Practical and Economical Design Aspects of Precast Concrete Large Panel Building Structures

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Abstract: Precast concrete shear walled structures, also called large panel systems, are a good solution for multistoried residential and commercial buildings. This paper describes the practical and economical aspects of designing and constructing these kinds of structures.

The large panel systems are made of large precast walls and slabs that are connected to each other in vertical and horizontal direction. The precast wall panels should be load bearing members and shall be capable of carrying the vertical and lateral loads. The wall panels can be connected to each other in various ways and together with the floor diaphragm they will form box type structures (figures 1 to 4). The external precast wall panels shall be a finished product and no cement plaster shall be required.

The precast concrete structures with load bearing wall panels have several advantages compared to RCC frame structures.

- No brickwork infill walls are required
- Superior quality and durability of the high grade concrete panels
- No plastering required on the precast panels

Figure 1. Large precast panel construction

Figure 2. Large precast panel construction

- Saves time and manpower
- The thin precast wall structure increases the carpet area
- Better health and safety standards for laborers during construction

As quality and speed of construction are becoming more important for builders the precast large panel system could prove to be a viable solution. But in every building project the following aspects are important.

- Architecture
- Structure
- MEP Services
- Manufacturing
- Erection

The importance of these aspects shall be briefly explained in this paper.

Architectural design aspects

Full advantage of precast concrete construction can be achieved when the buildings shall been designed for high construction speed and maximum repetition. The architect should be considering the following points in his design:

- Integration of architecture, services and structure has to be achieved.

Figure 3. Large precast exterior wall panels

Figure 4. Large precast interior wall panels

- Prepare design with simple and symmetrical layouts and elevations
- Avoid many offsets and re entrant corners in the building plans
- Achieve standardization and repetition in the precast elements
- Use modular grids with multiple spacing of 1200mm for standard slabs
- In case of standard precast slab sizes the modular design can have a big impact on the costing
- Minimize joints and plan location of joints
- In façade minimize horizontal or low sloped elements that can collect dirt
- Keep precast elements as large as possible
- Design should not be a conversion of cast in-situ structure
- Not everything has to be made in precast
- Explore the unique capabilities that can be achieved with precast concrete
- When using prestressed floor slabs prepare building layouts with larger floor spans
- Avoid last minute design changes when precast production has started

Modular design

Modular design is important when the proposed precast system is utilizing standardized precast production methods with less flexibility. For example when using standard slab sizes the modular design is guided by the standard size of the precast slabs. Positioning and alignment of other precast elements like walls, columns and beams has to be planned as per the modular system. It may prove cost effective to avoid offsets and align the load bearing structural elements. Modular design principles can be strictly followed but give less freedom to the architect. In case other production methods are used with more custom components the architect shall have more freedom in his design.

In any kind of precast building the position of lifts, staircases and shafts are critical and have to be properly planned

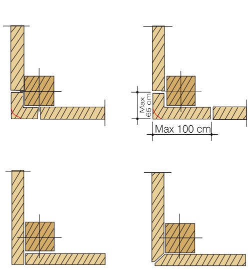


Figure 5. Modular design possibilities

Figure 6. Mass production of standard slabs

where they do not complicate the layout of the load bearing walls and precast floor slabs.

Architectural features and finishes

The exterior of the large panel buildings will be formed by the load bearing precast wall panels. The concrete surface of the panels will be exposed and can have factory made finishing like sandblasting, polishing, exposed aggregate finish and form line finishing. Various color finishes of the precast panels are possible by changing the type of cement, type of aggregates and by using pigments in the concrete mixture (figure 7). Precast wall panels can also be provided with false joints to achieve a better architectural design patterns (see figure 8).

Figure 7. Exposed aggregate finish

Figure 8. False joints in precast panel

Cantilevered balconies can be made by providing cantilevered brackets on the precast cross walls and resting the balconies on these brackets. The precast balconies can also be made cantilevered with protruding top reinforcement connecting to the rcc topping of the floor slab. Cantilevered sunshades are a common feature in Indian building projects. The precast walls are generally made on flat steel moulds and it is not possible to make the sunshade as one part with the wall. Sunshades can be prefabricated and connected in a later stage to the precast walls.

Flexibility in layouts

Flexibility in the layout of precast concrete building projects can be achieved by creating larger floor spans with larger open spaces. Especially in office buildings this concept will provide a lot of advantages to the end user (see figures 9 and 10). The non load bearing partition walls can be made as light weight blocks, dry walls or other suitable light weight systems.

