NATION'S FIRST HIGH-RISE TOTAL PRECAST CONCRETE RESIDENTIAL BUILDING – STATE OF THE ART OF PRECAST TECHNOLOGY IN INDIA

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ABSTRACT

Through the last decade, India has seen unprecedented developmental changes with rising standard of living amongst the masses. Significant and sustained increase in housing demand, coupled with considerable shrinkage in skilled labor has challenged the industry, which could result in a shortfall of several million houses in the next few years. Traditionally, residential houses in major cities of India have been multi-storied high-rise apartments suitable for modular construction. Precast construction methodology fits perfectly as an alternative for traditional construction with shorter construction duration and reduction in labor, while exceeding quality standards of conventional construction practices in India. This paper describes the design and planning of a project consisting of six 23 storied total precast residential buildings (1.2 million square feet) in Mumbai (Seismic Zone 3 Coastal Region). It elaborates upon the challenges faced and deviations from the traditional precast practices used overseas, in order to suit local construction needs. Phase 1 (three buildings) was constructed with approximately 30% reduction in labor, as compared with traditional construction labor. In conclusion, the paper infers that Precast Methodology for Residential Buildings is a successful and proven technique for modular mass housing, even if the technology is at an inception stage in India.

Keywords: Accelerated Construction, Design-Build, Creative/Innovative Solutions and Structures, Producer Project Report

INTRODUCTION

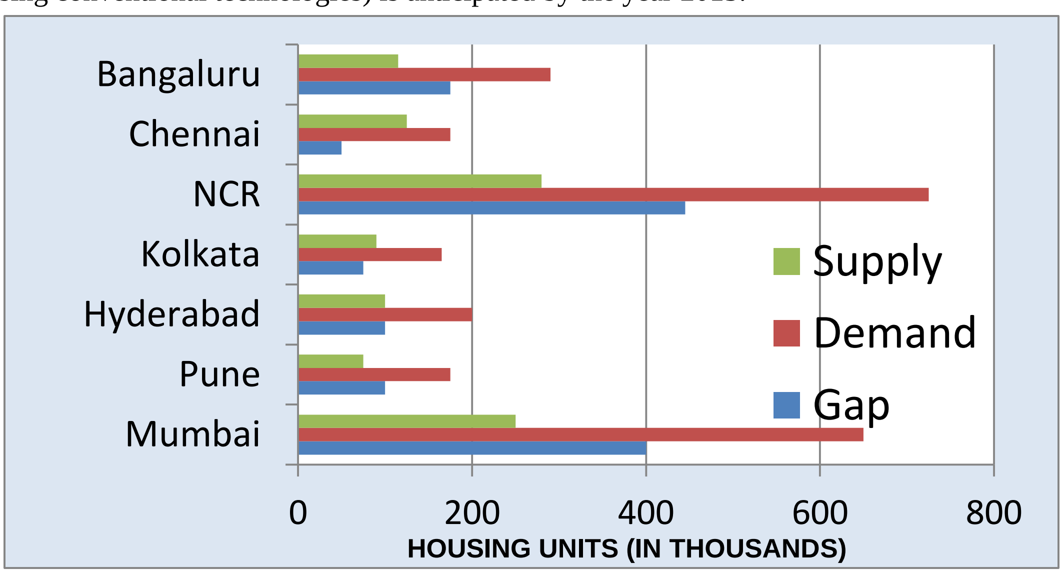
With a population of over one billion and ever increasing standard of living, provision of mass housing at affordable rates in the shortest possible time frame has been a burning issue that India has faced over the last couple of years. Moreover, recent shortage of skilled labor in the Indian construction industry leading to slower rate of construction has compounded this problem. To cater to this growing demand and supply gap, Indian construction industry is undergoing a drastic change of breaking away from conventional construction practices in search of innovative and efficient ways for constructing residential buildings[1]. Mechanization has been identified as a key formula to be successful in this pursuit. This paper describes a first ever high-rise, total precast residential building project in India. Use of precast technology option was conceived as a fitting answer to the challenges noted above. Mechanized large scale construction with minimal labor, excellent productivity and superior quality compared to conventional construction technologies were perceived as the prime benefits of this technology for residential building construction.

BACKGROUND

PRIMARY REASONS BEHIND THE NEED OF NEW TECHNOLOGY IN INDIA

Demand and Supply Gap

India has witnessed continuously evolving socio-economic changes over the last few years leading to improved standard of living across the masses. This has been even more apparent in the Metro cities that have provided ample growth opportunities across all economical sections of the society. Better living standards have translated to higher aspirations for young families resulting in higher housing demand – a major ambition for a typical family in Economically Weaker Section (EWS) or Middle Income Group (MIG) category. According to Cushman and Wakefield in 2011, a demand of 3.94 million apartments at a staggering Compounded Annual Growth Rate of 11 % is predicted in the next five years[2]. This is even more evident in the Metro cities where shortfall of more than double the current housing supply capability of Indian industry (using conventional technologies) is anticipated by the year 2015.



Source: Cushman & Wakefield Research

Fig. 1 Metro Cities – Demand/Supply Projections for 2011-2015

The housing requirement scenario, required housing including homeless population, temporary houses and congested housing as per criteria established by the Government of India, indicate even more shortage of housing. Per the Ministry of Housing and Urban Poverty Alleviation, Government of India, an overall housing shortage of 18.78 million units was estimated in Urban India in the year 2012[3]. Per a recent study, the housing requirement in urban and rural housing together, based on the next five year growth in population, is estimated as high as 89 million houses[4].

