PALAIS ROYALE, A TREND SETTER

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Introduction:

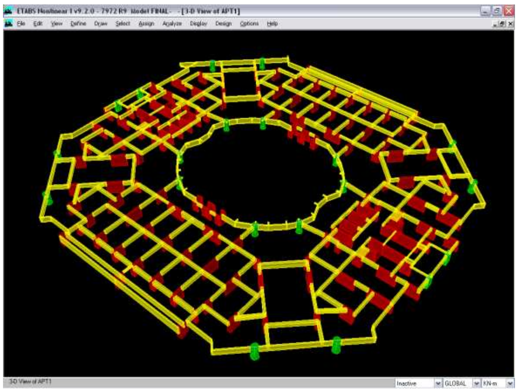
Palais Royale (pronounced as pa-lai ro-yaal) is a French phrase which means a Royal Palace.

Location:

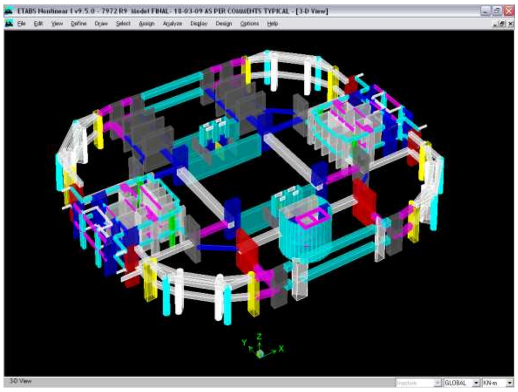
Situated in the heart of south Mumbai, Worli Naka, the building with a height of 295 m above the ground level has a total structural height of 325 m from the bottom of the foundation to the top of the elevation cap. The base dimensions of the octagonal prismatic building are 84m x 86 m. The construction area of the building is over three million sq.ft. with 88 slabs.

Structural Systems:

The residential levels have been provided with a conventional column / beam and solid slab configuration. Presence of an atrium in the centre as a Brahmasthan requirement has provided the structural advantage of the supports being on the periphery.



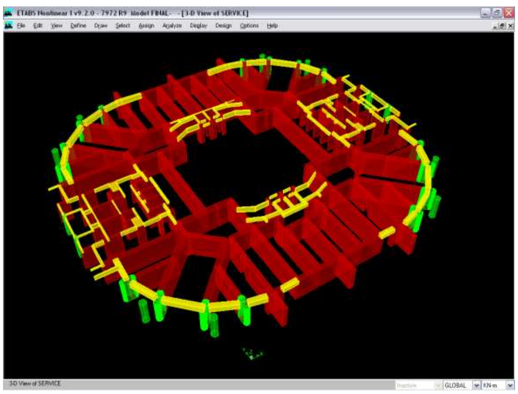
APARTMENT LEVEL FRAMING



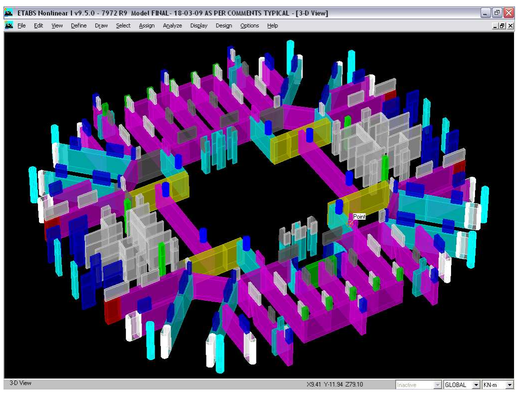
AMENITY LEVEL FRAMING

Transfer Level:

In order to transfer the loads of the 244 residential columns to the foundation through the 88 lower columns, transfer girders are provided at +76 m level. The depth of these RCC girders is 9 m and the widths are varying from 1200 mm to 1500 mm as per the design and bearing requirements.



TRANSFER GIRDER FRAMING



TRANSFER LEVEL

The Parking and Amenity Levels:

Structural system below transfer girder level comprises predominantly of Post Tensioned Flat Slab except in the Brahmasthan where the 25 m x 22 m rectangular area is framed by strong posttensioned beams. The amenity areas carry huge loads, the average intensity of the superimposed loads (SDL +