Figure 9. Flexibility with large open spaces

Figure 10. Flexibility with large open spaces

Structural design aspects

India being an earthquake prone country the seismic resistant requirements are the most important criteria of the structural design. Looking at the requirements we can draw the conclusion that the basic earthquake resistant design rules are suitable for precast concrete buildings. Generally the following design rules should be followed:

- Simple and symmetrical building layout

- Uniform distribution of mass and structural stiffness over the height of the building.
- Avoid torsion
- Achieve ductile behavior of the structure
- Avoid progressive collapse of the structure

Simple, symmetrical and uniform buildings are normally easy to optimize and very much suitable for precast concrete construction.

Precast floor slab systems

Basically three different floor slab systems can be considered for multistoried precast buildings.

1. Prestressed precast hollow core slabs
2. Precast half slabs with lattice girder reinforcement
3. Precast solid slabs

Prestressed precast hollow core slabs

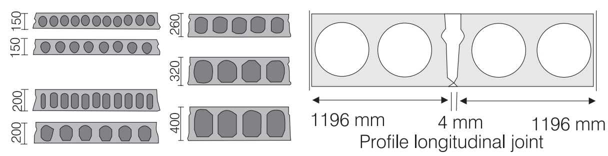
These are prestressed floor slabs with longitudinal voids (figure 11). The presence of the voids results in material savings and weight savings. With hollow core slabs large one way spans can be achieved and no temporary propping is required. Hollow core slabs only have longitudinal prestressing reinforcement and no other reinforcement. Due to manufacturing methods it is not possible to make slabs with anchored tie bars, protruding stirrups or embedded welded plates. Diaphragm action is achieved through special joint design. Especially in high seismic zones an rcc topping has to be added to join the slabs and achieve proper diaphragm action (figure 12).

Figure 11. Hollow core slabs

Figure 12. Hollow core with RCC topping

Structural design aspects for using hollow core floor slabs in multistoried residential buildings are as follows:

- Standard width of the slabs is 1200mm.
- Some hollow core suppliers are also providing slabs of 2400mm.
- For large scale projects with many repetitions it could be useful to have a combination of 1200mm and 2400mm slabs.
- Floor slab layout has to be designed on a multiple grid of 1200mm and 2400mm.
- Slabs can be cut in longitudinal direction if required to achieve different size of slab. However longitudinal cutting should be avoided as much as possible.
- Minimum slab thickness can be 100mm but most manufacturers offer minimum thickness of 120mm or 150mm.
- No propping required to support the hollow core slabs during the construction phase.
- Camber and deflection should be checked in design and detailing.
- Minimum 60mm rcc topping is recommended for diaphragm action and prevention of progressive for multistoried buildings.
- In case of rcc topping the top surface of the hollow core has to be roughened.
- It is difficult to place MEP services within the hollow core slabs, services have to be placed either below or above the slab.
- Connection of the hollow core slabs to the shear walls has to be properly designed and detailed for transfer of vertical and lateral loadings.
- Pay attention to fixation of hollow core units in between load bearing walls. Provide extra top reinforcement at this location.



Profile	h (mm)	b (mm)	Weight (joints filled kN/m^2	Joint filling l/m^2(*)
HC-200	200	1196	2,60	7,0
HC-265	265	1196	3,80	10,0
HC-320	320	1196	4,10	12,0
HC-400	400	1196	4,65	17,0

Figure 13. Example of different hollow core slab sizes

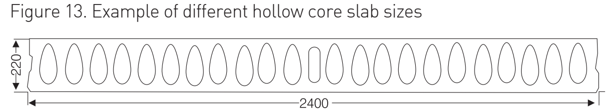


Figure 14. Example of 2400mm wide hollow core slab

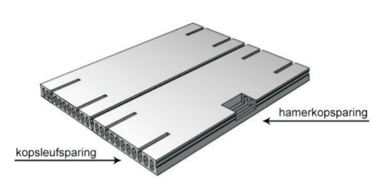


Figure 15

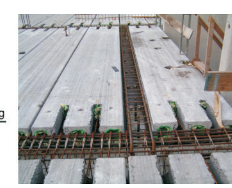


Figure 16

Precast half slabs with lattice girder reinforcement

These are composite slabs made of precast concrete planks of 50mm thick with an rcc topping. The bottom reinforcement is placed within the precast planks and the top reinforcement is placed within the rcc topping. Basically the composite slab behaves the same as an rcc one way slab or two way slabs. The precast planks serve as the shuttering and have to be supported during casting and curing of the concrete. It is a very flexible system where size of planks can be easily adjusted and MEP services can be placed in the rcc topping.

