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Thesis Proposal

La Jolla Commons Phase II Office Tower

San Diego, California

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Executive Summary

La Jolla Commons Phase II Office Tower is a multi-tenant office building in San Francisco, California. The building is thirteen stories above grade with two parking levels below grade. The gravity system is a concrete flat plate slab on a rectangular grid of columns; the lateral system consists of concrete shear walls at the building core. After analyses performed in Technical Reports 1 through 4, it was determined that there were no obvious deficiencies in the building's structural design.

As a result, a scenario has been developed in which the building owner would like the structural engineer to develop an alternative steel design for the building structure. The floor system will be comprised of composite metal deck on composite steel beams and girders. The lateral system will be a combination of the existing shear walls at the core and additional steel moment frames around the building perimeter. Furthermore, the structure will be analyzed in the office space for vibrations due to human live loading. Also, the owner would like the engineer to limit any impact on the building's current layout and architecture.

The breadth studies will be a continuation of this scenario. The owner would like the engineer to consider the cost and schedule impacts of implementing the steel system in place of the concrete system. As a result, a detailed cost analysis and schedule will be developed and compared to the original system, allowing for the determination of the most efficient design. Furthermore, the owner is concerned about the fire protection of the steel system. Therefore, an analysis on materials and layouts for protection of the building's structural system will be performed. Options will be compared for cost and effectiveness for presentation to the owner.

Masters of Architectural Engineering (MAE) requirements will be used throughout the analysis and design process of the new steel system. Material from *AE 530 – Computer Modeling of Building Structures* will be used in the creation of the ETABS lateral model and the RAM Steel gravity model. Also, material from *AE 538 – Design of Earthquake Resistant of Buildings* will be used to design and detail the concrete shear walls and steel moment frames.

The main goal of this thesis project is to develop a better understanding of steel behavior under seismic loading and to better understand the advantages and disadvantages of steel and concrete structural systems.

Purpose and Scope

The purpose of this report is to propose a scenario which requires a redesign of the lateral and gravity systems of La Jolla Commons Phase II Office Tower. The new systems will then be compared to the existing systems for efficiency and performance. This report outlines this scenario, the intended methods of redesign, and the tasks required to complete the design and analysis proposed. A schedule, including milestones and target dates, is included. Also, some background information about the building has been included early in this report.

Building Introduction

La Jolla Commons Phase II Office Tower (LJC II), rendered in Figure 1, is a high-rise structure located in San Diego, California. This Seismic Category D structure reaches 198 feet above grade with 462,301 square feet of floor space, including two underground parking levels. LJC II is a very modern style and open building, featuring flat plate reinforced slabs on a rectangular column grid. This creates a very spacious office area for the building tenant, LPL Financial. LJC II features 13 stories of office space, a penthouse, and two underground levels of parking.

Figure 1 | South East Elevation *(Hines & AECOM)*

La Jolla Commons Phase II Office Tower is very similar to its sister building, Tower I. Although identical in architectural style, Tower I has a steel structure unlike Tower II. Figure 2 shows the two towers side by side, while Tower II is under construction. The two towers help to unite the La Jolla Commons Campus around a green space and pedestrian area. Eventually, the campus will feature two acres of park space, surrounding the existing and proposed buildings. The campus will also eventually include a restaurant, bar, spa, gym, and meeting spaces. A view of the site plan can be viewed in Figure 3.

Figure 2 | South East Elevation *(Hines & AECOM)*

LJC II is built underneath a flight path, controlled by the Federal Aviation Administration (FAA). After negotiations, the building's height was limited to its current height of 198 feet.

Figure 3 | Building Site Plan *(Hines)*

After LJC Tower I achieved a LEED-CS Gold rating in 2008, Tower II was expected to reach a prestigious level of sustainability as well. LJC II includes features such as reclaimed water reuse, under-floor air distribution, double pane glazing with low emissivity coating, and energy efficient lighting systems. Furthermore, LJC II is the first Class A Net-Zero office building in the United States, and it is the nation's largest carbon-neutral office building to date. Through methods of reduced consumption and onsite generation, LJC II will actually return more power to the grid than it will use annually. LJC II also received a LEED-CS Gold Certification upon structure and shell completion.

Structural Overview

Structural Framing Summary

La Jolla Commons Tower II is a, cast-in-place concrete structure using mild reinforcing. The foundation consists of a concrete mat, ranging in thickness from 3 feet to 6.5 feet. The gravity system consists of two-way, flat plate, reinforced concrete slabs supported by a rectangular grid of reinforced concrete columns. The lateral system is a series of shear walls located at the building's core. Also, due to high seismic loading (seismic category D), the lateral system includes collector beams on the Ground Level and Lower Level 1, which are used to transmit the earthquake loads from the diaphragm into the shear walls. The building also features two 15 foot cantilever sections at the North and South ends. The mechanical penthouse, located on the roof, is framed in steel wide-flanges and hollow structural steel members with a moment frame acting as the lateral system.

