[Helios Plaza]

Houston, Texas

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Structural Option
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[THESIS PROPOSAL]

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Executive Summary

The purpose of this report is to present and discuss the proposed thesis investigations for Helios Plaza. Helios Plaza is an office building that houses the IST and oil trading divisions of its owner BP. The plaza is located in Houston, Texas near other office buildings and suburban housing. The overall building height is 113' with a typical floor-to-floor height of 15'.

With respect to the overall structural system of Helios Plaza, the gravity system mainly consists of a one-way concrete pan joists system supported on concrete columns, but certain areas are composite steel deck supported on long-span, castellated steel wide flanges. Lateral forces in the building are resisted by concrete moment frames and some steel HSS beams welded to concrete filled steel pipe columns. The overall effect of this design results in a relatively high building self-weight, requiring the use of large spread footing foundations and seismic loads controlling design in one direction.

In an attempt to remedy the large building weight, a composite steel system is proposed as an alternative to the existing system. It has been shown in previous explorations that a composite steel system is feasible in strength design and has potential to reduce the weight of the building. The potential effects of switching to steel would be reduction of seismic loads resulting in wind loads controlling in the East-West direction, reduction of spread concrete footing sizes, and schedule saving.

This proposal would entail the redesign of both the gravity and lateral system of Helios Plaza. The preferred methods of design are RAM Structural Systems for the gravity system and ETABS for the lateral system. To further explore the design of the steel structure, several connections will be designed as well.

An impact of switching to steel framing is the addition of bracing members. Currently, there are no existing braces in Helios Plaza since all of the lateral loads are handled by the moment frames. The architectural impact of adding the steel braces will be assessed and potentially incorporated as a feature of the building.

Background

Helios Plaza is a corporate campus located in Houston, Texas that is comprised of three main structures. The first structure, which is the focus of this report, is a six-story office building that houses the IST and oil trading divisions of BP, the building owner. In addition to the office building, there is a 1,909 car capacity parking deck adjacent to a five megawatt combined heat and power plant separate from the office building. Construction was completed in September 2009. The office building will be referred to as Helios Plaza throughout the rest of this document.

The six-story office building is 423,500 gross square feet with an overall building height of 113 feet. The typical floor-to-floor height is 15 feet with exception at the first floor, the lower roof level and the roof level. The first floor height is 21.5 feet, the lower roof level is 17 feet and the roof level is 14 feet higher than the lower roof. Figure 1 represents these dimensions below.

