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December 2010 6

PRECAST CONCRETE ELEMENTS Structural precast concrete in Melbourne, Australia

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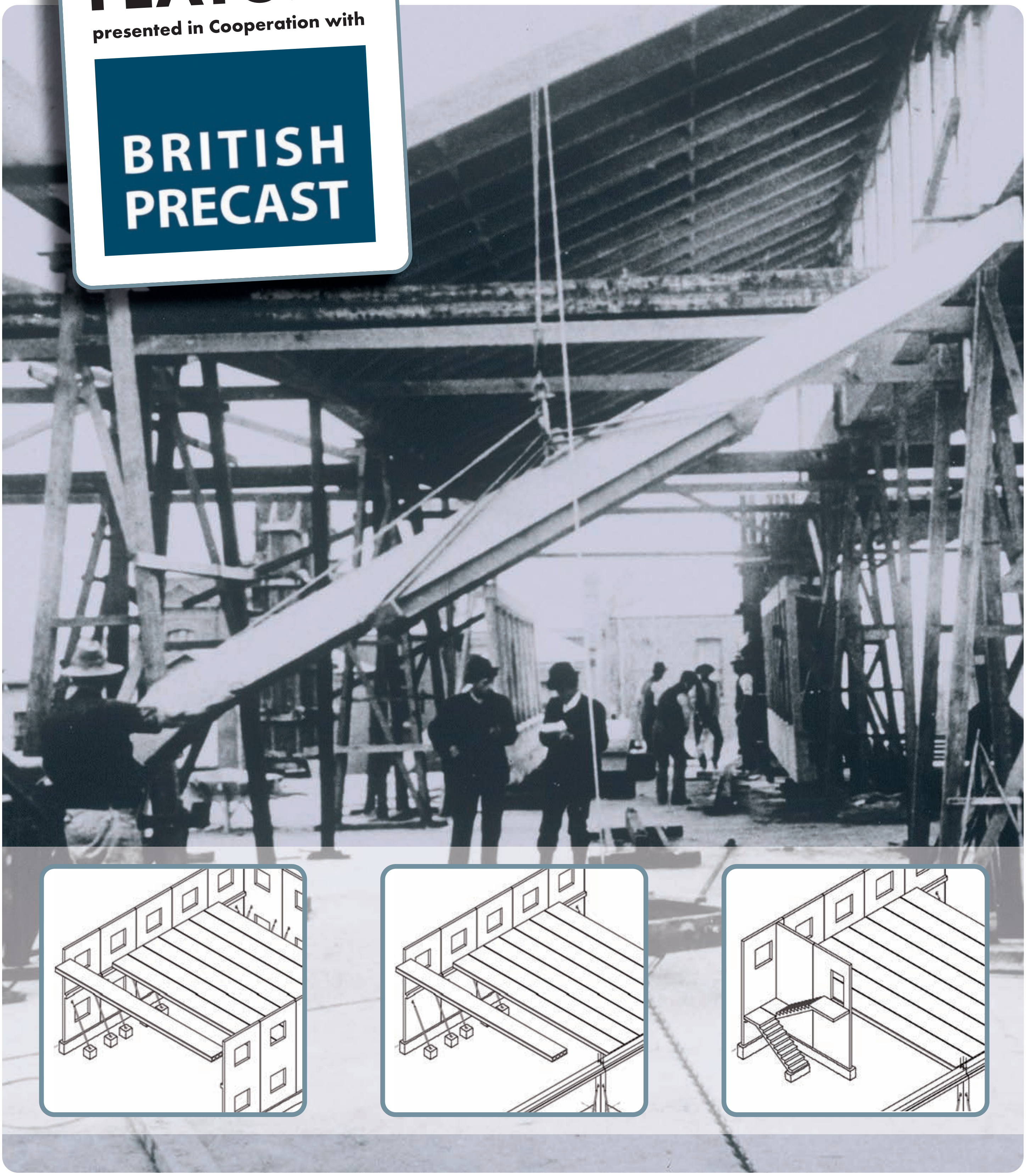

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Structural precast concrete in Melbourne, Australia

Since its early application in tilt-up construction for industrial buildings, precast concrete has evolved to become the dominant form of multi-storey construction in Melbourne. Flat panel load-bearing walling with in-situ or precast floors is the preferred construction method for multi-storey residential buildings, and precast skeletal frames with precast flooring is common on multi-storey commercial buildings.

