AE SENIOR THESIS 2012-13
THESIS PROPOSAL

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Structural Option
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The Optimus

Signature Boutique Offices
India

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Executive Summary

The main objective of the proposal is to identify a challenge and propose a solution to that challenge. The solution is to be outlined by showing all the tasks, tools and schedule to solve the challenge. The Optimus is a 17 story office building with 5 stories of parking garage, ground floor retail and a recreation space at the roof. The building is 252 ft tall and located in India. It is a part of a huge redevelopment project that consists of residential and commercial spaces. The flat slab floor system provides an open floor plan and customizable space for the offices. The building has a large glass and metal facade, a stone wall and a green wall as part of the building envelope. The main gravity system consists of flat slabs supported on reinforced gravity columns and lateral system is a reinforced concrete shear wall located around the elevator shafts.

The original reinforced concrete design of The Optimus is an efficiently designed structural system that fits well with the architecture. Although, it has a highly advanced look it is designed as a typical reinforced concrete system. This kind of a structural system is very prominent in India and a vast majority of buildings are made up of concrete. However, there is a high demand of high-rise buildings, eco-friendly buildings and innovative architecture and structural systems that can help reflect the development in the metros of the country. The innovations and new challenges are already under way and two buildings have set examples. The first is the tallest residential tower in the city of Mumbai that is under construction and the other is India's tallest steel building. India is still new to construction of high-rise steel buildings however, several professionals involved in this industry are moving towards this globally accepted material - Steel. In order to study the advantages of steel it was decided to change the existing reinforced concrete system of The Optimus to a composite steel system. The composite steel system consists of completely redesigned steel gravity system and braced frame concrete-encased lateral system. The floor system is either a concrete on metal deck or a composite system. A typical girder to column connection will be design and checked for efficiency. Similar to the lateral system, there will be changes in loading on the foundation system. Hence, the foundation system will undergo a schematic redesign for new superstructure. The redesigned structural system will be compared to the existing system based on costs, constructibility and architecture. The cost information will be obtained from the structural engineer on the existing project.

The amount of changes in the structural system has a huge impact on the architecture of the building. Hence, as part of the first breadth the interior, exterior and the facade of The Optimus will be redesigned to integrate with the structural system. The architectural modeling will be accomplished using Autodesk Revit Software. Further, the redesigned architectural system will be compared to the existing system.

The change in the architectural system includes change in the facade of the building. As part of the breadth 2, the redesign of the facade will be performed using energy modeling using Autodesk project Vasari software. Thermal and Daylighting due to facade will be of primary interest. Thus, a complete schematic study will be performed on the building facade system.

Building Introduction

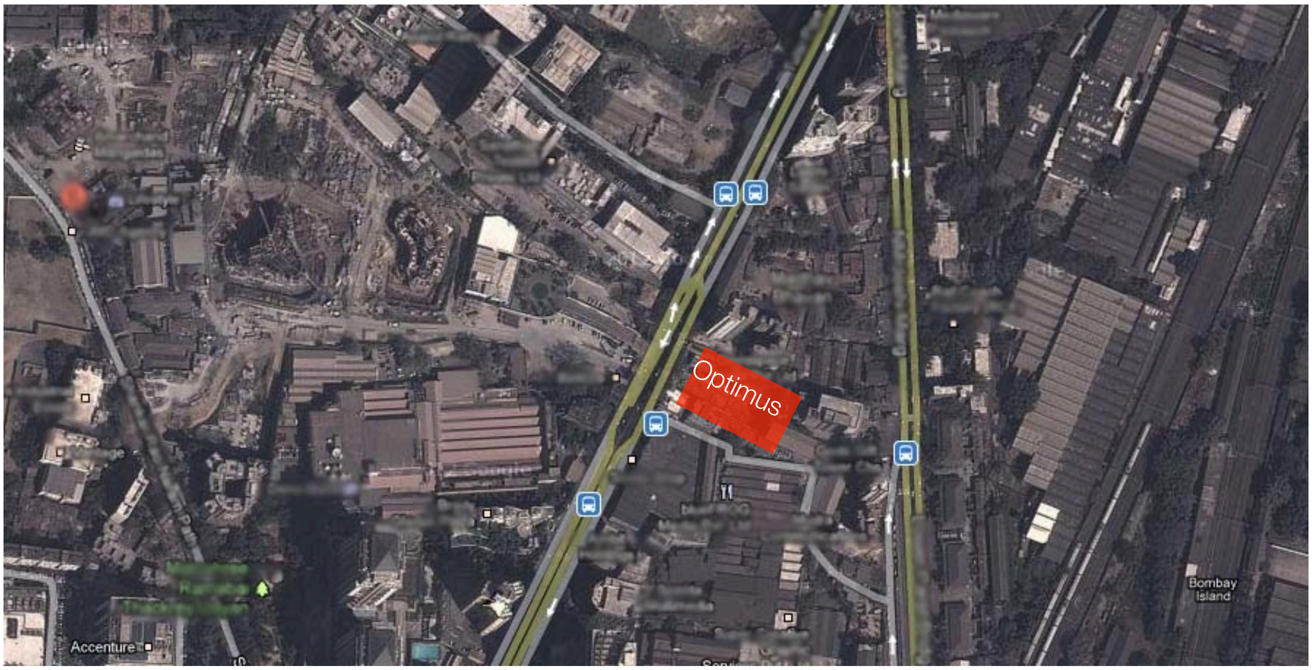


Figure 1 Aerial map from Google.com showing the location of the building site.

