD^3}{12} = \frac{6000 \times 0.275^3}{12} = 7812.5 \times 10^6\ mm^4$$

$$Q_{60mm} = (60 \times 6000) \times \left(\frac{250}{2} - \frac{60}{2}\right) = 34.2 \times 10^6 mm^3$$

$$q = \frac{235.5 \times 34.2 \times 10^6}{7812.5 \times 10^6} = 1.031kN/mm$$

If the longitudinal shear force from the above calculation is resisted over 6m width by 9 rebar trusses, each with 2 x N6 rebar at 100mm centres then the shear resistance provided by the trusses is:

$$\varnothing V_{long} = \frac{0.8 \times 500MPa \times 28mm^2 \times 18\ bars}{100\ mm\ spacing} = 2.02kN/m\ resistance$$

In this case the shear resistance of the rebar is sufficient to resist any longitudinal shear forces at the in-situ/precast interface.

5. AUSTRAL DECK DESIGN AS FORMWORK

This section is to demonstrate the process of designing Austral Deck as formwork complying with the stability, strength and serviceability limit stage criteria specified in AS3610-1-2010 Formwork for Concrete – Part 1 Documentation and surface finish.

The process is used to determine the maximum spanning capacity of Austral Deck based on the structural properties and construction loads in order to define the temporary propping requirement of a concrete slab constructed using Austral Deck.

The specifc calculations in this document apply to a simply supported double span Austral Deck panel for the variable structural properties and construction loads listed on 5.3.1. However the calculations also provide guidance for other situations.

Charts 2 and 3 in 5.4.8 and 5.4.9 can be used as a guide for Austral Deck as formwork under construction loads for various slab thickness and steel lattice girder reinforcement con gurations.

Austral Deck – Construction Load Analysis software can be used to determine prop spacing for a variety of structural properties and construction loads.

The software can be downloaded via the Austral Precast website www.australprecast.com.au

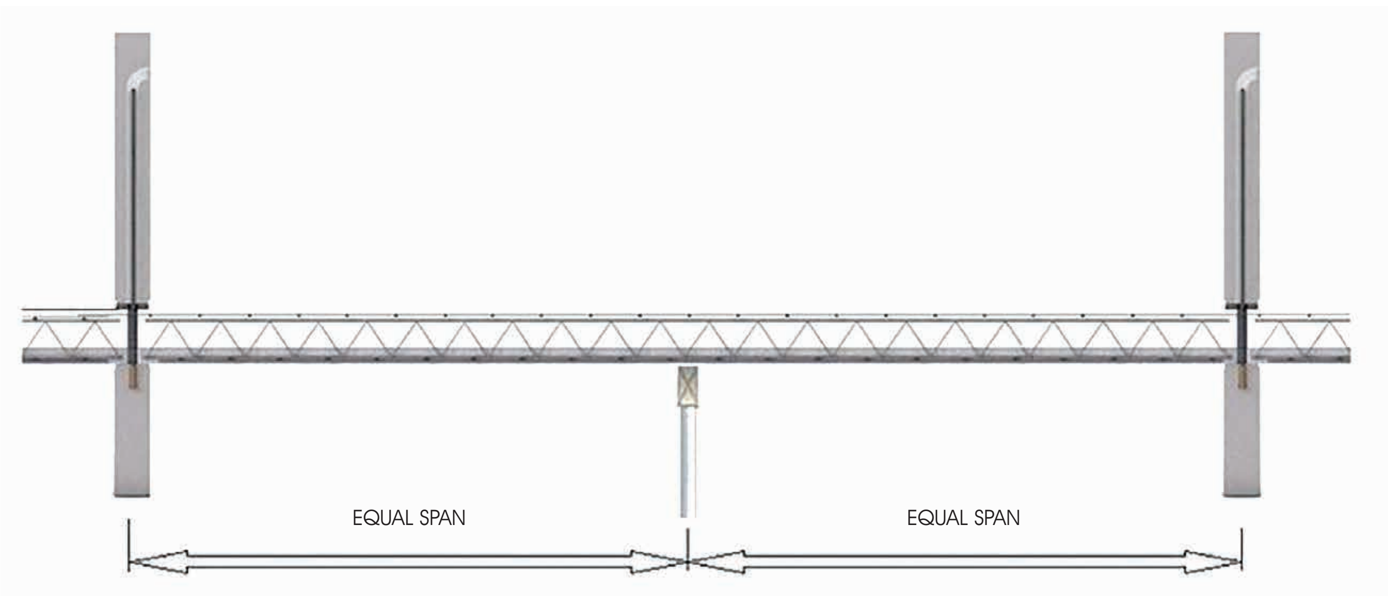


Figure 27 – Interior Support During Construction

5.1 Stage one: Design as formwork

The precast element of Austral Deck must be designed as formwork for construction loads since it is utilised as permanent formwork. The strength of the precast element required to span between temporary and permanent supports during construction is gained from the lattice girder type reinforcement that is partially embedded in the precast concrete.

The top chord of the lattice girder type reinforcement is not embedded in the precast concrete so Austral Deck must be designed as formwork using a combination of the Australian Standard for Concrete Structures (AS3600-2009) and Steel Structures (AS4100-1998) along with the Australian standard for loading (AS1170) and formwork (AS3610-2010).

It is recommended that the design engineer uses strict deflection criteria when designing as formwork for construction loads to alleviate any significant cracking.

5.2 Design Criteria and Specifications

5.2.1 Strength

The Panel must resist the bending and shear action effects from all the appropriate load combinations.In the case of a simply supported panel the following load combinations are appropriate.

Stage I – prior to placement of concrete

$1.25G+1.5Q_{uv}+1.5M_1$ (1)

Stage II – during placement of concrete

$1.25G + 1.25G_c + 1.5Q_{uv} + 1.5M_2$ (2)

$1.25G + 1.25G_c + Q_c$ (3)

Stage III – after placement of concrete

$1.25G + 1.25G_c + 1.5Q_{uv} + 1.5M_3$ (4)

If the panel is considered a primary member as per AS 3610 – 1995, then these loads must be multiplied by a factor of 1.3. For example:

Stage I – prior to placement of concrete

$1.3(1.25G + 1.5Q_{uv} + 1.5M_1)$ (5)

5.2.2 Stiffness

The panel stiffness must be such that the deformation under the appropriate load combination does not exceed chosen limits, using either the limits specified in AS 3610.1 – 2010, Table 3.3.2 (Form face deflection) or otherwise chosen. In the case of a simply supported panel the following load combinations are appropriate:

Stage II – during placement of concrete

$G + G_c + Q_{uv}$ (6)

Stage III – after placement of concrete

$G + G_c + Q_{uv} + M_3$ (7)

While AS 3610 – 1995 does not require the addition of Q_{uv}, it has been added to be in line with the intentions of AS 1170.0 – 2002.

5.2.3 Surface Finish

The surface finish of the panel soffit conforms with the physical quality of a “Class 2” surface finish as specified in AS 3610.1 – 2010. The surface class chosen for the in situ slab is also used to define the maximum allowable deflection limits.

5.2.4 Panel Capacity

The strength and stiffness of the panel is dependent on the truss, panel size and geometry. During construction the applied loads are resisted by the action of the truss members and panel concrete. The resistance provided by any mesh or additional reinforcement bars is ignored.

The following structural checks are performed:

STRENGTH	a) Top Chord Compression
	b) Top Chord Tension
	c) Bottom Chord Compression
	d) Bottom Chord Tension
	e) Concrete Panel Compression
	f) Diagonal Compression
	g) Concrete Tensile Strength
SERVICE	a) Deflection
	b) Cracking

The maximum allowable span is calculated for each case.

5.2.5 Maximum Span

The maximum span is selected on the basis that the design action, calculated from the factored load combinations, does not exceed the capacity of the panel.

A summary of the calculations showing the maximum span for each action is given in the table below:

DESIGN ACTION		MAX SPAN (m)
POSITIVE BENDING	Top Chord Compression	3.41
	Bottom Chord Tension	3.37
NEGATIVE BENDING	Top Chord Tension	3.95
	Bottom Chord Compression	1.33
	Concrete Panel Compression	5.59
SHEAR	Diagonal Lacing Compression	5.13
CRACKING	Concrete Tensile Strength	2.23
	Flexural Cracking	3.96
DEFLECTION	Serviceability Deflection	3.05

The maximum span for the given configuration is therefore:

Maximum Span	3.05m

The bottom chord compression limit can be ignored if the bottom chord is completely embedded in the panel concrete for its full length. Control for concrete tension can also be ignored as it is based on the uniaxial tensile strength of the concrete panel rather than the flexural tensile strength. This implies that the concrete is allowed to crack but is controlled by the limits set out in Section 9.4.1 of AS3600-2009.

5.2.6 Stacked Materials

The maximum span loadings include factors M_1, M_2 and M_3 for the live loadings of stacked materials. AS 3610 – 1995 gives these values as 4.0 kPa for before and after the placement of concrete (M_1 and M_3), and 0 kPa for during the placement of concrete (M_2).

The maximum span may be increased by decreasing these loads. In such a case, this lowered load limit must be clearly indicated in the formwork documentation and construction controlput in place to ensure it is not exceeded.

5.2.7 Assumptions

1) Vertical and horizontal action effects from environmental loads have been ignored (e.g. wind uplift, river currents). If relevant, appropriate strength and service loads should be calculated with reference to AS 3610 – 1995, Table 4.5.2.

2) The value for stacked materials during Stage I (M_1) applies also to Stage III (M_3) and during Stage II the value for stacked materials (M_2) is 0 kPa.

3) The effects of form face deflection and construction tolerances can be ignored.

4) The deviations specified for form face deflection, in AS 3610.1 – 2010, Table 3.3.2, will be interpreted as the deflection criteria for the panel as per the following extract:

SURFACE CLASS	DEFLECTION LIMIT
1	Lesser of 2mm or span/360
2	Lesser of 3mm or span/270
3	Greater of 3mm or span/270
4	Greater of 3mm or span/270
5	N/A

5) The welds connecting diagonal wires to the top and bottom chord of the truss are capable of transmitting the full design action effects.

6) Truss geometry is as per the following table:

TRUSS TYPE	WIRE SIZE (mm)			
	TOP	BOTTOM	DIAGONAL	HEIGHT
T90/10	9.5	6.3	6.3	92
T110/10	9.5	6.3	6.3	111
T150/10	9.5	6.3	6.3	154
T190/10	9.5	6.3	6.3	191
T110/12	11.9	6.3	6.3	112
T150/12	11.9	6.3	6.3	155
T190/12	11.9	6.3	6.3	192

5.3 Panel Properties

Overall Slab Thickness, d =	250	mm
Minimum Cover to Bottom Reinforcement =	20	mm
Concrete Density, r =	2400	kg/m³
Concrete Strength at Loading, f_{cm} =	20	MPa
Concrete Modulus of Elasticity, E_{cj} =	22,610	MPa
Panel Width, b =	2,500	mm
Precast Panel Thickness, t_p =	75	mm
Number of Truss per Panel, n_t =	10	
Number of Voids, n_v =	0	
Void Width, b_v =	N/A	mm
Void Thickness, t_v =	N/A	mm
Class of Surface Finish =	2	
Number of Spans (based on supports) =	2	

The panel concrete properties (f_{cm}, E_{cj}) are at the time of lifting from casting beds.

5.3.1 Construction Loads

Panel Dead Load, G =	1.87	kPa
In-situ Slab Dead Load, G_c =	4.29	kPa
Construction Live Load, Q_{uv} =	1	kPa
Concrete Mounding Load, Q_c =	3	kPa
Stacked Materials, M_1 =	4	kPa
Stacked Materials, M_2 =	0	kPa
Stacked Materials, M_3 =	4	kPa

* Although AS 3610 – 1995 states that the concentrated load Q_c will apply over an area of 1.6 x 1.6m, it has been applied over the full area of the panel.

