High Rise SKY Towers, Mumbai – Construction Challenges

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**Biography**

Amitabh Kumar is Vice President at Indiabulls Real Estate Limited at Mumbai with overall responsibility for Civil Construction projects of INDIABULLS Group (About 14.5 million Sq. ft, under construction). He has done M. Tech. (Civil) from Indian Institute of Technology, Kanpur, India. He is Member American Society of Civil Engineers (M.ASCE).

He is a proven leader in project execution with more than 24 years of rich and qualitative experience in Project Management, Civil Construction Projects. Possess expertise in executing projects for, High Rise Towers, IT Park and Commercial Buildings. He is adept in planning and executing construction projects involving contract administration, resource planning with a flair for adopting modern construction methodologies in compliance with quality standards as per ISO 9001. He is proficient in swiftly ramping up projects with competent cross-functional skills and ensuring on time deliverables within pre-set cost parameters.

Amit Singhal

**Biography**

Amit Singhal is Senior Engineer at Indiabulls Real Estate Limited at Mumbai with various important responsibilities for the construction of SKY Towers of INDIABULLS Group. He has done B.Tech (Civil) and M.Tech (Structural Engineering) from Indian Institute of Technology, Bombay, India.

His current assignments and responsibilities are engineering, planning, co-ordination, monitoring, technical improvement and innovation at SKY Towers.
Abstract

Sky Towers consists of four high rises - Sky, Sky Forest (Twin Towers) and SKY Suites, 257 to 300+ meters height, under construction in Mumbai, India with area of about 8 million sq. ft. Significant Construction Challenges are faced due to the population density in downtown Mumbai, design changes during construction, functional office complexes in the compound and the recent introduction into the Mumbai market of automated formwork systems and other equipments. Flat PT slab was selected for speed of construction and economy. ACS (Automatic Climbing System) for core walls proceeding method is adopted to reduce the construction time. Climbing platform SCP and Automatic climbing formwork are used based on core geometry and predetermined construction sequence. Generic panel slab formwork with drop heads is used for flexibility to adopt different geometry, early stripping and crane independent faster construction. Guided climbing formwork is used for few peripheral walls. MEVA-ALUFIX panels are used for columns and other walls. Equipment has been planned after studying the towers’ geometry and site logistics. Eight hoists are being installed in phases. Four high performance pumps are used for the initial 150m height and above 150m four high pressure pumps are planned along with standby. Seven self climbing concrete placer booms are being erected in phases. Design changes influenced the selection and placement of equipments. Variable storey height was a challenge to optimize and synchronize climbing sequence of ACS, Tower Cranes and Placer booms. Erection of equipments was challenging due to space constraints, the fast track construction schedule and the densely populated area. High performance concrete and temperature control concrete is made available through in-house plants and other grades (M40, Lean concrete) are sourced from outside. Design mix keeps on changing during construction due to the variability in raw materials.

Keywords: SKY Towers, Equipment Planning, Construction,

Introduction

Sky towers are four high rises residential buildings situated in the densely populated area of south Mumbai. Indiabulls Sky is envisioned as Mumbai’s most dynamic destination, assimilating a world class financial district and branded luxury residential development on approximately 20 acres of prime property in the downtown Mumbai. The approximately 8 million sq. ft project (ultimate comprehensive built up area including parking decks and basements) is master planned to creatively integrate the existing Office development with luxury residential towers, in the 257 to 300m+ height range, making them one of the most iconic and visually arresting structures in the city.

The project is split into three distinct parcels (Jupiter Mill, Plot no - 882 and Elphinstone Mill). The residential development on each is branded differently (Sky Forest at Jupiter, Sky at Parcel 882 and Sky Suite at Elphinstone) as depicted in Table 1, Fig. 1 and Fig.2.

