# 360 State Street

## New Haven, Connecticut

STRUCTURAL THESIS PROPOSAL

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15 JANUARY 2010

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Senior Thesis: www.engr.psu.edu/ae/thesis/portfolios/2010/szd125/index.html

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*Executive Summary*

360 State Street is a new landmark for New Haven, Connecticut. It consists of street level retail, four stories of parking, and five-hundred rentable apartment units. The design of the building couples sustainable resources and tactics with location and architectural allure. Overall, the building reaches 32 stories and makes a statement about the convenience and romance of an urban lifestyle.

The intent of this report however; is to identify a problem and propose a potential solution as an in-depth thesis study. The report includes a general overview of 360 State Street's structural systems, three topics of research, and strategies to obtain design solutions.

Summarizing the previous technical reports, this document establishes the need to further investigate the use of staggered steel trusses as the main framing system. The objective of this study is to provide an alternative solution that can be recommended to the owner given that it can address the shortfalls of the existing systems. Additionally, the project goals include a structure that is more durable, marketable, and attentive to sustainable issues.

As the main topic of study in this report, it is proposed to redesign the gravity and lateral systems of 360 State Street using traditional steel framing and hollow core precast planks. The design intent is to increase the strength and rigidity of the structure while minimizing the floor depth by shortening spans. Additionally, the new system aims to decrease the overall building weight in order to optimize the foundations.

In related topics, a study of the building's envelop will be compared to an alternative glass façade. Thermal properties will be explored as well as its hanging system's structural performance. Marketability will also be considered to ensure 360 State Street will maintain its architectural appeal. Furthermore, a cost and schedule analysis will be conducted to compare the viability of the proposed systems. The thesis project will conclude with a recommendation to the owner.

Furthermore, the scope of the study is defined in an outline provided within this report. Tasks and strategies are listed and illustrated in a timetable. The goal is to complete the majority of the research and design by Spring Break in mid-March 2010. Thereafter, the final report and presentation will be prepared for its showcase in April. Bi-monthly progress checks were additionally established to ensure the project develops in a timely manner.

*Introduction*

360 State Street is an innovative building project developed by Becker + Becker Associates. Located in downtown New Haven, Connecticut, the building is situated on the corner of Chapel and State Street just two blocks east of the historic town green. As the newest addition to the city's skyline, the project consists of thirty-two stories of retail, parking, and residential living space. Architecturally, it features a landscaped garden terrace and a façade composed of precast panels, ornamentation, and glazing. As a whole, the building's location and design encourages a sustainable lifestyle and creates an attractive urban environment.


Figure 1: Rendering of 360 State Street

The following report is a proposal consisting of a main topic and two subtopics that will be researched through the second half of a year-long thesis project. The focus will be directed towards the upper twenty-six stories of the building because any changes made will impact the overall design the most significantly. The depth of the study will consist of a structural concentration narrowed down to a particular problem noticed through the previous technical assignments. The breadth subjects will focus on related topics regarding the overall building design. Typically chosen topics consist of a building envelop study and a cost & schedule analysis. Furthermore, the report will outline the tasks and strategies required to solve the posed design problems. A timetable will also be provided to illustrate the progress of the overall thesis project.

The following contents supply an overview of the existing structural systems within 360 State Street State. As the report progresses into the problem statement and solutions, keep in mind the following objectives:

- ♦ Longevity and durability of the structure.
- ♦ Positive marketability of the proposed changes.
- ♦ Conscious, sustainable design decisions.

It is intended to understand why the existing design was chosen as well as to recommend an alternative design that can offer the above objectives. Redesigning a particular system may increase the overall quality of construction which can lead to a longer life of the building. Each design decision additionally, has to be made with viability in mind. The owner/developer would not approve changes that would counteract his or her goals. And most importantly, the proposed topics will include design decisions that will prevent the occurrence of common problems.