This paper will detail and illustrate the concepts that have been adopted and developed in Melbourne to suit the local market. Buildings range from two to several storeys and from a few hundred to tens of thousands of square metres. Many are of mixed construction, incorporating precast with other structural systems.

Precast concrete construction requires two distinct design phases. The first is the structural design of the building for the in-service conditions and is carried out by the Project Engineer. The second is the design for erection and is generally the responsibility of the Builder and Precaster. The erection design is entirely dedicated to the design for handling, transportation, and erection of individual components and for the structural stability of the building throughout the erection process. The purpose of these requirements is to ensure that the erection of precast buildings is 'engineered' and fully documented prior to arrival of the crane and components onsite.

Precast concrete in Melbourne is far from a new phenomenon. Throughout its evolution it has developed from simple modular components through to fairly complex designed components that are still simple to manufacture and erect. The idea of standardisation rather than modulation has enabled the use of easily produced components in architecturally challenging designs.

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History

The use of precast concrete in Australia dates back to the early part of the 1900's with the construction of a number of highly innovative structures. A notable example was a large three level building constructed in 1911 as a showpiece for the processing and sale of Australian wool. Known as the Bowtruss Building, the reinforced concrete design was based on the French developed "Considiere system" but was adapted to make extensive use of precast concrete. The perimeter walls were precast concrete infill panels between in-situ columns.

The concrete roof covered a column free area of 50x54 metres and was a completely precast concrete saw-tooth profile supported on six in-situ concrete bow-trusses. Precast elements were all poured on site and erected using shear-legs and block and tackle. This was one of the most technically advanced reinforced concrete buildings of its time and the clear span roof far exceeded the largest previously constructed roof spans. Unfortunately due to degradation of the concrete this structure was demolished in 1990.

Although the availability of mobile cranes in the 1920's and 30's led to the development of numerous systems of precast concrete in Europe and the United States they were not used to any extent in Australia. The exception was the Fowler system introduced in the 1930's for precast housing and which over a period of 30 years was developed by the Housing Commission to build multi-storeyed units of up to 35 floors. By 1960 with the development of prestressed concrete and large capacity mobile cranes there were precast concrete plants operating in all main Australian cities producing structural elements including double and single Tees, various forms of floor planks and a range of rectangular and inverted Tee floor beams. These elements were ideally suited to the construction of long span open floors in low-rise buildings such as shopping centres, parking stations and schools. Double Tees were used on a number of multi-storeyed steel framed commercial buildings, but the use of complete precast frames for commercial buildings was rare.

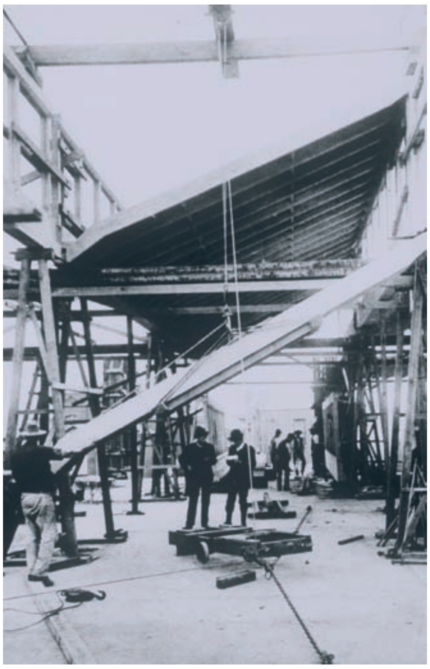

Fig. 1: Bowtruss Building

By 1970 the market for structural precast in Australia had declined dramatically and what had been a booming industry some ten years earlier virtually ceased to exist. There were many reasons for this turn around but fundamentally the products being produced could not compete financially with alternative forms of construction.