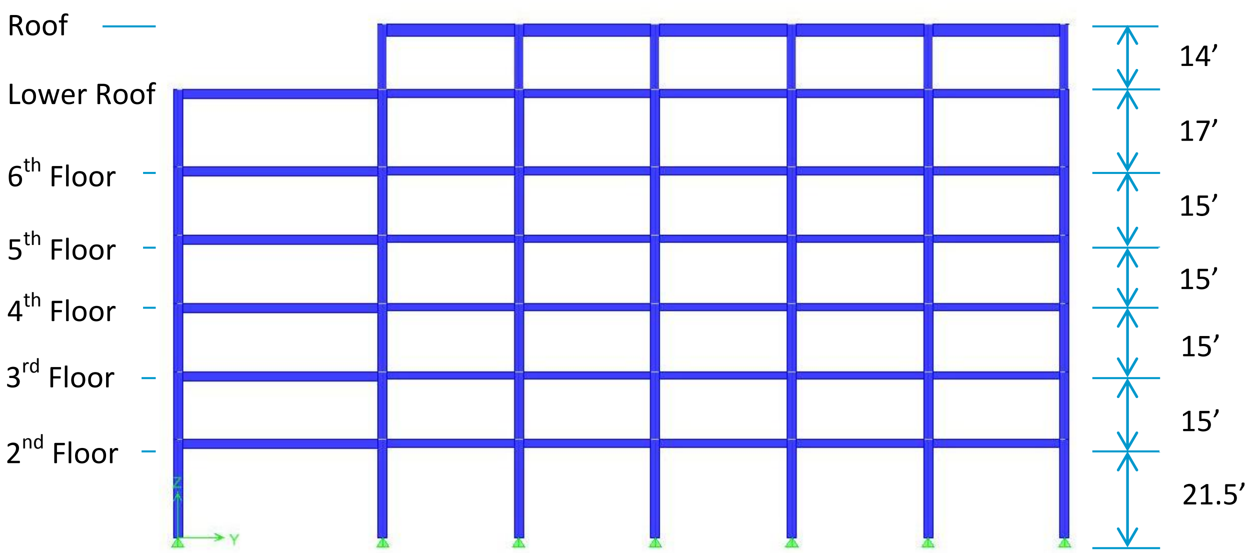

Figure 1: Building Frame Section

One of the more unique aspects of the office building is a result of the oil trading division wishes. The traders requested large, open areas to work in and these spaces are accommodated on the second, fourth and sixth floors. To make these areas more open, the floors above (i.e. the third floor, fifth floor, and lower roof level) are cut out over the trading floors to create double story spaces. To further the open feeling, the number of columns used is limited, which in turn creates long-span situations. Figures 2 and 3 on the next page illustrate simplified versions of the floor plans.