*Architectural Overview*


Figure 2: Interior View of Public Club Room

Previously, the corner of Chapel and State Street consisted of an abandoned building with an adjacent parking lot that occupied an acre and half of land. With its redevelopment, 360 State Street now covers the site with the exception of a small plaza in the northwest corner. The building begins one level below grade; this area functions as the loading dock for the retail space. The primary entrances are located at grade. A parking garage extends from the second to the fifth floor with a ramp that circles the elevator core. On the sixth level, the residential tower begins. Its area is roughly a third of the building's footprint and is centered on the site. The sixth level contains all the amenities which include a fitness center, library, and lounge. The lower roof also doubles as a terrace for 360's residents. It consists of a landscaped garden, an outdoor pool, and a patio. The residential tower extends from the seventh to the thirty-first floor. The units include studio, one, two, and three bedroom apartments. At the roof of the building is a mechanical room which houses 360's cooling towers.

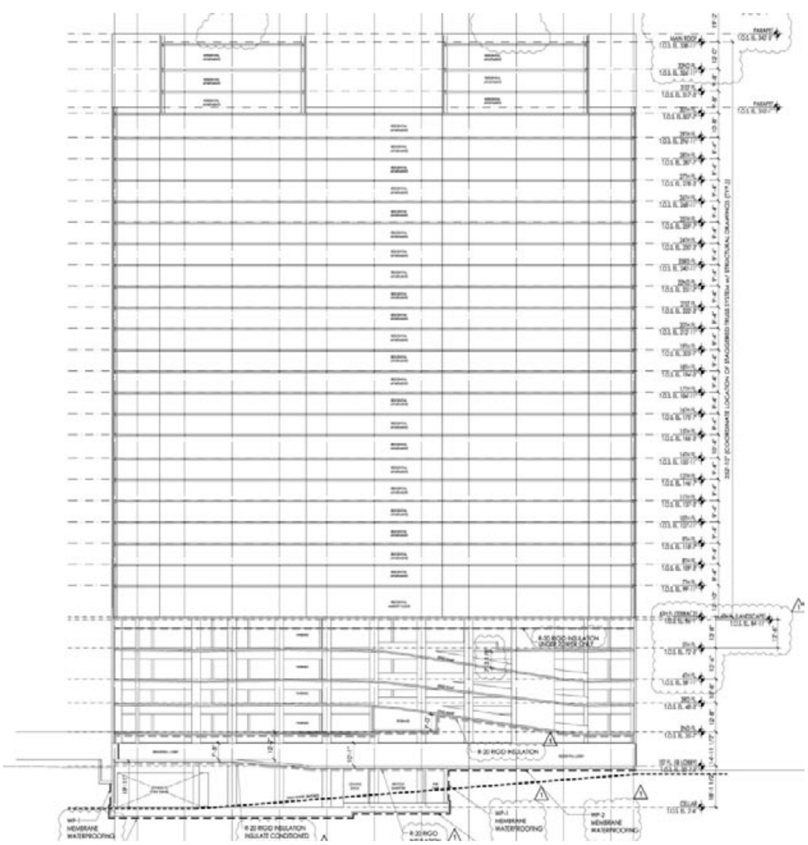


Figure 3: North-South Building Section of 360 State Street

Overall, 360 State Street tops off at 338'-7", the second tallest building in New Haven. It is clad with architectural pre-cast concrete panels, masonry, and glazing. Ornamentation also decorates the façade on the lower levels. Sustainable features include recycled building materials, rooftop gardens, and geothermal walls. The design goal is to achieve LEED® Silver certification and to encourage an urban lifestyle. 360 State Street is a milestone to the city's redevelopment and environmental efforts.

*Existing Structural Systems*

*Foundations*

The foundation of 360 State Street is a reinforced concrete mat slab located 17' – 3" below grade. The slab varies between 36" to 68" in thickness depending on the programmed area's function. A mat slab was chosen as the primary support because it can evenly distribute heavy column loads across the entire building's area and sufficiently resist hydraulic uplift. It was also chosen based on New Haven's geology and the building's proximity to water. Supporting the slab is a series of pressure injected footings and mini-piles that have a capacity of 75 to 100 tons. Additionally, a foundation wall runs along the perimeter of the residential tower's footprint and 40" x 40" concrete piers provide extra support to the retail space. Overall, the foundation is underpinned to the adjacent Pitkin Tunnel.

