
PRECAST CONCRETE CONSTRUCTION HANDBOOK

*An explanatory handbook to
Code of Practice for Precast Concrete Construction 2003*

Structural Division
The Hong Kong Institution of Engineers



Foreword

It is my great honour to represent the Structural Division of the Hong Kong Institution of Engineers to express our sincere gratitude to the Working Committee for writing this Handbook on the Code of Practice for Precast Concrete Construction 2003.

There has been a long history of adopting precast concrete construction in Hong Kong. With the advancement of technology, its application nowadays is not only limited to linear or planar concrete elements, but also to volumetric precast concrete units covering both structural and non-structural applications. The design, manufacture, and fabrication of the precast concrete elements or units and quality control throughout the construction process are therefore of utmost importance to ensure the quality and safety of the works. Thanks to the hard work of the Working Committee, this Handbook has successfully integrated expert knowledge in all these aspects and provides a practical guide to all practitioners for understanding the Code for successful application of precast concrete construction.

The Handbook is written to elaborate the Code on major concerns and adopts the same paragraphing of the Code for easy referencing. It translates the wealth of knowledge and experiences in precast concrete construction in Hong Kong into its content with a large number of tables, figures, and photos to facilitate readers to comprehend the requirements in the Code and grasp their actual applications on site. It also embraces a comprehensive list of design examples covering most if not all the major design issues, sample outlines on quality assurance system, sample specifications on precast concrete construction, and project examples on wide adoption of precast elements for sharing with users. I trust you will find this handbook practical and useful. I highly recommend you to read it and share it with others.

Last but certainly not least, I would like to thank the Working Committee, led by Ir Dr. Eddie S. S. LAM for their time and dedicated efforts in writing this Handbook. Without their contribution, the completion of this Handbook would not have been possible.

Ir Martin W. T. TSOI
Chairman
Structural Division, HKIE
May 2015

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Prepared by: Joint Structural Division

Technical Committee:

Chairman:	Ir Dr Eddie S.S. LAM	The Hong Kong Polytechnic University
Members:	Ir Chris W.Y. CHENG	Gammon Construction Ltd
	Ir Tony P.C. CHEUNG	Meinhardt (C&S) Ltd
	Ir Kenith K.K. HO	Meinhardt (C&S) Ltd
	Ir S.C. LAM	Housing Department
	Ir Dr S.S. LAW	The Hong Kong Polytechnic University
	Ir Stephen Y.C. LEE	Buildings Department
	Ir Philip S.W. SHAM	Housing Department
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	Ir Aldows H.C. TANG	Meinhardt (C&S) Ltd
	Ir Ben W.K. TSE	C M Wong & Associates Ltd
	Mr Conrad T.C. WONG	Hong Kong Construction Association
	Ir Gary C.L. WONG	Yau Lee Construction Co. Ltd
	Secretary:	Dr Ivy F.Y. HO
Dr B. LI		The Hong Kong Polytechnic University

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1 GENERAL

1.1 SCOPE

This Handbook serves to provide practical guidance and examples to practitioners on the application to buildings of the Code of Practice for Precast Concrete Construction 2003 (“**the CoP**”). The Handbook does not intend and has made no attempt to interpret the CoP nor to override the requirements as specified in the CoP.

With the advance of production techniques and equipment for transportation and erection, precast concrete construction is feasible and cost effective (Gibb 1999). Compared with traditional construction methods, it offers ease of quality control, increase in productivity, improved site safety, reduction of construction waste on-site, etc. (CIRIA 1999). In fact, it is now common to couple standardized/modularized precast elements with traditional construction methods to improve buildability and to reduce cost (BCA 2005).

In Hong Kong, precast concrete construction was first introduced into building projects in the 1980s by the Hong Kong Housing Authority for public housing. It has been progressively applied to the private sector following recommendation by the Construction Industry Review Committee Report (CIRC 2001) for the wider adoption of precast concrete in the construction industry. Another motivating influence is the implementation of Joint Practice Notes No. 1 and 2 (JPN1:2001, JPN2:2002) promoting green and innovative building technologies and prefabrication. In 2002, precast elements accounted for about 17% of the concrete volume used in public housing projects (Chiang *et al.* 2006). By the end of 2008, a total of 396 private building projects with one or more green features, such as non-structural prefabricated external walls, were approved by the Building Authority (Director of Buildings).

1.2 DEFINITIONS

Unless expressly stated otherwise, the Handbook uses the same terminology as defined in Section 1.2 of the CoP. The following are typical examples of the terminologies adopted in the CoP.

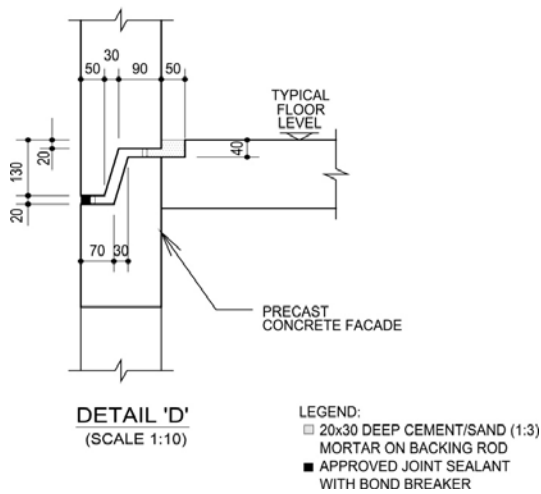


Figure 1.1 Back-up material inserted in a joint to control the depth and back profile of sealant.

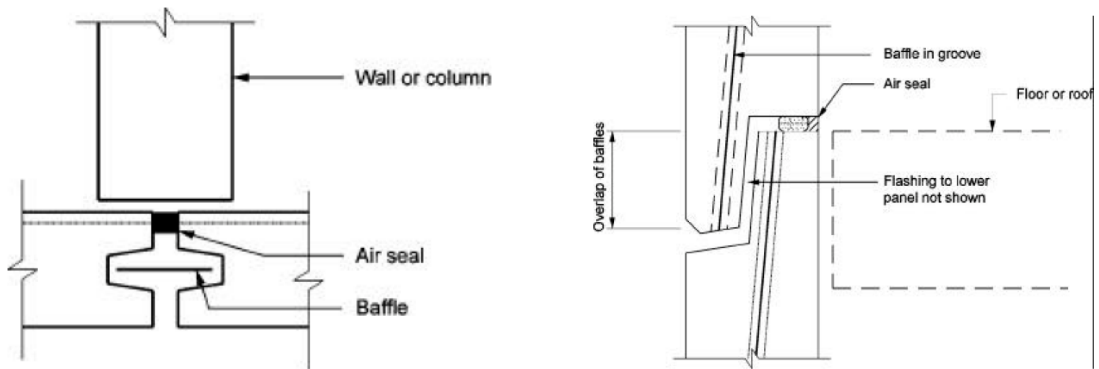


Figure 1.2 Baffle is inserted in grooves to block the passage of rain or water.

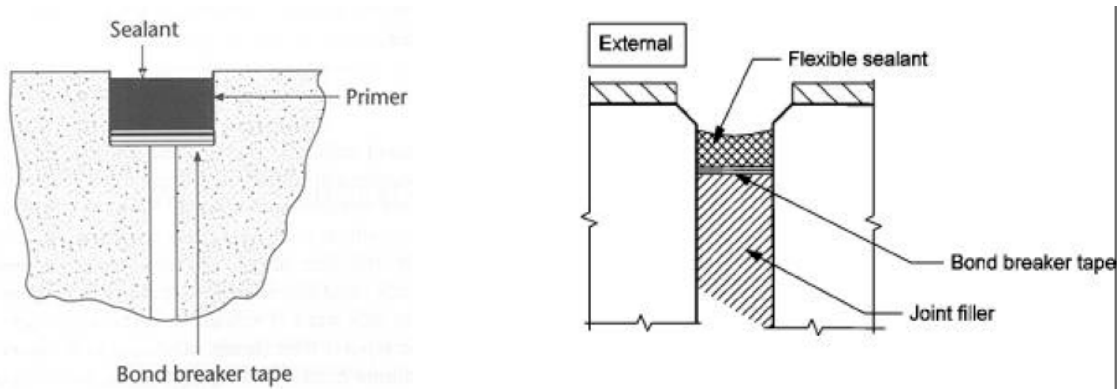


Figure 1.3 Bond breakers are inserted to prevent joint sealant from adhesion to the back of the joints.

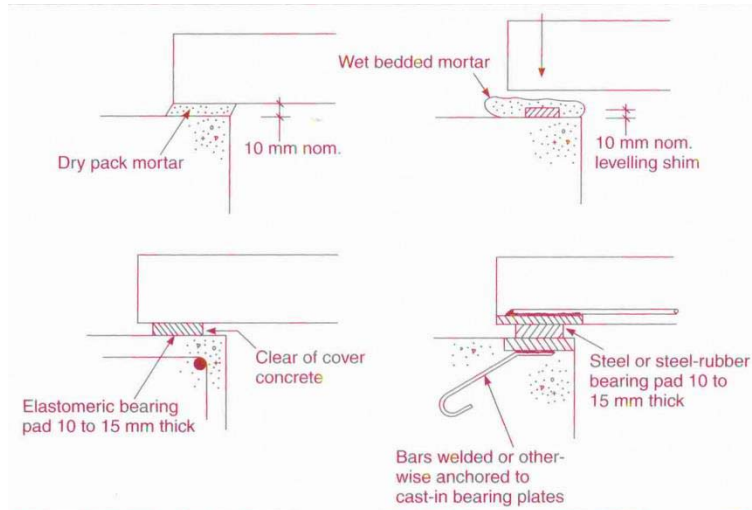


Figure 1.4 Examples and definitions of bearings.

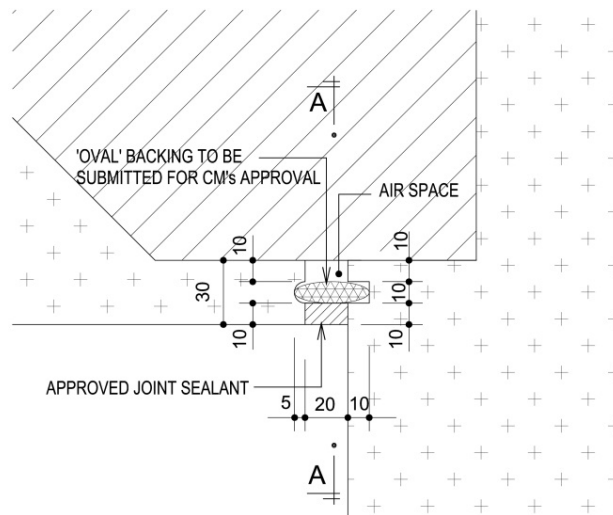


Figure 1.5 Gasket is elastic material that forms a seal when compressed.

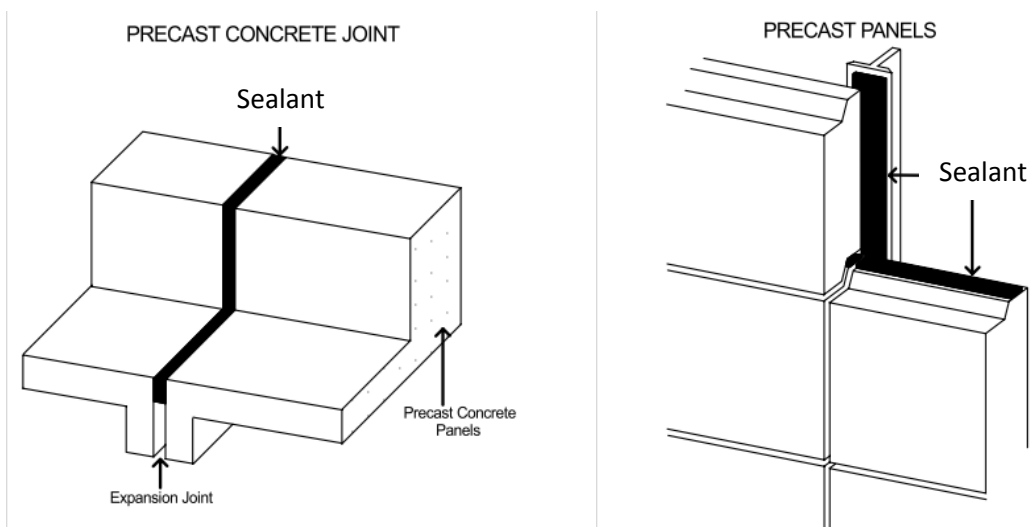


Figure 1.6 Sealant seals a joint by adhering to appropriate surfaces within the joint.

1.3 SYMBOLS

Unless expressly stated otherwise, the Handbook uses the same terminology as defined in Sections 1.3 of the CoP.

G_k	characteristic dead load
Q_k	characteristic imposed load
f_{cu}	characteristic strength of concrete
f_y	characteristic strength of reinforcement

1.4 ABBREVIATIONS

For ease of reference, the following abbreviations are adopted in this Handbook.

CoP	Code of Practice for Precast Concrete Construction 2003
Concrete Code 2013	Code of Practice for Structural Use of Concrete 2013
Steel Code 2011	Code of Practice for Structural Use of Steel 2011
FRC Code	Code of Practice for Fire Resistance Construction 1996
PNAP	Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers
B(C)R	Buildings (Construction) Regulations, Chapter 123 Subsidiary Legislation

2 DESIGN

2.1 SCOPE

2.1.1 General

The primary objective of the CoP is to outline the design, fabrication and construction practices for precast elements. Consideration has been given to the provision of adequate strength, durability and overall serviceability of precast members with respect to their intended functions.

The CoP is equally applicable to structural and non-structural precast elements that are factory-produced for use in building structures and is intended to provide minimum standards for precast elements.

2.1.2 Standards and codes of practice

Precast elements must be designed and constructed in accordance with the B(C)R, Code of Practice, Practice Notes for Authorized Persons, Registered Structural Engineers and Registered Geotechnical Engineers and Practice Notes for Registered Contractors. The main Code of Practice and Practice Notes related to the CoP are as follows:-

Code of Practice:

Code of Practice for Fire Safety in Buildings 2011
Code of Practice for Fire Resistance Construction 1996
Code of Practice for Precast Concrete Construction 2003
Code of Practice on Wind Effects in Hong Kong 2004
Code of Practice for Structural Use of Concrete 2013
Code of Practice for Structural Use of Steel 2011

Practice Notes

APP-105, Water Seepage
APP-143, Quality Control and Supervision of Precast Concrete Construction
PNRC 63, Quality Control and Supervision of Precast Concrete Construction
PNRC 67, Building External Finishes – Wet-fixed Tiles

The design of precast elements generally follows the CoP and is based on the limit state design method with due consideration to durability and fire resistance. Other alternative design approaches may be used, provided sufficient justifications are given.

2.2 PLANNING

2.2.1 Standardisation

To maximize the environmental attributes of precast elements, the adoption of standardized precast elements is desirable. Standardized precast elements are well suited for mass production because the fabrication process is automated

so as to minimize labour costs, to minimize waste generation and to optimize the use of formwork. By contrast, the production of non-standardized precast elements requires modification to formwork and this could be uneconomical, impractical and increases the risk of error. An additional advantage in standardizing precast elements is the obvious saving in learning time on site and in speed of construction.

To facilitate the use of standardised precast elements, it is necessary to co-ordinate the designs of different precast element shapes at the conceptual stage. For example, when prefabricated wall panels are used to form the building envelope, it is desirable to minimize the types of different prefabricated wall panels. By refining the architectural layout, the building faces can be formed by combining a number of different prefabricated wall panels. As a result, dimensions and geometry of individual prefabricated wall panels can remain unchanged to maximize possible reuse.

2.2.2 Buildability

To take full advantage of precast elements in making the construction easier and cost effective, proper planning and detailed design is necessary. Some of the main practical concerns include:-

1. Limitations at the factory may affect the method of fabrication
2. Transportation from factory to construction site
3. Limitations of the construction site for storage of precast elements
4. Ease of erection
5. Connection details between precast elements and structural members

All of the above have to be planned in advance at the design stage so that coordination between architect, engineer and contractor is necessary.

When developing the master programme, a lead time is required for setting up and/or preparing the factory for the fabrication of precast elements. This may be off-set by consolidation of the building form in advance so that the master programme may be adjusted to allow for the lead time. For example, the time needed for the construction of podium is usually sufficient to absorb the lead time required for fabrication of precast elements.

2.2.3 Voids and buried conduits

With proper planning and coordination of the design, it is possible to incorporate voids and service openings when fabricating the precast elements. Alternatively, openings may be drilled or cut to size but this may cause difficulty in avoiding the reinforcement.

Notwithstanding that the CoP allows cast in or buried conduits to be installed within the reinforcement layers of precast elements, it is advisable to design the routing of all water-borne piping as separate from structural elements (in accordance with APP-105 on Water Seepage).

2.2.4 Layout plan

Construction drawings and structural layout plans are both required. Construction drawings should provide sufficient detail (including formwork detail, curing of precast elements, handling at early age, etc.) for the fabrication of the precast elements. Structural layout plans comprise a comprehensive set of drawings to such detail as recommended in ADM-8 on Structural Design Information. Main details of the structural layout plans are as follows:-

1. Materials including concrete and reinforcement
2. Grade and characteristic strength of structural materials
3. Concrete cover, corrosion protection and fire resistance
4. Method statement on workmanship and/or construction
5. Sufficient floor plans, sections and elevations with dimensions, levels and identification of all members
6. Connection details

2.2.5 Compatibility

In general, the structural engineer is required to carry out detailed design of the precast elements. The contractor is required to fabricate the precast elements and prepare a detailed method statement for their erection. Coordination between the two parties is necessary to ensure compatibility at all stages of construction. In general, the structural engineer will take the coordination role in overseeing the overall planning and design of the precast elements.

2.2.6 Demolition

It is necessary to provide detailed construction drawings and well documented joint details and method statements to facilitate proper planning for future demolition. To design and plan for future demolition of a structure, and precast elements in particular, it is recommended that reference is made to the Code of Practice for Demolition of Buildings 2004 and the Building (Demolition Works) Regulations.

2.3 STABILITY

2.3.1 General

Stability of the complete structure and of individual components must be considered at all stages of construction. Cast-in-situ structural elements of a precast concrete structure must form a stable structure (i.e. excluding the contribution of precast elements, if any). Precast elements must not be relied upon, before the joints and connections have gained sufficient strength, to transmit forces between cast-in-situ structural elements and precast elements. Table 2.1 shows typical combinations of stabilizing systems. If necessary, cross walls, sway frames and/or temporary bracing have to be arranged to

provide sufficient stiffness for stability.

Table 2.1 Typical combinations of stabilizing system

Stabilizing component	Frames	Load bearing walls	Load bearing facade
Cantilever column	Yes		
Frame with moment resisting connections	Yes		
Floor diaphragm	Yes	Yes	Yes
Shear wall		Yes	Yes
Central core		Yes	Yes

It is necessary to maintain horizontal stability, for example when transferring wind load and other horizontal loading to the foundation. The design for a notional horizontal load of 1.5% of the characteristic dead load is required only if wind loading is not governing. The provision can also be referred to Concrete Code 2013 at clause 2.3.1.4(a).

Adequate propping and bracing must be provided at all stages of construction and must be designed and specified on the drawings with detailed method statements.

For a frame structure comprising individual precast elements, it is necessary at the construction stage to consider the stability of cantilevered columns. After the joints have gained sufficient strength, stability of the structure is provided by making use of the flexural and shear continuity at the joints. Alternatively, structural walls (e.g. core walls, shear walls) can be used to resist lateral load and to transfer lateral load to the foundation. Precast floors are designed to carry in-plane horizontal loads by diaphragm action in a manner similar to that of a deep beam.

Braced frames, elevator shafts, stair cores (or service cores) are effective structural systems providing lateral stability and the additional cost of utilizing them as stabilizing system is negligible. This simplifies connection detailing as the load transferring mechanism for horizontal force is concentrated on members of these rigid restraints.

Stability at all stages of erection must be carefully considered. Temporary bracings are often necessary.

2.3.2 Displacement

2.3.2.1 General

In assessing the lateral deflection of a building solely due to wind, elastic analysis can be conducted using the elastic modulus for normal-weight concrete based on Concrete Code 2013 at clause 3.1.5 and can be estimated by the following equation for concrete cube strengths between 20 and 100 N/mm² (extracted from Concrete Code 2013, equation 3.1).

$$E_c = 3.46\sqrt{f_{cu}} + 3.21$$

where E_c and f_{cu} are the respective short-term elastic modulus and cube compressive strengths in kN/mm^2 and N/mm^2 respectively. Typical values are given in Table 2.2 for easy reference.

Table 2.2 Elastic modulus against cube strength for normal-weight concrete

E_c (kN/mm^2)	f_{cu} (N/mm^2)
20	18.7
30	22.2
40	25.1
50	27.7
60	30.0

In assessing the deflection due to gravity loads, it is necessary to compare the effect of long term deflection against the limiting value of $\text{span}/250$, where span is that of the member under consideration.

2.3.2.2 Connection deformation

Connections are generally designed with such necessary restraint as to prevent them from excessive deformation.

2.3.3 Disproportionate collapse

Disproportionate collapse is defined as the spread of an initial local failure from element to element resulting in the collapse of an entire structure or a disproportionately large part of it. A building should not be vulnerable to extreme loads that may cause partial or total collapse. A properly designed and detailed structure with sufficient provision for structural integrity is able to resist the loading without forming a collapse mechanism after failure of the first link.

To reduce the risk of disproportionate collapse, it is necessary to prevent the propagation of a possible initial failure. This can be achieved by (wherever practically and economically viable) providing an alternative load path to prevent progressive collapse when local damage occurs. If this is not viable, the structure should be designed in such a way that the chance of local failure is kept to an acceptable minimum. For example, sufficient ties must be provided and the resistance of some key elements strengthened for added protection.

2.4 DURABILITY

2.4.1 General

The principal cause of deterioration of a reinforced concrete structure in Hong Kong is the corrosion of reinforcement, leading to subsequent cracking and the spalling of the concrete cover. This can be prevented by ensuring high

impermeability of concrete. With the above in mind, to ensure the design life and durability of precast elements, it is necessary to specify a suitable concrete mix and to provide sufficient concrete cover. A rich mix reduces the permeability of concrete whereas concrete cover protects the reinforcement in accordance with the expected exposure condition and fire resistance requirements. Other considerations include shape and size of the precast elements, protection and maintenance, production, transportation, storage, installation and design of joint details.

Alternatively, the rate of corrosion can be reduced by restricting the diffusion of air and/or moisture into the concrete by improving its quality (e.g. increasing its strength, “sheltering” concrete with an impermeable layer such as finishes, reinforcing the concrete cover using steel wire mesh).

It is possible to enhance durability by improving the surface of concrete using permeability formwork. In general, the compaction of concrete drives excess air/water to the formwork surface resulting in a less dense and more porous surface. By inserting a layer of filter lining adjacent to the formwork (hence the term permeability formwork), excess water and air can escape and drain via the filter lining so that a dense matrix of better quality concrete can be achieved at the cover zone. Typically, filter lining is made of polypropylene fibres in rolls of varying length.

The durability of concrete can also be improved by controlling or alleviating the formation of micro-cracks. Adding micro-fibres into the concrete mix can “hold” the cementitious matrix of the concrete together to reduce localized cracking.

2.4.2 Shape of precast unit

In general, there is no specific restriction on the shape of precast elements. However, it is necessary to recognize the tolerances attainable during construction by making allowance for the differences between factory tolerances and those of normal site construction. Therefore, for irregularly shaped precast elements, due consideration must be given to constructability in addition to design.

Sharp corners or sudden changes in section should be avoided or should be checked against possible stress concentrations and strengthened to prevent possible cracking or spalling of concrete.

Precast elements subjected to discharge of water (e.g. canopies, balconies, toilet units) should be designed and detailed with good drainage to prevent standing pools or entrapped moisture.

2.4.3 Concrete cover

Concrete cover is governed by concrete mix proportion, exposure condition and fire resistance. Table 2.3 (extracted from Concrete Code 2013) specifies the nominal cover to all reinforcement (including links), maximum free

water/cement ratio and minimum cement content for a designed mix using 20 mm nominal maximum sized normal-weight aggregates. Tables 2.4 and 2.5 (extracted from the FRC Code) specify the minimum dimensions and nominal cover for different types of structural member for different fire resistance periods.

Table 2.3 Nominal cover, water/cement ratio and cement content for different grades of concrete

Exposure condition	Type of exposure						
Mild	Internal concrete surfaces. External concrete surfaces protected from the effects of severe rain or cyclic wetting and drying e.g. concrete finish with mosaic tiles, painting or rendering. Concrete surfaces continuously under water, or rarely dry - not sea water. Concrete in contact with non-aggressive soil.						
Moderate	Internal concrete surfaces exposed to high humidity e.g. bathrooms and kitchens. External concrete surfaces exposed to the effects of severe rain or cyclic wetting and drying e.g. fair faced concrete, concrete with cladding secured by dry or mechanical fixing, curtain walling.						
Severe	Concrete surfaces exposed to sea water spray through airborne contact but not direct exposure, i.e. structures on or near the coast. Concrete surfaces exposed to corrosive fumes.						
Very Severe	Concrete surfaces frequently exposed to sea or flowing water with $\text{pH} \leq 4.5$. Concrete in sea water tidal zone down to 1 m below lowest low water level.						
Exposure condition	Nominal cover to all reinforcement (including links) (mm)						
Concrete grade	C20/25	C30	C35	C40	C45	C50	\geq C55
Mild	35	30	30	30	25	25	25
Moderate	-	40	35	35	30	30	30
Severe	-	-	-	50	45	45	45
Very Severe	-	-	-	-	-	55	50
Max. water/cement ratio	0.65	0.65	0.60	0.55	0.45	0.40	0.35
Min. cement content (kg/m ³)	290	290	290	300	340	380	380
Notes: For slabs under mild exposure, nominal cover may be taken as 25 mm (for concrete of grade C35 or above) or 30 mm (for concrete grade of C30 or below). For prestressed concrete, concrete of grade C30 or below should not be used and the minimum cement content should not be less than 300 kg/m ³ .							

