THE UNIVERSITY SCIENCES BUILDING

NORTHEASTERN, USA

Proposal

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Table of Contents

Executive Summary

The main purpose of this proposal is to identify issues and challenges with the existing structural design and to propose a solution for these issues. In addition, a construction management and mechanical breath will be proposed. To assist these solutions, tasks, tools and a semester long schedule are provided.

This new 209,000 square foot University Sciences Building is located in the center of the University, nestled in between surrounding campus buildings. The building consists of classrooms, offices, laboratories and collaborative open spaces. It is essentially two buildings connected by a 4 level passage. The building's one- of-a-kind cantilevers make for an interesting structural project. Building 1 is constructed with concrete on the first 3 levels and steel on the remaining 5 levels. Building 2 has a concrete foundation and steel on the 4 above grade levels. The floor systems in Building 1 is a one way reinforced concrete slab on the lower floors and composite steel deck with concrete topping on the upper floors. The lateral system consists of 16 braced frames and 3 shear walls with varying heights.

As originally designed, the structural system performs well under all structural loads. The prolonged schedule and over budget project have been attributed to the erection of the structural system. Other system delays may have been victim to this as well. These proposed solutions are intended to improve the construction schedule and cost while maintaining its structural integrity. In Technical Report 2, a two was flat plate alternative floor system was designed to be 12" thick, which gains over 18" of additional plenum space. Also, the price per square foot was found to be about $4 dollars cheaper than the existing system. With respect to this research, I now propose a two way concrete flat slab floor system with drop panels as well as changing the braced frames to concrete shear walls. This proposal assumes that the Technical Report 2 floor system will be redesigned with drop panels to assist with the long spans (e.g. punching shear). Research will be conducted to design the most efficient system. This will also hold true for the design for the concrete shear walls.

As per this proposal's schedule, the investigation of the proposed solutions will follow a logical schedule to help reach a final design as well as address the breadths. Two breadth topic investigations will be of interest in the semester to come. The first topic is construction management investigation. The primary focus of this study will be a detailed phased plan to maximize the construction efficiency. Along with the phase plan will be a detailed cost estimate with the proposed adjustments. The second investigation will pertain to the mechanical system. Changing the structural system from steel to concrete may change the loading in some areas. Also, the additional plenum space may be utilized to redesign a more efficient system. The breath will include research into

multiple alternative systems and equipment. Although research may prove that only slight adjustments to the existing mechanical system will be necessary.

Building Introduction

The University Sciences Building is a pioneering sciences facility pushing the envelope on innovative research and education. The 209,000 square foot dual building is strategically nested on a 5.6 acre site on the urban university in Northeastern, USA. The building includes 300+ offices, state-of-the-art laboratories, classrooms, lecture halls, a 250 seat auditorium, and a 147 space parking garage. The University's standard building aesthetics include a symmetrical layout and typically a beige brick veneer. The USB's extravagant cantilevers and complex building enclosures express the University's commitment to innovative architecture and sustainability.

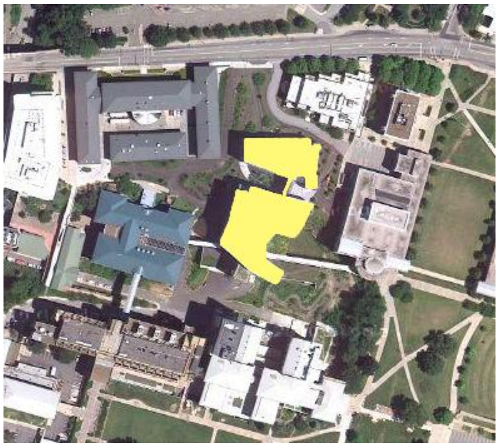


Figure 1 – Google Maps aerial view of site

The building was designed around the common idea of atrium space and the majority of other open spaces exposed to light, predominately through curtain wall systems. The intent was to let these open areas serve as collaborative spaces for interaction among students, researchers, and professors. The featured atrium of the building is its 3 story helical structure, which serves as a ramp to levels 3–5 with classrooms intermediately located through its core (Figure 2).