** The loads from stacked materials, M, may apply to one span only.

5.3.2 Load Combinations

STAGE	LOAD COMBINATION	LOAD	UNIT	EQUATION
I	$1.3\,(1.25G + 1.5Q_{uv} + 1.5M_1)$**	12.78	kPa	(5)
II	$1.3\,(1.25G + 1.25G_c + 1.5Q_{uv} + 1.5M_2)$**	11.96	kPa	
II	$1.3\,(1.25G + 1.25G_c + Q_c)$*	15.86	kPa	
III	$1.3\,(1.25G + 1.25G_c + 1.5Q_{uv} + 1.5M_3)$**	19.76	kPa	
	STIFFNESS			
II	$G + G_c + Q_{uv}$	7.16	kPa	(6)
III	$G + G_c + Q_{uv} + M_3$**	11.16	kPa	(7)

5.3.3 Design Load

Therefore the design loads are as follows:

Strength, w* =	19.76	kPa
Service, w_s =	11.16	kPa

5.3.4 Truss Properties

Austral Deck Truss Type, T =	T190/12	
Average Truss Spacing, T_s =	250	mm
Truss Height, T_h =	192	mm
Truss Bar Yield Strength, f_{syt} =	500	MPa

5.3.5 Top Chord

Bar Diameter, d_t =	11.9	mm
Area, A_t =	1,112.2	mm²
Strut Length, L_t =	200	mm
Effective Length, I_t =	180	mm
Radius of Gyration, r_t =	2.98	mm

5.3.6 Bottom Chord

Bar Diameter, d_b =	6.3	mm
Area, A_b =	623.4	mm²
Strut Length, L_b =	200	mm
Effective Length, I_b =	200	mm
Radius of Gyration, r_b =	1.58	mm

5.3.7 Diagonal Lacing

Bar Diameter, d_w =	6.3	mm
Area, A_w =	623.4	mm²
Angle of Web, q =	62.5	degrees
Strut Length, L_w =	216.5	mm
Effective Length, I_w =	151.5	mm
Radius of Gyration, r_w =	1.58	mm

5.3.8 Mesh

Mesh =	SL72	
Wire Diameter, d_m =	6.8	mm
Area, A_m =	448	mm²

5.3.9 Capacity Calculations

The number of spans (based on the number of temporary supports) affects the coefficients used when calculating the maximum spans:

$M* = jw*L^2 \longrightarrow L = \sqrt{\frac{M*}{jW*}}$

NO. OF SPANS	j_1, POSITIVE MOMENT	j_2, NEGATIVE MOMENT
1	0.125	N/A
2	0.096	0.125
≥3	0.101	0.121

5.3.10 Top Chord Compression

In accordance with AS 4100 – 1998 Steel Structures, Clause 7.1 – $N* \leq \Phi a_g N_2$

Where Φ =	0.9	
Form Factor, k_f =	1	
Section Capacity, $N_s = k_f A_n f_y$ =	556.1	kN
λ_n =	85.57	
a_a =	18.77	
a_b =	0.50	
λ =	94.95	
η =	0.27	
ξ=	1.07	
a_c =	0.58	
Limit State Capacity, $\Phi a_c N_s$ =	288	kN
Truss Height, T_h =	192	mm
Limit State Moment Capacity, $M*_{tc}$ =	55.28	kN.m
Maximum Span based on Moment Capacity of Top Chord in compression, L_{tc} =	3.41	m

5.3.11 Top Chord Tension

In accordance with AS 4100 – 1998 Steel Structures, Clause 7.1 – $N* \leq \Phi A_g f_y$

Where Φ =	0.9	
Limit State Capacity, $\Phi A_g f_y$ =	500	kN
Truss Height, T_h =	192	mm
Limit State Moment Capacity, $M*_{tt}$ =	96.09	kN.m
Maximum Span based on Moment Capacity of Top Chord in tension, L_{tt} =	3.95	m

5.3.12 Bottom Chord Compression

In accordance with AS 4100 – 1998 Steel Structures, Clause 6.1 – $N* \leq \Phi a_c Ns$

Where Φ =	0.9	
Form Factor k_f =	1	
Section Capacity, $N_s = k_f A_n f_y$ =	311.7	kN
λ_n =	179.6	
a_a =	11.05	
a_b =	0.50	
λ =	185.11	
η =	0.56	
ξ =	0.68	
a_c =	0.20	
Limit State Capacity, $\Phi a_c N_s$ =	56.88	kN
Truss Height, T_h =	192	mm
Limit State Moment Capacity, $M*_{bc}$ =	10.92	kN.m
Maximum Span based on Moment Capacity of Top Chord in compression, L_{bc} =	1.33	m

5.3.13 Bottom Chord Tension

In accordance with AS 4100 – 1998 Steel Structures, Clause 7.1 – N*≤ΦAgfy

Where Φ =	0.9	
Limit State Capacity, $\Phi A_g f_y$ =	281	kN
Truss Height, T_h =	192	mm
Limit State Moment Capacity, $M*_{bt}$ =	53.87	kN.m
Maximum Span based on Moment Capacity of Top Chord in tension, L_{bt} =	3.37	m

5.4 Panel Properties

5.4.1 Diagonal Lacing Compression

Where Φ =	0.90	
Form Factor, k_f =	1.00	
Section Capacity, $N_s = k_f A_n f_y$ =	311.72	kN
λ_n =	136.07	
a_a =	13.93	
a_b =	0.50	
λ =	143.03	
η =	0.42	
ξ =	0.78	
a_c =	0.32	
Limit State Capacity, $\Phi a_c N_s$ =	89.21	kN
Maximum Span based on shear Capacity of Diagonal Lacing, L_{ds} =	5.13	m

The maximum span us calculated from the greatest shear at any point along the slab:

$V* = j_3 w * L \longrightarrow L = \frac{V*}{j_3 w}$

Where j_3 is a constant that depends on the number of spans.

NO. OF SPANS	j_3
1	0.5
2	0.625
≥3	0.6

5.4.2 Concrete Panel Compression

Transformed Section:

For serviceability limit state, the panel is analysed as an uncracked section using the Transformed Area method to determine the stresses in the steel and concrete.

Steel Elastic Modulus, E_s =	200,000	MPa
Concrete Elastic Modulus, E_{cj} =	22,610	MPa
Modular Ratio, n =	8.85	
Distance from Soffit to Top Chord =	221.9	mm
Transformed Top Chord Area =	9,838	mm²
Distance from Soffit to Bottom Chord =	29.9	mm
Transformed Bottom Chord Area =	4,891	mm²
Panel Concrete Area =	187,500	mm²
Distance to the Neutral Axis, y_g =	46.29	mm
Second Moment of Inertia, I_g =	4.07E+08	mm⁴

In accordance with AS 3600 – 2009 Concrete Structures, Clause 8.1.3:

Concrete Strength at Loading, f'_c =	20	MPa
Concrete Strength Factor, a_2 =	0.85	
Compressive Area Factor, γ =	0.85	
Φ =	0.60	
Effective Cross Section Depth (equal to panel thickness t_p), d =	75	mm
y_g =	46.29	mm
k_u =	0.62	
Limit State Capacity, ΦN_c =	1,003	kN
Truss Height, T_h =	192	mm
Limit State Moment Capacity, $M*_{pc}$ =	192.6	kN.m
Maximum Span based on moment capacity of Top Chord in tension, L_{pc} =	5.59	m

5.4.3 Control for Concrete Tensile Strength

AS 3600 – 2009, Clause 3.1.1.3 defines the tensile strength for a given concrete member, this has been used to ensure that the deflection calculations are accurate without using the cracked second moment of area.

$M*_{pt} = \frac{f'_{ct.f} \, 'Ig}{y_g}$ where $f'_{ct.f} = 0.6 \sqrt{f'_c}$

$f'_{ct.f}$ =	2.68	MPa
Limit State Moment Capacity for concrete strength, $M*_{pt}$ =	23.61	kN.m
Maximum Span based on controlling to concrete tensile strength, L_{pt} =	2.23	m

5.4.5 Crack Control for Flexure

AS 3600 – 2009, Clause 9.4.1 states the requirements for crack control in flexure to be deemed controlled. Part (c) provides a limit based on the steel stress, which is used to define another maximum span limit.

Largest reinforcement diameter, d_b =	6.8	mm
Steel Stress Limit, σ_{steel} =	362.3	MPa
Area of Bottom Chord Steel, A_b =	623.4	mm²
Area of Mesh Steel, A_m =	447.5	mm²
Total Area of Bottom Steel =	1,071	mm²
Equivalent Axial Force, N* =	387.99	kN
Truss Height, T_h =	192	mm
Limit state moment capacity for Steel Stress, $M*_{pf.s}$ =	74.49	kN.m
Maximum Span based on Flexural Cracking =	3.96	m

5.4.6 Deflection

The maximum deflection of the panel can be calculated from either of the following questions:

For an absolute value of a deflection limit,

$$\Delta = \frac{j_4 w_s L}{EI} \longrightarrow L = \sqrt[4]{\frac{\Delta EI}{j_4 w_s}}$$

Where j_4 is a value that varies based on the number of spans and Δ is the deflection limit. For a span: deflection ratio limit,

$$\frac{L}{\beta} = \frac{j_4 w_s L}{EI} \longrightarrow L = \sqrt[3]{\frac{EI}{\beta j_4 w_s}}$$

Where j_4 is a value that varies based on the number of spans and β is the span : deflection ration limit.

As the precast slab in assumed to be cracked for deflection calculation, only the steel truss members are used for the values of E and I. Any reinforcing mesh is not treated as contributing to deflection control as it is not assumed to be sufficiently attached to the truss frames.

NO. OF SPANS	j_4
1	0.0130
2	0.0092
≥3	0.0099

Surface quality class =	2	
Maximum deflection (absolute) =	3	mm
Maximum deflection (ration), β =	270	
Area of tensile steel, A_{st} =	623.4	mm²
Distance of tensile steel, d_{st} =	29.9	mm
Area of comprehensive steel, A_{sc} =	1,112.2	mm²
Distance to comprehensive steel, d_{sc} =	221.9	mm
Neutral axis height for steel truss only, d_{sn} =	152.9	mm
Second moment of inertia for steel truss only, I_s =	1.47E+07	mm⁴
Maximum span based on absolute limit, $L_{def.abs}$ =	3.05	m
Maximum span based on ration limit, $L_{def.rat}$ =	4.74	m
Maximum span based on serviceability limits, L_{def} =	3.05	m

5.4.7 Maximum Spans Summary

Top chord compression limit =	3.41	m
Top chord tension limit =	3.95	m
Bottom chord compression limit =	1.33	m
Bottom chord tension limit =	3.37	m
Diagonal lacing compression limit =	5.59	m
Concrete panel compression limit =	5.13	m
Concrete tension control limit =	2.23	m
Flexural cracking limit =	3.96	m
Deflection limit =	3.05	m
Governing limit =	**1.33**	**m**
Governing limit, ignoring bottom chord compression and flexural cracking =	**3.05**	**m**

When choosing the maximum allowable span, the bottom chord compression limit may be ignored in some situations. The bottom chord compression limit can be ignore if the bottom concrete panel is assumed to provide sufficient restraint to prevent buckling. When choosing the maximum allowable span, the concrete tension control limit may be ignored. This limit may be ignored as it is based on the uniaxial tensile strength of the concrete panel, as opposed to the flexural tensile strength. As the precast panel is not typically going to be axially loaded, this is not relevant.

The horizontal loading of the framework (AS 3610 – 1995, Clause 4.4.5) must also be provided for. This will typically be a role of the edge form designer.