Building Materials

La Jolla Commons Phase II Office Tower, primarily a concrete structure, employs several concrete and reinforcing types, shown in Tables 1 and 2, depending on the use in the building. Although concrete is the main structural material, information regarding steel is provided in Table 3 for the penthouse framing.

Concrete Strengths (at 28 days, 0.5 max cement ratio)		
Slab on Grade	3500 PSI	Normal Weight
Foundations	5000 PSI	Normal Weight
Shear Walls	6000 or 7000 PSI (per plans)	Normal Weight
Slabs and Beams	5000 PSI	Normal Weight
Columns	6000 or 7000 PSI (per plans)	Normal Weight
Basement Retaining Walls	5000 PSI	Normal Weight
Cantilever Retaining Walls	5000 PSI	Normal Weight
Built-up Slabs	4000 PSI	Light Weight (110 PCF)
All Other Concrete	4000 PSI	Normal Weight

Table 1 | Concrete Usage and Strengths

Steel Reinforcement	
Typical Reinforcing Bars	ASTM A-615, Grade 60
Shear Wall and Diaphragm Reinforcing	ASTM A-706
Welded Rebar	ASTM A-706

Table 2 | Steel Reinforcement and Standards

Structural Steel	
All Structural Steel	ASTM A-572, Grade 50 OR ASTM A992
Steel Braced Frame Beams and Columns	ASTM A992
Structural Tubing	ASTM A-500, Grade B (Fy = 46000 PSI)
Structural Piping	ASTM A-53, Grade B (Fy = 35,000 PSI)

Table 3 | Structural Steel and Standards

Foundation

The foundation system design was provided by Nabih Youssef Associates, the structural consultant for LJC II, after review of the geotechnical report and recommendations of the geotechnical engineer, Christian Wheeler Engineering. The final design consisted of a reinforced concrete mat foundation.

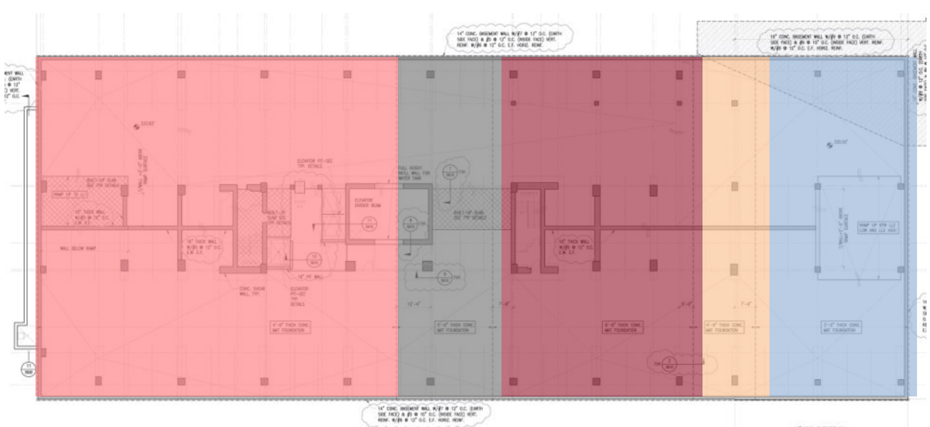
Foundation Walls

As stated above in the Building Introduction, La Jolla Commons Tower II has two levels of underground parking. As a result, concrete foundation walls were utilized around the building perimeter to hold back soil loads. Typical foundation walls are 14" thick concrete with #7 bars at 12 inches on center (o.c.) at the exterior and #5 bars at 12 inches o.c. at the inside face, vertical reinforcement. Also, #6 bars at 12 inches o.c. were provided for horizontal reinforcement.

The southeast corner, the area requiring surcharge loading, has 16 inch foundation walls with #9 vertical bars at 12 inches o.c. (outside face) and #6 bars at 10 inches o.c. (inside face). Also, #6 horizontal bars were provided at 12inches o.c. The thicker walls are necessary due to increased soil pressures due to soil saturation.

