ARTICLES FROM NUMBERS 16 AND 17 • JULY 1997 AND JANUARY 1998

• N A T I O N A L •
PRECASTER

NATIONAL PRECAST CONCRETE ASSOCIATION AUSTRALIA

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PRECAST Floors 1

Before selecting any building material or construction process, the design and construction team must examine a range of techniques and materials generally accepting a solution which will eliminate, or at least minimise, the factors which may otherwise induce risk and often, cost into the project.

Developments in the precast concrete flooring market have seen a number of systems become available in Australia; all provide the advantages inherent in precast concrete construction; which in turn demands that the design and construction team thoroughly examine the product characteristics when making their choice of materials.

Fundamentally, the issue of cost will predominate, but gone are the days when cost of materials was the sole concern. The realisation that, simplicity of construction, time to completion; issues such as minimising site activities and thereby reducing noise and site pollution, improving the quality of living by attention to issues such as limiting noise transmission between dwellings have now begun to receive the attention that they so thoroughly deserve.

Looked at individually, the *advantages* of precast concrete include:

- Off-site manufacture of the flooring system. Manufacture can occur parallel to site establishment, earthworks and footings.
- The near elimination of formwork, propping and on-site steel-fixing minimising on-site labour and the impedance of following trades.
- Delivery to site to the contractor's requirements. No site storage required.
- Fixed cost.
- Rapid placement rates of 1000 m^2/day are common. This in turn can result in early completion of the project, giving an early return on investment.
- Rapid closure of the structure allowing early follow-up by finishing trades at the under-level.
- Safe working and storage platform created at the upper level. After the crane has placed the floor panels it is common for it to then lift brick/block palettes to the working level before leaving the site.
- The precast panels are generally cast on smooth, level beds or moulds ensuring that the underside of the panel which becomes the soffit or ceiling is itself smooth and capable of receiving decoration direct. Alternatively, simple suspended ceiling systems are available.
- Reduced site labour component with the workforce operating in a factory environment far more congenial than a building site.
- Inclement weather problems measurably eliminated.
- Flexibility in the siting of non-loadbearing partition walls.
- Site environmental issues massively reduced particularly noise and clean-up requirements.
- Ongoing marketing advantages including:
  - Significant noise reduction between floors and occupancies so essential in medium density construction. Whilst authorities generally call for an STC (Sound Transmission Class) of 45, precast flooring elements can easily achieve STC ratings of 45–59. (The larger the STC value the greater is the sound insulation).
  - Excellent resistance to fire.
  - The concrete floor, given advantageous orientation can provide most useful passive solar energy properties.
- Finally, in respect of advantages, it should be noted that mainstream precast concrete suppliers all have third party Quality Assurance. Apart from the peace of mind that such Quality Assurance offers, it further eliminates the need for on-site inspection, necessary when insitu construction occurs.

These advantages add up to a very powerful reason to investigate the use of precast concrete on your next project. They can be summarised as – ***the Minimisation of Risk.***

PRECAST CONCRETE FLOOR METHODS

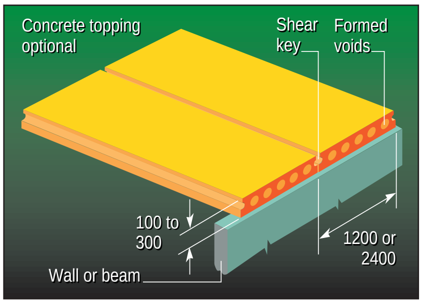
There are a number of precast concrete floor methods and suppliers, but availability varies throughout Australia. Contact the National Precast Concrete Association if in doubt regarding availability.

Further, it should be noted that the transporting of floor elements over a distance is not necessarily prohibitive since floor panels are generally flat sections and numerous panels can be transported in a single load.

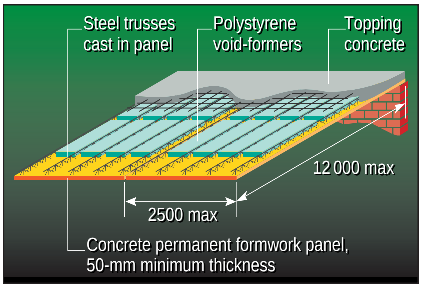
Discuss the issue of distance and cost with the supplier rather than simply dismiss it. The planning team and later the site management must give consideration to access for both crane and delivery vehicle. This may have an effect upon the delivery programme, construction sequence, the site layout of storage areas, site offices etc.

Articles in following editions of this Digest will discuss the proprietary flooring units available. These include:

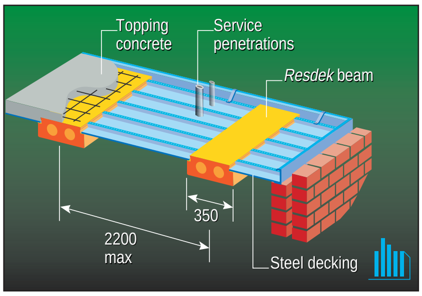
Hollow Core Panels: a prestressed extruded panel in a variety of thicknesses to suit spans, loads etc.



