33 Harry Agganis Way

Boston, Massachusetts

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Structural Option

Advisor: Dr. Boothby

Revised Thesis Proposal

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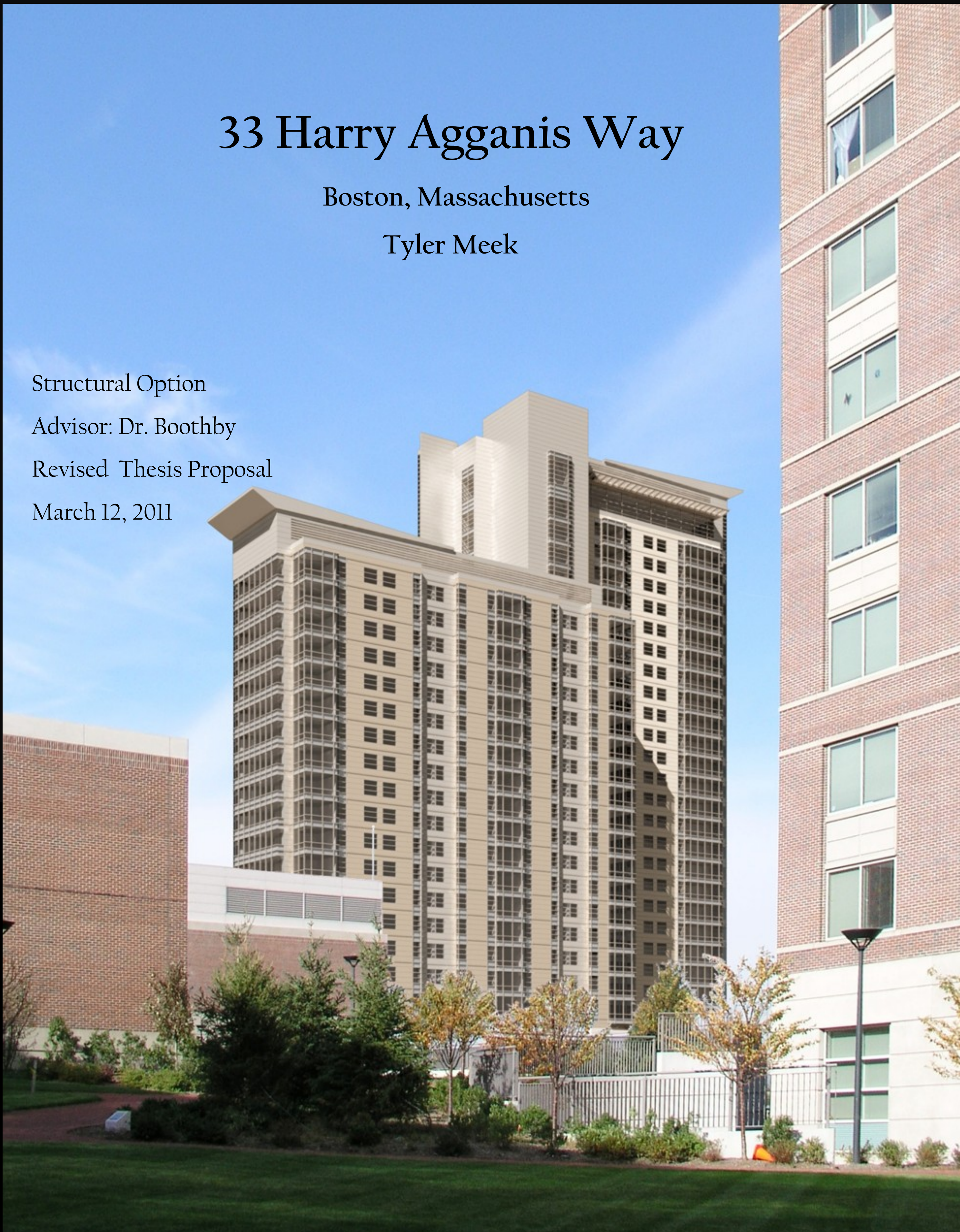


Table of Contents

Executive Summary

Res Tower II is a 26 story, 296 foot tall, dormitory located in Boston, Massachusetts. There are three levels of public lobby and presentation space with 23 levels of private study and living spaces. A steel framing system supports the lightweight concrete composite floor system and the lateral loads are resisted by moment connected steel braced frames pinned to a mat foundation.