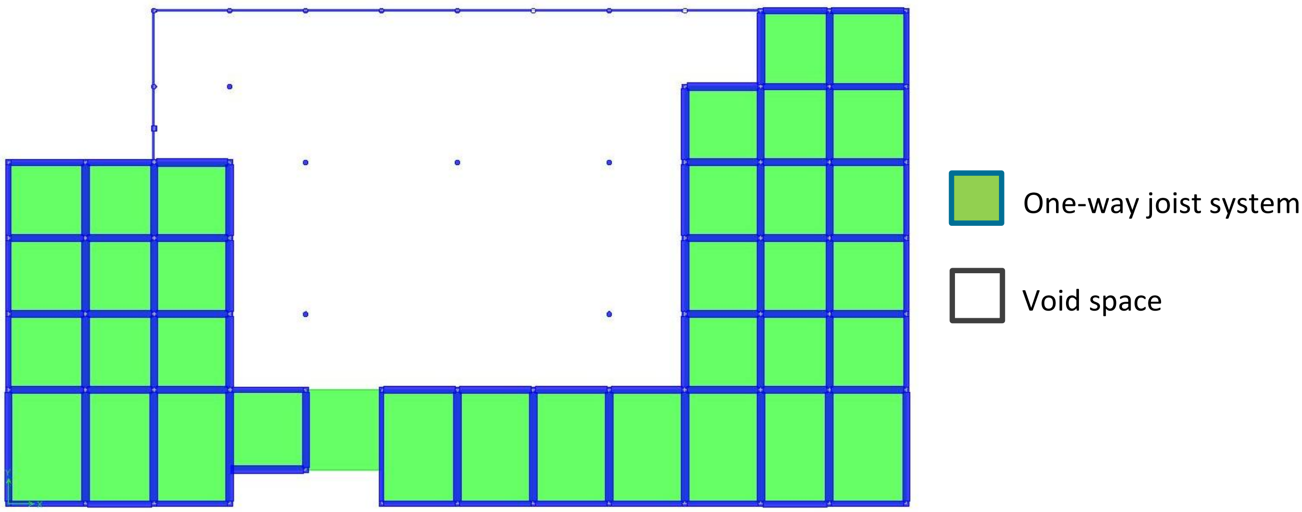

Figure 2: Cut-out Floor over Trading Floor

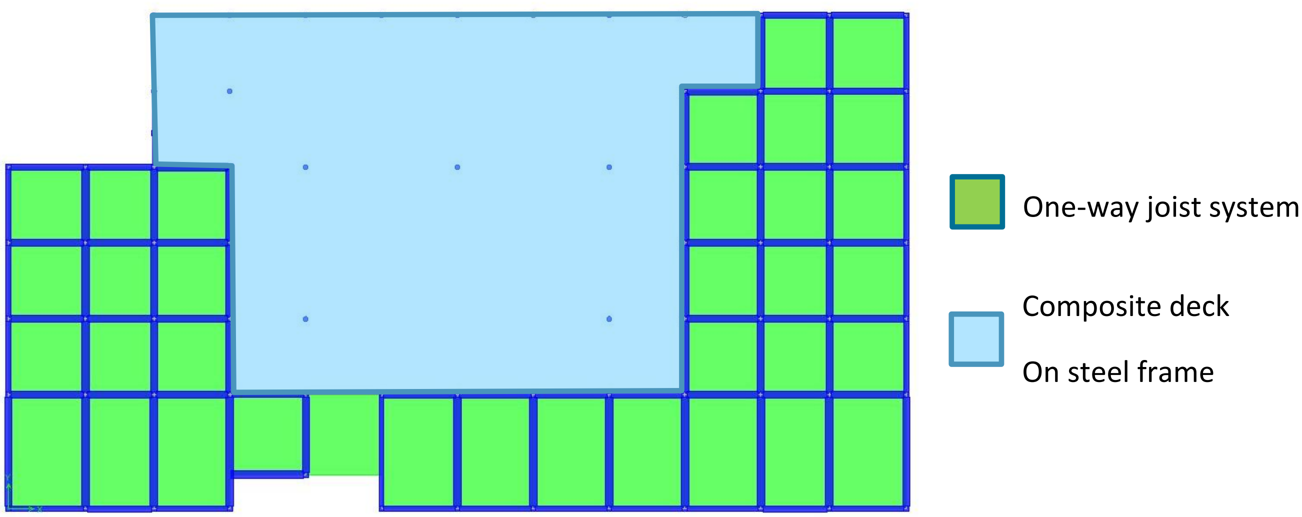

Figure 3: Composite Deck at Trading Floor

Structural System Overview

The main structural system of Helios Plaza is framed in reinforced concrete. Gravity loads are handled largely by square concrete columns, although concrete filled steel pipe columns are used for aesthetics in larger spaces. For shorter spans, averaging thirty feet, concrete girders in combination with pan beams are used. For longer spans of forty-five feet, post tensioned girders are employed. Finally, for spans of sixty feet, castellated wide flanges shapes are used to reduce the weight-span ratio while maintaining strength.

The floor is mainly a concrete one-way system that uses 66" span, 6" wide skip joists typically. In mechanical rooms, two-way slabs are used to distribute the larger loads more evenly to the supporting members. Composite decking with lightweight concrete is used over the long span steel members in the trading rooms.

To resists lateral loads, the building relies on the typical framing members to perform as concrete moment frames. In the trading floor areas, 2' diameter steel pipe columns are filled with 7000 psi concrete and moment connected to 14" Ø HSS steel beams that run the perimeter of the building.

Foundation

The site had to be extensively dewatered prior to the excavation for the project because of the porosity of the soil in Houston. Also, the soil has a high clay content which required the delivery of soils with better bearing capacity to the site.

Spread concrete footings are placed at the base of all grade level columns. The typical depth of the footings is three feet below the member that they are supporting. Their sizes range from 4' x 4' x 15" to 17' x 17' x 57".

Retaining walls are only used in the southeast corner of the building where there is a sub-grade basement with access to the adjacent parking structure via a tunnel. At level one, the floor is a slab on grade with thickness ranging from 5" to 12". Grade beams are also implemented at level one sized at 42" x 30".

Columns

Rectangular concrete columns are the predominant system used in Helios Plaza. For the most part these normal weight columns are 24" x 24" in size at all floors except level one where there is an increase in size to 30" x 30". The concrete strength decreases as the levels increase from 6000 psi at the basement level and level one to 5000 psi at levels two and three to 4000 psi for levels four through six. The basement level only occurs in the southeast corner of the building to allow access from the underground tunnel to the rest of the building. The basement area is only fifteen percent of the ground floor area. This space is spanned at level one by post-tensioned girders and one-way pan joists and can be seen in Figure 4.