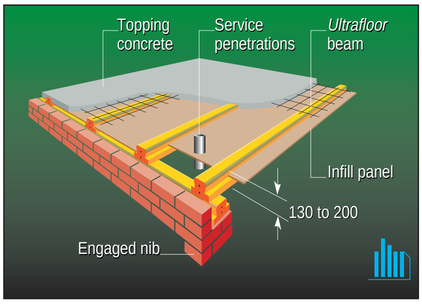
Transfloor/Humeslab, a wet-cast panel with included bottom reinforcement. Typically 50 mm thick, the panel acts as permanent formwork.



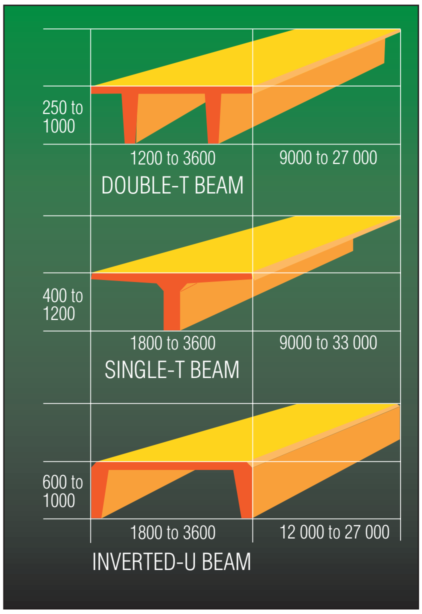
Resdek, a beam and infill arrangement. Uses a prestressed beam with 'Bondek' infill panels.



Ultrafloor, a beam and infill system having prestressed bearers and joists and cementitious board, infill panel.



Single/Double Tee units. Suited to large uninterrupted spans. ■



PRECAST Floors 2

HOLLOW CORE FLOOR PLANKS are precast, prestressed units produced on long-line beds using slide forming or extrusion methods. Plank widths are usually 1200 mm wide, though some manufacturers can produce 2400 mm wide units. These wider units may require increased crane capacity but offer greater speed of placement, less joints, grouting and sealing. Thicknesses vary from 150–300 in 50 mm increments, the thickness being determined by span, loading, fire rating and cover to reinforcement to satisfy exposure conditions. Planks may be used as plain sections or topped to give a composite unit, the topping being used to increase plank capacity or fire rating and provide a flat, uniform surface or, alternately, provide required falls.

Plank Width Most manufacturers provide 1200 mm wide planks. Some manufacturers can offer a 2400 mm wide unit. Obviously, economic advantage occurs if designers incorporate these modular values in their design. If this is not possible, planks can be sawn longitudinally by the manufacturer, or partially widths cast. Alternatively, an insitu pour can be made to make-up the non-standard dimension but such treatment tends to nullify the many advantages of using a precast floor system. This concern may be mitigated if an insitu topping is to be used, when the infill pour and topping placement can be paralleled.

Plank Depth As an initial guide, the load-span graphs (**Figures 1, 2, 3 and 4**) may be used to determine a likely plank depth. Deflection limits are usually considered as:

- floor slabs; the ratio of span to overall depth is usually in the range of 35–40
- roof slabs; in the range of 40–45 and
- for handling purposes the span to depth ratio should not exceed 45.

Where deflection is likely to be more critical ie. machinery, sustained live loads, plank thickness may need to be increased. High fire rating requirements increase cover, reducing the effective depth of the plank and hence may require increased plank depth.

Design Requirements The design of hollow core floors is generally undertaken in two stages; firstly a Preliminary Design when the general layout, the overall dimensions of the plank and the typical details are selected to suit the building requirements, and secondly a Final Design when the details of the planks – strand patterns, connections, embedded items are decided and the shop drawings produced.

The preliminary design is carried out by the Structural Engineer responsible for the project and is incorporated in the contract documents. Where the detailed final design is left open for the Manufacturer by way of a performance specification, the Structural Engineer must provide on the general arrangement drawings full details of the design criteria so that a plank designed to these criteria meets the requirements of the structure. These criteria include vertical loads and lateral forces to be resisted, interface with other construction materials and building elements and the forces to be transmitted through connections.

The manufacturer usually advises the most economical connection type and details the items to be embedded in the planks. The remainder of the connection to the supporting member should be detailed in the contract documents. In this way the scope of work and extent of items to be provided by the Manufacturer and by the Builder is clearly defined.