During the construction phase of Res Tower II, issues occurred with the steel connections of the braced frames. These issues were caused by complicated connections and the foundation interfering with the diagonal bracing members attached to the base of some columns. Issues also appeared in the central corridor of the residential levels where diagonal bracing members had to be designed to avoid the area of connections above the floor slab and created tripping hazards.

To avoid these issues either modifications will be made to the existing lateral system or a new lateral system will need to be designed. As a part of technical report 2, a staggered truss system was evaluated for strength and serviceability under gravity loads. As part of the structural depth for this thesis, an attempt will be made to design the trusses to carry all gravity and lateral loads on the building, thus avoiding complicated connections with multiple members. If the truss design for gravity and lateral loads is in efficient, the trusses will be designed as gravity supporting members only and modifications will be made to the existing lateral system. As an alternative to the existing lateral system, the trusses will be used only for gravity loads and a new lateral system will be designed. Possible new lateral systems could be concrete shear walls or new braced steel frames.

Two breadth analyses will also be done as part of this thesis. The first breadth analysis is an architectural study the visual dynamic of exposing the trusses on the interior of the building. The second breadth will be a detailed site logistics plan and schedule comparison of a design using staggered trusses versus the original design. As a part of the site logistics plan, construction management decisions will be made such as using a shake-down area or time delivered steel.

Introduction

Located on the Boston University Campus, 33 Harry Agganis Way, which will be referred to as Res Tower II, is a 27 story, steel framed dormitory. It is located on the northwest corner of the John Hancock Student Village, bordered by the Charles River and Commonwealth Ave. Because two more dormitories are planned for the JH Student Village and the cost of developing in Boston is so high, the footprint of Res Tower II had to be as small as possible, thus forcing the structure to be tall.

The south tower is 19 stories tall with a fan room and mechanical penthouse on the top level. A student activity space, with large windows and a terracotta surfaced walkout space, occupies the 27^{th} story of the north tower. The roof of the north tower supports a fan room, large air handling units and other large service equipment. Floors 3 through 26, aside from the spaces mentioned above, are all private residential areas with some study rooms and computer labs mixed in. The first two levels of Res Tower II serve as the public and service offices for the rest of the building.

The façade of Res Tower II is a panelized skin comprised of terracotta and a metal panel rainscreen. This façade is a curtain wall system with its self-weight being supported by the floor above it; this can be assumed to be a continuous load due the small spacing of hung supports.

Res Tower II utilizes four main roof systems, all of which include gypsum under-laminate board, a vapor retarder and an adhered roofing membrane; the prior three aspects will be referred to as the typical roof assembly. Where mechanical equipment is being supported the typical roof assembly is placed on concrete deck while on the outer edges of the building, a metal deck is used. On the 26^{th} story, to support the walkout space mentioned above, terracotta pavers on concrete deck are combined with the typical roof assembly to create an attractive and durable roof system.

Structural Systems

Foundation

Haley & Aldrich performed the geotechnical studies for the JH Student Village area and provided the report in which H&A explain site and below-grade conditions along with recommendations for the structure. A net allowable soil bearing pressure of 6 kips per square foot (ksf) was recommended for the design of foundations on the natural, undisturbed glacial deposits below the site. A recommended design groundwater level was also given which is on average 10-12' below the bottom of the existing foundation.

Res Tower II utilizes a mat foundation system with two main thicknesses, 4'-3"and 3'-9". Logically, the taller tower is supported using the deeper mat foundation to resist the higher loads transferred by the braced frames. The foundation step occurs between grid lines 9 and 10. The typical reinforcement in the east-west direction is #10's spaced at 10" on center top and bottom while in the north-south direction, the reinforcement is #9's spaced at 10" on center top and bottom. Additional reinforcing cages are placed under the braced frame columns with the anchor bolts of these columns being tied to the bottom of the cage to increase the resistance to uplift. A detail of this connection is shown below in figure 1.