The Optimus is a new building rising in the economic capital of India. The building is owned by Lodha Group, one of the prime developers in the city and is designed by Pei Cobb Freed and Partners Architects LLP, New York. It is part of the large redevelopment project that used to be a textile mill. The project consists of residential buildings, offices, parking garages and retail spaces. The Optimus is mainly an office building designed to cater the needs of small and medium size companies who look for office spaces in the business district of the city. It is 17 stories tall with 5 stories of parking and ground floor retail.

The design of The Optimus is functional and elegant. Although the building is located in tight boundaries it makes efficient use of space by expanding vertically. To cater the requirements of the offices, it offers open and customizable floor space. The spacing of the structural and architectural elements offer flexible partitioning for office areas. The building provides recreational facilities that include a gymnasium, roof garden, green balcony spaces at every floor and a garden at the lobby area. The 2 basements and first 3 levels are dedicated to parking with 5th level as garden, lobby and office. The office spaces start from 6 to 17th story and 18th story contains a roof garden.

Figure 2 Rendering showing roof garden

Just like the interior, the exterior of the building is efficient in utilizing the available resources at the same time maintaining its aesthetic qualities. The envelope of the building is designed to fit into the fabric of the city which also becomes an important architectural feature of the building. Three kinds of materials decorate the facade: metal, stone and plants. The north facade, that faces residential apartments, provides a view of green wall to the apartment buildings and the south facade provides a panoramic view of the city to all the office spaces.

Figure 3 Rendering of the building entrance

The south facade is dominated by a bold and modern look with metal cladding and windows offset inside to provide solar shading in the interior. The front facade facing the main street shows a play of all materials on the facade: stone, metal and green wall giving a rich look to the building front.

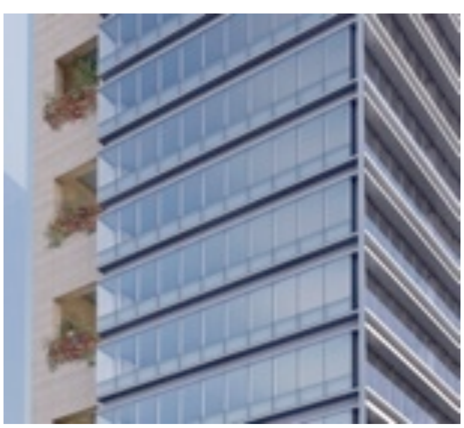


Figure 4 Rendering of the building facade

The structure of the building complements the architectural features. A successful building is achieved when its structure and architecture integrate without compromise. The structure plays an important role in facilitating the show of different materials on the facade and in achieving an open floor plan. Most of the columns in the floor area are pushed to the exterior so that interior is open. The facade forms the skin of the building concealing the columns and overall structural system of the building. This facilitates different architectural features in the exterior and interior of the building.

Structural System Overview

Structural system of The Optimus is designed by Leslie E. Robertson Associates R.L.L.P. It has been optimized to increase floor space area, to celebrate the architecture and economize the overall cost of the building. In order to achieve these goals, reinforced concrete was chosen as a prime material to design the structural members. The properties of concrete allow fluidity in design. It also facilitates design changes during construction. Concrete is a preferred material over steel for construction in India because it is easily available. Also, the labor for concrete based construction is cheaper as compared to steel The structural system of the building consists of flat slabs supported by columns and shear walls that sit on a mat foundation.

Foundations

The geotechnical investigation report was performed by Shekhar Vaishampayan Geotechnical Consultants Pvt. Ltd. and special care was taken to avoid disturbances to adjacent buildings as the site is tightly surrounded by factories and residential buildings. As the building has two basement floors, the geotechnical investigation included excavation qualities of the site. The quality and the bearing capacity of the soil was determined.

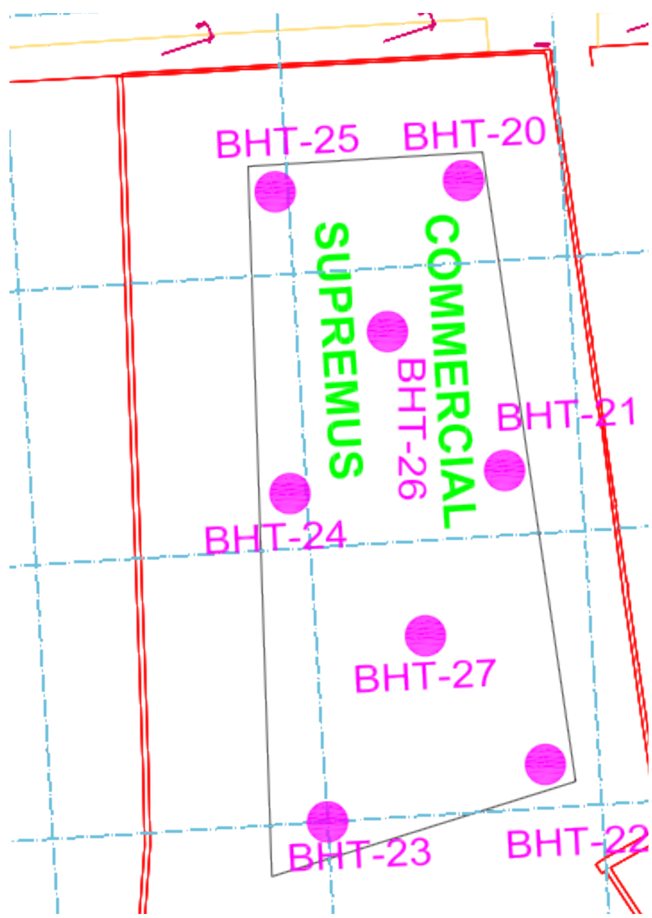


Figure 5: Test Boring Plan

In order to perform the analysis eight boreholes were drilled and soil samples were collected and analyzed. It was discovered that soil properties consisted of filled up soil, medium to stiff clay, weathered rock and highly to slightly weathered tuff. The minimum depth of excavation was determined to be 12.5 m / 41 feet below ground level. The basement raft was decided to be placed 10 m / 33 ft below ground level. Lateral pressures due to soil and water table was determined and basement retaining walls were designed to support these pressures. Shoring piles were built to retain soil from excavation area during construction of basement floors. The ground water table was determined to be present at a depth of 1.00 m / 3.3 ft below ground. This was a conservative figure chosen by the geotechnical consultant to account for the built of water pressures during heavy monsoon season in the city.