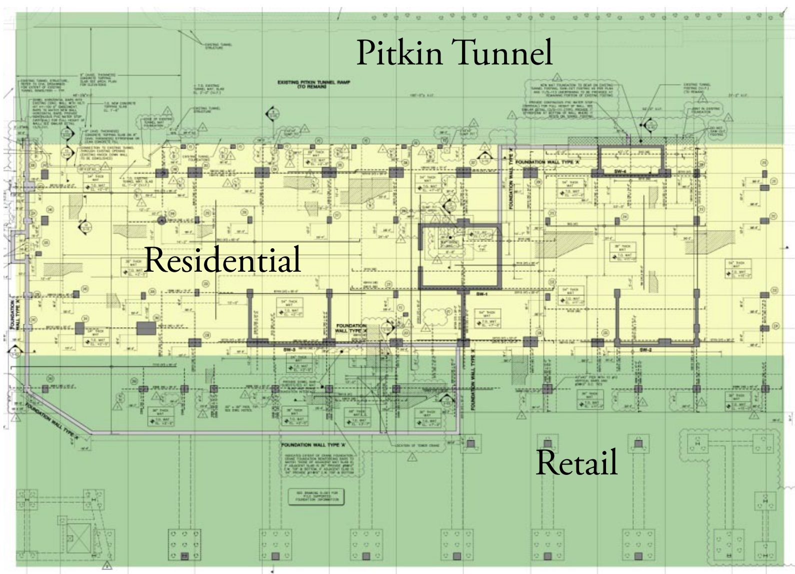


Figure 4: Foundation Plan; shading illustrates building's different functions.

*Floor Systems*

360 has a variety of concrete floor systems distributed throughout the building. At ground level, there is a 12" slab-on-grade which covers two-thirds of the building's footprint. Between the second and fifth floor, three different slabs are used for each third of the building. The center portion consists of a 10" cast-in-place slab that supports the elevator lobby and unit storage rooms. Above the Pitkin Tunnel, a 7" post-tensioned slab supports the tenant parking. The last third of the footprint is composed of an 8" two-way flat plate slab that is supported by a series of post-tensioned beams and columns.

The intermediate floor between the concrete base and the residential tower has a 12" cast-in-place slab. The lower roof or terrace is composed of a 2" 18 gage galvanized composite floor deck with 3 ¼" concrete. The remainder of the building consists of 8" hollow core pre-cast planks that are supported by staggered steel trusses.

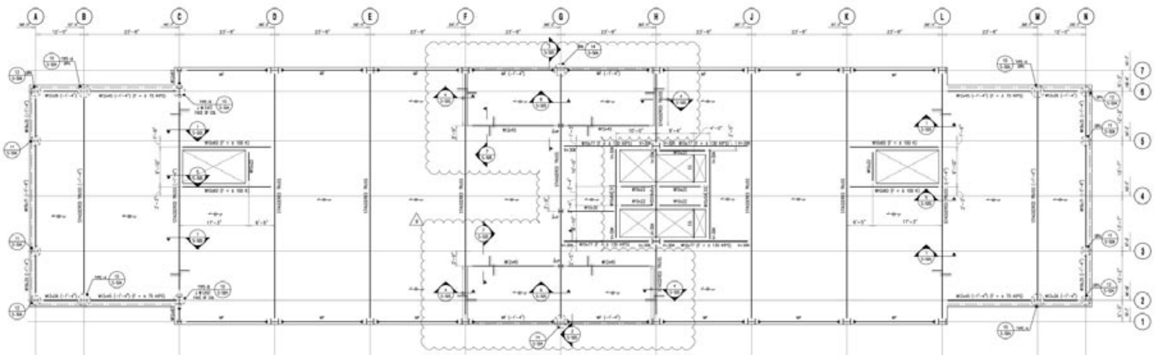


Figure 5: Typical Framing Plan for Residential Tower

*Gravity Systems*

Reinforced concrete is the primary material used in the first six stories of the building. Supporting the floor systems are post-tensioned beams and columns spaced at 24' east to west. Within the center portion of the building, the spacing is 14' north to south however; the columns along the exterior are spaced at 50' to provide room for maneuvering and parking cars.