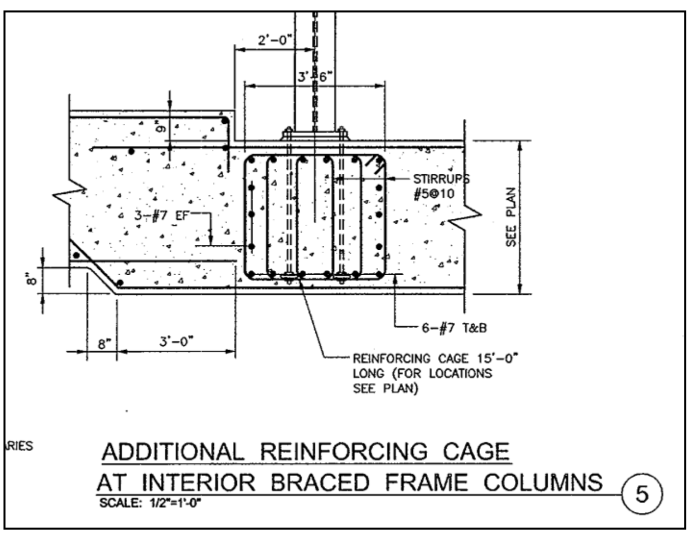


Figure 1: Additional foundation reinforcing

A 9" deep trench runs along the center of each towers foundation, parallel to the length of the building. This trench is filled in with 4000 psi concrete and reinforced with welded wire fabric after the erection of the interior columns in this area. In figure 2 below, the trench is shaded and outlined in red with the lateral force resisting system columns marked in blue.

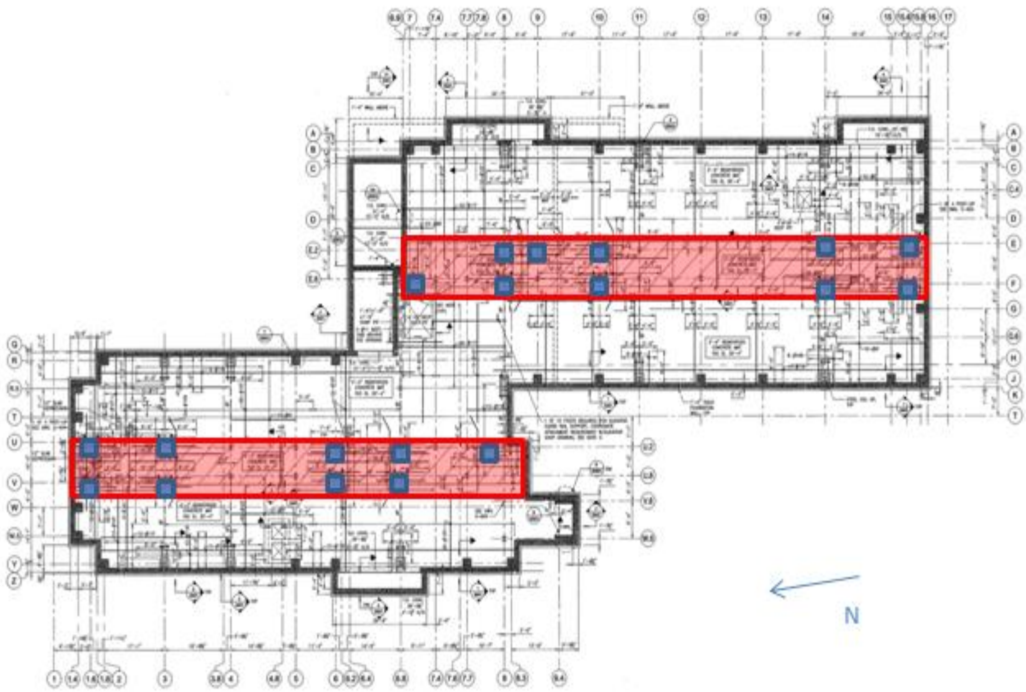


Figure 2: Foundation Trench

Floor Construction

The typical floor construction for Res Tower II is 3" 18 gage galvanized steel deck with 3-¼" lightweight concrete topping, a total thickness of 6 ¼", and 6 x 6 welded wire fabric reinforcement. This is used everywhere except the loading dock and trash compactor area on the first floor. The floor system for these areas is comprised of 3" 16 gage steel deck with 6" normal weight concrete topping, a total thickness of 9", and epoxy coated reinforcement of #7's spaced at 12" on center in the bottom of the flutes and #5's spaced at 12" on center in the top running each way. All deck is designed to act compositely with beams.

Decking typically spans about 8'-9" supported by beams ranging in size from W14s to W18s. These composite beams span roughly 23 feet to girders or columns. The girders have the same range in sizes as the beams. These spans create a typical bay size of 17-18' * 24'-23'. The actual bay sizes vary moderately from typical dimensions. Figure 3 shows a typical floor plan for floors 3-18.