Skilled Labor Shortage

The improved life-style has also led to a significant shortage in skilled labor force in construction industry, since most of the labor force prefers comfortable service oriented daily wages jobs that that are available in abundance recently, instead of opting for laborious construction work in challenging environments. Figure 2 shows labor pool comparison between the year 1995 and the year 2005 as reported by the Indian Government's Five Year Planning Commission (2007-2012). It should be noted that even if the overall labor pool size has increased, the overall percentage of skilled workers has decreased drastically indicating that most of the addition in the labor pool has been in the unskilled section[5].

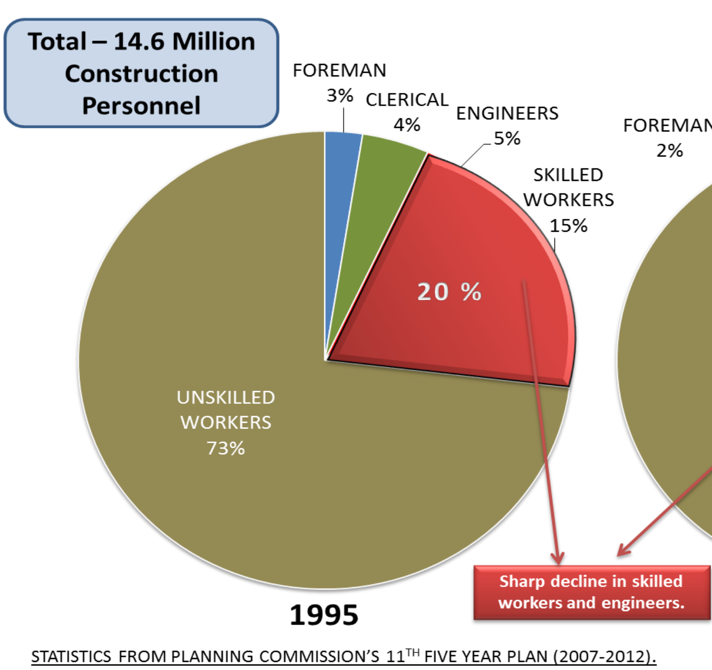


Fig. 2 Sharp Decline in Skilled Workers and Engineers available in India

PRECAST TECHNOLOGY AS A FITTING SOLUTION TO CURRENT INDUSTRY NEEDS

The inherent advantages of faster construction and low manpower requirements provided by precast technology provide an ideal solution to the primary challenges noted above. In addition, superior quality control and better working environment (factory versus construction site environment) provides added advantages to the labor force.

Also, traditionally, the Metro and Tier 1 cities in India have focused on high-rise structures for residential buildings that provide optimum usage of land. Most of these cities provide higher Floor Space Index (FSI) promoting such developments. These high-rise structures inherently have modular repeating layouts on majority of levels. Also, several towers in a particular project may also have repeated layouts leading to same apartment plans in as much as 60-75% of the total square footage of a project. This works well for adaptation of precast technology as an innovative solution for the current Indian construction industry.

PROJECT DETAILS

Pragati Towers project in Mumbai, India consists of eleven residential high-rise, total precast buildings using precast concrete system. This is the first ever project in the high-rise segment in India that used total precast system. All towers rise about 70 m above ground. Each tower consists of over 300 apartments with a total construction area of around 2.6 million square feet. The project was developed by Larsen & Toubro Realty Limited and Omkar Realtors & Developers Private Limited Joint Venture. The project was designed and constructed by Larsen and Toubro Construction (L&T Construction). L&T Construction appointed Innovela Building Solutions as the structural design consultant. The design was approved by Dr. Kelkar Consultants Private Limited as the Owner’s consultant and by Dr. A. Meher Prasad, Professor, Indian Institute of Technology, Madras as an independent consultant.

Fig. 3 Completed Towers (Part 1 of Phase 1)

The project is divided into two phases. Phase 1 consists of six towers and phase 2 has five towers. As of today, three towers of Phase 1 are complete and the next three are under construction. Phase 2 is scheduled to start during the later part of this year. All apartments of Phase 1 are identical that made precast technology a viable option to consider. Figure 4 shows the overall layout of Phase 1 of the project. Table 1 shows the overall scope of precast construction for Phase 1 Buildings along with other building details.

Table 1- Pragati Towers – Phase 1 Project Details

Pragati Towers - Phase 1 – Six High-rise Buildings	
Overall Built Up Area	1.2 million square feet
Structural Frame	G + 23 Levels
Total Apartments	2024 Apartments; 14-16 Apartments per Level
Structural System – Superstructure	Large Panel Precast Shear Walls
Structural System - Substructure	Pile Foundation or Raft Foundation
Ground and Terrace Work	Cast In Situ
1st to 23rd Floor Work	Precast Members
Total Precast Member Count	~ 40,000

Fig. 4 Pragati Towers - Overall Phase 1 Layout

A typical apartment floor plan is shown in Figure 5. Each apartment comprising of 269 square feet of carpet area, consists of a living room, a study room, and a kitchen along with toilet and bath units, planned for typical EWS family of four. Figure 6 shows the precast panel layout used for the project.