The Structural Engineer is responsible for the checking of any Manufacturer's calculations and for the review and approval of the shop and erection drawings. The Structural Engineer should ensure that these drawings comply with the intent of the design and that the proper design loads, connection details, fire rating and openings have been provided for.

The Architect reviews the shop drawings to ensure that the geometry and details are compatible with the final architectural drawings.

Load Distribution Hollow core planks are usually designed as simple one way spanning slabs. When the planks are installed and the keys grouted the individual planks act together and transfer forces from one plank to another. Frequently hollow core slabs are subject to non-uniform loading in the form of concentrated

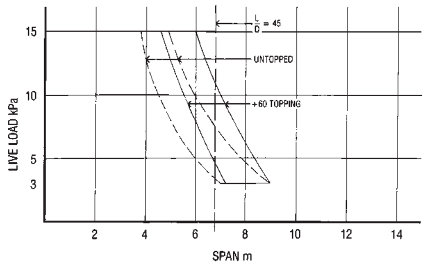


Figure 1 *150 plank*

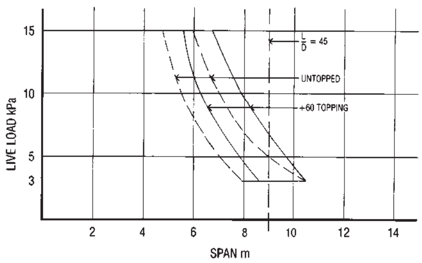


Figure 2 *200 plank*

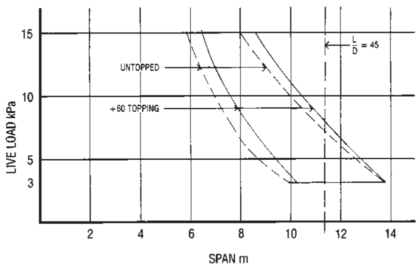


Figure 3 *250 plank*

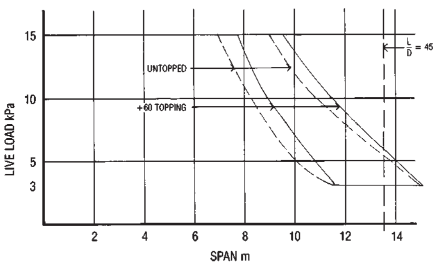


Figure 4 *300 plank*

	Fire Resistant Period (minutes)					
	30	60	90	120	180	240
Effective thickness (mm)	60	80	100	120	150	170
Concrete thickness between cores and between cores and exposed surface (mm)	25	25	25	25	30	34
Required cover (mm)						
Simply supported span	20	25	35	40	55	65
Continuous span	15	20	25	25	35	45

loads, live loads or load concentrations at openings. The interaction between the planks allows these load concentrations to be shared by several planks.

The ability of planks to distribute loads has been demonstrated by full scale testing and explained by a combination of shear stresses induced in the grouted keyways and by transverse bending in the planks. For design purpose an effective load resisting width can be used to calculate design bending moments and shears. This effective width depends upon the span and is illustrated in **Figure 5**.

This concept of an effective width can be used to account for the effect of items such as masonry partitions, local equipment loads and openings in slabs.

Continuous Spans Hollow core planks usually have a reinforced topping. Continuous spans can be obtained by designing reinforcement in the topping or the grouted cores or keyways to resist the calculated negative moments at the supports.

The choice between a simple span and continuous design depends upon the relative economics of the two systems. Usually the prestressing strand is more cost effective than normal reinforcement in resisting bending stresses so a simple span arrangement would be adopted. Where reinforcement for structural integrity ties or shrinkage control is placed in the topping its negative moment capacity is low so the plank should usually be designed for the full simply supported positive moment.

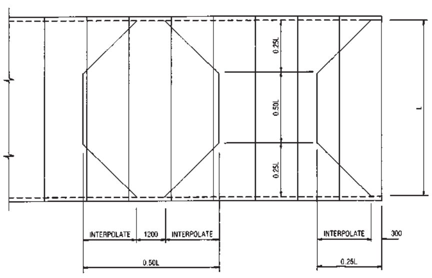


Figure 5 *Effective width for load distribution*

Preliminary Design Check List

1. Determine a feasible arrangement for columns, walls and beams. Note preferred options for structural efficiency.
2. Establish the basic design data:
   a) Occupancy of the structure
   b) Fire rating (building regulations)
   c) Sound transmission class (building regulations)
   d) Exposure classifications and durability requirements (AS 3600).
3. Determine the minimum slab thickness from step 2(b) and (c) and the minimum concrete strength and cover from step 2(b) and (d).
4. Select a suitable overall depth of plank and topping to satisfy deflection control from the guideline values.
   Typical Span/Depth Ratios are:
   Floors 35–40
   Roofs 40–45
5. Determine the dead and live loads (AS 1170). Note: Special loads such as masonry partitions, wheel loads, machinery vibrations and construction loads should be considered separately.
6. Check the strength capacity of the plank from the preliminary selection graphs Load v Span in **Figures 1 to 4**.