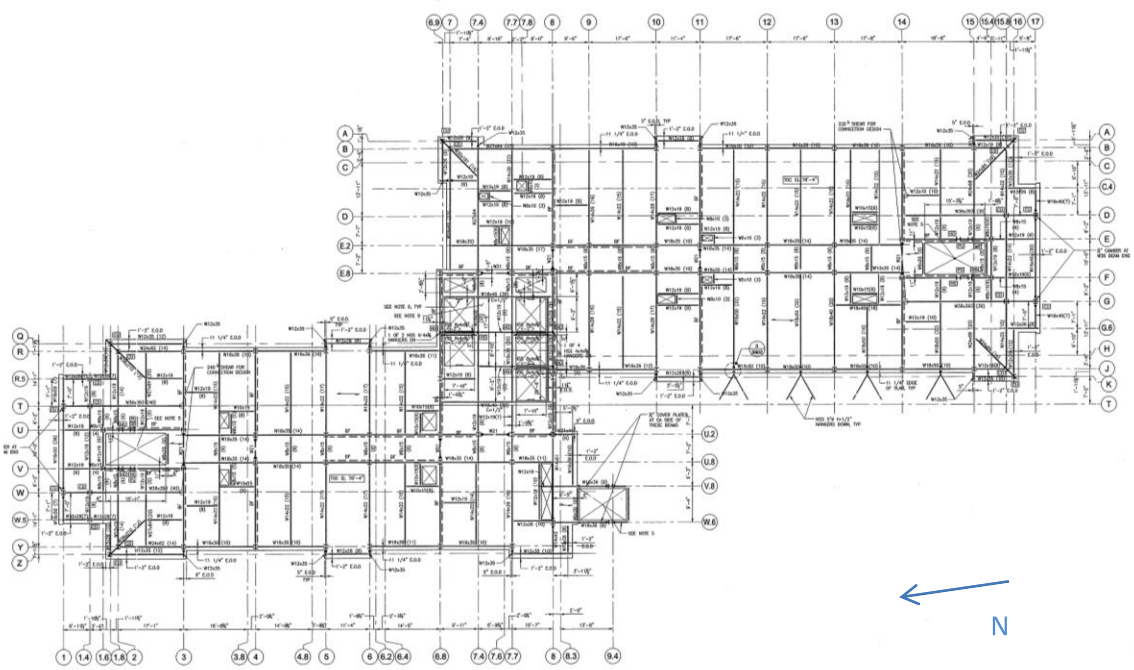


Figure 3: Typical Floor Plan

Lateral System

Steel braced frames are used to resist the lateral loads placed on the structure. At the termination of these columns, extra reinforcement is added to better tie the columns to the foundation and resist overturning forces. All columns in these braced frames are W14's ranging in size from W14x61 near the top of the structure to W14x398 for the bottom columns. The diagonal bracing members are W12's ranging in size from W12x152 to W12x45. This braced frame construction is categorized as a concentrically braced frame in ASCE7-10 for which an R value of 3.25 is prescribed but due to the moment connections, an R value of 5 was used by the engineer for design. To allow for corridors to pass through the center of these braced frames, moment connections were made. Figure 4 shows an elevation of a braced frame with the moment connections clearly shown. The braced framed locations are highlighted in figure 5.