Mat Foundation Design

The foundation for La Jolla Commons Phase II Office Tower was designed as a reinforced concrete mat foundation with varying thicknesses and reinforcement. Originally, a system of footings and grade beams were considered for the foundation. The mat foundation was chosen for several reasons. First, the large area it covers helps to reduce the soil pressure created by the overturning moment associated with seismic loads. Second, the construction of one large mat was simply easier than forming all of the footings and grade beams required for the alternative system. Figure 4 shows the variation in mat thickness across the foundation.



4' – 6" Thick
5' – 6" Thick
6' – 6" Thick
4' – 9" Thick
3' – 0" Thick

NORTH

Figure 4 | Mat Foundation Thicknesses - S1L2

Gravity System

Floor System Overview

La Jolla Commons Tower II is rectangular building that is 315 feet long by 123 feet 8 inches wide. The building features a flat plate, two-way slab system on a rectangular column grid. As shown in Figure 5, the slab varies in thickness from 10 inches to 14 inches. The exterior edge of the slab at each level is framed by an 18 inch spandrel beam.

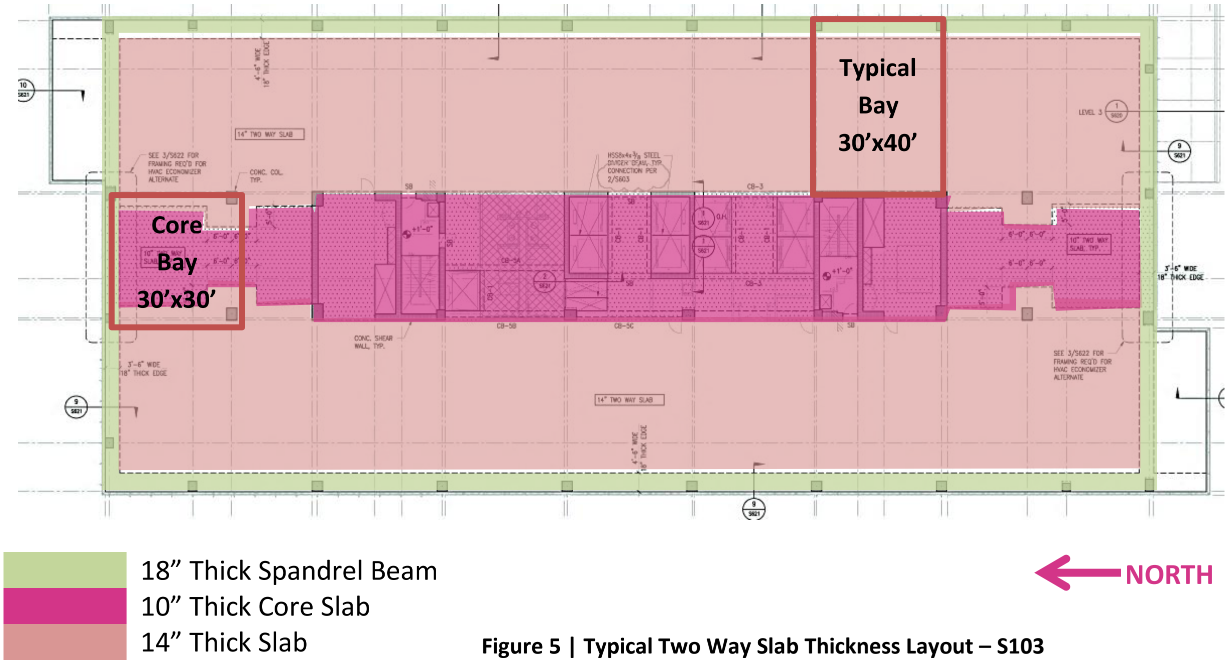


Figure 5 | Typical Two Way Slab Thickness Layout – S103

Reinforcing of the slab varies based on direction and slab thickness. As with the mat foundation, the floor system has increased sizes and frequency of rebar near the core (where the shear walls are located). Reinforcing also varies based on column strip and middle strip locations. As required by ACI 318-08, reinforcing for the slab does not exceed a spacing of 18 inches.

Typical bay sizes are 30 feet by 40 feet at the east and west sides of the core. Bay sizes in the core vary due to shear wall placement. Also, column spacing at the core does not exactly match that of the exterior columns; however, the largest core bay size is 30 feet by 30 feet. Figure 5 calls out the two typical bay sizes.

Camber of the structural slabs is used extensively for La Jolla Commons Tower II. Due to the fast construction of LJC II, construction loads were significant and played a major role in the design. Designers assumed that the slab would be loaded to the limit during construction, causing cracking. The slab was then analyzed for creep as a cracked section to determine the worst possible conditions; deflections were great enough that camber was required. Nabih Youssef Associates consulted documents such as ACI 435 to determine creep and shrinkage.