The result was that the precasting industry concentrated on high value elements such as architectural cladding panels and non-structural components. This was in contrast to Australia's near neighbour New Zealand where earthquake considerations and resulting USA influence led to the extensive use and development of structural precast concrete.

In 1971, at the onset of a building boom, escalating labour costs saw building developers look to alternative forms of construction to minimise labour content. Site precasting of walls for industrial buildings became common place. The rapid development in the use of precast walling created a demand for precast flooring and framing systems and hence, a resurgence in the structural precasting industry. Continuing escalation of construction costs also resulted in greater emphasis on off-site production where costs and productivity could be better controlled.

Why it works

The construction industry in Melbourne has recognised that precast buildings are not simply in-situ, steel or timber structures converted to precast. As such many Melbourne designers consult with the local precaster during the preliminary evaluation stages.

This consultative approach has been strengthened by the development of precast systems that allow for significant flexibility while still remaining economically viable. Due to the relatively small market within Australia, components are typically designed as project specific elements rather than expecting the structure to be designed to suit standard precast components. This has been achieved by standardising the component type and method of connection rather than trying to produce repetitive elements. This concept results in precast structures that do not need to be repetitive or modular and allows greater architectural freedom.

With Australian buildings generally requiring small production runs the manufacturing and erection process of precast structures imposes a number of considerations upon both design and construction. In this market the following factors need to be considered when establishing design concepts:

- The high cost of on-site labour means that savings in the time of construction will have a more significant influence on project cost than any possible savings made by a reduction in material quantities.
- The labour content of the manufacturing process can be significant and elements should be detailed to ensure minimisation of labour even at the cost of extra material.
- The structure should be composed of a small number of different types of elements to restrict the number of moulds required. Elements should be standardised so that variations of basic types can be produced in the same mould.
- Connections should be simple and quick to construct so that speedy and continuous erection can be maintained. It should not be necessary for the crane to support an element after placing and during alignment.
- Setting up and adjusting the precast elements should require no fixed scaffolding or only mobile scaffolding that can be quickly moved to new working positions.

Application of these concepts has resulted in the evolution of the following types of structural systems:

- Panelised structural envelope. A building incorporating structural precast walling and/or exposed spandrel panels with a precast floor system spanning between walls. Floor systems act as horizontal diaphragms to transfer horizontal loads to the shear walls.
- Structural precast skeletal frame. A building incorporating a structural precast frame of columns and beams with a precast floor system. The frame is usually pin-jointed but can be moment resisting. Lateral loads are carried by shear walls on pin-jointed frames and by frame action on moment resisting frames. Floor systems act as horizontal diaphragms to transfer horizontal loads to the walls or frame.
- Hybrid structure. As the name suggests a building combining more than one of the above structural systems.
- Mixed construction. This term is used to describe buildings that incorporate precast concrete combined with other structural materials. For example, a structure with precast flooring supported on a steel frame or masonry walls, or a panellised structural envelope with an in-situ concrete floor.

While, in Australia, many examples of traditional precast methods can be found, it has been the acceptance and development of mixed construction methods that have allowed the precast industry to flourish. It is crucial that designers appreciate that the most appropriate structural solution is very much project related, must be evaluated on a building-by-building basis and may incorporate a number of construction materials and methods. This optimum solution generally results in a rectangular grid. Unlike traditional in-situ concrete construction, the most economical is usually with precast floor slabs spanning the longest dimension. This is due to the fact that, with precast slabs, and in particular hollowcore slabs, the cost penalty of increasing the slab span from 8m to 12m, or from 12m to 17m is very small. Framed structures supporting beams should therefore span the shorter dimension to allow the beam depth to be minimised.