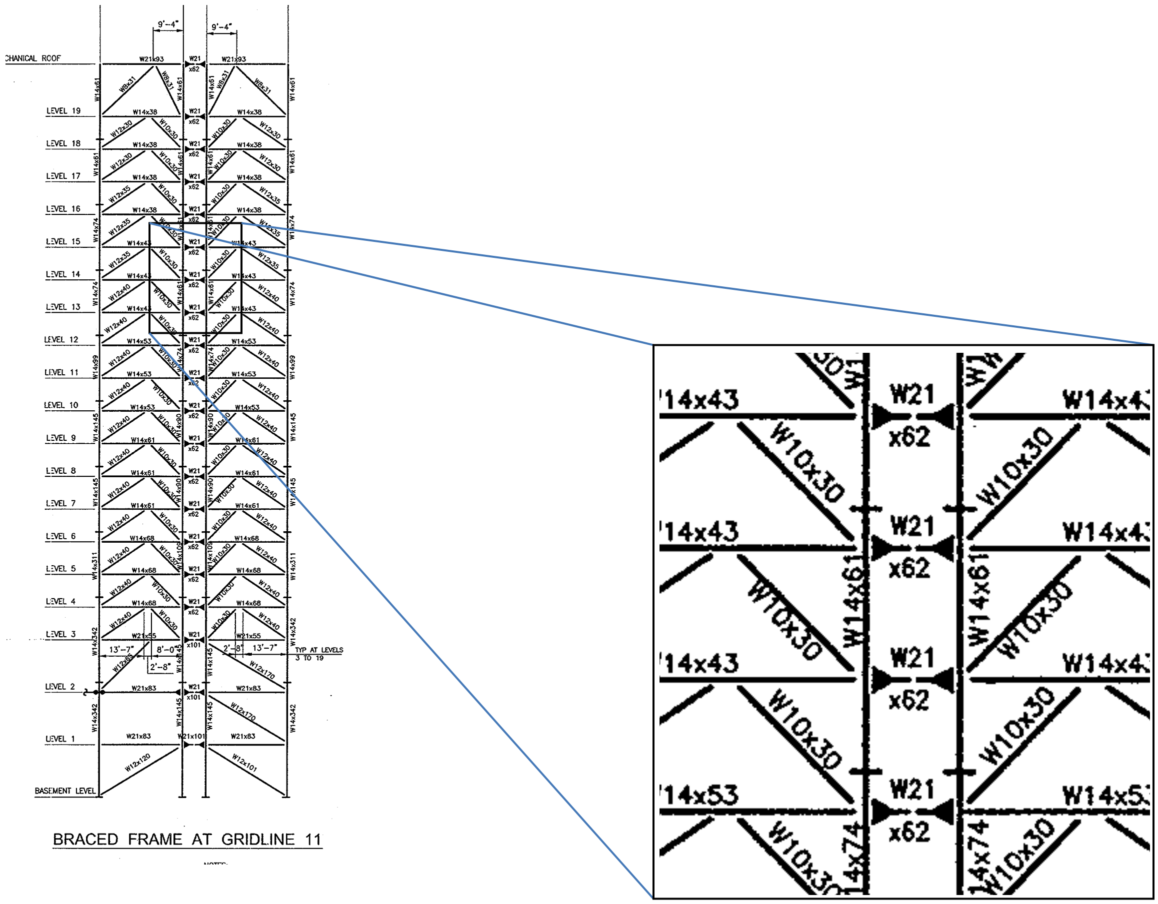


Figure 4: Braced frame elevation with moment connection

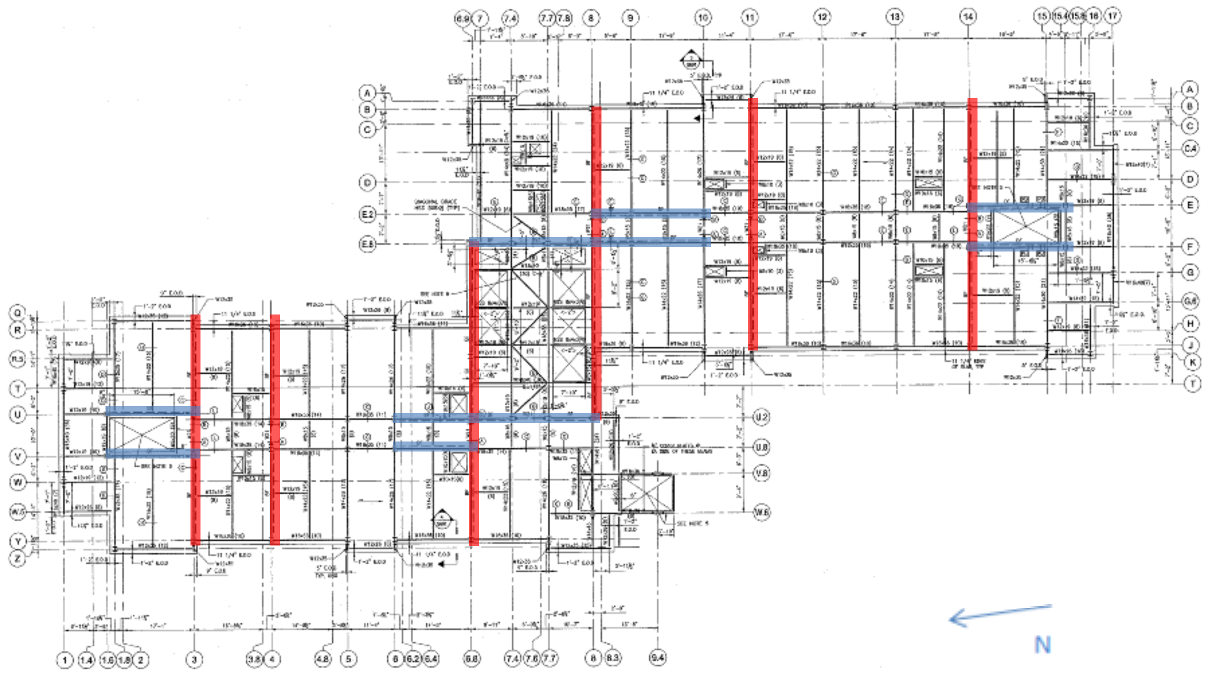


Figure 5: Typical plan with braced frame locations highlighted

Due to the slender shape of the building in the short direction, the braced frames in this direction (highlighted in red) have wider bases than the braced frames in the longer direction (shown in blue). The wider base provides a more effective geometry for transferring lateral loads to the foundation in the form of vertical loads.