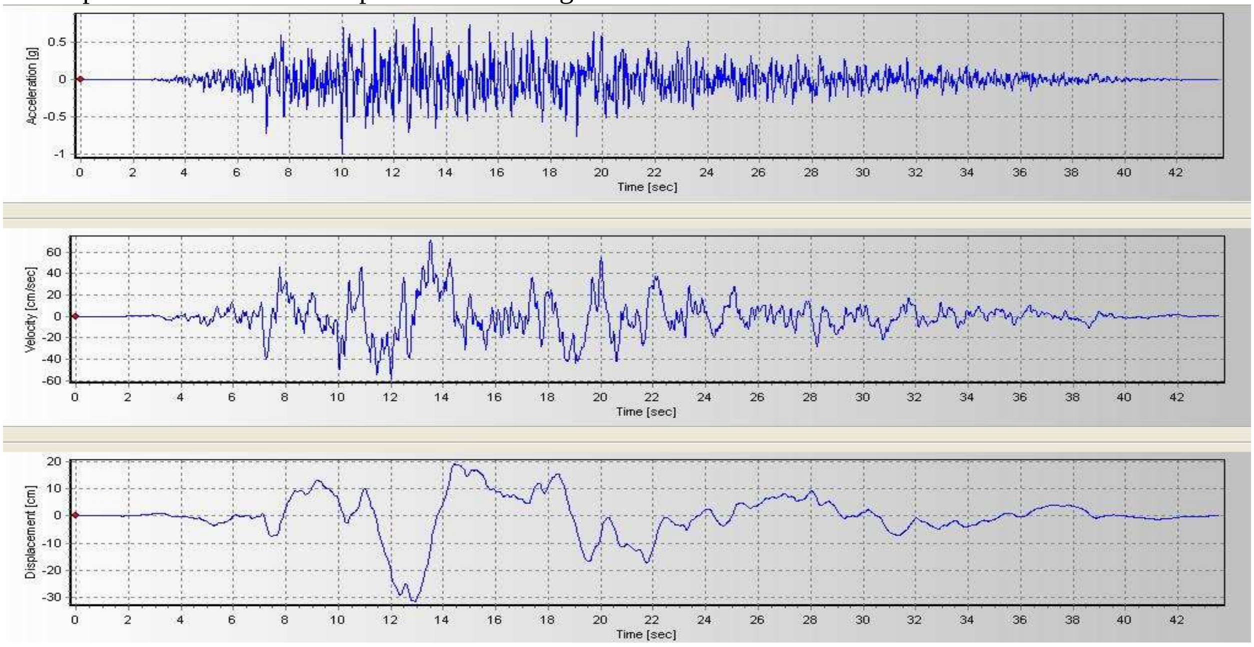
LL) being as high as 35 kN/sq.m at the swimming pool level. The parking levels are designed for the possibility of double stacked parking. Seismic design is corresponding to Earthquake Zone III aimed at operational level performance – maximum allowed drift ratio being 1000 and acceleration in wind limited to 5 milli-g.

Wind tunnel tests:

Wind tunnel tests by RWDI showed that for a 10 year return period the Total Peak Acceleration in simulated wind conditions was 7.2 milli-g against the criteria of ISO 10137:2007 of 14 milli-g (extrapolated from the criteria for 1 to 5 year return period to 10 year return period).

Site Specific Seismic Studies :

For the first time in India, site specific seismic studies were conducted for a residential building, with the help of IIT Roorkee. The spectrum was assigned in the ETABS model as an additional load case.



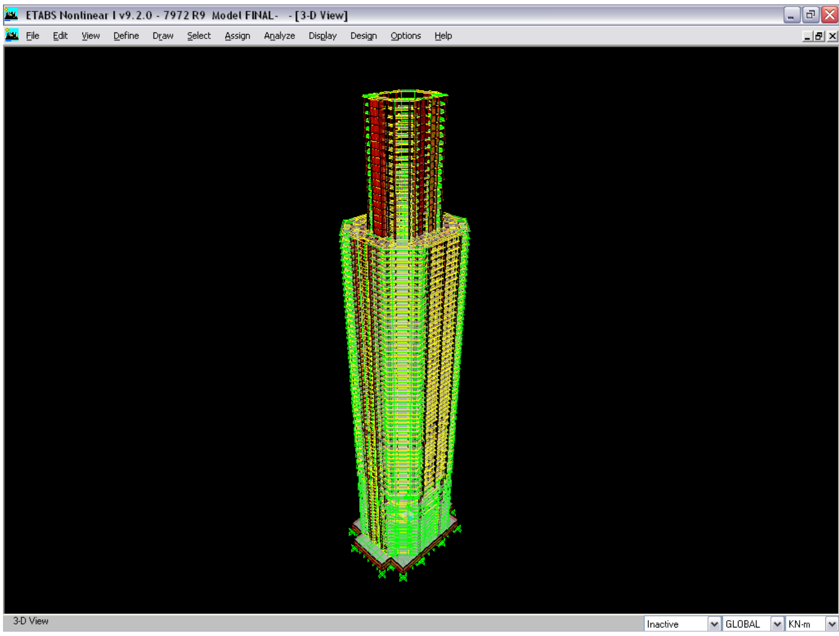
SITE SPECIFIC TIME HISTORY SCALED TO UNITY