Simon graduated from RMIT in Melbourne and commenced working as a consulting engineer. In 1993, he moved to Hollow Core Concrete as part of their in house design team. Simon's role has changed from a designer to site manager, then into the role as production manager and now General Manager of Hollow Core Concrete. Through these roles he has been involved with all facets of design and construction of precast structures. Simon is a current member of BD-066 – Tilt-Up Concrete Construction, and a member of the fib Commission 6: Prefabrication.

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Shear walls are the most effective and economical method of providing stability for low to medium rise buildings. Most buildings have lift or stair shafts that can readily be used as shear walls that are designed as deep beams or box structures cantilevering from the footings. Providing full capacity moment or torsional connections between structural components to generate frame action is expensive and rarely warranted in the Australian market where there are only minimal requirements for earthquake loading.

Carrying lateral loads by cantilever action of precast columns or walls can be an economical option on one or two storeyed buildings where the Australian Building Code requires post-fire stability of external walls. Columns or walls, in these cases, are designed to cantilever from the foundations with a moment resisting connection at the base.

Components

While the types of components that can be produced and used within this form of construction are only limited by the imagination, the success of precast in Australia has been due to the ability to standardise on a range of components.

Standardisation is often misconstrued as modulation or repetition. Standardisation applies to section types and details rather than to specific components. For example two completely different structures can be designed and erected using standardised components simply by adjusting beam depths, column lengths, wall panel positions and different floor systems.

Application of the above concepts has resulted in use of the following standardised component types.

Columns

Precast columns can be produced as either multi-storey corbelled columns or single floor-to-floor elements. In the Melbourne market, the single storey floor-to-floor column is the most economical. The additional cost of erecting a greater number of single floor-to-floor columns is more than offset by the saving in the elimination of corbels or cast-in beam fixings as required for multi-level columns.

Single storey reinforced columns are simple to design, detail and construct, and to accommodate connection details, tend to be conservatively sized. They are manufactured from high strength concrete and where possible with reinforcement limited to four corner bars with nominal ties. This approach results in extremely simple components that are easy to mass-produce.

The base connection is generally analysed as a pin joint with eccentric loading due to erection requirements and localised effects at the top and bottom of the column taken into account. Once loads and bending moments are established the design process is the same as an in-situ column.

Beam bearing areas and transfer of axial load from column through the beams to the lower column needs to be considered in the design. Extra reinforcement is usually provided at the top and bottom of the column to resist splitting. Columns may be rectangular or provided with corbels to give the required bearing area for the supported beams.

Beams

Precast beams have been developed with simplicity and practicality in mind. Typically, they are an inverted Tee or 'L-Shaped' profile and are designed as prestressed or partially prestressed and continuous for imposed loads. The precast floor components sit directly on the ledge of the beam. The beams are also designed so that no propping is required during the erection of the supported floor.

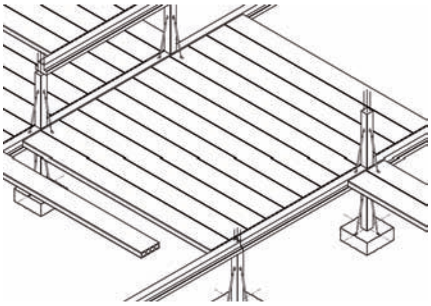

Fig. 3: Structural Precast Skeletal Frame

With floor-to-floor height columns the beams sit directly on top of the columns. Dowels protruding from the columns pass through ducts within the end of the beams to provide the connection to the column. This simple connection between beams and columns eliminates the need for difficult and expensive corbelled or mechanical shear type connections.

One of the critical design cases for the beams and the beam to column connection is the design for torsion loading during erection. It is inevitable that at some stage during erection the beam will be loaded on only one side, causing the beam to 'roll' on the column. The beam column connection must be designed and detailed to resist this torsional load.

While the use of this type of one-way skeletal structure is a very simple and effective method of construction it does require a slightly increased overall beam depth compared to the alternative in-situ concrete band beam system. However, with most commercial buildings in Australia having suspended false ceilings projecting beams are not an issue and if necessary it is generally more economical to increase the overall building height by a small amount than to reduce beam depths.