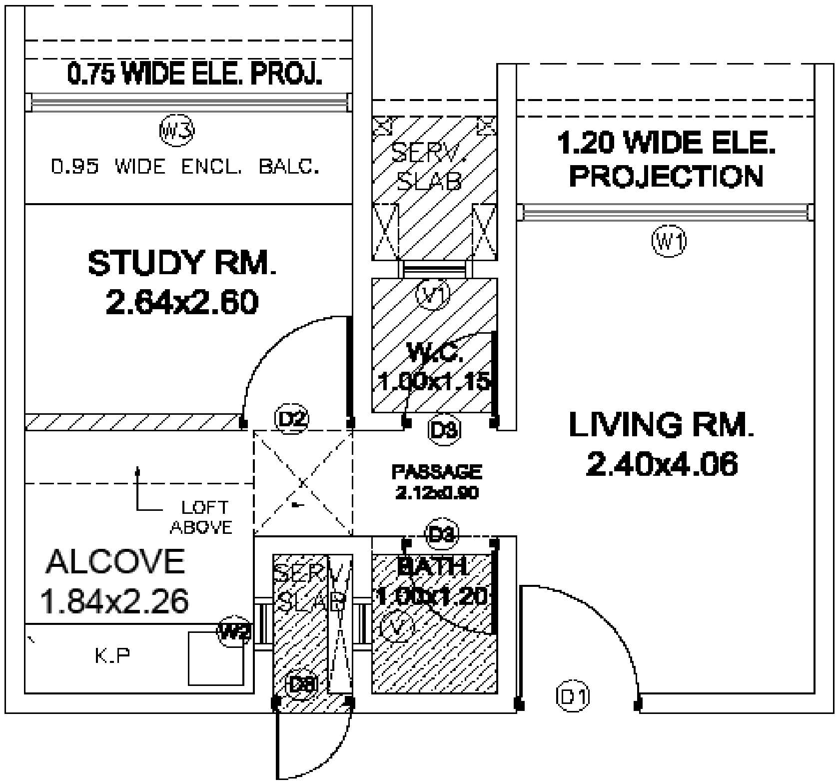


Fig. 5 Pragati Towers - Typical Apartment Floor Plan

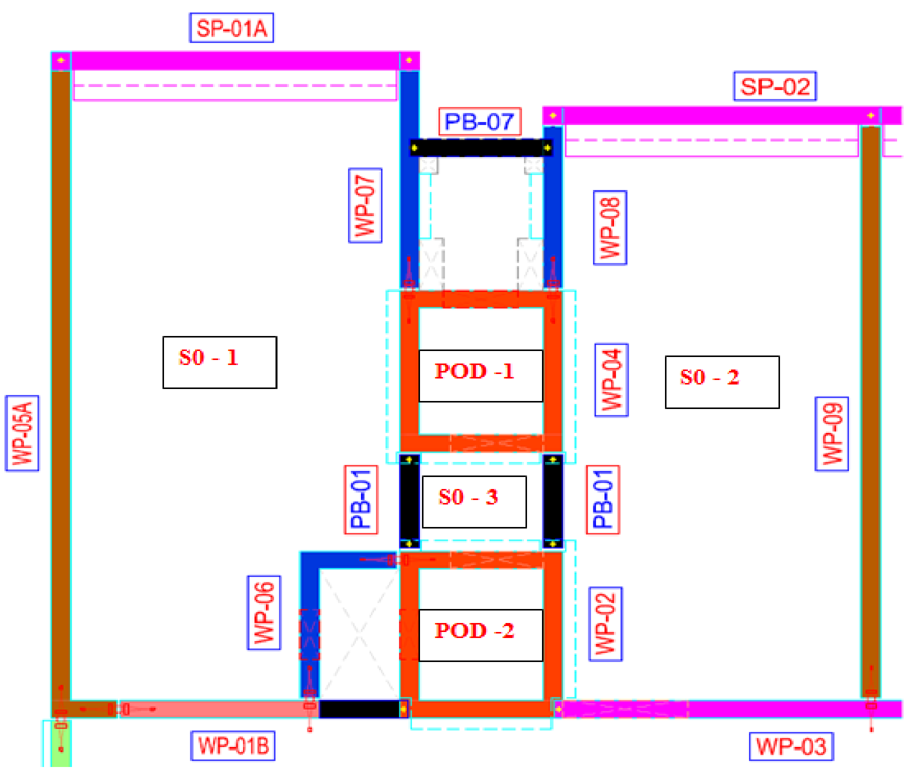


Fig. 6 Pragati Towers - Precast Panel Layout for the Typical Apartment Floor Plan

DESIGN CONSIDERATIONS

DESIGN CODES

Mumbai region is categorized as Seismic Zone 3 (Moderate Seismic Zone - typical Seismic Zones are defined from Zone 2 (Least Active) to Zone 5 (Highest)). Mumbai is also a coastal city with design wind speed of 44m/s (~ 98.5 mph) which was considered for this project. Seismic Forces governed the design. The Bureau of Indian Standards (BIS) specifies building codes in India. IS 456-2000[6] is regarded as the primary building code for reinforced concrete structures. IS 1893–2002[7] provides guidelines for earthquake resistant design and IS 13920–1993[8] provides detailing requirements for ductility in concrete structures subjected to seismic forces. IS 11447-1985[9] provides design guidelines for large panel prefab construction. IS 15916-2010[10] is the most recent addition that provides guidelines for Design and Erection of Prefabricated Concrete.

DESIGN PHILOSOPHY

As precast technology was used for the first time for a high-rise residential structure in India, the emulative design philosophy was selected based on mutual agreement between the Client, Consultant and Contractor. Onsite, wet grouted joints for horizontal and vertical connections between walls and in-situ concrete joints for slab-to-wall and slab-to-slab joints, termed as “stitched” joints were selected. ETABS software was used to build the structural model for analysis. Various modeling approaches were considered and compared to come up with the design forces at all joints in the structure. The complete design approach is not in the scope of this paper. However, the various options considered have been compared by Dr. M. Prasad et al. (2013)[11].