5.4.8 Single Span

Variables: 75mm precast, f_{cmi} 20MPa, SL72 mesh, 20 cover, Class 2 finish.

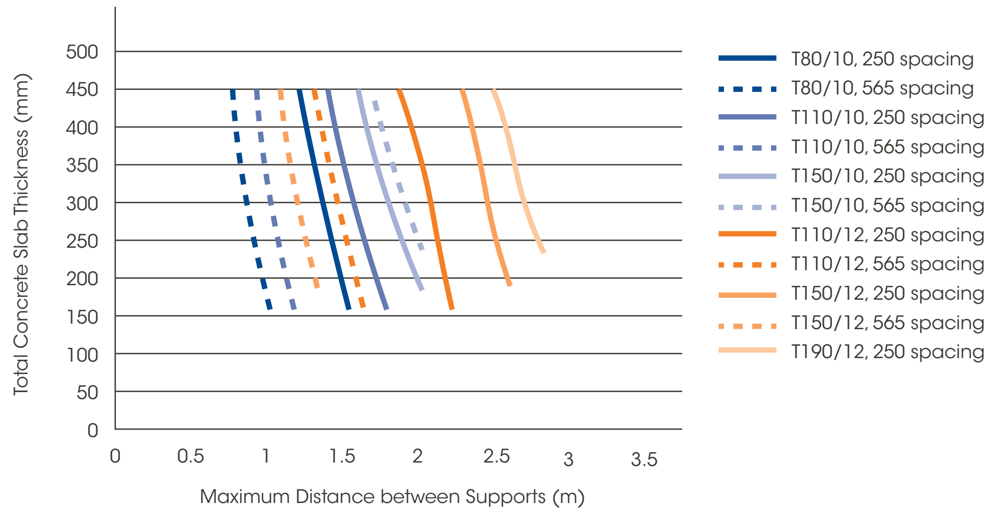


Chart 2 – Maximum distance between supports for single span

5.4.9 Two Span

Variables: 75mm precast, f_{cmi} 20MPa, SL72 mesh, 20 cover, Class 2 finish.

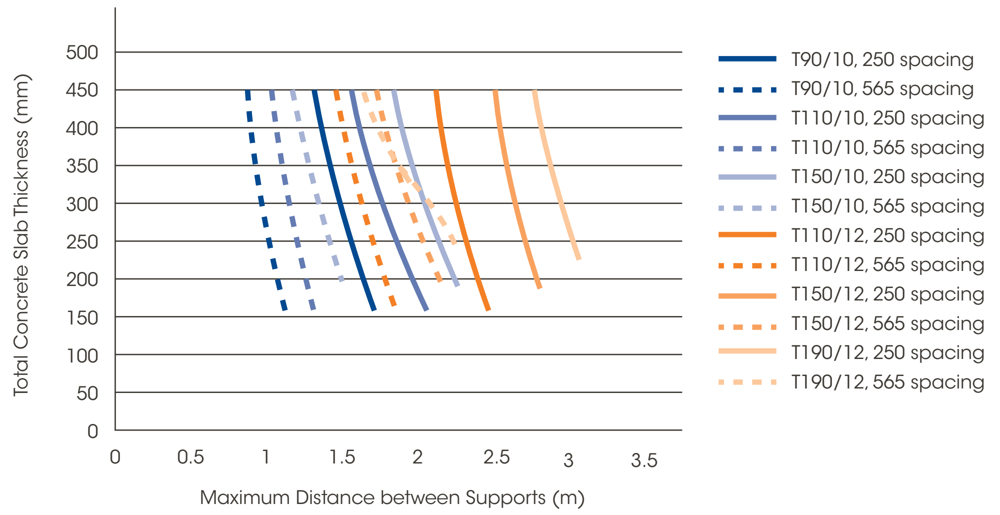


Chart 3 – Maximum distance between supports for multi span

* The information in the graphs are indicative, should be used as a guide only and does not replace the need for qualified structural design engineer.

** The information in the graphs has been generated in accordance with Australian Standard™. Formwork for concrete. AS 3610 AS 3610-1995 Formwork for Concrete and AS3610.1-2010 Formwork for concrete – Part 1 Documentation and surface finish

6. EXAMPLE MODELS AND CALCULATIONS

6.1 *Sensitivity Analysis of Two-Way Slabs – Example 1*

The example below is an example of the changes for a simple two-way slab spanning multiple grids. Three cases for the example are produced:

- Case 1: Idealised 2-way stiffness (KMr=KMs=1)
- Case 2: 75% two-way stiffness (KMr=1, KMs = 0.75)
- Case 3: 50% two-way stiffness (KMr=1, KMs = 0.50)

The example uses:

- 2 x 2 spans of 6.5m between columns
- 300 x 300 concrete columns
- 3kPa Live Load and 1.5kPa Superimposed Dead Load (SIDL)
- 250mm Austral Deck slabs with 17% weight reduction
- Default values for creep and shrinkage coefficients
- 30 year load history for cracked section deflection calculations

The slab is orientated such that R is Left-Right and S is Up-Down on the page. Reducing KMs effectively reduces stiffness about the S direction. This is the equivalent of the planks orientated in the Up-Down direction. For this example, there might be 2 plank spans in the up-down direction, but 5-6 spans in the Left-Right direction.

The results indicate the following:

Design Case	Idealised 2-way	75% Secondary Stiffness	50% Secondary Stiffness
Mid-span Deflection	31.5 mm	36.1 mm	46.7 mm
Primary +ve Moment	38.1 kNm	41.1 kNm	44.6 kNm
Primary -ve Moment	-117 kNm	-120 kNm	-138 kNm
Secondary +ve Moment	38.1 kNm	37.8 kNm	36.6 kNm
Secondary -ve Moment	-120 kNm	-104 kNm	-101 kNm

Table 9 – Differential stiffness results for Three Austral Deck slabs

As the above example is only 2 x 2 spans, there is only limited options for moment redistribution, but the results still indicate increased deflections up to 50% and redistribution of secondary moments into primary moments.

Results would also be more pronounced for rectangular grid layouts, such as 6m x 8.5m, rather than square grid layouts, which do not naturally lend themselves to primary and secondary span directions.

The following screen captures are results on the above options.

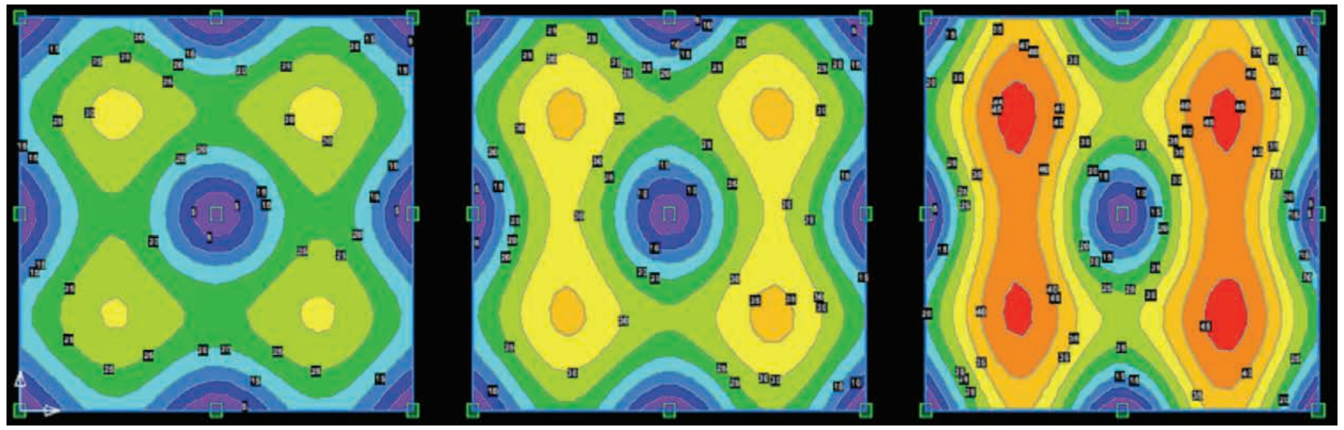


Figure 28 – Long term (30 year) deflection for 100%, 75% and 50% secondary stiffness

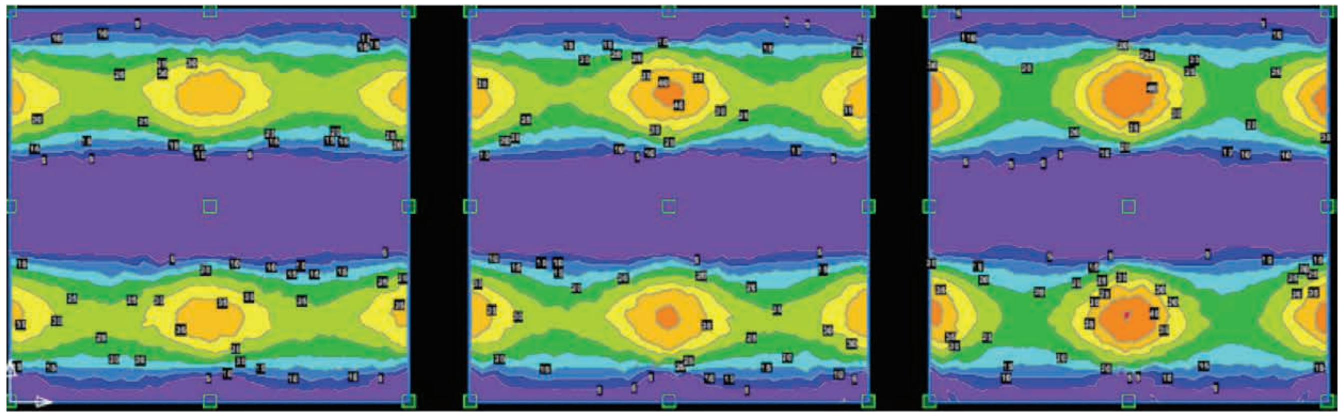


Figure 29 – Primary positive moment (about R axis)

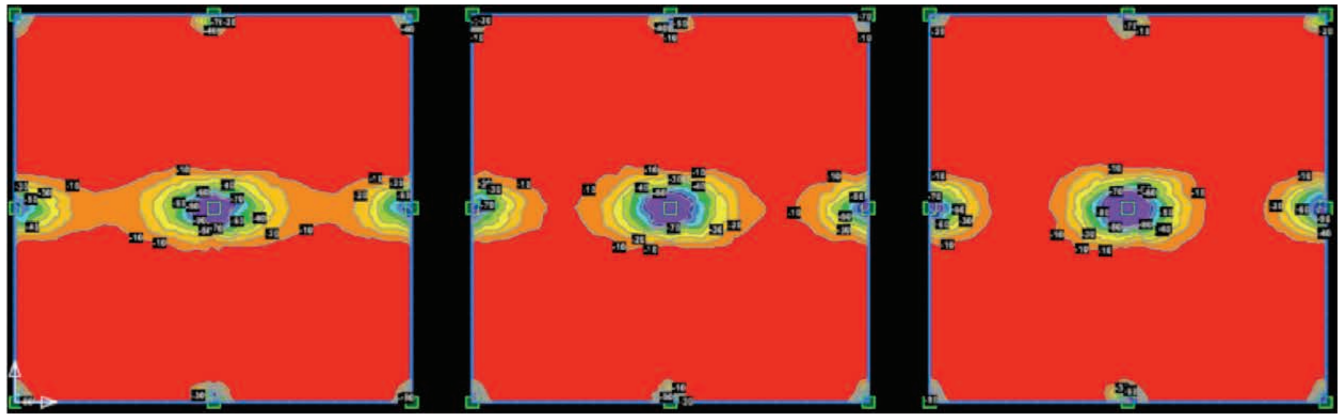


Figure 30 – Primary negative moment (about R axis)