Table 2.4 Minimum thickness for different fire resistance period

Construction and materials	Minimum thickness (mm) for fire resistance period of		
	4 hours	2 hours	1 hour
Reinforced concrete walls			
(a) containing >1% vertical reinforcement	180	100	75
(b) containing <1% vertical reinforcement	240	160	120
Floors and landings of solid reinforced/prestressed concrete construction	170	125	100
Reinforced concrete columns and hangers			
(a) fully exposed	450	300	200
(b) 50% exposed	350	200	160
(c) One face exposed	240	160	120
Width of reinforced/prestressed concrete beams	280	200	200
Waist of stair slab of reinforced concrete construction	170	125	95

Table 2.5 Concrete cover for different fire resistance period

Construction and materials	Concrete cover (mm) for fire resistance period of		
	4 hours	2 hours	1 hour
Reinforced concrete walls			
(a) containing >1% vertical reinforcement	25	25	15
(b) containing <1% vertical reinforcement	25	25	25
Floors and landings of solid construction			
(a) reinforced concrete			
(i) simply supported	55*	35	20
(ii) continuous	45*	25	20
(b) prestressed concrete			
(i) simply supported	65*	40	25
(ii) continuous	55*	35	20
Reinforced concrete columns and hangers			
(a) fully exposed	35	35	25
(b) 50% exposed	35	25	25
(c) One face exposed	25	25	25
Beams			
(a) reinforced concrete			
(i) simply supported	80*	50*	30
(ii) continuous	60*	40	30
(b) prestressed concrete			
(i) simply supported	90*	70*	30
Stair slab of reinforced concrete construction	55*	35	20
Note: * Reinforcement consisting of expanded metal lath or a wire fabric not lighter than 0.5kg/m ² with 2 mm diameter wire at not more than 100 mm centres or a continuous arrangement of links at not more than 200 mm centres should be incorporated in the concrete cover at a distance not exceeding 20 mm from the face.			

2.4.4 Protection and maintenance of joints and connections

2.4.4.1 General

To ensure durability of a structure, it is necessary to protect the embedded reinforcement from corrosion, thereby preventing cracking and spalling of the concrete cover.

2.4.4.2 Protection of steel

The connections between precast elements and structural members must be properly filled with concrete or grout. It is necessary to provide sufficient bonding between the concrete or grout and the parent substrate to prevent delamination at the joint surface. This can be achieved if the filling material (i.e. concrete or grout) is compatible with that of the parent elements and structures. Sufficient concrete cover must be provided to protect the steel reinforcement in accordance with clause 2.4.3 above. Whenever necessary, bond strength between concrete or grout and steel reinforcement must be checked.

In general, this is a matter of quality workmanship. Proper supervision of topping, concreting or grouting is required to ensure quality protection of reinforcement.

2.4.4.3 Protection of fixings

Fixings are generally protected by concrete or grouting acting as cover. If sufficient cover cannot be provided, exposed connection details (e.g. brackets) can be protected by hot dip galvanizing or using an alternative material such as stainless steel. In such cases, it is necessary to prevent possible bimetallic action due to the dissimilar materials by avoiding the mixing of galvanized and non-galvanized reinforcement, and steel reinforcement and stainless steel reinforcement.

2.4.4.4 Maintenance accessibility

Connections between precast elements and structural members are usually non-accessible and must be properly protected from corrosion. In the case of expansion/contraction joints and flexible joints, access must be provided for regular inspection and proper maintenance. In such cases, demountable access, which is easily and safely accessed must be provided.

2.4.5 Movement

To ensure durability of a structure, reasonably anticipated movement must be considered in the design. Movement is allowed by the incorporation of joints detailed as given in clause 2.7.7 below.

In the application of precast elements to high-rise buildings especially for structural use, provision for possible movement due to the elastic shortening of

vertical members must either be considered in the design or provided for at the construction stage.

2.4.6 Thermal gradient

If necessary, assessment of crack widths is made by reference to Concrete Code 2013 clause 7.2.

2.4.7 Other effects

This is a general provision concerned with other indirect effects that have to be considered including loading changes, temperature differentials, creep, shrinkage, etc. The above can be satisfactorily dealt with by proper design and construction of the precast elements.

This sub-clause specifies two areas of concern namely, (a) limiting the cracking and deformation arising from early-age thermal movement, creep, shrinkage, etc; and (b) minimizing restraints on structural components by providing bearings or movement joints, or if restraints are inevitable, the design should take into consideration any significant effects that may arise.

With proper design of the precast elements and control during fabrication and curing, possible effects due to temperature differentials, early stage creep and shrinkage can be reduced. Concerns related to minimizing restraints on structural components are best dealt with when specifying the joints between the precast elements and parent substrate.

2.5 LOADINGS

2.5.1 General

The appropriate loads should be based on the B(C)R and the relevant codes of practice. Dead load can be estimated based on the dimensions of the members with due consideration of finishes, floor-screed, etc. Imposed loads specified in the B(C)R are only minimum standards and actual conditions must be fully explored when specifying the imposed load. Wind load is required to be considered in the design of a precast member when exposure to wind conditions in the construction stage or in service after construction is anticipated. Recommendations on the design wind load are found by reference to Code of Practice on Wind Effects in Hong Kong 2004.

Variations in load distribution (with time) during construction should also be considered, e.g. variations in propping loads due to the effect of prestressing.

The CoP specifies two types of loading, namely construction loads and notional horizontal forces. Construction loads should not be less than 1.5 kN/m². Notional horizontal force caters for vibration reasonably anticipated during construction and should not be less than 1.5% of the characteristic dead load. When in doubt, construction loads and notional horizontal forces should

be estimated based on actual conditions.

2.5.2 Demoulding forces

When a newly-cast precast element is lifted from its casting bed or formwork, it will be subjected to self-weight and demoulding forces caused by adhesion between the precast element and casting bed or formwork. Different kinds of precast element may have different demoulding forces. Demoulding force is affected by shape, self-weight, surface roughness of casting bed, strength of concrete, etc. Table 2.6 shows examples of equivalent load factors for demoulding forces. It is assumed that form oil is applied and that the moulds have removable side forms. Forces applied to a precast element (i.e. self-weight plus demoulding force) are accounted for by multiplying the self-weight by an equivalent load factor.

Table 2.6 Examples of equivalent load factors for demoulding force

Type	Equivalent load factor
Flat precast concrete slab	1.3
Flat precast concrete beam	1.3
Flat precast wall panel (cast horizontal)	1.3
Precast façade with formed rebates or reveals (e.g. bay window, A/C hood, façade toe, architectural projection)	1.4

2.5.3 Handling and transportation

Dynamic loads and impact forces during handling, transportation and erection of precast elements are incorporated by applying a load factor to the self-weight in a way similar to that for demoulding forces. Table 2.7 shows the load factors for handling and transportation.

Table 2.7 Load factors for handling and transportation

Stage	Load factor
Yard Handling	1.2
Transportation	1.5
Erection	1.2

Care must be taken with respect to these load factors. At the factory, the controlling factor is likely to be 1.3 as associated with demoulding, rather than 1.2 for yard handling. Likewise, if the same lifting method is used for transportation and erection, load factor of 1.5 for transportation will be the controlling factor and not that of 1.2 for erection.

For safety reasons, it is not recommended to allow any person or construction material to be placed on precast elements during lifting. Therefore, live load on precast elements at the lifting stage is usually neglected.

Under severe wind conditions, the lifting of precast elements is not

recommended. Therefore, wind load on precast elements is ignored at the lifting stage.

2.6 MATERIALS

2.6.1 General

In general, the B(C) R specifies the standard for cement (regulation 50), sand (regulation 11), aggregate (regulation 51), water (regulation 52), admixtures (regulation 53) and reinforcement (regulation 54).

2.6.2 Alkali-aggregate reaction

2.6.2.1 Alkali-silica reaction

Alkali-Silica Reaction is a chemical reaction which occurs over time in concrete between the highly alkaline cement paste and reactive non-crystalline (amorphous) silica found in many common aggregates. This reaction causes the expansion of the aggregate by the formation of a swelling gel of silicate hydrate. The gel increases in volume with water and exerts an expansive pressure inside the material, causing spalling and loss of strength of the concrete, finally leading to its failure. This chemical reaction can cause serious expansion and cracking in concrete, resulting in critical structural problems.

The CoP recommends a means of reducing the risk of alkali-silica reaction by limiting the reactive alkali content of concrete expressed as equivalent sodium oxide per cubic metre (to be less than 3.0 kg), to use low alkali cement or to replace part of the cement by pulverized fuel ash.

2.6.2.2 Alkali-carbonate reaction

Alkali-Carbonate Reaction (ACR) is similar to Alkali-Silica Reaction in that the alkaline environment of concrete attacks the aggregate that includes reactive particles. The alkaline environment reacts with dolomite limestone, replacing it with less stable and expansive products. This reaction usually occurs in early age concrete and structures may show cracking within the first few years after construction. Once ACR begins, it will continue until the reactants (i.e. dolomite and hydrated lime) are exhausted. Because of this, structural damage caused by ACR can only be repaired by complete replacement of affected members.

ACR can be prevented by the use of non-reactive aggregates, reducing available hydroxides, controlling moisture and temperature and minimizing porosity.

2.6.3 Chlorides in concrete

Chloride added to the concrete at the time of mixing is often referred to as Internal Chloride. This category includes calcium chloride accelerators for

rapid hardening concrete, salt contaminated aggregates and the use of sea water or other saline contaminated water.

Chloride ingress into the concrete from the environment is often referred to as External Chloride. This category includes both de-icing salt as applied to many highway structures and marine salt, either directly from sea water in structures such as piers, or in the form of air-borne salt spray in structures adjacent to the coast.

The effect of chloride salts depends to some extent on the method of addition. If the chloride is added at the time of mixing, the calcium aluminate within the cement paste will react with the chloride to some extent, chemically binding it to form calcium chloroaluminate. In this form, chloride is insoluble in the pore fluid and is not available to take part in damaging corrosion reactions.

The ability of cement to chemically react with the chloride is, however, limited and depends on the type of cement. Sulphate resisting cement, for example, has low calcium aluminate content and is therefore less able to react with the chlorides.

When chlorides ingress from an external source, particularly in conditions of saturation and low oxygen availability, insidious pitting corrosion of the reinforcement may occur, causing massive localised loss of cross section. This can occur in the early stages without disruption of the concrete underneath.

The chloride ion content of admixtures for normal concrete shall not exceed 2% by mass of admixture or 0.03% by mass of the cementitious content, whichever is the less (B(C)Rr53(2)). The total chloride content of normal concrete shall not exceed 0.35% by mass of cement in the mix (B(C)Rr56(3)).

To determine chloride content in concrete, dust samples are usually collected by drilling incrementally using a percussion drill and collecting the dust (after discarding the first 5mm) at 5-25mm, 25-50mm, 50-75mm and 75-100mm intervals. These samples are then tested in the HOKLAS accredited laboratory in accordance with BS 1881: Part 124: 1988.

2.7 DESIGN CONSIDERATIONS

2.7.1 General

The recommended methods for the design and detailing of reinforced concrete and prestressed concrete given in the Concrete Code 2013 are also applicable to precast elements. Spanning directions shall conform to the actual structural behaviour of the completed structure and the completed structure shall be designed in accordance with the Concrete Code 2013 under permanently applied design loads.

Pursuant to the CoP, design consideration should include handling stresses; early lifting of precast elements; temporary stages / erection sequence; lifting

inserts; bracing design; design for movement; design of ties; and design of bearings. In addition to general design considerations, the above also caters for both the construction stage and robustness. These are further elaborated in the following sections.

The CoP applies equally to structural and non-structural precast elements that are factory-produced for use in building structures and is intended to provide minimum standards for precast elements.

2.7.2 Handling Stress

To prevent possible damage arising from handling, storage, transportation and erection of precast elements, consideration should be given at the design stage to loads on erected elements at the construction stage and demoulding, storage, transportation and erection of precast units on site.

Regarding the loads on erected precast elements at the construction stage, the appropriate loads as specified in the B(C)R and the relevant codes of practice should be used. Design considerations should also be given to construction loads, notional horizontal loads and accidental loads (see Section 2.5.1), demoulding (see Section 2.5.2), and transportation and handling (see Section 2.5.3).

2.7.3 Early lifting of precast element

Where precast elements are lifted and handled prior to gaining full strength, the precast elements should attain concrete strengths not less than the minimum values specified in Table 3.2 of the CoP (see Section 3.9).

Precast elements should be designed, using these lower strengths, to span between lifting points without excessive cracking or deflection. For prestressed concrete, consideration should also be given to stresses resulting from the transfer of prestressing forces.

Minimum concrete strength should be checked before the commencement of any first lifting and handling, e.g. by cross-reference to the maturity curve of the trial mix or by carrying out compression tests on concrete cubes with the same age as the precast element at the time of lifting.

2.7.4 Temporary stages/erection sequence

The critical loading for precast elements may occur during the construction phase and, hence, temporary conditions may govern the design of precast elements. Therefore, consideration should be given to each phase of construction including those specified in the CoP:

- precast sections of composite elements which are required to support self-weight plus construction load prior to casting of an in-situ topping;
- lower precast floor slabs and precast stair flights which support propping to upper levels during installation; and

- bearing or halving joints which support higher temporary construction loads because of back propping to upper levels.

In general, structural action and load paths during the temporary stages are different from those at the permanent stage. This could lead to problems in structural integrity, structural continuity and higher stresses in individual members. All of these must be considered in the design at temporary stage which includes consideration of a suitable construction sequence.

Precast elements supporting propping to upper levels shall be checked against their concrete strengths attained at that stage to ensure they are able to sustain the construction loads from above. Timing of the removal of the supporting props at lower levels, if any, shall be checked to ensure the precast elements are not overstressed by the applied loads from above based on the concrete strengths attained at that stage.

2.7.5 Lifting inserts

2.7.5.1 General

In the design of lifting inserts, it is necessary to optimize the number and locations of lifting inserts so that the lifting insert capacity (safe working load) and stresses acting on the precast element will remain within acceptable limits. It is necessary to consider the strength of concrete at the age of lifting (see Section 2.7.3). Due consideration must be given to the locations of inserts so that the failure of any one insert does not cause failure of the entire lifting system thereby ensuring the element can still be safely supported.

The CoP specifically stresses that all lifting inserts should be purpose designed proprietary products and reinforcing bars may only be used as lifting inserts if specifically designed and installed for that purpose.

The lifting inserts are usually referred to by their maximum load carrying capacities. Therefore, their safe working loads are considerably less depending on conditions. Typically, lifting inserts shall be designed with a factor of safety of 4 and should make reference to Table 2.4 of the CoP if in doubt.

2.7.5.2 Anchorage

To warrant a load carrying capacity of lifting inserts, the inserts should have adequate embedment or anchorage. Hence, proximity to a free edge or other concurrently loaded lifting devices, insufficient depth of embedment will reduce the load carrying capacity of lifting inserts. The manufacturer's instruction on lifting inserts and safe working loads can be referred to.

2.7.5.3 Additional reinforcement

Sometimes additional reinforcement is required in the vicinity of a lifting insert to generate its full load carrying capacity, e.g. to enhance the bearing

stress, shear stress, punching shear stress. It should be detailed in accordance with Concrete Code 2013 and the manufacturer's recommendations.

2.7.6 Bracing design

Bracing should be designed for both construction and wind loading. Bracing is used to increase lateral stiffness and a factor of safety of 2 is recommended. It is not necessary to brace individual precast elements but bracing is normally implemented in the case of a volumetric precast unit which is vulnerable to damage during handling, such as a precast bathroom.

2.7.7 Design for movement

Provision for movement is of great importance in precast construction and determines the type, number and spacing of joints. All causes of movement must be taken into account and summated together, if appropriate, to derive the cumulative movement. Causes of movement in structures include creep deformations; early age thermal shrinkage; long term shrinkage; differential settlement; thermal movement due to seasonal changes of temperature; and thermal movement due to temperature difference between internal and external environments.

In general, it is not easy to predict the magnitude of movements. Due regard should be given especially to ambient temperature and age of precast elements and stage of construction at the time of formation of the joint. Further, it may be necessary to take into account the effects of eccentric moments caused by eccentricities deriving from production and erection tolerances and cumulative movement at joints.

Cumulative loading from the upper floors is generally avoided by the provision of physically separated joints between the precast facades at consecutive floors. Typical details are illustrated in Figure 2.3.

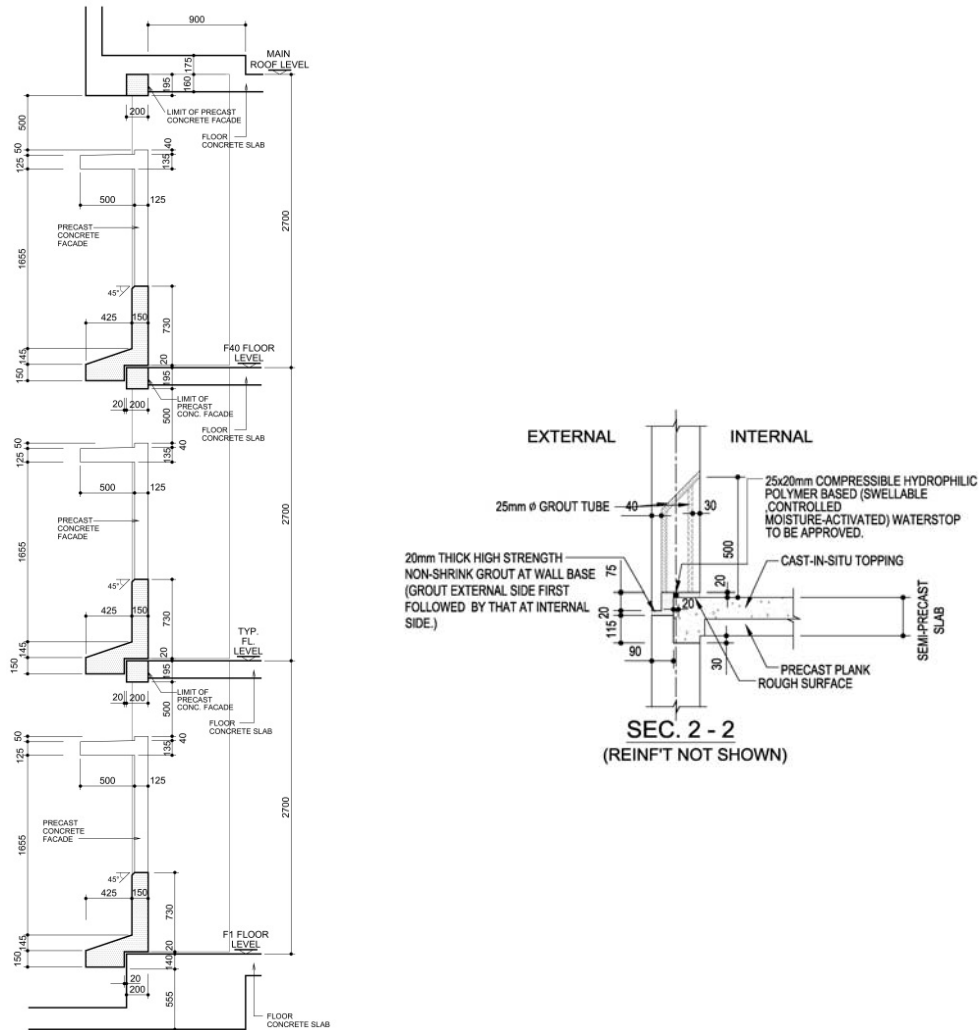


Figure 2.3 Typical details of separated joint between precast facades.

2.7.8 Design of ties

2.7.8.1 General

Provision of ties prevents progressive collapse of a structure due to accidental load. This provision basically follows Concrete Code 2013 at Clause 2.2.2.3 on Robustness. It is stated that structures should be planned and designed so that they are not unreasonably susceptible to the effects of accidents. In particular, situations should be avoided where damage to small areas of a structure or failure of single elements may lead to collapse of major parts of the structure. Alternative load path provision should be made. Design loads for robustness include notional horizontal load and loads on key elements.

- Regarding notional horizontal load, it is mentioned that all buildings should be capable of resisting a notional design ultimate horizontal load applied at each floor (including roof) level simultaneously equal to 1.5% of the characteristic dead weight of the structure between mid-height of the storey below and either mid-height of the storey above or the roof surface for the uppermost floor (i.e. the design ultimate wind

load should not be taken as less than this value).

- For key elements, appropriate design loads should be chosen having regard to the importance of the key element and the likely consequences of its failure, but in all cases an element and its connections should be capable of withstanding a design ultimate load of 34 kN/m^2 , to which no partial safety factor should be applied, from any direction. A horizontal member, or part of a horizontal member that provides lateral support vital to the stability of a vertical key element, should also be considered as a key element. For the purposes of this clause, the area to which these loads are applied will be the projected area of the member.

2.7.8.2 Provision of ties

In a structure with precast elements forming part of the structural frame, e.g. precast slabs, precast columns and precast beams, it is necessary to maintain continuity of reinforcement by lapping the reinforcement or providing ties joining the precast elements with other members. In the design, ties are designed to provide the tensile force as specified in the CoP. Although this provision does not apply to non-structural precast elements, it is still good practice to provide a fair degree of continuity between the non-structural precast elements and the structural frame.

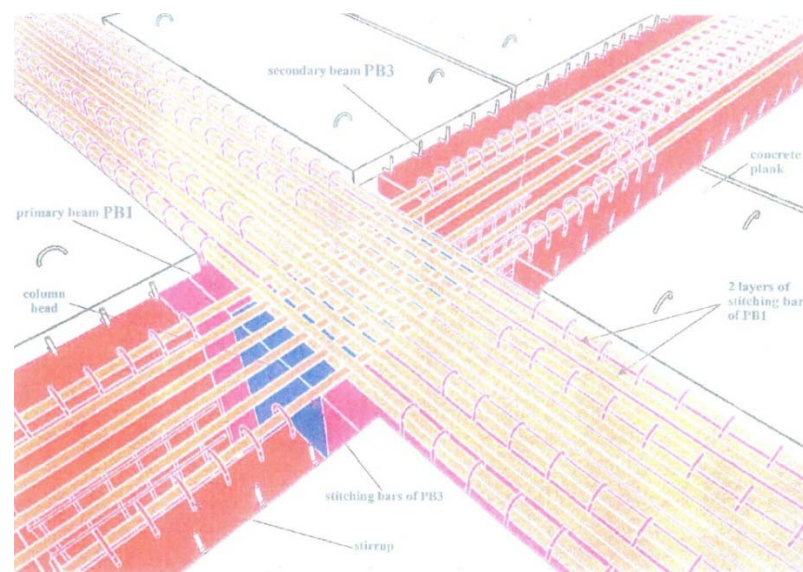


Figure 2.4 Provision of continuity of reinforcement by stitching bars.

It is possible to satisfy the provision of ties by proper detailing without increasing the number of elements. For example, ties can be provided by proper lapping of some of the bottom reinforcement between the precast slabs.

2.7.8.3 Types of ties

Five types of ties are specified and these are shown in Figure 2.5 (extracted from the CoP) for easy reference.

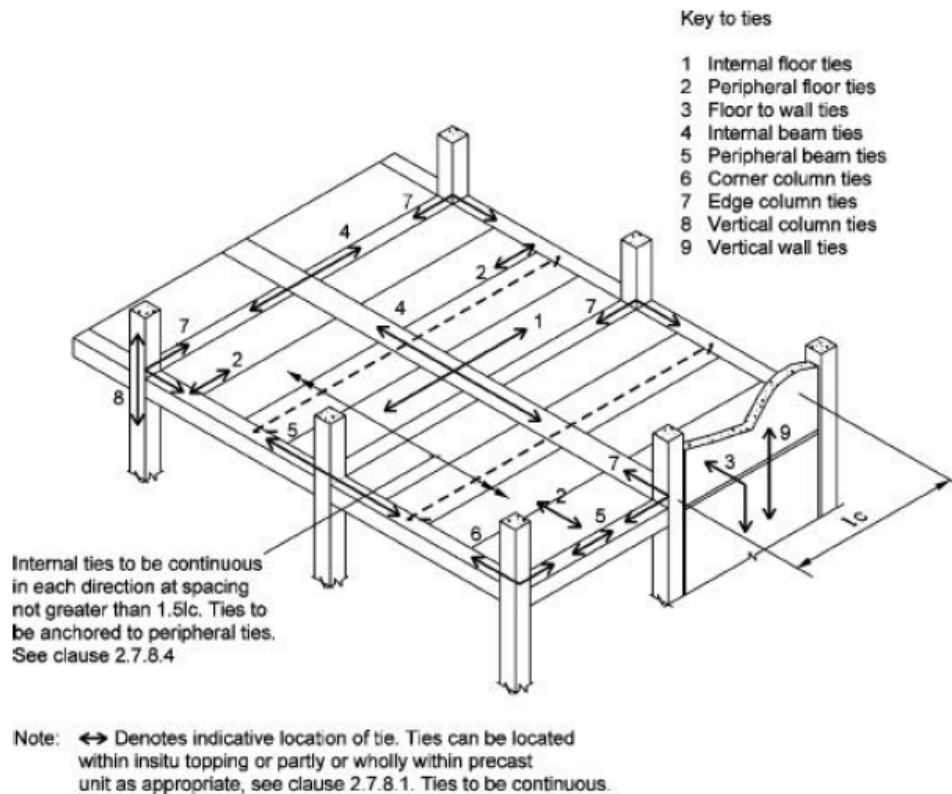


Figure 2.5 Typical examples of ties in a building.

