PART VI.
SPECIAL CONCRETE APPLICATIONS

PRECAST CONCRETE

CEMENT CONCRETE
& AGGREGATES AUSTRALIA

This Section discusses precast concrete – a very broad topic. The variety in just the structural applications of precast is quite extensive and includes bridge beams, wall panels, precast columns, piling, culverts, road barriers, tanks, retaining walls, pipes, paving slabs, stormwater management devices, manholes and many others.

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In terms of broad categories, precast is probably best separated into three main areas – structural precast, architectural precast and hollow-core. This categorisation still leaves products like concrete pipes which arguably sit outside the three broad, general categories. By the simplest definition, precast concrete elements are ones which are cast in positions or locations other than where they reside in the final structure. In practical terms this means that they are cast either in a factory or in a yard near (ideally) to where they will be used. This also means that the precast element needs to be moved to the actual construction site and then lifted into place by a crane or some other system. This method of construction has both benefits and risks, and these will be described in some detail in appropriate parts of the discussions following. There is some overlap between this section and other sections in this Guide document and these will be highlighted in the various discussions. Without doubt, there has been (and is) a desire in building construction to reduce costs and to de-clutter construction sites to improve efficiency and safety and importantly, environmental performance. Precast concrete contributes to these aims and will (arguably) continue to grow in importance as a concrete construction method of choice for these and other reasons.

1. HISTORY

Precast concrete use arguably began with the Romans. They used concrete widely throughout Europe, and in some cases, this involved them casting concrete into moulds for the construction of aqueducts, culverts and tunnels. It is generally considered that the first use of a modern 'precast' concrete system may have been by W.H. Lascelles in the UK in about 1875, who introduced a new and innovative housing system [1]. Australia was an early adopter of all things concrete, including precast concrete. The history of Australia's early precast concrete use is described in the NPCAA's *'Precast Concrete Handbook'* [2]. Some of these early and developmental uses included:

- In 1904 – the Bradley's Head lighthouse (Sydney) used precast piles to support four precast shell sections that were filled with mass concrete. It is still in use today (**Figure 20.1**);
- In 1908 – a fully-precast trestle wall system was built at Miller's Point Wharf (Sydney) (**Figure 20.2**);
- In 1910 – centrifugal-spun reinforced concrete pipe was invented by W.R and E.J Hume;
- In 1910 – precast concrete was used in the construction of the Denny Lascelles Austin Wool Store in Geelong;
- Between 1917 and 1932 – the NSW railways department built about 145 railway stations and other buildings using precast;
- In 1946 – Monier (a company previously formed under another name) used hollow precast panels (the Monocrete system) for the construction of houses, schools and other buildings;
- In 1952 – a precast, post-tensioned frame was used for the construction of the Warragamba Ice Tower;
- Throughout Australia, names like Monier, Humes and Rocla were expanding the use of precast concrete in a wide range of applications.

Figure 20.1 – Bradley's Head Lighthouse, built in 1904[20.1]

After the early forays into general precast concrete construction, precast entered the market as a component of housing and large commercial and residential buildings from the 1960's and 1970's – depending on which State being considered. The use of precast concrete panels in the iconic Sydney Opera House (completed in 1973) provided an example of its versatility and architectural applicability. The huge subsequent expansion of architectural applications and the advent of hollow-core systems have further enhanced the reputation and scope of precast concrete applications.

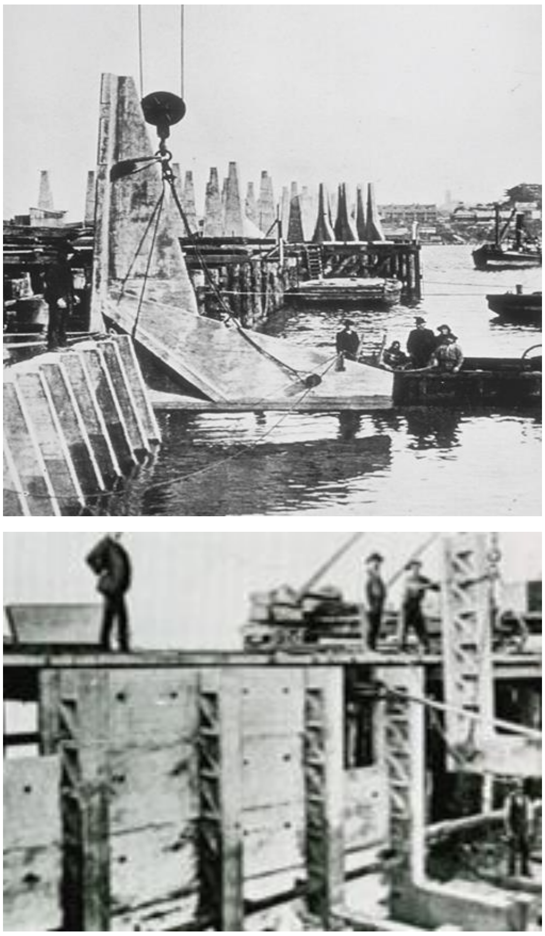


Figure 20.2 – Millers Point Wharf, built in 1908

2. MANUFACTURE OF PRECAST CONCRETE

2.1 GENERAL

Precast concrete elements are, effectively and by definition, elements that are manufactured remotely from their final position in a structure. In some cases, the elements (e.g. bridge beams) may be produced hundreds of kilometres from their final location, while in other cases (e.g. tilt-up panels) they may be cast only metres from their final destination. While these are broadly similar situations, in practice they reflect quite different circumstances and require different approaches. The discussion below aims to provide an overview of the important topics involved in manufacturing and using precast concrete. It is important to note that precast concrete applications are not limited to any single element of construction but can be applied in an integrated manner (**Figure 20.3**) to create highly robust structures for most building applications. The variety of potential end-uses of precast concrete are such that it is difficult to adequately cover them all in a single document.

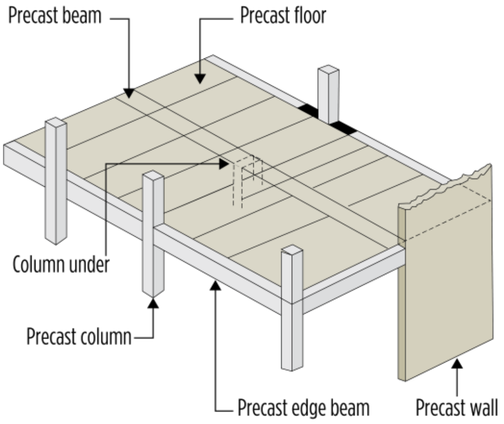


Figure 20.3 – Building Structure using Integrated Precast Elements

2.2 FACTORY PRODUCTION OF PRECAST

The factory production of any item allows for much higher levels of control over production than are able to be achieved 'on-site'. It also allows for a much wider range of production options – options that can be optimised depending on the type and number of elements being produced. In planning for the production of precast concrete, consideration needs to be given to things like (a) the size of the element(s), (b) the required rate of production (e.g. this differs for railway sleepers and bridge beams), (c) the availability of (and need for) steam curing, (d) reinforcement requirements, and (e) the need for prestressing. These issues are also affected by (a) the size, layout and location of the factory, (b) the skill levels in the workforce (for both design and concrete placing and finishing), (c) the level of automation available, and (d) the availability of concrete supply (e.g. capacity of in-house production or availability and cost of external supply). The manufacturing of precast concrete elements is a highly competitive market and a strongly regulated one if attempting to supply to Government agencies.

Good planning, good management and a high level of technical skill are fundamental to success in this industry.

The concrete mix used is typically intended to achieve high strengths, often at least 65 MPa. While ideally (to achieve early and rapid strength gain) cement-only mixes would be used, concerns about durability (particularly ASR), heat of hydration and (more recently) environmental issues means that the use of SCM's is not only routine, but is mandated in some cases. While this has some implications for the rate of strength gain, there are benefits to be had in terms of improved workability, however this is less critical with the advent of modern admixtures – most particularly the use of PCE-based HRWR and MRWR admixtures to produce flowing concrete with low W/C ratios. Increasingly, flowing concrete is used in precast manufacture, and its importance has grown due to the need to overcome problems related to the noise associated with compaction of concrete as well as issues related to congestion in highly reinforced elements and also to ensure the high levels of compaction needed to achieve (a) required strength performance and (b) high levels of durability.