Precast Floor Systems

There a number of precast flooring components available, including:

- Hollowcore slabs
- Composite Beam with block-infill
- Solid Prestressed or reinforced slabs
- Single and Double Tees (no longer readily available in Melbourne)

Although interchangeable to some extent, each of these forms of flooring has an optimum span range. This optimum range depends not only on direct cost but indirect costs such as any requirements for temporary propping during erection and the method of support or connection to the supports. Statutory requirements to provide a safe workplace during erection also have an impact on the choice of flooring. The systems as discussed in this paper where floor spans range up to about 17 metres generally use hollowcore slabs as the flooring system.

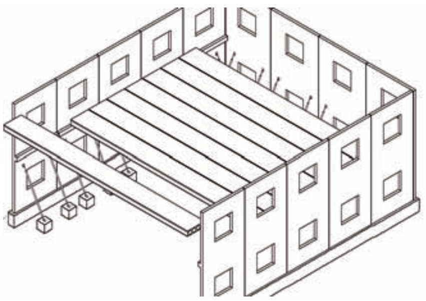

Fig. 2: Panelised Structural Envelope

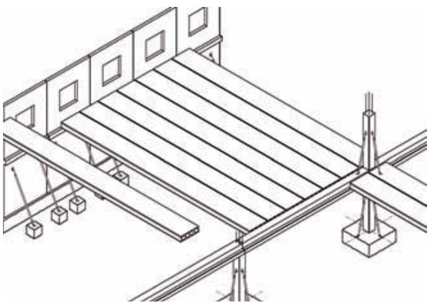

Fig. 4: Hybrid Structure

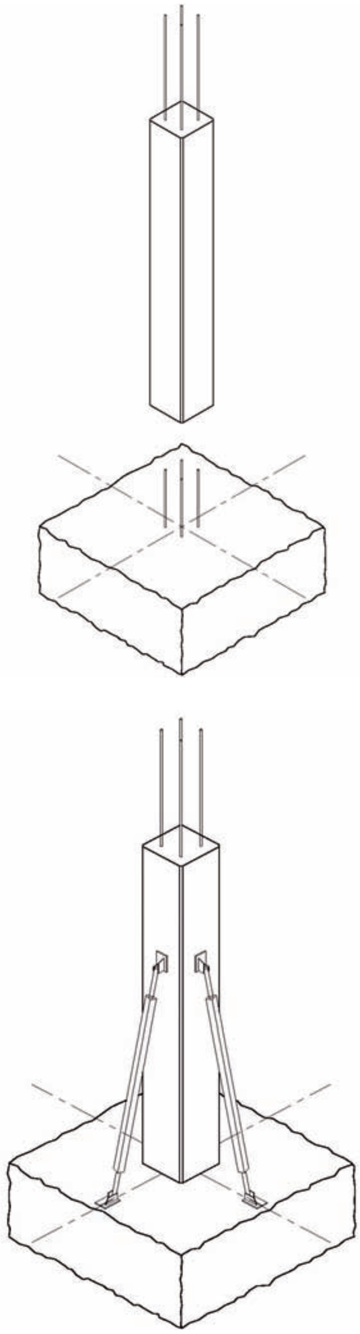

Fig. 5a, b: Floor-to-Floor Precast Columns

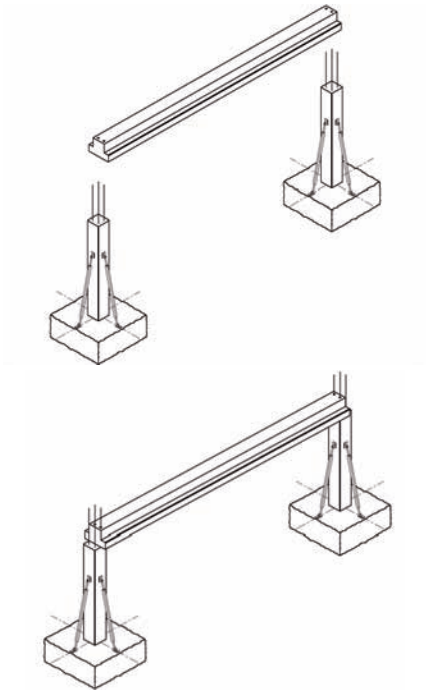

Fig. 6a, b: Precast Beams

In virtually all cases, a structural screed is used to act compositely with the slabs and to simplify tying the structure together. The exception is on short spans in residential buildings where un-topped slabs are frequently used. The optimum thickness of the screed is about 60mm but the prestress induced hog in the slabs needs to be taken into account in setting the geometry.

Hollowcore slabs are usually designed as simply supported, as it is more economical to provide the strength in the positive moment area than to generate both positive and negative moment capacity. Shear can become critical where high negative moments are activated and in these cases one or more cores may need to be opened and filled with concrete.

Precast Wall Panels

Historically, precast wall panels have been used in many forms of structure as a façade element. However, by incorporating these elements as structural components they are able to provide vertical load-bearing capacity and lateral stability to the structure as well as providing the inherent thermal and acoustic benefits.

External panels are typically multistorey panels with either a concrete corbel or steel shelf angle to support the precast floor system. Cast in inserts are used within the in-situ topping screed to tie the structure together. Internal panels are often floor-to-floor panels supporting the floor system directly on top of the panel. Dowels protruding from the panels pass through the floor to provide the connection to the panel above.
Due to the advances in design and knowledge of these components, both structural and architectural benefits in shape, colour and texture, are achievable.

Stair Flights