Fire Rating The fire rating or fire resistance period of a floor is specified in the building code as the period in minutes during which the floor must retain its structural adequacy, integrity and insulation when subjected to the standard fire test.

The Concrete Structures Code AS 3600 specifies the design for fire resistance to be met either by testing or calculation or by proportioning members to comply with certain rules.

In practice the deemed to comply rules are adopted usually as a convenient method of compliance. Two criteria must be satisfied.

- Insulation requires a minimum effective thickness of concrete and a minimum thickness of concrete between adjacent core and between a core and the exposed surface.
- Structural Adequacy requires a minimum concrete cover to the strand.

The deemed to comply requirements of AS 3600 are summarised in the **table** above.

Proximity to cores and difficulty in ensuring full bond make strand covers in excess of 45 mm undesirable. Continuity should be seriously considered when fire resistance periods of 3 hours or more are required. It is good practice to locate the strands in the flange section, not in the web or near the web-flange junction. For the purpose of fire rating, a slab is considered as continuous if under imposed load it is flexurally continuous at least at one end.

For a hollow core plank the effective concrete thickness is taken as the nett cross sectional area divided by the width of the cross section. If the effective thickness of a plank is not sufficient to achieve the required fire rating, this can be increased by either providing a concrete topping or an insulating layer to the soffit.

The equivalent thickness of a hollow core plank depends upon the size and spacing of the cores. As these vary with the particular machine there are some small differences in the deemed to comply fire resistance levels of the planks provided by different manufacturers. In practice these differences tend to be significant only for the higher fire ratings and for planks that are not topped. As a concrete topping is frequently provided for fire rated planks, the higher ratings can be met by all hollow core products without difficulty.

For untopped planks the grouted joints have been shown by fire tests to provide a fire resistance level at least equal to that of the plank section.

If the required cover to the strand results in an inefficient design for the specified load capacity, this can be overcome by applying an appropriate thickness of insulating material to the soffit.

Sound Insulation Hollow core floor planks can provide high levels of acoustical resistance to both sound transmission and impact noise. One important parameter which is used to measure the resistance of a material or system to sound transmission is the Sound Transmission Class rating. The larger the value of STC the greater the sound insulation.

Building codes specify minimum value of sound insulation for floors and walls separating different occupancies in residential buildings. A floor separating flats must have an STC not less than 45. A 100 thick concrete slab without joints is deemed to comply with this rating. A 150 hollow core plank untopped with grouted joints also meets this requirement. ■

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PRECAST Floors 3

HOLLOWCORE PLANKS are compatible with most structural building materials and methods. Economic advantages can be obtained by designing to accommodate the 1.2 or 2.4 m modular plank width. Typical construction details include:

