Enhancing Build-ability Using Precast Concrete Technology

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Abstract

Though precast construction is in use for almost 80 years, it continues to be the least understood construction method in the developing countries. Only a limited number of countries in North America, Europe, Australia, Japan and some parts of South East Asia have explored the method of precast construction. As the construction industry revolutionised the usage of equipment, high grade concrete and steel, there has been substantial development in the precast concrete industry. Precast concrete components adopted to satisfy both architectural and structural applications have resulted in many recent examples of high quality buildings.

This paper will deal with the various aspects of façade construction using precast concrete technology in high rise residential buildings with respect to Buildability. It will also discuss the advantages of precast technology over conventional methods and address some aspects of design, connection, production planning, quality control in fabrication and erection of precast components. One case study of a completed residential projects in which the authors were involved in the design, production and installation will also be discussed.

Introduction

Precast concrete is the concrete which has been cast and cured in a location other than its final destination. The distance travelled from the casting yard to the site may be a few metres or may be hundreds of kilometres, depending on the value added by adopting precast construction.

Precast concrete beams for very large crude carrier jetties for Jurong Island in Singapore were produced 40 km away from the site and were transported to the site, see "(Figure 1)". "(Figure 2)" shows architectural facades with window openings and structural walls which were produced about 5 km from the site.

Figure 1 — VLCC Jetties

Figure 2 — Precast Bay Window and Walls

The very existence of precast concrete industry and quite a few successful building projects achieved using precast concrete is proof that the technique is practical and economical. "(Figure 3)" shows residential apartment building "The Esparis" in Singapore under construction. Housing and Development Board (HDB) in Singapore is responsible for building all public housing in Singapore. These houses make up around 80% of the island's housing. These are built using almost 70-80% precast elements including Façade walls, columns, load bearing walls, pre-stressed precast planks, staircases, lift walls etc. The key to success using precast concrete is to be able to offer the client, architect and consulting engineer a solution that is, buildable, economical and faster to build "(ref. 1,2,3)".

Figure 3 — The Esparis Executive Condominium Under Construction

Precast frames offer the advantages of simplicity in design and production with flexibility of application, permitting a wide range of facde treatments. Façade elements like precast bay windows in "(Figure 2)" with protruding ledges is a classical example of a wide range of surface features provided to the designer with a bagful of options. The precasting operation transfers the manufacturing and storage content of the project away from site, thereby eliminating many of the problems which a contractor may face when executing conventional construction namely, wet weather; lack of site space; noise; and waste disposal. "(Figure 4)" shows various precasting operations namely, mould preparation, concreting, curing, demoulding and storage during production of a precast façade element. Precast concrete façade elements can be produced to extremely high levels of accuracy because of the controlled factory environment and the use of quality steel forms or moulds; this provides for quick, easy erection and connection.

Figure 4 — Various Operations In The Production Yard During Production of Façade Elements

Planned delivery times, coupled with speed of erection made possible by the Product accuracy, results in shorter overall construction time - giving quicker closure of the structure and façade, hence allowing rapid follow-up by successive finishing trades. It depends on the location, type, function and physical details of the structure. Logically, the parallel off-site manufacture, accuracy of product, and speed of erection will provide savings over the total project. These savings can be enhanced by utilising the application of applied finishes and paints in the precast factory providing safer and quicker completion. In civil structures, smooth, off-form finishes are the norm. Requirements for surface texture and colour control can be customized based on the needs of any project. Likewise, for exposed structural members and building elements, a wide variety of surface textures and finishes is achievable.

Connections For Precast Components

Connections are defined as the system or assembly used to tie a precast member to the supporting structure or to an adjacent member. In the design of connections structural redundancy is generally eliminated to minimise forces. Where possible it is prudent to design a statically determinate system, which will accommodate long-term, incremental volume-change movement. Consideration of the behavior of connections both during erection and the life of the structure is necessary. Practical and economical connection design should consider the manufacture of the elements and construction techniques, as well as the performance of the connections for both serviceability and ultimate limit states "(ref. 2,3)".

General Design Criteria for connections: A connection must resist the forces to which it will be subjected during its lifetime. Some of these forces are apparent, for example those caused by dead and live gravity loads, wind, earthquake, and soil or water pressure. Others are not so obvious and are frequently overlooked. For the purpose of design of connections, ductility should be considered. Ductility in building frames is usually associated with moment resistance (rotational ductility) and in the case of precast structures may have a major impact on connection design.