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<tr>
<th>Items</th>
<th>Height (m)</th>
<th>Remarks</th>
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<tr>
<td>Sky Tower</td>
<td>257</td>
<td>2 Basements + 11 Parking +</td>
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<tr>
<td></td>
<td></td>
<td>2 Club + 2 transfer +</td>
</tr>
<tr>
<td></td>
<td></td>
<td>41 Residential/ Refuge/Service</td>
</tr>
<tr>
<td>Sky Suite</td>
<td>291</td>
<td>3 Basements + 13 Parking +</td>
</tr>
<tr>
<td></td>
<td></td>
<td>2 Club + 1 Transfer +</td>
</tr>
<tr>
<td></td>
<td></td>
<td>52 Residential/part refuge/service</td>
</tr>
<tr>
<td>Sky Forest</td>
<td>284</td>
<td>3 Basements + 16 Parking +</td>
</tr>
<tr>
<td>(Twin Towers)</td>
<td></td>
<td>2 Club + 1 transfer +</td>
</tr>
<tr>
<td></td>
<td></td>
<td>50 Residential/part refuge/service</td>
</tr>
</tbody>
</table>

Table 1: Brief on stacking, Sky Towers
Rendering of Sky Towers is shown in Fig. 3 – 6. Construction of the structural frame for all towers is under progress.

Fig 1: Location plan

Fig 2: Locations of existing and proposed buildings
Structural System Brief Description

3 dimensional FEM analyses have been carried out using ETABS. Model includes non-linear construction sequence analysis to capture exact load distribution between core and outer frame / shear walls. Structures are analyzed for seismic forces corresponding to Zone III using response spectrum method as per IS – 1893: 2002. Lateral load resisting system comprises of ductile design with R = 5 as per IS – 13920: 2002.

Wind tunnel test was carried out for SKY tower and was subsequently conducted second time, on revised model, to incorporate changed massing and configuration by RWDI, Bedfordshire UK using High frequency force balance (Fig 7). Wind loads are based on 3 second gust and wind speed of 44 m/sec, for open terrain, at 10 m height with 50 years of return period. For acceleration calculation, wind speed of 32.5 m/sec (based on wind climate study for Mumbai by RWDI) with 10 years return
period was considered. Desktop study has been conducted and wind tunnel test is under progress for Sky Forest and Sky Suite.

The Sky tower accelerations at the top floor for 10 years return period was reported to be 9.3 milli-g with 1.5 % critical damping which is within acceptable limits of ISO Residential (10 mg) and RWDI residential (15 mg) as shown in fig 8.

**Lateral Load Resisting System**

The main structural form consists of a reinforced concrete peripheral frame / shear walls with central core walls. All towers are having at least one transfer floor due to different layout of parking and residential floors. Outriggers beams / walls have been provided at refuge levels, to connect outer frame and central core, to improve the lateral stiffness.

The core wall and staircase wall thickness vary from 600 to 900 mm. The core walls are typically linked through series of 900 - 1300 mm deep RC
link beams. The link beam width typically matches with the adjacent core wall thickness.

**Floor Framing Plan**

The Parking floor framing system consists of 225 to 300 mm PT reinforced concrete flat slab with perimeter beam connecting the columns. The residential floor plan is having large sunken terraces, sunken toilets, hence framing of residential floors is mix of Post – tensioning and conventional RCC slab of 175 – 250 mm. The floor framing system within the interior core consists of conventional Flat Slab with beams.

PT Slab – Core Wall connection, PT tendons anchors are placed a distance equal to one slab depth away from the face of the wall.

**Foundation System**

Sky Tower is founded on 3500 mm thick RC raft. Sky Suite & Sky forest - North core is founded on a 3500 mm thick raft and columns are founded on combined footings. Sky forest – South tower core is founded on 3500 mm thick RC pile supported raft foundation due to variation in underlying rock characteristic. The piles are of 1200 mm diameter, embedded approximately 11.0 m in rock. Piles are founded at final elevation of -27.0m.

Raft utilizes M - 40 concrete with GGBS to mitigate the heat of hydration. Crystallization water proofing method has been adopted for Raft.