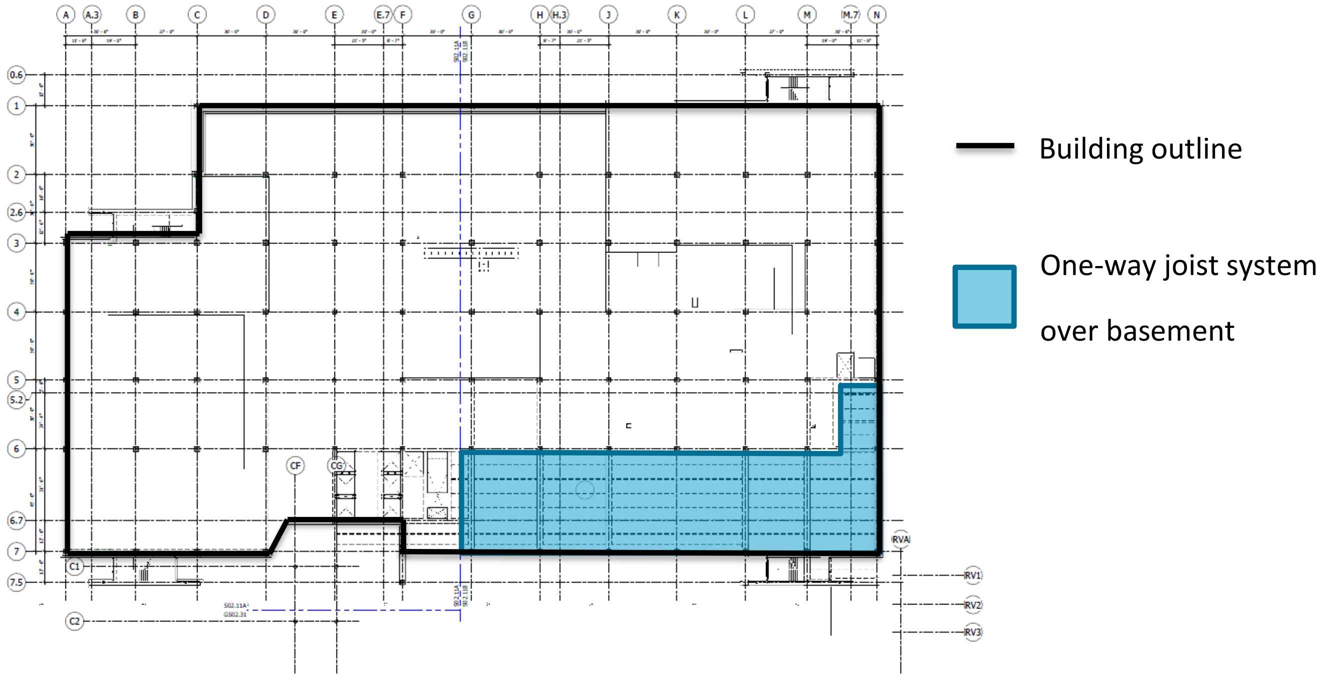

Figure 4: Basement Area

In addition to the rectangular concrete columns, concrete filled steel pipe columns are used in the double story trading spaces. These columns are 24Ø and are fillet welded to a metal plate at the base. This plate is then tied to the floor or foundations with anchor rods. The concrete strength used in these pipes is 7000 psi.

Floor Systems

As with the rest of the structural systems in Helios Plaza, the floor system is split into two main categories, one-way pan joists and composite deck. The one-way pan joist system has a welded-wire reinforced (WWR), 4" slab that rests on 16" deep pan typically. The one-way system frames into girders that range from 20" to 33" deep with a width ranging from 24" to 36". Girders also span in the same direction as the one-way joist system, but these are there to create concrete moment frames to resist lateral loads.

Post-tensioned girders are used all along the south face of the building that span in the North-South direction. This is necessary to meet the strength requirements for the 45' distance that these members span. The tendons are typically bundled in groups of four and the minimum final post-tension force is 351 kips. Their locations can be seen in Figure 5 on the next page.