The second half of the building is the slender residential tower which is made up of steel shapes. The beams and columns are primarily found along the exterior perimeter with the exception of those that support the elevator core. Unlike most buildings, 360 uses a system of staggered trusses for its interior framing. There are eleven trusses overall which span 62' across the width of the building.

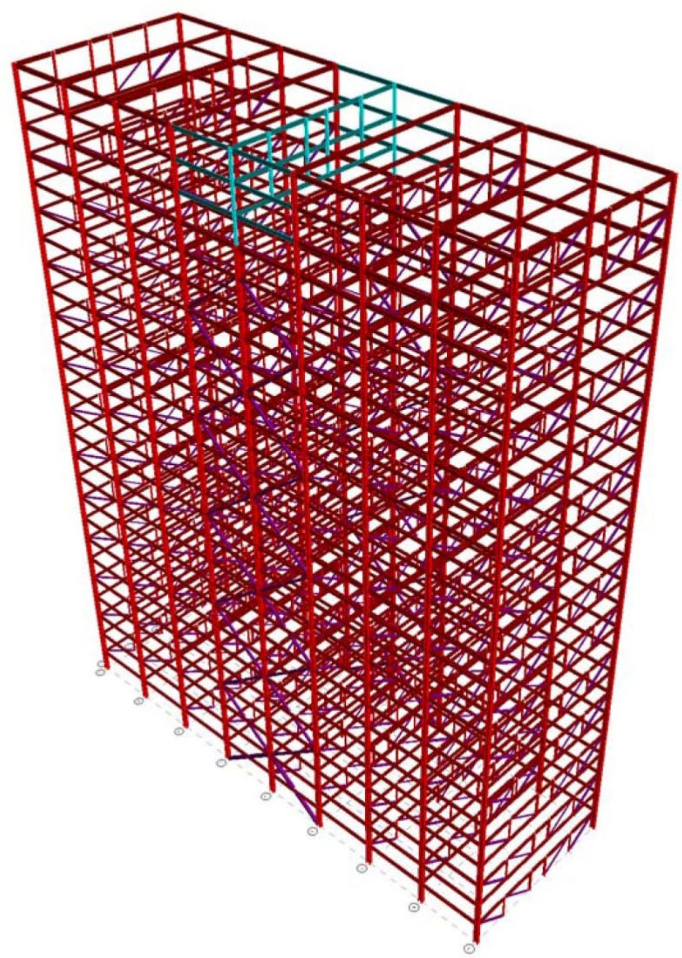


Figure 6: 3D Model of Existing Framing System

*Lateral Systems*

Although the beams and columns create 360 State Street's skeleton, the floor slabs, shear walls, and cross-bracings give the structure stability. The lateral systems help distribute wind and seismic forces across the entire frame as well as increase its rigidity. Four main shear walls are located in the concrete base, one of which encases the elevator core. None of these walls continue past the fifth floor however; steel cross-bracings continue through the residential tower. The braces consist of hollow structural sections that zigzag along the North/South face of the building. The staggered trusses previously mentioned also help support in the East/West direction.