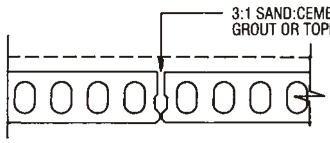

Figure 1 *Grouted shear key*

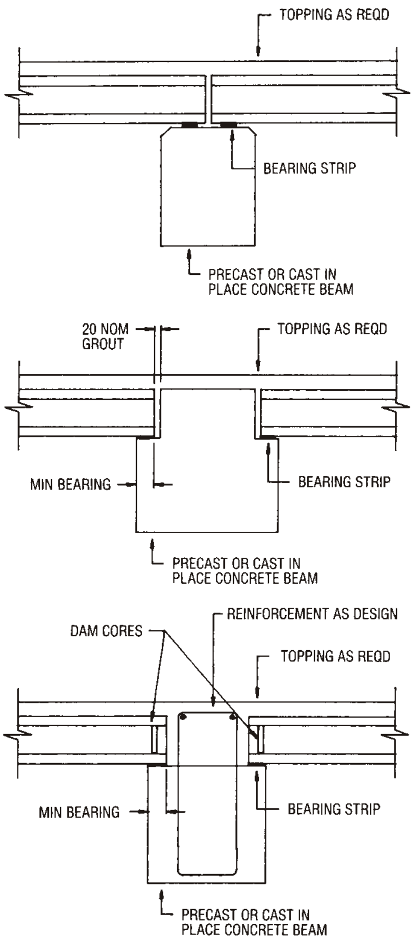

Figure 2 *Typical bearing connections to concrete beams*

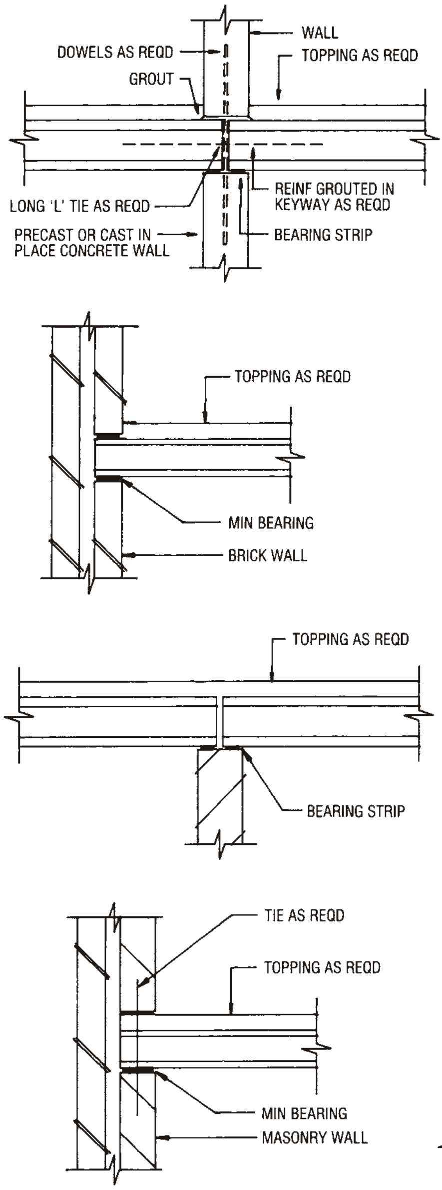

Figure 3 *Typical bearing to masonry walling*

Table 1 Recommended Minimum Bearing (mm)

Plank Thickness	Minimum Bearing (mm) Concrete/masonry	Steel
150, 200	80	70
250, 300	120	100

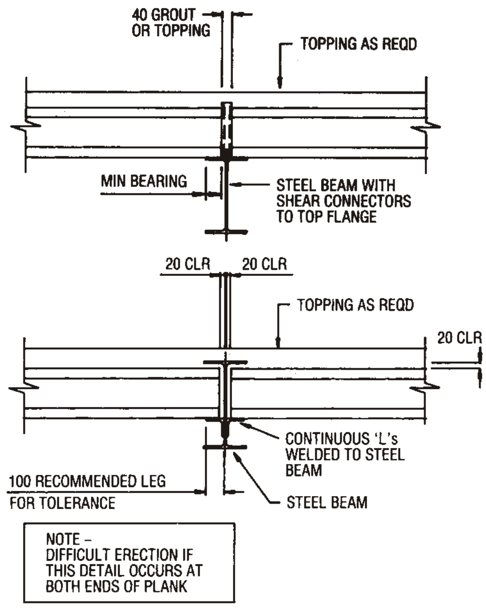

Figure 4 *Typical bearing to steel beams*

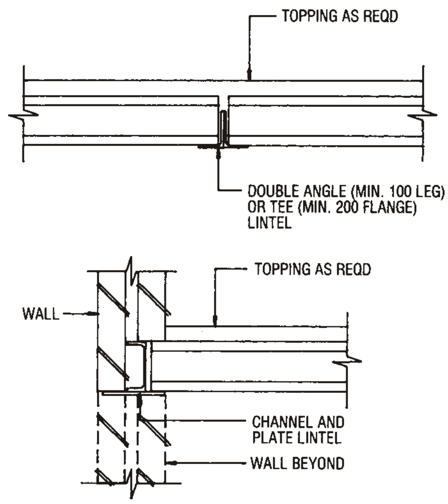

Figure 5 *Typical bearing at lintels*

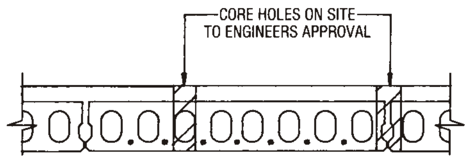

Figure 6 *Core holes locations*

Forces acting at an interface between hollowcore planks and the bearing material are specified by the design structural engineer. Detailing of the connection is generally performed by the manufacturer.

Connections should allow for the volume change movements that normally occur in precast elements. Cracking or spalling may result if such movement opportunity is not provided.

Detailing for minimum bearing widths, grout clearance etc should allow for realistic tolerances of construction.

Hollowcore plank tolerances are shown in **Table 2** below.

Table 2

Length	+10 mm	–10 mm
Width	+3 mm	–6 mm
Thickness	+3 mm	–3 mm
Squareness at ends	+6 mm	–6 mm
Wind	10 mm per 3000 mm	
Location of strand	+3 mm	–3 mm
Differential camber between adjacent units	2 mm/m span but not greater than 15 mm	

Irregular bearing surfaces should be provided with a bearing strip, set back from the edge of the support.

Planks supported on masonry walls require a bearing strip or slip joints to separate the different materials and prevent cracking or spalling of the brickwork. Rendered walls and cornices should be detailed to permit some movement in accordance with good building practice.