Figure 6: Connection construction photo

Some of the braced frames in perpendicular directions utilize the same columns making for very complicated connection details and erection processes. To successfully portray these connections, 3 dimensional models had to be built, presented and provided for the contractors. Because of this, the design phase of the schedule had to be extended and more risk was taken by the structural engineer who designed the connections. A construction photo of these connections is shown in figure 6.

Figure 7 shows the trench mentioned in the foundation section and one of the further issues encountered due to the connections of the braced frames. Where the columns terminate, some of the foundation had to be cut away to allow for the columns to be placed due to the large connections for the diagonal bracing members. A last minute adjustment of this type is both unnecessary and disruptive. This issue also pushed the steel erection schedule and caused delays in the overall construction schedule.

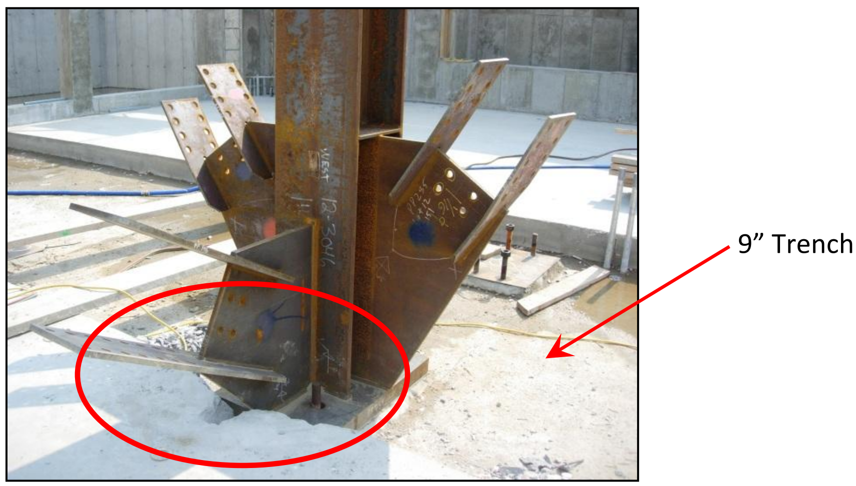


Figure 7: Foundation braced frame connection issues

Design Codes & Standards

Original Design	Thesis Design
Massachusetts Building Code 6th Edition	2009 International Building Code
1993 BOCA National Building Code	American Society of Civil Engineers (ASCE7-10) And ASCE7-05
American Institute of Steel Construction (2005 Manual)	2005 AISC Steel Manual

Table 1: Design codes vs. Thesis codes

Structural Materials

The materials listed in the chart below are specified in the structural drawings via the General Notes page of the structural drawings (S000) or general notes on the individual framing plans.

Material Properties		
Material		Strength
Steel	**Grade**	**fy = ksi**
Structural Shapes	A992	50
Plates	A36	36
Angles	A36	36
Structural Tubes	A500, B	46
Structural Pipes	A53, B or A501	30
Column Base Plates	A572, 50	50
Concrete	**Weight (lb/ft^3)**	**f'_c = psi**
Mat Foundation	145	4000
Slabs (Dock & Trash)	145	4000
Walls	145	4000
Typ. Slabs	115	3000
Reinforcing Steel		**fy = 60 ksi**
Welding Electrodes	E70 XX	**70 ksi**

Table 2: Material properties

Problem Statement

Technical reports one and three proved that the structure for Res Tower II is adequate in both strength and serviceability requirements. However, as mentioned in the section above that describes the lateral system, constructability issues were caused by complicated steel connections and amplified by insufficient connection details. Acknowledging that the use of braced frames may have been to avoid using concrete in cold environments or driven by availability of materials, an alternative lateral system may be better suited for Res Tower II. The elevation of each braced frame had to be designed one-by-one to avoid penetrating the central corridor of the dormitory levels. If a system could be designed that worked with the corridor instead of just avoiding it, that system may be found to be more effective.