2.7.8.7 Corner column ties

The CoP has emphasized the need to provide corner column ties (not explicitly dealt with in Concrete Code 2013). Provision of corner column ties is the same as that specified in Clause 2.7.8.6 for horizontal ties to columns and walls.

2.7.8.9 Tie anchorage

The requirement on tie anchorage is based on that specified in Concrete Code 2013.

2.7.8.10 Continuity of ties

The CoP specifies a minimum thickness of insitu concrete section to be (a) at least the total dimension of the bar diameter (or two diameters at laps) and (b) twice the maximum aggregate size plus 10 mm. For example, requirement (a) specifies the insitu topping of a precast beam with top reinforcement to be installed by stitching bars on site and requirement (b) provides the minimum thickness of insitu concrete section in a semi-precast slab.

To provide continuity, tension lap length is the requirement between ties and insitu topping bars. Alternatively, continuity of tie is assumed if anchorage is provided by the enclosing links. In such cases, the tensile resistance of the enclosing links should take into account the additional tension caused by the design tension in the ties.

2.7.8.11 Anchorage in structures

For all structures with five or more storeys, the CoP requires the precast floor or roof units to be effectively anchored if these units are not utilised to provide the ties. In general, it is good practice to consider extending the above to all structures regardless of the number of storeys.

2.9 COMPOSITE CONCRETE CONSTRUCTION

2.9.1 General

2.9.1.3 Relative stiffness

When the concrete strengths of the two components of a composite member differ by more than 10N/mm^2 , a transformed section making allowance for such a difference should be used. Otherwise, the concrete gross section should be used.

2.9.1.4 Precast pre-tensioned units designed as continuous members

For continuous members, parts close to supports will carry a hogging bending moment with the ends of precast pre-tensioned units at the bottom of the section under compression. This lengthens the prestress tendons in the precast elements and relieves the compressive stresses due to prestress at the ends of the units over the transmission length of the tendons.

2.9.1.5 Differential shrinkage

Many factors affect the differential shrinkage coefficient but the main ones consist of: age and quality of concrete in the individual components, thickness and surface condition of components and volume-surface ratio.

Incompatibility of the free shrinkage strains induced in the individual components by differential shrinkage produces a self-equilibrating distribution of axial stresses. These stresses produce creep and must be taken into account in the design.

Taking a precast T-beam with an in-situ concrete flange as an example, shrinkage in the precast T-beam always lags behind that of the top flange because of the difference in widths, surface conditions and volume-surface ratio. Consequently, a positive curvature develops initially that would cause upward deflection at the end of a cantilever. A maximum upward deflection eventually occurs when shrinkage of the thin top slab is mature. After that, differential shrinkage causes negative curvature and downward deflections.

The increased stresses are compressive at the top and the bottom of the composite beam at different stages of the shrinkage process. These stresses aggravate the stress condition at the bottom of the precast unit particularly when an approximately triangular distribution of stress due to prestress exists.

2.9.1.7 Average horizontal design shear stress

The total design horizontal shear force is distributed over the shear area (contact width \times distance between points of maximum and zero moments) in a pattern compatible with the vertical design shear force diagram because the vertical design shear stress is always associated with a compatible design horizontal shear stress for equilibrium at a point.

2.9.1.8 Nominal links

The spacing in this clause refers to a uniform spacing.

2.9.1.9 Links in excess of nominal

The horizontal shear stress is obtained for the composite section when under both superimposed dead load and live load.

v_h in the equation is the calculated design shear stress.

2.9.1.11 Structural topping

Maximum aggregate size should not exceed three-quarters of the thickness of the structural topping.

Thickness of the structural topping may be included in computing the depth of a member if integral action with the precast element has previously been achieved through control of strength and placing in conformity with the requirements in Clause 2.9.1.7.

3 CONSTRUCTION

3.1 PRODUCTION PLANNING

Generally, the production cycle is one day for a non-complicated precast element. In planning the production of precast elements, time of construction of each floor is a key factor in estimating the number of precasting moulds. For example, in a project consisting of 15 precast façades per storey and a working cycle of 6 days per storey, the number of mould required is $15/6$ or 3.

A storage area in the precast yard should be sufficient to accommodate precast elements delivered to the construction site and extra precast elements in case of emergency delivery.

Example of a working schedule for production planning is shown in Figure 3.1.

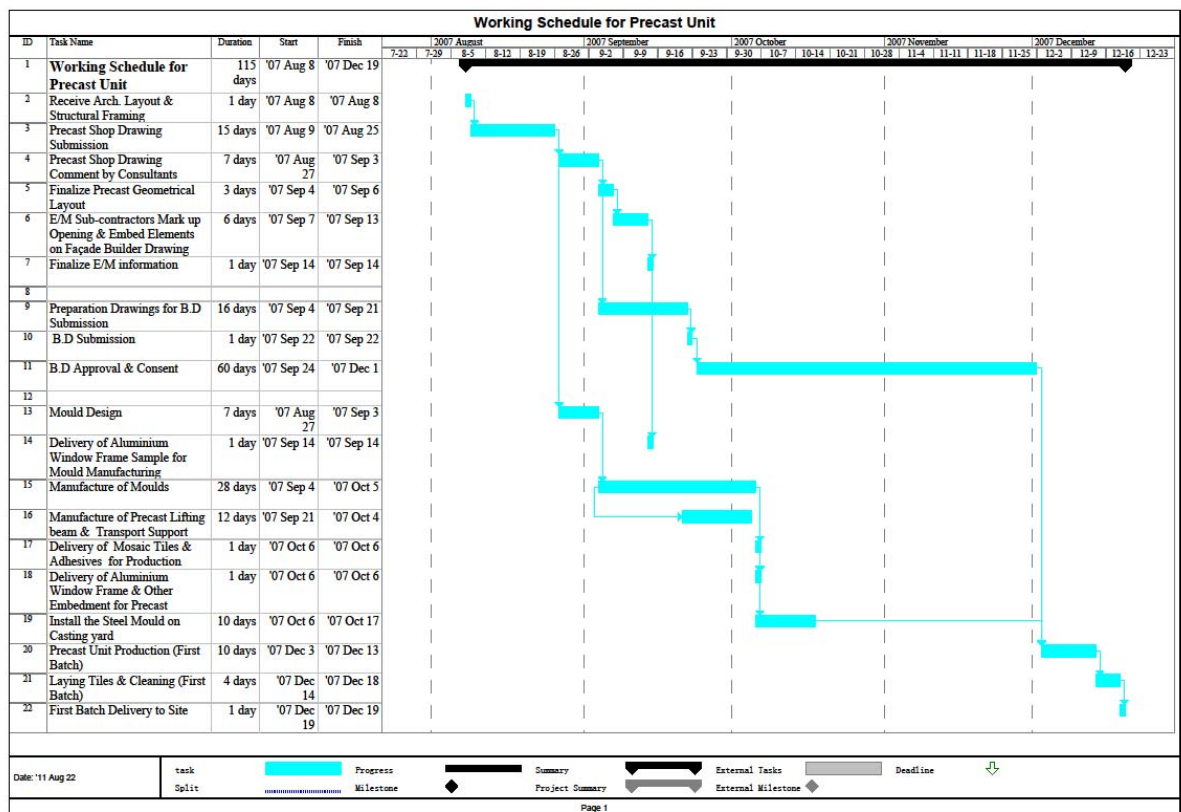


Figure 3.1 Example of a working schedule for precast unit.

For the production of precast elements, the precast manufacturer requires about or at least 1.5 months for manufacturing the moulds and 0.5 month for production of the precast units. Therefore, the precast shop drawing (showing geometrical size) should be consolidated at least 2 months in advance of the scheduled date of delivered to site. All the above should be allowed for in addition to the time required for approval and consent by government or client.

Embedded items including window frames, E/M pipe sleeves and openings in precast elements should be delivered to the precast yard before production.

Unlike traditional in-situ construction, this requires coordination and approval of embedded items at an early stage. For projects with a large number of precast elements, time required for the above would be much longer and has to be taken into account.

3.2 MOULDS

3.2.1 Materials

Moulds can be made of any suitable material including steel, timber, glass reinforced concrete or a combination of these. The selection of the mould materials will depend on the several factors highlighted in the CoP. Locally, the steel mould is the most common type owing to its robustness and precision. In general, the steel plate thickness adopted for mould design and fabrication varies from a minimum of 4.5mm to 6.0mm, which can be used over 100 times with proper care and maintenance.

3.2.2 Tolerances

To enhance cost competitiveness, adjustable moulds should be adopted where possible, for greater flexibility and variety in the production of precast concrete elements.

3.2.4 Recesses, sleeves and boxouts

Moulds should be designed to allow for appropriate placing and compaction of the concrete. Adequate numbers of braces, ties and struts should be provided for proper casting and hardening of the concrete.



Figure 3.2 Applying mould release agent.



Figure 3.3 Steel mould with specified roughness and precision.



Figure 3.4 Combined use of steel mould and timber mould.



(a)



(b)

Figure 3.5 Examples of mould orientation: (a) vertical and (b) horizontal.

3.3 *CAST-IN CONNECTION*

Three basic types of in-situ concrete connections commonly used in precast construction are

- A thin topping layer is cast to form a composite member, typically used with floor units such as hollow-core and double-Ts. It also acts as a levelling screed and may not be mechanically connected to the unit. Longitudinal shear due to bending is transferred by bonding and is also a function of the roughness of the interface.
- Composite construction is such that the in-situ concrete is a major component of the structural member. A typical example is a beam-shell where the precast unit forms the soffit and sides of the beam and contains the longitudinal reinforcement or prestressing wires and the shear steel. This type of construction allows continuous members to be easily formed by placing negative reinforcement in the in-situ concrete over supports. Simple spans are usually propped until the in-situ concrete attains sufficient strength to carry the dead weight on the

composite section.

- As a splice to connect a precast unit into a structure. This is an effective detail in structures where beam or column continuity is required as in earthquake-resistant construction. Bond length of the bars being lapped dictates the length of the splice. It may be necessary to connect large main bars by welding.



Figure 3.6 Use of thin topping on slabs and beams.



Figure 3.7 Cast-in connection on beams and columns.

3.4 *LIFTING INSERTS*

3.4.1 **General**

Three common types of lifting inserts used in precast concrete are:

- Reinforcement bar with omega “ Ω ” shape lifting insert. It is used in thin precast elements, such as a precast partition; and precast elements of shallow depth, such as a semi-precast slab.
- Lifting anchor with bulky head with U bars reinforcing the bottom head.
- Lifting anchor with eye for reinforcement bar to pass through.

Lifting capacity of lifting inserts depends on the material strength of the insert and, more important, the strength of surrounding concrete. Clear instructions must be specified on concrete strength requirements for lifting, especially for the first lifting out of the mould.

Examples of lifting inserts are shown in Figure 3.8 below.

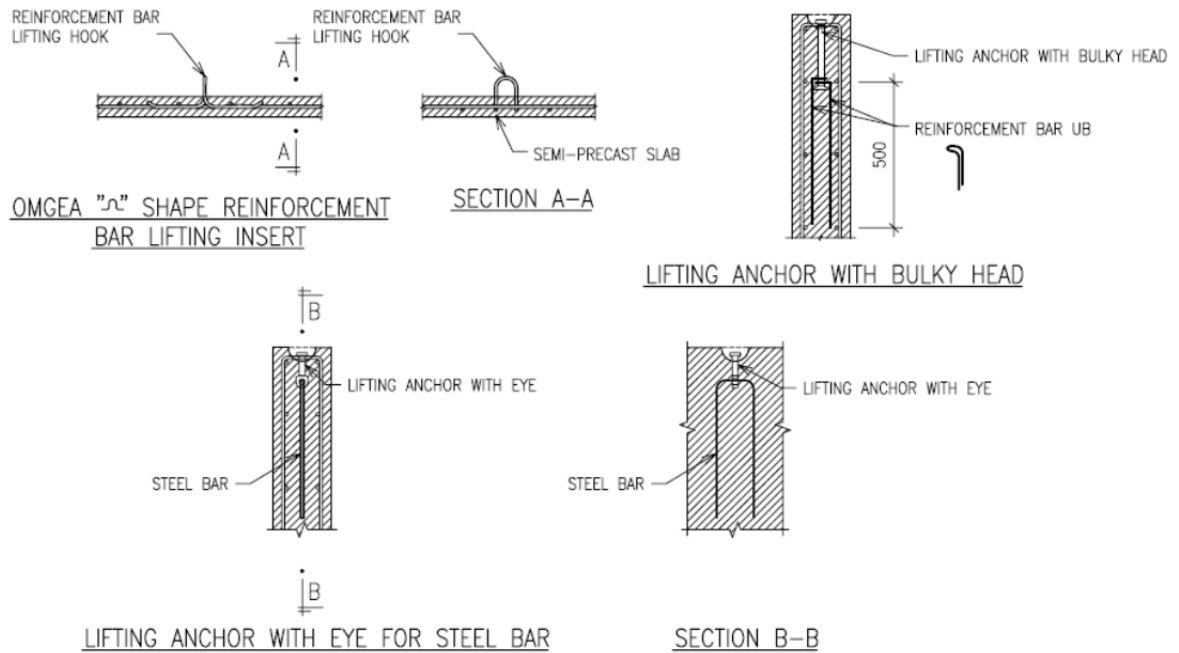


Figure 3.8 Examples of lifting inserts.

3.4.2 Lifting position tolerance

If the lifting anchor is offset substantially when compared with the drawings, the centre of gravity of the lifting point may be offset substantially from the centre of gravity of the precast element. This may cause the precast element to become out-of-balance and incline during lifting (i.e. not vertical in the lifting stage) making it difficult to handle, especially during installation.

3.5 SURFACE FINISHES

3.5.1 Types of finishes

Decorative finishes for precast concrete products combine the traditional skills of the concrete artisan, the design skills of the professional engineer and the practical experience of the manufacturer.

Knowing that these skills are available, architects can direct their efforts towards combining shapes, textures and colours to achieve the desired effect on the structure in its environment. While the finishes described in this clause are most commonly used on wall panels, the information provided is, in most cases, relevant to any precast elements requiring special finishes.

The finishes listed in the code are the ones commonly used in the industry today. The list does not cover all finishes nor is it intended to suggest limitations in developing new finishes. With the exception of a water-washed finish, the usual casting orientation is face-down.

3.5.2 Production

Building facades may be oriented such that sunlight just grazes the surface at a particular time of day. This causes otherwise imperceptible ripples, projections and misalignments on the surface to cast long shadows and be grossly exaggerated in appearance. Precast concrete, like any building surface, is subject to manufacturing and alignment tolerance so that this effect cannot be avoided.

3.5.3 Tiled finishes

In addition to tiled finishes, other types of finishes are available.

a) Smooth off-form

Trueness of the surface plane is a critical requirement, especially for a flat surface. The mould face must be carefully checked for compliance with tolerance criteria. The mould face is generally of concrete or flat steel sheet and there is no additional treatment to the panel surface after stripping from the mould. This may at first be thought to be a low-cost finish, but is not necessarily so. A requirement to produce a face of appropriate quality and level of colour uniformity, without any blotchiness of the face, may outweigh the costs of some more sophisticated finishes.

Smooth off-form units may be expected to contain minor surface imperfections. Joints in steel plates, minor variations in the surface texture of the steel or concrete casting table and voids caused by entrapped air may be visible in these finishes.

Such finishes are the most difficult of all precast finishes to repair.

Chamfers to the edges of panels are essential to minimize chipping.

Cement dominates the face colour. The fine aggregate (sand) exerts a minor influence and oxides have a considerable influence. Note that the sand colour becomes noticeable when a surface is exposed, as in sandblasting or acid-etching. Coarse aggregate colour has no impact unless heavy vibration of concrete induces aggregate transparency, in which the presence of the coarse aggregate is visible as a hazy, shaded outline. The use of a plasticizer may generally control this effect.

Moulds must be constructed to prevent leakage. Wherever possible, tapers should be built in, so that the mould does not need to be dismantled after every casting and can therefore be permanently sealed.

Smooth off-form units produced with high-cement-content mixes may exhibit some surface crazing after curing. This is usually visible only when viewed at very close quarters or with some magnification. Such crazing has no effect on durability or strength.

It is recommended that wherever possible, off-form surfaces be modulated by grooving, shaping or profiling. Such techniques provide an architectural design opportunity by developing light and shade, and minimizing the visual effect of any minor discolouration.

b) Sandblasted

A good off-form surface is required for this finish. When the concrete is about a week old, the surface is sandblasted to remove the matrix and expose the aggregate. The depth of the blast is determined by the desired texture and the target colour. Sandblasting is carried out on units poured face down. Hence, it may be used on flat panels or on panels with ribs, grooves or other features, thus giving tremendous scope for crisp architectural detail.

The type and hardness of the abrasive is selected to give the required result. Silica sand should not be used for health reasons. Experienced manufacturers select suitable sandblasting techniques and the specification should concentrate on the required appearance. The abrasive is carried by air or by an air and water mixture. It is a medium-cost way of achieving an excellent architectural finish. The technique requires considerable skill in the preparation of shop details, in mix design, in pouring technique and in the blasting operation itself.

While sandblasting is used on returns and other parts of panels not cast horizontally, finishes on such surfaces will not often match horizontal surfaces perfectly. This is not usually a problem but should be dealt with during the sample-approval process. Sandblasting is always followed by a light acid wash to provide an even, clean finish. It may be combined with other finishes such as painting or polishing in the one panel.

Varying degrees of sandblasting are possible and are normally typified as follows:

Light exposure: Cement surface skin is removed to expose the fine and some coarse aggregate.

Medium exposure: Exposes approximately equal amounts of fine and coarse aggregate.

Deep exposure: Coarse aggregate becomes the dominant surface feature.

c) Acid-etched

A very good off-form surface with minimum voids is required for these finishes. It is achieved by casting concrete against a smooth, hard surface. About a week after removal from the form, the product is washed with an acid solution and scrubbed to remove the cement skin. The result is a smooth, sand-textured surface.

The panel surface is first wetted and acid is brushed over the surface until the desired depth is achieved. The panel is then thoroughly rinsed. The acid used is generally undiluted commercial grade 33% hydrochloric acid. It is possible to achieve a lightly etched effect with phosphoric acid but the reaction is slow and leaves a white surface laitance and irregular aggregate exposure.

High cement content and good compaction used in precast panels alleviate the risk of chloride penetration to the reinforcement. Testing by the Volhardt Method has shown that etching poses no threat to the durability of good-quality concrete and has been accepted by the industry as a standard.

d) Hammered-nib or fractured-fin

This finish is achieved by casting concrete against specially-textured or patterned formwork to create ribs. After removal from the mould, the hardened surface is treated mechanically by breaking the nibs with a hammer to create the desired effect. It is necessary to carry out full-scale trials to establish a mix design which will provide a suitable aggregate grading and colour.

e) Form liners

Form liners are used to produce patterned, profiled finishes. Polystyrene can be cut to shape to produce relatively cheap form liners for single pours. Flexible form liners made from silicone or polyurethane can be used for intricate shapes with slight undercuts if required.

Imported form liners are available. In Australia, they are generally produced in the form of master patterns. These types of moulds are useful for difficult shapes. They are expensive but become economical when there is good repetition.

Depending on the quality of the liner material and the complexity of the formed shapes, it is possible to produce 200 pours from a single form liner.

f) Painted

Paint, in a variety of textures, is often site-applied to precast elements. It is most commonly used on smooth surfaces (i.e. off-form or those cast against form liners).

Gloss finishes are to be avoided due to the high cost of surface preparation necessary to provide a satisfactory appearance. High-build paint is recommended unless very high mould standards are achieved. Although paint finishes are not as durable as other finishes, they do provide the opportunity to change the appearance of a building by repainting as well as providing a limitless colour choice. Manufacturers can also undertake the painting of panels before delivery.

g) Brick- or tile-faced

Traditional clay brickwork or tiled finishes can be simulated in precast wall panels by (a) full bricks and (b) brick wafers or tiles.

Construction is effected by first placing a veneer of brick wafers or tiles into the mould and casting the concrete panel behind it. The wafers or tiles are held in place by the bond between them and the concrete. There is a basic conflict between clay, which expands, and concrete which shrinks. The designer and manufacturer must take account of this to prevent separation of the veneer.

h) Stone-faced

In much the same way as brick- or tiled-faced finishes, a stone-faced appearance can be provided by placing natural stone pieces into the mould prior to casting the panel.

Usually, natural stone is mechanically fixed to concrete with stainless steel pins. A bond breaker is placed between the concrete and the stone where necessary to prevent adhesion which would result in cracking of the stone facing due to temperature differential and concrete shrinkage.



Figure 3.9 Smooth off-form finishes.



Precast facade



Precast toilet unit

Figure 3.10 Tiled finishes.



Figure 3.11 Decorative finishes on precast façade with granite cladding.

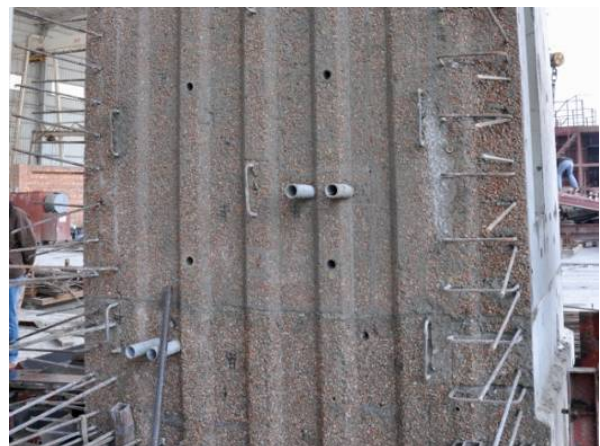


Figure 3.12 Water-washed finishes at the connection.

3.6 ***PREFABRICATED METAL FRAMES***

Prefabricated frames such as windows should be protected to avoid damage by fresh concrete.

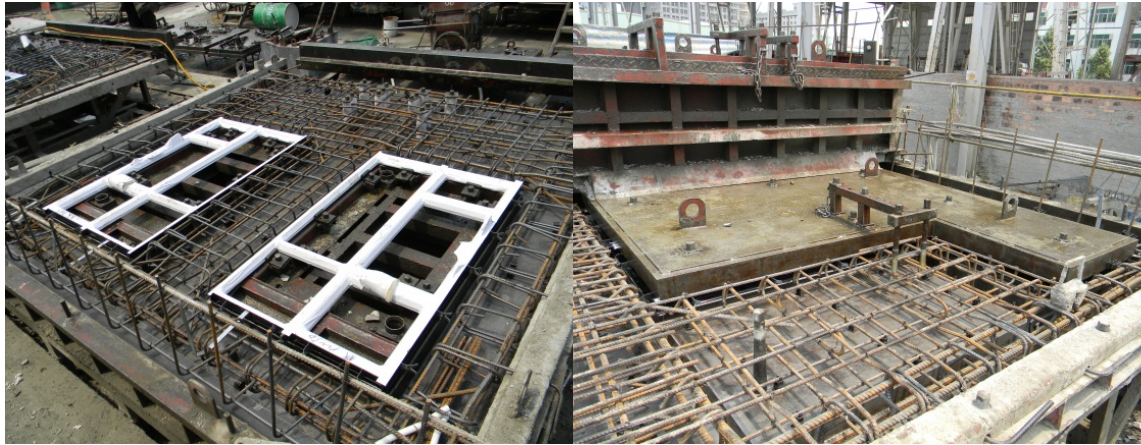


Figure 3.13 Examples of prefabricated frames.

3.7 *PRE-CONCRETING CHECK*

Prior to concreting, the condition of the mould shall be inspected since it directly influences the quality of the precast concrete product:

- The mould form shall be level and the flatness of the base of the mould and the squareness and stiffness of the mould form examined and the mould kept free from spillage.
- Manufacturers shall ensure that the dimensions of the mould are within the tolerances specified in accordance with CoP.
- The mould shall be clean and free from debris (e.g. from the previous precasting operation).
- Form oil or release agent and retarder shall be applied to the surface of the mould to be in direct contact with concrete. They shall be applied in accordance with the manufacturer's instructions. Over application may lead to puddling on the concrete surface.

Reinforcing bars and cast in items such as lifting inserts, window frames and earthing lugs shall be fixed only after preparation of the mould:

- Rebar size, spacing, lap length and cover requirement shall be checked in accordance with the approved drawings and within the tolerance limits.
- Lifting inserts shall possess adequate length of embedment to prevent damage during lifting.
- A sufficient number of spacers, chairs and supports shall be properly placed and secured to achieve the required concrete cover during casting.

- Window frames shall be installed and fixed in place according to the approved shop drawings, and with full electrical continuity to the earthing lugs and façade.
- Reinforcing bars and all cast in items shall be clean and free from contamination by mould oil and cement grout before casting, as this may lead to poor bonding to the concrete.



Figure 3.14 Checking of rebar, lap length, cover and lifting inserts before concreting.

3.8 **CONCRETE PLACING**

Density, uniformity and surface quality of precast concrete products depend on the workability of concrete, placing and the compacting procedures used during the production process.

The workability of a concrete mix is presented in detail in the Concrete Code handbook. Attributes which relate to measuring the workability of concrete are as follows:

- Consistency depends on the degree of dryness and wetness of the concrete mix.
- Deformability is a measure of workability for low to medium workability concrete.
- Flowability is a measure of workability of high workability concrete.
- Passing ability measures the ability of a concrete mix to pass through narrow gaps.
- Segregation resistance or cohesiveness relates to the potential separation of some ingredients due to free falling and sliding along surfaces during the placing of concrete.