Figure 2 – Helical ramp

The sophisticated and 'edgy' design of the façade expresses the University's movement to push the envelope for not only the sciences but also its architecture. The material used to clad the building is a unique zinc material, for it is rarely used regionally in construction. Both the black zinc molded squares and the sliver aluminum window trim give the building a different and uneven appearance which sparks interest towards the building.

Figure 3 – South Cantilever

Each floor's different floor plans presents one of a kind overhangs and cantilevers which really express the structure of the building (Figure 3). The placement of key structural components are carefully placed to preserve optimal structural function from floor to floor.

Structural Overview

The University Sciences Building sits upon a Site Class C (Geotechnical Report verified with ASCE 7-05 Chapter 11) with drilled 30'' caissons, caisson caps, spread, continuous, stepped footings, grade beams and column footings. Levels 1-3 of Building 1 and level 4 of Building 2 have concrete beams and slabs with a combination of concrete columns and steel encased columns. The upper floors of both buildings support a composite beam/slab system and continue with steel and encased columns. The lateral systems consists of shear walls and braced steel frames. The shear/retaining walls start from the grade and end at various heights around the building. The braced frames are composed of wide flange chords with HSS diagonals that also reach various heights.

Foundations

The design and analysis of foundations are in accordance with the geotechnical report provided by Construction Engineering Consultants, Inc and ASCE 7-05. Schematic and design development stages were conducted with a safe assumption that the soil class was solid rock. The majority of the University's soil has been geologiclly tested to show this. Following the release of the geotechincal report was released, it was found that the site class was different than anticipated, was a site class C was determined appropriate. This induced a complete redesign of Building 2's foundation along with using a flowable for backfill for Building 1. Flowable fill is entrained with fly ash, cement, and other agents to generate negligible lateral pressure on surrounding foundation walls , however the fill maintains a compressive strength of 500 psi.

In has been concluded from the structural drawings that the allowable soil/rock bearing pressures for spread footings on weathered shale are 6000 psf. Likewise for siltstone/sandstone allowable pressures are 12000 psf. In addition, caissons socketed 5' into siltstone/sandy stone are to have an allowable pressure of 50 ksf.

The building load path initiates from the floor systems to columns and then respective caissons or interior column footings. Exterior perimeter caissons are connected with grade beams to interior caissons or grade column foundations. The slab on grade (SOG) is to be poured onto compacted soil to support 500 psf and a minimum of 6" of compacted Penn DOT 2A or 2B material. Furthermore, the fill must be compacted to 95% of the optimum dry density per ASTM D 1557. A vapor barrier is then required to be placed between the fill and the slab.

Expansion joints are used between the footings and floor slabs to minimize differential settlement stresses. The slab on grade is designed to have an f'c of 4500 psi of normal weight concrete and a mix class C.

Floor Systems

Due to the complexity of the floor layouts, bays occur irregularly and are comprised of a variety of beam sizes and lengths (Refer to appendix E for floor plans). In Building 1, floors 1 - 3 utilize concrete reinforced beams that range in size from 50"x24" to 10"x12", integral with formed 6" reinforced slabs. The upper floors utilize composite and non-composite beam construction. These floor systems range from 1" x 20 gauge metal deck with 5" reinforced concrete topping to 2" x 18 gauge metal deck with 4.5" reinforced concrete topping. The most recurring slab is a composite 2"x18 GA deck with 4.5" normal weight concrete topping, which is found in both building 1 and 2 on floor 4-roofs. Areas on levels 4 and 5 of Building 1 brace the metal decking between beams and girders with L4x4x3/8".