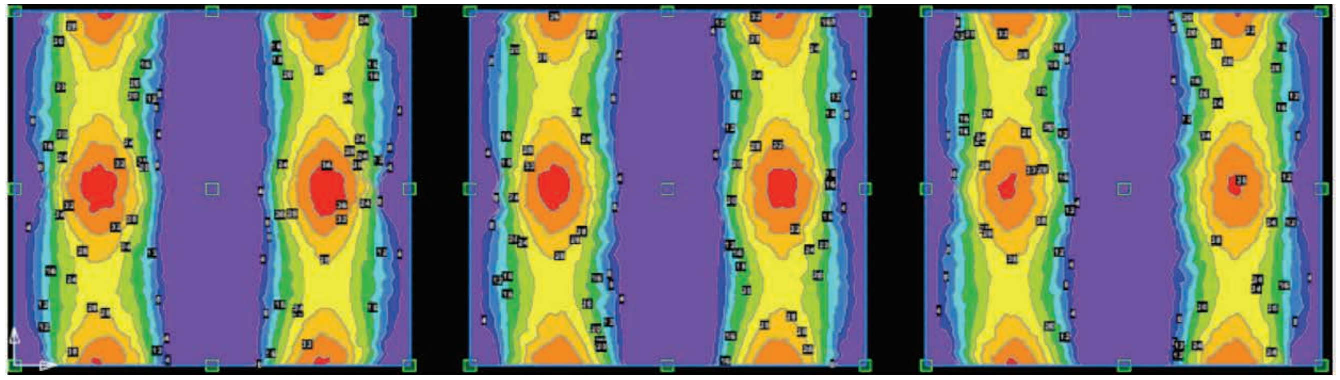


Figure 31 – Secondary positive moment (about S axis)

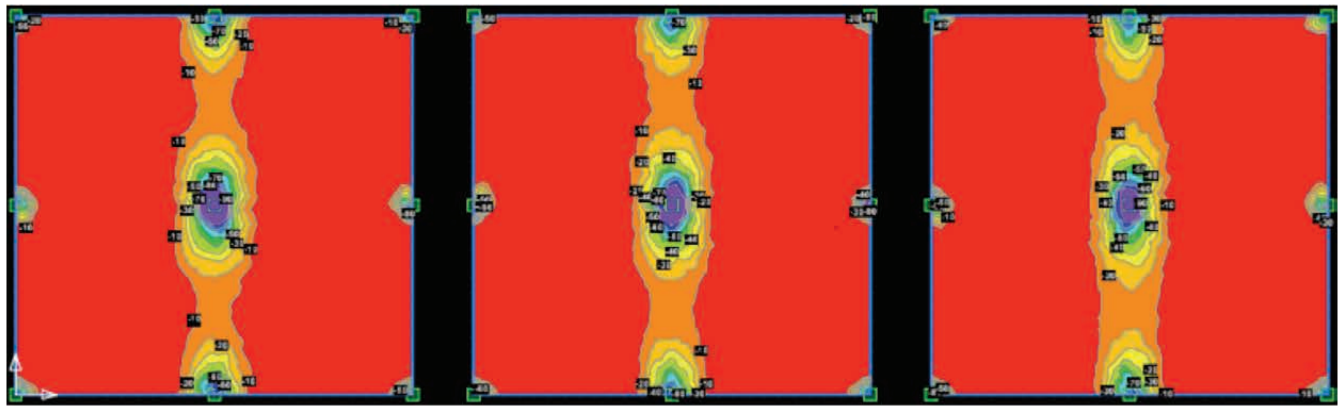


Figure 32 – Secondary negative moment (about S axis)

6.2 *Worked Calculations*

Using the example model from section 3.3, some further worked calculations are taken below. In this case, the bathroom setdowns are removed for simplicity.

The design loads and slab features are as follows:

Design Properties	Value
General Loading	Residential
Superimposed Dead Load	1.0kPa
Live Load	2.0kPa
Slab Thickness	230mm
Precast Thickness	60mm
Columns	400x400
Shrinkage Restraint	11% (Minimal walls)

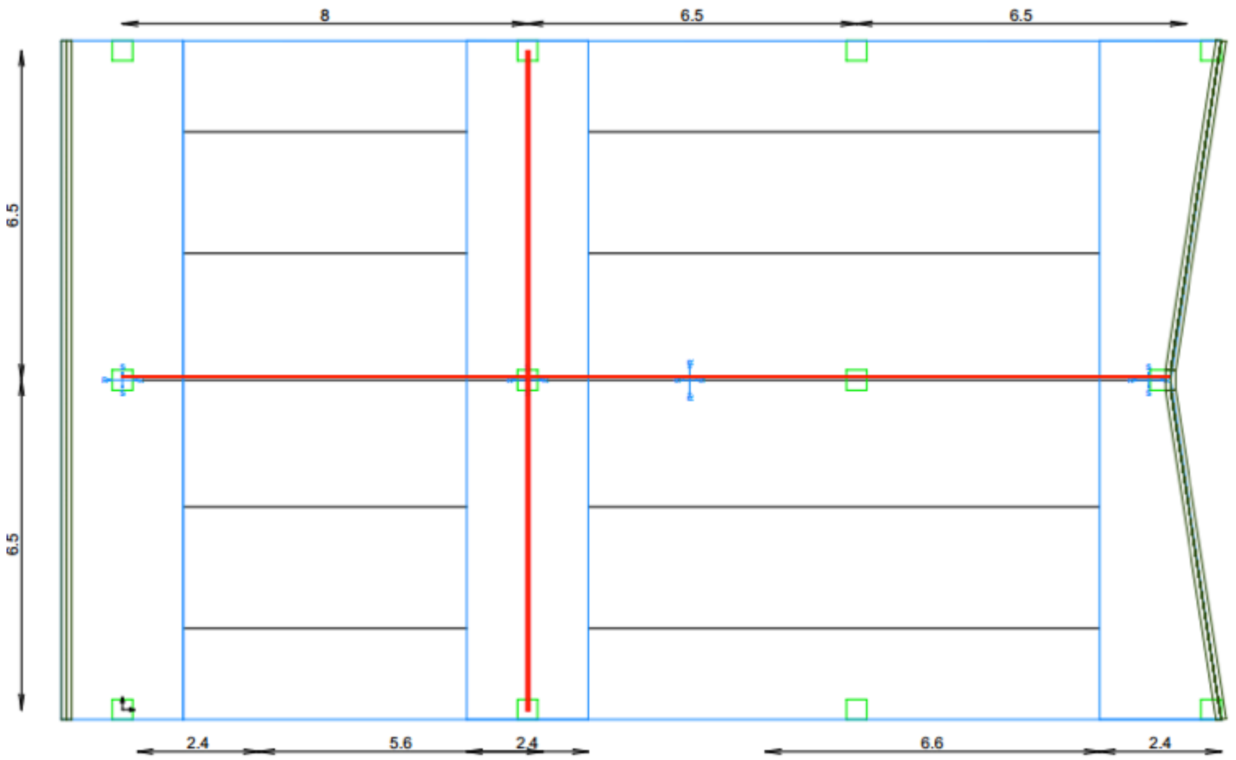


Figure 33 – Example Slab

Two full design strips will be taken as examples, highlighted above in Red.

6.2.1 Strip 1 – Vertical Span

The above strip is 230 thick, with 2 equal spans of 6.5. It carries tributary width of approximately 7.5m, but in practice this amount is reduced due to the semi-two-way nature of the slab.

The bending moment diagram for the above slab is as follows:

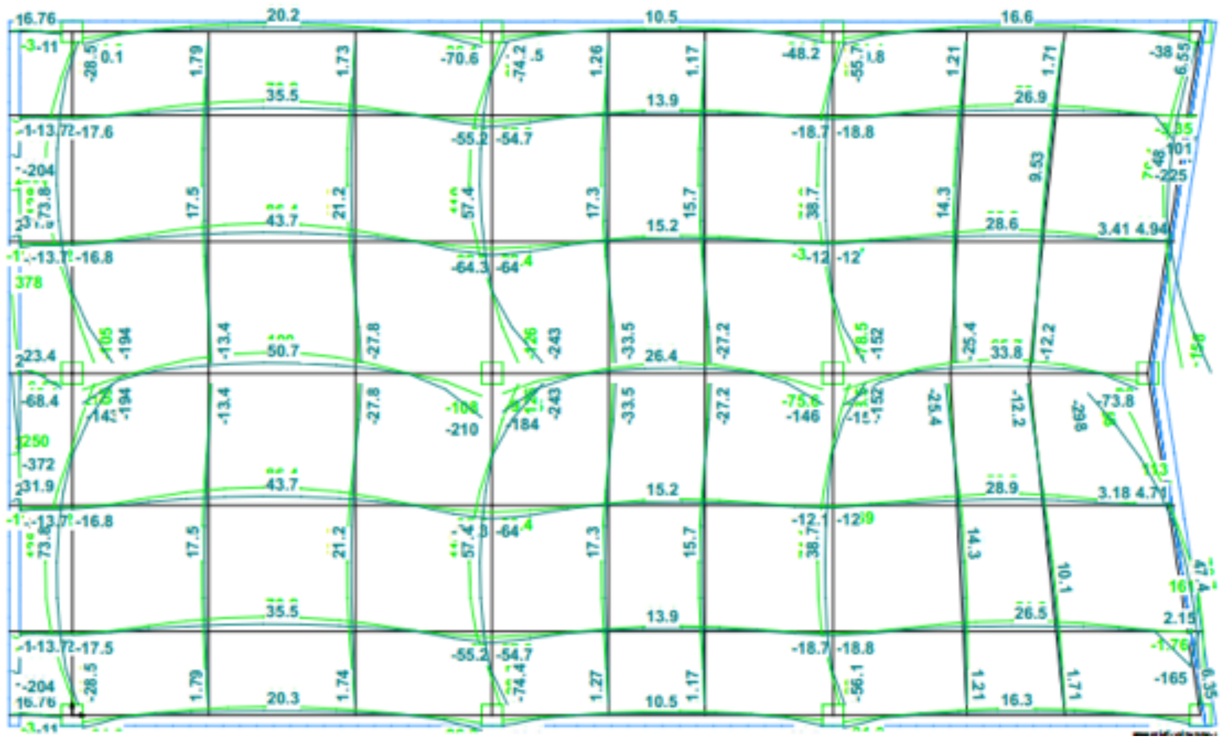


Figure 34 – Example Slab

The maximum positive strip bending moment for the design strip is 110kNm over the 2.5m plank width, or 44.0kNm.

To satisfy this moment, reinforcement of 630mm2/m is needed, as follows:

$$ØM_{uo} = 0.8 \cdot A_{st} \cdot f_{sy} \cdot d - \left(\frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c}\right)$$

$$= 0.8 \cdot 800 \cdot 500 \cdot (194 - \left(\frac{630 \cdot 500}{2 \cdot 0.85 \cdot 1000 \cdot 40}\right)$$

$$= 47.72kNm > 44.0kNm$$

630mm^2/m can be supplied as N12 bars at 200mm centres (565mm^2/m) laid on top of SL92 mesh (287mm^2/m), or total 852mm^2/m.

The neutral axis depth, 194mm, is based on the total slab depth:

$$d = 230 - 30\ (cover) - 6\left(\frac{N12\ bar}{2}\right) = 194mm$$

Negative moment over the columns is 243kNm/m over 2.5m width.