Factors affecting workability include size and shape of aggregate, mix proportions, cement content, admixtures used and concrete temperature during placing and compaction.

Procedures and precautions for placing concrete are detailed in the Concrete Code 2013. Vibration and compaction of concrete is the principal method for consolidating concrete. Fresh concrete must be properly vibrated so that once hardened, its strength and durability are fully realized.

Studies have shown that proper vibration enhances compressive, tensile and flexural strength and resistance to deterioration by increasing the density of concrete and eliminating voids, honeycombing and entrapped air due to poor placement of concrete.

The use of vibration tables, external form vibrators, and surface vibrators are examples of external vibration/compaction techniques that are applicable in precast concrete production. Form vibrators shall be mounted on the form to induce vibration in the mould, which is then transmitted to the concrete. The number and locations of external vibrators used shall be strategically planned to best distribute their impact. Surface vibrators are installed on the concrete surface, exerting their effects at the top surface and consolidating from top down. They are used mainly in precast slab construction. Vibration tables are used to vibrate the frame that supports the mould and are usually used for elements cast in small moulds. The table is isolated from the ground with springs or neoprene isolation pads to prevent undesirable vibrations affecting other production processes.

Proper vibration and compaction shall be carried out, in particular in congested areas with a lot of steel reinforcement. When all air, entrapped in pockets and voids has been released, vibration is considered sufficient. This is demonstrated when air bubbles cease to emerge at the concrete surface.



(a) Using a vibration table

(b) Using an external vibrator

Figure 3.15 Concreting and compaction of concrete.

3.9 **DEMOULDING AND LIFTING**

A precast concrete product shall only be demoulded and lifted when the designed compressive strength of the concrete has been achieved. This can be assessed by compression tests on cubes cured under the same environment as the precast element itself. The minimum concrete strength at which a precast element can be lifted from the mould shall be based on the calculated concrete stresses at the lifting points, stresses caused by the transfer of prestressing forces or handling, the anchorage length of inserts and the type of precast element.

To overcome additional suction and frictional forces during demoulding, the minimum concrete strength for lifting may be higher than the recommended value specified in the CoP. It depends on the design and shape of the mould and the precast element. Flat mould suction increases in the presence of water and can be relieved by first lifting one edge of an element gently. Frictional forces are induced by contact and bonding between concrete and the vertical sides of the mould. To reduce friction, the mould shall be designed with adequate draw or removable sides or vibrated gently while lifting one edge of the member. The CoP also suggests the use of a high quality demoulding agent to reduced suction and frictional forces.

Embedded hardware, threaded inserts, dowel connectors and removable sections of the moulds are usually attached to the mould with bolts, pins and clamps. Before demoulding, all bolts and pins connected to the mould shall be loosened and all clamps removed. Side forms, window capping shall also be detached from the element. Failure to remove all bolts and pins is a common cause of failure of lifting insert and the formation of cracks on the concrete surface.



Figure 3.16 Detaching the mould from a precast element.



Figure 3.17 Sequence of lifting of a precast façade (from top and left to right).

3.10 CURING

Curing has four major objectives:

- To maintain a suitable environment for new concrete to produce as much gel as possible so as to develop its full strength potential and reduce its permeability for better protection of the steel reinforcement from corrosion
- To avoid damage by plastic cracking and early age thermal cracking
- To avoid damage by shock vibrations due to nearby activities
- To avoid damage by premature loading caused by movement of adjacent parts of the structure

Therefore, the scope of curing includes:

- Moisture control to prevent premature drying out of the concrete mix due to solar radiation and wind that may lead to plastic shrinkage cracking of the free surfaces not in contact with mould surfaces.

- Thermal control to prevent large temperature rises and drops, which could cause serious thermal cracking problems.
- Vibration control, which is particularly important if the precast plant is located on or near a construction site, or adjacent to any activities involving vibration.
- Movement and deformation control, required if the mould might move during the curing process.

Curing of precast elements is usually achieved firstly by accelerated curing, followed by a normal curing process (i.e. sprinkling water and keeping the elements moist with a curing membrane). Steam curing, described in the CoP, is a subset of accelerated curing. The chemical cement hydration reaction takes place more rapidly with increased curing temperature and results in greater early strengths and efficiency in the production of precast products. In practice, elevated temperatures and addition of moisture during the steam curing process are both used in order to accelerate the rate of strength gain. The following explains the stages of a steam curing process:

Stage 1 – Fresh concrete in the mould is allowed to achieve its initial set before putting the concrete in contact with steam or hot air. Steam is applied within a suitable enclosure that permits free circulation of the steam. Precautions shall be taken to prevent moisture loss from the concrete.

Stage 2 – The precast element is heated to a maximum temperature of 70⁰C at a heating rate usually within 10⁰C per half hour. A curing temperature exceeding 70⁰C may result in delayed ettringite formation which is detrimental to concrete strength. Gradual increase in temperature ensures a small thermal gradient between the surfaces and the interior of the concrete element.

Stage 3 – Temperature and pressure of the environment are maintained for a sufficient duration, depending on the thickness and shape of the section.

Stage 4 – The temperature is lowered at a rate not exceeding the rate of heating and the pressure is normalized.

Low pressure steam curing refers to steam curing as mentioned in the CoP and above. High pressure steam curing, also known as autoclaving, is used for the production of concrete masonry units. This technique is designed specially for concrete of extremely low water cement ratio.

Other methods of accelerated curing are also available. For example, the heat curing technique increases concrete temperature by conduction and convection. The temperature of the mould is increased by a flowing fluid such as oil or water in contact with the mould. The direct contact between concrete and the mould results in conductive heat transfer and increases the curing temperature. Electrical resistance curing increases curing temperature by the dissipation of heat generated in the current carrying metal formwork, reinforcing steel bars or the concrete itself.

3.10.1 Normal curing

Precast elements achieve design strength by curing at a certain temperature and for a certain length of time during production. In addition to CoP, it is good practice to monitor the ambient temperature. If the environment is at 24⁰C or above, normal curing is recommended. If the ambient temperature is hot (e.g. prolonged exposure to direct sunlight for several hours), it may be necessary to moisten the concrete surface by adding water to the surface.

3.10.2 Steam curing

This method is usually used when the temperature of the environment is less than 24⁰C. It can help to speed up the curing time in achieving adequate strength for demoulding.

Table 3.1: Temperature versus curing time for different precast concrete products.

Products	Temperature	Curing Time
Precast Façade, Precast Partition Wall, Precast Slab, Precast Beam, Precast Column, Precast Refuse Chute, Semi-precast Slab, Precast Bathroom, etc.	Above 20 ⁰ C	2 hours
	16 ⁰ C ~ 19 ⁰ C	3 hours
	12 ⁰ C ~ 15 ⁰ C	4 hours
	Below 12 ⁰ C	5 hours

At the initial stage, concrete and moulds should be covered with a tarpaulin sheet before putting into the steam chamber. Steam is released in the first hour to increase the temperature to 70⁰C. Water is sprayed inside the steam chamber for 3 to 5 minutes, once an hour, until the target curing time is reached. Afterwards, the steam chamber is allowed to cool down. The temperature inside the chamber then drops down to the surrounding environmental temperature within an hour.

At the second stage, water must be poured on the precast elements until the 4th day of curing.

Steam curing has the advantages of speeding up the production of precast elements and increasing the strength of precast elements in the early stages.

Steam curing is appropriate when the ambient temperature is below 24⁰C. In such a situation, the precast elements are placed inside the steam room and sealed with a non-porous membrane. The temperature inside the steam room is sealed by a non-porous membrane and controlled by a centralized thermal system. The steam inlet injects the steam into the steam room. The temperature inside the steam room will increase to reach the target temperature. The time period required for curing depends on the temperature at the time.



Figure 3.18 Application of water to precast unit for normal curing.

3.11 HANDLING

The handling of precast concrete units encompasses demoulding, loading, transportation, unloading, storage and site erection. The optimum solution for economical handling is the ability to demould a unit and tilt it into a position similar to its storage position and its final configuration when installed in the buildings. Re-handling and turning of units between demoulding and final installation adds extra cost and increases the danger of accidental damage; hence handling must be reduced to a minimum.

The following outlines some handling considerations for various construction stages:

- Delivery of precast elements, e.g. loading, transportation and unloading, shall be properly planned so that unnecessary site storage and handling is minimized to prevent damage. Transportation regulations shall be observed, as this may affect the size, weight and timing of shipments. The route shall be studied as conditions including bridge restrictions, nearby buildings or power lines, restricted turning radii and natural obstacles may determine the choice of transportation route.
- Once the unit is loaded onto the vehicle, it shall be attached firmly to the supporting members and fastened with a position locking device. Units shall be loaded with proper supports, frames, blocking, cushioning and tie downs to prevent or minimize in-transit damage. Dunnage shall be placed across the full width of each bearing location to separate stacked members. Prior to unloading the unit from the vehicle to the storage area, visual inspection shall be made before the removal of bracing, chains, straps and protection for edges of the units.
- Storage sequences shall be properly planned to minimize the effects of handling during erection. Storage areas shall be relatively level, firm and well drained to avoid any differential ground settlement which may

damage the stored elements and it shall be large enough to permit easy access for handling of the precast elements. Locations of supports, stacking configuration and sequences shall be in accordance with the approved shop drawings. Horizontal precast concrete elements such as precast slabs, beams and hollow core panels can be stacked and supported separately using strips of wood or battens across the full width of the designed bearing points. The support spaces shall be aligned to reduce induced stresses. Precast walls and façade panels are usually cast horizontally and rotated for storage in upright positions with racks and stabilizing walls to support their weight.

- For site erection, the rigging sequence and method shall be considered. Locations of lifting devices and lifting points shall be compatible with the method of shipment so that patching and repairing are minimal. It shall be aimed at ease of erection and connection of the precast unit to the structure. Lifting devices shall be standardized and installed in various precast elements so that frequent changes of lifting method can be avoided. Precast elements shall be rigged for balancing, remaining vertical and in line with their centres of gravity to prevent undesirable and excessive movement which may induce additional stresses on the elements and lifting devices due to dynamic loading.



Figure 3.19 Rotatable steel rack for ease of lifting.



Figure 3.20 Temporary supports for façade in the factory.



Figure 3.21 Proper storage to avoid excessive stresses and possible damage to precast units.

3.12 POST-CONCRETING CHECK

3.12.1 General

The CoP discusses items to be checked and the checking shall be performed in two stages; immediately after demoulding and when the precast units are ready for dispatch. A list of production tolerances, which defines the limits to variations of size and shape of individual precast concrete members, to ensure that the member will fit the structure without difficulty, is given in the CoP.

3.12.2 Production Tolerances

The tolerances given in the CoP are for normal circumstances. More stringent dimensional tolerances may be required if the structure is sensitive to deviations in dimensions. In general, the tolerance limits are acceptance criteria. However, even if the tolerance limits are exceeded, they may be considered acceptable if:

- Exceeding the tolerances does not affect the structural integrity or architectural performance of the member.
- The member can be brought within tolerance by structurally and architecturally satisfactory means.
- The total erected assembly can be modified economically to meet all structural and architectural requirements.

When proposing a set of production tolerances, the following factors shall be taken into account:

- Effect of forms on dimensions: Rigid forms are used to fabricate architectural precast panels where appearance or function dictates the need for the closest tolerances. Their sides are permanently fixed to ensure the highest degree of dimensional accuracy. The downside of a fixed mould is the frictional forces induced by the sides of the formwork. Some moulds are designed as flexible forms with semi rigid joints so that the side forms can be removed during demoulding. Since the end dividers or removable side forms are not permanently and rigidly attached to the form, they have the potential to move during placement and vibration of the concrete. As a result, they are less likely to achieve precision linear plan dimension, than is the case with rigid forms.
- Temperature and shrinkage effects on dimensions: The effect of differential temperature on a plane member can induce bowing and cambering. For long members, the temperature effects may lead to lengthening and shortening of the length of the product.

3.12.3 Surface finish

The surface finish of precast concrete elements must be inspected before use, e.g. to ensure degree of conformity to surface requirements. The surface finish shall be checked and inspected for defects after production. Examples of surface defects include cracks, air pockets, chip-off damage, obvious discolouration, honeycombing and excessive pinholes. In particular, crack formation is a common surface defect for precast concrete as a result of additional loads due to demoulding and lifting. Cracks may form during initial lifting due to friction between the elements and the casting mould forms when the concrete strength is still low.

Cracks may cause the precast element to break or fracture easily. Cracks can be formed due to moisture, thermal shrinkage, demoulding, lifting and transportation. Although cracks cannot be totally avoided, they should be eliminated as far as possible. The following recommendations shall be considered to minimize crack formation:

- Adopt a proper curing method, curing time and temperature to prevent cracks due to dehydration, shrinkage, and thermal gradient.
- Conduct cube tests to ascertain the concrete strength of the elements before demoulding and lifting.
- Apply an appropriate form release agent uniformly to the mould surfaces to minimize friction.
- Increase the sectional thickness of the precast element and design the element properly to prevent stress concentrations on surfaces.
- Adopt proper handling techniques.

If the precast element is acceptable for repair, all loose concrete must be removed from the affected area. Edges of the repair shall be chiselled to allow keying action of the repair material. All surfaces must be clean, sound and sufficiently rough before the application of the patching material.

All defects found in the precast element should be repaired. The method of repair should be guided by the CoP, Construction Standard CS1:2010 or as approved by the Engineer. Material used for repair should be adhesive and suitable for the precast element. The repair must not affect the strength of concrete and its finish and texture must match that of the existing precast elements.

3.13 *LIFTING EQUIPMENT AND ACCESSORIES*

Lifting equipment such as mobile cranes, gantry cranes, forklifts, etc., must be carefully selected to ensure that lifting of precast elements is carried out within the rated capacity of the lifting equipment. The supports for the lifting

equipment must be checked to ensure that adequate supporting capacity is provided.

Lifting accessories may comprise combinations of lifting beams or frames, slings or cables, hooks or shackles, etc. The selection of each of these components should be predetermined to take into account the forces exerted on them with respect to all aspects of the lifting operations.

Lifting beams or frames are usually tailor made to suit the precast elements, especially for slabs or prefabricated volumetric units which may be easily damaged during handling. Lifting beams or frames shall be designed to withstand the required weight of the precast units as well as the axial compression in the beams or frames due to an inclined sling during lifting. An impact factor as prescribed in the relevant code of practice should be applied to the structural design.

Personnel suitably qualified in accordance with the relevant regulations must regularly inspect all lifting equipment prior to and after use. Results of such inspections must be properly recorded and be available for subsequent inspection by the Engineer upon request.

Some precast elements such as prestressed hollow-core floor slabs must be handled by means of lifting clamps, straps or slings as they may have no lifting inserts. Lifting equipment of this type can wear out easily and should be regularly inspected. Location of lifting points should be clearly indicated on the drawings.



Figure 3.22 Gantry cranes.



(a) Lifting a precast unit



(b) Lifting a precast staircase



(c) Lifting a precast facade



Figure 3.23 Examples of lifting beam/frame.



(a) Precast staircase



(b) Double-Tee panel slab

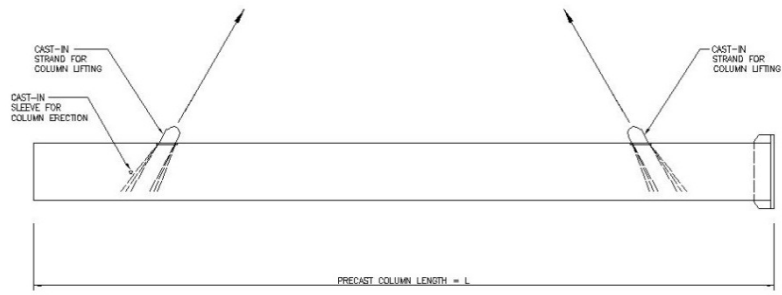
Figure 3.24 Examples of lifting hooks.



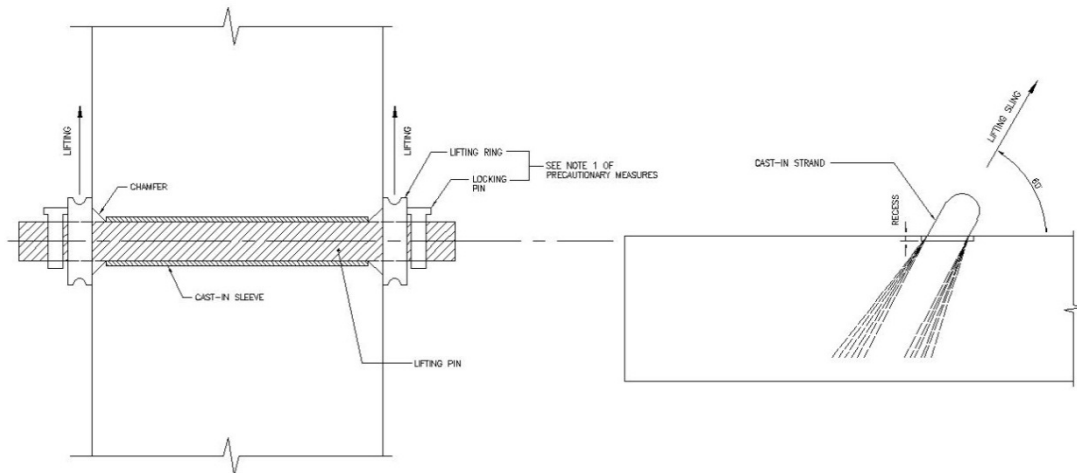
Figure 3.25 Example of lifting pin for a 30 ton precast column.



Figure 3.26 Precast units must be stored safely with adequate supports.



ELEVATION



TYPICAL SECTION AT CAST-IN SLEEVE FOR COLUMN ERECTION

TYPICAL DETAILS OF CAST-IN STRANDS FOR COLUMN LIFTINGS

Figure 3.27 Examples of cast-in sleeve and cast-in strands.

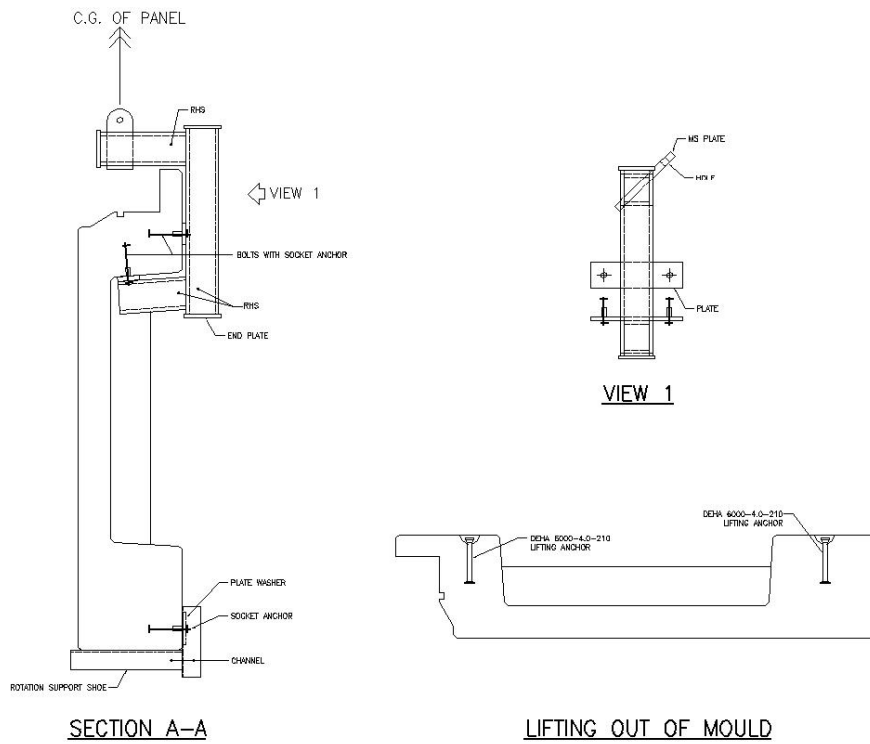
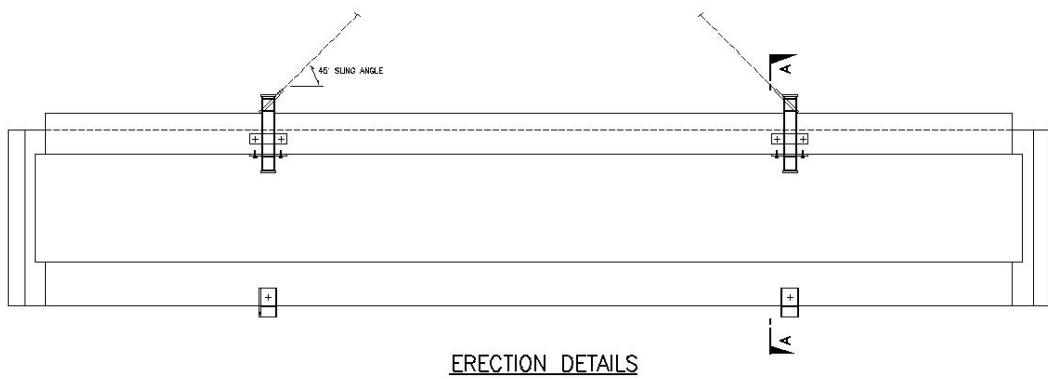


Figure 3.28 Erection detail of a precast panel.

3.14 FACTORY AND SITE STORAGE

Storage areas must be large enough for precast elements to be stored properly. They should provide adequate room for lifting equipment and for the maneuvering of transporting vehicles. The storage ground area must be hard, level, clean and well drained to permit organised storage.

Precast elements can be damaged by incorrect stacking and storage. Locations of support points, e.g. dunnage, for precast elements are critical and should be noted on the shop drawings.

Supports must be arranged to avoid twisting or distorting of precast elements and must be adequate to transfer the weight of the stacked units to the ground without excessive settlement.

Stored and stacked units should be protected to prevent accidental damage. Support material should be non-staining to prevent discolouration. Lifting points should be well protected and kept accessible while the units are in storage.

Precast elements must be stored safely with adequate supports so as not to endanger the workers.



Figure 3.29 Examples of supports.

3.15 TRANSPORTATION

3.15.1 Delivery

Precast elements must be loaded carefully on to delivery vehicles to prevent damage. Weight and size of precast elements should be considered at the design stage to ensure that the precast elements can be transported by truck.



Figure 3.30 Ensure no undesirable stresses to the precast elements due to flexing of truck.



Figure 3.31 Pre-plan sequence of lifting to avoid multiple handling of precast elements.

3.15.2 Loading and storage on transporters

To protect the edges throughout their journey, proper devices should be used to support, secure and wedge the precast units. The units should be adequately secured and supported to prevent them from overturning, shifting or being damaged during transportation. Chain blocks or tie wire, together with a steel frame, are usually used to hold precast elements in position during transportation.

3.16 ERECTION ON SITE



(a)



(b)



(c)



(d)

Figure 3.32 Erection process of precast staircases (a) voids reserved for installation; (b) and (c) steel bars to be plug in the reserved voids and; (d) grouting the voids.



Figure 3.33 Verticality of precast façade adjusted to erection tolerances (right: levelling shim).



Figure 3.34 Proper popping and temporary support.

3.16.2 Erection safety

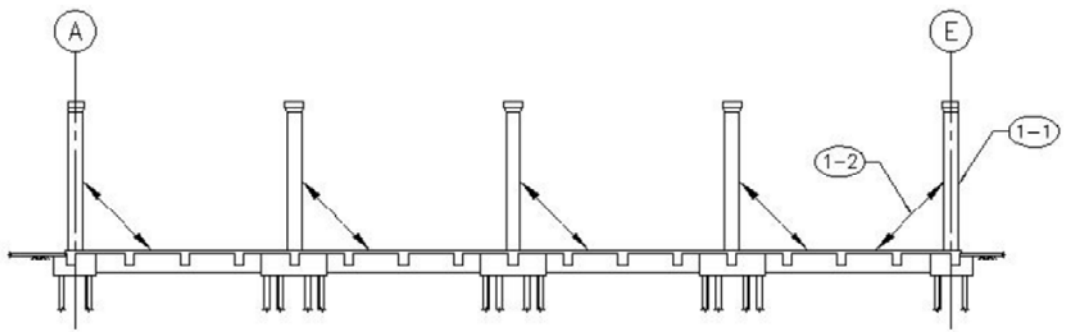
In precast construction, erected precast elements are initially in a temporary condition before being connected to the parent in-situ structure. Since many are temporarily installed around the peripheral areas of buildings, the safety of workers during installation is of paramount importance.

The absence of peripheral scaffolding in precast construction is a major difference from conventional construction. As a result, steel working platforms are provided for workers. The height, width, strength and connections of working platforms should be thoroughly considered to match the precast construction circumstances. In some cases, a temporary detachable handrail is necessary at the installation areas.

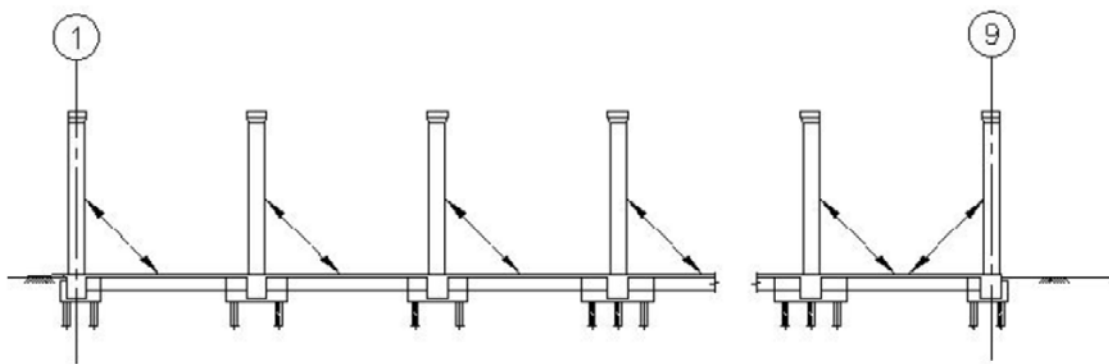
3.16.9 Propping

Erection is one of the critical steps to be attended to in precast construction. The CoP specifies the requirements and considerations in respect of erection preparation, safety, sequences and tolerance as well as the temporary supporting system.