**Construction of SKY Towers**

Proposed towers are in the densely populated area of down town Mumbai. Movement of materials, noise issues, local regulations on working time, and sand shortage due to ban on sand dredging etc. are the day to day challenges in the construction. Existing residential towers and functional offices pose constraints on working hours, logistics and scheduling of construction activities.

**Design Changes**

Design changes pose challenges in the construction, equipment placement and equipment sequencing. There were major changes in the core area (Fig 9 to 12); floor height; residential floor plan etc. as per market forces and changing regulations.

In this paper, few major design changes have been covered.

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**Fig. 9:** Revised core layout at residential level, SKY Tower

**Fig. 10:** Old core layout at residential level, SKY Tower
Construction of Super Structure

Construction schedule for the towers is very tight, to deliver these high rises fast and to reduce the interest burden. For typical parking floors 10 days slab cycle and for residential floors 7 days slab cycle is targeted for structural work. To achieve the target, the following strategic approach has been adopted:

- Detailed planning and simulation for typical Slab cycle with Zones
- Develop optimum transportation system with large capacity high speed equipment
- Utilize optimum formwork system to accommodate building shapes along the building height
- Develop logistic plans throughout the construction period
- Optimum use of available high-rise construction technologies

Construction technologies

Following are the key construction technologies used to achieve 7 days slab cycle:

- Core proceeding method with auto climbing formwork System (ACS)
- Guided climbing system for external RC walls.
- Light weight panel formwork for Columns
- Generic panel slab formwork system with drop head
- Concrete placing booms, high performance pumps, high capacity tower cranes and high speed hoists with large capacity.
- High performance concrete suitable for providing high strength, durability and pumping

Auto climbing system

Shuttering and reinforcement binding for shear wall is time consuming activity as compared to the other structural vertical elements. ACS for core walls proceeding method has been adopted to reduce the construction time by taking core construction out of the critical path. Automatic climbing platform SCP – 400 in Sky Tower and SKE – 100/50 (DOKA) in Sky Forest as well as Sky Suite have been used, based on core geometry and predetermined construction sequence. The configuration has been further modified to accommodate design changes.
Considering reinforcement congestion in 600 to 900 mm thick core walls, external vibrators (Wacker Neuson) are being used for proper concrete consolidation (fig. 13).

**Light weight panel formwork (Column and wall)**

Circular columns have been cast with steel / FRP shuttering. Columns shape changes to rectangular in residences where light weight Alufix panels has been adopted for ease in handling. Centre core wall and staircase walls construction is followed by flat slab construction. For Sky suite, Mivan type Aluminum shuttering (walls outside core to be constructed along with slab) has been planned considering large number of shear walls outside core area.

Different types of shuttering systems have been adopted for vertical elements at different levels (fig 15 – fig 20).

**Guided Climbing System**

External RC wall needs special attention. Guided climbing system using crane has been used for external walls with one trailing plate form (fig 14).

**Fig 13:** Use of external vibrators at SKY Tower

**Fig 14:** Meva Guided climbing formwork installation in progress for outer walls at SKY Tower

**Fig 15:** Shuttering system at parking level, Sky Tower
**Fig 16:** Shuttering system at residential level, Sky Tower

**Fig 17:** Shuttering system at parking level, Sky Suite

**Fig 18:** Shuttering system at residential level, Sky Suite

**Fig 19:** Shuttering system at parking level, Sky Forest
Fig 20: Shuttering system at residential level, Sky Forest

**Slab Formwork System**

Generic panel slab formwork with drop heads is used for flexibility to adopt different geometry, early stripping, easy installation, lightness, and crane independent faster construction at Sky tower and Sky Forest (fig 21). The slab shoring system consists of two levels of shores and one level of re shore. 1.5 set of panels are planned with 2 set of props for Sky tower as well as Sky Forest.

For Sky Suite, Slab Mivan type Aluminum shuttering has been planned.

Intensive training in a systematic way has been carried out for newly introduced equipments in Indian market, adopted for Sky Towers.

Fig 21: Meva Deck formwork installation in progress at SKY Tower

**Construction Sequence**

Centre core wall and staircase walls construction is followed by flat slab construction.