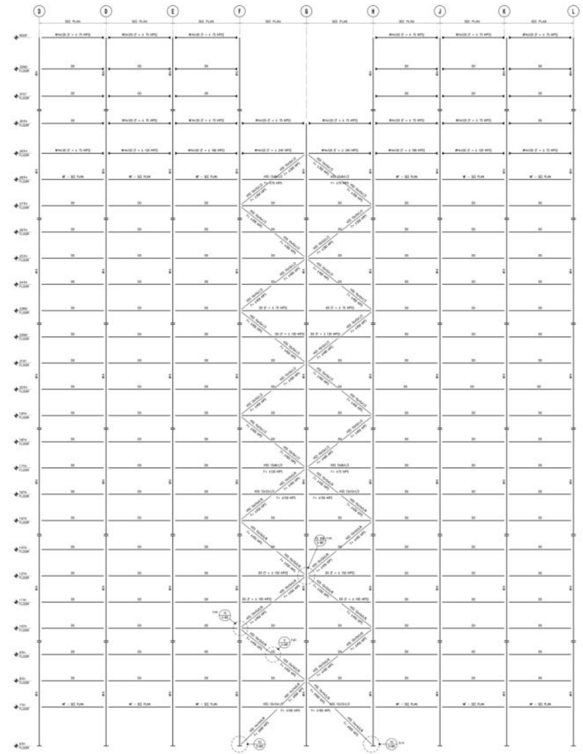


Figure 7: Elevation of North/South Steel Cross-Bracing

*Roof Systems*

The main roof is composed of the same 8" hollow core planks that are present on the lower levels. Additionally, a waterproof membrane, 12" R40 rigid insulation, ½" DensDeck prime cover board, and EPDM roofing membrane are layered on top. A pre-cast parapet wall runs along the perimeter of the roof at a height of 3' – 6". Flashing and another waterproof membrane tie the construction together. The lower roof has a completely different structure. It is supported by a 2" 18 gage galvanized composite floor deck with a 3 ¼" concrete slab. This level is used as a terrace and includes a landscaped garden which requires the addition of a drainage mat, filter fabric, and a waterproofing membrane to the construction.

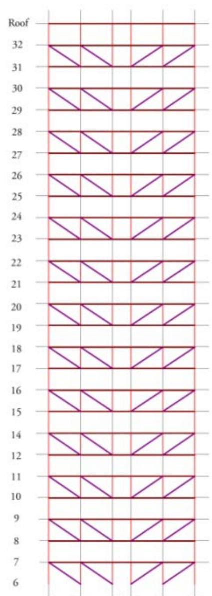



Figure 8: Staggered Trusses in Frame E

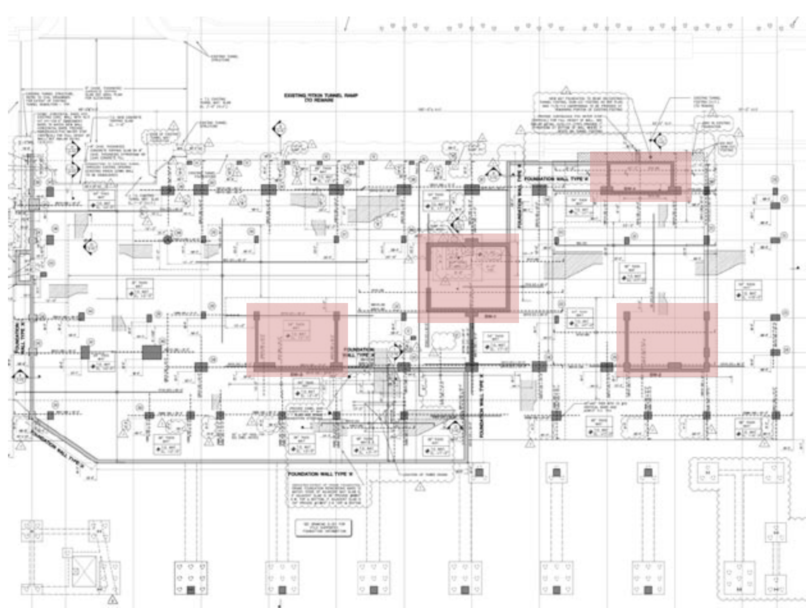


Figure 9: Shear Walls are highlighted on Foundation Plan

*Problem Statement*

| Project Goal: | To recommend a viable structural design that can effectively carry all load types while maintaining the current architectural layout and provide durability. |
|---|---|

The existing design of 360 State Street's gravity systems include a series of staggered steel trusses connected by spandrel beams and hollow core precast planks. The lateral systems are composed of the same trusses with the addition of X-braces and a moment frame in the upper stories. The challenges faced by the original designers included maintaining an open floor plan for layout flexibility and keeping material costs at a low. The gravity systems were deemed sufficient in *Structural Technical Report I* (Duk, S) however; a lateral analysis conducted in *Structural Technical Report III* (Duk, S) recommended further investigation into the capabilities of staggered trusses. Considering that trusses dominate the frame, the question now being asked is whether or not the original design was the best solution for the overall building.