This can be provided with 3450mm2 reinforcing in a similar way, with a traditional reinforcing layout over 2.5m:

$$ØMuo = 0.8 \cdot A_{st} \cdot f_{sy} \cdot\ d - \left(\frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c}\right)$$

$$= 0.8 \cdot\ 3350 \cdot 500 \cdot \left(194 - \frac{3350 \cdot 500}{2 \cdot 0.85 \cdot 2500 \cdot 40}\right)$$

$$= 244.08kNm > 243kNm$$

3,350mm^2 can be supplied by 17 x N16 bars, or N16 at 150mm centres over 2.5m width.

6.2.2 Strip 2 – Horizontal Span

Similar to Strip 1, the positive moments are 100, 50.9 and 65.7kNm in the design strip spans 1 to 3 respectively.

We take Span 1 as an isolated plank, and achieve the moments thus:

$$ØM_{uo} = 0.8 \cdot A_{st} \cdot f_{sy} \cdot d - \left(\frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c} \right)$$

$$= 0.8 \cdot 1350 \cdot 500 \cdot \left(194 - \frac{1350 \cdot 500}{2 \cdot 0.85 \cdot 2500 \cdot 40} \right)$$

$$= 102.6kNm > 100kNm$$

1350mm² is provided by N12 at 250mm centres plus SL92 mesh.

For spans 2 and 3, we use 65.7kNm as the critical moment, which is achieved with N12 at 300mm centres.

The negative moment for the horizontal span is 210kNm and 151kNm at the two internal columns.

$$ØM_{uo} = 0.8 \cdot A_{st} \cdot f_{sy} \cdot \left(d - \frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c} \right)$$

$$= 0.8 \cdot 3350 \cdot 500 \cdot \left(180 - \frac{3350 \cdot 500}{2 \cdot 0.85 \cdot 2500 \cdot 40} \right)$$

$$= 228.06kNm > 210kNm$$

Note the reduced cover d=180mm, for the second layer of rebar.

This moment is resisted by 3,350mm² or N16 at 150mm centres over 2500mm.

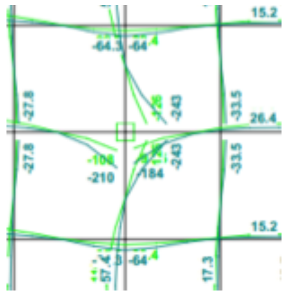
6.2.3 Check on Column Strip Width

As all of the above strip runs are considered column strips, check that the strip width allocation is appropriate with AS3600.

In this case, the bottom reinforcing is suitable (with the column strip being 2500mm wide) but the top reinforcing will fail clause 9.1.2, which states:

In two-way flat slabs, at least 25% of the total of the design negative moment in a column-strip and adjacent half middle-strips shall be resisted by reinforcement or tendons or both, located in a cross-section of slab centred on the column and of a width equal to twice the overall depth of the slab or drop panel plus the width of the column.

For this example, in the horizontal span, the total column moment requirement is:



$$(210 + 64 + 64) \times 25\% = 84.5kNm$$

In the central portion, the width is 2 x D + Column,
= 2 x 230mm + 400mm = 860mm.

Over 860mm, N16-150mm is 1152mm2, which provides moment of
$ØM_{uo} = 78.5kNm < 84.5kNm$.

This fails clause 9.1.2.

The designer can choose either to increase the reinforcing in this location, or to close the bar centres over the column.

6.2.4 Check on Secondary Moment Direction

The secondary negative moments are not addressed in this example, as the reinforcing bars are laid traditionally at the top and 2nd layers.

The secondary positive moments, however, can only be resisted by the SL92 mesh case in the precast plank, plus extra bars laid on top of the precast at reduced cover (60mm).

In this example, the secondary moment is 40.8kNm over 2.5m.

The moment capacity in the plank using SL92 mesh (287mm2/m) is:

$$ØMuo = 0.8 \cdot A_{st} \cdot f_{sy} \cdot \left(d - \frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c} \right)$$

$$= 0.8 \cdot 287 \cdot 2.5 \cdot 500 \cdot \left(194 - \frac{287 \cdot 2.5 \cdot 500}{2 \cdot 0.85 \cdot 2500 \cdot 40} \right)$$

$$= 55.6kNm > 40.8kNm$$

However, there are breaks in the planks every 2.5m.

To account for the breaks, "cracker" bars are placed over the breaks, which have cover of approximately 70mm to the bar centre (d=230-65-12/2 = 159mm)

The cracker bars should be N12 at 400mm centres (700mm² over 2500mm):

$$ØM_{uo} = 0.8 \cdot A_{st} \cdot f_{sy} \cdot \left(d - \frac{A_{st} \cdot f_{sy}}{2 \cdot 0.85 \cdot b \cdot f'_c} \right)$$

$$= 0.8 \cdot 700 \cdot 500 \cdot \left(159 - \frac{700 \cdot 500}{2 \cdot 0.85 \cdot 2500 \cdot 40} \right)$$

$$= 44kNm > 40.8kNm$$

So cracker bars of N12 at 400mm centres are placed, centred over the plank joints.

The cracker bars should be at least one splice-length each side of the joint, or approximately 1200-1500mm in total.

6.2.5 Check on Punching Shear

Punching shear checks are first completed against the in-situ portion of the slab.

In the case of the central column in the above example, the punching shear forces are:

Punching Shear Reactions	Value
V*	584kN
Mr*	0.02kNm
Ms*	32.3kN
Ms*	32.3kN

First check the in-situ portion (D=160mm, dom=125mm) in accordance with AS3600:

$$f'_{cv} = 0.17 \left(1 + \frac{2}{\beta_h} \right) \sqrt{f'_c} \leq 0.34 \sqrt{f'_c} \quad (\text{but } \beta_h = 1)$$

$$f'_{cv} = 0.34 \sqrt{f'_c} = 2.15MPa$$

$$d_{om} = 125,\ u = 4 \cdot (400{+}125) = 2100mm$$

$$ØV_{uo} = 0.7 \cdot 125 \cdot 2100 \cdot 2.15 = 395kN < 584kN\ (fail)$$

Next try the full depth (D=230mm, dom=195mm):

$$d_{om} = 195,\ u = 4 \cdot (400 + 195) = 2380mm$$

$$ØV_{uo} = 0.7 \cdot 1\,95 \cdot 2380 \cdot 2.15 = 698kN > 584kN\ (OK)$$

Check torsion strip reduction, (a=400+195=595mm)

$$ØV_u = ØV_{uo} \Big/ \left(1.0 + \frac{u \cdot M_v^*}{8V^* \cdot a \cdot d_{om}} \right)$$

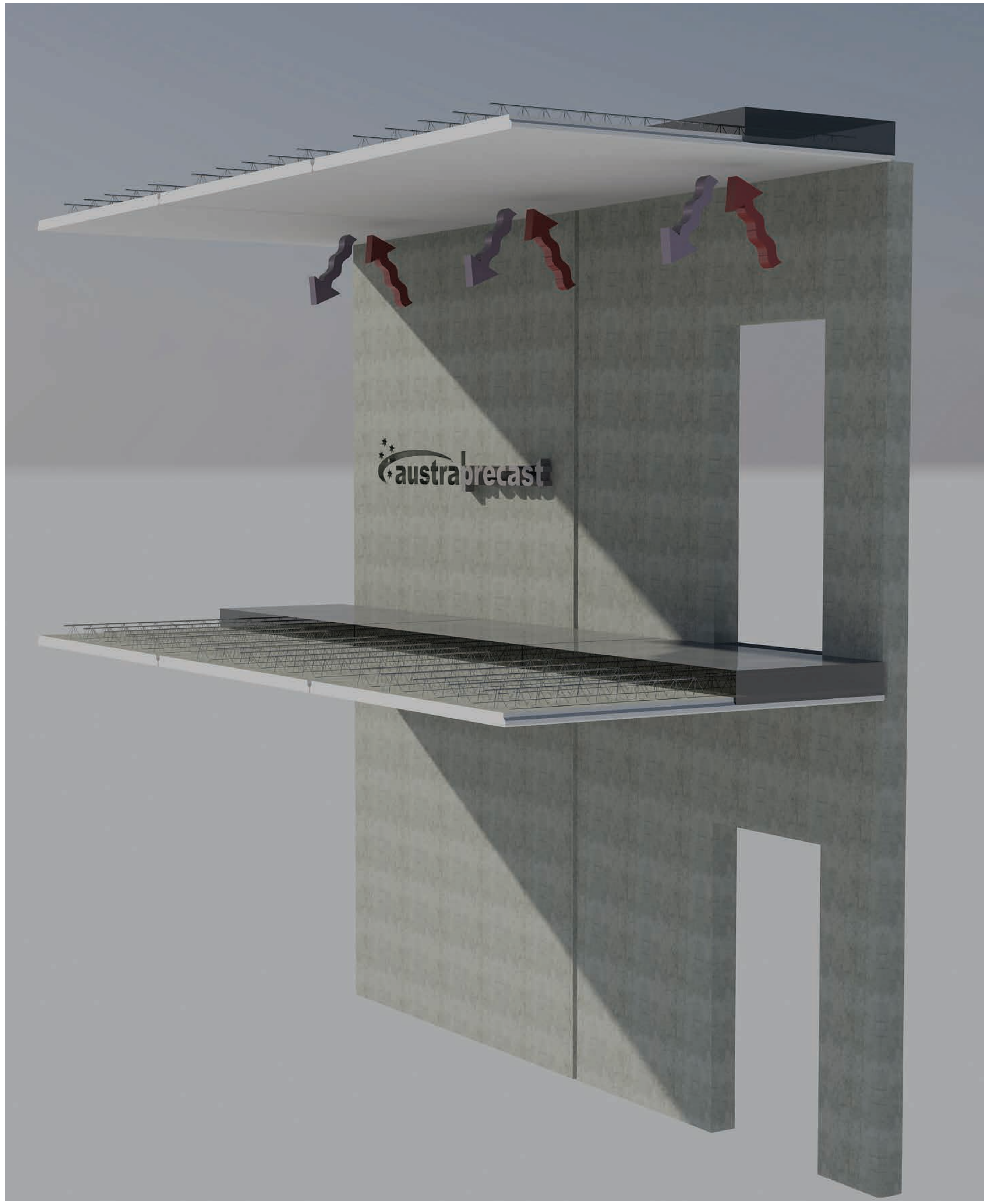
$$ØV_u = ØV_{uo} \Big/ \left(1.0 + \frac{1.0 + 2380 \cdot 32.3}{584 \cdot 595 \cdot 195} \right)$$

$$ØV_u = 698 \Big/ \left(1.0 + \frac{2380 \cdot 32.3 \times 10^3}{8 \cdot 584 \cdot 595 \cdot 1\,95} \right)$$

$$ØV_u = 698 \Big/ 1.1418 = 611.3kN\ (OK)$$

As punching shear fails on the in-situ portion alone, but passes when including the precast portion, the designer should ensure that the total reinforcing bars in the trusses are sufficient to "hang up" the load between the precast and in-situ portions of the slab. If not, then shear studs should be considered.

7. FIRE AND THERMAL RESISTANCE



7.1 Fire Resistance Period

7.1.1. Austral Deck Profile

Any concrete slab must be designed to achieve a fire resistance period[1] (FRP) for structural adequacy, integrity and insulation of not less than the required fire resistance level[2] (FRL) as specified in The National Construction Code – Building Code of Australia (NCC-BCA).

Chart 4 shows FRP for insulation of various slab thicknesses constructed using Austral Deck. The FRP has been calculated in accordance with Australian Standards: Concrete Structures, AS3600-2009, Clause 5.2.1 – Insulation for slabs, and modified taking into account Austral Deck profile – Figure 35 and 36.