A full method statement, which includes details of the handling of the precast elements, rigging arrangements, use of machinery as well as the erection sequence, shall be prepared, checked and endorsed.



Elevation

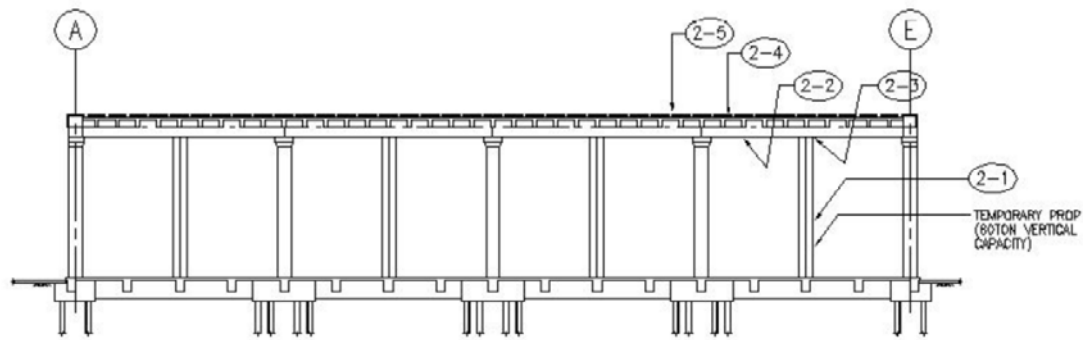


Side View

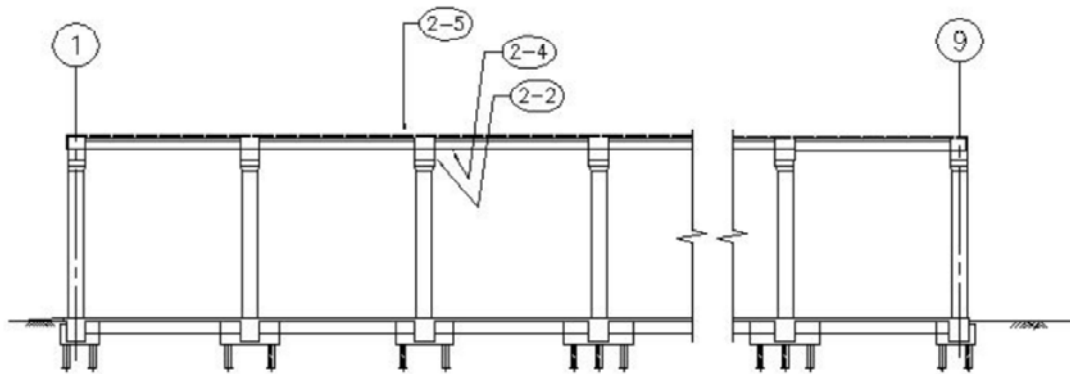
STAGE 1 – COLUMN ERECTION

- 1-1 ERECT P/C COLUMNS.
- 1-2 AFTER THE GROUT STRENGTH (FOR COLUMN BASE AND CONNECTION) ACHIEVE 40MP_a, DISMANTLE THE PUSH AND PULL PROP.

Figure 3.35(a) Erection of precast columns.



Elevation



Side View

STAGE 2 – CONSTRUCTION OF 1/F

- 2-1 ERECT TEMPORARY PROPS ON FLOOR.
- 2-2 ERECT P/C MAIN BEAMS WITH CRANAGE ON TO THE CORBEL OF COLUMN. INSTALL STEEL SHIMS/CONCRETE PACKERS BETWEEN MAIN BEAM AND STARTER BARS OF COLUMN.
- 2-3 INSTALL STEEL SHIMS/WEDGES BETWEEN TEMPORARY PROP AND SOFFIT OF MAIN BEAM TO ENSURE THE MAIN BEAM IS PROPERLY SUPPORT ON THE PROP.
- 2-4 ERECT THE P/C DOUBLE TEES ON MAIN BEAM WITH CRANAGE. INSTALL STEEL SHIMS OR CONCRETE PACKERS.
- 2-5 FIX REBAR AND CAST IN-SITU TOPPING AND UPPER PORTION OF MAIN BEAM.

Figure 3.35(b) Construction sequence of precast columns, beams and slabs.

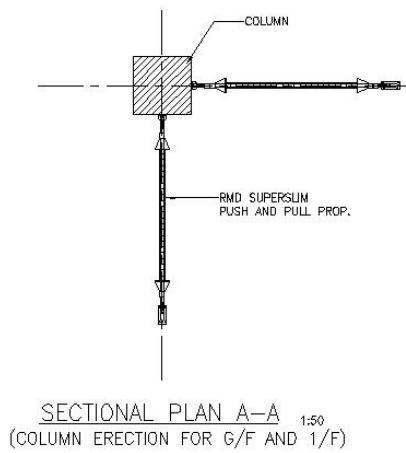
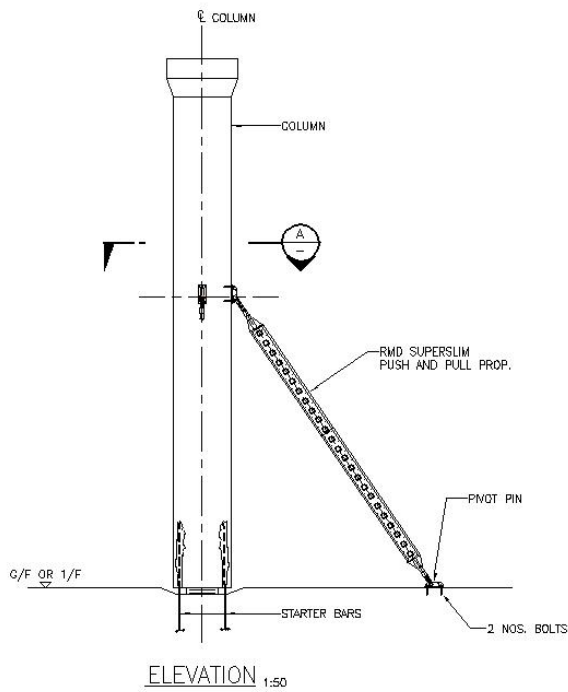


Figure 3.36 Example of stabilizing precast columns during erection.

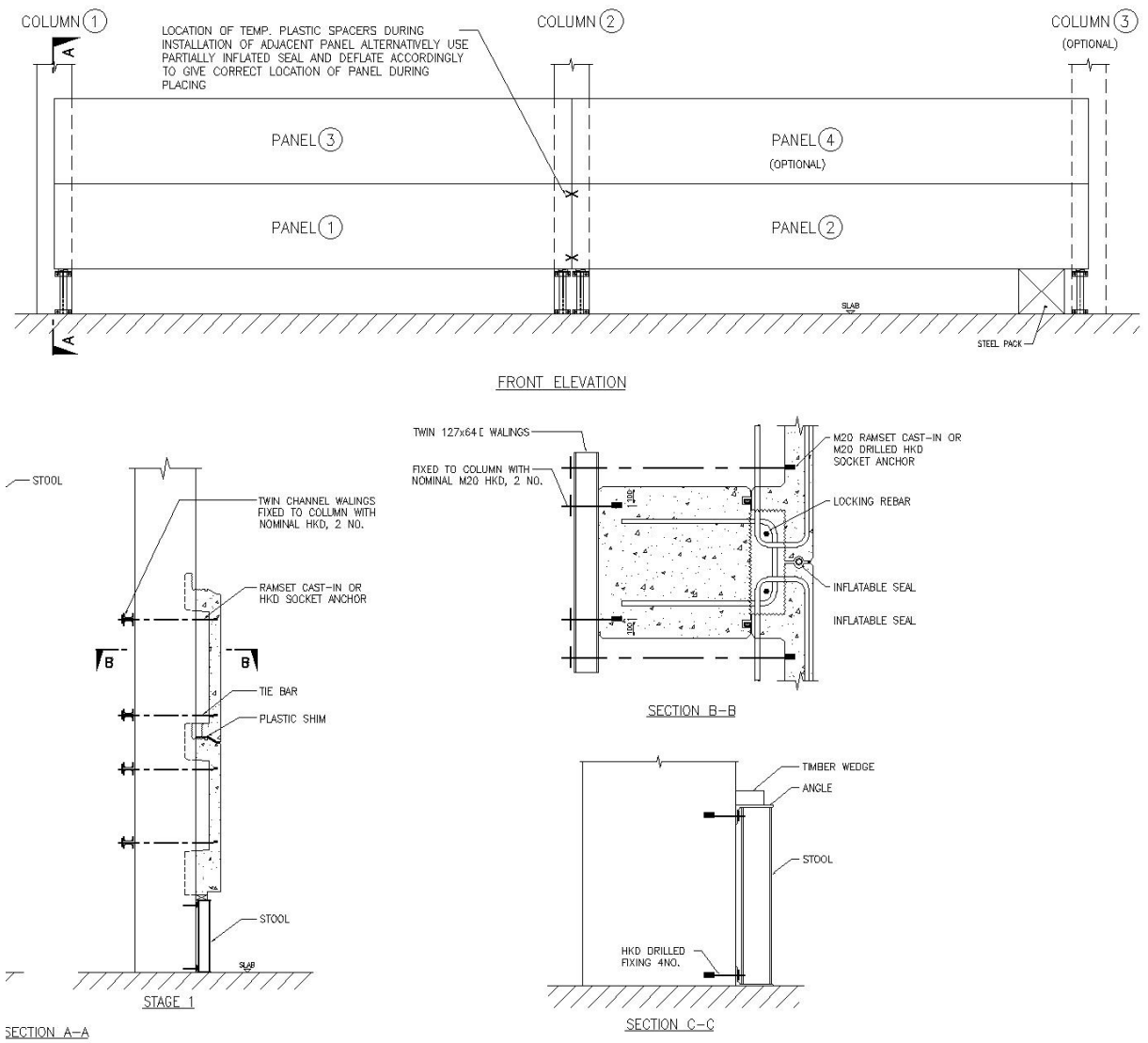
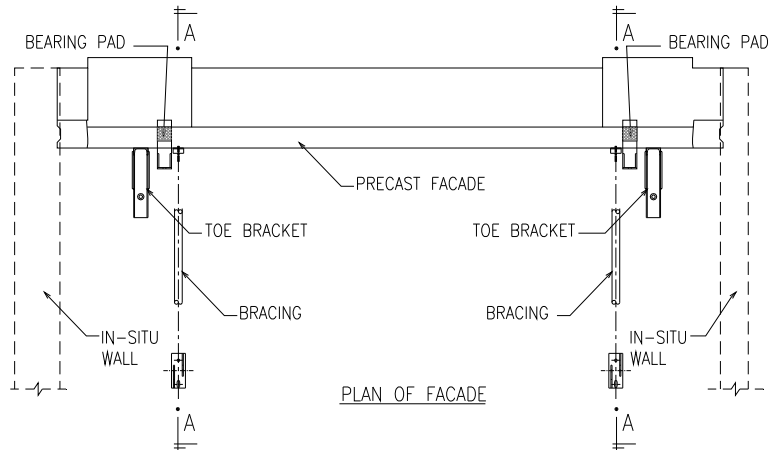


Figure 3.37 Example of erection of a 10 ton precast façade.



METHOD STATEMENT FOR THE INSTALLATION OF PRECAST FACADES

STAGE 1

- (1) LIFT THE PRECAST FACADE FROM STORAGE TO DESIRED WORKING POSITION.

STAGE 2

- (1) INSTALL THE INCLINED TEMPORARY BRACING AND TOE BRACKET.
- (2) ADJUST THE PRECAST FACADE TO ITS FINAL LEVEL BY DRIVING BEARING PAD OF FLOOR N-1 PRECAST FACADE TOP.
- (3) RELEASE THE LIFTING ANCHORS ARRANGEMENT.
- (4) SET THE PRECAST FACADE TO VERTICAL BY ADJUSTING THE TEMPORARY BRACING.

STAGE 3

- (1) FIX STEEL REINFORCEMENT OF THE ADJACENT IN-SITU STRUCTURAL R.C. WALL.
- (2) INSTALL THE FORMWORK TO THE IN-SITU STRUCTURAL R.C. WALL
- (3) CONCRETE THE IN-SITU STRUCTURAL R.C. WALL.

STAGE 4

- (1) DISMANTLE THE INCLINED TEMPORARY BRACING ON NEXT DAY OF CONCRETING IN-SITU WALL.
- (2) CONSTRUCT THE FLOOR SLAB.

STAGE 5

- (1) REPEAT STAGE 1 TO STAGE 4.

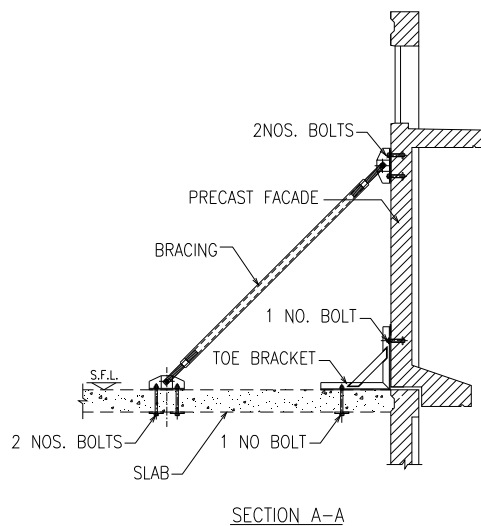


Figure 3.38 Method of erection for precast façade.

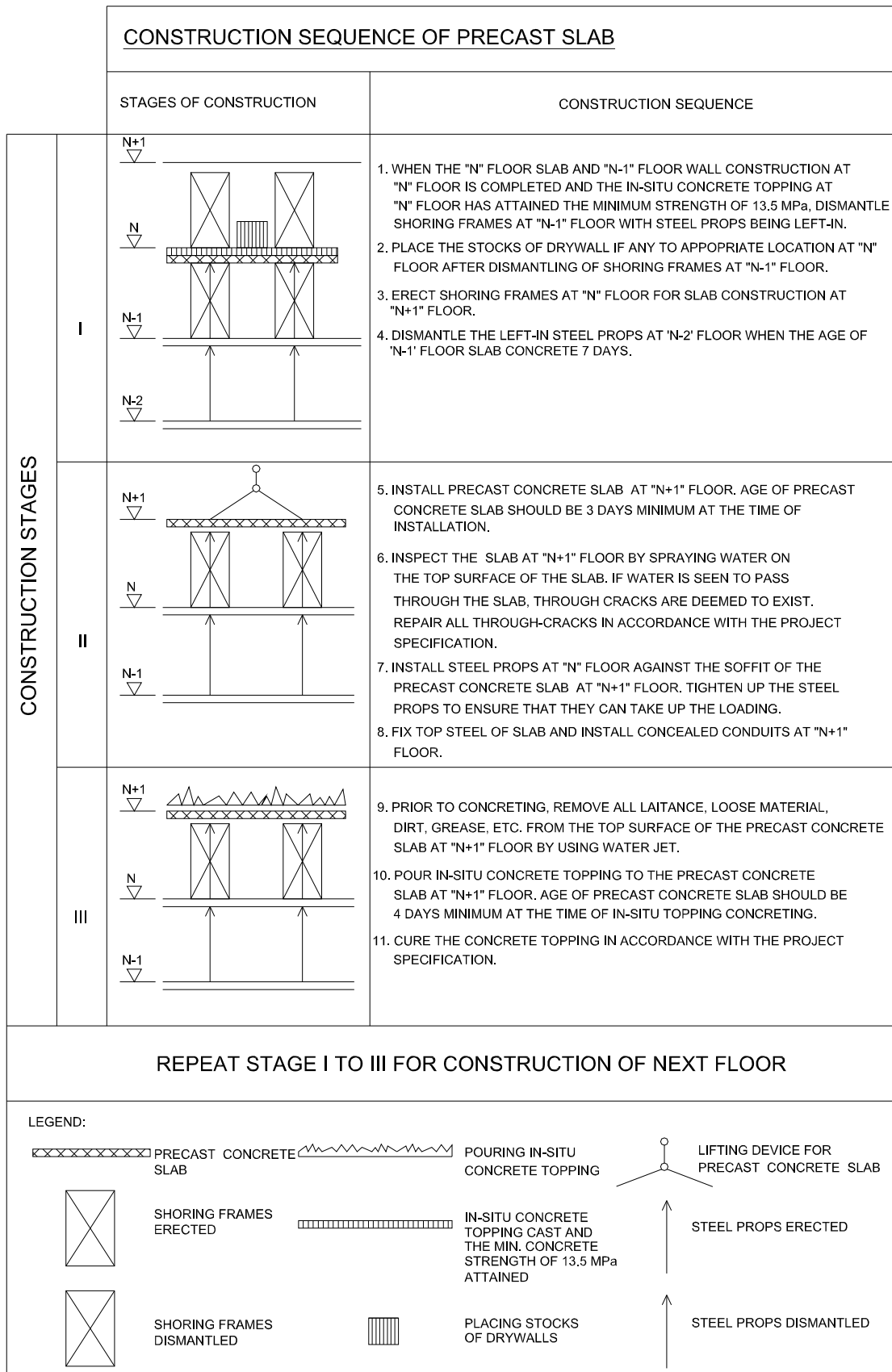


Figure 3.39(a) Method of erection for precast slab.

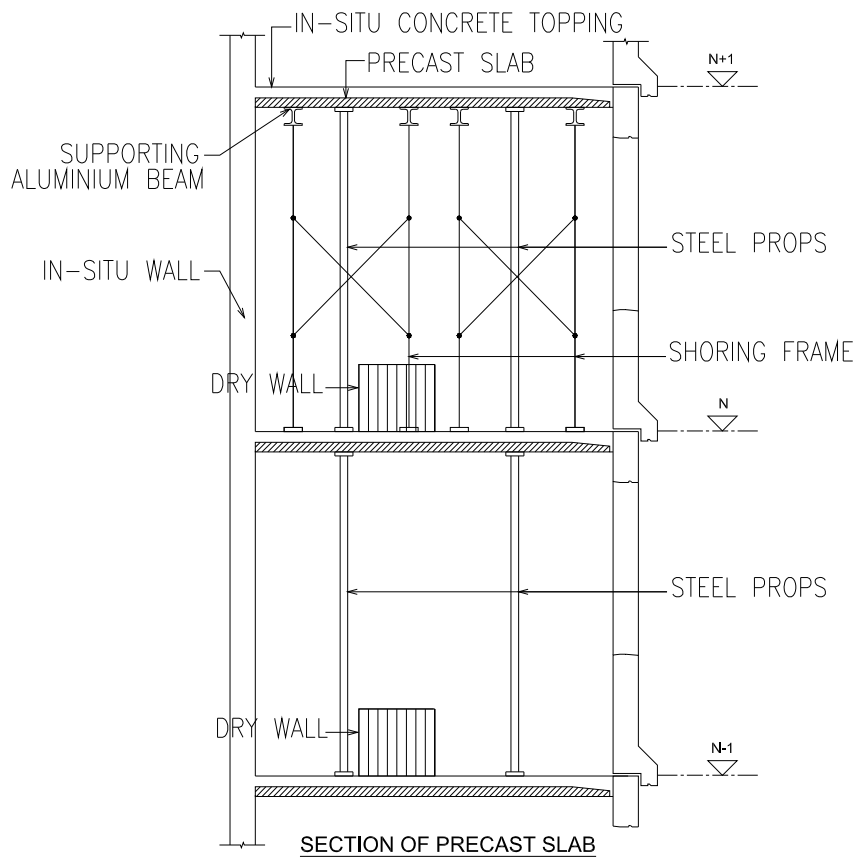
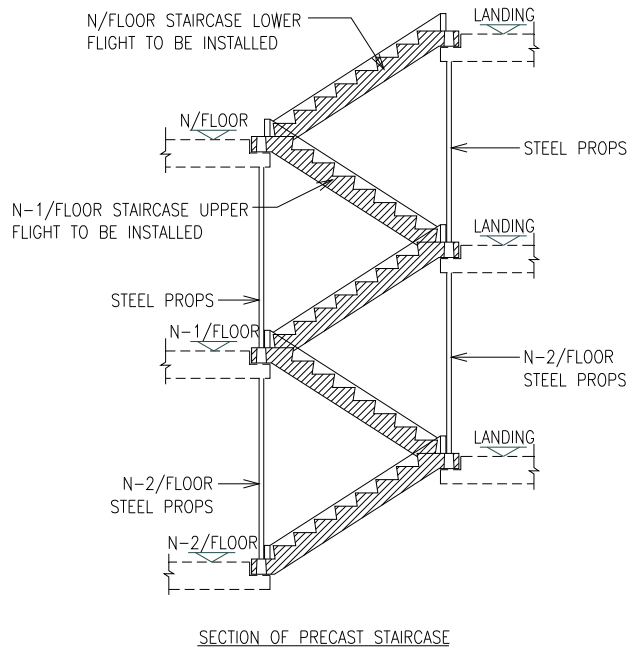


Figure 3.39(b) Sectional view of erection of precast slab.



METHOD STATEMENT FOR THE INSTALLATION OF PRECAST STAIRCASE

STAGE 1

- (1) CONSTRUCT THE SUPPORTING BEAM & LANDING IN THE 'N'/FLOOR.
- (2) LIFT THE PRECAST STAIRCASE FROM THE STORAGE YARD TO THE INTSTALLATION LOCATION. ('N'/FLOOR STAIRCASE LOWER FLIGHT & 'N-1'/FLOOR UPPER FLIGHT)
- (3) LOWER THE PRECAST STAIRCASE ONTO THE SUPPORTING MEMBER.

STAGE 2

- (1) ADJUST THE LEVEL OF THE PRECAST STAIRCASE BY USING BEARING PADS WITH ADEQUATE THICKNESS.
- (2) RELEASE THE LIFTING CHAIN SLING.

STAGE 3

- (1) FILL UP THE GAP BETWEEN THE PRECAST STAIRCASE AND THE SUPPORTING MEMBERS BY NON-SHRINK GROUT.
- (2) FILL UP THE GAP BETWEEN THE PRECAST STAIRCASE AND THE ADJOINING RC WALL BY NON-SHRINK GROUT.

STAGE 4

- (1) REMOVE 'N-2'/FLOOR STEEL PROPS.
- (2) CONSTRUCT THE SUPPORTING BEAM AND HALF LANDING IN THE 'N+1'/FLOOR.
- (3) STRIKE THE SIDE FORMS ON THE NEXT DAY. THE PROPS TO THE BEAM SOFFIT SHALL REMAIN UNDISTURBED. THERE SHALL BE 2 LEVELS OF STEEL PROPS UNDER THE SUPPORTING BEAM TO SPREAD THE LOADING TO THE LOWER FLOORS.

STAGE 5

- (1) REPEAT SEQUENCE STAGE 1 TO STAGE 4 FOR THE FLOOR ABOVE.

Figure 3.40 Method of erection for precast staircase.

4 QUALITY CONTROL

4.1 FACTORY

4.1.1 General

For the design, construction and quality control of precast concrete works, reference should be made to the recommendations and guidelines given in the CoP.

The duties of the Authorized Person (“AP”), the Registered Structural Engineer (“RSE”) and the Registered Contractor (“RC”) in providing adequate supervision to ensure quality precast concrete works are carried out, are clearly stated in PNAP APP-143 and the CoP. Production requirements for the manufacturer (“Manufacturer”) are also mentioned in the same PNAP and CoP. These are summarized in the table below:

Duties of the AP/RSE

- Ensure precast concrete works comply with provisions and standards of the Buildings Ordinance (“BO”) and the approved plans.
- Provide qualified supervision for the fabrication, erection and examination of the precast units to conditions stipulated by the BO and in the approved plans.
- Provide adequate and qualified supervision for the carrying out of the precast concrete works.
- Ensure the Quality Assurance Scheme (“QAS”) provided by the manufacturer satisfies the purpose in that the manufacturer has made adequate provisions ensuring the production of the precast elements complies with the provisions of the BO and the approved plans.
- Prepare a statement to confirm the purpose (signed by the project RSE) and submit together with the QAS prepared by the manufacturer in application for consent to commence work.
- The RSE to assign a structural quality control supervisor (T3 TCP under the RSE’s stream) to supervise the precast concrete production works at a frequency of not less than once a week. Provide supervisory personnel at the factory and an inspection log book recording details of the supervisory personnel and details of the production, inspection, auditing and testing carried out for the production of the precast units. Make sure the log book is available for inspection at all times by keeping the log book at the site office.
- Carry out inspections and audit checks of the factory and the production of the precast elements at least once every month. Prepare audit reports for submission. Endorse the audit reports prepared by the

Authorized Signatory of the RC. Submit all audit reports to the BD for record purpose.