In Sky Forest, at residential level construction sequence is different due to layout of the duplex upper deck. The floor plate of upper deck of Duplex is quite small compared to lower level comprising of large living areas. Upper Deck slab will be resting on floating columns. The construction of lower floors is planned to proceed without constructing upper deck. Construction of Upper deck slab with floating columns will follow subsequently and hence will not be on critical path. This methodology prohibits use of concrete placer booms for upper deck. For concreting of duplex upper deck a concrete rotary distributor (Putzmeister – RV 13) has been planned, which will rest on the pre constructed lower duplex level.

**Major Equipments**

Selection of right equipment and placing them at strategic location in plan is critical to ensure speedy construction and delivery of men and materials. Selection of optimal equipment and vertical transportation system for construction requires ongoing analysis and constant modification due to dynamic nature of project during course of construction.

Sky Towers are one of the unique project and newly introduced construction technologies and
equipments to Mumbai market has been harnessed to its full potential.

**Tower Cranes**

Eight high capacity internal self climbing tower cranes (Model – MC 205 B, 10 tons capacity, 110 m/min lifting speed, 75 HP Power) has been optimally selected. Location on plan has been decided as per building geometry, existing buildings in proximity and site logistics. Six tower cranes out of eight have already been erected.

In case of Sky Forest, two high capacity self climbing cranes were planned initially but with the evolving design, four such cranes have been planned with anti collision devices. Tower crane locations are shown in fig 22 – 24.

Tower crane details like boom length, height etc. is given in Table 2.

<table>
<thead>
<tr>
<th>TC Number</th>
<th>SKY Tower</th>
<th>SKY Suite</th>
<th>SKY Forest</th>
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<tbody>
<tr>
<td>TC1</td>
<td>TC2</td>
<td>TC3</td>
<td>TC4</td>
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<tr>
<td>Boom Length (m)</td>
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<td>25</td>
<td>40</td>
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<tr>
<td>TC5 &amp; 7</td>
<td>TC6 &amp; 8</td>
<td>TC7</td>
<td>TC8</td>
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<tr>
<td>40</td>
<td>30</td>
<td>40</td>
<td>30</td>
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**Max Tip Load (Ton)**
- 4.7
- 6
- 4
- 4.7
- 4
- 5.1

**Free Standing Height (No. of Mast)**
- 44.7 (14)
- 38.7 (12)
- 44.7 (14)
- 44.7 (14)
- 44.7 (14)
- 38.7 (12)

**Climbing Height under Hook(m)**
- 278
- 272
- 304
- 304
- 305
- 289

**Table 2: Tower Crane Specification**

**Concrete Placer Booms**

Seven self climbing concrete placer booms (Putzmeister MXR 32 – 4 Multi, 19.5 meters) have been planned and five have already been erected. Placer booms can either be placed in core lift shaft or rest on slab inside the core / outside core area. With due consideration of building geometry, climbing sequence of ACS and tower cranes locations, placer booms have been placed on slab inside the core. Tower crane and placer boom location for all the towers is shown in Fig 22 to 24.

![Fig 22: Tower crane and placer boom Location, SKY Tower](image-url)
Fig 23: Tower crane and placer boom Location, SKY Suite

Fig 24: Tower crane and placer boom Location, SKY Forest
**Hoists**

Eight hoists are being installed in phases as per construction sequence of towers (Fig 25 - 28).

**Fig 25:** Hoists location (Ground Floor), SKY Tower

**Fig 26:** Hoists location (Transfer Level), SKY Tower

**Fig 27:** Hoists location (Ground Level), SKY Suite
Fig 28: Hoists location (Ground Level), SKY Forest

<table>
<thead>
<tr>
<th>Specs</th>
<th>Hoist 1 &amp; 2</th>
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<th>Hoist 5 &amp; 6</th>
<th>Hoist 7 &amp; 8</th>
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<td>Model</td>
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<td>Scando 650 FC /32/39</td>
<td>Scando 650 FC /32/39</td>
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<tr>
<td>Capacity (kg)</td>
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<td>3200</td>
<td>3200</td>
<td>2900</td>
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<tr>
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<td>3.9 m X 1.5 m</td>
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<td>Speed (m/min)</td>
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<td>Club - Terrace</td>
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<td>Service Height (m)</td>
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<tr>
<td>Location</td>
<td>Sky Tower</td>
<td>Sky Tower</td>
<td>Sky Suite</td>
<td>Sky Forest</td>
</tr>
</tbody>
</table>