The combined effects of shrinkage, creep and temperature differences can cause severe stresses on precast concrete elements and their supports if the end connections restrain movement. A connection should either be able to accommodate these strains or be strong enough to withstand the induced forces, or a mixture of the two. A connection should be durable for the environment in which it is placed. Many precast concrete connections are not vulnerable to the effects of fire and require no special treatment.

Maximum economy of precast concrete construction is achieved when connection details are kept as simple as possible, consistent with adequate performance and ease of erection. Furthermore, complex connections are more difficult to control and will often result in poor fit in the field. This can contribute to slow erection and less satisfactory performance. Precast concrete manufacturers should be allowed to use alternative details, methods or materials, provided the design requirements are met. These will often result in the most economical and best performing connections. Much of the advantage of precast, pre-stressed concrete construction is due to the possibility of rapid erection of the structure. To fully realize this benefit, and to keep costs within reasonable limits, field connections should be kept as simple as possible.

Loadbearing Connections For Wall Elements: The connections of a wall element must be detailed to carry the required design loads in service and allow quick and easy erection. There are a number of means of splicing or connecting walls into a structure. The most common are by grouted dowels. As precast concrete units are accurately made factory products, advantage can be taken of this by connecting precast to precast. Loads are transmitted either by direct bearing or by dowelled connections. Close attention to detail, planning, manufacture and site activities is required.

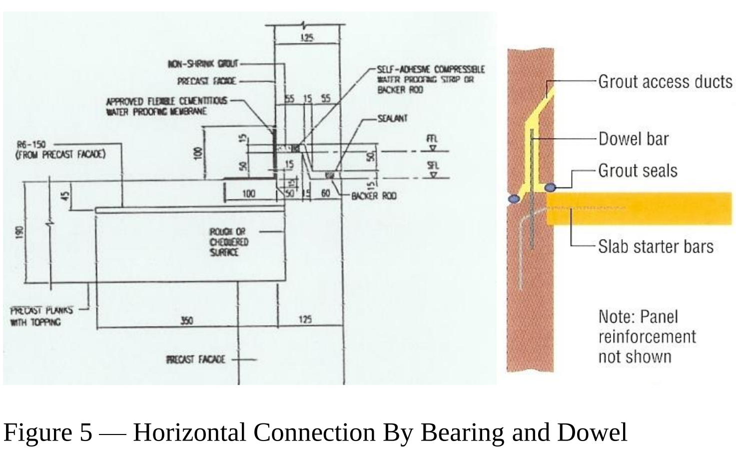

Figure 5 — Horizontal Connection By Bearing and Dowel

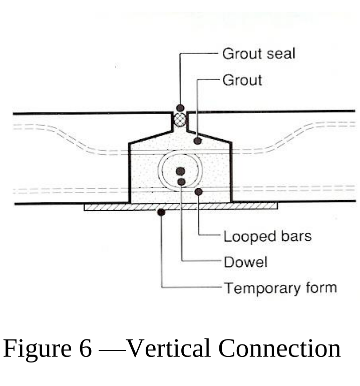

Figure 6 —Vertical Connection

Load transfer is through grout or dry packed mortar. "(Figure 5)" shows the horizontal joint at slab level. Vertical Joints are connected by in-situ grout or concrete. The adjacent panels to be connected will have protruding bars as shown in "(Figure 6)". Progressive collapse must be considered in load bearing wall panel construction. Providing alternative load paths in the structure by continuity of reinforcement across joints does this. Realistic erection tolerance should be provided for.

Water Proofing For Façade Walls: Providing a waterproofing solution to all the precast concrete external walls is a very important aspect in precast construction. Water proofing for horizontal joint is achieved by a 3 tier barrier. "(Figure 5)" shows the horizontal joint which is provided with a nib. This gives a gradient for the water vapors to climb up. External face or the active face of the joint is covered by sealant which is a tested and guaranteed product. Inner face of the joint is also provided with waterproofing membrane. For vertical Joints, sealant is provided at the external face and the inner part is provided with membrane.

Case Study Of The Esparis Executive Condominium

Project Brief: It consists of 5 Blocks of 10-Storey Residential Flats (274 units) Environmental deck with Basement carpark, Swimming pool, tennis court, children's play ground & club house refer to "(Figure 7)". Located at Pasir Ris Drive 4, its total gross floor area is 34,955 M^2. Total duration of project is 27 months.