Duties of the RC

- Maintain the quality of the manufacturing of the precast elements.
- Provide continuous supervision of the carrying out of the precast concrete works.
- Employ (or the manufacturer to employ) a consultancy firm, independent of the manufacturer, to carry out regular technical audits of the factory and the production of the precast units at a minimum frequency of once per month.
- Provide qualified supervision for the fabrication, erection and examination of the precast units to conditions stipulated by the BO and in the approved plans.
- Assign a quality control coordinator (T3 TCP under the RC's stream) to provide continuous supervision of the precast concrete production works. Provide supervisory personnel at the factory and an inspection log book recording details of the supervisory personnel and details of the production, inspection, auditing and testing carried out for the production of the precast units. Make sure the log book is available for inspection at all time by keeping the log book at the site office.
- Carry out inspections and audit checks of the factory and production of the precast units at least once every month by the Authorized Signatory of the RC. Prepare and submit the audit reports to the AP/RSE for endorsement and onward submission for record purposes.

Duties of the manufacturer

- Precast concrete elements shall be manufactured by a factory possessing an ISO9000 quality assurance certification.
- Nominate a QAS for the production of the precast elements for approval by the AP/RSE and subsequently to make application for consent to commence works.
- Maintain the quality of the manufacturing of the precast elements.
- Employ (or the RC to employ) an independent consultancy firm to carry out regular technical audits of the factory and the production of the precast elements at a minimum frequency of once per month.

The QAS shall cover but not be limited to the following items:

- Quality control tests of materials such as concrete mixes and re-bars,

finishes and building services provisions.

- Calibration of laboratory equipment for quality control tests, such as the frequency and standards adopted for the equipment used for the cube compressive strength test.
- Efficiency and operational control of equipment at the casting yard such as number of moulds employed and demoulding details.
- Production process such as details of the curing procedure and associated controls.
- Testing procedures and requirements such as tests on cast elements and installed finishes.
- Frequency and extent of inspection by staff of the manufacturer.
- Frequency and extent of audit by the independent parties employed by the manufacturer or the RC.
- Documentation certifying that the precast elements have been manufactured under a certified quality assurance scheme and in accordance with the specification and the approved plans.

Example of a list of QAS content is given in Annex A.

REFERENCES

- ACI 523.2R-96, Guide for Precast Cellular Concrete Floor, Roof, and Wall Units.
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Pfeifer D.W. and Landren R. (1982), Energy Efficient Accelerated Curing of Concrete for Plant Produced Prestressed Concrete, *PCI Journal*, March-April, 1982, pp. 94-107.

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Popovics S., A Review of The Concrete Consolidation by Vibration, *Materiaus et Constructions*, Vol. 6, N 36, 1973.

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Precast Prestressed Concrete Parking Structures: Recommended Practice for Design and Construction, PCI Committee on Parking Structures, PCI, 1988.

State-of-the-art of Precast/Prestressed Sandwich Wall Panels, PCI Committee Report, 1997.

ANNEX A

Example of a Quality Assurance System

1. Organization Chart
2. Casting yard
 - set up of yard
 - number of moulds with estimated production rate
 - machinery employed
3. Production procedures (casting and transportation of the precast units within the yard)
4. Quality control procedures on materials and check points for
 - concrete
 - re-bar
 - couplers
 - finishes
 - building services installations
5. Quality control procedures on production and check points
 - approved plans used
 - shop drawings used
 - moulds assembling
 - re-bar fixing
 - couplers fixing/welding work
 - finishes and building services installation
 - concreting work
 - curing
6. Calibration of testing equipment (responsible parties, frequency, and standards)
7. Testing of precast units such as dimensional check, cover meter test, pull-out test for tiled finishes, bonding test for building services installation, etc.
8. Concrete repair procedures
9. Handling of non-compliant precast units with corrective/preventive action
10. Inspection forms
11. Identification system of the precast units
12. Audit by independent parties

ANNEX B

Example of a specification for precast concrete

DESIGN

GENERAL

Justifications (calculations etc.) are to be provided to demonstrate that the insitu structural members and the precast concrete units/volumetric precast concrete components (precast units) are not subject to excessive stresses arising from the erection method of the precast units and to demonstrate the adequacy of any temporary supports which may be required.

All necessary designs, calculations and drawings are to be approved prior to mass production of the precast units.

DESIGN STANDARDS

Building structures must comply with Concrete Code 2013 issued by the Buildings Department and the relevant regulations, PNAP, codes of practice, etc., currently in use. The precast units must also comply with the CoP.

Design of the joints (the jointing system between precast units and the in-situ concrete structure), including the structural connections e.g. steel couplers for connecting the reinforcement bars, must be able to transmit the worst anticipated combination of moment, shear, axial force, temperature stresses, shrinkage, creep and torsion and cater for all movements of the building structure during the erection of the precast units and during and after the construction of the building structure.

RESISTANCE TO PROGRESSIVE COLLAPSE

Design the precast units both as an assembly of individual walls and floors and as a complete unit to behave integrally with the building structure. Design the building structure and the precast units to prevent progressive collapse of the building.

DEFORMATIONS

Design the precast units to be located in the structure and not to deform excessively before the joints and connections are completed.

LOADING

Design the precast units (load bearing or non-load bearing) to sustain all possible loadings acting upon them. In particular, take the following loading conditions into account:

1. Dead loads and superimposed loads;
2. Wind loads in accordance with the Wind Code;

3. Eccentric loads which arise either as a result of the centre of gravity of the precast units being offset from the support or from random inaccuracies occurring during construction. Allow a minimum of 25 mm eccentricity in the design for such random inaccuracies;
4. Tensile loads if the precast units are designed to be hung from the top or from the sides;
5. Buckling loads if the precast units are subject to vertical compression;
6. Temperature stresses;
7. Temporary loads which arise during demoulding, storage, lifting, transporting and erection of the precast units. In particular, design for the complex stresses arising when lifting from the stacked position into the lifting position;
8. Loads placed on the precast units in both temporary and permanent situations should take creep into consideration on vertical elements of the precast units which may be more highly stressed than outer adjacent precast or in-situ vertical load bearing elements; and
9. Accidental load if taken as a measure for preventing progressive collapse of the building.

SHOP DRAWINGS

Fully dimensioned shop drawings are to be approved prior to mass production of the precast units.

DESIGN TOLERANCES

OVERALL TOLERANCES

Design the precast units and the associated joints/connections for attaching the units to the in-situ structure, other precast units, architectural and building services installations, including all cast in elements, to conform with the relevant tolerances given in the CoP.

PRECAST UNIT MANUFACTURE TOLERANCE

Propose a set of manufacturing tolerances which satisfies the overall tolerances given in the CoP taking into account erection tolerances.

PRECAST UNIT ERECTION TOLERANCE

Propose a set of erection tolerances that is in compliance with the overall tolerance allowed when taken together with the set of manufacturing tolerances proposed and taking into consideration all possible interfaces when erecting adjacent precast units and/or constructing in-situ elements.

SCOPE OF THE WORK

GENERAL

Define (the extent of) the precast units including the architectural and building services installations to be cast with the precast units in the factory.

LIFTING AND LOCATING DEVICES

Design lifting and location devices for embedding or fixing to the precast units in accordance with the CoP.

Allow a minimum safety factor of 4 for lifting inserts under normal circumstances.

Make necessary provisions in the precast units to prevent local rupture or cracking as a result of using lifting and locating devices.

LOCATION POINTS

Make provision on each precast unit for locating, plumbing and levelling to the designed location within acceptable tolerance limits.

PERMANENT JOINTS/CONNECTIONS

Design permanent structural joints/connections using one, or a combination of both, of the following methods:

1. In situ connection by which the precast units are joined monolithically with the building structure.
2. Mechanical connections by which the precast units are secured to the building structure at attachment points using brackets, cleats, bolts, fixings, couplers and welds.

ERECTION RESTRAINTS

Design vertical and horizontal restraints for temporary connection of the precast units to the building structure so that displacement of the precast unit cannot occur until the permanent structural joint/connection is completed.

ADJUSTMENT DEVICES

Provide the precast units with separate vertical and horizontal adjustment devices. Do not use adjustment devices in the vertical plane for horizontal location devices or horizontal restraint. Do not design any adjustment devices in the horizontal plane to take permanent loads.

INSITU JOINTS/CONNECTIONS

GENERAL

Design the insitu joint/connection:

1. to withstand the loads to be sustained by the units and the stresses induced by the precast units to the building structure;
2. to be watertight; and

3. to be of the same or a higher grade concrete than that of the precast units.

REINFORCEMENT, SHEAR CONNECTORS, ETC

Ensure reinforcement, shear connectors, etc. used for the permanent structural joints/connections are adequately embedded or anchored into the building structure.

VERTICAL JOINTS

For vertical in-situ joints, provide measures to prevent development of cracks during hardening of the grouting material. Observe manufacturer's recommendations.

Use non-shrink grout with aggregates or concrete with non-shrinking additives to fill voids with minimum dimension larger than 150 mm and only non-shrink grout for voids with minimum dimension less than 150 mm.

JOINT WIDTH

Joint width shall not be less than 6 mm.

LOAD BEARING FIXINGS

Design the fixing so that the supporting area is adequate to carry the weight of the precast unit taking into account the strength of concrete of the supporting elements achieved at the time of erection of the precast unit.

Design the fixing to sustain the forces due to restraint of the relative movement between precast units and the building structure.

WEATHERPROOF JOINTS

GENERAL

Design weatherproof joints between the precast units and the building structure or between two adjacent precast units to ensure air and water tightness and in accordance with the CoP and BS 6093:2006.

SUBMISSIONS

DRAWINGS AND METHOD STATEMENT

Shop drawings and method statement are to be approved and should cover the following items:

1. Layout arrangement of moulds, casting methods (horizontal or vertical), demoulding methods with tilting mechanism if used;
2. The complete procedures for manufacture of the precast units, which should include fabrication, moulding, curing, demoulding, application of finishes, lifting, transportation, storage and erection of the precast units;

3. Details to ensure that dimensional accuracy can be achieved;
4. Method of protecting the precast units and the finishes, fittings and cast in building services installations from damage;
5. Minimum concrete strength required for demoulding, handling, transporting and erecting the precast units;
6. Design and position of lifting devices;
7. Calculated weights of the precast units; and
8. Details of prefabricating the finishes and building services installations.

QUALITY CONTROL PROCEDURES

Quality control procedures for the manufacturing and erection of the precast units are to be approved.

PROGRAMMES

The programme for the design, production and testing of trial samples, mock-up assembly, manufacture, erection and testing of installed precast units including dates for clearing the area of any on-site casting yard and associated plant upon completion of manufacture of the precast units is to be agreed.

LOADING OF INSITU STRUCTURAL MEMBERS

Provide justifications to demonstrate that the insitu structural members are not subject to excessive stresses arising from the erection method of the facade units and to demonstrate the adequacy of any temporary supports which may be required.

DESIGN OF MOULDS

Provide mould designs indicating clearly the material, casting methods (horizontal or vertical), tilting mechanism (if any), moulding and demoulding sequences and the provision for attachments of openings for window fixing and finishes to be used.

MATERIALS

GENERAL

Use concrete mixes for the precast units which are compatible with the defined exposure conditions of the internal and external faces of the units.

NON-SHRINK GROUT FOR PRECAST UNITS

APPROVED MIX

Use non-shrink grout (designed grout mix or pre-packed grout product) or a cement based product which contains Portland cement, selected sand, aggregate and non-shrink additives and comply with their application requirements including testing requirements.

Pre-packaged non-shrink grout products must comply with the manufacturer's recommendations.

QUALITY REQUIREMENTS

Define quality requirements of the grout based on the 28-day strength, chloride content, initial and final setting time and free expansion.

WEATHER PROOF JOINTS

GENERAL

Weatherproofing materials are to comply with the CoP and BS 6093:2006 and are to be approved.

MORTAR STOP BACKING RODS

Polyethylene foam or other approved inorganic type.

DETAILS OF WEATHERPROOFING

Details of weatherproofing materials including technical information, samples, test reports and proven performance records of proposed materials are to be approved.

WORKMANSHIP

FACTORY

The following details are to be approved:

- a. The set-up of the factory for the manufacture of precast units such as plant and curing and storing facilities.
- b. Details of the manufacturer such as organisation structure, the Quality Assurance Scheme and the audit plan for the Precast Concrete Construction Audit.
- c. Details of the laboratory for carrying out the tests and issuing test certificates for works carried out at the factory, which should be accredited either by Hong Kong Accreditation Scheme (HKAS) under the Hong Kong Laboratory Accreditation Scheme (HOKLAS), or an equivalent organization which has signed a mutual recognition agreement with HOKLAS.

QUALITY ASSURANCE SCHEME FOR MANUFACTURING PRECAST UNITS AT THE FACTORY

Ensure that the factory for the manufacturing of the precast units operates on an approved Quality Assurance Scheme certified under ISO 9000.

Observe requirements stipulated in CoP, PNAP APP-143 and PNRC 63.

QUALIFIED SUPERVISION

Assign a quality control coordinator with the minimum qualification and experience of a Grade T3 TCP in the civil or structural engineering discipline under the Registered Contractor's stream in the Code of Practice for Site Supervision to:

1. Certify all control documentation and test certificates required for the QA Scheme;
2. Provide continuous supervision of the precast concrete production work at the factory; and
3. Perform technical audits on the manufacturing of the precast units.

Record the names and qualifications of the quality control coordinator in an inspection log book. The details of precast production, inspection, auditing and testing should also be recorded in the log book by the supervisory personnel. The log book should be kept in the factory and a copy kept at the building site office.

The Authorized Signatory of the Registered Contractor is to carry out inspection and audit checks of the factory at least once every month and submit a monthly audit report to the RSE for endorsement and onward submission to the Buildings Department.

METHOD STATEMENT

A method statement, covering the following, is to be approved:

1. Mould set up, inspection, approved mix, demoulding, curing, finishing and lifting;
2. Method of preinstalling the window frames or windows;
3. Method to rectify connections which are out of position but within tolerances;
4. Details of the proposed means of support and storage of the precast units in the factory; and
5. Erection of the precast units at their final locations in the structure.

SUBMISSION AND PILOT PRODUCTION RUN BEFORE APPROVAL

Before granting approval for mass production, carry out a pilot production run to demonstrate the technical capability and effectiveness of the Quality Management System.

Carry out a trial run to demonstrate the manufacturing process including installation of windows, lifting operation, curing, storage, fixing of mosaic tiles, quality tests at factory laboratory, applied finishes and quality controls in accordance with the required drawings and specification.

PRODUCING PRECAST UNITS

MOULDS

Construct moulds from steel or other materials to produce the precast units to the standard suitable for the surface finishes specified and within permitted tolerance

limits.

Incorporate the requirements of all trades such as blockouts, recesses, notches, embedded metal works or any other items before casting the precast units.

SURFACE FINISHES

Finish faces of the precast units to give even surfaces (textured or untextured as required) suitable for fixing external finishing such as paint and ceramic tiles.

REQUIREMENTS OF OTHER TRADES AND COMPONENTS

Incorporate the requirements of all trades such as blockouts, recesses, notches, embedded metal works or any other items before casting the precast concrete components units.

CURING

GENERAL

Define curing requirements. Curing proposals are to be approved. Carry out a full scale trial to demonstrate the satisfactory performance of the proposals before approval can be granted.

CURING BY APPLICATION OF HEAT

Heat curing by means of steam, hot air, etc. is to be approved. Carry out a site trial to demonstrate the adequacy of the proposed method before approval can be granted.

DEMOULDING GENERALLY

Demoulding proposals are to be approved, which should include quality controls on the minimum strength of concrete to be attained before demoulding.

Do not lift precast units until the concrete has attained a strength adequate to resist the resultant stresses without inducing cracking or other damage to the concrete.

ACCURACY AND TOLERANCES

CHECKING TOLERANCES

Check the manufacturing dimensional tolerances of the precast units by an approved method at an approved rate.

LIFTING, TRANSPORTATION AND STORAGE

GENERAL

Ensure that the design of the lifting mechanism for precast units provides a safe and robust means of lifting and holding the component in a truly vertical position and is adjustable to ensure verticality if necessary. Ensure that:

1. The design for lifting takes into account all loads on the component, friction against mould faces, snatch, impact and self-weight of all fittings, lifting frame and equipment with an appropriate factor of safety;
2. Any lifting system that has a number of bolts, chains or ropes that work in parallel, is either designed such that all internal loads are calculable and statically determinate or, if not, that each bolt, chain, or rope possesses sufficient reserve of strength for any likely load distribution; and
3. The equipment is capable of supporting the component if any single individual fastening, chain or bolt fails, taking into account any realignment of the component as it moves to place the centre of gravity under the new lifting arrangement.

Do not lift precast units for at least 24 hours after casting or until the concrete has attained a strength adequate to resist the resultant stresses without inducing cracking or other damage to the concrete.

LIFTING FRAME

Lift precast units by means of purpose-made steel lifting frames.

LIFTING INSERTS AND SUPPORTS

Determine exact number, size and location of lifting inserts and proper supports with locations for transportation and storage of the precast units with factors of safety stipulated in the CoP.

Locate lifting points such that the line of the resistant force passes through the centre of gravity of the facade unit.

LIFTING PLANT AND EQUIPMENT

Ensure plant used for lifting including cranes, hoists, lifting frames, hooks, etc possess adequate safety margins, are maintained in good working order and are regularly tested. Maintain crane cable in a sound condition.

LIFTING UNITS

Maintain all cables connecting the lifting frame and the lifting points of the precast units vertical during lifting of the components. Provide the cables with devices for adjustment of their lengths.

STORING UNITS

Store the precast units in the vertical plane on a level, well drained and maintained concrete surface and protect against staining or physical damage. The precast units shall be supported in the storage area by a device to prevent toppling.

TRANSPORTING FROM FACTORY

Stack precast units vertically on vehicles during transportation from the factory. Support the units on cradles so that the units are completely protected against damage or being over-stressed. Ensure the transportation of the precast units complies with transportation regulations.

ERECTING PRECAST UNITS

STANDARD AND SEQUENCE

Erect precast units in a sequence to be approved.

QUALITY CONTROL PROCEDURES

Carry out erection of the precast units in an approved procedure covering the following:

1. Protective measures to avoid cracking and chipping;
2. Protective measures to avoid damaging and contaminating the preinstalled finishes, fittings and building services installations;
3. Checking the accuracy of the insitu structural members receiving the precast units, including location and level of all bearing surfaces, joints, bolts, horizontal and vertical restraining devices and adjustment devices. Carry out checking by means of a template or measurement frame or a similar approved method;
4. Checking of erection tolerances;
5. Provision and removal of temporary works;
6. Procedure for grouting of joints; and
7. Testing related to the jointing system.

LIFTING UNITS INTO POSITION

Do not allow devices such as sockets or bolts for lifting purposes to be used for fixing the precast units to the main structure.

WEIGHT OF PRECAST UNITS FOR TRANSPORTATION AND CRANEAGE

Indicate in the method statement the maximum weight of the precast units including the weight of any props, supporting frame, protection or packing to ensure the weight shall not be exceeded when lifting the precast units.

TEMPORARY SUPPORT

Calculation of the temporary supports must be approved.

During fixing of the precast units, prop adjacent insitu structural members adequately to avoid excessive deflection or adverse stresses.

Maintain all temporary supports, props and restraints in position during casting of concrete/grout in the structural joint. Remove temporary supports, props and restraints upon satisfactory testing.

PREPARING AND PLACING GROUTING MATERIALS

The method of preparing and placing grouting materials in structural joints between the precast units and in-situ structural members must be approved.

TESTING

TRIAL SAMPLES

Produce full size trial samples complete with joints, windows, glazing, electrical conduit system and installations and all finishing at ground level for Approval prior to mass production of the precast units.

FULL SCALE MOCK UP

Provide for approval full scale mock up to demonstrate that the precast units, the system of joints and the erection procedures are adequate prior to mass production of the precast units.

Ensure a mock-up to demonstrate that the use of the precast units is feasible and safe and that the precast units are constructable and architecturally and functionally satisfactory when gauged against buildability; tolerances; accuracy; quality; manufacturing process; and joint integrity.

Construct the mock-up in strict accordance with the commented shop drawings and all methods of the study mock-up joint assembly are to faithfully represent actual job conditions. Do not use special measures or techniques that are not representative of those to be used on the building;

Carry out a watertightness test on the mock up on the precast units. Carry out watertightness tests of the joints of the precast units and joints of the windows cast in. Where a jointing system is constructed in combination with joint sealing compound, carry out the watertightness test prior to the application of the sealing compound to test the watertightness of the joint.

Conduct tests to finishes, fittings and building services installations to be cast in the precast units in accordance with the relevant requirements.

Allow adequate time for approval prior to mass production of the precast units;



Figure A1 Watertightness test on the mock up on the precast units.

SITE WATERTIGHTNESS TESTS

Carry out watertightness tests to the installed units.

Carry out watertightness tests to the joints located at the external faces of the building and joints of windows cast in. Where a jointing system is constructed in combination with a joint sealing compound, carry out the watertightness test prior to the application of the sealing compound to test the watertightness of the joint.

COMPRESSIVE STRENGTH TESTS

Carry out compressive strength tests on concrete cubes, made from the concrete used for casting the precast units.

Carry out compressive strength tests on cores taken out from the precast units.

Carry out compression tests on grout cubes for each day of grouting.

TESTING OF FIXINGS

Carry out tensile tests and shear tests to fixings and anchors.

SITE TESTING OF JOINTS AND CONNECTIONS

Allow sufficient time in the construction cycle of the building structure for carrying out welding integrity tests prior to grouting the joints. For proprietary couplers used, test in accordance with manufacturer's recommendations.

SURVEILLANCE INSPECTION

Carry out inspections at the manufacturer's factory of precast units manufactured off-site. Carry out open-up inspections when necessary. Before installation of the precast units, carry out open-up inspections on site.

ANNEX C

Example of a particular specification on volumetric precast concrete construction

DESIGN

DEFINITION OF VOLUMETRIC PRECAST CONCRETE CONSTRUCTION

Construction of three-dimensional precast concrete building components or units, with fixtures, fittings, finishes and building services installations.

Define in drawings (the extent of) the components/units that will adopt volumetric precast construction, i.e. Volumetric Precast Components (VPCs), and the fixtures, finishing, fittings and building services installations to be preinstalled in the VPCs.

STABILITY

Design the VPC components to be stable at all times.

MOCK-UP

SIZE OF MOCK-UP

The mock-up shall be at least 2 storeys high, comprising all the different types of VPCs that will be adopted to demonstrate all interfaces and joints with adjacent in-situ or precast elements.

EXTENT OF COVERAGE OF STUDY MOCK-UP

The mock-up should include all internal and external finishes, doors and windows, electrical lighting, fittings, sockets, concealed conduits, sanitary fittings, internal and external services, plumbing and drainage, and any other accessories required for the proper functioning of the VPCs for erection.

MAINTENANCE MANUAL

The maintenance manual for the replaceable structural items of VPC components is to be approved. This should be developed in parallel with the study mock-up and should include, but not be limited to the following information:

1. A clear and concise description of the method used to construct the replaceable structural items concerned.
2. A method statement covering the procedures for replacement of damaged or otherwise defective materials or structural components, and materials and components that have a design life less than the design life of the VPCs and will therefore require replacement during the life of the VPCs.
3. Recommendations for routine maintenance, cleaning, suitable cleaning agents and any special inspection method of the materials and/or components of the

- replaceable structural items.
4. The terms and conditions of any guarantees or warranties associated with the installed materials and components of the replaceable structural items.

WORKMANSHIP

PROGRAMMES

The following are to be agreed prior to mass production of the VPCs:

1. Programme for manufacturing VPCs showing the rate of manufacture for each month and the dates for clearing the area of on-site factory (if any) and associated plant upon completion of the manufacture of the components.
2. Programme for the erection of the VPCs showing the rate of erection for each month. Make due allowance for all restrictions on the age of concrete in the handling, storage, transportation and erection of the VPCs. Make also due allowance for the construction programme of the buildings.

MANUFACTURING OF VPC

MOULD ASSEMBLY

Ensure the moulding and demoulding details are practical for mass production of the VPCs.

CURING BY APPLICATION OF HEAT

Heat curing by means of steam, hot air, etc. is to be approved. Ensure that the total chloride content of the concrete mix for VPCs, subject to heat curing, is less than 0.1% by weight of that of the cement. Carry out a trial to demonstrate the adequacy of the proposed method.

CONCRETE STRENGTH BEFORE DEMOULDING

Demould the VPCs only after concrete has achieved the required strength. Make the necessary concrete cubes in pairs from the same batch of concrete used for casting the VPCs and cure the concrete cubes under the same conditions as the concrete in the VPCs.

REQUIREMENTS OF OTHER TRADES AND COMPONENTS

Incorporate the requirements of all trades such as blockouts, recesses, notches, embedded metal works, building services installations or any other items etc. that are pre-installed in the VPCs before casting.

SIZE AND WEIGHT OF VPC COMPONENTS FOR TRANSPORTATION AND CRANEAGE

Indicate in the method statement the maximum projected horizontal and vertical dimensions of the component, including any protection, packing or protruding steel, beyond transportation vehicles, to ensure compliance with the limitations and requirements stipulated by local legislation.

Indicate in the method statement required for approval the maximum weight of the VPCs including the weight of any props, supporting frame, protection or packing to ensure this weight will not be exceeded when lifting the VPCs.

TEMPORARY STORAGE SUPPORT

Provide temporary support for storage of VPCs that does not place excessive bearing, compressive, tensile or flexural stresses on the component or cause damage or unintended deformations of the component including the finishes and building services installations contained therein.

Provide calculations to demonstrate that the likely deformation of VPCs, temporarily supported in the storage yard, is not detrimental to the manufacture tolerances, and, after erection, to the overall tolerances.

Ensure that stacking of VPCs does not generate unintended bearing, compressive, tensile or flexural stresses on the component or cause damage or unintended deformations of the VPCs including the finishes and building services installations contained therein.

TRANSPORTATION

Ensure wagons are equipped with suspension systems to minimize shock loading. Comply with relevant transportation requirements and regulations including those issued by the Government.