*Proposed Solution*

| Proposal: | To redesign the gravity and lateral systems of 360 State Street in order to ensure a strong and rigid structure. |
|---|---|

An investigation was conducted by the structural engineers and construction management team of 360 State Street to identify the most cost-effective structural system possible for the architectural design. Staggered steel trusses were most likely chosen for their dual-ability to act as a gravity system as well as a lateral system. Additionally, the prefabricated structural elements would have been an ideal solution to the limited storage space available on site. For the purpose of this report, an alternative design will be recommended for the overall framing systems within 360 State Street.

The redesign will consist of a more traditional steel frame composed of W-shapes and hollow structural sections. The existing floor system composed of hollow core planks will be maintained. The design goals of this project will include the following:

- Increase strength and rigidity with additional structural elements.
- Minimize floor depth by shortening span lengths.
- Decrease overall building weight.
- Optimize lateral systems and foundations.

Note: Material cost and construction time will be considered in breadth topic.

Based on the results of the previous technical reports, the new design will attempt to capitalize on the shortfalls of the original design. Heavy gravity loads will be reduced and more evenly distributed throughout the structure; floor-to-floor heights will decrease from 9' – 4"; and story drift due to lateral forces will be minimized. Most importantly, the design will consider the quality of materials to ensure a durable structure that can withstand use and time. Ultimately, the objective is to recommend an alternative solution that matches the owner's goals of maximizing rental space.

*Breadth Topics*

| | |
|---|---|
| Building Envelop | To design a glass façade that will consider marketability, energy consumption, and structural performance compared to the existing façade. |

This breadth will propose an alternative glass façade design as a study into the marketability and longevity of the structure. The current façade of 360 State Street consists of glazing, masonry, and architectural precast panels. Spandrel glass is featured alongside 1" thick clear glass windows with aluminum mullions. With the proposed material, the appearance of the building will significantly change thus affecting its curb appeal. The idea is to design a façade that can generate new interest in the structure if the current program does not prove profitable. This study will include a comparison of the thermal properties of the existing and proposed façade as well as the hanging system that ties it to the framing. Structural considerations will also be included in this section and accounted for in the new framing design. Note: Material cost and construction time will be considered in next breadth topic.

| | |
|---|---|
| Construction Management | To develop a cost and schedule analysis comparing the existing to the proposed structural and façade designs. |

The redesign of the gravity and lateral systems will significantly impact the overall cost of the project as well as the construction schedule. In this breadth, a detailed estimate will be conducted for the structural elements in both the existing and proposed framing systems. The estimate will also include the façade variations investigated in the above breadth. Additionally, a schedule will be developed to compare construction time required for both the framing and façade designs. A discussion of material availability, delivery methods, and site logistics will be included. This breadth will provide the information required to summarize this report and determine if the alternative solutions are viable. Furthermore, it will verify the use of staggered steel trusses in terms of cost and construction time.

*Solution Methods*

The study will begin with an in-depth analysis of the staggered steel trusses. An individual truss will be investigated to verify if it can handle the gravity load combinations outlined in ASCE 7 – 05. Additionally, one frame consisting of the trusses will be analyzed similarly to the study conducted in *Structural Technical Report III* (Duk, S). Hand calculations will be completed and a computer generated model will be created in RAM Structural Systems. These results will be compared to those of the proposed framing system.

The redesign of the gravity system will incorporate the information provided by an AISC design guide on low to mid-rise steel buildings. Keeping the architectural floor plans in mind, the layout of columns and beams will be determined by the location of walls. The goal is to obtain a framing plan that will have the least negative impact on the original floor plans. Member sizes will be determined using the *AISC Steel Construction Manual, 13th Edition* as well as the recommendations provided by a computer model.

The new lateral design will incorporate the existing concrete shear walls from the base of the building. Extending the height of the four original walls will be initially considered. Locations for additional shear walls will also be investigated by identifying where loads can easily be distributed to the columns below. Following an initial design, a computer model will be generated to determine the necessity for further lateral support. If additional support is required, the use of brace frames and moment connections will be considered. The design of the shear walls will follow the guidelines within ACI 318-08. Sizing diagonal members and detailing moment connections will be determined by the *AISC Steel Construction Manual, 13th Edition.*

The design criteria found in the original structural drawings will be used for this report along with ASCE 7 – 05 and the 2005 Connecticut State Building Code. The building envelop breadth will consist of research found through manufacturer's catalogs. The program Trane TRACE™ will be used to create an energy model to compare the thermal properties of the two different façades. Also, a real estate agent will be contacted to determine the marketability and viability of dramatically changing a building's façade in downtown New Haven. For the construction management breadth, the R.S. Means books will be used as a reference for initiating the cost and schedule analysis however; the $MC^2$ software will be used to develop the detailed estimate. Suppliers/Vendors will also be contacted for information.