To increase the rate of strength gain steam curing is often used. Steam curing, if properly managed, produces concrete strength sufficient to permit daily production turnaround to be achieved without (a) unnecessary damage to the concrete element and (b) increasing safety risks when lifting the element. Steam curing is applied in a defined sequence that must be observed to achieve optimum strength performance. By its very nature, steam curing results in lower 28-day strength of the concrete than that achievable when curing at ambient temperatures using the same concrete mix – although the amount of strength loss can be minimised by managing the steam curing regime.

Steam curing is carried out as a four-phase operation. The four phases are known as (1) the delay or 'preset' period, (2) the temperature-rise period, (3) the steaming period (which includes 'soaking' at maximum temperature), and (4) the cooling period. The delay period is important – without it, final concrete strengths can be severely compromised. The extent of the delay period is dependent on a number of factors including the size and shape of the element, the cement content of the concrete mix and the type of cement being used. The temperature-rise period also needs to be managed carefully – with larger elements requiring slower heating to prevent large temperature gradients (and resultant stresses) developing in the element. Typically, the rate of rise is about 20°C ± 5°C per hour. If the temperature rate of rise is too great, then there is potential for localised (surface and test specimen) over-heating and this can affect the 28-day strength. For both technical and economic reasons, a balance needs to be achieved between peak temperature and cycle time. High temperatures (>70°C) are also associated with the potential development of Delayed Ettringite Formation (DEF) which is an expansive reaction that can occur in hardened concrete and which can result in severe cracking at later ages. The steaming period is typically maintained for periods in the order of 12 hours. The last phase of the steam curing cycle is the cooling phase. Controlled cooling is more critical for larger elements as thermal cracking can occur with poor control. For some large elements covers are required after stripping until (nearly) ambient temperatures are reached in order to prevent thermal cracking. After precast elements are cooled, they may be wet cured to improve/maximise strength performance – though this is not routinely done.

***NOTE**: To monitor or check strength gain performance the concept of 'maturity' is often used. A 'maturity' value is calculated as the product of temperature × time (i.e. °C × hours) and strength performance for a given mix and curing chamber can be calibrated against 'maturity'. Similarly, the effect on strength performance of changes to elements (temperature and time) of the steaming phases can be assessed.*

Formwork for precast varies with the nature of the end-product. In a factory environment where standardised elements are produced, steel formwork is used to allow repeated use of the forms which provides cost effectiveness. Where beams or columns specific to a particular building design are being cast, the formwork may be for one-off use and in this case, timber is more likely to be used to construct formwork as it is of low cost and more readily able to be purpose-built.

Many precast items are also prestressed – a process that is relatively easy to carry out in a 'factory' environment. Precast railway sleepers are invariably pre-tensioned (see Part I *'Principles of Plain, Reinforced, Pre-stressed and Fibre Reinforced Concrete'* in this Guide) and almost always steam-cured. They are typically de-tensioned in a controlled manner after overnight steaming – provided strength test results on cylinders subjected to the same curing regime meet quality requirements. Sleepers are routinely produced in high-throughput systems and being highly standardised items, are eminently suitable for factory precast production.
*(**NOTE**: In some modern plants, steam curing for railway sleeper production is no longer practised as some modern concrete mixes are able to achieve required strengths in a reasonable time without using external heating.)*

In a factory production environment, there is an expectation from engineers and end-users that high levels of product quality will be achieved. To consistently achieve high quality there needs to be a high level of attention to detail. Between castings, moulds must be checked for damage and rigorously cleaned to ensure finish quality is high. The dimensions of these highly engineered elements need to be checked before each pour, including checks on adequacy and placement of reinforcing. Tendons need to be properly tensioned and de-tensioned, and in the correct order. Concrete mixes need to be tested and strength performance monitored at the end of the construction cycle to ensure that the element is able to be safely lifted. Concrete workability needs to be suitable for the element design so that the concrete is able to be placed (around reinforcement and into tight corners) and compacted to achieve the required finish and strength and durability performance. For major projects where precast elements need to be properly sequenced into the build, a suitable identification system must be maintained so that elements are delivered to the job in the correct order for erection.

2.3 TILT-UP PRODUCTION

Tilt-up, which began in the USA, was first introduced into Australia in the 1960's, but did not gain prominence until about the 1980's. Its use is mainly for panels used in low-rise structures and was initially primarily used in industrial situations. This has now changed and tilt-up is now being used in new markets for the construction of residential housing, for schools and in a range of non-commercial applications.

Tilt-up panels are usually cast 'on-site' or adjacent to their final location and consequently do not need to be transported from a factory. They are lifted into place by crane, and this can be done in an efficient way by casting multiple panels at the site and erecting these simultaneously while the crane is available. Panels do not need to be solid concrete facades but can include allowances and rebates for windows and doors as required in the final structure.

A tilt-up panel or panels can be cast onto a base slab, singly or stacked in layers, with the top surface of each layer being coated with a bond-breaker (sometimes these include a curing compound) to allow removal of the upper panel when required. Panel quality is important, especially where multi-storey structures are involved. Panels need to be accurately sized and square and tight manufacturing and building tolerances apply. Panel finish is also important. Even for industrial buildings, variable panel colours and textures and mottled finishes create complaints. Once stood in the final structure even small variations in colour and finish within and between panels become very obvious. The colour variations will often diminish over time as the concrete ages, but when the building is first erected, colour contrasts are immediately apparent. While arguably one of the advantages of using tilt-up is that it does not require a factory set-up and also does not require highly skilled workers, the quality expectations in terms of both concrete performance and appearance mean that poor quality work will generally not be accepted.

If decorative or architectural requirements exist there are a number of techniques used to improve panel appearance (see sub-section 4). Exposed aggregate, colour and texture contrasts and grooves and shallow recesses can be used to enhance surfaces or break up monotonous (grey) concrete surfaces. These effects can be achieved in several ways – by using coloured concrete; by applying various texturing processes; and by placing strips on the slabs on which the panel is being cast to provide shallow recesses to break up the 'plain concrete' facade.

When designing and building with tilt-up, the location and detailing of services and joints is of great importance in ensuring that both the buildability and effectiveness of the structure are maximised. Joint widths must allow movement due to thermal changes and be sufficient to cater for erection tolerances. Reasonable widths between panels are typically 15-25 mm. Sealants are used to fill the joint and to allow for movement in the structure. The sealants are of limited depth and are bonded only to the two sides of the joint, which necessitates a clean, well compacted concrete surface on each side. At the corners of tilt-up buildings special care is required. 'Over-sail' joints or mitred joints can be used, but mitred joints require extra care during construction as they are more prone to breakage during lifting and placing of the panels (**Figure 20.4**). Erection tolerances can be absorbed in the joint gaps and the design joint width must be sufficient to absorb them.

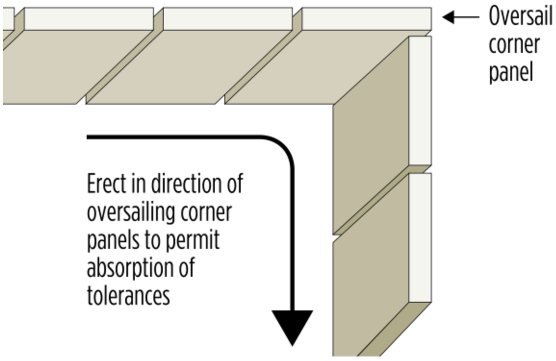


Figure 20.4 – Over-sail Joint used in Tilt-up Panel Construction

As noted, when panels are cast, either singularly or in multiples, a bond-breaker is used to allow individual panels to be separated and erected once the required strength has been obtained. These bond-breakers not only allow concrete panels to be separated but will also prevent coatings (e.g. paint or render) from adhering to the surface. If such coatings are required, then any residual bond-breaker must be removed before the coating is applied. If not, the coating will generally just 'sheet-off' in due course.

Panels will invariably have 'lifting lugs' inserted in them to allow them to be moved into final position by crane. For aesthetic reasons these lugs will need to be removed or coated/covered in the final structure.

Panel lifting is a critical activity and it is necessary for the panel to be of sufficient strength for the lift to occur safely. The lift may need to occur before 28-day strengths have been achieved and if so, consideration must be given to the 7-day minimum strength requirements of AS 1379. If these strengths are insufficient then a Special Class concrete with a specified 3-day or 7-day strength may be required, as may project testing to confirm that the required strength has been achieved before attempting to lift the panel.