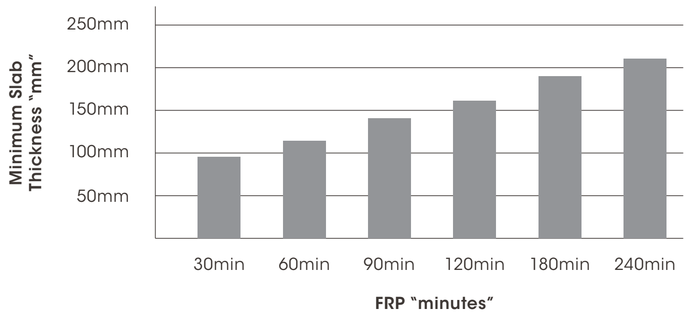


Chart 4 – Fire Resistance Period[3] for insulation for solid slabs constructed using Austral Deck profile.

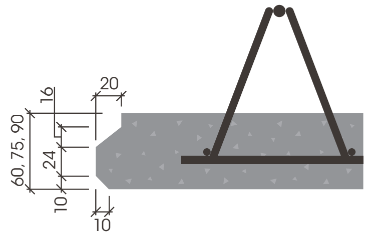


Figure 35 – Austral Deck side profile.

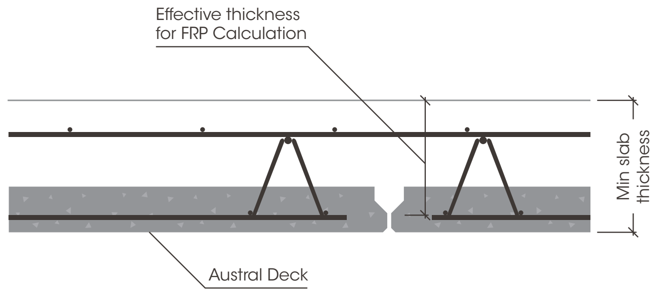


Figure 36 – Effective thickness for FRP calculation Austral Deck profile.

7.1.2. Thermal Resistance

Austral Deck, as part of the concrete slab can be designed to achieve energy efficiency provisions as specified in The National Construction Code Volume Two – Building Code of Australia (BCA).

The Thermal resistance coefficient "The R- Value" (4) of the Austral Deck slab is affected by the precast panel thickness, overall slab thickness, the use of slab voids, the use of other insulation materials, flooring and ceiling material.

The National Precast Concrete Association of Australia (5) "NPCAA" has developed a software to calculate the R Value of Austral Deck considering all the above factors. Copy of the software can be downloaded via the NPCAA website: www.nationalprecast.com.au/r_value_calculator/

7.1.3. Definitions and References

(1) Fire resistance period (FRP)

Time, in minutes, for a member to reach the appropriate failure criterion (i.e., structural adequacy, integrity and/or insulation) if tested for fire in accordance with the appropriate Standard. Source Australian Standards, Concrete Structures, AS3600-2009, Clause 5.2.5

(2) Fire resistance level (FRL)

Fire resistance periods for structural adequacy, integrity and insulation, expressed in that order.

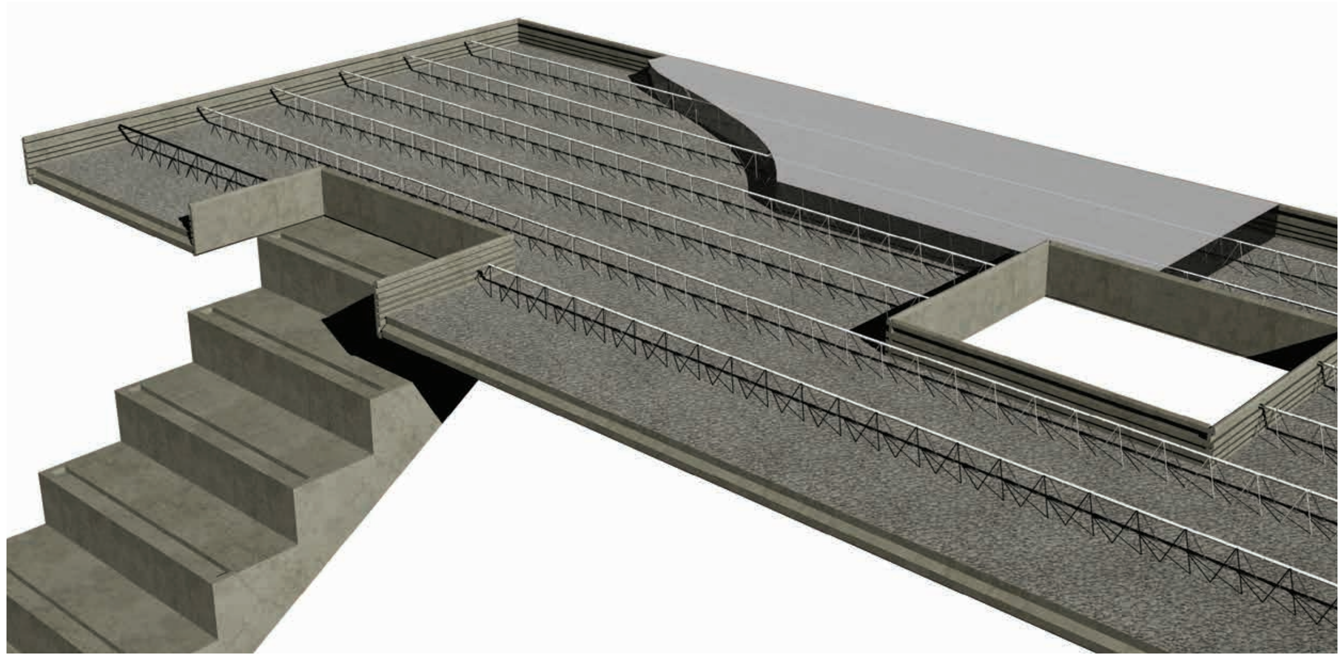
NOTE: Fire resistance levels for structures, parts and elements of construction are specified by the relevant authority, e.g., in the Building Code of Australia (BCA). Source Australian Standards, Concrete Structures, AS3600-2009, Clause 5.2.4

(3) Section 5 of AS3600-2009 outlines the requirements for the fire resistance of slabs. It is assumed that the criteria for integrity is considered to be satisfied if the design meets the criteria for both insulation and structural adequacy for that fire resistance period as per clause 5.3.1 of AS3600-2009

(4) The R-value of a substance is its direct measure of its resistance to transferring energy or heat; R Values are expressed using the metric units (m2.K/W). The amount of degrees kelvin temperature difference required to transfer one watt of energy per one square meter of a substance.