DESIGN OF CONNECTIONS

Horizontal Connections – Wall-to-Wall Connections

All vertical walls with a few exceptions were treated as Shear Walls. Vertical connections transferred tension load at several locations even in the presence of several shear walls and relatively significant dead load on all walls. Continuous non-contact lap spliced dowel system using corrugated dowel tubes was selected to provide continuity in the vertical dowels. Non-shrink and non-metallic grout was used to fill the dowel tubes after lapping the dowels. The same grout was also targeted to fill the horizontal stacked wall-to-wall joints during the dowel tube grout filling activity. As a conservative approach, all dowels in the wall-to-wall joints (provided for tension as well as shear forces at joint) were continued throughout the height of the building for the completed buildings. Figure 7 shows the typical vertical stacked wall dowel connection.

Horizontal Connections – Wall-to-Slab Connections

During erection, the slab was supported by the bearing wall and temporary shoring. The slab and wall were then stitched together on-site to have emulative wall-slab joint. Figure 7 shows the typical wall-slab joint. Notched half-slab concept was used to limit on-site pour volume. As a conservative approach, the slab was designed as a simply supported slab. All slab-wall joints were detailed such that the in-situ stitching pour connected the members without any gaps in between to achieve emulative behavior. Necessary reinforcement per the prevalent codal requirements was provided in the stitched joint. High flow concrete with one grade higher compressive strength than the compressive strength of the precast panels to be connected was used in the stitched joint.

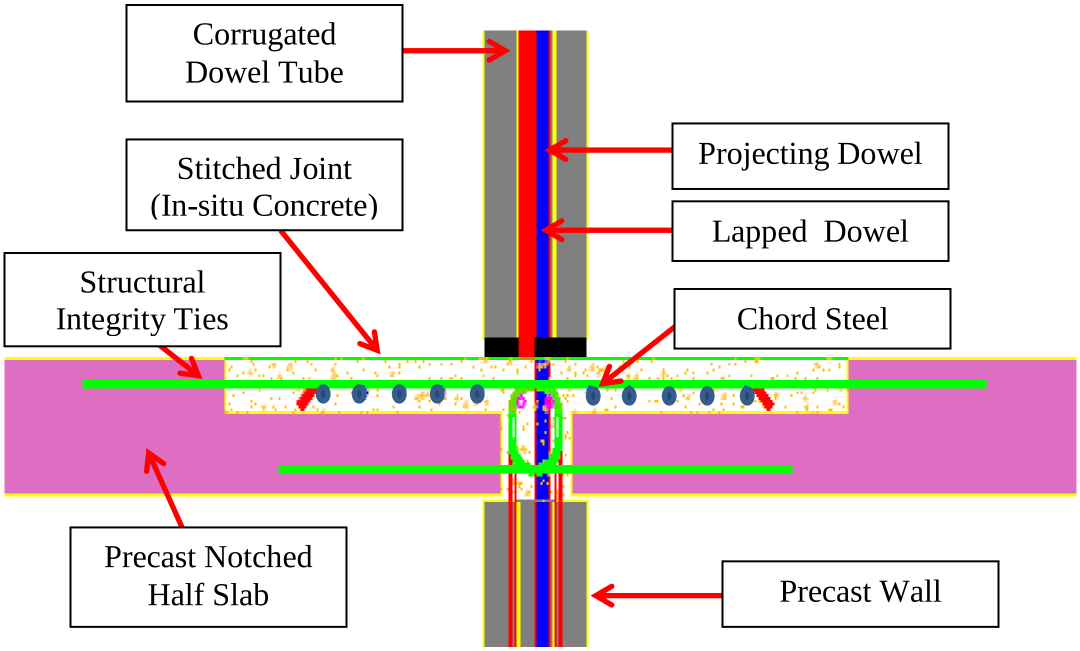


Fig. 7 Pragati Towers – Typical Wall-to-Wall Dowel & Wall-to-Slab “Stitched” Joint Connection