Gravity Framing System

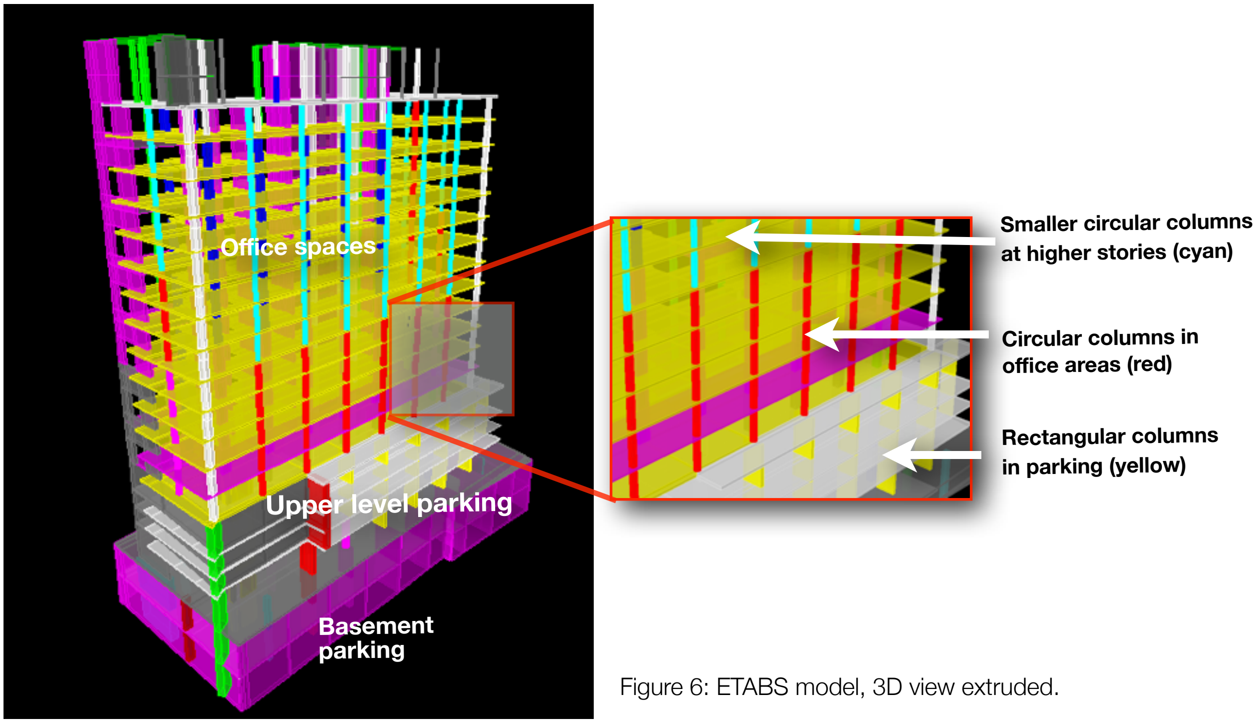


Figure 6: ETABS model, 3D view extruded.

The reinforced concrete framing system of The Optimus is developed to fit different types of floor spaces from the basement to top floor. The column, beam and slab system are chosen to fit with the architecture of the building as well as to act as architectural elements.

Architecture and structural system integration is seen in the columns of the building that change its cross sectional properties and layout as the space progresses from basement to the top of the building. The columns from the basement to the level 5 are rectangular and oriented parallel to the parking spaces. These rectangular columns transition to circular and square columns in office spaces from level 5 to the top level. This transition occurs with the use of transfer girders, columns brackets and adjustments to account for eccentricity in the columns. The columns sizes range from 1.5 ft to 3 ft in width and 1.5 ft to 7 ft in length. Circular columns range from 1.5 ft to 3 ft in diameter in the office areas. the building has a peculiar column with cross section of a parallelogram. This column is located at the entrance of the building and defines the corner of the building from the base to the top adding to the architecture.

Beams integrated with flat slab are present in the parking areas.Transfer girders are present at the fifth level where the floor plan changed from parking to office. Beams are also used to transfer lateral loads from facade to the columns and shear walls. The 8 - 12 inch slabs connect to the columns with drop panels ranging about 8 in additional depth. Drop panels mainly exist at parking spaces and thin drops are added at slabs in office spaces. The slabs also create interaction between the columns and core walls of the building and help distributing gravity loads.