Concrete used in these panels must meet the durability requirements described in AS 3600. Their thickness also needs to be such that appropriate fire-rating requirements are met. Insulation can also be provided to accommodate concerns or issues about thermal and/or acoustic performance. Insulation may be used to overcome any concerns about condensation within the building.

3. STRUCTURAL PRECAST CONCRETE

3.1 GENERAL

Structural precast concrete includes elements like beams and columns for bridge and building construction, bridge deck slabs, wall panels, retaining walls, lift wells, stair wells and stair units and others. In many of these applications, the element would previously have been cast on-site with the need for extensive formwork, large labour force, delays while concrete gained strength (which inhibits the activity of following trades) and increased safety risks due to (a) the higher level of activity on the job site and (b) clutter due to the presence of formwork and falsework.

Using factory-made precast elements (a) allows greater accuracy levels in the element to be achieved, (b) provides high levels of certainty about concrete quality, (c) results in fewer site delays as the precast element can be delivered to site when actually required without concerns about weather delays etc., and (d) lower safety risks. There are also indirect benefits through lower levels of waste and less raw material movement on site. In some cases, stronger (prestressed) precast elements allow the use of thinner elements which results in less concrete being used and therefore overall environmental performance is improved through 'dematerialisation'.

There is a wide variety of structural precast elements in use, with the main groups being (a) beams and girders, (b) columns and (c) wall panels. Some of the types of each and their primary uses are discussed in the following.

3.2 BEAM AND GIRDER TYPES

Some of the most common beam and girder types are:

Tee Beams – These beams may be obtained in either single or double-tee configurations and provide a very efficient structural shape (**Figure 20.5**). These beams may be of varying widths but are typically about 2,400 mm wide. The depths of the beams vary but they are typically about 600-1,000 mm for single and 400-700 mm for double tees. They are cast in long pre-tensioning beds and the units themselves may be produced in a range of lengths – from 12-24 m for double-tees and 15-30 m for single tees. When pre-tensioning these beams with tendons that run the full length of the beam problems with over-stressing can occur and it is usually necessary to de-bond the tendons partially to reduce stress levels. Within the structure the beams are typically topped with a nominal 32 MPa reinforced screed to provide the final floor finish (**Figure 20.5**).

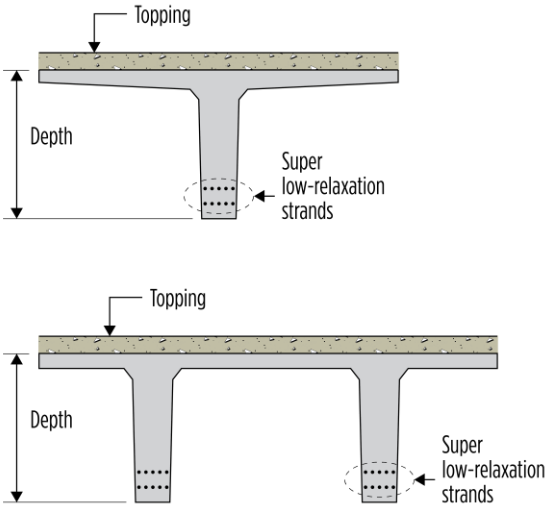


Figure 20.5 – Single and Double Tee Beams with Cast In-situ Concrete Topping

Main Beams – These beams are major structural elements and their design varies with the needs of the structure. Typical types are rectangular beams, Tee-beams, L- (or spandrel) beams and ledger (or inverted Tee) beams (**Figure 20.6**). The beams may be reinforced or pre-tensioned. The spandrel and ledger beams may be used to span clear sections and to support flooring or transverse beams.

Beam Shells – These are long, U-shaped members that contain the main beam reinforcement and that can also be used to support floor planks. They usually sit on a column and become integral with the planks and the topping concrete through the reinforcement detailing when the floor is finished (**Figure 20.7**).

Bulb Tee Beams – These are beams used in bridge construction. These prestressed beams have span widths that are typically 1,200 mm and variable depths from 1,200-1,700 mm and are used in the construction of long span (18-40 m) structures. They are topped with about 200 mm thick, high strength (typically 40 MPa) concrete to form the bridge deck.

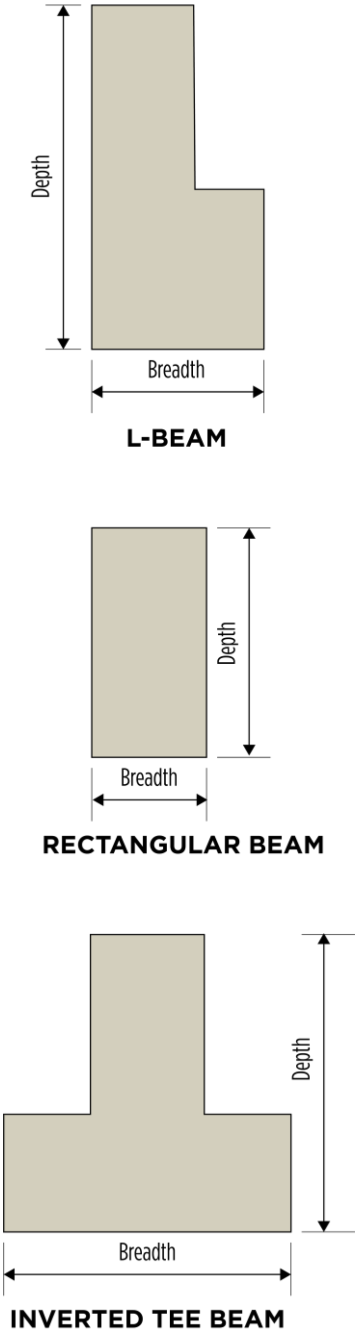


Figure 20.6 – Common Precast Concrete Beam Shapes

Super-Tee Box Girders – These are prestressed, precast girders used for bridge construction that come in two forms – 'open top' and 'closed top'. Beam widths vary from 1,800-2,400 mm and depths for both types vary from about 750 mm to 1,800 mm. They are useful for spans up to about 40 m. Concrete used for the deck should be high quality (e.g. 40 MPa) and be well placed and cured, with depths typically of 150-200 mm (**Figure 20.8**).

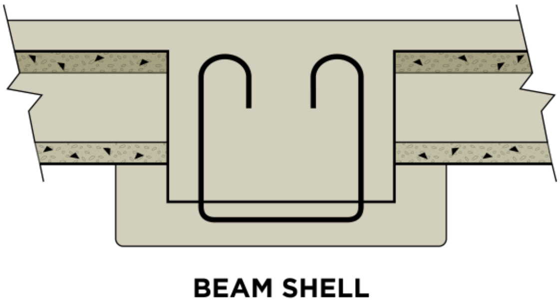
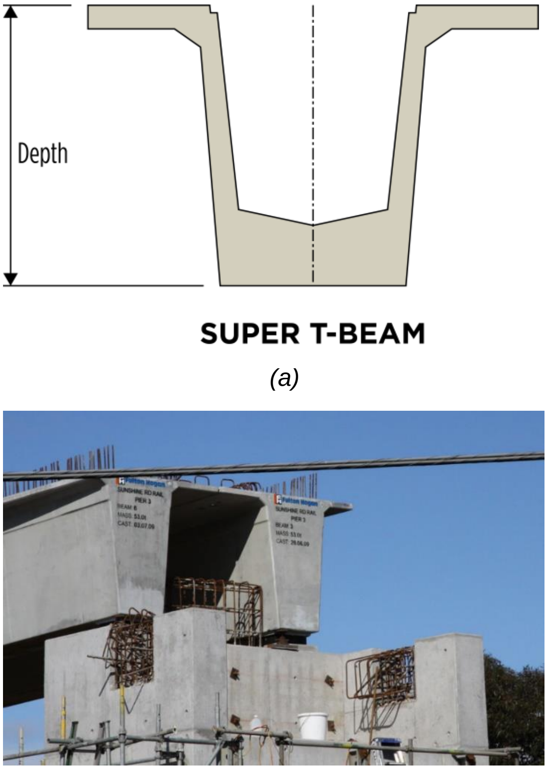


Figure 20.7 – Beam Shell – Integral with Floor Panels and Topping



(a)

(b)

Figure 20.8 – Super Tee-Girder: (a) Section; (b) In-Situ

I-Girders and Broad-Flange Girders – These are similar girder types, with the broad-flange type being effectively I-girders with extended flanges that when assembled have about a 30 mm space between the girders. They are prestressed girders using nominal 50 MPa concrete for construction. Both are used in bridge construction for bridges with up to a 30 m span, and where the concrete deck is typically about 200 mm of nominal 40 MPa concrete (**Figure 20.9**).