*Tasks & Tools*

**Depth – Redesign of Gravity & Lateral Systems**

i. Analysis of Staggered Steel Truss
   - Model individual truss & frame in RAM Structural Systems
   - Load truss & frame to obtain gravity results
   - Load truss & frame to obtain lateral results
   - Check gravity results w/ hand calculations
   - Check lateral results w/ hand calculations

ii. Design Steel Framing
   - Verify loads from *Structural Technical Report I*
   - Determine desired framing layout (must be compatible with architectural layout)
   - Model frame in RAM Structural Systems (or ETABS)
   - Size members w/ AISC Steel Manual

iii. Design Lateral System
   - Verify loads from *Structural Technical Report I & III*
   - Determine desired lateral frames (obtain a design guide)
   - Model frames in RAM Structural Systems
   - Experiment with location of frames & types

iv. Design Confirmation
   - Output computer generated results
   - Hand calculate gravity & lateral results
   - Check serviceability

v. Discussion
   - Determine load paths
   - Analyze effects on foundation
   - Compare existing & proposed systems

*Tasks & Tools*

**Breadth – Building Envelop**

i. Existing Façade
   - Establish design – gather information
   - Model one typical floor plan in Trane TRACE™
   - Find & analyze typical hanging detail

ii. Proposed Façade
   - Research design – gather information
   - Model one typical floor plan in Trane TRACE™
   - Find & analyze typical hanging detail

iii. Marketability
   - Research information regarding façades
   - Speak with real estate agent or manufacturer