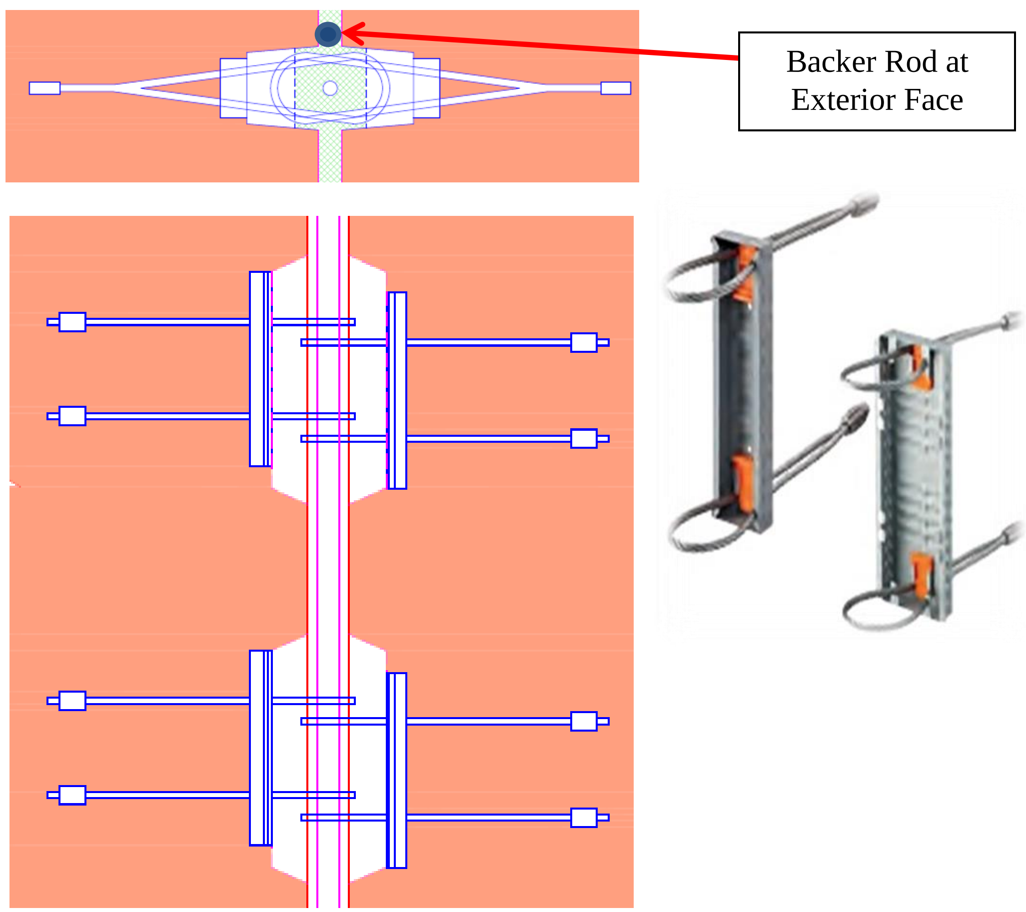


Fig. 8 Pragati Towers – Typical Wall-to-Wall Vertical Loop Connection

Vertical Connections – Wall-to-Slab Connection

All wall panels were connected together at vertical joints as well to achieve emulative behavior. For erection feasibility, where the panels had to be erected vertically down to make the projected dowels connections, flexible wire loop shear key connectors were used across the vertical joints. Figure 8 shows the typical vertical wall-to-wall connection used. Adjacent shear key connectors at a joint were looped together using continuous rebar placed on-site. The joint was then grouted using non-shrink and non-metallic grout to seal it.

DIAPHRAGM DESIGN

Semi-rigid diaphragm was considered in the model and forces at critical locations at the top level were calculated to provide chord steel accordingly. Chord steel needed at critical locations was provided throughout the level. All levels were detailed with the same chord steel layout that was required by the top level. The chord steel was placed in the "stitched" joint (Figure 7) and lapped per codal requirements for continuity.

STRUCTURAL INTEGRITY (PROGRESSIVE COLLAPSE) DESIGN

Due to the high density occupancy of the building, progressive collapse design consideration was one of the primary design concerns expressed by the Consultant during the initial stage when precast technology was considered for this project. Recently, IS 15916-2010[10] has specifically provided prescriptive guidelines for Indian precast construction. Additional ties (horizontal and peripheral) required per the guidelines were provided in the stitched connections as shown in Figure 7 to tie the slabs together. At exterior walls where the slab is only at one side of the wall, specific ties to connect the wall to the slab per the requirements were provided. Vertical dowels were also checked for the vertical tie requirements and continuity was ensured.

WATER TIGHTNESS

The joint design was looked at, taking into consideration the local tropical climate with heavy monsoons. The grouted joints helped achieve water tightness. Backer rods were placed at the exterior face of exposed to weather joints to prevent water entry. In addition, waterproofing sealant was applied at these joints as an additional line of defense. The gable end faces of the buildings were looked at in great detail due to the direct exposure to heavy rains. As shown in Figure 9, the horizontal joints on these elevations were detailed with an additional overlapping nib covering the joint across the length to avoid direct exposure of rain water. The nibs also provided a horizontal band as an architectural feature on the elevation (Figure 3 - White Bands).

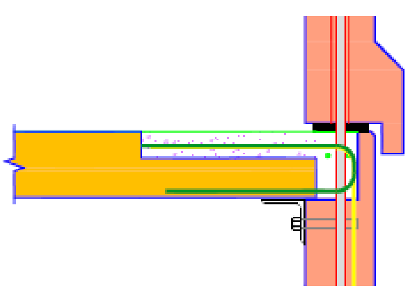


Fig. 9 Pragati Towers – Gable End External Wall Joint Detail

PROJECT PLANNING AND OPERATIONS

PRELIMINARY PRODUCTION AND ERECTION PLANNING

Due to the size of the project and other logistics and available transportation infrastructure constraints, two dedicated site-based factories were established - one next to the site for large members, and another about 10 km from the site for the balance production. Due to limited available site storage space, overall production rate was back calculated such that minimal surplus stock was stored at site. Due to the temporary nature of the production facilities and relatively small sized panels based on the floor plan, all members were designed as conventionally reinforced precast members instead of prestressed components. Due to scarcity of heavy-duty tower cranes in India, precast panel weight was kept under 6 tons (~13 kip). Figure 10 shows the precast panel layout. Most members were designed to be flat panels with a few exceptions such that majority of the production could be planned on flat beds or battery molds. To control costs, all molds were indigenously made instead of importing molds. Steel molds dedicated to individual panel type (all fixed side rails) were used considering high pour repetition.