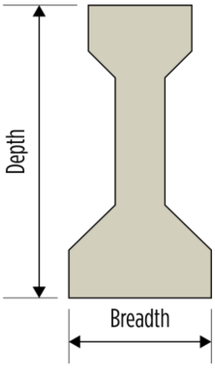


Figure 20.9 – I-Girder

3.3 PRECAST COLUMNS

Precast columns may be used in buildings constructed from precast elements or may also be used where in-situ cast concrete is being used for floors. The columns are usually cast in the maximum length able to be handled when considering (a) transport to the job, and (b) site crane capacity. Prestressing is used where appropriate to cope with transverse loads that may be encountered in the structure. If only axial loads are expected, then normal reinforcing can be used. Where additional columns are required to accommodate the height of the building, these columns are spliced to the lower column(s). Splicing is done at locations where there is minimal bending likely – this typically being between floors. These columns have the advantages of being able to be specifically designed for the building, have assured strength performance and reduce both formwork on site and construction times (**Figure 20.10**).

To anchor the columns to the base of the building several options exist. The most common is a bolted connection to a base plate that is anchored to the floor. A socket connection can also be used, where the column is grouted into a socket located in the building floor. Alternatively, the column can be connected into the base with a dowelled connector – the dowels being grouted into the base and connecting through into the column reinforcement. Splicing of columns is usually done by grouting in (up to eight) dowels that connect the two columns.

Figure 20.10 – Precast Concrete Columns supporting Structural Beams

3.4 WALL PANELS

Wall panels may be produced as conventional (factory-produced) precast concrete elements (using either reinforced concrete or prestressed concrete), as tilt-up elements (see 2.3) or as hollow-core (see 5.2) panels. The following discussion will describe the general requirements for precast concrete wall panels.

While there are advantages to using precast concrete wall panels of all types, there are also important considerations that need to be understood. As these panels are often load-bearing they need to be properly designed, and where door and window openings are included the design issues are more complex and critical. Allowance must be made in the design for the provision of services (e.g. water and power) to the final structure as retrofitting of these in the building would be problematic. The erection of wall panels is also critically important to ensure the safety of personnel on the construction site (see 7.7). Panels need to be propped until fixed into place, and the proper fixing of panels to adjacent structural elements is fundamental. The panels also need to contain embedded fixtures to allow safe lifting and to allow props to be attached while construction is progressing. These fixtures must be removed, and the area where they were located repaired in the final structure. In addition, the construction site conditions must allow for the movement of the (large) cranes which are used to stand and align the panels. From an environmental perspective, these (relatively) high strength panels and the construction method leads to them having a high level of 'embodied energy' (see Part X *'Environmental Considerations'* in this Guide).

Precast wall panels may be plain or provided with one of a variety of possible decorative surface finishes providing aesthetic/architectural appeal. The application of architectural finishes will be discussed elsewhere (see sub-section 4). Precast may also be used in the manufacture of cladding panels which primarily provide a decorative function (**Figure 20.11**). Regardless of their finish, precast concrete wall panels serve a number of critical functions in building construction.

Figure 20.11 – Precast Cladding Wall Panels

Fire resistance is a key function of wall panels and the panel thickness is a key determinant of the fire rating and performance requirements are prescribed in AS 3600. Panels are usually between 120 mm and 170 mm thick which typically provides either 2-hour or 4-hour fire protection, respectively. In any circumstance, 100 mm thick panels are generally the minimum in order to provide sufficient cover to reinforcing steel. Not only is the fire rating of the panel itself important, but so too is the contribution of the joints. Where sealants are used, a detailed method of application and their fire rating performance need to be supplied by the sealant provider.

Ideally, panels should be made to the largest dimension that can be transported to site and lifted by an available crane (see 7.4). When panels are located in the structure the normal joint width between precast panels is about 20 mm; with about 35 mm allowed between panels and in-situ concrete elements. Joint sealing is an important aspect for ensuring that the structure is weather-proofed, that any differential movement of adjacent elements does not affect weatherproofing and in some cases, that fire rating requirements are maintained. There are several joint types that are regularly used – as described in the NPCAA publication [3] on *'Joints in Precast Concrete Buildings'*. There are a range of sealant types that may be used and these need to have (a) water-proofing capability, (b) the appropriate adhesion characteristics and (c) be able to retain their filling capability in a range of temperature conditions. Sealants must be properly emplaced – typically with a backing rod, and sufficient time must be allowed for them to cure properly. The surface of the concrete where sealants are applied must be clean and free from loose material. Compression-seal joints may be used where the structure does not allow gun-applied sealants to be properly used.

Joints may also be provided using (a) grouting or (b) in-situ concrete. In these cases, the minimum joint spacings between precast elements must be not less than 20 mm and 150 mm, respectively.

Panels provide both structural support and improved thermal performance. From a structural perspective, panels can be designed for use as load-bearing walls and to provide lateral stability in the building. By virtue of their inherent thermal characteristics (e.g. heat capacity) and by incorporating design features to shade the inside of the building they can significantly improve comfort levels and heating and cooling performance of a building – and also provide good sound insulation. The panels can be designed to include window and door openings and panels can also be designed to carry floor and column loads in a variety of situations (**Figures 20.12**, **20.13** and **20.14**).

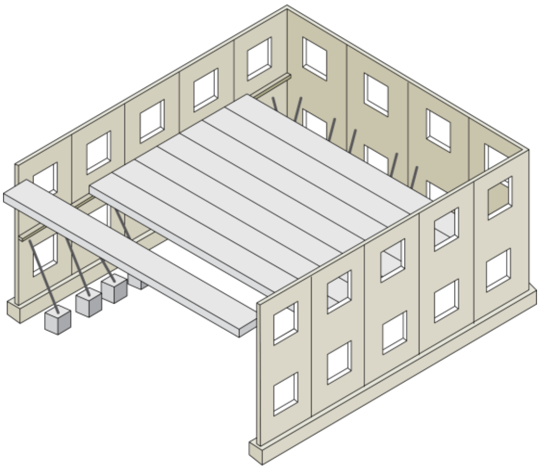


Figure 20.12 – Two-storey Panel Building with Window Openings

Figure 20.13 – Internal Precast Wall Panels – loadbearing walls to support precast flooring

The thermal performance of precast concrete wall panels can lead to concerns about condensation within buildings in certain weather and ambient conditions. To limit concerns about condensation in buildings using precast concrete wall panels, it is common to insulate the internal surface of the walls and also to ensure adequate heating of the building and the provision of ventilation.