iv. Discussion

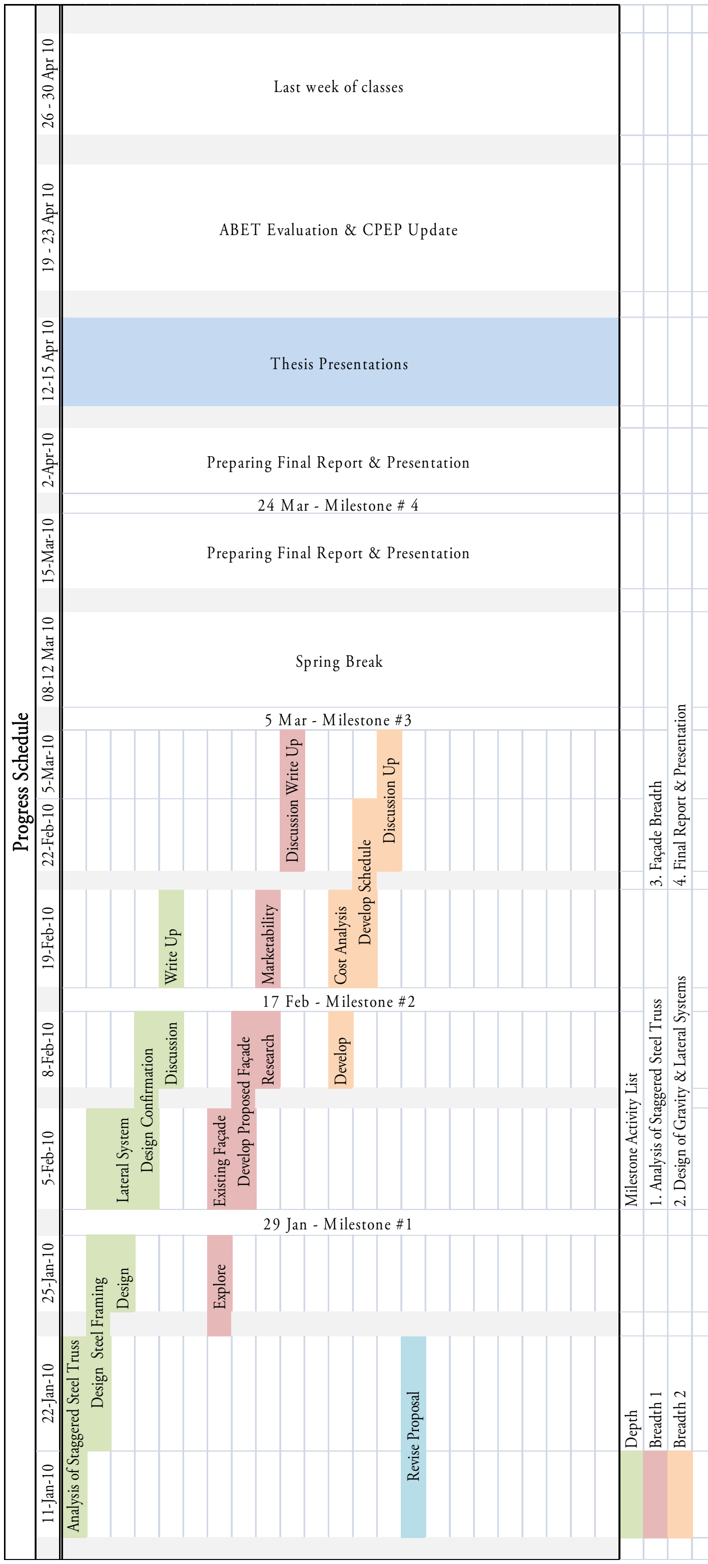
**Breadth – Construction Management**

i. Cost Analysis
   - Research information (*R.S. Means* or vendor)
     - Framing
     - Façade
   - Develop estimate

ii. Schedule Analysis
   - Research information (*R.S. Means* or vendor)
     - Framing
     - Façade
   - Develop schedule using Microsoft Project (or equivalent)

iii. Discussion
   - Compare cost for framing
   - Compare cost for façade
   - Compare schedule for framing
   - Compare schedule for façade
   - Viability

*Schedule*


Progress Schedule
11-Jan-10
22-Jan-10
25-Jan-10
5-Feb-10
8-Feb-10
19-Feb-10
22-Feb-10
5-Mar-10
08-12 Mar 10
15-Mar-10
2-Apr-10
12-15 Apr 10
19 - 23 Apr 10
26 - 30 Apr 10
Analysis of Staggered Steel Truss
Design Steel Framing
Design
Lateral System
Design Confirmation
Discussion
Write Up
Explore
Existing Façade
Develop Proposed Façade
Research
Marketability
Discussion Write Up
Develop
Cost Analysis
Develop Schedule
Discussion Up
Revise Proposal
29 Jan - Milestone #1
17 Feb - Milestone #2
5 Mar - Milestone #3
Spring Break
Preparing Final Report & Presentation
24 Mar - Milestone # 4
Preparing Final Report & Presentation
Thesis Presentations
ABET Evaluation & CPEP Update
Last week of classes
Depth
Breadth 1
Breadth 2
Milestone Activity List
1. Analysis of Staggered Steel Truss
2. Design of Gravity & Lateral Systems
3. Façade Breadth
4. Final Report & Presentation

*Conclusion*

The second half of the thesis project will consist of an in-depth study of 360 State Street's framing system. More specifically, the gravity and lateral systems will be redesigned to provide durability and longevity to the structure with a more traditional steel frame. The use of staggered steel trusses will be compared to the alternative solution. The objectives include minimizing the slab thickness of the hollow core planks, decreasing the overall building weight, and optimizing the lateral systems and foundations. Furthermore, two related breadth topics will be researched to analyze the marketability and viability of the design. A new glass façade will be proposed to increase the curb appeal of the structure. Thermal and structural performance will be considered and compared to the existing façade. To summarize the findings, a cost and schedule analysis will be completed to provide the owner with numbers to quantify his or her investment. Overall, the study will compare and recommend the best design solution for 360 State Street.

Additionally, an outline is provided of how each design/research aspect will be completed. A timetable with benchmarks is established for the completion of tasks and bi-monthly progress checks are included to ensure development of this project.