Steel beam supports may be detailed for separate or composite action depending on the design requirements. If the overall depth of construction is critical, support angles may be welded to the web thus reducing the floor depth. Note that clearances are needed between the planks and beam for satisfactory erection and this arrangement should not be used at both ends of the planks. Bolted splices in steel beams should be detailed so that they do not interfere with the bearing of the planks.

Planks are often topped to increase the structural capacity of the floor. This also provides a convenient means of levelling the top surface, dealing with set downs for floor finishes and removing the effects of camber. Contraction joints should be provided at regular intervals and at the ends of planks to control shrinkage cracks.

Where untopped planks are used care is required in setting the level of supports and in selecting planks to reduce the effects of differential camber between units. Structural integrity ties may be required in both longitudinal and transverse directions. These may be bar or strand grouted into keyways or joints at the ends of planks, in which case care is needed in setting out the planks to ensure that the keyways line up.

Where concrete or masonry walls continue over the floor planks and a topping is provided there are two options for the construction sequence. The topping may be placed prior to erecting the wall over so that it is continuous throughout the floor or the topping may be placed after the wall is erected in which case it will be interrupted by the wall. The choice depends on both design and construction factors.

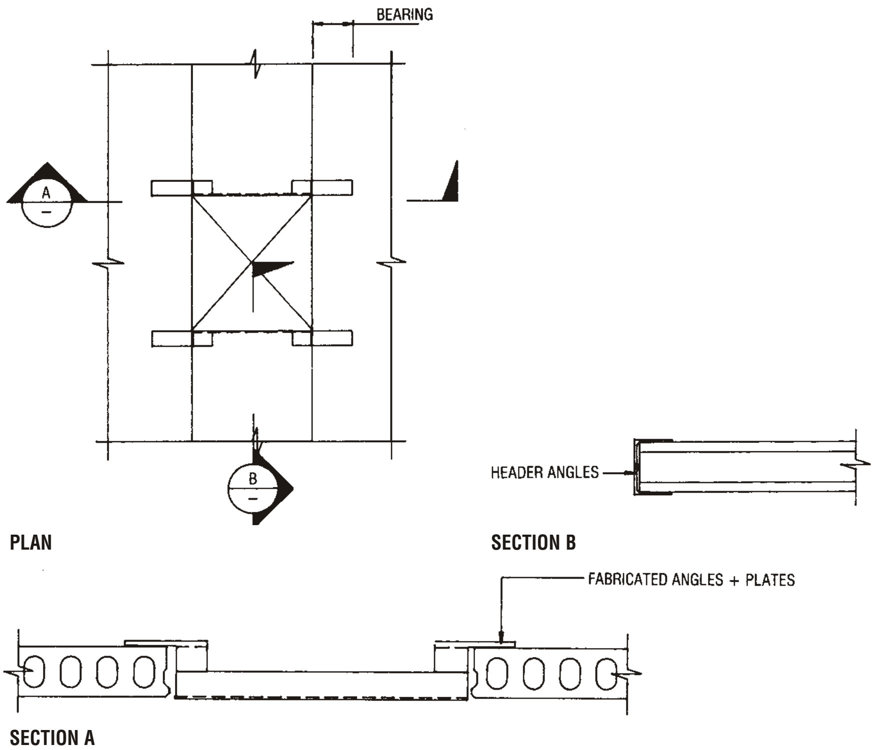

Figure 7 *Framing larger openings*

Erecting 200 mm 8 m span hollowcore planks on loadbearing blockwork at a townhouse development in Braddon, ACT

Where cantilevers are required care is needed in both design and construction to avoid overstressing and possibly cracking the planks at the support. Both the construction loads and final service loads should be considered. Some temporary propping may be required.

Penetrations and blockouts in planks should not cut through the strand unless this has been allowed for in the design. Any coring on site should be restricted to defined parts of members. Where large penetrations are required full width headers may be used to support the end of a plank and transfer the load to adjacent planks which are designed for the additional load.

Fixings and support hangers should be installed strictly in accordance with the manufacturer's directions. Where heavy loads require support, through bolts should be used to provide the necessary security.

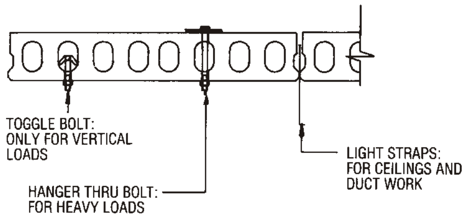

Figure 8 *Typical hanger arrangements*

Summary Given adequate design and documentation and with early dialogue between client and manufacturer, hollowcore planks can regularly be delivered to site within a week of a firm order.

Placement rates of 600–1000 m^2/day are attainable significantly reducing construction time.

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Semi-precast panels being placed on site

SEMI-PRECAST Floors 4

This is the fourth in a series of articles covering available precast concrete solutions for floors. This article outlines the basic design principles for 'semi-precast element floors' with special consideration to correct detailing for earthquake design.