Problem Solution

In technical report 2, alternative gravity systems were compared using many criteria including: strength, feasibility, and cost. A staggered truss system with hollow core planks was found to meet all the requirements above and proved to be a viable option that would not only allow for open space but also work well with the existing floor plan. Only a gravity analysis was performed for the staggered truss system and therefore more studies will have to be done to fully understand how well this system can be implemented into Res Tower II. The main concern would be how the trusses react when subjected to lateral loads. Multiple options will need to be evaluated to determine the best use of the trusses. These options would be:

- Designing the trusses as the main lateral load resisting system.
- Using the staggered truss system as a strictly gravity system and using the existing lateral system
- Designing a new lateral system that works well with the existing floor plan and using the trusses to only resist gravity loads.

Breadth Study I

Using a staggered truss system will have a direct impact on the interior spaces of Res Tower II. In some cases, the story deep trusses will run through open spaces such as the 26th story meeting lounge and two study lounges. This study will follow the decisions to exclude some trusses and allow others to interact with the existing architectural scheme.

Breadth Study II

The second breadth study will focus on the creation of an efficient site logistics plan based on the new structural steel design. Additionally, the original construction schedule will be compared to a new schedule that utilizes either a shake-down area or time delivered steel for the staggered truss system.

MAE Course Related Study

Utilizing the knowledge gained from AE 534, Steel Connections, typical connections will be designed for the trusses. Two typical connection types will be designed:

- Top or bottom flange member to the column web
- Diagonal and vertical web members to the top or bottom flange member

Task and Tools

Staggered truss analysis:

- Staggered truss as main lateral resisting system
    1. Determine most efficient locations and geometry of trusses
    2. Using a computer modeling program determine the required member sizes to support and transfer both gravity and lateral loads (RAM, ETABS, STAAD)
    3. Investigate the amount of moment transferred to columns due to coupling effect of trusses (Model output)
- Staggered truss as gravity system with existing lateral system
    1. Redesign trusses to have adequate strength for only gravity loads (RAM, ETABS)
    2. Investigate truss design to determine if both flange members require connection to columns (AE 534, Modeling program)
- Staggered truss as gravity with new lateral system
    1. Use the truss design from above
    2. Determine best material for new lateral system (Concrete shear walls, Steel braced frames)
    3. Design new lateral system with to meet required strength and serviceability requirements (ASCE7-05, ACI 318-08, ETABS, RAM)
- Comparison of new designs
    1. Discuss and compare results to define best option for redesign