Roof System

The roof system for La Jolla Commons Phase II Office Tower is similar to that of the floor system. The main difference in the gravity system is the introduction of drop panels on the roof system. Drop panels are utilized on the roof level due to high loads associated with the rooftop mechanical equipment. Aside from this, the slab is 10 inches thick and features an 18 inch edge beam.

Concrete Columns

The entire gravity system is supported by a series of columns of various sizes on a rectangular column grid. Column sizes range from a maximum size of 42 inches by 42 inches at Lower Level 2 (lowest level of the underground parking garage) to a minimum size of 24 inches by 24 inches at the penthouse. Vertical reinforcing varies significantly based on column height, dimensions, and location. However, all columns have #5 ties spaced at 4 to 6 inches on center. Minimum requirements from ACI 318-08 (CBC 2010) for spacing and quantity of reinforcement have been met. When the columns were designed, they were considered fixed when applying only gravity loads to account for any eccentricity in the loading. However, when the lateral system was designed, the columns were considered pinned. In the event of an earthquake, the column bases would crack and create a pinned condition; the columns would, therefore, take minimal lateral load.

Lateral System

Shear Walls and Moment Frame

La Jolla Commons Phase II Office Tower has a lateral system of special reinforced concrete shear walls; moment frames are utilized for the lateral support of the penthouse at the roof cooling tower. All lateral systems were designed and detailed following Chapter 21 of ACI 318-08 for earthquake loading. See Figure 6 for the concrete shear wall layout for the lateral force resisting system.

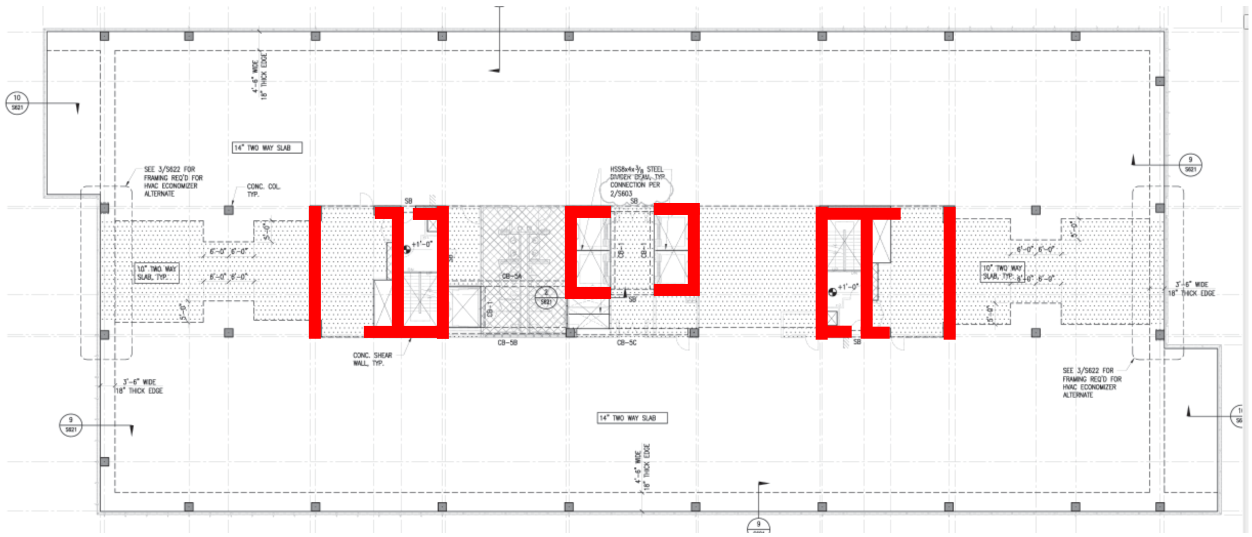


Figure 6 | Typical Shear Wall Layout – S109

NORTH

Collector Beams

Collector beams are utilized on Lower Level 1 (upper level of parking) and the Ground Level of LJC II. Collector beams are used in high seismic areas to transmit earthquake forces into the main lateral system components. These elements give you the stiffness to transmit the forces through the diaphragm which cannot efficiently transmit the earthquake loads to the lateral system on its own.

Collector beams mainly run in the north-south direction, except for a few collector beams in the east-west direction on the Ground Level. Collector elements provide a direct path for the lateral loads from the diaphragm into the shear walls. This is especially important if the shear walls are not continuous, are spaced far apart, or are minimal, as is the case with the shear walls in the north-south direction. ACI 318-08 covers the requirements of collector elements in great detail in Section 21.11.