Floor System

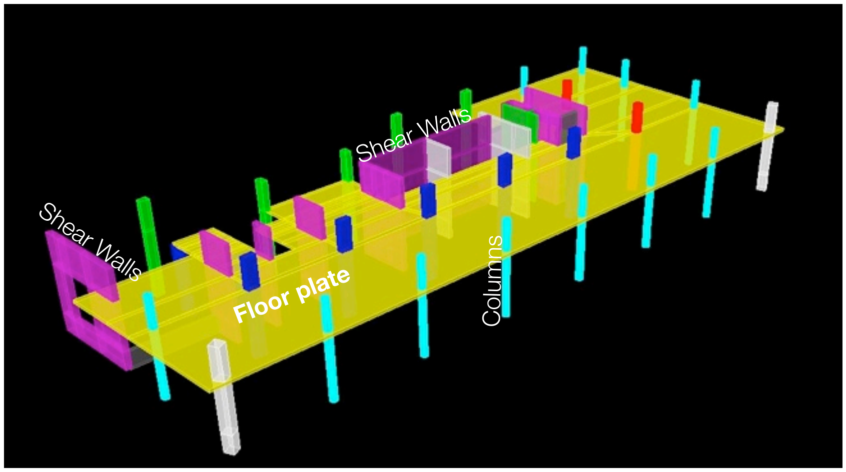


Figure 7: ETABS model, 3D view of floor plan.

Floor system of The Optimus typically consist of two-way flat slabs with drop panels. Flat slabs provide a floor to ceiling height of about 10 to 15 feet which provides ample of space for mechanical ducts and electrical wiring. Besides the floor live loads, the flat slabs support the facade that is attached to the perimeter of the slabs. The slabs also help transfer lateral loads from the facade to the shear walls around the stairwell and elevator.

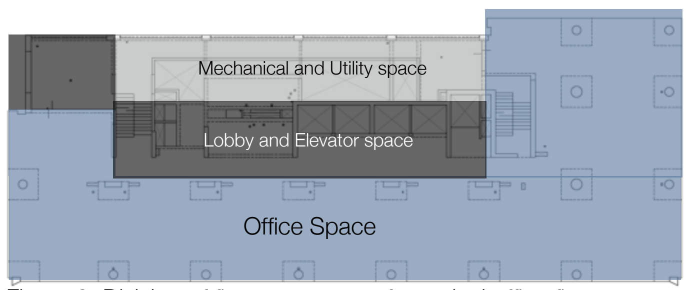


Figure 8: Division of floor space area for typical office floor.

The slabs are 8” thick and typical size of drop panel is 4’6”x4’6” x 8”. The primary purpose of the drop panel is to reduce deflections and punching shear in 27’6” long spanning slabs. A secondary purpose is to help the slab increase the moment carrying capacity. However, this is majorly carried by the top and bottom reinforcement.

Slab depths have been increased to 11.5” in fire areas also called refuge areas where there is a higher chance of live load occurring during a fire. The utility areas that house mechanical equipment have thicker slabs to support mechanical and electrical equipments. The slabs in parking spaces have larger drop panels and additional hidden beams to support live load due to vehicles.

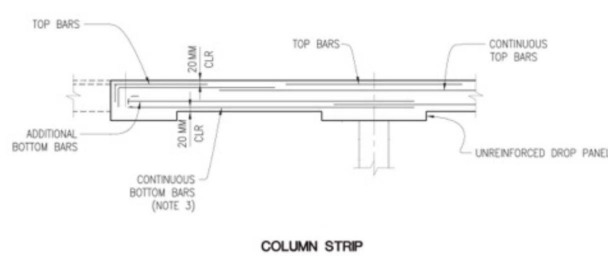


Figure 8: Section of column strip for typical slab

Lateral System

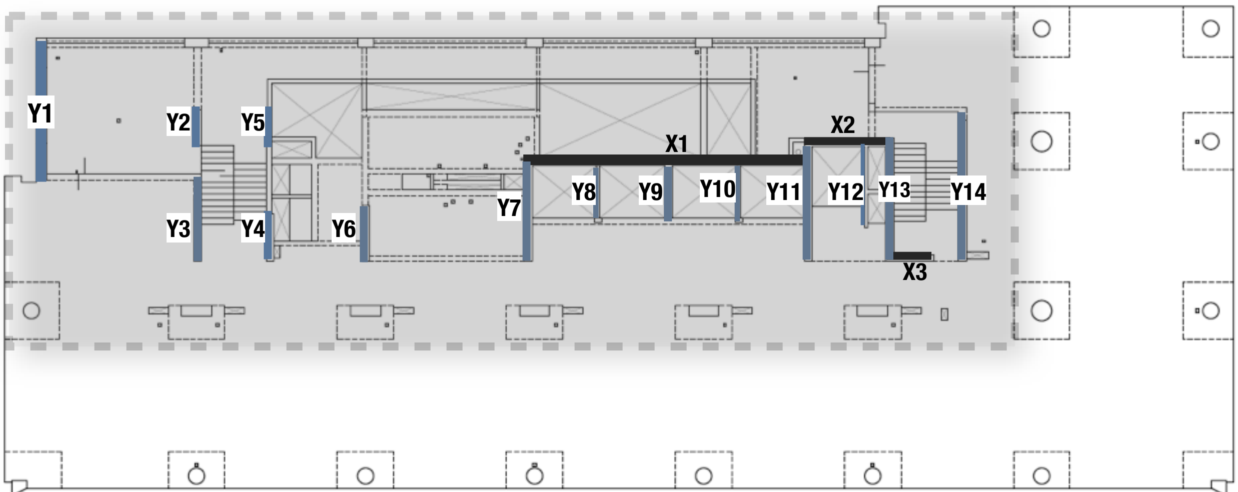
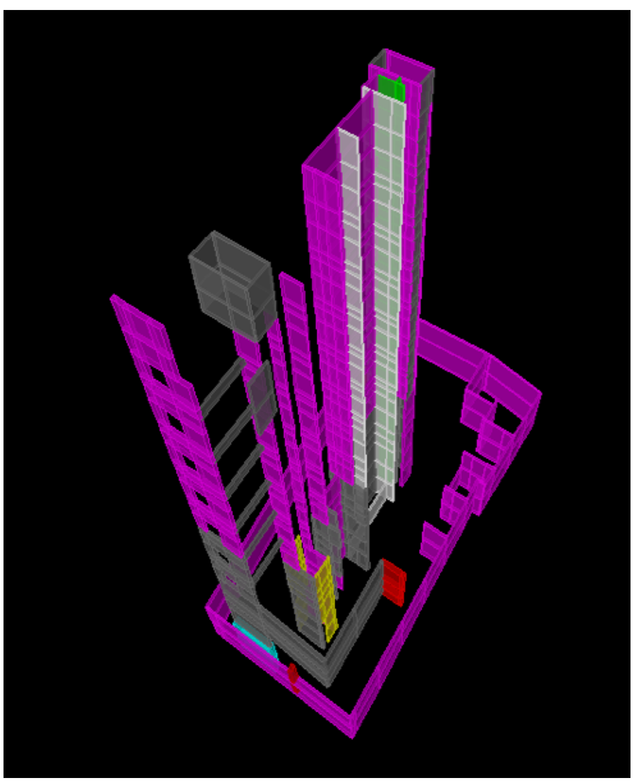