Soil Profile:

Soil consultants estimated a safe bearing pressure of 150 T/sq.m with settlement less than 25 mm. Modulus of subgrade reaction of 6500 T/m3 was recommended for the design of raft foundations. Cross-hole velocity test yielded average values of Poisson's Ratio, Young's Modulus and Shear Modulus as 0.32, 5200MPa and 200 MPa respectively showing excellent characteristics of the rock profile. Due to presence of weak soil for the upper 8 to 9 m, soil retention system was erected in the form of contiguous concrete infilled tubular steel piles, held to the bedrock with inclined pre-stressed rock anchors.

Computer Model:

A combination of shell diaphragm and membrane diaphragm was chosen to simulate framing conditions of the structure, in order to optimize the run time and the computer memory. The flat slabs at the parking and amenity levels have been treated as shell elements contributing to the lateral stiffness.



ETABS MODEL **PERSPECTIVE OF THE BUILDING**

At the residential levels, the lateral resistance is derived from the beam/column frame action. Hence, the diaphragm is modeled as a membrane. Cracked section properties were assigned in accordance with the code recommendations.

The foundation raft was analyzed using SAFE, using the reactions obtained from the Etabs Analysis.

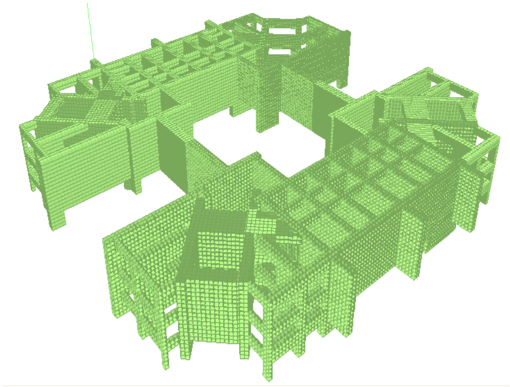
Analysis Results:

Considering the overall maximum lateral deflection of the building being only 300 mm occurring at the top level, the general performance of the building is well controlled. The massive proportions and the enormous stiffness of the building are evident from the modal frequencies found to be 0.1206 Hz for Mode 1 in Y direction, 0.1349 Hz for Mode 2 primarily in X direction and Mode 3 showing 0.1515 Hz primarily in Z direction as torsion. Fortunately, significant differential elastic shortening of columns and shear walls due to vertical loads was not observed.

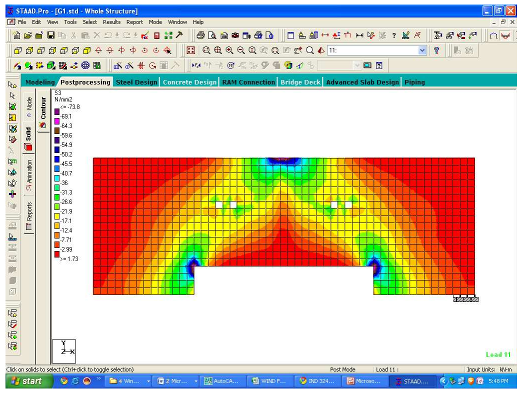
Salient Aspects of Seismic and Wind Design

1. Extensive reference to international guidelines:
- **(a) CTBUH guidelines for seismic design of tall buildings (2008)**
- **(b) Los Angeles Tall Buildings Structural Design Council guidelines for tall buildings (2008)**
- **(c) Pacific Earthquake Engineering Research Centre – seismic performance objectives for tall buildings (2008)**

2. Generation of site specific response spectra and time-histories (undertaken for the first time for a civil application in India).
3. Palais Royale being treated as a Special Structure as defined by IS-1893 (2002).
4. Minimum design base shear scaled to 1 % of the seismic weight.
5. Intrinsic damping for seismic & wind design = 1%
6. Structural elements modeled using cracked section properties.
7. Importance factor of 1.5 used.
8. Seismic deflections under DBE controlled to H/750.
9. Wind accelerations under 10 year return period wind pegged at 10 milli-g