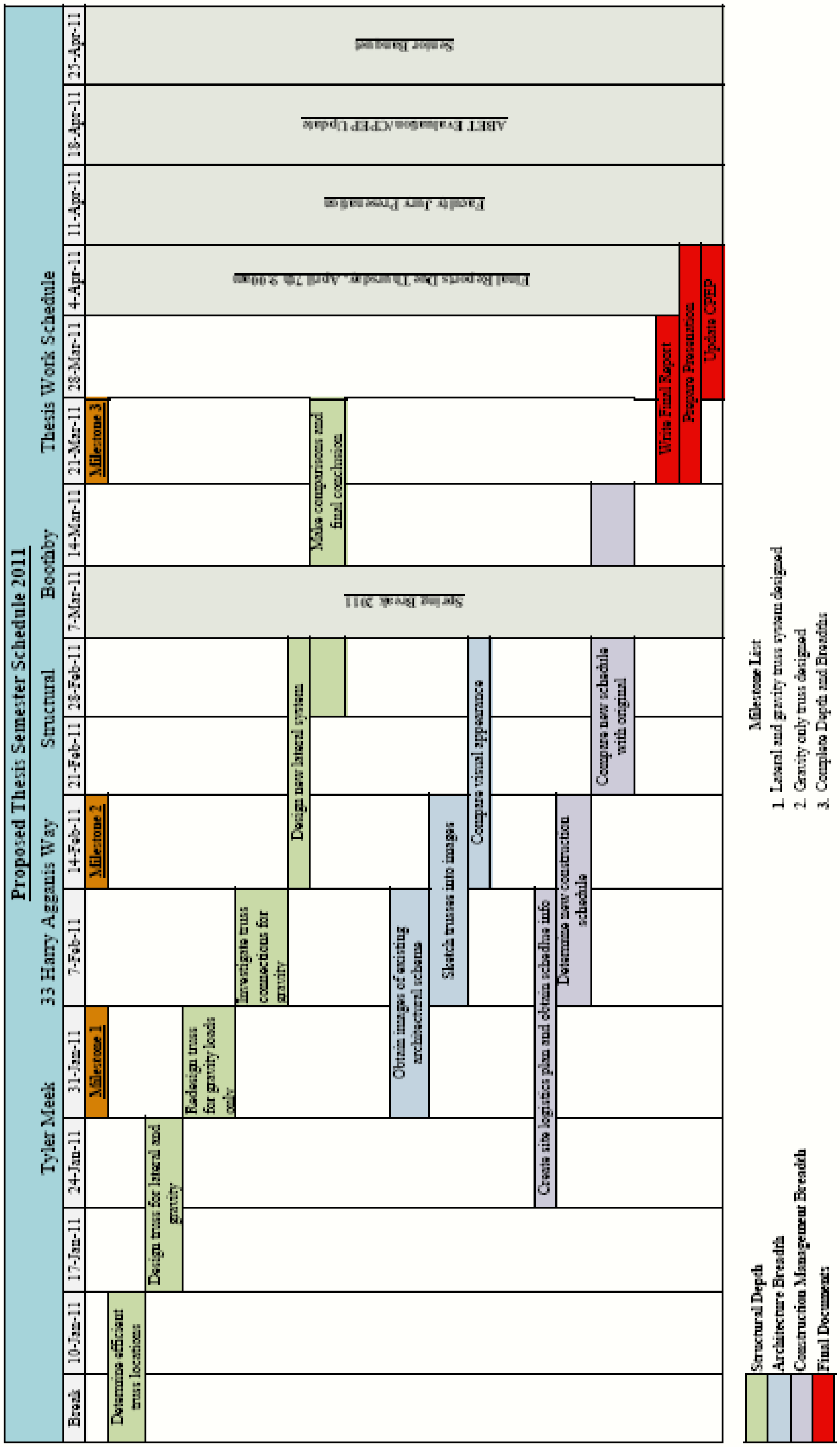
Breadth Topic I (Architecture Breadth)

- Interior appearance
    1. Make decisions to include or exclude certain trusses
    2. Sketch trusses to scale in photo of existing lounge
    3. Compare visual appearance

Breadth Topic II (Site Logistics Plan)

- Site logistics plan
    1. Shake-down
    2. Time delivery
- Create new construction schedule
- Compare original schedule to schedule for staggered truss

Time Table



Proposed Thesis Semester Schedule 2011
Tyler Meek 33 Harry Agganis Way Structural Boothby Thesis Work Schedule
Break
10-Jan-11
17-Jan-11
24-Jan-11
31-Jan-11
7-Feb-11
14-Feb-11
21-Feb-11
28-Feb-11
7-Mar-11
14-Mar-11
21-Mar-11
28-Mar-11
4-Apr-11
11-Apr-11
18-Apr-11
25-Apr-11
Determine efficient truss locations
Design truss for lateral and gravity
Redesign truss for gravity loads only
Investigate truss connections for gravity
Milestone 1
Milestone 2
Milestone 3
Design new lateral system
Make comparisons and final conclusion
Obtain images of existing architectural schema
Sketch trusses into images
Compare visual appearance
Create site logistics plan and obtain schedule info
Determine new construction schedule
Compare new schedule with original
Write Final Report
Prepare Presentation
Update CPEP
Spring Break 2011
Final Reports Due Thursday, April 7th 9:00am
Faculty Jury Presentations
ABET Evaluation/CPEP Update
Senior Banquet
Structural Depth
Architecture Breadth
Construction Management Breadth
Final Documents
Milestone List
1. Lateral and gravity truss system designed
2. Gravity only truss designed
3. Complete Depth and Breadths

Conclusion

The structural depth for this thesis will be to redesign the structural system of Res Tower II. A staggered truss system will be used for the new gravity system and possibly the lateral system. If the trusses designed for lateral loads are deemed inefficient, two further options will be investigated that utilize the staggered truss system to carry only gravity loads. The first option will be to modify the existing lateral system to avoid the connection issues that were encountered during the construction process. Designing a new lateral system using either concrete shear walls or new braced frames is the second option. These three alternative solutions will be compared and evaluated to select the best option.

An architectural study will be performed to document how changing the structural system will alter the appearance of Res Tower II. A detailed design of a new site logistics plan will include a decision to create the schedule using a shake-down area or time delivered steel. The new schedule will then be compared to the original construction schedule.