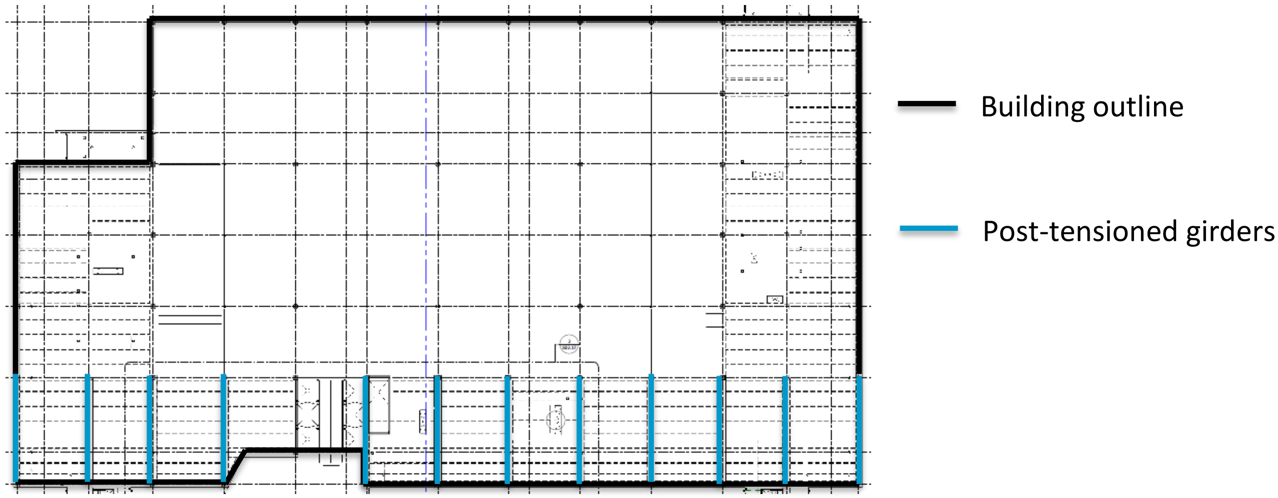

Figure 5: Post-Tensioned Girder Locations

Two-way slabs are implemented in areas where mechanical equipment is housed on every floor. The slabs are typically 10" thick, but in some cases they are 12" thick. Bathrooms usually share the same bays as the mechanical rooms because cutting holes in this system is efficiently achievable.

The second main floor system used in Helios Plaza is a composite deck on w-shapes. The change occurs because of the move to long span castellated beams to accommodate open, double story spaces for the trading floors. Spans of 60' dominate these spaces and the castellated beams vary between CB24x100 and CB30x44/62. In addition to the weight saving caused by punching out parts of the web, the beams are cambered 1.5" and 1.75" to meet deflection limits. The composite section used is typically 3 1/2" light weight concrete over 2" composite deck. The concrete is reinforced with additional WWR. Figure 8 below shows all three of the floor systems in adjacent bays of the building.