Figure 20.14 – Precast Wall for a Lift Shaft and Stair Core

4. ARCHITECTURAL PRECAST CONCRETE

4.1 GENERAL

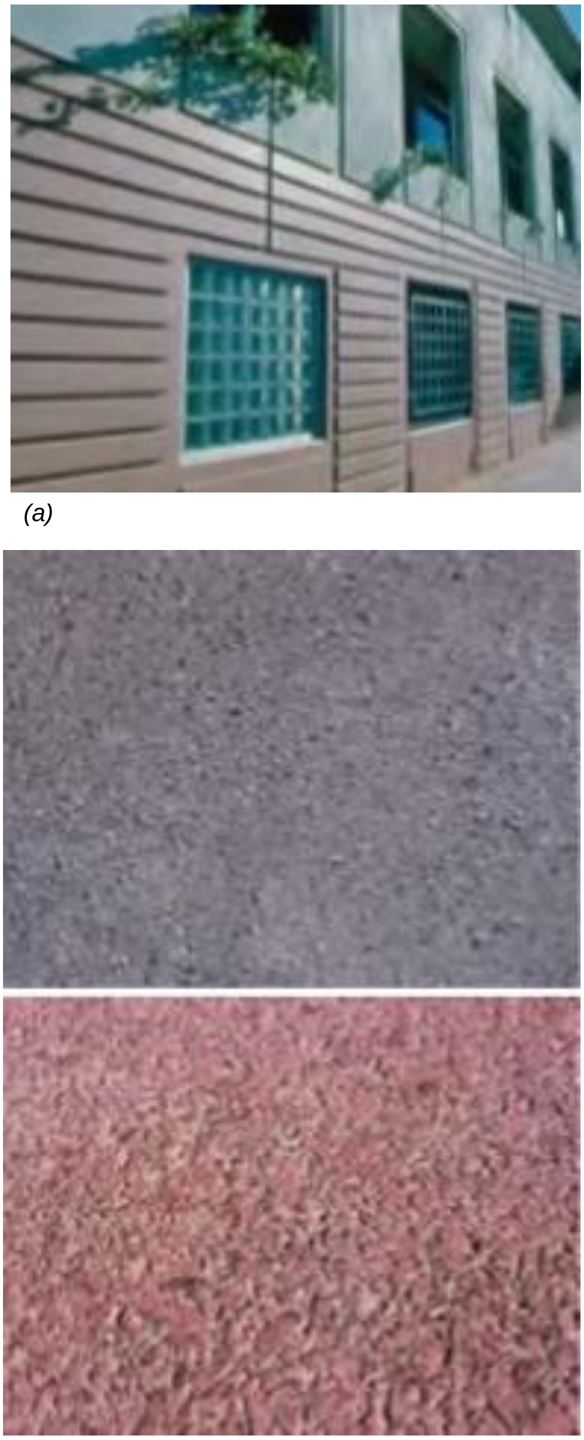
Architectural precast units typically apply the types of finishes that are common in other concrete types and styles, but their application can be much more obvious through their use in commercial building facades, in panels decorating roadsides and public open spaces and for large public structures like Government buildings, Courthouses and museums. Architectural precast panels have led the movement to replace the 'grey panel' view of concrete construction with the new, colourful and complex textures and designs that typify modern concrete.

Generally, the complexity and consistency of colours, textures and designs that can be achieved with precast are not as readily or consistently able to be achieved with in-situ concrete construction. The manufacture of precast in factory environments provides higher levels of accuracy and consistency that are generally not able to be achieved on site. The scope of finish types available to be used with concrete are described in detail in the CCAA Guide T57 *'Guide to Off-Form Concrete Finishes'* and potential problems with managing surface finishes have been described in Section 16 *'Control of surface finishes'* in this Guide. There are several main methods of achieving architectural finishes with precast concrete and these will be discussed in the following.

In all cases where aesthetic and architectural expectations are involved, it is important that before full-scale production begins, trial panels created in realistic production situations are prepared. Not only do such panels illustrate the quality of finish that should be achieved, they stand as a record of what was/is able to be achieved and should reduce the level of complaint and aggravation that can occur when the 'real' job has been completed. Obviously, the same materials and casting and finishing processes must be used for the trial panels as are being used in the 'real' job. It should be noted that casting in vertical or horizontal positions can alter the orientation of aggregates and alter the appearance of concrete, as can source and proportions of colouring oxides, W/C ratio, type and extent of curing and lastly (and importantly) – time. The appearance of the concrete surface may change as is equilibrates with the local environment. In some cases, efflorescence may also occur.

4.2 EXPOSED AGGREGATE FINISHES

There are a variety of ways that the off-form or finished face of a concrete element can be altered by physically altering the surface quality and texture (**Figure 20.15**). These techniques normally require a high level of skill to ensure they are carried out properly and consistently over the entire visible surface. It should also be noted that coloured concrete may be used with all of the methods below to enhance the appearance of the finished surface.



(a)

(b)

Figure 20.15 – (a) Ribbed Finish using Timber Battens; (b) Acid Etching (top-light; bottom – medium)

Conventional Exposed Aggregate – The aggregate sitting just below the surface of the finished concrete can be partially exposed to create a highly decorative surface – without a major impact on serviceability. This is usually carried out on horizontal surfaces but can, with care, be carried out on vertical faces. In an alternative approach, the surface of the concrete can be 'seeded' with a decorative aggregate – placed on the surface of the plastic concrete and then rolled into the surface. In the usual method of exposure, the paste is gently washed away from the aggregate, to a depth of about 30% of the depth of the maximum aggregate size. This is carried out immediately prior to the concrete setting. In some cases, a mild retarder is sprayed onto the surface which allows the surface paste to be washed away while the underlying concrete remains unaffected. For precast panels, the washing process may be assisted by a slight tipping of the panel to allow the removed paste and water to flow away from the finished face.

Grit Blasting – This method involves the use of an air-driven blasting medium to erode the surface of the concrete providing a quite gentle, even 'matt' surface. A variety of blasting media are available including glass and copper slag. Care needs to be taken if/when these processes are carried out in the open as they create large amounts of fine dust and it is likely that the crystalline silica content in that dust may be high.

Honing and Polishing – It is possible, with higher strength concrete, to cut away the top few millimetres of the concrete surface using 'polishing' devices to create a polished surface. This is done in multiple stages with quite large machines, which requires that edges and corners be hand-polished to extend the finish across the whole panel surface. The polished surfaces can be used in combination with other surface textures and colours to create a huge range of high-quality, decorative surface effects.

Other Mechanical Methods – Any device or system that can be used to decorate the surface of a precast concrete panel without affecting the structural performance of the panel can be employed to create decorative finishes. Ideally the system should not be too labour intensive and should create a consistent finish. Examples include (1) bush-hammering – the use of an impact device to remove 1-2 mm of the surface to reveal the underlying aggregate, (2) rope finish – where the concrete is cast against a 'rope liner' which is removed once the concrete hardens, and (3) ribbed finishes – where 'ribs' are laid along the mould to create geometric patterns that break up an otherwise bland concrete surface. Whenever the use of large areas of panel are proposed, the use of artificial joints to break the surface up will both improve the appearance and help to hide any imperfections in the finished surface.

Acid Etching – The use of quite dilute solutions of mineral acids (e.g. hydrochloric acid or phosphoric acid) can be used to remove a thin layer of paste from the concrete surface. This method provides and even finer finish than grit blasting. To control the effect of the acid it is best to wet the surface of the concrete with water before applying the dilute acid solution. The depth of etching is proportional to the strength of the acid solution and the contact time.

4.3 OFF-FORM FINISHES

There is a massive range of options available for achieving bold and exciting off-form finishes. For simple trowelled surfaces, coloured or not, it is very difficult to achieve uniform texture and colour consistency across a large panel. In such situations, it is usually necessary to include indents or some other means of breaking the surface down into smaller sections as noted above. There are however, many options to create textured, off-form surfaces using materials as simple as timber, as well as a variety of form materials (from timber with plastic coatings through to rubber form liners) that may impart highly complex designs onto the concrete surface. When combined with colour and other surface finishes the range of options is as huge as it is decorative (**Figure 20.16**).

4.4 APPLIED FINISHES

There are several types of applied finishes including – coatings (renders and paint) and attached tiles or stone slabs.

Where coatings like render or paint are used, it is important to ensure that the concrete surface is clean and able to accept the coating. If bond breakers or curing compounds have been used in the manufacture of the concrete panel some residues may remain, and these may cause the coating to fall off in sheets relatively soon after application. Cleaning of the concrete surface should always be carried out and a trial application of the coating would provide extra certainty. A significant cost issue with the use of these coatings is the need to maintain or replace them from time to time.