(5) Published with an approval from NPCAA

8. TYPICAL INSTALLATION DETAILS



8.1 Typical Wall Connection – End Support

8.1.1. End Support to External Precast Wall – Option 1

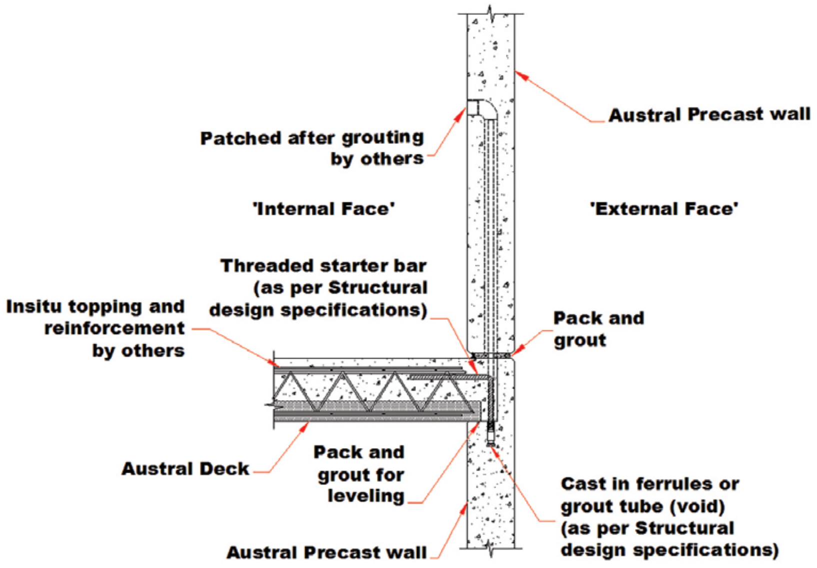


Figure 37

8.1.2. End Support to External Precast Wall – Option 2

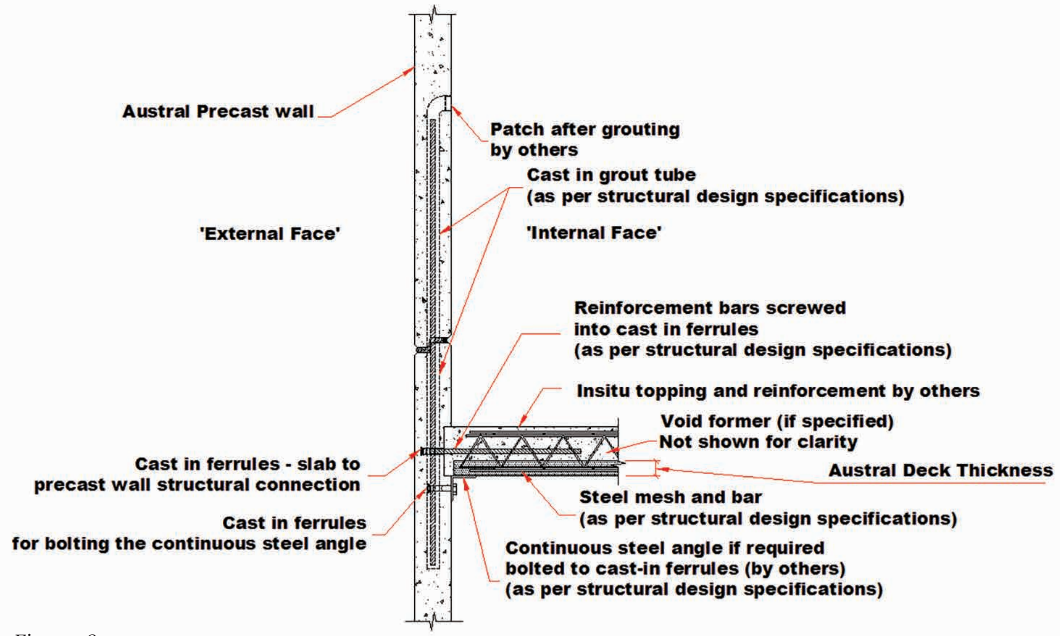


Figure 38

8.1.3. End Support to Internal Precast Wall

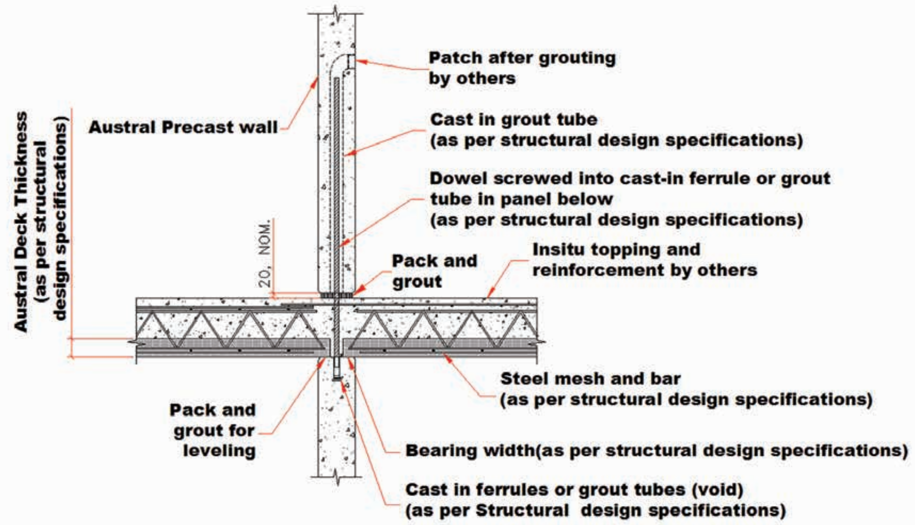
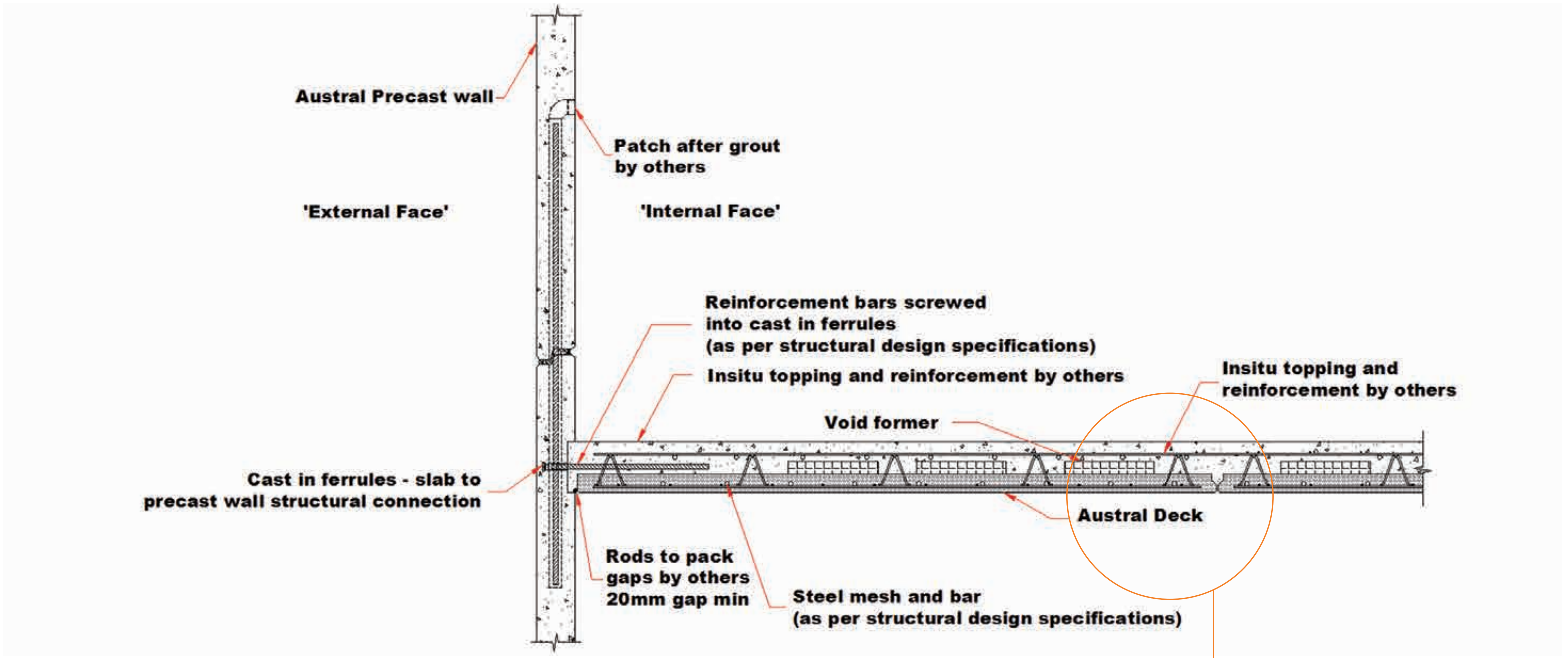


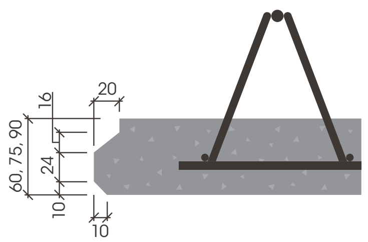
Figure 39

8.2 *Typical Wall Connection – Longitudinal Side*

8.2.1. Longitude Side to External Precast Wall



8.2.2. Side Joint Details



Austral Deck side profile.