Table 4: Main Hoist Systems

Climbing Sequence of Equipments

Climbing sequence and lifting of major equipments is critical to achieve desired slab cycle and should not be on the critical path. Climbing sequence was carefully decided for each tower after studying the building section, proximity of towers and limitations of equipments. Variable storey height was a challenge to optimize and synchronize climbing sequence of ACS, Tower Cranes and Placer booms.
Fig 29: Sky Tower under construction
**Fig 30:** Sky Forest under construction

**Fig 31:** Sky Suite under construction

**Fig 32:** Sky Suite and existing commercial towers

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Fig 33: SCP 400 and Placer boom, Sky Tower

Fig 34: Placer Boom in action, Sky Tower

Erection of Equipments

Erection of equipments was challenging due to space constraints, the fast track construction schedule and the densely populated area. Equipments were brought on site after planning the other construction material requirement, site logistics, erection plan for that equipment and restricted traffic movement (fig 35-37).
Fig 35: Placer boom erection, Sky Tower

Fig 36: Tower Crane erection, Sky Tower

Fig 37: Tower Crane erection, Sky Forest

Concrete Pumping & Planning
1/24/2011
The utilization of high strength concrete and concrete pumping technologies is critical for high rise towers and it requires following consideration:

- Selection of optimum mix design, with excellent flow properties and desired slump
- Capacity to deliver concrete at ~ 300 m height with required discharge rate
- Proper design of pipeline
- Quality control of pumping system and placing method

Table 5 shows the grade of concrete used / planned in Towers.

<table>
<thead>
<tr>
<th>Elements</th>
<th>Location</th>
<th>Sky Tower</th>
<th>Sky Suites</th>
<th>Sky Forest</th>
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<tbody>
<tr>
<td>Column and Wall</td>
<td>B 2/3 – P1</td>
<td>M70 (SCC)</td>
<td>M70</td>
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<td>Typical Parking</td>
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<td>M60</td>
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<td>Residential</td>
<td>M70, M60</td>
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<tr>
<td>Slab and Beam</td>
<td>Up to Typical Parking</td>
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<tr>
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<td>Residential</td>
<td>M50 + Accelerator</td>
<td>M50 + Accelerator</td>
<td>M50</td>
</tr>
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</table>

Table 5: Concrete Grade used at Towers

Five high performance pumps (91/152 bar) are being used for the initial 150 m height (one standby). Above 150 m five high pressure pumps (140/205 bar) has been planned (one standby).

Concrete requirement for the project is enormous and couldn’t be met entirely from outside source. Initially two onsite RMC plants were operational in elphinstone mills, as construction progressed plants have been shifted to nearby available plot (Fig 38). High performance concrete and temperature control concrete is made available exclusively through these in house plants (60cum/hr with chiller) and other grades (M40, Lean concrete) are sourced both from outside and in house plants. Mix designs were prepared for different concrete grades including SCC M70. Design mix keeps on changing during construction due to the variability in raw materials. Artificial crushed sand has been used (up to M60 grade) due to non availability of river sand for a considerable period.
**Conclusion**

High rises like Sky towers needs careful planning for right equipments, formwork system, concrete planning, construction sequence and site logistics. Wind tunnel study plays crucial role during design phase. The design changes after onset of construction poses a challenge and needs dynamic decision making and revision of construction strategy. Such changes in core need special attention for Automatic climbing systems.
Fig 39: RMC Plants location (A) and Sky Towers Location (B) – Distance between A to B is ~ 2.5 km.

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