Figure 9: Shear Walls labelled for a typical office floor plan.



The Main Lateral Force Resisting System consists of shear walls present at the core of the building. The shear walls envelope the elevator and stairwell which is the best way to achieve continuity in the walls from bottom to the top without adding obstructions in the floor area. The walls span from the base to of the building to the roof and range 8 inch to 20 inch thick. The walls connect to each other through the floor slab or link beams to act as a unified system against wind and seismic forces. There are 14 short length walls in the North-South direction and 3 long shear walls in the East-West direction. The shear wall X1 in the East-West direction is a major element that is 47 ft long 16 inch thick supporting the transverse loads. The wall Y1 is a major element in supporting loads due to torsion because the wall is located farthest from the center of rigidity giving a larger moment arm.

Figure 10: Shear walls in 3D extruded view.

Design Codes

As the building is located in India, the Indian Standard (IS) code is used to design The Optimus. However, the American codes are used in this report while performing analysis. This will also provide a comparison between the two codes and also a look into the design from the perspective of the american rules.

- Minimum design loads for Buildings other than seismic loads

IS Code	Description
IS 875 (Part 1): 1987	Dead loads
IS 875 (Part 2): 1987	Imposed loads
IS 875 (Part 3): 1987	Wind loads
IS 875 (Part 5): 1987	Special loads and load combinations

- Seismic Provisions for buildings

IS Code	Description
IS 1893: 2002	Criteria for earthquake resistance design of structure
IS 4326: 1993	Earthquake resistant design and Construction of Buildings - Code of Practice
IS 13920: 1993	Ductile Detailing of Reinforced concrete Structures subjected for Seismic Forces - Code of Practice

- Building code requirements for Structural Concrete:

IS Code	Description
IS 456: 2000	Plain and Reinforced Concrete - Code of practice
SP 16	Structural use of concrete. Design charts for singly reinforced beams, doubly reinforced beams and columns.
SP 34	Handbook on Concrete Reinforcement & Detailing
IS 1904	Indian Standard Code of practice for design and construction foundations in Soil: General Requirements

IS Code	Description
IS 2950	Indian Standard Code of Practice for Design and Construction of Raft Foundation (Part –1)
IS 2974	Code of practice for design & construction of machine foundation
IS 2911	Code of practice for design & construction of Pile foundation (Part I 1o IV)

- Building code used for Structural Steel

IS Code	Description
IS 800: 1984	Code of practice for general construction in Steel

- Design codes to be used for future design:

  American codes to analyze the existing conditions.

American Code	Description
ACI 318-11	Concrete Design Code
ASCE 7-10	Minimum design loads for Buildings and Structures for Dead, Live, Wind and Seismic loads.

Materials

Materials used on this project help achieve efficiency in the structural system. This is achieved by economizing the use of material with respect to increasing height. Hence, higher strength concrete is used in the shear walls and columns in the lower floors. As we go higher, the material strength decreases.

Use of the material	Indian Code	American Code
	Material	Equivalent Material
Raft and pile foundations	M40	5000 psi
PCC	M15	3000 psi
slabs and beams	M40	5000 psi
Perimeter basement wall except Grid A	M40	5000 psi
Perimeter basement wall on Grid A	M60	7000 psi
Walls, Columns and Link beams from foundation for 5th floor	M60	7000 psi
Walls, Columns and Link beams from 5th floor to above	M40	5000 psi

Concrete					
Indian Code			**American Code**		
Concrete Grade	**f'c (psi)**	**Ec (ksi)**	**Equivalent Concrete type**	**f'c**	**Ec = 57000√f'c (ksi)**
M60	7000	5614.3	High strength concrete 28 days	7000 psi	4768.9
M40	4700	4584.3	Ordinary ready mix	5000 psi	4030.5
M15	1750	2807.2	Ordinary ready mix	3000 psi	3122.01
fck is 28 compressive strength for 150mmx150mm cube. Poission's ratio = 0.2 Coefficient of thermal expansion = 9.9x10-0.6 per deg C.			f'c - specified compressive strength of concrete. Coefficient of thermal expansion = 5.5×10^{-6} per deg F. Poissions ratio = 0.2		
Reinforcement					
According to IS: 1786 Fe 415 (Fy = 415 MPa/ 60 ksi) or Fe 500 (Fy = 500 MPa) steel bars are used.			According to ASTM A615, deformed and plain carbon steel bars are used with Fy = 60 ksi.		

Problem Statement

The existing structural design of The Optimus is adequately optimized according to the requirements of the owner, architect, structural engineer and all the professionals involved in the project. This fact has been proved in the technical reports and, also that the structural system is integrally designed with all other systems. Overall, the Optimus fits well with the type of construction that is widely accepted and used all over India.