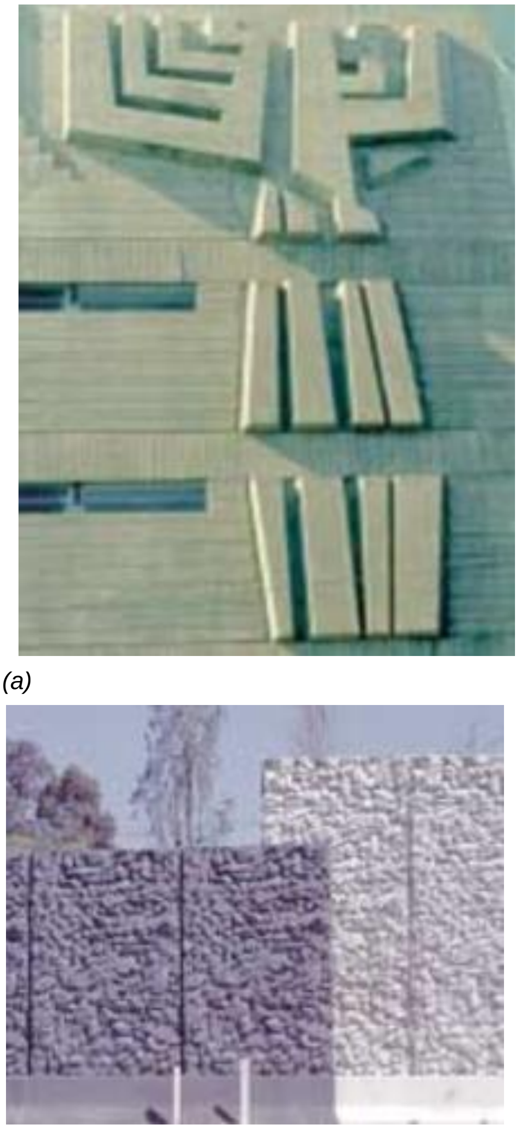


Figure 20.16 – Decorative Panels, Effects Created using (a) Timber Forms and (b) Rubber Form Liners

When solid decorative materials like tiles or natural stone facing materials are to be used in conjunction with precast concrete, it is important that the likely interaction of these materials be understood. It is possible that these non-concrete materials will have different levels of expansion to the base concrete when the structure is exposed to heat and cold, and this will in due course create bond issues between the base concrete and the decorative material. Tiles may be adhered using cement-based adhesives. Where solid decorative facing materials are used a connector may need to be bonded into the concrete and then connected to the facing material, with an insulating layer being provided between the concrete and the facing material to separate them (**Figure 20.17**).

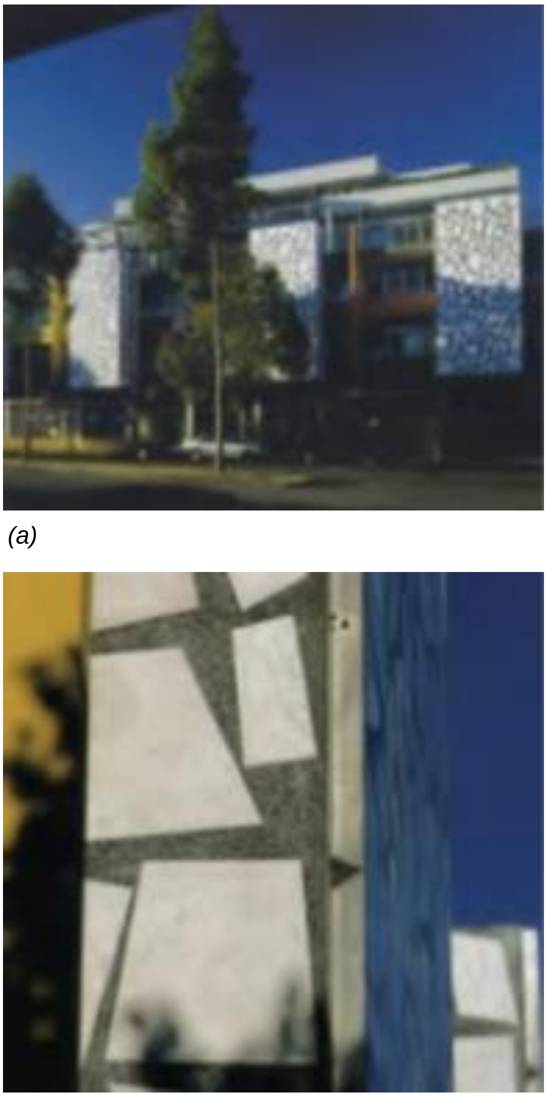


Figure 20.17 – Randomly Shaped Marble Pieces Mechanically fixed to Backing Concrete

5 HOLLOWCORE

5.1 GENERAL

Hollowcore systems are becoming increasingly popular as the construction industry moves more towards off-site construction solutions to replace in-situ construction which brings with it a range of inherent issues. While these issues have been discussed previously, it is worth noting that they include variable concrete element quality, site safety, speed of construction and site congestion. Hollowcore is being applied in two significant areas – concrete wall panels and concrete flooring, and these will be discussed separately below.

5.2 HOLLOWCORE WALL PANELS

Hollowcore wall panels are usually produced in standard panel sizes of either 1,200 mm or 2,400 mm width, though narrower panels can be made by casting smaller panels or saw-cutting larger panels. Wall thicknesses can range from 150 mm to 300 mm and the shape and size of the cores can vary with the manufacturing equipment. Casting beds can be up to 200 m long and working panels are cut to length by saw-cutting. Wall panels can be designed and built for load-bearing or non-load bearing situations. The resultant panels are strong, lightweight units. They can be designed to meet relevant fire and noise rating requirements as well as durability requirements as specified in AS 3600.

Hollwcore wall panels can be produced with a variety of finishes including most of those described in sub-section 4. Exposed aggregate, ribbed and broom finishes are available from some manufacturers, and the panels (in all finishes) are available in a range of colours.

Panel fixing to adjacent building elements is carried out using standard fittings that are widely available. With a now quite long history of use of hollowcore panels these fittings are 'tried and tested'. The fitting types are detailed in the NPCAA *'Hollowcore Walling – Technical Manual'* referenced at the end of this Section.

5.3 HOLLOWCORE FLOORING UNITS

Hollowcore flooring is provided primarily as units of varying widths (but typically 1.2 m wide) and they can cover spans of up to 20 m. These units may be referred to as 'planks', 'slabs' or 'panels'. They range from 100 mm to 400 mm in thickness and they are invariably prestressed. The panels are truly 'hollow' – with from 4 to 6 hollows longitudinally – these hollows occupying two-thirds to three-quarters of the panel thickness. The panels are cast on long beds – up to 200 m long – and the working panels are saw-cut to length while on the bed (**Figure 20.18**).

Figure 20.18 – Hollowcore Planks of Varying Thickness

When used for floor construction in large buildings they are usually overlayed with a reinforced slab of cast in-situ concrete to provide a level floor. They can however be simply grouted together along their lengths to form the working floor. The soffit of the panels can be treated in various ways to form a ceiling for the floor below. The panels can be painted, or a texture finish applied; they can be lined with plasterboard or, a hanging ceiling can be affixed to the panels. The hollow cores in the panels can be used as service ducts.

The long spans do not require propping or formwork to support them, and following trades have a lot of space to carry out their work – both beneath the floor or using the new floor as a work platform. When using floor panels, fewer people are required on site and the sites have lower levels of congestion. During construction, the panel production process and the building construction process can be synchronised so that panels are delivered and emplaced when and as required in what has been described as being like building with a ‘meccano set’. The panels can be supported by masonry walls, precast or in-situ concrete walls and beams made of either prestressed concrete or steel (**Figure 20.19**).

Figure 20.19 – Long Span Hollowcore Flooring provides Space during Construction and Use

The panels have a high level of design flexibility and can be designed to accommodate high loads, openings and cantilevers – while meeting durability and noise and fire ratings for a wide range of building types. When determining the most appropriate panel design, a defined process is usually undertaken, with steps similar to the following:

- Initially assess the structural design in terms of columns, wall and beams and load paths;
- From the nature and location of the building assess noise and fire rating requirements and (AS 3600) durability requirements;
- Determine the minimum panel thickness, concrete strength and depth of cover required;
- Taking account of the design and likely deflections, determine span lengths and panel thickness requirements;
- Determine dead and live loads;
- Check the strength capacity of the panels given the span and load conditions;
- Consider the topping requirements (particularly the thickness) to ensure that the camber (due to the prestressing) in the panel is accounted for and that there is sufficient concrete cover to all reinforcement.

There are fairly standard design requirements for the thickness of the panels based on the span length/thickness ratio. The ranges for this ratio are typically 30-35 for floors and 35-40 for roofs, however any situation where the ratio exceeds 30 should be checked to ensure there is adequate vibration stiffness. As a result of the prestressing, the panels have a camber which generally requires the application of a (reinforced) cast in-situ concrete topping to provide a flat floor surface. The degree of camber expected can be calculated based on the design load and the degree of prestress. Excessive camber can be reduced by adding extra prestressing strands. The degree of camber tends to decrease over time due to the combined forces of concrete creep and some loss of prestress.