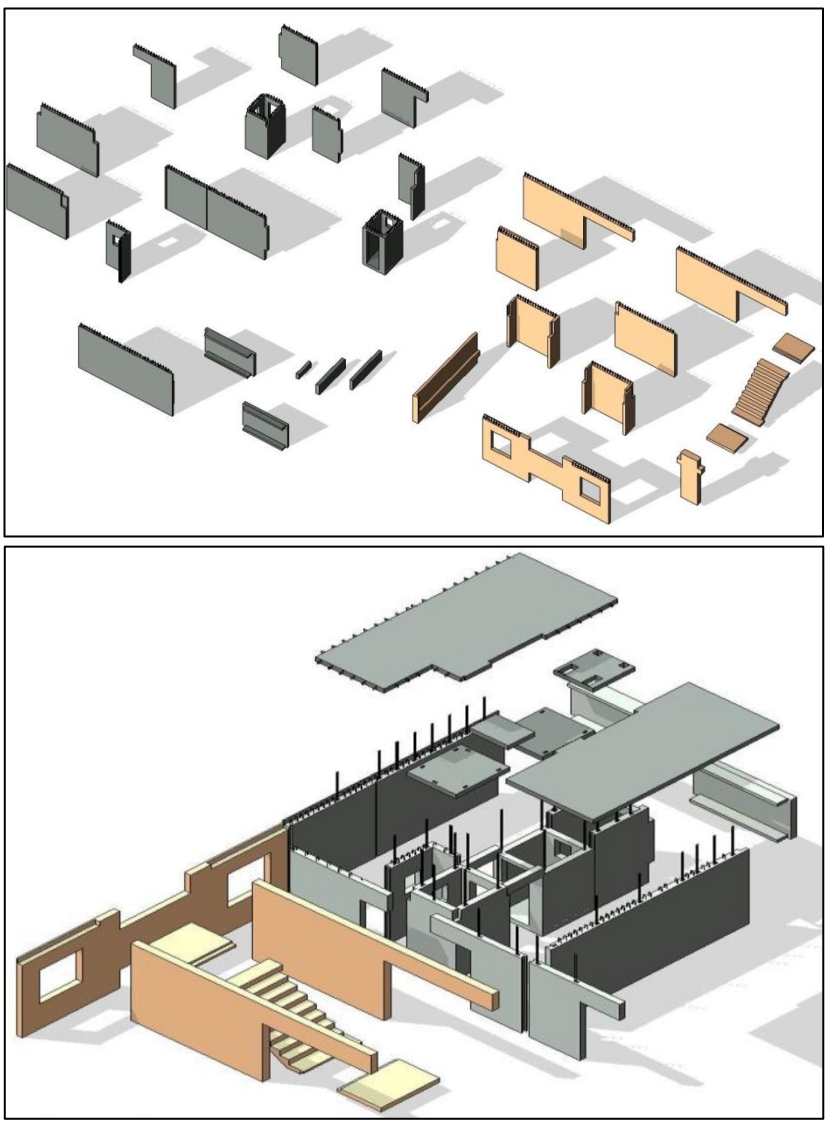


Fig. 10 Pragati Towers – Typical Precast Panel Layout

SITE LOGISTICS AND TRANSPORTATION PLANNING

The city of Mumbai, known as the financial capital of India, is always busy and bustling. Congested roads leading to extended travel times in peak hours is not an uncommon sight. The project site for Pragati Towers, located in the heart of the city, was no exception. Thus, site based dedicated factories were preferred contrary to global practice of centralized factories. Figure 11 shows a bird's eye view of the site entrance. Detailed trailer movement and space optimization studies were carried out to calculate maximum number of trips per day for the trailers coming from site and the nearby off-site factory.