Precast stair flights are manufactured to incorporate the stair flight and landings as a pre-finished product. They are popular due to the flexibility they provide on the building site and by giving immediate access to the construction level; they can completely eliminate use of temporary access towers.

Other Components

Other components that are often incorporated into precast construction include items such as solid structural wall panels, precast balcony units, spandrel beams and other variations to those already mentioned.
The success of many mixed construction projects has been due to the successful inclusion of non-standard components with standardised components to provide architectural freedom.

Connections

The emphasis on connection design is simplicity. The objective is to provide a connection that serves as many functions as possible while being simple and quick to secure. This is why the majority of connections are pin-jointed connections.
Footing to column connections use dowel bars projecting from the footing with matching cast-in grout tubes in the base of the column. The column is lowered directly over the dowels on to preset levelling shims. The dowels act firstly as locating pins and secondly, form a pinned joint when the grout tubes and base are fully grouted.

The column to beam connection comprises dowels projecting from the top of the column over which the beam, again with matching grout tubes, is lowered directly on to preset levelling shims on the column. Grout tubes are kept large in relation to the bar diameter to allow the use of high flow grout rather than pressure grouting to fill both seating gap and grout tubes.

To prevent the beam from rotating either during erection or in service, a coarse threaded bar is used for the dowels. This allows nuts and washers to clamp the beam to the column. By using this type of connection the dowel can project above the top of the beam to enable the next level of column to be erected, in a similar fashion to the footing to column connection.

Hollowcore support on wall panels can be by direct bearing on top of the wall or with a concrete or steel corbel on the face of the wall. Direct bearing is the most economical solution but is not favoured for external walls. The concrete corbel is cheaper to produce but has the disadvantage of disrupting the manufacturing process of otherwise flat wall panels. The steel corbel is an expensive alternative unless it can be incorporated into the wall panels during casting. In all cases the wall is tied into the floor system with tie bars screwed into inserts cast into the wall.

Erection Design

In Melbourne, the State Workcover Authority has published an Industry Standard, "Precast and Tilt-up Concrete for Buildings". This is a safety based standard and compliance is mandatory. Whereas Australian design codes set out minimum design requirements; the Industry Standard explains how to attain those minimum requirements within a safe working environment.