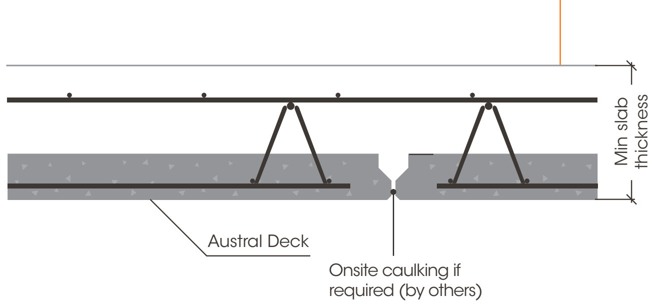


Figure 40

8.3 *Typical Wall Connection – Internal Precast Wall and Double Wall*

8.3.1. End Support – Internal Precast Wall Under

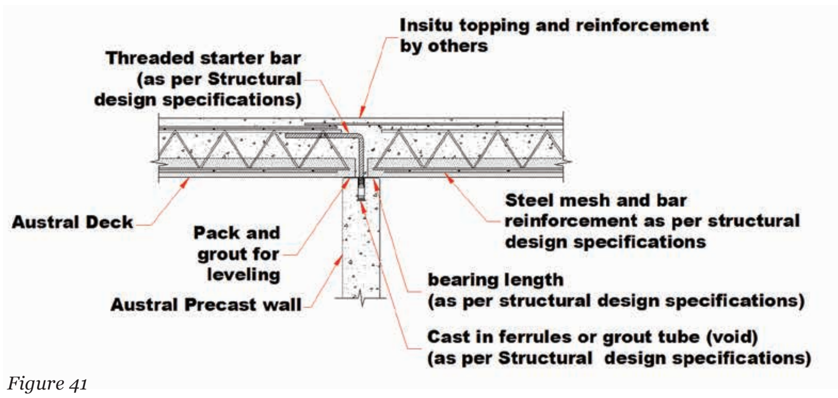


Figure 41

8.3.2. Mid Span – Internal Precast Wall Above

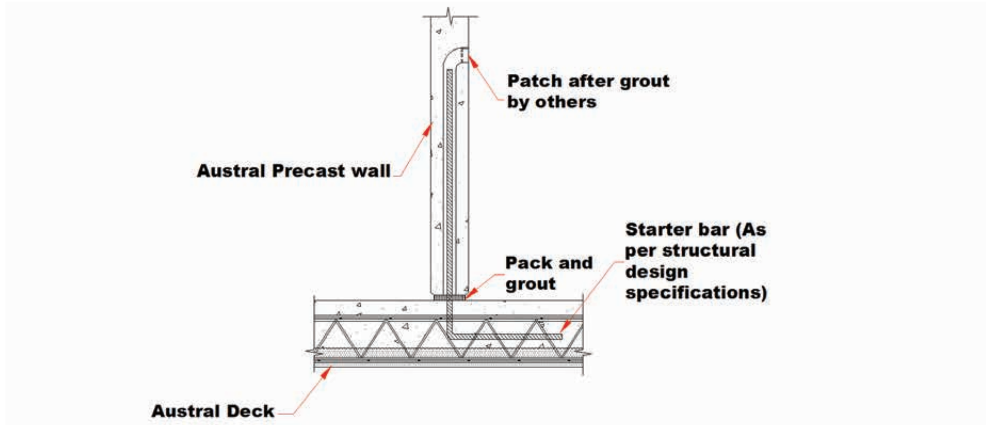


Figure 42

8.3.3. End Support – Double Wall Connection

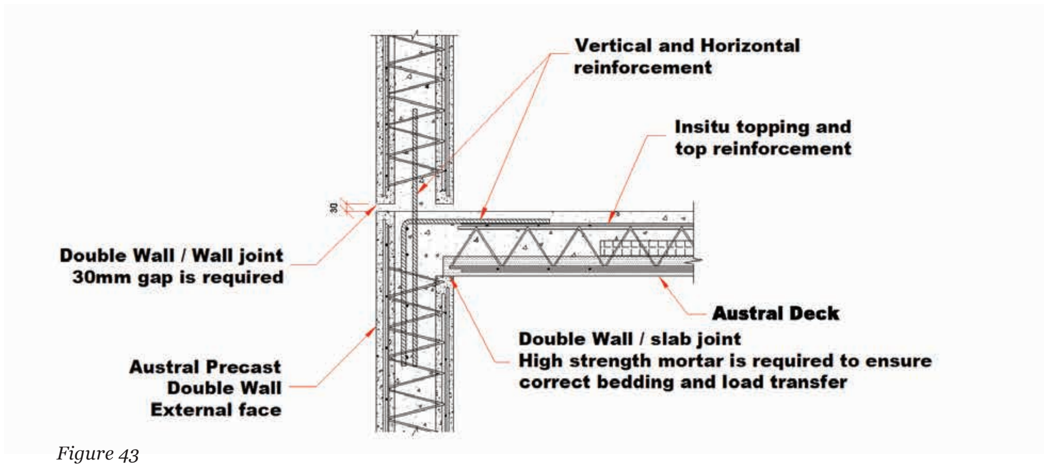


Figure 43

8.4 *Typical Beam Configuration*

8.4.1. Beam Reinforcement within Slab Thickness

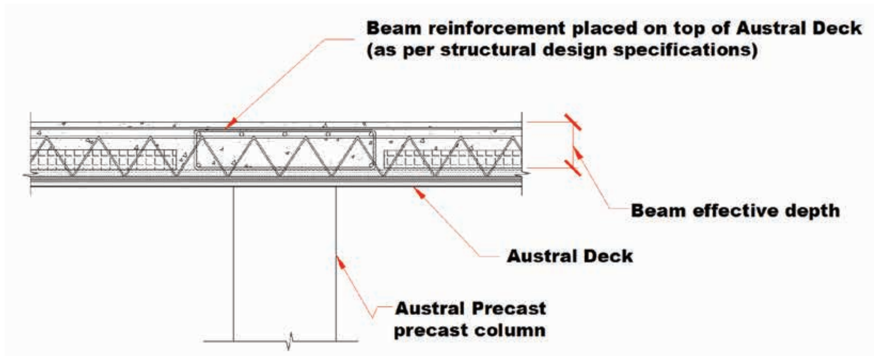


Figure 44

8.4.2. Precast Beam

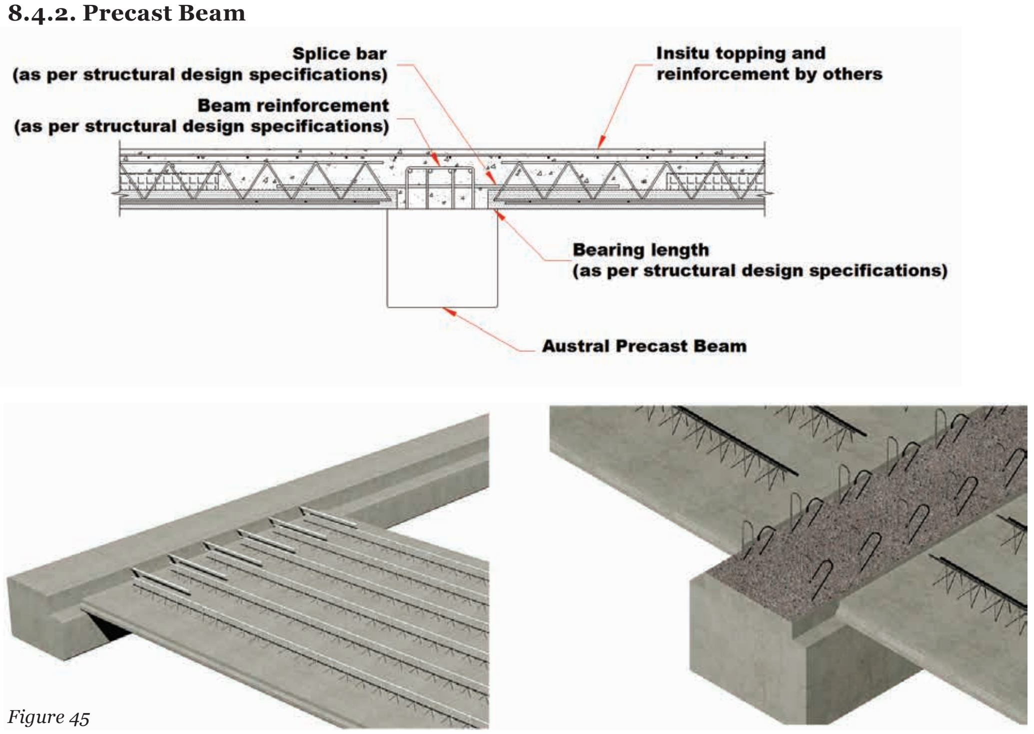


Figure 45

8.4.3. Band Beam formed by Austral Deck

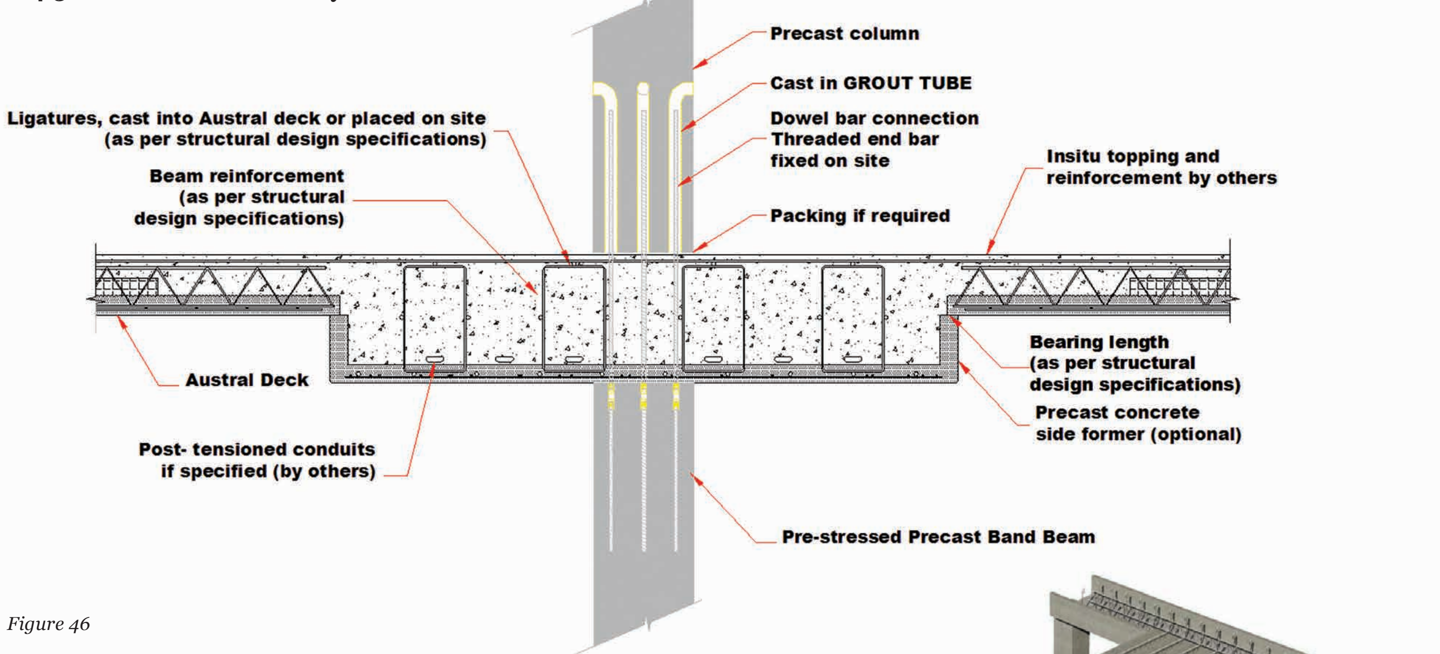


Figure 46

8.5 Balcony and Cantilever Arrangement

85.1. Balcony and Cantilever Arrangement

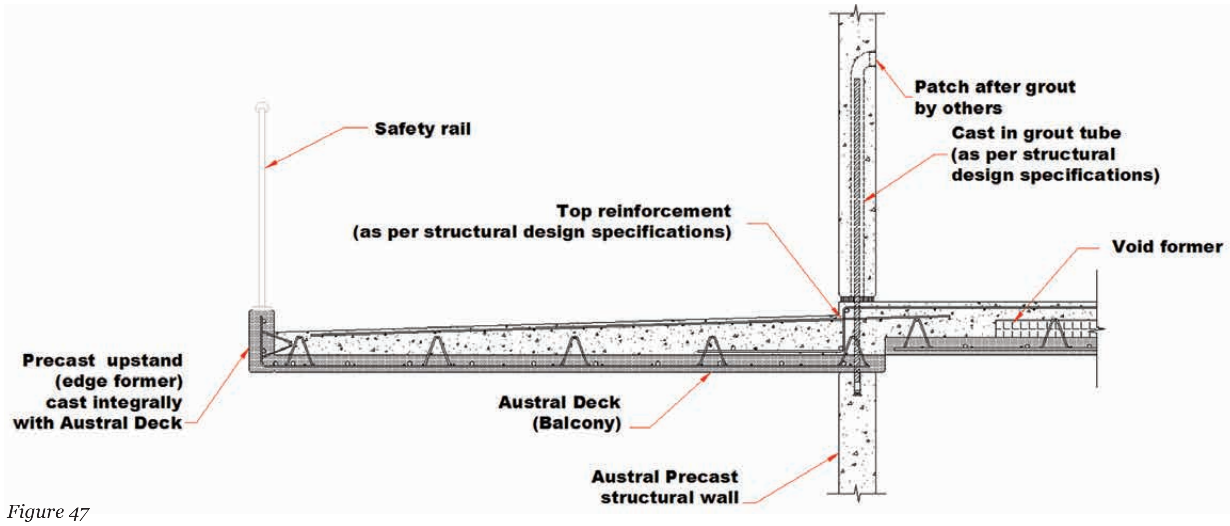


Figure 47

8.5.2. External Precast Wall with Balcony

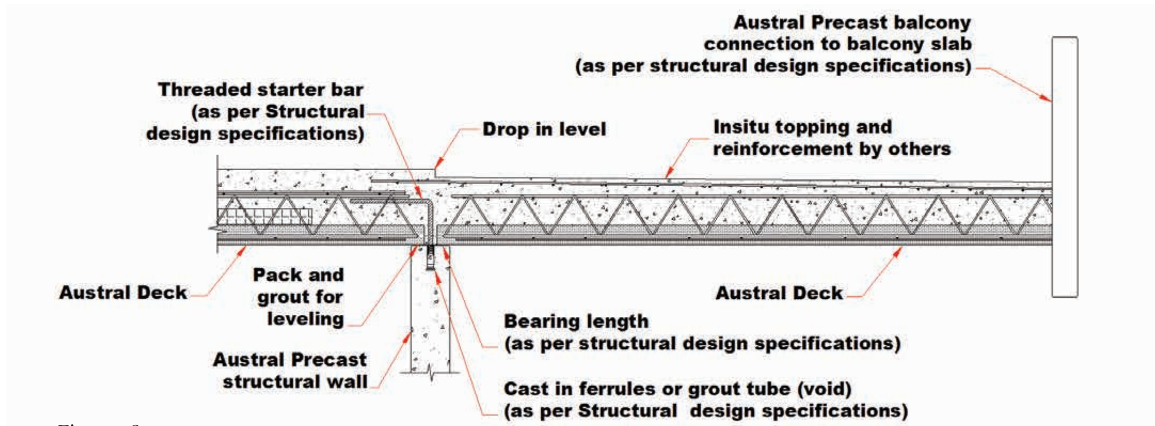
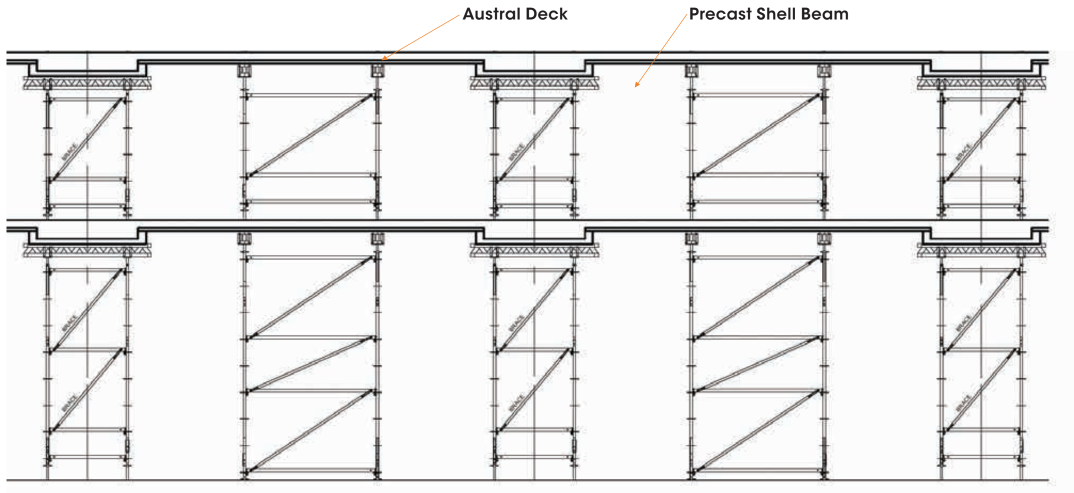


Figure 48

8.6 Proposed Propping Arrangement



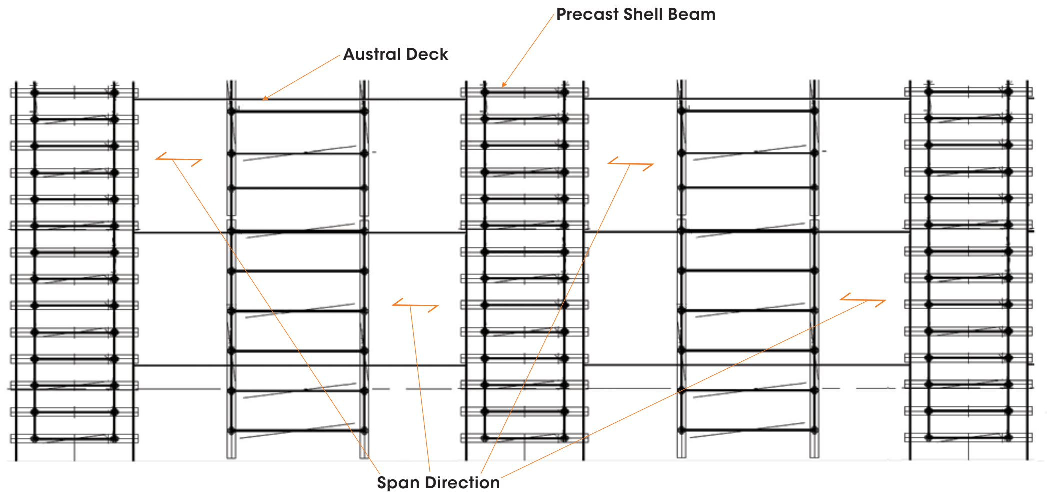


Figure 49

The propping design is provided and shall be certified by the supplier of the props. The props will be certified to carry the defined construction loads.

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