Majority of the buildings in India are constructed using reinforced concrete. This is because, labor and resources for concrete construction are easily available. The knowledge and problem solving help for designing concrete structures is also readily available due to widespread accepted concrete design. Concrete design is also given primary importance while teaching in universities across India. Because of the deeply accepted methods of concrete construction among architects and owners; it is understandable that structural engineers lean towards the more profitable choice.

However, there have been some progress in steel construction industry mainly in the metropolitan cities like Mumbai. As these cities grow, the demand for taller building rises. Each year the city of Mumbai comes up with a taller building. The requirement for taller and more refined buildings has generated the need for new technologies. Also, the country is trying to catch up with the green building revolution that is going on globally. The need to look into new technologies and taller building structures has led to introduction of steel framed structures in the city of Mumbai. This is evident from the completion of the tallest steel building in Mumbai. In 2011, the new office building - Sunshine Towers was built with a steel gravity system and a reinforced concrete shear wall system. The owner of the project claimed that the option of steel building is beneficial over concrete in India. They also claimed that construction speed increased by 50% by using steel and had a lesser environment impact as compared to concrete. Not only the developers, but also the Bureau of Indian Standards has awakened to the advantages of steel construction. They have responded by reviewing and rewriting the Indian Steel code (IS800) and educating the structural engineers via seminars and short courses.

Figure 11: A page of magazine article on the tallest steel tower in India obtained from the Owner's website.

As India advances towards steel construction and taller building structures, it was decided to convert the structural system of The Optimus from reinforced concrete to a composite steel system for the senior thesis. The composite steel structural system consists of steel gravity members and a reinforced concrete core. In order to prove the advantage of steel construction over concrete, it was decided to perform a cost-benefit analysis and compare the existing concrete and composite steel system. The analysis would be based on cost of the structural system, constructibility, available rentable space and environmental impact. A design change in the structural system impacts all other systems of the building. Hence, it was decided to explore the integration of Structure-Architecture-Facade by studying the impact on the architectural and facade of the building due to the change in structural system. The author is interested in learning design with concrete as well as steel. Therefore, having spent the first part on studying concrete design it was a good idea to spent the rest half of the thesis learning and designing using Steel.

Proposed Solution

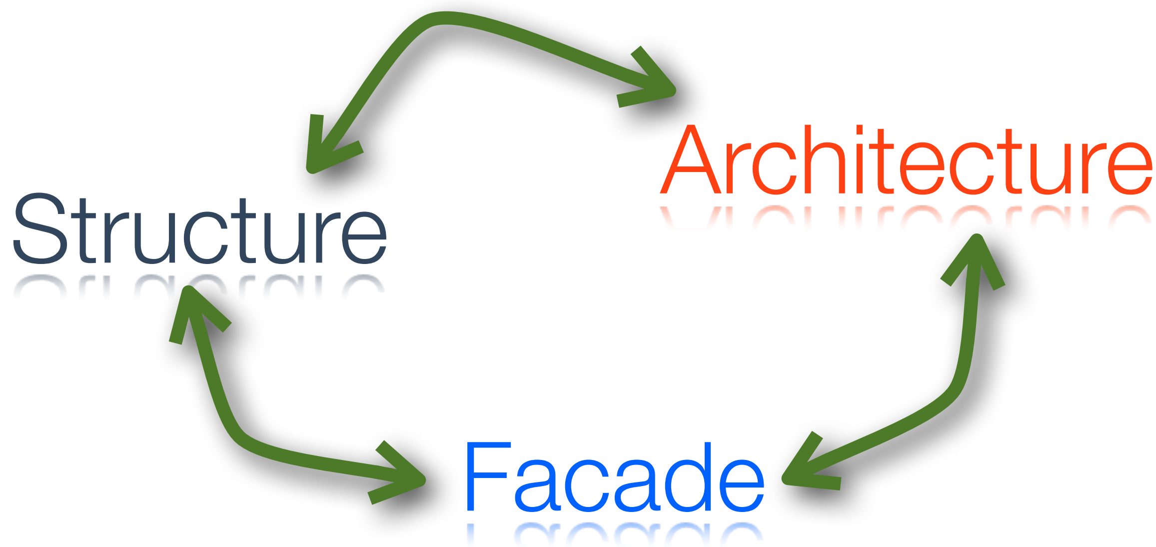
Depth

In order to look into steel design and the benefits of steel buildings in India, the existing system of The Optimus will be converted from reinforced concrete system to a composite steel system. The gravity system will consist of steel framed gravity system and lateral system will consist of concrete-encased steel columns with steel braced members. The steel lateral system is chosen to increase pace of construction as compared to a reinforce shear wall system. The concrete-encasing of columns of the lateral system will help fire-protection and help reduce the size and weight of steel members during erection.

The columns locations for the new steel system will be decided in the process, keeping in mind the integration of structure with the architecture of the building. Two types of floor system will be designed: Concrete on metal deck and composite floor system. The two floor systems will be weighed according to cost, constructibility and architecture and one system will be selected. Although, the building is located in India, American codes will be used to design the building. This is to support and strengthen the background of the author’s knowledge on the international and American codes which are widely accepted all over the world. The lateral system analysis will be performed using ASCE 7-10 MWFRS Directional procedure for wind loads and Equivalent lateral force procedure for seismic loads. Finite Element Modeling will be performed on the new design and required optimizations will be carried out.