THE SYSTEM

The semi-precast element floor has been widely used in Europe and elsewhere for over 40 years. Overseas trends indicate that this precast flooring system is a favoured method for construction of suspended concrete slabs and in some parts of Europe it accounts for 60% of all suspended work reaching production rates of 80 million square metres per year. In Australia this type of flooring (known as Transfloor or HumeSlab) has been in use since 1982 and offers many advantages over cast insitu floors while maintaining the full structural integrity and monolithic requirements of the slab.

The system uses a combination of precast reinforced concrete panels and poured insitu topping as a means of constructing suspended concrete slabs. Wire trusses and all of the bottom reinforcement is embedded in the precast panels while the top reinforcement is included on site. The use of site-placed reinforced concrete effectively ties all the precast elements together providing safety, rigidity and structural redundancy.

DESIGN

The structural design of precast concrete floors should not only deal with the calculation of bending moment and shear force capacity of the separate units, but also with the total coherence of the floor. In the final stage, the individual components should be connected in a manner that ensures adequate overall capacity with interaction between the units and the supporting structure.

Design for Bending Accepted principles of Ultimate Strength Theory apply to the design of precast element floors since the finished slab can be considered as monolithic.

The system is usually designed to span uniaxially (one-way action), however, two-way action can be achieved by omitting void formers and placing additional bars on top of panels in the transverse direction.

In a uniaxial design the precast panel contains all of the bottom reinforcement required in the final design. This will consist of a light fabric, truss bottom chords and additional bar reinforcement (**Figure 1**).

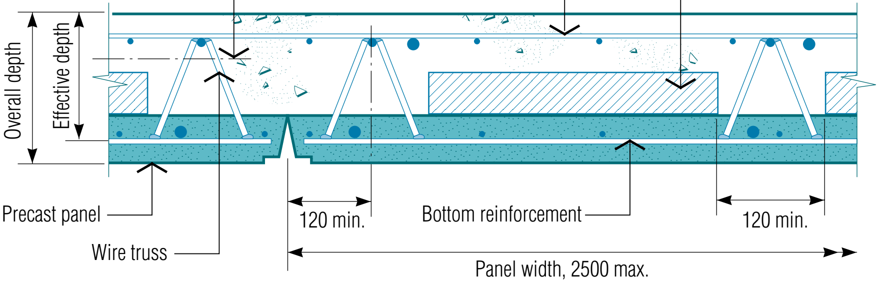

Figure 1 *Typical slab cross section*

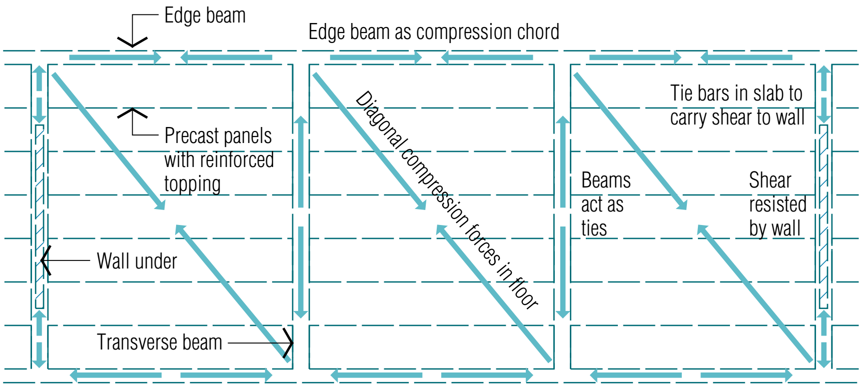

Figure 2 *Actions in a diaphragm (Strut and Tie Model)*

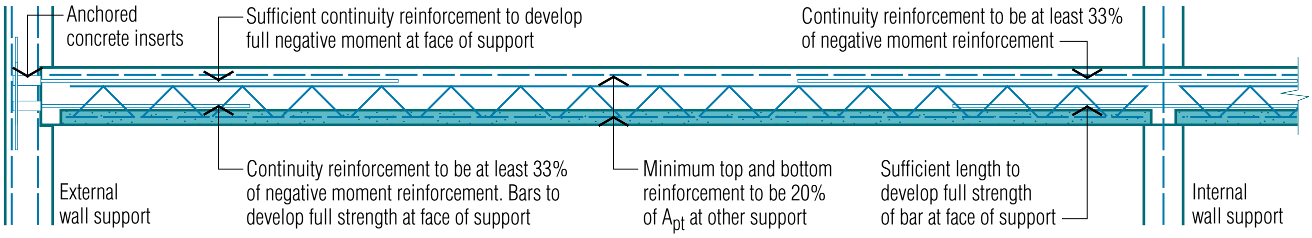

Figure 3 *Typical slab reinforcement details for earthquake loading (AS 3600)*

Precast/insitu Interface The required capacity at the interface can be calculated in accordance with relevant design codes. The level of surface roughness is somewhat open to interpretation but can be considered as rough with small ridges and undulations. The surface roughness achieved during the casting process is satisfactory when, at the same time, truss web members are used as shear plane reinforcement.