ANNEX D

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Design Example 1: Lock-in stress in precast plank during construction

For domestic flat slab, consider semi-precast slab of 160 mm thick overall with 70 mm thick precast plank at the bottom.

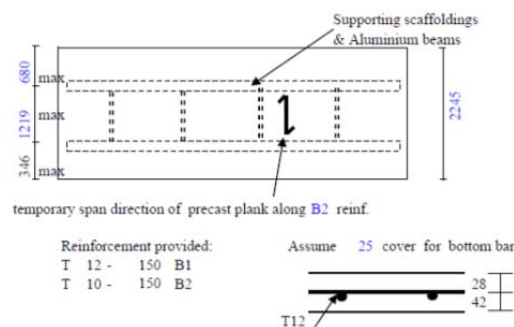
$$\text{Slab self-weight} = 0.16 \times 24 = 3.84 \text{ kN/m}^2$$

$$\text{Construction live load} = 1.5 \text{ kN/m}^2$$

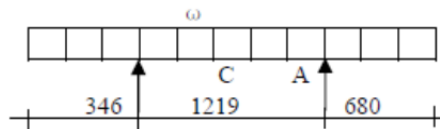
Under ultimate limit state,

$$\text{Design factored load} = 1.4 \times 3.84 + 1.6 \times 1.5 = 7.8 \text{ kN/m}^2$$

Consider the typical layout diagram of supporting props during construction and the slab reinforcement provided as follows:



Consider 1 m width; Ultimate moment is to be determined for the lock-in stress during construction as follows:



$$l_1 = 680 \text{ mm}; l_2 = 1219 \text{ mm}$$

$$\begin{aligned} \text{Maximum hogging moment at A} &= w l_1^2 / 2 \\ &= -7.8 \times 0.682 / 2 \\ &= -1.8 \text{ kNm} \end{aligned}$$

$$\begin{aligned} \text{Maximum sagging moment at C} &= w l_2^2 / 8 - (\text{Hogging moment at A})/2 \\ &= 0.55 \text{ kNm} \end{aligned}$$

$$b = 1000 \text{ mm}$$

$$d = 42 \text{ mm (under hogging moment which is greater)}$$

$$f_{cu} = 25.9 \text{ MPa (at the age of 5 days)}$$

$$K = M / (b d^2 f_{cu}) = 0.039 \text{ (Concrete Code 2013 Cl.6.1.2.4)}$$

$$A_s(\text{req.}) = M / (0.87 f_y z) = 113 \text{ mm}^2$$

$$A_s(\text{prov.}) = 523 \text{ mm}^2 \text{ (T10-150)}$$

$$\text{Stress induced in reinforcement } s_1 = (113/523) \times 0.87 f_y = 86 \text{ MPa}$$

Under permanent stage,

$$\text{The original design sagging moment along B2 direction} = 7.44 \text{ kNm}$$

The stress in reinforcement under permanent design load case is calculated as follows:

$$b = 1000 \text{ mm}$$

$$d = 160 - 25 - 12 - 5 = 118 \text{ mm}$$

$$f_{cu} = 35 \text{ MPa}$$

$$K = M / (bd^2f_{cu}) = 0.015 \text{ (Concrete Code 2013 Cl.6.1.2.4)}$$

$$A_s(\text{req.}) = M / (0.87f_y z) = 166 \text{ mm}^2$$

$$A_s(\text{prov.}) = 523 \text{ mm}^2 \text{ (T10-150)}$$

$$\text{Stress induced in reinforcement } s_2 = (166/523) \times 0.87f_y = 127 \text{ MPa}$$

$$\text{Total stress} = s_1 + s_2$$

$$= 86 + 127$$

$$= 213 \text{ MPa}$$

$$< 0.87f_y = 400 \text{ MPa} \quad \text{OK}$$

The lock-in stress in reinforcement during construction is superimposed to the steel stress under permanent case to check with the reinforcement yield stress limit.

Design Example 2: Notional horizontal load

Consider the length and the thickness of a precast wall segment be 1485 mm and 200 mm respectively. The floor-to-floor height is 2700mm and the slab thickness is 325 mm. Then the dead weight of the precast wall structure is calculated as follows:

$$\begin{aligned}\text{Weight} &= 1.485 \times 0.2 \times (2.7-0.325) \times 24 \text{ kN/m}^3 \\ &= 17 \text{ kN}\end{aligned}$$

$$\begin{aligned}\text{Notional design ultimate horizontal load} &= 1.5\% \times \text{Dead Weight} \\ &= 1.5\% \times 17 \text{ kN} \\ &= 0.3 \text{ kN}\end{aligned}$$

The cover is assumed to be 30 mm. Then

The effective depth $d = 200 - 30 - 8 = 162$ mm (16 mm bar diameter)

$$\begin{aligned}\text{Notional design ultimate horizontal shear stress} &= 0.3 \times 1000 / (1485 \times 162) \\ &= 0.001 \text{ N/mm}^2 \text{ which is negligible}\end{aligned}$$

Design Example 3: Demoulding, Yard Handling and Transportation

At the age of 1 day of the precast element, $f_{cu} = 15 \text{ MPa}$ (Grade 35 Concrete)

For semi-precast slab with smooth mould with form oil,

Demoulding load factor = 1.3 (CoP Table 2.1)

Yard handling load factor = 1.2 (CoP Table 2.2) – not control

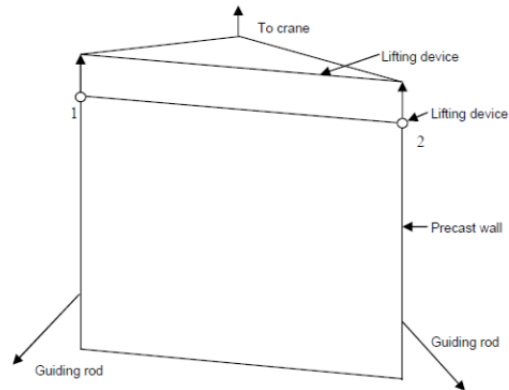
At the age of 3 days of the precast element, $f_{cu} = 23.1 \text{ MPa}$ (Grade 35 Concrete)

Transportation load factor = 1.5 (CoP Table 2.2)

As concrete strength is much greater at the age of 3 days of 23.1 MPa than at the age of 1 day of 15 MPa (54% larger) while the loading is only about 15% larger (load factor is increased from 1.3 to 1.5), demoulding stage will be the control case if the lifting point is the same.

Design Example 4: Early lifting of precast wall.

A special lifting device, designed by the contractor and approved by the structural engineer, is used to lift up the precast unit to avoid any damage. A precast partition wall is assumed to be hanged up at 2 points as illustrated below.



For maximum lifting force of $V=24$ kN with minimum $f_{cu} = 15$ MPa attained at the lifting stage,

$$\text{Bond stress} = 0.5 \sqrt{f_{cu}} = 1.94 \text{ MPa (Concrete Code 2013 Cl.8.4.4)}$$

Each lifting point will have T12 u-shaped steel bar anchored into precast concrete. Then the shear at each end of the anchor bar is equal to half of the total load applied to the lifting point.

$$\begin{aligned} \text{Anchorage length required} &= V / (2 \times 0.5 \sqrt{f_{cu}} \times \text{bar size} \times \pi) \\ &= 165 \text{ mm} \end{aligned}$$

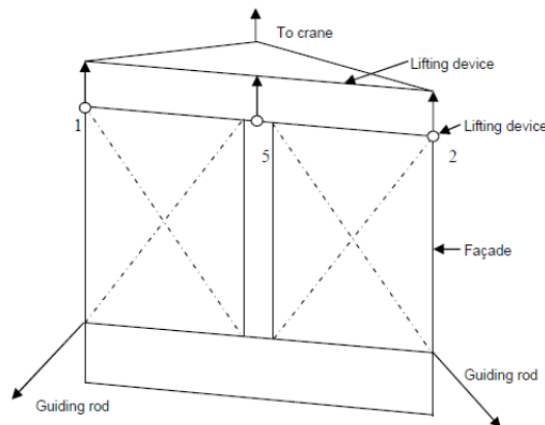
$$\text{Adopt anchorage length} = 450 \text{ mm}$$

$$\begin{aligned} \text{As required} &= V / 0.87f_y \\ &= 60 \text{ mm}^2 < \text{As provided T12 U-bar} \\ &= 226 \text{ mm}^2 \text{ OK} \end{aligned}$$

Design Example 5: Factor of safety for lifting

Precast façade is to be delivered from the fabrication yard to the site for installation. During the delivery, the lifting of precast façade is essential. The precast façade is assumed to be hanged up at 3 points as illustrated below.

A special lifting device, normally designed by the contractor and approved by the structural engineer, is used to lift up the façade to avoid any damage. The façade is free to swing, and therefore wind load is not considered for the checking during lifting stage.



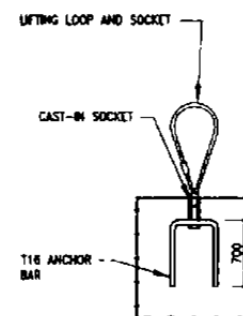
Consider the maximum load at the lifting point be $V = 33 \text{ kN}$ with safety factor of 4 to be adopted,

$$\text{Factored } V = 33 \times 4 = 132 \text{ kN}$$

Bond stress $= 0.5 \sqrt{f_{cu}} = 1.94 \text{ MPa}$ ($f_{cu} = 15 \text{ MPa}$ at lifting stage) (Concrete Code 2013 Cl.8.4.4)

Consider the typical lifting point detail as follows:

Each lifting point will have T16 u-shaped steel bar anchored into precast concrete. Then the shear at each end of the anchor bar is equal to half of the total load applied to the lifting point.



$$\begin{aligned} \text{Anchorage length required} &= V / (2 \times 0.5 \sqrt{f_{cu}} \times \text{bar size} \times \pi) \\ &= 678 \text{ mm} \end{aligned}$$

Adopt anchorage length = 700 mm

$$\begin{aligned} \text{As required} &= V / 0.87f_y \\ &= 330 \text{ mm}^2 < \text{As provided T16 U-bar} = 402 \text{ mm}^2 \text{ OK} \end{aligned}$$

Design Example 6: Check precast strip with lifting inserts installed

Design Example 5 is referred. Consider the column strips at the two ends of the precast façade where the lifting inserts are installed.

For factored lifting force = 132 kN,

$$\begin{aligned} \text{As required} &= V / 0.87f_y \\ &= 330 \text{ mm}^2 < \text{As provided } 4\text{T}12 = 452 \text{ mm}^2 \text{ OK} \end{aligned}$$

Steel reinforcement of 4T12 is required to be provided vertically along the side post of the precast façade to resist the tension induced during lifting.

Design Example 7: Design of ties

Design Data:

Dead Load G_k	= 5.5 kPa
Live Load Q_k	= 2.5 kPa
Span l_c (X – direction)	= 8 m
Span l_c (Y – direction)	= 8.5 m
No. of Storey n	= 4
Floor Height h	= 3 m

(a) *Internal ties*

$$F = 20 + 4 \times 4 = 36 \text{ kN/m} < 60 \text{ kN/m}$$

Under X – direction,

$$T = [(5.5 + 2.5) / 7.5] \times (8/5) \times 36 = 61.4 \text{ kN/m} (> 1.0F = 36 \text{ kN/m})$$

Provide 1T16 per meter width

Under Y – direction,

$$T = [(5.5 + 2.5) / 7.5] \times (8.5/5) \times 36 = 65.3 \text{ kN/m} (> 1.0F = 36 \text{ kN/m})$$

Provide 1T16 per meter width

(b) *Peripheral ties*

Under X and Y – directions,

$$T = 1.0F = 36 \text{ kN/m}$$

Provide 1T12 per meter width

(c) *Horizontal ties to columns and walls*

Under X and Y – directions,

$$T = 2.0 \times 36 = 72 \text{ kN/m} \text{ or } T = (3/2.5) \times 36 = 43.2 \text{ kN/m} (< 72 \text{ kN/m})$$

$$T = 3\% \times 796 = 24 \text{ kN}$$

Hence $T = 43.2 \text{ kN/m}$

Provide 1T12 per meter width

(d) *Vertical ties to columns and walls*

$T = \text{Max. design column load}$

$$= (1.4 \times 5.5 + 1.6 \times 2.5) \times 8 \times 8.5 = 796 \text{ kN}$$

Provide 7T20

Design Example 8: Design of bearing

A reinforced concrete precast beam of 500mm width is supported on a reinforced concrete corbel with 400mm depth at the outer edge. Both beam and corbel will be grade 35D/20. The beam is rested on the corbel with dry bearing. The ultimate vertical reaction load from the beam is 100kN.

According to Section 2.7.9.4 of the CoP,
Design ultimate bearing stress = $0.4f_{cu}$ (for dry bearing)
= 0.4×35 MPa
= 14 MPa

According to Section 2.7.9.3 of the CoP,
Effective bearing length is the lesser of
Bearing length = Beam width = 500 mm or
One half of bearing length plus 100 mm = $(500/2) + 100 = 350$ mm or 600 mm
Then the effective bearing length is taken as 350mm.

According to Section 2.7.9.2 of the CoP,
Net bearing width = ultimate support reaction / (effective bearing length x ultimate bearing stress)
= $100 \times 1000 / (350 \times 14) = 20.4$ mm; or 40 mm,
whichever is greater.

The net bearing width is taken as 40 mm.

According to Table 2.5 of the CoP,
For grade 35 reinforced concrete (in general), distance assumed ineffective measured from the outer edge of the corbel support = 15 mm

According to Table 2.6 of the CoP,
Assume there are vertical loops of 12 mm diameter bar at the bearing of supported member, distance assumed ineffective measured from the end of supported beam = the greater of 10 mm or nominal end cover. Nominal end cover is assumed to be 30 mm. Then the distance assumed ineffective measured from the end of supported beam is taken as 30 mm.

The allowance for inaccuracies due to construction and erection is considered as 25 mm.

As illustrated in Figure 2.5 of the CoP,
Nominal bearing width = ineffective bearing due to spalling at supporting corbel +
net bearing width +
ineffective bearing due to spalling at supported beam +
allowance for inaccuracies
= 15 mm + 40 mm + 30 mm + 25 mm
= 110 mm

The width of the corbel provided should be larger than 110 mm.

Design Example 9: Precast Beam

A precast beam (B6) as shown in Figure A.1 is checked for all construction stages including temporary stage and permanent stage. For temporary state, various load factors are multiplied to the self-weight for demoulding, lifting and erection stage and the strength of concrete is applied according to the age of construction. For permanent stage, dead load and live load are considered but wind load is excluded in this example.

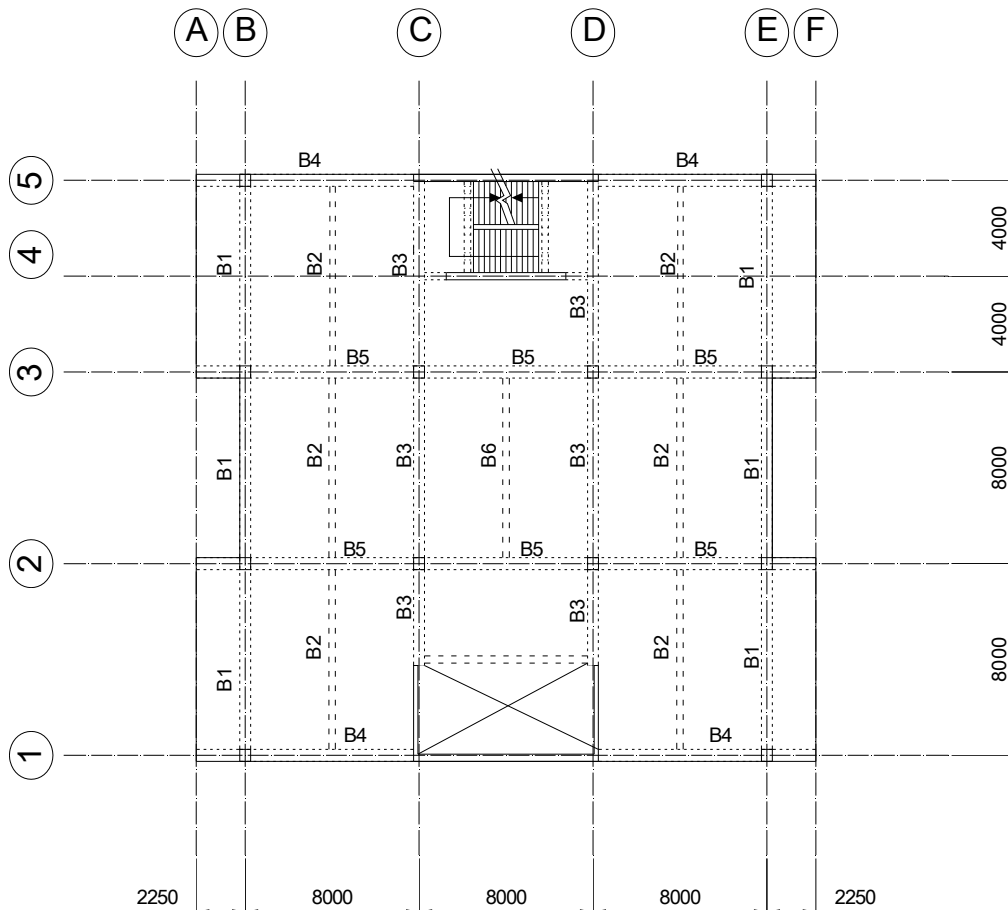


Figure E9.1. Typical floor plan of reinforced concrete building

Design data

- Unit weight of reinforced concrete is 24 kN/m^3 .
- Load factors for dead load and imposed load are 1.4 and 1.6 respectively.

Material data

- Concrete is Grade C35.

Stage	Concrete strength (MPa)
Demoulding	15.0
Lifting	15.0
Erection	24.5
Permanent	35.0

2. Reinforcement Strength

Type	Characteristics strength (MPa)
Y	460
R	250

Design for permanent stage

The beam is assumed to be simply supported on both ends with the dimensions as shown in Figure A.2.

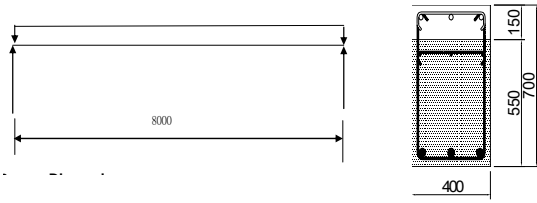


Figure E9.2. Beam B6

1.0 Dimensions

Span (L) = 8000 mm (400 mm width, 700 mm depth)

Slab thickness = 150 mm

Loading width = 4000 mm

2.0 Other Properties

Concrete strength (f_{cu}) = 35 N/mm²

Strength of longitudinal bars (f_y) = 460 N/mm²

Strength of links (f_{yv}) = 460 N/mm²

Cover (c) = 35 mm

3.0 Loading

Dead load

Self weight = $24 \times 0.4 \times (0.7 - 0.15)$
= 5.28 kN/m

Self weight of slab = $24 \times 0.15 \times 4$
= 14.4 kN/m

SDL (1.2 kPa) = 1.2×4

= 4.8 kN/m

Total = 24.5 kN/m

Imposed load

LL (5 kPa) = 5×4
= 20 kN/m

The design load w = $1.4 \times 24.5 + 1.6 \times 20$
= 66.3 kN/m

Maximum bending moment = 530 kNm

Maximum shear = 265 kN

4.0 Design against bending

Effective depth = 639 mm

$A_{s,req} = 2348 \text{ mm}^2$

Provide **3T32** main bar,

$A_{s,prov} = 2413 \text{ mm}^2$

5.0 Design against shear

Shear stress $v = 1.04 \text{ N/mm}^2$

$v_c = 0.69 \text{ N/mm}^2$

Since $0.5v_c < v < v_c + 0.4$, nominal shear links are provided using **T10-250(2L)**.

6.0 Horizontal shear stress (CoP Cl. 2.9.1.6)

Neutral axis of the beam is

$(d-z)/0.45 = (639 - 564)/0.45 = 167 \text{ mm}$.

As the interfacial line is inside the compressive zone of the concrete stress block, horizontal force is calculated from the area of concrete slab under compression.

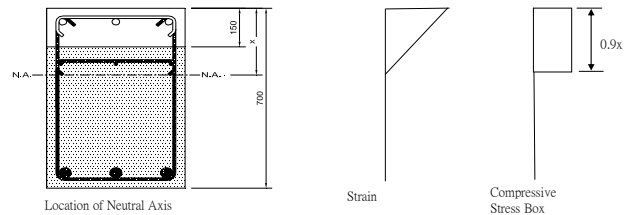


Figure E9.3. Interfacial line and neutral axis of beam

Thickness of the slab (t) = 150 mm

Compression force = $0.45f_{cu}bt = 945 \text{ kN}$

Distance between maximum moment and zero moment = $L_h = L/2 = 4000 \text{ mm}$

Average horizontal shear stress according to the CoP Cl. 2.9.1.7 is $V_{h,ave} = T/bL_h = 0.59 \text{ N/mm}^2$.

The vertical shear force distribution is the same as horizontal shear stress distribution for a uniformly loaded beam. The ultimate horizontal shear stress is given by $v_h = 2v_{h,ave} = 1.18 \text{ N/mm}^2$

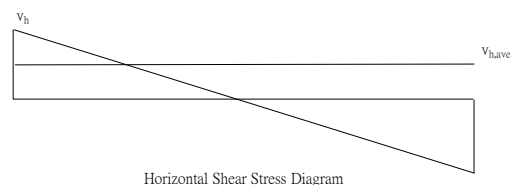


Figure E9.4. Horizontal shear stress distribution

Surface condition is assumed to be brushed, screeded or rough-tampered finished. Hence, $v_{h,prov} = 2 \text{ N/mm}^2$ according to the CoP Table 2.10.

Nominal links according to the CoP Cl. 2.9.1.8 is $A_{h,req} = 600 \text{ N/mm}^2/\text{m}$ or provide **T10-250(2L)**.

Design for erection stage

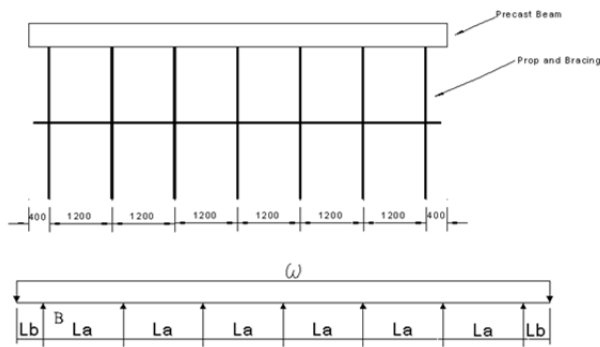


Figure E9.5. Prop and bracing of the beam

1.0 Dimensions

Beam Span (L) = 8000 mm (400 mm width, 550 mm depth)

Spacing between props is 1200 mm, $L_a = 1200$ mm and $L_b = 400$ mm

2.0 Other Properties

Concrete strength at erection stage is assumed to be 70% of 28 days strength, or 24.5 N/mm^2 .

Strength of longitudinal bars (f_y) = 460 N/mm^2

Strength of links (f_{yv}) = 460 N/mm^2

Cover (c) = 35 mm

3.0 Loading

Dead load

$$\begin{aligned} \text{Self weight} &= 24 \times 0.4 \times (0.7 - 0.15) \\ &= 5.28 \text{ kN/m} \end{aligned}$$

Erection load factor = 1.2

$$\text{Total} = 5.28 \times 1.2 = \underline{6.34 \text{ kN/m}}$$

Imposed load

$$\begin{aligned} \text{Construction load (1.5 kPa)} &= 1.5 \times 0.4 \\ &= \underline{0.6 \text{ kN/m}} \end{aligned}$$

$$\begin{aligned} \text{The design load } w &= 1.4 \times 6.34 + 1.6 \times 0.6 \\ &= 9.8 \text{ kN/m} \end{aligned}$$

Maximum hogging moment = 0.79 kNm

Moment coefficient for sagging moment is found by moment distribution,

$$\begin{aligned} \text{Ultimate sagging moment} &= mwL_a^2 \\ &= 0.091 \times 9.8 \times 1.2^2 \\ &= 1.29 \text{ kNm} \end{aligned}$$

Maximum shear = 5.90 kN

4.0 Hogging moment

Effective depth = 489 mm

$$A_{s,req} = 4 \text{ mm}^2$$

Provide **3T16** main bar,

$$A_{s,prov} = 603 \text{ mm}^2$$

4.1 Sagging moment

Effective depth = 489 mm

$$A_{s,req} = 7 \text{ mm}^2$$

Provide **3T32** main bar,

$$A_{s,prov} = 2413 \text{ mm}^2$$

5.0 Shear

Shear stress $v = 0.030 \text{ N/mm}^2$

$$v_c = 0.68 \text{ N/mm}^2$$

Since $v < 0.5v_c$, nominal shear links are provided. Provide **T10-250(2L)**, $A_{sv}/S_{v,prov} = 0.628$

Design for lifting stage

1.0 Dimensions

Beam Span (L) = 8000 mm

Beam Width = 400 mm

Beam Depth = 550 mm

To ensure that no additional steel reinforcement is required in this stage, location of hanger is determined by maintaining equal hogging moment and sagging moment.

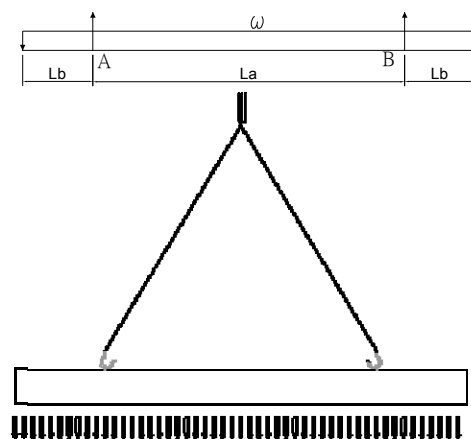


Figure E9.6. Lifting configuration

2.0 Other Properties

Concrete lifting strength is assumed to be 15 N/mm^2 according to the CoP Table 3.2.