After the design of the lateral and gravity system, a typical girder to column steel connection will be designed. Steel connections add to a significant percentage to the cost of the structural system. Hence, design of an efficient connection and its cost analysis will be beneficial to overall cost-benefit analysis and study of the constructibility of steel system in India. The redesign of the superstructure will cause changes in the foundations. The current MAT foundation will be reevaluated and schematic design of the foundation will be performed.

After the entire redesign of the building is complete, the new system will be compared to the existing system based on cost and constructibility of the structural system. All the cost information will be based on the current market prices in India. The information is being provided by the structural engineer on the project.



Breadth 1: Architecture

Structural system and Architectural system of a building are always complementary to each-other. The integration of the two systems is very important to avoid any compromises in either during construction. The modifications in structural system will not only be made to optimize the building structure, but also to preserve and refine the architectural design goals that the building is made for. The existing building promises an open floor plan and flexible space for offices. These architectural goals will be met by efficient layout of columns and beams. The structural redesign will also affect the exterior of the building, mainly the facade. The architectural breadth will also consist of redesigning the facade to reinforce the design goals of the existing facade. All these modifications will be carried out by creating a Revit Architecture and Revit Structure integrated Model of the building. The Revit model will be of a significant help to perform visual analysis and renderings of interior and exterior architecture of the building.

Breadth 2: Facade Study

As a part of the integrated process, modifications to architecture and structural system affect the comfort level of building occupants. The internal environment of the building can be optimized by modifying the facade and adjusting the lighting and thermal qualities of the building. In the second breadth study, the architectural modifications made to the facade will be analyzed from the perspective of thermal comfort and daylighting. The analysis will be performed by importing the Revit model into Autodesk Project Vasari which will perform energy analysis of the entire building. As the client is interested in improving the building performance, analysis will be performed to inform the client how close the building is to achieve a minimum LEED certification and steps required to achieve one. Thus, the depth and the two breadth analysis will complete a cycle of modifications that the image at top of this page represents.

Tasks & Tools

Depth: Design, Analysis and Comparison of Steel composite system

Task 1: Design the Steel gravity system.

- ✦ Determine gravity loads from ASCE 7-10 and use superimposed dead loads provided by Structural engineer on the existing project.
- ✦ Determine approximate columns locations keeping in mind to maintain the architectural importance of spaces. Select and design a cost effective floor system for office and parking: Composite or Non-composite.
- ✦ Size the rest of the gravity system using hand calculations and AISC Steel Manual.
- ✦ Model the system in ETABS and use it to design the steel gravity members. Ensure consistency between ETABS output and hand calculations.
- ✦ Determine rough cost of the existing and modified system from the information provided by Structural engineer in India.

Task 2: Determine lateral loads for modified gravity system

- ✦ Determine lateral loads using wind and seismic information of the building location.
- ✦ Use ASCE 7-10 MWFRS Directional procedure to determine wind loads.
- ✦ Use ASCE 7-10, Equivalent lateral force procedure to determine seismic loads.
- ✦ Perform modal response spectrum analysis.
- ✦ Apply the loads on the FEM model in ETABS.

Task 3: Design a composite braced frame lateral system

- ✦ Use ETABS Finite Element modeling to extract loads on lateral members.
- ✦ Determine sizes of composite columns, braced members and size of shear studs.
- ✦ Determine effects of construction sequence on the size of lateral members.

Task 4: Connection Design: Design a typical girder-to-column connection

- ✦ Determine loads at a Girder-Column connection from ETABS Model.
- ✦ Design an efficient connection using AISC Steel Manual.
- ✦ Estimate cost of the connection.

Task 5: Reevaluate foundations

- ✦ Determine new loads on the foundations from the new gravity and lateral system.
- ✦ Determine change in thickness and reinforcement of the existing foundation.
- ✦ Determine rough cost of the new foundation.

Task 6: Perform a rough cost estimate and cost comparison of Steel vs Concrete System

Breadth 1: Architectural modifications

Task 1: Exterior and Interior modifications

- ✦ Create Revit Model to generate plans and elevations of the modified building.
- ✦ Determine the effects of structural modifications.
- ✦ Optimize structure to fit with the architecture.

Task 2: Facade Modifications

- ✦ Determine the changes to the facade due to structural modifications.
- ✦ Perform required modifications and optimization to the facade.
- ✦ Apply changes to the Revit Model.

Task 3: Compare to the existing architecture

- ✦ Perform a comparison of the existing and redesigned building based on visual appearance and rentable space.