During manufacture of the panels they are prestressed using multi-strand arrangements. For thinner panels prestressing strand is used in the bottom of the panels, while for thicker panels prestressing strand is placed at the top and bottom of the panel. The concrete strengths used are typically 40-65 MPa, while for the reinforced toppings, 32 MPa or 40 MPa concrete is generally used.

In the building itself, the Hollowcore panel system should be tied to the support structures using grouting or cast in-situ concrete using ties that link to the support beams and/or topping concrete. The panels should be connected by way of grouting to ensure load transfer and to allow the whole structure to act as a monolithic system. Where the panels sit on support structures there may need to be a bearing support in the form of a thin (e.g. 3 mm) neoprene pad or similar to limit damage to the support structure (e.g. for a masonry wall). Penetrations through panels, if large, should be cut in the factory. In some cases, headers must be included during construction to allow load transfer to adjacent panels. For smaller penetrations that are cut on site, care must be taken that in the process of cutting the penetration, no prestressing strands are cut.

6 OTHER PRECAST PRODUCTS

Other types of precast concrete products commonly available are used in applications such as landscaping and for a wide range of civil engineering structures.

In civil engineering structures, examples of the application of precast concrete include tunnel linings, piling, manholes, culverts, bridges (railway, road and footbridges), septic and sewerage systems, sea walls, desalination plants, marine structures, sports stadiums, crypt systems and many others.

Landscaping applications include retaining walls, bollards, park benches, slabs and steps in parks and playgrounds, wheel-stops and kerbs and other architectural features (**Figures 20.20** and **20.21**).

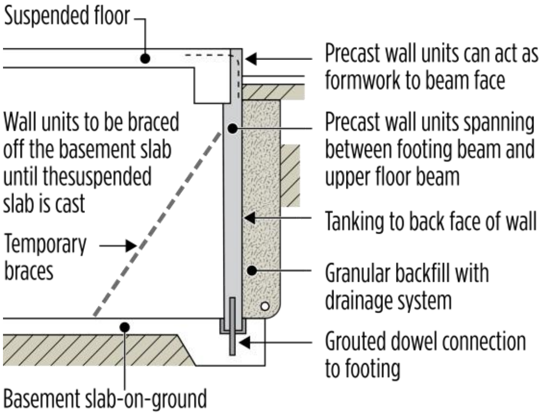


Figure 20.20 – Precast Concrete Retaining Wall Structure

For these applications in particular, it is the combination of several features that makes precast concrete a useful option for planners, designers and architects. These features include strength and durability, wide range of designs possible, consistency of products (due to manufacture in a factory environment and using moulds), wide range of colours and finishes possible and design flexibility through the ability to mould an initially plastic product.

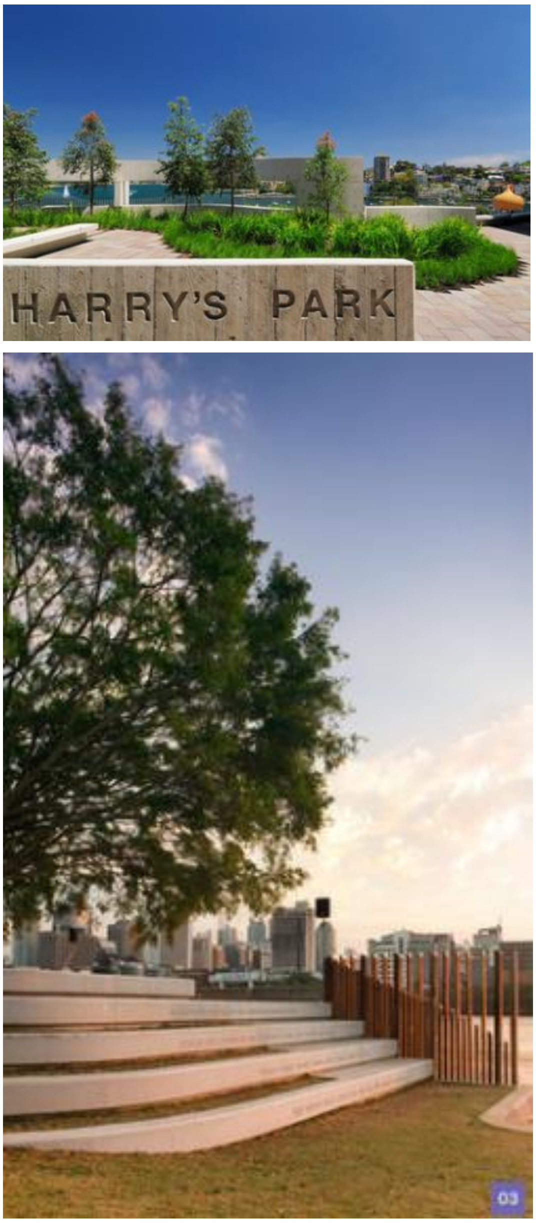


Figure 20.21 – Precast Elements used for Urban Landscaping

7 SAFETY DURING THE TRANSPORT AND USE OF PRECAST CONCRETE ELEMENTS

7.1 GENERAL

A national Code of Practice for the use of precast concrete elements has been prepared by the Australian Government and is referenced at the end of this Section. This code applies to building construction only and not to the use of precast concrete for, for example, bridge beams, pipes and culverts. It is also noted by the NPCAA that there are aspects of this Code that conflict with other more modern approaches and that this Code is to be re-written. The following provides a general review of safety practices relating to the use of precast concrete elements only.

While the use of precast concrete elements undoubtedly reduces a number of safety concerns at building sites (see Part IX, Section 28 *'Occupational Health and Safety'*), it does however create some specific issues. Precast concrete elements are very heavy and quite large and once delivered to site, need to be craned into position. After being placed in position they need to be stabilised until connection into the final structure occurs. The final structure needs to have sufficient load bearing capability, in both the individual elements and the overall structure, to cope with both live and dead loads that may be experienced by the structure during its life. These serviceability expectations are only able to be met if the design, manufacturing and construction activities are properly undertaken.

Rigorous safety assessments are required at all stages of the design, manufacture, transport and erection of precast concrete elements and the key elements in each area will be described in the following. The basic requirement is that there should be in place a rigorous system or set of systems that are able to (a) identify hazards in all of the stages, (b) eliminate hazards wherever possible, (c) develop control measures to reduce risks from any hazards that are not able to be eliminated, (d) educate and inform people as to the risks, and (e) document all processes, procedures and systems used in risk management.

7.2 DESIGN OF PRECAST CONCRETE ELEMENTS

The broad elements that require consideration during the design phase include (a) provision of adequate documentation including design drawings, site plans, shop drawings and erection documentation, (b) actual structural design, and (c) plans for storage, handling, transport and erection of the elements. Where multiple designers are involved in various parts of the planning and design then they all need to contribute to the health and safety planning. All relevant documentation should be available at the work sites. Where risks cannot be managed out of the project then documentation should include work instructions to manage remaining risks. If proprietary equipment is being used, then all relevant product information should be included within the project documentation.

Structural design drawings prepared by a qualified engineer need to include all relevant engineering information including critical dimensions, reinforcement detailing, connector locations, concrete specifications, grouting sequences and service locations. These drawings must be properly authorised.

Planning for the actual construction requires plans that describe the locations of each concrete element and the construction sequencing. Site-specific issues that might affect construction including location, traffic issues and the presence of site obstructions must be assessed and documented.

Shop drawings need to be prepared and ultimately signed off by the design engineer. These should include the numbers of elements required; their size and weight; reinforcement requirements; concrete requirements to meet AS 3600 specifications; nature and location of fixing and lifting inserts; any bracing required; propping requirements for each element, and clear identification of each element.

Erection documentation should include every aspect of the erection process. This includes sequencing, bracing and grouting.

7.3 STRUCTURAL DESIGN

Structural design involves the detailed design of the elements, transport and erection processes to ensure that applicable requirements of AS 3850 (Parts 1 and 2) and AS 3600 are met. In a broad sense this requires detailed assessment of manufacturing requirements, erection method(s) and their requirements, likely load expectations and stability of the structure during and after erection.

Particular consideration must be given to joints and jointing methods and materials as well as fixing inserts which should be provided on the shop drawings.

7.4 DESIGN FOR HANDLING, STORAGE AND TRANSPORT

The main considerations requiring assessment in this phase include (a) the size and shape of the elements, (b) how they will be lifted (by edge or face and whether they will be rotated), (c) cast-in fittings, (d) load issues when handling and storing, and (e) additional reinforcement requirements.