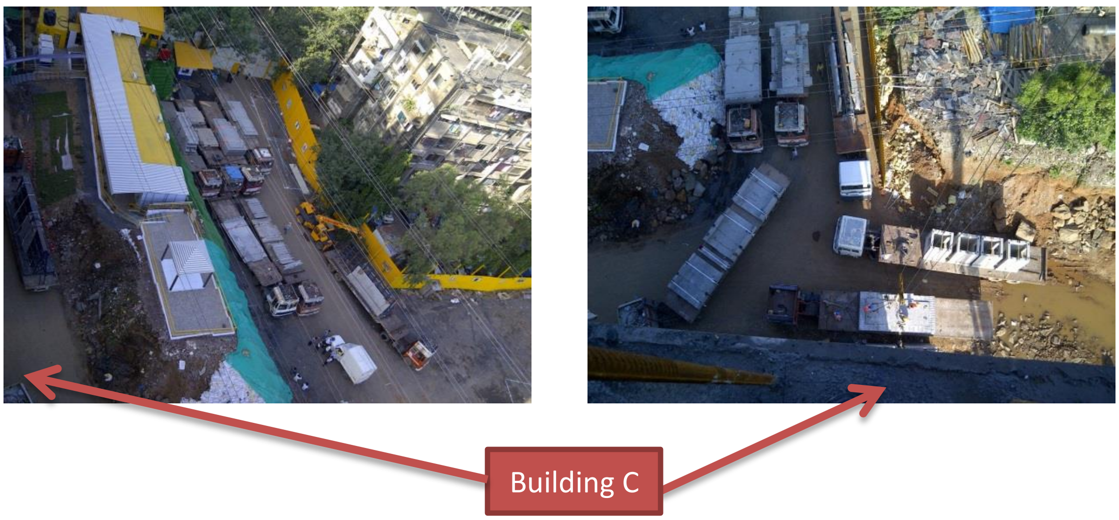


Fig. 11 Pragati Towers – Phase 1 Site

FABRICATION, STORAGE AND HANDLING

At both factories, predominantly battery molds were planned for panels with minimal opening and inserts; flat beds were planned for the remaining panels and indigenously built operable full height 3D molds were used for the toilet and bath units. The Client had some reservations regarding joint details with respect to water leakage. Thus the toilet and bath units were cast monolithically as a single 3D unit in order to avoid panel joints. Considering high mold repetition, all molds were built using steel plates. With the same consideration, individual molds were made for each member with member specific geometry to reduce preparation time. Thin foam pads were used in between the rail and flat bed joints to prevent slurry loss and achieve finished edges. Mold release oil was applied per international standard practices. Rebar cages were prefabricated for all molds. High flow concrete with high early strength concrete mix was selected that needed minimal vibrations. Plate vibrators and needle vibrators were used as required. Manual, concrete bucket, delivery system was selected to control operating costs. Mumbai climate is typically warm through the year with high relative humidity. Thus, initial wet curing followed by majority of air curing was selected instead of accelerated curing. All members were stored per the design intent (walls vertical and slabs horizontal) except the wall panels that were cast in flat beds. Due to limited availability of storage space, fabrication was planned in a just-in-time manner so that only limited stock was in excess. The site activities were planned for minimal storage and most panels were lifted off directly from the truck trailers to the building. Traditional 40 feet trailers were used. For Battery Mold panels, special A frames were prepared for vertical transportation. Figure 12 shows a few photos of the overall fabrication process adopted.

Flat Bed Mold

Battery Mold

Toilet/Bath 3D POD Mold

Finished Toilet/Bath PODs

Storage Yard

Panel Transportation

Fig. 12 Pragati Towers – Fabrication and Transportation Activities

ERECTION PLANNING

Heavy duty tower cranes with tip capacity ranging from 4-6 ton (8.8-11 kip) with a tip radius of 40-50 m (~ 130-164 ft) were selected. Due to close proximity of the buildings (8-10 m (~ 26-33 ft)) the cranes were positioned such that the crane radii did not interfere with each other. Tower A crane was selected with a luffing jib to prevent interference with the adjacent crane. Depending on the schedule, at times adjacent tower cranes were used to erect portions of other towers. Typical erection was sequenced from one end of the building to the other end, going up level by level. Grouting of vertical connection dowels was followed immediately after the slabs were erected and the stitching activity was completed within one day of erection. All members were braced for a minimum of two levels below the working floor. On an average, around 50 panels were erected per crane per day. Overall the erection pace translated to 5 flats per day on an average and 10 flats per day at peak for the work of three towers. Precast work of all three towers was completed just under 11 months. Figure 13 shows the overall erection plan for individual buildings along with a photo of erection in progress.