Breadth 2: Facade Study

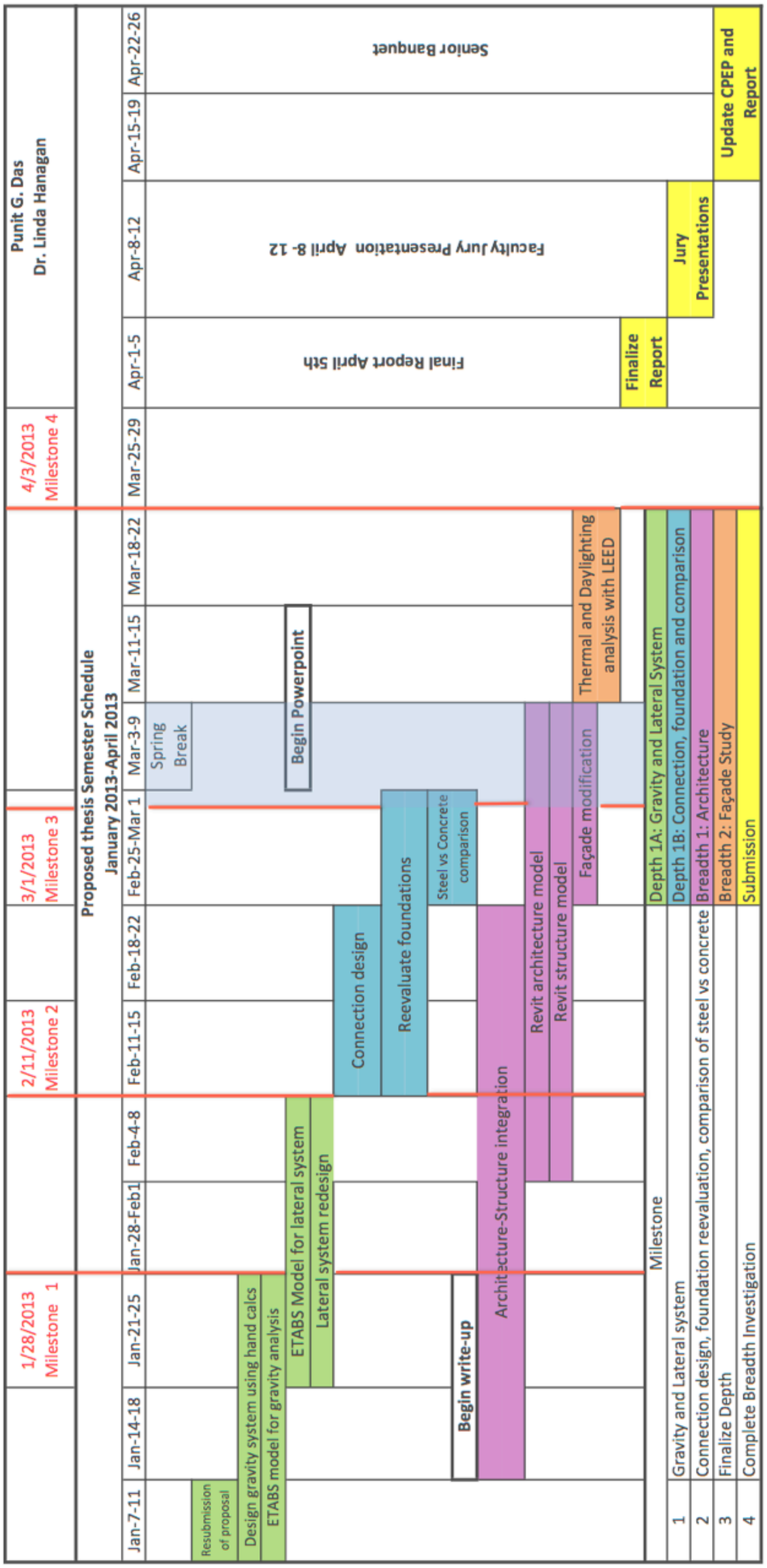
Task 1: Thermal and daylighting analysis of modified facade

- ✦ Determine thermal properties of the materials used in facade.
- ✦ Perform daylighting analysis and energy modeling by importing the Revit model into Project Vasari.

Task 2: LEED certification study of facade

- ✦ Determine the requirements to achieve LEED certification.

Schedule


Punit G. Das
Dr. Linda Hanagan
Proposed thesis Semester Schedule
January 2013-April 2013
1/28/2013
Milestone 1
2/11/2013
Milestone 2
3/1/2013
Milestone 3
4/3/2013
Milestone 4
Jan-7-11
Jan-14-18
Jan-21-25
Jan-28-Feb1
Feb-4-8
Feb-11-15
Feb-18-22
Feb-25-Mar 1
Mar-3-9
Mar-11-15
Mar-18-22
Mar-25-29
Apr-1-5
Apr-8-12
Apr-15-19
Apr-22-26
Resubmission of proposal
Design gravity system using hand calcs
ETABS model for gravity analysis
ETABS Model for lateral system
Lateral system redesign
Connection design
Reevaluate foundations
Steel vs Concrete comparison
Begin write-up
Architecture-Structure integration
Revit architecture model
Revit structure model
Façade modification
Spring Break
Begin Powerpoint
Thermal and Daylighting analysis with LEED
Final Report April 5th
Finalize Report
Faculty Jury Presentation April 8- 12
Jury Presentations
Senior Banquet
Update CPEP and Report
Milestone
1 Gravity and Lateral system
2 Connection design, foundation reevaluation, comparison of steel vs concrete
3 Finalize Depth
4 Complete Breadth Investigation
Depth 1A: Gravity and Lateral System
Depth 1B: Connection, foundation and comparison
Breadth 1: Architecture
Breadth 2: Façade Study
Submission

Conclusion

The proposed redesign of the The Optimus is based on the design principle of integration of building system. It accounts for the integration of structure, architecture and facade. These are the 3 main aspects of the building design that can help achieve efficiency in construction and cost through optimizing the three variables and achieving a balance. Eventually designing a cost-effective, eco-friendly building that maximizes human comfort.

The primary part of the redesign is to convert the existing conventional reinforced concrete structural system to a composite system. The composite system consists of a steel gravity system and braced frame concrete encased column lateral system. A single change in part of the structural system has bearing on several other systems of the building. The redesign of the gravity system, affects the lateral system and the foundation of the building. Designing a typical steel connection is also a part of the design of the structural system. Eventually, the redesigned system will be compared to show the advantages and disadvantages of concrete over steel in a high-rise system. The comparison between the existing and the redesigned system will be based on the present conditions of the construction industry in India.

Changes in structural system is made in conjunction with the architectural system of the building as part of the breadth 1. Interior, exterior and facade of The Optimus will be redesigned responding to the change in structural system. As part of the breadth 2, the architectural changes in the facade will be optimized using energy modeling primarily daylighting and thermal analysis. The breadth 2 completes the cycle of the Structure-Architecture-Facade; thus, completing the cycle of integrated optimization.