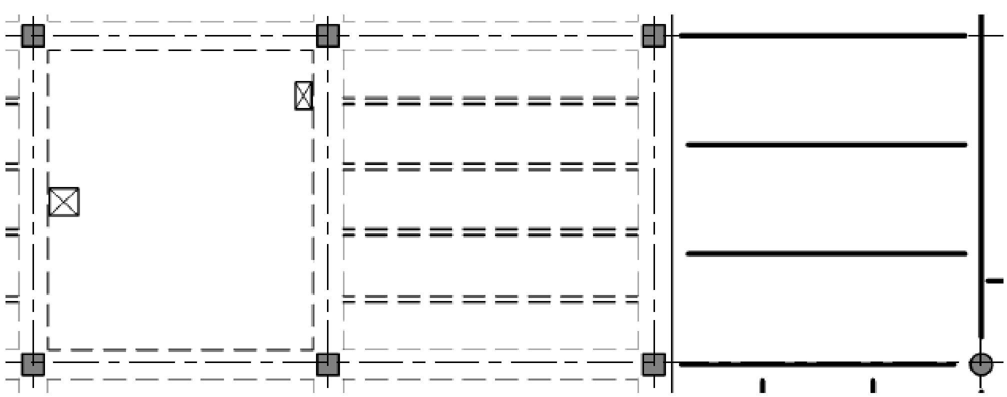

Figure 8: All Three Floor Systems in Adjacent Bays

Lateral Systems

Lateral forces are resisted in Helios Plaza by concrete moment frames. As mentioned before, girders run in the same direction as the one-way joist system to make up the frames in the East-West direction, while girders running in the North-South direction carry the pan joist loads in addition to transferring lateral load. When a double story occurs, several lateral resisting frames are interrupted and load transfers from the building's enclosure directly to moment frames are not possible. The force is instead transferred perpendicularly by horizontal circular HSS members to the one-way joists or to the floors above and below by the steel pipe columns. These beams are welded to the steel pipe columns and a detail can be seen below in Figure 9.

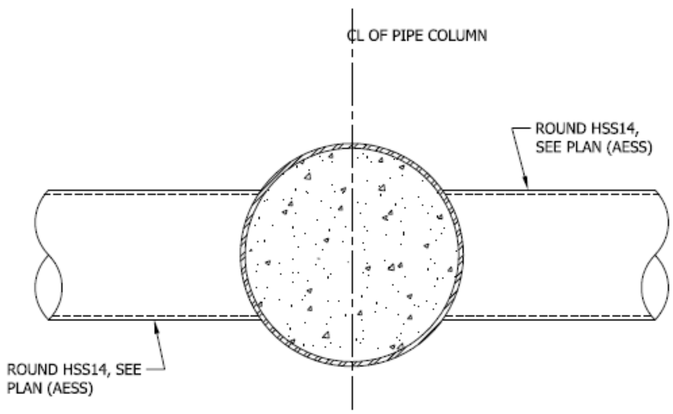

Figure 9: Round HSS Members Framing Into Each Other

Steel members that compose the floor system for the trading areas are not effective lateral members. They are not framed with moment connections and essentially only function to make a rigid diaphragm and to carry gravity loads. Overall, the building consists of twenty-two moment frames.

Codes and References

Helios Plaza was designed following all of the applicable guidelines for the state of Texas as well as the city of Houston. For the purpose of this technical assignment, the latest design codes will be utilized without specific regional additions.

Original Design Codes

- National Model Code:
  - 2003 International Building Code with City of Houston Amendments
- Design Codes:
  - Texas Architectural Barrier Act Standard
  - ANSI/AWS Structural Welding Code
- Structural Standards:
  - American Society of Civil Engineers, SEI/ASCE 7-02, Minimum Design Loads for Buildings and Other Structures

Thesis Design Codes

- National Model Code:
  - 2009 International Building Code
- Design Codes:
  - Steel Construction Manual 13th edition, AISC
  - ACI 318-05, Building Code Requirements for Structural Concrete
- Structural Standards:
  - American Society of Civil Engineers, SEI/ASCE 7-10, Minimum Design Loads for Buildings and Other Structures

Materials

Concrete		f'c (psi)
Spread Footings		4000
Basement Walls		6000
Slabs	On-Grade	3500
	Level 2	5000
	Level 3-6	4000
	Metal Deck	3500
Columns	Basement	6000
	Level 1	6000
	Levels 2-3	5000
	Levels 4-6	4000
	Steel Pipe Infill	7000
Beams		Same As Columns
Girders		Same As Columns
Reinforcement		**Fy (ksi)**
Rebar	#7 to #18	75
	All Other Sizes	60
Welded Wire	Smooth	65
	Deformed	75
Post-Tensioning Steel		**fs (ksi)**
Tendons		270
Concrete Masonry		**f'm (psi)**
All Types		1500
Structural Steel		**Fy (ksi)**
Wide Flange Shapes		50
Edge Angles/Bent Plates		36
HSS		42
Baseplates		36

Table 1: Material Strengths

Problem Statement

An effective concrete moment frame system is employed in Helios Plaza in combination with post-tensioned girders for long span situations. Despite the efficiencies of the design, the mainly concrete structure of Helios Plaza is massive enough to cause seismic loads to control in the East-West direction and require large spread footings. The large footings have a negative impact of the cost of the project while the mass amount of concrete adversely affects the scheduling of the project.