Figure 7 — Key plan of The Esparis Executive Condominium

Project Team:
Developer/Owner: City Developments Ltd.; Architect: Team Design Architects Pte. Ltd.
Design and Build Contractor: Ando Coporation; Structural Consultant: Meinhardt(Singapore) Pte. Ltd
M&E Consultant: Squire Mech Pte. Ltd; Precaster: Hong Leong Asia Ltd
Precast Consultant: WP Brown Singapore

Structural System: The structural system consists of vertical Precast Components see "(Table 1)"and in-situ flat slab system. Precast loadbearing elements include Columns, external walls and house hold shelter walls. Other elements include, bay windows, and architectural façade. Precast wall joints require vertical pour strips and hence, it can't be dry construction. The connection details discussed previously are followed in most cases. However, in the case of columns and shear walls, corrugated ducts are used instead of splice sleeves for cost considerations. Various precast components including the precast façade elements for a typical unit are shown in "(Figure 8)"

Table 1 — Details of Precast Elements

INSTALLATIO NSEQUENCE	UNIT C4 / C4X (h) Marking Ref.	ITEM	WEIGHT (tonnes)	LIFTING REQ'T Gears/Hook
1	C4-HS	HS WALL	4.50	3
2	C4-SW2	SHEAR WALL	4.29	2
3	C4-SW3	SHEAR WALL	1.71	2
4	C4-HBW3	BAY WINDOW	1.42	3
5	C4-FA2	FAÇADE	2.59	2
5	C4-SW1	SHEAR WALL	4.70	2
6	C4-FBW1	BAY WINDOW	2.77	4
7	C4-AL1	AC LEDGE	3.24	4
8	C4-C1	COLUMN	2.09	1 hole
9	C4-FBW3	BAY WINDOW	3.50	4
10	C4-HBW1	BAY WINDOW	2.18	3
11	C4-HBW2	BAY WINDOW	2.18	3
12	C4-SW4	SHEAR WALL	2.85	2
13	C4-FBW4	BAY WINDOW	4.27	4
14	C4-C4	COLUMN	1.39	1 hole
16	C4-C3	COLUMN	1.39	1 hole
17	C4-RC	REFUSE CHUTE	3.30	4
18	C4-AL2	AC LEDGE	5.10	4
19	C4-C2	COLUMN	3.11	1 hole
20	C4-PD1	DUCT	0.60	2
21	C4-PL1	PLANTER	1.80	2
22	C4-FBW2	BAY WINDOW	4.41	4