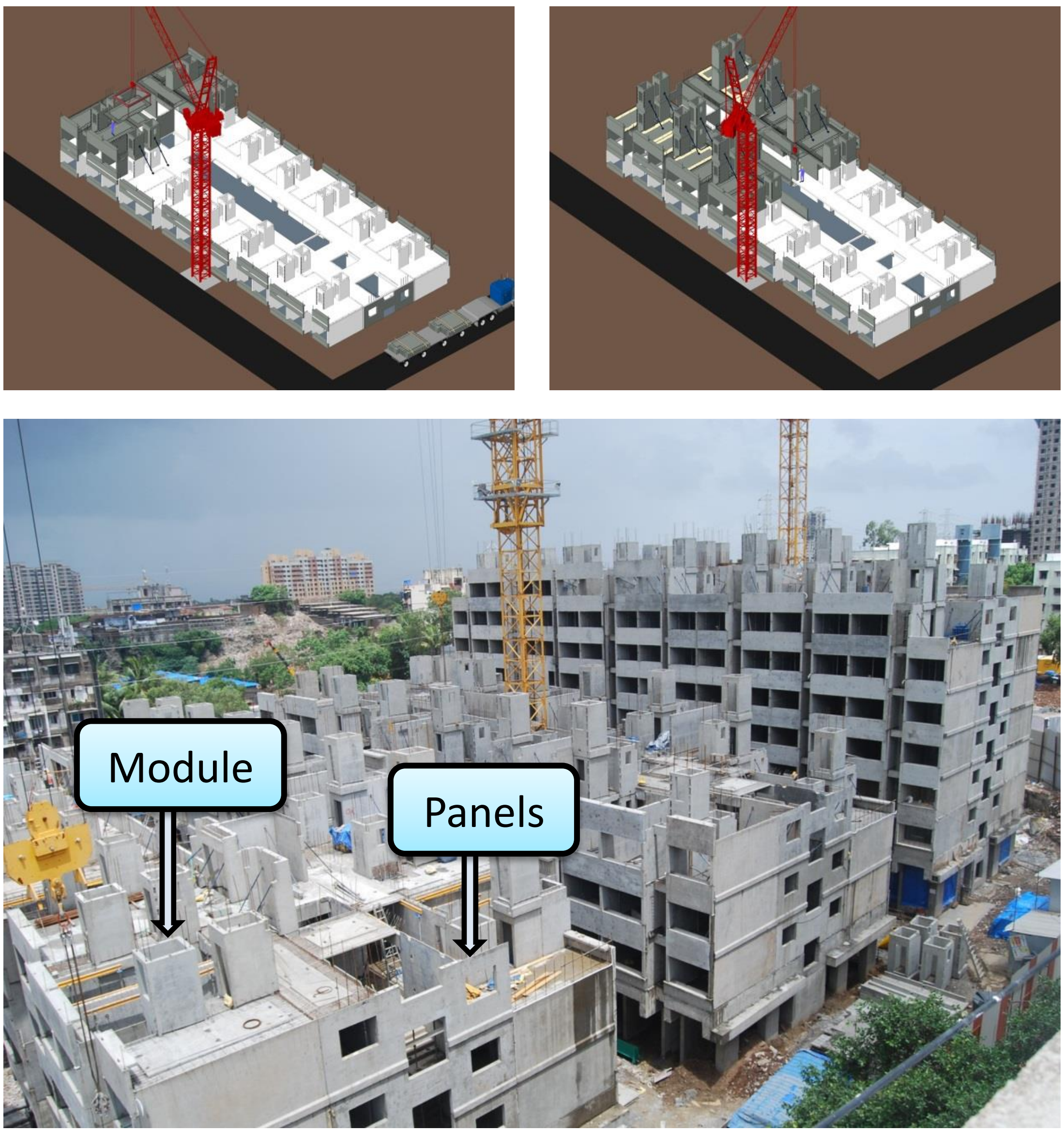


Fig. 13 Pragati Towers – Erection Progress

EXTERIOR AND INTERIOR FINISHING

Exterior/interior finishing was completed using site applied paint schemes. All exterior surfaces were cast on mold face and did not need additional surface preparation. Interior surfaces were refinished with primer and painted. On both faces, traditional sand-cement plaster coat used in conventional construction was avoided leading to substantial savings in time and labor typically needed for high-rise construction. All other interior finishing activities were similar to those typically used in conventional construction options. Electrical conduits and plumbing pipes were kept exposed per the Client's request. Figure 14 shows a few pictures of the finished apartments.

Outside Corridor

Apartment Interior

Fig. 14 Interior Finishing of Completed Building

CHALLENGES FACED AND TACKLED

The task of taking up a high-rise residential building using precast technology in itself was a daunting task. There was a steep learning curve for all involved to understand the technology and global standard practices and apply the learnings to the project in a workable fashion within the available resource constraints. Several aspects and standard practices used overseas were modified to fit the Indian construction practices[12]. Some of the major aspects discussed in the paper are summarized below along with the respective solutions followed, in contrast with standard global practices, to adopt this technology. The knowledge and understanding acquired during this process will be carried forward to the new projects underway.

TECHNOLOGY ACCEPTANCE BY THE CLIENT AND CONSULTANT

The Client and Consultant graciously accepted the technology based on the examples of precast buildings from around the world. Most examples were selected such that they matched a majority of project parameters on Pragati Towers with respect to customer needs, architecture, seismic design and site logistics. Without the Client's cooperation, patience and willingness to experiment with a new technology, this project could not have been conceived and materialized.

DESIGN PHILOSOPHY

Jointed construction has been a widely accepted design philosophy globally for precast concrete construction. It offers the added advantage of speed and ease of construction. However, in-situ reinforced concrete system has been the most accepted system for residential construction over the last few decades in India. Thus, emulative design approach was followed instead of jointed design approach. Several methodologies were proposed and mock-up samples and load tests of critical connections were completed to come up with the final feasible options that would satisfy the design intent.

DESIGN OF CONNECTIONS

Overseas standard emulative connection details such as sleeve connectors and loop connectors were weighed against the local design constraints such as cost and production/erection feasibility instead of blind adoption of methods used overseas. The approaches that worked well such as loop connectors were used with minor modifications. On the other hand, some approaches such as sleeve dowel connecters were avoided for high import costs and strict tolerances required for erection and production. Notched half slab concept was used which provided the comfort of jointed construction to a certain extent along with viable detailing to achieve emulative behavior.

INFRASTRUCTURE PLANNING

Precast construction approach used worldwide inherently has a central producing plant that caters to the projects within a defined radius around it. However, it was quickly concluded that in the current Indian infrastructure context, this approach may not suit well. Instead, the concept of dedicated site based temporary factory was followed to escape from the challenges of transporting large and heavy panels through the existing public infrastructure system.

FABRICATION MOLDS

Global factories typically use long line flat beds for majority of production to be simultaneously used for multiple projects. Since a dedicated factory system was used here and the project demanded heavy product repetition leading to several pours of each panel, panel specific steel molds were used to reduce set-up time. The molds were quantified to optimize the specified usage life.

ERECTION CRANES

Heavy-duty construction cranes are not widely available in India. The available cranes come at significantly higher rates compared to traditional light duty cranes used in conventional construction. Member geometry was optimized such that the overall weight is mostly just under the crane capacity to have a balance between weight limit and lowest possible number of panels for faster erection. Precast panels were laid out level by level instead of covering multiple levels primarily to work around the maximum panel weight restrictions.

CONCLUSION

Current challenges of huge demand and supply gap in housing market, and acute shortage of skilled labor has necessitated the Indian Construction industry to break away from the conventional construction methodologies. Precast Construction option would be one of the fitting solutions, provided the hiccups based on Indian construction constraints are worked out. A fairly modular and repetitious nature of typical residential high-rise or mass housing projects in India bodes well for the use of precast technology. The Pragati Towers project showcased the viability of precast concrete technology in India by successfully implementing the technology and drastically reducing the structural system completion time, while providing a superior quality product. Phase 1 (three buildings) was constructed in eleven months with approximately 30% reduction in labor force, as compared with traditional construction labor force requirements for similar sized projects. Based on this track record, precast technology could certainly be quickly established as a proven technique for modular mass housing projects, even if the technology is currently at an inception stage in India.

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