Proposed Solution

Alternate floor systems were explored in Technical Report II that would be able to maintain the existing column layout of Helios Plaza. Based upon the results of this study, a composite steel floor system was shown to be a viable alternative to the concrete system currently in place.

Utilizing steel as the main structural component for the building will have several impacts on the project. First, the overall building weight will be reduced. This could potentially lead to lower design loads for the lateral system and smaller spread concrete foundations. Smaller lateral loads could have the second order effect of even further reduced member sizes. Secondly, the schedule could be reduced due to the fast erection time of steel members. Additionally, the elimination of two frame disciplines on the site could lead to cost savings on labor and further schedule saving.

As part of the redesign, both the gravity and lateral system will need to be considered. In regards to the lateral resisting system, both braced frames and moment frames will be explored. As mentioned before, the potentially reduced lateral loads could result in smaller braces or member sizes.

Undesirably, the proposed floor system most likely will lead to an increase in the floor depth. Technical Report II showed that for a typical bay, the floor depth is expected to increase by 2.75". This will negatively affect other trades, such as mechanical space and could end up increasing the overall building height or decreasing the ceiling height. Another disadvantage resulting from the transition to steel is larger deflections in the slab. A final consideration is the necessity to provide fireproofing in some form, which will add to the cost of the building.

Analysis will be carried out that explores the merits and demerits of switching to a fully steel structure.

Breadth Topics

MAE Considerations:

Applying knowledge gained from the Computer Modeling of Building Structures course, preliminary design of the structural system will be performed using two computer programs. First, RAM Structural System will be used to get trial member sizes for the gravity system. The rough member sizes returned by the model output will then be standardized to eliminate excessive member sizes. Next, the preliminary shapes will be placed into the computer program ETABS to be analyzed for lateral force resistance. Based upon the loads retrieved from analysis, different frames will be designed by hand and compared with each other based on procedures learned in the Earthquake Resistant Design of Buildings course. Finally, several steel connections will be designed dependent on the type of lateral system chosen, using concepts learned in the Design of Steel Connections course.

Breadth I: Cost and Schedule

The first breadth topic will deal with construction management concepts. The proposed system will be analyzed and compared to the cost and schedule of the original system. Based upon the results of Technical Report II, the proposed system will be more expensive, but the additional cost of the superstructure may be offset by potential reduction the foundation size. Using RSMeans as a source of costing information, this will be achieved. Additionally, the schedule impacts will be compiled in the computer program MS Project and compared between the two systems.

Breadth II: Architecture and Aesthetics

The second breadth topic will deal with the architectural impact of changing the structural system. Three areas of interest will be the addition of lateral braces, increase in floor thickness, and the reduction of column sizes. Firstly, the addition of lateral braces will take up space that is currently open. The existing structure is composed entirely of orthogonal members and the braces will hinder movement and views in the building unless they are designed appropriately. Secondly, the increase in floor thickness will affect the floor to floor heights and will need to be handled to try and maintain the existing ceiling heights. In preserving existing floor to ceiling heights, the mechanical systems spaces also need to be respected while remaining within local zoning limits for overall building height. Finally, the possible reduction in column size may provide, albeit a potentially negligible amount of, extra floor space to be utilized in the building.

Tasks and Tools

I. Design Steel Structure (RAM/ETAB/AE 538/AE597A)

i. Create RAM Structural System model to determine trial sizes for gravity system.
ii. Standardize member sizes for ease of procurement and construction.
iii. Create ETABS model using preliminary gravity system determined above. Use the analysis software to determine controlling load case and retrieve story force data.
iv. Design braces by hand using design procedure from AE 538 notes and AISC Design Guide Provisions.
v. Check designs with an updated ETABS models. Several different bracing options will be designed to compare with regards to architecture and cost.

II. Architecture and Aesthetics

i. Analyze existing façade for aesthetics.
ii. Research architectural precedents where lateral bracing has been used as a building feature.
iii. Determine bays where lateral bracing will interrupt the floor plan and exterior views least.
iv. Analyze proposed façade for aesthetics and compare to existing façade.