Figure 17. Precast half slab with lattice girders

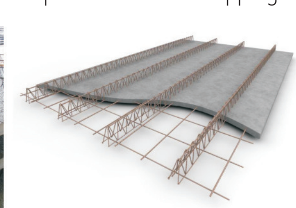


Figure 18. Precast half slab with lattice girders

Structural design aspects of precast planks with lattice girders:

- Standard width is generally 2,4m or 3,0m, but can also be customized to room sizes.
- Flexible system, any type of slab size can be made.
- Bottom reinforcement is placed in the precast plank.
- Top reinforcement is placed inside the rcc topping.
- Minimum thickness is generally 50mm precast plank with 100mm rcc topping.
- Propping of the slabs during casting and curing of concrete is required.
- MEP services can be placed inside the rcc topping.

Figure 19. Example of lattice girder reinforcement

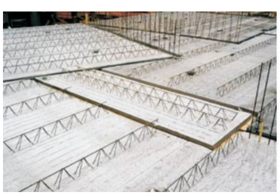


Figure 20. Complicated slab layout

Figure 21. Top reinforcement

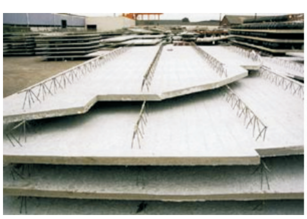


Figure 22. Various precast slab shapes

Figure 23. Casting of concrete topping

Precast solid slabs

Precast solid slabs without topping (Figures 24 to 27) can come in different systems. The slabs are made as traditionally reinforced solid slabs that are generally supported by load bearing walls at all sides. If the connections with the walls are properly detailed and executed then rcc topping can be avoided.

The connections between the solid slabs and the walls can be made by protruding reinforcement like u-bars or by site welded steel plates.

The solid slabs can be made on stationary steel tables and during erection can be supported by props or by erection angles. All the services can be embedded inside the solid slabs during the production process.

Design aspects of solid precast slabs:

- Size of the slabs can be customized.
- Flexible system but weight of the slabs has to be checked as they are heavier than hollow core or precast planks.

Figure 24. Solid slab with welded plates

Figure 25. Erection of solid slab with welded plates

Figure 26. Solid slab with protruding reinforcement

Figure 27. Solid slab with stitching reinforcement

- All reinforcement is placed inside the slab.
- Connection to the precast shear walls can be by protruding reinforcement like u-bars, reinforcement couplers or site welded steel plate connections.
- In case of proper detailing then rcc topping can be avoided.
- All provisions for MEP can be placed inside the slabs.

Lateral load resisting system

The structural behavior of precast concrete large panel buildings with shear walls is different than rcc frame structures. The shear walls are to be considered as cantilevering from the foundation (see figures 28 and 29).

The precast floor units have to be properly joined together to act as a floor diaphragm that transfers the lateral loads to the shear walls. The connections between the floor diaphragm and the shear walls have to be properly detailed. The shear walls will transfer the lateral loads to the foundation by acting as cantilevered walls.

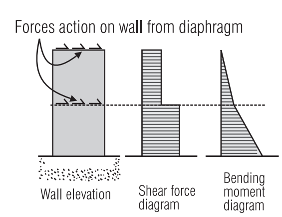


Figure 28. Forces acting on shear wall

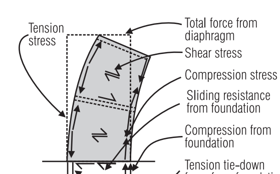


Figure 29. Forces acting within shear wall

Connections

The wall panel connections can be classified into horizontal joints and vertical joints. The horizontal joints have to transfer vertical loads as well as lateral loads. The vertical joints can be open and not transferring any loads or they can be connected to transfer shear loads.

In many countries the horizontal joints between precast wall panels are made with grouted corrugated ducts. The precast wall panels are lowered into position over the vertical reinforcement bars which are protruding from the below element (see figure 30). The ducts and the horizontal joint are fully filled with non shrink high strength grout with at least 10MPa higher strength as the precast concrete. In the plastic hinge regions the ducts can be provided over the full height of the precast wall and the reinforcement bars can be lapped inside the duct. Another option is to use the splice sleeve type 2 connection according to ACI 318 (see figure 31). It can also be decided to design the bottom stories, where yielding will occur, in cast in-situ concrete.