Design Codes and Standards

Codes and Standards

- ✓ *California Building Code 2010* (CBC 2010 Adopts IBC 2009 with some additions and changes)
- ✓ *Metal Building Manufacturers Association*
    - MBMA Recommended Design Practice Manual
- ✓ *American Iron and Steel Institute*
    - Applicable sections of the AISI Specifications
- ✓ *American Society of Civil Engineering*
    - ASCE 7-05 (as Adopted by IBC 2009) – Minimum Design Loads for Buildings
- ✓ *American Concrete Institute*
    - ACI 318 – 08 (as Adopted by IBC 2009) – Building Code Requirements for Structural Concrete

Special Seismic Code Considerations

ACI 318 – 08 Chapter 21 is referenced quite often in the design of LJC II. This chapter is for the design of concrete Earthquake-Resistant Structures. This section discusses detailing requirements for all aspects of earthquake resistant building components, including structural and non-structural elements.

ASCE 7 – 05 Chapter 12 is also used quite often in the design of LJC II. This chapter details the Seismic Design Requirements for Building Structures, including system selection and load analysis. Based on this section, LJC II has a Type 1B Extreme Torsional Irregularity, which would need to be considered.

Design Scenario

As previously mentioned, La Jolla Commons Phase II Office Tower is a completely concrete structure. After the investigations in Technical Reports 1 through 4, there are no obvious problems with the building's current structural system. Therefore, a scenario has been created in which the building owner, HINES, would like the structural engineer to design a composite steel structure. The owner would like the structural engineer to investigate the implications of the steel redesign on the construction schedule and building cost as compared to the concrete structure. The structural designer must investigate the potential serviceability issues associated with switching the system from concrete to steel; the main one to be investigated is vibrations due to human live loading.

It has also been requested by the owner that the lateral system be modified to include steel moment frames around the building perimeter in addition to the shear walls at the core. The structural engineer must consider cost and schedule effects of the additional frames and provide a recommendation as to their effectiveness and feasibility.

Learning Objectives

La Jolla Phase I Office Tower, the building nearly identical to La Jolla Phase II Office Tower, is a steel structure located right next to LJC II. The building's lateral system also consists of shear walls at the core, much like Tower II. Therefore, the design of Tower II in steel is possible and considerably feasible. One learning objective of this redesign is to investigate both systems and gain a better understanding of the advantages and disadvantages of a steel versus a concrete gravity system. By considering the effects of changing the structural system on the schedule, cost, and serviceability conditions, the advantages and disadvantages of the floor systems can be critically compared from several viewpoints, allowing the designer to make a more informed decision.

The lateral system for LJC II is special reinforced concrete shear walls. Many of the shear walls are very thick and require significant reinforcing. In order to learn more about the seismic detailing for steel moment frames and their efficiency in resisting lateral loads, the incorporation of steel frames as part of the lateral system will be investigated.

An investigation of structural vibrations due to human live loading will be performed for the steel gravity system in the office space. This will be done because the spans are quite long for many of the steel girders, and vibrations are more of a concern with the steel system than the concrete system.

Overall, the goal of this redesign is to develop a better understanding of the design of steel structures and special steel moment frames and a better understanding of the cost, schedule, and serviceability considerations for steel versus concrete. Another major goal is to develop a better understanding of the design of steel structures for seismic loading conditions.

Proposed Methods and Solution

The building's gravity system will be redesigned in composite steel utilizing the same column locations as the original concrete system, limiting impact on the current building layout and architecture. The gravity system for the two underground parking levels will remain concrete. Because the gravity system consists of many members of the same length and loading, beams and girders will be initially designed by hand to determine appropriate member sizes using the AISC Steel Construction Manual, Fourteenth Edition. Next, a detailed RAM Steel gravity model will be developed using the dead loads associated with the new system and the previously determined live loads. The model will aid in the determination of member adequacy when considering both strength and economy.

As determined in Technical Report 3, the floor system for the proposed redesign will consist of composite metal deck such as 2 VLI 18 with a 4.5 inch normal-weight concrete topping, total thickness of 6.5 inches. The girders are expected to reach a maximum depth of 30 inches, and the infill beams are expected to reach a maximum depth of 14 inches. See Figure 7 for the possible layout for a typical 30 ft x 40 ft bay. In order to limit the overall depth of the system, additional rows of columns may need to be added at mid-span. However, in order to limit impacts on the original architectural layout of the space, the original column locations will be investigated first. Different infill beam spacing and layouts will be investigated to determine the most efficient and "architecturally friendly" system. The columns will then be designed and tested using the RAM gravity model.