III. Cost and Schedule (RSMean/MS Project)

i. Create detailed schedule of existing concrete structure
ii. Create detailed schedule of proposed steel structure
iii. Perform detailed cost estimate of existing concrete structure
iv. Perform detailed cost estimate of proposed steel structure

IV. Design Steel Connections (AE534/AISC Steel Construction Manual)

i. Determine typical locations to be used for connection design. Most likely connections for beam-to-column, beam-to-girder, brace-to-girder and brace-to-column will be chosen.
ii. Determine desired connection types (i.e. moment or pinned).
iii. Retrieve loading information from ETABS model output.
iv. Design connections for economy in addition to constructability.

V. Miscellaneous (MS Office)

i. Perform comparison of existing system versus proposed system.
ii. Compose findings in final report format.
iii. Prepare final presentation.

Schedule

	Week 1 1/10-1/16	Week 2 1/17-1/23	Week 3 1/24-2/30	Week 4 1/31-2/6	Week 5 2/7-2/13	Week 6 2/14-2/20	Week 7 2/21-2/27	Week 8 2/28-3/6	Week 9 3/7-3/13	Week 10 3/14-3/20	Week 11 3/21-3/27	Week 12 3/28-4/3	Week 13 4/4-4/10	Week 14 4/11-4/17	Week 15 4/18-4/24	Week 16 4/25-4/29
Design Steel Structure									Spring Break				Final Report Due Thursday, April 7th 0900	Faculty Jury Presentations		Senior Banquet Dinner Friday, April 29th
Create RAM Model																
Standardize Member Sizes																
Create ETABS Model																
Design Braces By Hand																
Check Braces in ETABS																
Architecture and Aesthetics																
Analyze Existing Façade																
Research Architectural Precedents																
Locate Bays of Interest																
Analyze Proposed Façade																
Cost and Schedule																
Create Schedule of Existing Structure																
Create Schedule of Proposed Structure																
Perform Cost Estimate of Existing Structure																
Perform Cost Estimate of Proposed Structure																
Design Steel Connections																
Determine Connection Types																
Determine Areas of Interest																
Calculate Loads																
Design for Economy																
Miscellaneous																
Perform System Comparisons																
Write Final Report																
Prepare Final Presentation																
Milestone 1 - 1/28	Both Structural Computer Models Complete															
Milestone 2 - 2/18	Steel Connections Roughly Designed															
Milestone 3 - 3/4	Breadth Investigations Complete															
Milestone 4 - 4/25	Thesis Project and Presentation Complete															

Conclusions

Helios Plaza's structure primarily consists of concrete moment frames. The existing floor thickness is 20" with an overall building height of 113'. The main drawbacks of this system are large building weight and long construction time.

For the redesign of the building, a composite steel system is proposed. The advantages of this switch are reduced building weight and faster construction time. On the downside, steel construction is more expensive and would lead to a thicker floor system. The thicker floor system will lead to reduced plenum space or a higher overall building height.

As part of the redesign, both the gravity and the lateral system will need to be considered. Utilizing the computer programs RAM Structural System and ETABS, preliminary member sizes and controlling load combinations will be determined. The output from the models will then be used to design braces by hand in addition to several typical steel connections. The braces will be compared and a preferred solution will be entered into the ETABS model to retrieve final loading and force information.

Incorporation of Integrated Program knowledge will be drawn from three graduate level courses. The Computer Modeling of Building Structures course will be referenced to help build the computer models for analysis. The Earthquake Resistant Design of Buildings course will be referenced to help design lateral bracing members by hand. Finally, the Design of Steel Connections course will be referenced to determine appropriate steel connections and help economize their layouts.

Breadths of design will incorporate both architectural and construction management aspects. Architectural considerations such as views and occupant flow will affect the location of the lateral bracing members. Investigations will be performed in an attempt to incorporate exterior lateral bracing as an architectural feature of Helios Plaza. Construction management studies will focus on construction cost and schedule. The goal for cost focus is to determine whether or not the lighter structure will reduce the footing cost to offset the increased superstructure cost.