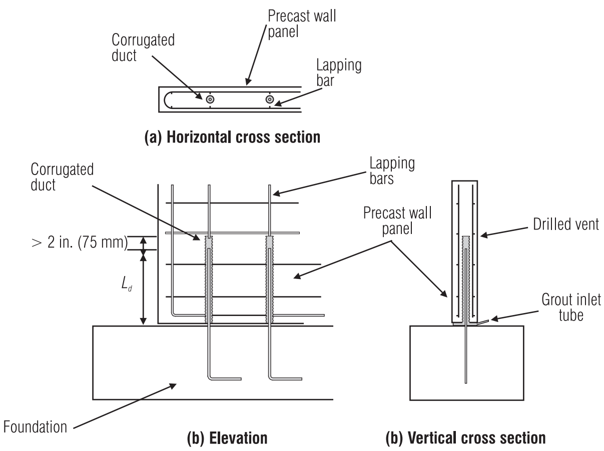


Figure 30. Connection through grouted corrugated ducts

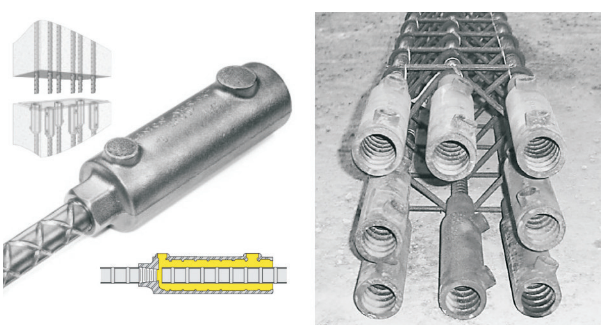


Figure 31. Splice sleeve connections

Filling of joints

Filling of horizontal joints with non shrink high strength cement based mortar or grout can be done in several ways:

1. Placing the precast wall in thixotropic mortar bed (see figure 32)
2. Fill the joint with mortar by hand placement
3. Pump thixotropic grout in the joint (see figure 33)
4. Fill the joint with flowable grout
5. Injection of flowable grout

Because of high temperatures in India and because clean filling has to be achieved it is advised to follow the third method and fill the joints by pumping thixotropic grout in the joints. Filling of the corrugated ducts is generally done by pouring flowable grout from the top or by injection/pumping from the bottom of the duct.

Vertical joints can either be structural joints which have to transfer shear forces or non-structural joints which don't have to transfer any forces. In case fully monolithic behavior has to be achieved the best option is to use a protruding reinforcement connection in combination with drop-in stirrups. To ease the manufacturing process the protruding reinforcement can

Figure 32. Placing wall in mortar bed

Figure 33. Pumping grout in horizontal joint

be replaced by coupler bars (see figures 34 and 35). It is advised to use these connections only for internal shear walls as the vertical joint has to be finished with plastering at both sides and this requires a lot of extra work.

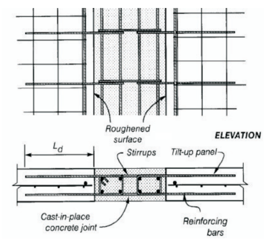


Figure 34. Vertical connection detail

Figure 35. Vertical connections between internal walls

MEP Services

In precast concrete building projects it is important that the MEP services consultants and the MEP vendors are part of the design team. Services like air-conditioning, electrical and plumbing have to be an integrated part of the precast design. For example wall panels can be provided with electricity conduits, electricity boxes and openings for ducts (see figures 36 and 37).

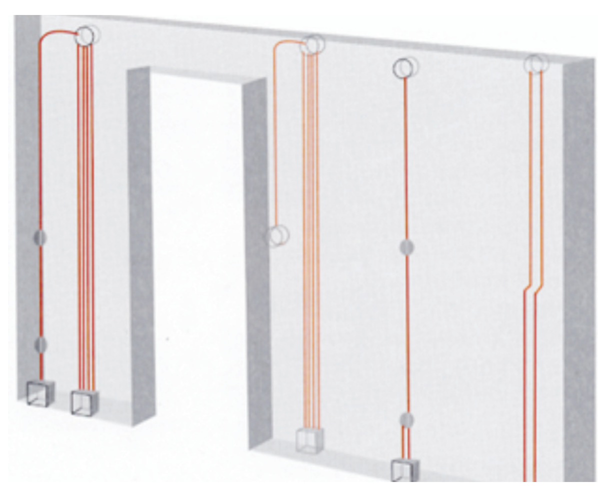


Figure 36. Electricity in precast wall panel

Hollow core slabs can be provided with electricity boxes and block outs. Placing MEP services within the hollow core slabs is not possible. Services have to be place above or below the floor, special hangers can be used (see figure 38). Precast planks with rcc topping can be provided with electricity boxes and block outs. Furthermore small conduits, ducts and plumbing pipes can be embedded in the rcc topping (see figures 39 and 40)