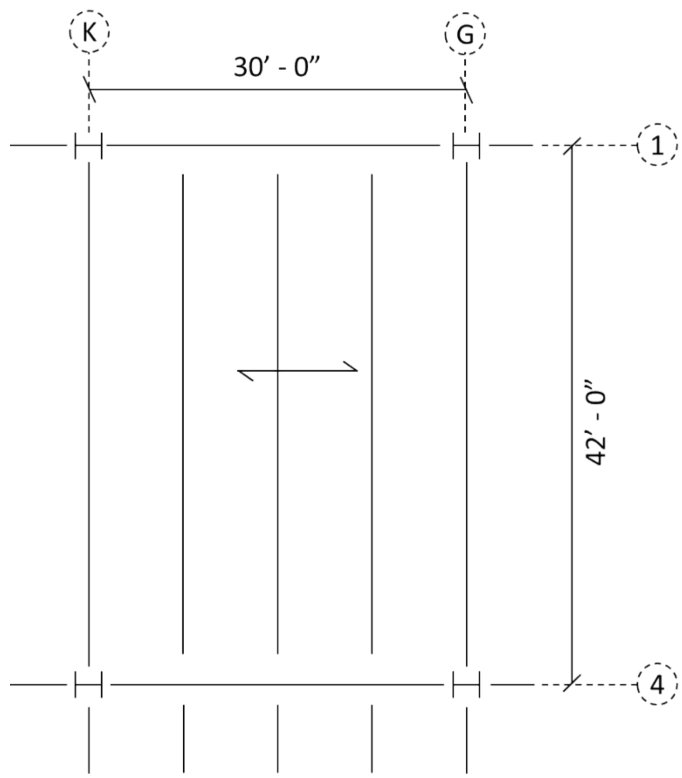


Figure 7 | Potential Steel Framing Layout

Once the development of the composite steel gravity system is complete, an analysis of the structure's lateral system will be performed. First, the building lateral loads will need to be recalculated using ASCE 7-10. ETABS 2013 will be used to perform a Modal Response Spectrum Analysis on the building's lateral system to determine the seismic loads. ETABS 2013 will also be used to generate the building wind loads. The ETABS 2013 model used in Technical Report 4 will be modified to accurately represent the shear walls. The model will then be modified to incorporate steel moment frames. A redesign of the concrete shear walls will need to be performed, and the moment frames will also be designed and detailed for seismic considerations. Figure 8 shows a potential layout for the added moment frames.