The size and shape of the elements determines the difficulty they may present when lifting and handling (e.g. bending and buckling), which requires lifting inserts to be appropriately placed. Lifting inserts need to be in sufficient number, to have sufficient capacity and to be appropriately located and anchored. Concrete strengths also need to be adequate for the lift to occur. Any cast-in fixings need to be suitable and should be standardised across the project to minimise issues.

Structural connections should be adequate to support loads likely to be encountered both during construction and operation of the building. Loading of elements may differ in the erection and operational phases and these need to be considered separately. Impact loads during construction, for example, may well exceed loads likely to be encountered during normal building operation. Additional loads or odd element shapes may require additional reinforcement to be used or support using ‘strongbacks’ to be employed during erection.

7.5 PREFABRICATION AND CASTING

All concrete materials and lifting and bracing inserts to be used in manufacturing the elements should meet the requirements of the relevant Australian Standard. Lifting inserts should be ‘cast-in’ only. Bracing inserts should preferably be ‘cast-in’ and should be capable of resisting all loads likely to be encountered during construction and should be appropriately located in the element.

Casting beds for on-site casting need to be properly located to take account of the need to move materials and cast elements and should have sufficient capacity to meet project requirements. If capacity requirements necessitate casting in stacks then additional care is required in relation to formwork, separation of elements and production sequencing. Once the elements have been cast, they must be marked to identify their location in the structure and tested for conformance with specification requirements.

7.6 HANDLING, STORAGE AND TRANSPORTATION

The handling and movement of the large precast elements create a number of safety risks. Ideally, with proper planning, the amount of handling of precast elements can be minimised. This is a basic element of risk management at this stage of a project. Ensuring that elements do not contact one another during handling reduces safety risks and the potential for damage to the elements.

Storage of precast elements also needs to be managed to reduce safety risks and damage. Temporary storage on suspended floors or beams requires engineering approval. Stored elements should be protected from impact from cranes or vehicular movement. Crane selection and operation are of critical importance to reduce safety risks during handling and erection. Ensuring that crane lifting capacity is appropriate is critical and use of a larger crane than is nominally required can reduce the number of lifts. Adequate clearance for crane operations (and particularly around power lines) must be maintained.

Transport of precast elements to the project site requires good planning. Load limits and site locations must be considered and a good traffic management plan at the site is required to ensure risks are minimised. Support frames on the trucks must be able to support the elements and need to be properly secured and remain so, particularly during loading and unloading of elements.

7.7 ERECTION

The erection of precast elements brings with it, significant safety risks. Proper planning of this phase of activity is fundamental. With systems involving supporting and bracing of elements during an ongoing construction process, there is a risk of progressive failure if one element falls and triggers a collapse of the whole structure. This eventuation must be prevented at all costs.

In the erection phase the safety issues require that only personnel involved in the erection process be present – in or around the structure. During movement of elements they should not travel over a person on the site and elements being lifted should lean away from the crane. After temporary erection has been completed, a thorough inspection of bracing and supports should be carried out. Operation of mobile equipment around braced structures should be prevented or minimised. Where 'working at heights' is occurring the appropriate measures to prevent falls must be in place.

Bracing and propping must be able to carry all required loads and should meet the requirements detailed in the shop drawings. Extra loads (e.g. installation of roof systems) should not be imposed on temporarily braced elements (**Figures 20.22** and **20.23**).

While some builders seek to increase productivity by erecting panels on recently poured slabs, the strength of the slabs must be properly considered to ensure safety during the erection process. Panel bracing is attached to the slab via an anchor, and these anchors are typically cast-in inserts in the slab. The strength of the slab must be sufficient to ensure that the inserts do not 'pull out' of the slab under load. The design methods in AS 3600 only apply for concrete strengths >20 MPa, while the concrete capacity design procedure in AS 3850.1 (Appendix B) is based on the characteristic compressive strength at 28 days. For a concrete age of <28 days the design must be based on the characteristic compressive strength at the age of loading. Any departure from the requirements of these Australian Standards must be signed off by the Erection Design Engineer.

Figure 20.22 – Bracing of Precast Panel – Braces fixed into Slab Floor and Panel[20.2]

Figure 20.23 – Bracing Panel while Construction Progresses

Proper consideration also needs to be given to embedment depths for the cast-in bracing inserts. For inserts where the embedment depth is <150 mm, small variations in embedment depth can affect the inserts' load capacity [4].

Grouting can be applied once the structure has been properly positioned and aligned. Supporting structures should not be removed until the grout has gained sufficient strength.

7.8 CONNECTION INTO THE FINAL STRUCTURE

The erection program and its effect on the whole structure need to have been considered in the project planning. All likely loads – whether related to construction activities or other conditions (e.g. wind loads) – should have been accounted for. Connection of the concrete elements into the whole structure should follow the design requirements and any variation from these needs to be approved by the design engineer.

8 PRECAST CONCRETE AND THE ENVIRONMENT

In addition to some of the engineering benefits that precast has over conventional in-situ concrete casting, it also has some environmental benefits.

Through its manufacture in a factory environment, greater control over element dimensions and concrete quality can be achieved. In both cases this allows a reduction in material quantities – less concrete due to higher precision and less cement due to greater control over strength performance. Both yield lower levels of embodied energy and embodied CO_2 when considering the environmental performance of the as-built structure, though the implications of using steam curing where it is used must also be factored into any calculations.

The greater control over factory production also leads to lower levels of waste of both raw materials and plastic concrete.

From a comfort perspective, the insulating characteristics (both thermal and sound) of precast concrete construction are advantageous. Further, there are no volatile organic compounds emitted from concrete.

The durability of high-quality concrete means low risks from water and pest damage and as a highly durable material precast concrete will retain its serviceability over many decades.

9 REFERENCES

1) National Precast Concrete Association Australia and Concrete Institute of Australia, *'Precast Concrete Handbook'* (September 2002), ISBN 0 9577467 1 7
2) National Precast Concrete Association of Australia, *'Precast Concrete Handbook'* (October 2009), ISBN 978-0-9577467-3-2
3) National Precast Concrete Association of Australia, *'Precast Practice Notes – Joints in Precast Concrete Buildings'*, NPCAA (June 2003)
4) Worksafe Victoria, *'Erection of concrete panels on early-age low strength concrete'* (August 2017)

10 RELEVANT AUSTRALIAN STANDARDS

1) AS 1379 – *Specification and supply of concrete*
2) AS 1530.4 – *Methods for fire tests on building materials, components and structures, Part 4: Fire resistance tests for elements of construction*
3) AS 3600 – *Concrete structures*
4) AS 3610 – *Formwork for concrete*
5) AS 5100 – *Bridge design, Part 1: Scope and general principles*
6) AS 3850 – *Prefabricated concrete elements, Part 1: General requirements*
7) AS 3850 – *Prefabricated concrete elements, Part 2: Building Construction*

11 OTHER REFERENCES

1) Ryan WG and Samarin A (Eds.), *'Australian Concrete Technology'*, Longman Cheshire Pty Ltd (1992), ISBN 0 582 71245 9
2) CCAA, *'Guide to Concrete Flatwork Finishes'*, CCAA T59 (2008)
3) CCAA and Concrete Institute of Australia, *'Guide to Tilt-Up Design and Construction'*, CCAA T55 and CIA Z10 (2005)
4) CCAA and Standards Australia, *'Reinforced Concrete Design'*, CCAA Handbook T38 (July 2011), ISBN 878 1 877023 28 6
5) CCAA, *'Form Liners – Achieving Surface Relief and Texture'*, Briefing 06 (June 2002)
6) CCAA, *'Colour and Texture in Concrete Walling'*, Briefing 03 (September 2006)
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8) National Precast Concrete Association of Australia, *'Hollowcore Walling – Technical Manual'*, NPCAA
9) Australian Government, *'National Code of Practice for Precast, Tilt-Up and Concrete Elements in Building Construction'* (February 2008), ISBN 978 0 642 32784 0

End Notes:

20.1 The lower part of the figure was adopted from *'Bradleys Head Lighthouse - Sydney Harbour'*, by Wade Homewood, licensed under the Creative Commons Attribution-Share Alike 3.0 Unported license,- https://commons.wikimedia.org/wiki/File:Bradleys_Head_Lighthouse_Sydney.jpg

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