If an intentionally roughened surface is specified, care should be taken not to disturb the grain structure of the concrete or dislodge aggregates near the surface. A light broom finish is all that is required.

Vertical Shear If a voided slab is used the shear forces can only be carried by the concrete in the rib sections. Voids must be terminated in regions of high shear (at supports and point loads) and will generally not be included within one slab depth from the section at which the ribs are just sufficient to resist the applied shear.

The overall slab thickness is not normally controlled by shear strength requirements but, when required, the diagonal wires of the trusses may be treated as inclined stirrups provided the pitch of the wires does not exceed the depth of the slab, trusses extend through the full slab depth and truss spacing does not exceed the recommended stirrup spacing given in AS 3600.

Support Conditions The correct detailing of precast concrete involves consideration of the design, manufacture and construction requirements at the start of the project. It is important to consider detailing during the early design stages so as to obtain the full benefits of any precast system.

As with insitu floors, when designing composite precast element floors attention must be given to anchoring of reinforcement at the supports. Reinforcement end details are specified in the relevant design codes and the amount of reinforcement to be carried into the support will depend on the end restraint condition.

Connections between composite precast element floors and supporting members present few problems since continuity can be provided by lapping the panel reinforcement with bars projecting from the supporting beams or walls (**Figure 3**).

SEISMIC CONSIDERATIONS

Seismic considerations for precast element floors will follow the same design rules as for insitu floors but will require adequate detailing to achieve seismic integrity at the connections. The main criteria to consider is:

- Maintain structural integrity without collapse of all or a significant part of the structure.
- Achieve ductility of both precast elements and their connections.
- Provide structural continuity.

Transfloor panels connecting into a load bearing wall

Structural Integrity It has generally been found that insitu floor slabs acting monolithically with supporting beams are very capable of transmitting lateral forces unless the number of large openings is excessive. Precast element floors, acting monolithically, will adequately transmit lateral loads through diaphragm action. The strength and ductility of the overall structural system will depend on the integrity of the jointing details and in particular, the connections between the floor (horizontal diaphragm) and the supporting structure.

The majority of reported damage caused to precast construction during earthquakes is confined to the joints and connections and can be summarised as follows:

- Failure of connection between wall panel and roof system resulting in roof failure, tilting of wall panels and increased stresses in the lower level floor connections.
- Failure of connections between wall panels and the floor system.
- Flexibility of thin cast in place topping slab that forms the horizontal diaphragm causing overstressing and cracking resulting in separation from the precast elements.

The 1988 earthquake in Armenia highlighted some of the problems caused by inadequately detailed precast construction. A common form of construction for the medium rise residential buildings was to use precast concrete panels or frames for the vertical elements and precast concrete floor planks without the addition of a topping slab. These precast systems performed poorly due mainly to the inadequate provision of viable load paths and inadequate tying of the horizontal floor planks to the vertical elements and to each other for effective diaphragm action.

Diaphragm Action Horizontal loads from earthquakes are usually transmitted to the vertical cores or shear walls by the roof and floor acting as horizontal diaphragms. The floor can be analysed by the strut and tie method or by considering the floor to act as a deep horizontal beam. The central core, shear walls or other stabilising components act as supports with the lateral loads being transmitted to them as shown in **Figure 2**.

As stated by Clough (*Considerations in the Design of Precast Concrete for Earthquake Loads*, PCI Journal, vol 27), 'In zones of high seismic intensity, or with configurations which impose large in-plane compatibility forces under lateral load, diaphragms joined by cast in place reinforced concrete, usually are satisfactory'. It is essential to ensure that the topping is adequately bonded to the precast elements such as in precast element floors where the topping is bonded by mechanical connectors (wire trusses as in plane reinforcement). Without adequate bonding separation can occur and the topping may buckle when subject to diagonal compression from diaphragm action.

Detailing for Seismic Loads Designers should ensure that not only is there an adequate load path for the forces that need to be transferred between the diaphragm and any lateral force resisting elements, such as walls or frames, but that connections are detailed such that they adequately transfer the anticipated loads.

The comments in this section relate to 'Intermediate Moment Resisting Frames', defined in AS 3600 as moment resisting frames of ductile construction, complying with the additional requirements of Appendix A in AS 3600. The intent of these special detailing requirements is to improve the ductility and reduce the vulnerability of concrete structures in a manner consistent with the relatively low seismic hazard in Australia (**Figure 3**). ■

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