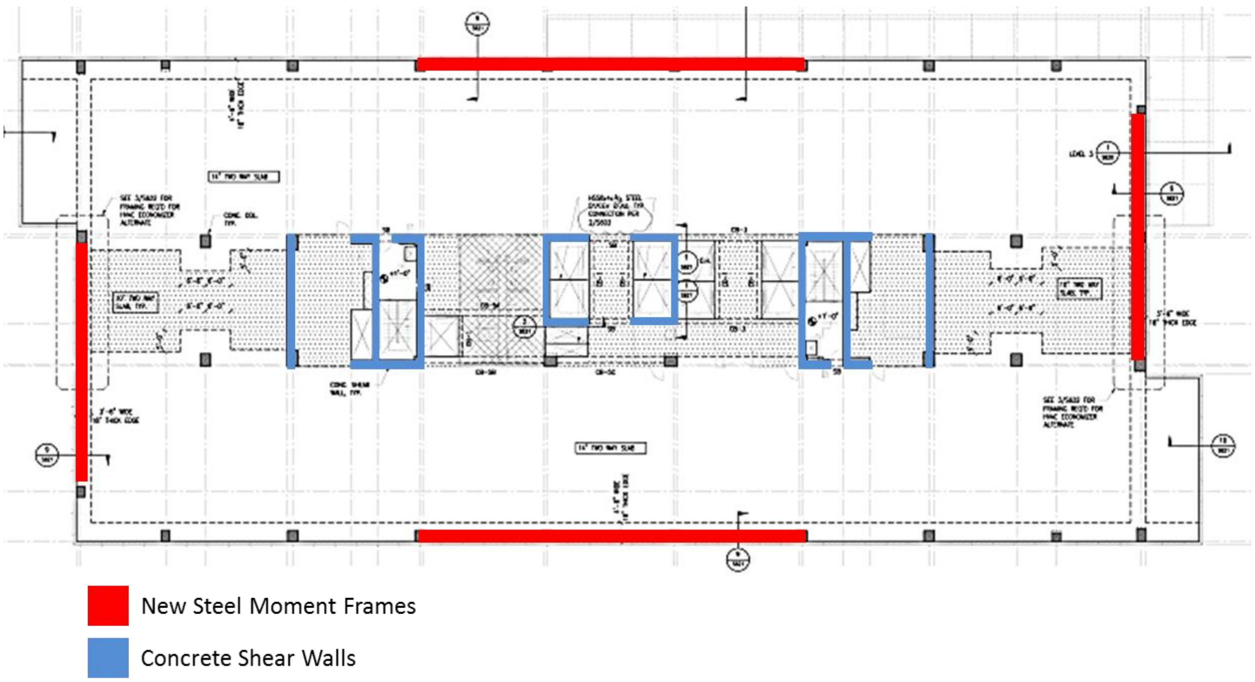


Figure 8 | Potential Lateral System Layout

An investigation of the vibrations associated with human activity on a typical bay of the steel gravity system will be performed. Calculations will be done by hand, following the provisions of AISC Design Guide 11: Floor Vibrations Due to Human Activity. These calculations may also be verified, if time allows, using the RAM Steel model.

MAE Requirements

Graduate level work will be used throughout the design and analysis of the proposed structural system. AE 530 – Advanced Computer Modeling of Building Structures will be utilized in the creation and evaluation of both an ETABS lateral model and a RAM Steel gravity model. Because the building is in SDC D, material from AE 538 – Earthquake Resistant Design for Buildings will be used to design and detail the building lateral system of concrete shear walls and steel moment frames. Also, additional work is being done to expand into an area of study not yet learned by the designer: vibrations analysis.

Breadth Studies

Cost and Schedule Analysis

A detailed cost estimate of the proposed structural system will be completed. This cost will then be compared to that of the existing structural system. In addition, a construction schedule for the redesigned system will be studied and compared to that of the existing structural system. These analyses will then be used to determine which system is more economical. RS Means will be used for most durations and costs; however, information will be requested from the project general contractor.