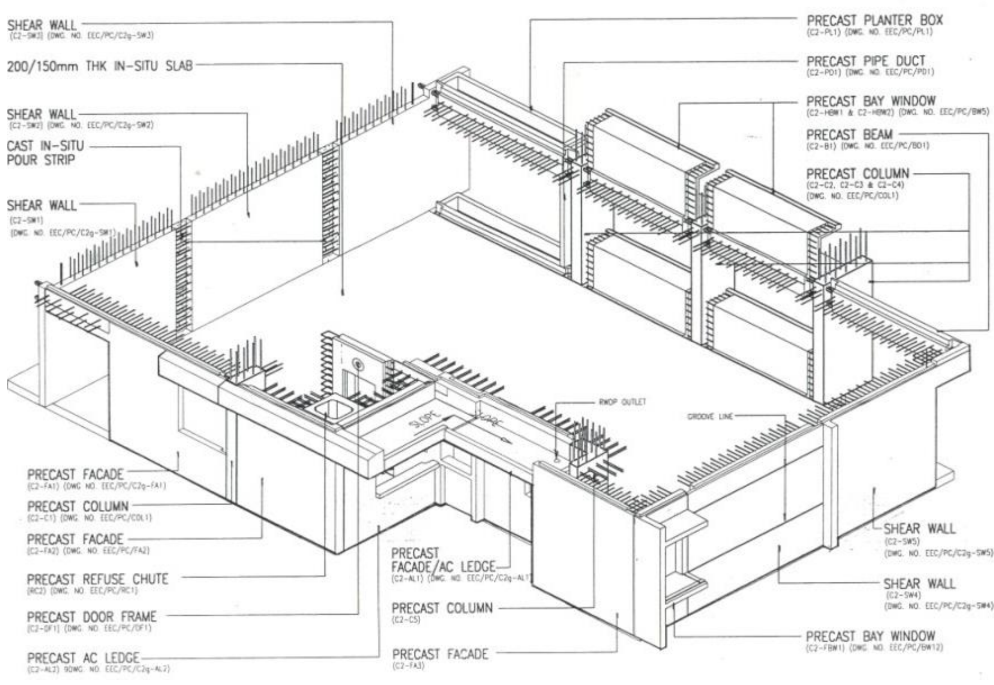

Figure 8 — Precast Facade Elements for Esparis Condominium Project at Singapore

Precast Operation

Production Planning and Moulds: It mainly depends on the construction schedule at site, the floor cycle time. The project was divided into 2 phases for construction. The critical phase had 3 blocks being constructed at the same time with a cycle time of 9 days per floor. Each block has 6 units per floor and each unit has about 22 precast components. Therefore, total no. of precast components per floor works out to be, 6x22x3=396. Assuming number of production days to be 6 days/week, minimum number of moulds required will be = (396/9)x(7/6) = 52. The procurement of moulds is a very important part to start the production process. As soon as the precast concept design is finalysed, the precast component body drawings which will be used for mould production have to be done. These drawings are as good as shop drawings and this has to be confirmed by all the consultants. Once these drawings are finalysed, the mould plate and support runners, frames have to be designed and mould drawings have to be prepared. Moulds are usually done with a number of pieces and hence the production staff should be trained to assemble and dissemble the moulds refer "(Figure 4)".

Each casting has to go thru checking of dimensions, features, recess, block-outs etc. After the reinforcements and fixtures are fixed, the concrete of appropriate strength will be poured and cured. For curing, steam curing may be an option if faster curing is required. After the curing, the component can be demoulded. After this the product is skimmed/applied finishes and marked with an identification number and sent to the storage yard. When required by the site, it is delivered to site.

<u>Delivery And Storage At Site:</u> As precast component is produced off-site in most cases, it is important to understand the approach roads, their turning radius, maneuverability of the transporting vehicle to and within the site and number of such vehicles that can be parked in the site. These must be marked on the site and reserved for these vehicles so that the space is not used for other purpose refer "(Figure 9)". Usually the precast components are delivered to site ahead of schedule by at least one floor. A part of considerable storage space is reserved for stacking the precast components. The space for storage and parking area for transportation vehicle are to be planned very meticulously considering the location of the tower crane and its boom length.

Figure 9 — Delivery and Storage of Precast Components at Site

<u>Installation:</u> This is the final and the most important process of the precast construction. Various operations during installation namely, preparation works, fixing rubber seals, hoisting, lowering, propping are shown in "(Figure 10)".

Figure 10 — Various Operations During Installation of Precast Components

After the installation is completed, the joints are filled with non-shrink grout or non-shrink concrete produced out of smaller aggregate (<10mm). Following are the important aspects considered during the installation of precast components:

- Lifting hooks in the precast components should be located such that the component when hoisted remains vertical for easy installation.
- Preparation works include marking offset line, checking shim plate level and rubber gasket.
- Check horizontal alignment, ensure panel plumb, gap between panel to panel.
- Secure the diagonal support.
- Seal all the horizontal joints. Prepare required grout mix and pressure grout until the pipe is full and overflow to

outlet pipe. Refer “(Figure 11)”.
- Keep the precast component undisturbed for 24 hours.
- Fix and lap joint reinforcement for vertical joint. Secure the formwork and cast the joint with small sized aggregates and grout mix.

Figure 11 — Preparation for Grouting and Vertical Connection Post Installation of Precast Components

Monitoring: To have smooth functioning of production, delivery and erection of precast components, monitoring of the following has to be done both at site as well as production yard.
- Production of precast elements as per site schedule and requirements.
- Marking of Precast elements appropriately
- Delivery to site
- Storage at site
- Erection of precast elements
- Maintain a record showing the progress of production, storage at plant, delivery, storage at site and erection of precast components.

Safety and environment: Provisions are made at the top of the precast components in the form of starter bars which can be used for providing safety barricade. Hazard analysis is done prior to all the activities and all the persons involved in the activity are briefed of the possible hazards. Environmental aspects and impact analysis is done and various parameters are monitored.

Conclusions

- Precast concrete construction is very much a viable solution where, quality, surface finish, speed and product quality are sought.
- Using precast construction around the building façade can minimize the problems at site by reducing staging, safety measures, construction of features etc.
- Precast infill walls provide rigid wall system for tall buildings as the reinforcements can be continued thru the voids of the infill walls.

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