Figure 37. Several openings in precast wall panel

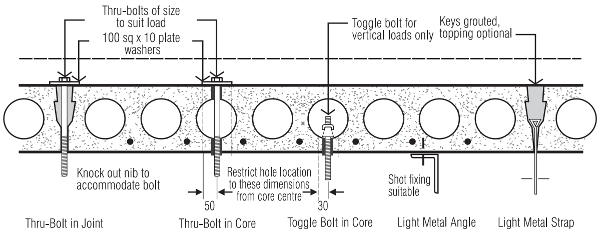


Figure 38. Typical load hangers for hollow core slabs

Figure 39. MEP services in topping of plank floor

Figure 40. Plumbing pipes in topping of plank floor

Precast manufacturing aspects

Basically there are two different types of precast plants which are the temporarily site based precast plant (casting yard) and the permanent precast plant. Furthermore we can differentiate between precast plants with ordinary reinforced precast concrete elements and plants where prestressed concrete elements are manufactured. In case prestressed concrete elements have to be produced the system usually requires long line beds on which the concrete elements will be formed either with casting machines or with shuttering sys-

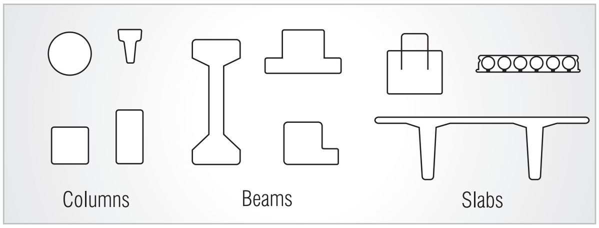


Figure 41. Industrialized building system components

tems. The prestressing steel has to be anchored in abutments which are heavy concrete foundations.

Some possibilities for precast factory equipment are:

- Stationary flat bed moulds
- Tilting tables
- Battery moulds
- Central shifter system with pallets
- Side shifter system with pallets
- Carrousel system with pallets
- Hollow core plant
- Other customized solutions

Industrialized precast building systems are consisting of standard prefab elements made in standard moulds with minimum customization and suitable for mass production (see figure 41).

Customized prefabrication systems are methods where the precast elements are made according to a standard concept but with flexibility to customize according to the requirements of the project. These customized systems require more flexibility in the shuttering and moulding.

The design and project team has to understand the capabilities and limitations of the precast manufacturing unit and following aspects have to be considered while designing.

- Type of factory? Conventional, semi automated or fully automated precast plant?
- Ordinary reinforced precast concrete elements and/or prestressed concrete elements?
- Horizontal tables or vertical battery moulds (see figures 42 and 43)
- Wooden side shuttering or steel side shuttering?
- Custom made wooden or steel moulds for special elements (see figure 44)
- Minimum and maximum size and weight of the precast el-

Figure 42. Circulating pallet system (flat moulds)


Figure 43. Battery mould (vertical moulds)


Figure 44. Custom made wooden mould


Figure 45. Standard reinforcement couplers

ements
- Production tolerances
- Standard embedded parts like anchors, lifting eyes, reinforcement etc.
- Minimum variation in embedded parts (see figure 45)
- Avoiding penetrations through the mould
- Stripping methods of the precast elements en consequences for design
- Shape of block outs and rebates
- Chamfer the edges of wall panels to reduce edge damage and to mask differences in alignment between panels at the joints.
- Detailing of the reinforcement cages
- Curing and finishing methods

Figure 46. Space for crawler crane


Figure 47. Casting rcc topping on precast slabs

Execution / erection aspects

Erection of the precast structure will be done by building cranes which can be placed at a fixed location like tower cranes or by mobile cranes which can move around the building (see figure 46). In case of mobile cranes or crawler cranes there should be enough space to maneuver comfortably around the building. The speed of the crane often determines the speed of erection, especially in case of high rise structures where it takes more time to lift the elements. Another important aspect of the erection sequence is the casting of the rcc topping on hollow core or plank floors and should be well planned.

Design aspects:

- Transportation and temporary storage of the precast elements
- Crane position and lifting capacities
- Lifting speed and speed of erection
- Lifting systems and safety aspects
- Space for movement of mobile cranes or crawler cranes (see figure 29)
- Easy access to connections
- Clean construction process
- Tolerances
- Easy and fast erection
- Erection sequence
- Grouting methods for joints
- Casting of rcc topping (see figure 47)
- Position of props and supporting structures
- Sealing methods for joints ◆