Concrete strength (f_{cu}) = 15 N/mm^2

Strength of longitudinal bars (f_y) = 460 N/mm²
 Strength of links (f_{yv}) = 460 N/mm²
 Cover (c) = 35 mm

3.0 loading

Dead load
 Self weight = $24 \times 0.4 \times (0.7 - 0.15)$
 = 5.28 kN/m
 Erection load actor = 1.5
 Total: 7.92 kN/m
 The design load $w = 1.4 \times 7.92 = \underline{11.1 \text{ kN/m}}$

4.0 Location of hanger support

To maintain sagging moment equal to hogging moment $w(L - 2L_b)^2 / 8 - wL_b^2 / 2 = wL_b^2 / 2$
 $L_b = L / 2(1 + \sqrt{2}) = 0.207L$
 So, $0.2L$ is assumed for cantilever in lifting stage,
 $L_a = 4800 \text{ mm}$
 $L_b = 1600 \text{ mm}$
 Ultimate hogging moment $M_h = 14.2 \text{ kNm}$
 Ultimate sagging moment $M_s = 17.8 \text{ kNm}$
 Ultimate shear on LHS at
 $A = V = wL_b = 17.8 \text{ kN}$
 Ultimate shear on RHS at
 $A = V = wL_a / 2 = 26.6 \text{ kN}$

5.0 Hogging Bending moment

Effective depth $d = 489 \text{ mm}$;
 $A_{s,req} = 76 \text{ mm}^2$
 Provide **3T16** main bar,
 $A_{s,prov} = 603 \text{ mm}^2$

5.1 Sagging Bending moment

Effective depth $d = 489 \text{ mm}$;
 $A_{s,req} = 96 \text{ mm}^2$
 Provide **3T32** main bar,
 $A_{s,prov} = 2413 \text{ mm}^2$

6.0 Shear

Shear stress $v = 0.136 \text{ N/mm}^2$
 $v_c = 0.678 \text{ N/mm}^2$
 Since $v < 0.5v_c$, nominal shear links are provided, **T10-250(2L)**, $A_{sv}/S_{v,prov} = 0.628$

7.0 Lifting Hook

According to the CoP Table 2.4, lifting inserts should be designed with a safety

factor (FOS) of 4. Since two hooks are used, the load of each hook,
 $P = wL / 2 \times 4 = 126.7 \text{ kN}$
 Use 25mm diameter bar $f_y = 250 \text{ MPa}$
 $P_{prov} = 0.87f_s \pi (\psi_s^2 / 4) \times 2 = 213.5 \text{ kN}$
 To check the bonding stress of the hook, reference is made to the Concrete Code 2013 Cl. 8.4.4. Assuming plain bar is used, the bonding stress of the hook is
 $f_{bu} = 0.28 \sqrt{f_{cu}} = 1.08 \text{ N/mm}^2$
 $Le = P / (f_{bu} \psi_s \pi) = 1490 \text{ mm}$
 Provide anchorage length 1500 mm.

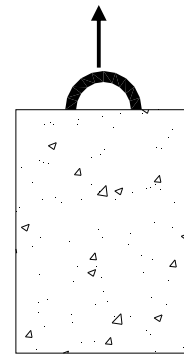


Figure E9.7. Lifting hook and lifting action

8.0 Horizontal Force

Assume the inclined angle of the string be 60 degree.

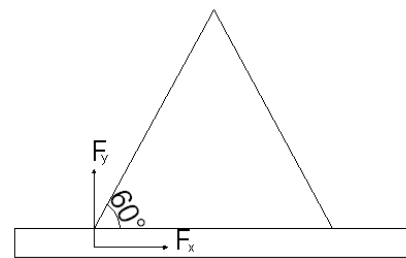


Figure E9.8. Lifting configuration

$F_y = wL / 2 \times 1.4 = 44.35 \text{ kN}$
 $F_x = F_y / \tan(60) = 25.61 \text{ kN}$
 $0.1F_c = 0.1 \times 15 \times 550 \times 400 / 1000 = 330 \text{ kN}$
 As compressive force acting on the element is smaller than 0.1 of the compressive strength, it can be designed as flexural beam ignoring the axial force by the Concrete Code 2013 Cl. 6.1.2.4. Thus, no compressive reinforcement is required.

Design for demoulding stage

1.0 Dimensions

Beam Span (L) = 8000 mm

Beam Width = 400 mm

Beam Depth = 550 mm

L_a = 4800 mm

L_b = 1600 mm

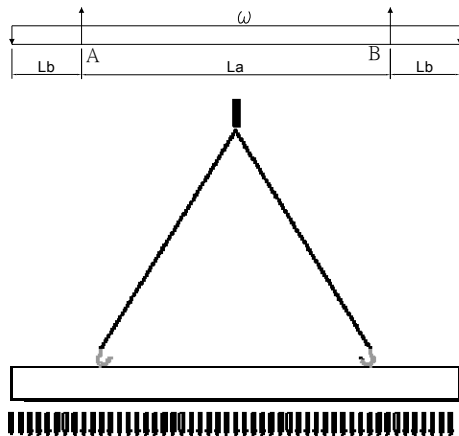


Figure E9.9. demoulding configuration

2.0 Other Properties

Concrete lifting strength is assumed to be 15 N/mm^2 .

Concrete strength (f_{cu}) = 15 N/mm^2

Strength of longitudinal bars (f_y) = 460 N/mm^2

Strength of links (f_{yv}) = 460 N/mm^2

Cover (c) = 35 mm

3.0 Loading

Assume lying flat with removable side forms, without rebates or reveals, and smooth mould finishes.

Dead load

$$\begin{aligned} \text{Self-weight} &= 24 \times 0.4 \times 0.55 \\ &= 5.28 \text{ kN/m} \end{aligned}$$

Demould load factor = 1.3

Total: 6.86 kN/m

As the load factor for demoulding stage is less than lifting stage, so checking is not necessary.

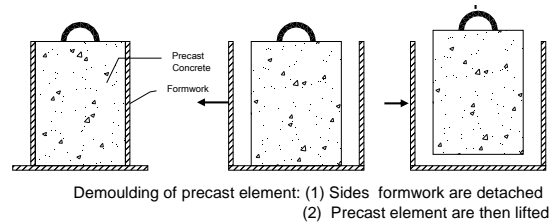


Figure E9.10. Demoulding sequence

ANNEX E

- Project 1. Proposed residential/commercial development at 108 Hollywood Road, Central
- Project 2. Redevelopment of Kwai Chung Flatted Factory
- Project 3. Tai Wai Maintenance Centre Property Development, Sha Tin Town Lot No. 529
- Project 4. Hung Hom Estate Phase 2
- Project 5. Area 77, Ma On Shan, Shatin, STTL 460 & 486 (To be known as STTL 548)
- Project 6. The Orchards

Project 1. Proposed residential/commercial development at 108 Hollywood Road, Central

Structural Engineer: C M Wong & Associates Ltd
Developer: Henderson Land Development Co. Ltd
Contractor: Heng Shung Construction Co. Ltd



Figure E.1. The development

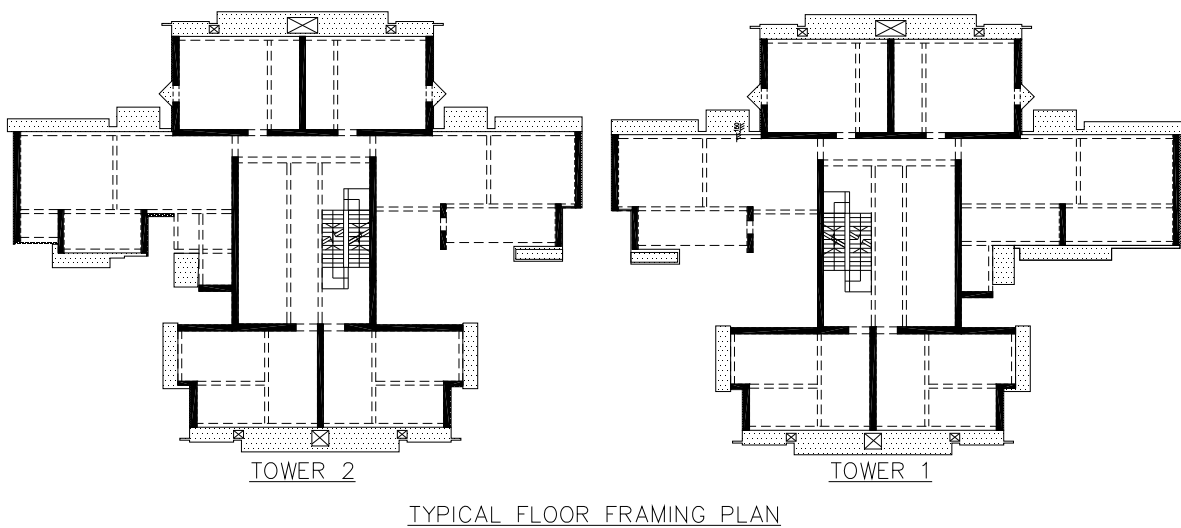


Figure E.2. Typical floor framing plan

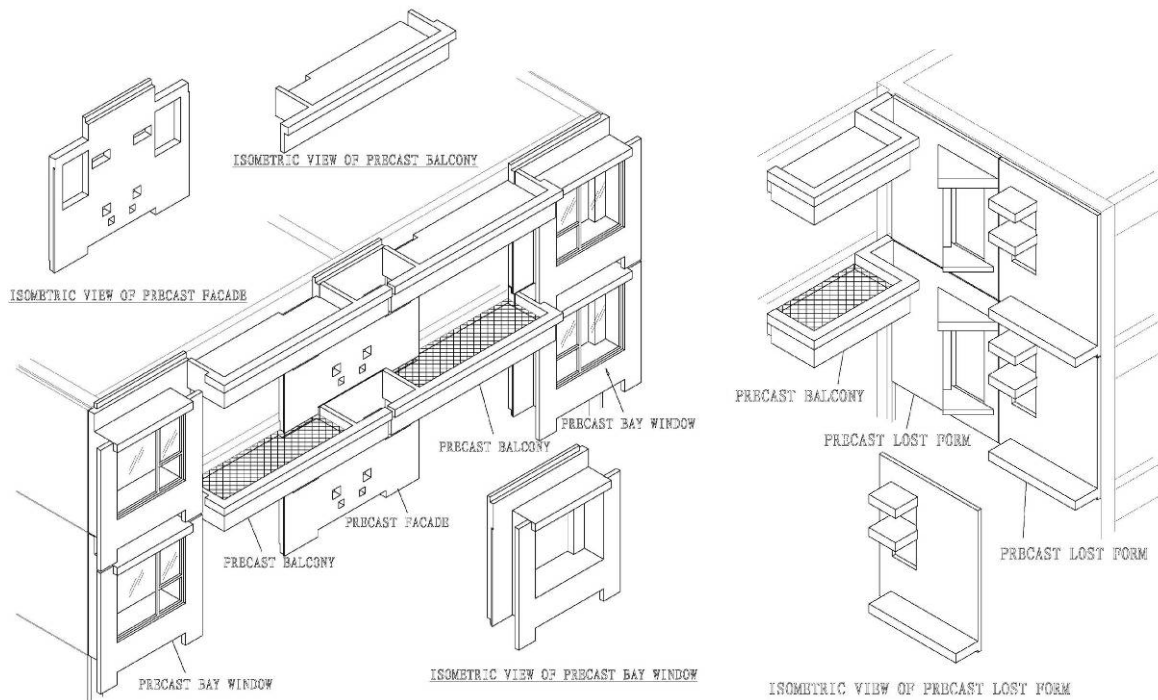


Figure E.3. Isometric view of precast elements

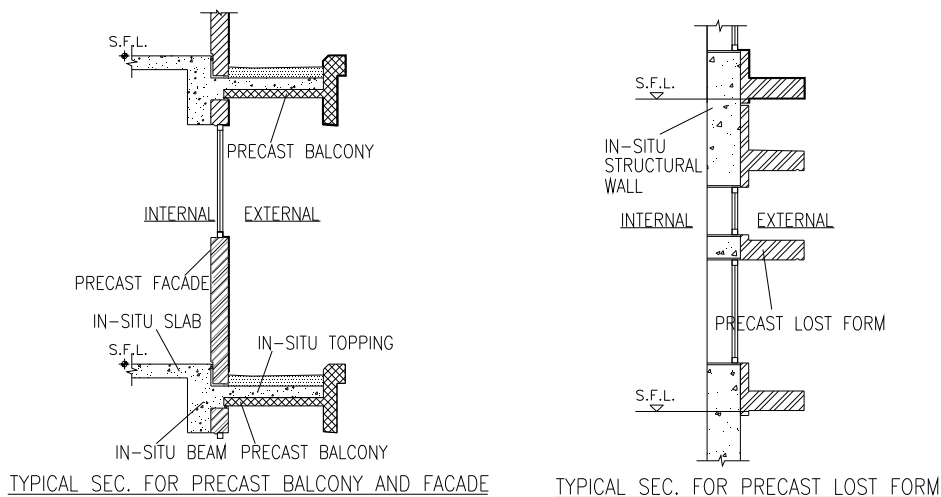


Figure E.4. Typical sections

Brief Description

- a) Precast balconies are constructed using semi-precast cantilever slabs with the bottom bars precast while the top bars cast in in-situ topping. The peripheral curb and down drop wall are also precast. Base plates for handrails are embedded in the precast curbs, thus avoiding the need to install base plates on site.
- b) Precast lost form is applied to A/C or utility platforms with the cantilevered portions supported by in-situ walls at permanent stage. Additional top bars in the cantilevers are anchored to vertical members as supports in the temporary stage.

Project 2. Redevelopment of Kwai Chung Flatted Factory

Structural Engineer: Structural Engineering Section 2,
Development and Construction Division,
Hong Kong Housing Department
Developer: Hong Kong Housing Authority
Contractor: Yau Lee Construction Co., Ltd.



Figure E.5. Kwai Chung Flatted Factory

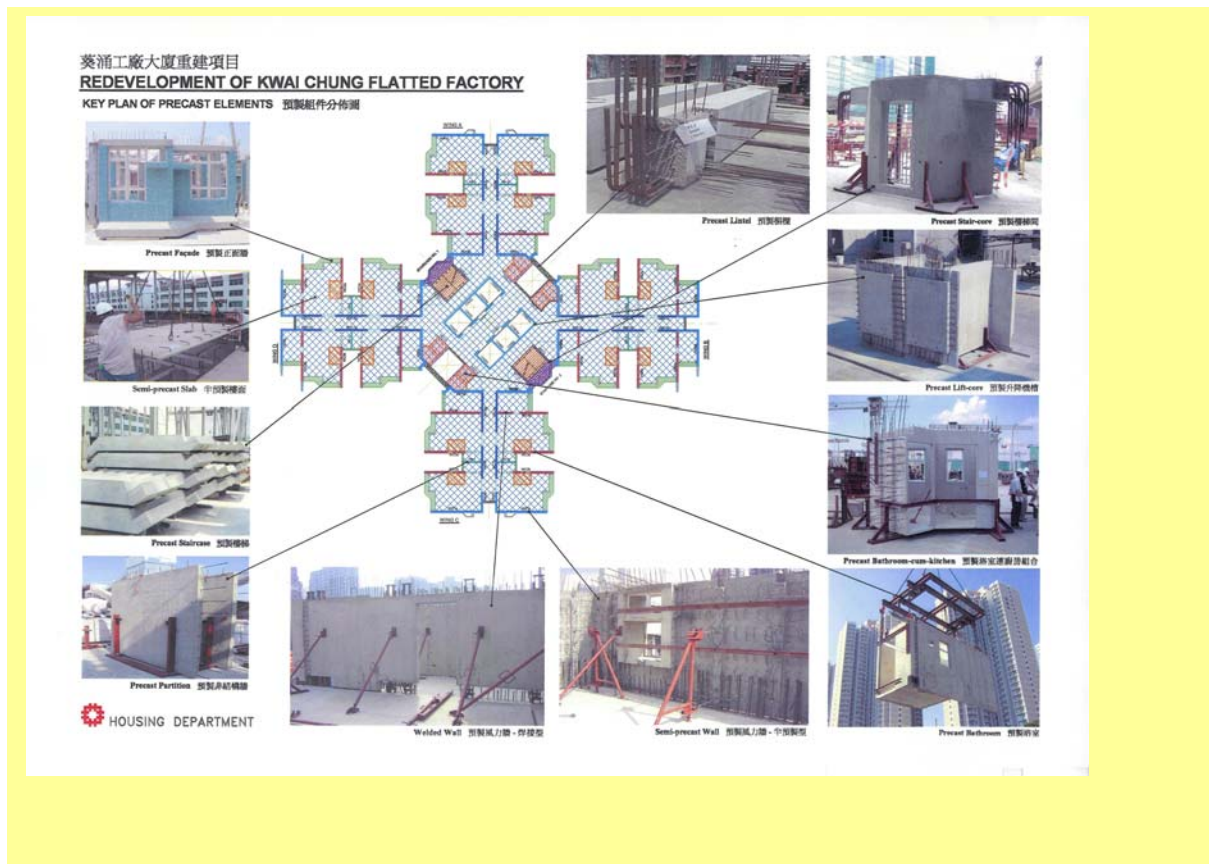


Figure E.6. Key features of precast elements

This is a pilot project experimenting on an innovative Enhanced Precast and Prefabrication System (“the System”) bringing greater precasting benefits of enhanced quality, site safety and environmental protection. This is the first implementation of the System in high-rise residential buildings in a public housing development using Large Scale Precasting of Structural Shear Walls and Volumetric Components.

The System was adopted in two 41-storey residential buildings, of basically wall-slab structural form. For each building, the precast concrete volume was substantially increased from 20% to a record **60%**, involving the following 11 types and about 10,000 pieces of precast elements:-

Conventional Precast Elements

- Façade, Semi-precast Slab, Staircase, Non-structural Partition and Lintel

New Initiatives

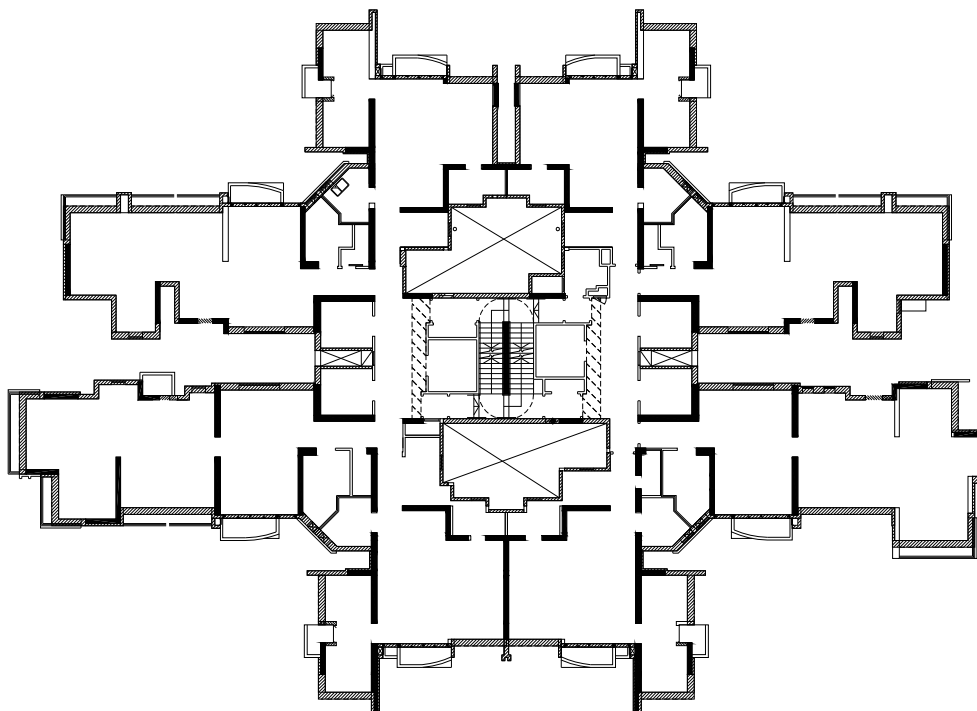
- **Precast Structural Shear Wall**
 - ‘Welded’ Wall
 - Semi-precast Wall (some with bay windows)
- **Volumetric Precast Components**
 - Bathroom
 - Bathroom-cum-kitchen
 - Lift Core
 - Stair Core

Project 3. Tai Wai Maintenance Centre Property Development, Sha Tin Town Lot No. 529

Structural Engineer: WSP Hong Kong Ltd
Developer: Cheung Kong (Holdings) Limited, MTRC
Contractor: China Overseas Buildings Construction Ltd



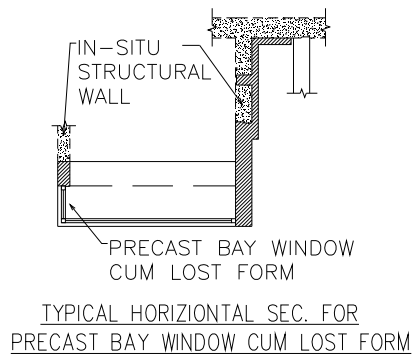
Figure E.7. Tai Wai Maintenance Centre Property Development



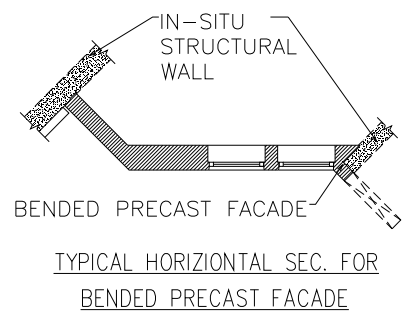
TYPICAL FLOOR FRAMING PLAN OF TOWER C1 (TOWER C2, C3 & C5 SIMILAR)

Figure E.8. Typical floor framing plan

a) Precast bay window cum lost form



b) Bended precast facade



c) Precast lost form cum Utility Platform

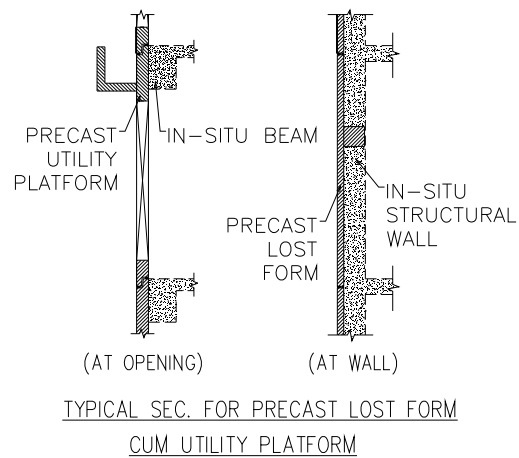


Figure E.9. Precast elements

Brief Description

- a) *Precast bay window cum lost form*: as the lost form is not heavy; it is combined with adjacent precast bay window. The advantages include eliminating vertical joints between 2 precast elements, saving time in installation and reducing temporary supports.
- b) *Bent precast façade*: the precast façade is bent to suit the shape of the external wall. The bottom beam of the precast façade is used to resist the tension effect.
- c) *Precast lost form cum Utility Platform*: the cantilevered utility platform is supported by a precast lost form and the lost form is anchored to an in-situ beam.

Project 4. Hung Hom Estate Phase 2

Structural Engineer: Meinhardt (C&S) Ltd
Developer: Hong Kong Housing Authority
Contractor: China State Construction Engrg (HK) Ltd



Figure E.10. The development



Figure E.11. Precast Elements

Brief Description

- Precast Bay Window – the cantilever slabs of the bay window introduce torsion to the top and bottom beams, and the whole façade is supported by structural elements at the two sides.
- Precast Staircase – the precast staircase is simply supported on corbels at both sides of the landing slabs. Dowel bars set in the corbels are cast permanently within small holes, temporarily formed, in the precast staircase.
- Precast Facade – the precast facade is fixed with the two sides supported permanently by the structural walls using hooks fixed to the main bars of the walls.

Project 5. Area 77, Ma On Shan, Shatin, STTL 460 & 486 (To be known as STTL 548)

Structural Engineer: Meinhardt (C&S) Ltd
Developer: Cheung Kong Properties
Contractor: Excel Engineering Company Limited



Figure E.12. The development



Figure E.13. Precast Elements

Brief Description

- Precast Bay Window – the cantilever slabs of bay window apply torsion to the top and bottom beams, and the whole façade is supported by structural elements at its two sides.
- Precast lost form – the lost form is supported by the permanent structural wall with hooks fixed to the main bars of the walls. The façade is fixed to two side supports at the temporary stage.
- Precast Balcony – the balcony comprises a semi precast slab with in-situ topping and rebars to provide a monolithic structure.
- Semi Precast Slab – the semi precast slab is supported by beams with in-situ topping and rebars to reduce formwork and loading during the temporary stage.

Project 6. The Orchards

Structural Engineer: Meinhardt (C&S) Ltd
Developer: Swire Properties
Contractor: Hip Hing Construction



Figure E.14. The development

Brief Description



- Precast staircase - designed as simply supported on in-situ RC beams/ in-situ landing slab with dowel shear bar for sliding stability.



- Precast staircase – A concrete block was used to fix the level of precast staircase.



- Hoisting of Precast Façade – The steel hoisting beam and chain link should be properly designed to maintain the stability and verticality of the precast façade during lifting.



- Temporary Support – Temporary steel bracing and brackets should be used to resist lateral wind loads and gravity load acting on the precast façade in the temporary stage.