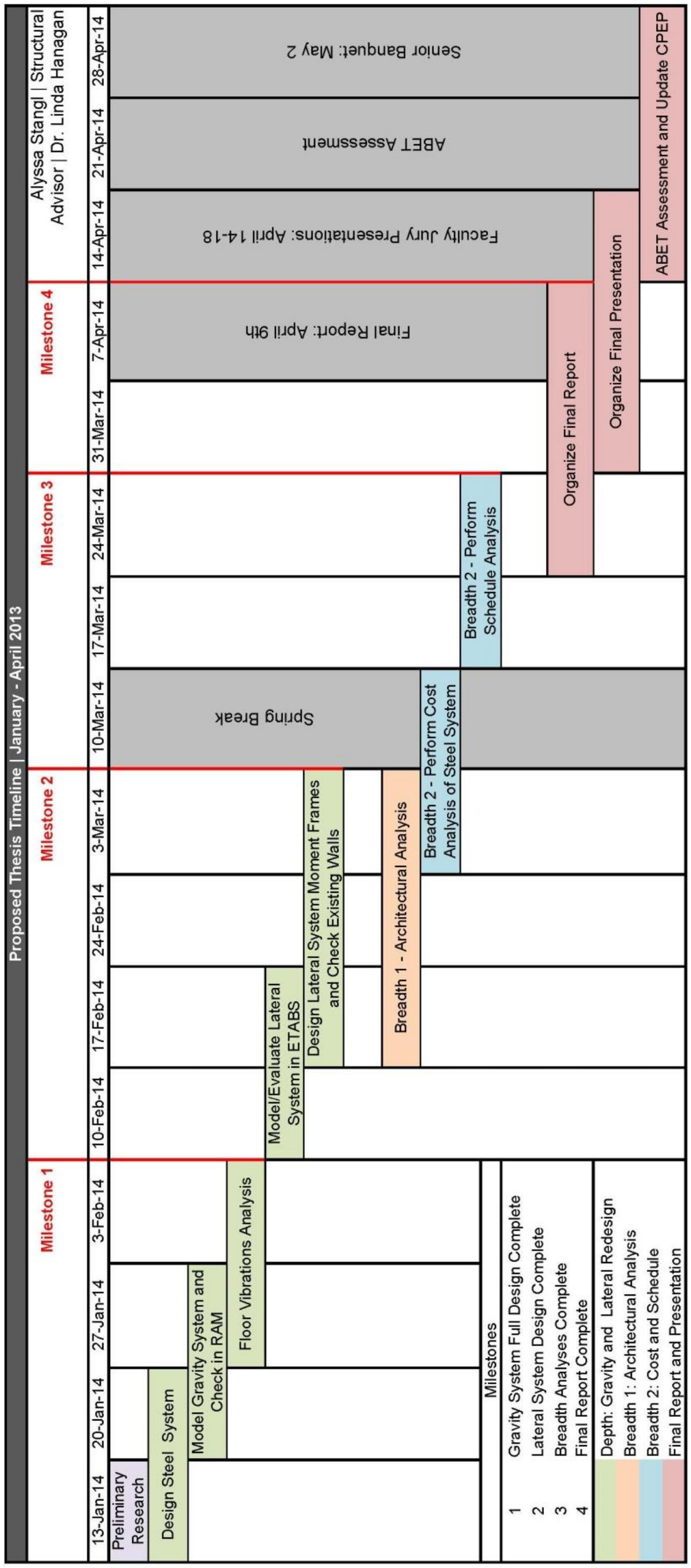
Architectural/ Fire Protection Analysis

Changing the structure from concrete to steel will have different effects on the building's architecture. One item to be investigated is the fire protection of the building structure. Although the structural slab will provide the 2 hour fire rating between floor levels, steel beams and columns will remain exposed. As a result, an investigation will be performed on the ceiling system, floor systems, and wall systems to determine their fire protection adequacy. Also, an analysis will be done on the curtain wall connections to the steel members to determine a fire protection solution. Furthermore, it is desired that the structural steel columns remain exposed and are not encased in gypsum or concrete; therefore, options for fire protection of the exposed columns will be investigated and compared for cost and effectiveness.

Tasks and Tools

1. **Research**
    a. Acquire detailed cost and schedule information for existing building
    b. Acquire AISC Seismic Design Manual and review
    c. Acquire AISC Design Guide 11: Floor Vibrations Due to Human Activity and review
2. **Design steel gravity system**
    a. Design floor members (slab, beams, girders, etc.)
    b. Design columns
    c. Check design of members in RAM Steel gravity model
3. **Vibrations analysis of floor system**
    a. Determine an area of a typical level where vibrations due to human live loading would be critical
    b. Check the beams and girders at this area using AISC Design Guide 11 to determine if the 0.5% acceleration limit is met.
    c. If criteria is not met, adjust this area of the floor design to meet 0.5% limit
4. **Design modified lateral system**
    a. Modify existing lateral model to accurately portray existing shear wall behavior
    b. Determine steel moment frame locations and sizes
    c. Use ETABS model to determine ASCE 7-10 seismic loads using Modal Response Spectrum Analysis and ASCE 7-10 wind pressures
    d. Design shear walls and moment frames
    e. Check strength and drift requirements
5. **Architectural/ Fire Protection Analysis**
    a. Determine critical members and connections for which to design fire protection
    b. Design fire protection for building structural elements
        i. Research potential options and products for protection
        ii. Compare the cost and effectiveness of different system options
        iii. Determine the best combination of fire protection options
    c. Develop design plan and specification for the fire protection of the building structure
6. **Perform cost and schedule analysis**
    a. Cost analysis
        i. Complete detailed cost estimate of the redesigned structure
        ii. Compare steel system estimate with cost of the existing concrete system
    b. Schedule analysis
        i. Create schedule for new structural system using Microsoft Project
        ii. Compare the construction times for each system.
7. **Final report and presentation**
    a. Prepare Final Report
    b. Prepare Final Presentation

Thesis Timetable



Conclusion

As discussed in previous sections of this report, the existing concrete structural system for La Jolla Commons Phase II Office Tower was determined to be adequate for the design loads and showed no major problems. As a result, a scenario has been developed in which the building owner would like the structural engineer to develop an alternative steel design for the building structure. The floor system will be comprised of composite metal deck on composite steel beams and girders. The lateral system will be a combination of the existing shear walls at the building core and steel moment frames around the building perimeter. Furthermore, the structure will be analyzed in the office space for vibrations due to human live loading.

The breadth studies will be a continuation of this scenario. The owner would like the engineer to consider the impacts on the cost and construction schedule as a result of the redesign; therefore, a detailed cost analysis and schedule will be developed and compared to the original system. This will allow the most efficient design to be determined. Furthermore, the owner is concerned that the change in the structural system will negatively impact the fire protection level of the building structure. Therefore, a detailed analysis will be done to design a fire protection plan and specification for the building structural system.

Masters of Architectural Engineering (MAE) requirements will be incorporated throughout the analysis and design process of the new steel system. Material from *AE 530 – Computer Modeling of Building Structures* will be used in the creation of the ETABS lateral model and the RAM Steel gravity model. Also, material from *AE 538 – Design of Earthquake Resistant of Buildings* will be used to design and detail the concrete shear walls and steel moment frames.

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