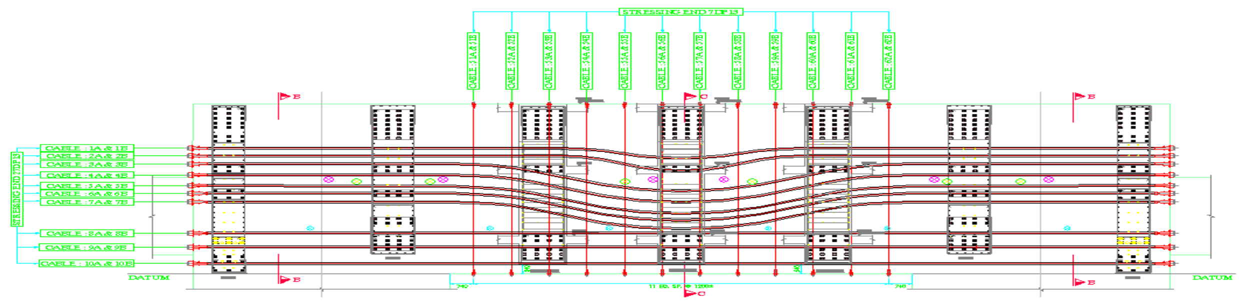


SOLID FINITE ELEMENT MODEL IN STAAD



STRUT-TIE ACTION : STESS PATTERN

The transfer girders were analyzed by Solid Finite Element Method. Both individual girder models and integrated layout model involving all girders and the three floor levels within the girder depth were assembled in STAAD-Pro. The stress patterns clearly indicated that the girders acted in conformity with strut-tie model corresponding to deep beam action. In-depth research was carried out to design the girders, which are probably the largest transfer girders being constructed in the world. The transfer girders have been provided with horizontal and vertical post tensioning to achieve monolithic behavior and deflection control. The post-tensioning is carried out stagewise to avoid excessive upward deflections in early stages of construction.



POST TENSIONING OF TRANSFER GIRDERS

Concrete Information:

M:80 concrete for columns and shear walls and M:60 concrete have been used for slabs and beams. With the help of an elite team of concrete experts, concrete manufacturers, admixture vendors, contractor's engineers and batching plant operators, innumerable trial mixes were tested for various performance criteria. Eventually, M:80 SCC was finalized with free water cement ratio of 0.225 and free water binder ratio of 0.23. With 450 kg cement content and 168 kg/cu.m fly ash, the target strength was 90 N/sq.mm. Micro silica content was tried starting from 0% and was varied up to 10% to examine the performance. The design was finalized with 5% i.e. 23 kg/cu.m micro-silica content. Minor adjustments are carried out for aggregate quality variation and moisture content on a routine basis.

Construction Methodology:

M:80 concrete, use of self compacting concrete, using surface retarders, introduction of retarded concrete to avoid cold joints, column cages, compulsory use of couplers for rebar splicing, Automatic Climbing System for Walls and cores etc. are some of the salient aspects of the construction method suggested by Sterling.

Mock ups:

A practice of setting up true scale mock-ups to study the veracity of the systems was adopted on this project. For example, two mock foundation blocks were cast with 3.5 m depth with reinforcing bars as per the actual design requirement, and were cast, cured and monitored for formwork system, feasibility of using SCC, temperature variation, thermocouple working, segregation characteristics, characteristic strength curve and Evalue. These mock-ups were tested two months in advance before commencing the actual foundation concreting. Similarly, bottom chord of 2 m depth of the overall 9 m deep transfer girder with all the rebars and other embedments was cast, which proved to be enormously helpful in understanding the complexities of rebar placement and in adopting suitable methodology prior to actual work at the 76 m level.

Present Status:

The construction has now reached 125 m, six typical apartment floors above the transfer girder level.

List of consultants

Architects	Talati and Panthaky Associates, INDIA
Structural Engineers	Sterling Engineering Consultancy Services Pvt.Ltd., INDIA
Structural Peer Reviewers	CBM Engineers, USA
Damper Consultants	Taylor Devices India, USA
Geotechnical Consultant	Mr. Jaydeep Wagh
MEP Services Consultants	Pankaj Dharkar Associates, INDIA
MEP Peer Reviewers	LEHR Consultants International, USA
Concrete Technologists	Dr. S.A.Reddi, S.G.Bapat
Project Management	Dongre Associates
Wind Tunnel Testing	RWDI, Canada
Post Tensioning agency	BBR India, Bangalore, India
Design Management	Anand Palaye Architects Colasce
Acoustics	Smita Chogle
Landscaping	Kishore Pradhan
Firefighting	SSN Corporation
Solar Energy	Entegra Infrastructure Ltd.
Lift Consultants	LBA Consultants Pvt.Ltd.
Façade Consultants	Fusion Cladding

Executing agencies

Principal Contractors	Raghuveer Infrastructure
Concrete Production	Constromat Consultancy Services
Micro silica	Elkem India
Reinforcement Fabrication	Ready Made Steel
Formwork	MEVA, Germany / Pranav Constructions Limited, India
Couplers	Dextra India
Reinforcement	Tata, SAIL
Concrete Embedments	Halfen-Deha
Waterproofing	Nina Concrete Systems Pvt. Ltd.
Cladding Material	Du-Pont

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