For precast concrete construction there are two distinct design phases. The first is the structural design of the building for the in-service conditions and is carried out by the Project Engineer. The second phase is the design for erection and is generally the responsibility of the Builder and Precaster.

Fig. 7: Apartment Building

In addition to the erection design, a detailed Work Method Statement is required that clearly describes the work process and associated risks, and defines responsibility for each phase of the work. The design for erec-tion must take into account the agreed erection sequence and detail the bracing requirements at each stage of the process. Bracing is the critical operation during precast erection particularly, where pin jointed floor-to-floor columns and walls are used.

The purpose of these requirements is to ensure that the erection of precast buildings is 'engineered' and fully documented prior to arrival of the crane onsite.

Conclusion

Precast concrete in Melbourne is far from a new phenomenon. In a market where weather has little impact on construction methods, precast concrete usually needs to rely on factors other than direct cost savings to compete.

Throughout its evolution it has developed from simple modular components through to fairly complex designed components that are still simple to manufacture and erect. The idea of standardisation rather than modulation has enabled the use of easily produced components in architecturally challenging designs.

Apart from safety, the most critical aspect of successful precast construction is the initial concept. To maintain all the advantages and reduce the limitations, it is imperative that the project be designed as a precast structure from the outset.

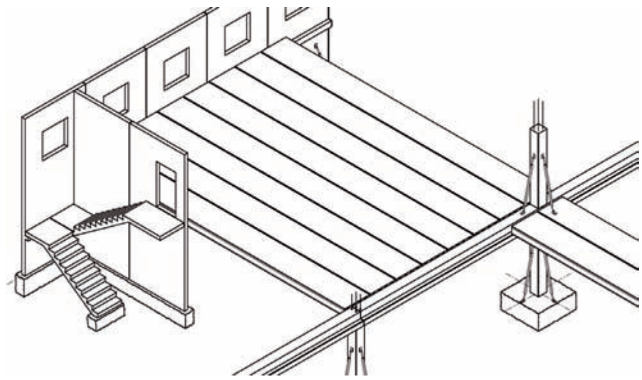

Fig. 8: Precast Stair Flights & Landings

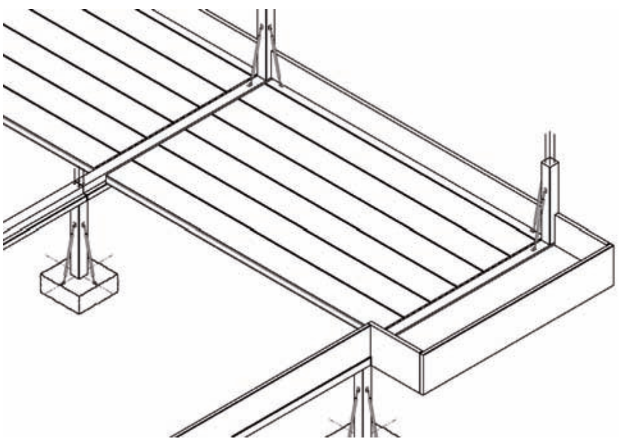

Fig. 9: Precast Balcony Units & Spandrel Panels

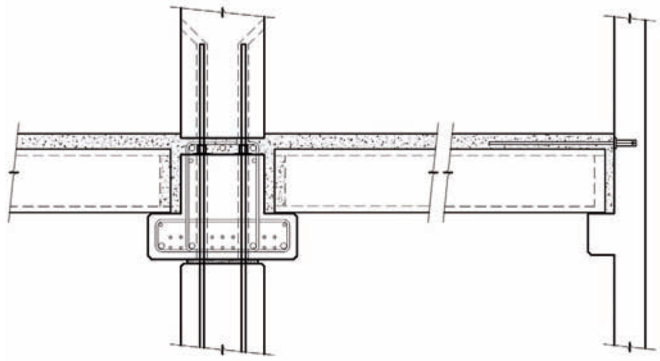

Fig. 10: Typical Connection Details

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FURTHER INFORMATION

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