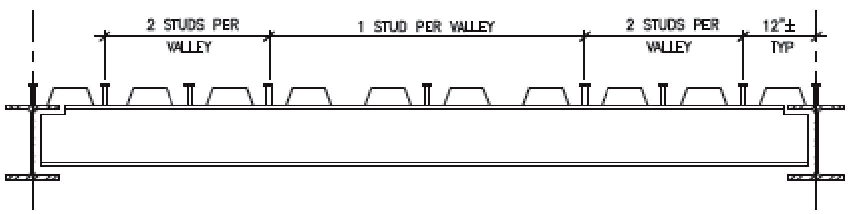


Figure 4. Perpendicular Decking Section – Case 3

The composite and non-composite decks are placed with the ribs of the deck perpendicular to the infill beams to maintain the rigidity of the system. This proved to be a conflict to construct with the placement of shear studs. Where it is efficient to place studs along the length of the beam uniformly normal to the valley and peaks of the deck, it was challenging to maintain this layout with the odd angling placement of particular beams (Figure 4).

Framing System

The USB has three different types of columns, reinforced concrete, encased A992 steel with concrete, and A992 wide flange steel. Reinforced concrete columns vary in size from 24" to 18" diameter circular columns and 16"x18" to 33"x37" rectangular columns. Also, wide flange columns range from W12x40 to W21x210. Levels 1 and 2 of Building 1 have both circular and rectangular concrete columns. Level 3 of Building 1 uses circular/rectangular encased steel and circular reinforced columns. This system is altered for three shear walls that start with a connection to a caisson cap at grade and rise 72’ to columns, likewise with Building 2. Framing girders are then connected to these columns with simple and complex connections. (e.g. pin-pin, moment). The layout of the girders and beams have been arranged with much complexity and provide a challenge for analysis. This complexity not only produced adversity for the fabricators and erectors, increased the price of the building, but also delayed the floor to floor connection schedule. The most nearly identified typical bay has 30’x27’ dimensions. .

An intricate and vital part of this structural framing system is the truss system in Building 1 which varies in height from Level 6 to the roof (Figure 5). These trusses are comprised of chord sizes as big as W30x292 and intermediate bracing elements as small as W14x53. Due to the complex cantilevers and floor plans, a system needed to be implemented to handle the buildings loads. The system is concealed in the building and parts where it can be seen (through some windows) presents and interesting look for the building.

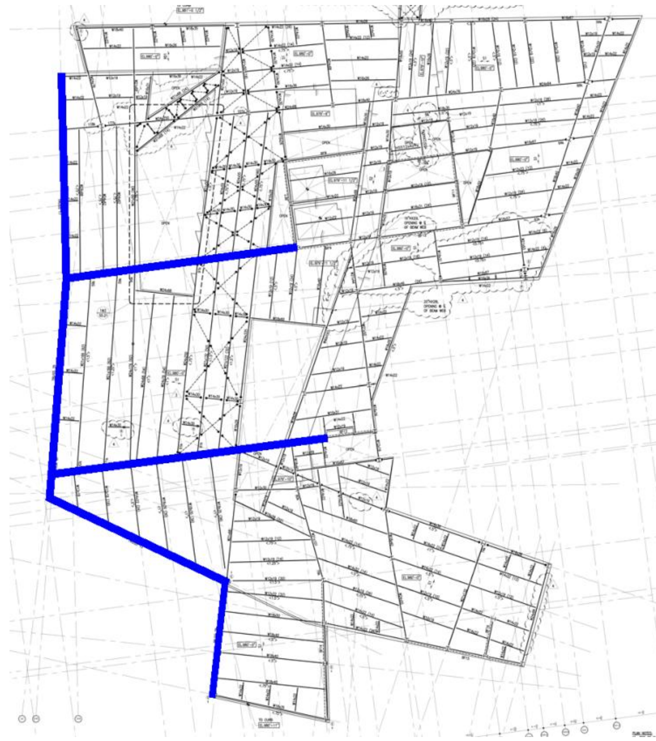


Figure 5. Highlighted truss elements from Building 1 Level 8.

Lateral System

The most common lateral force resisting system in The USB is braced frames. The USB utilizes 16 different braced frames between the two buildings. The majority of these are framed within a single bay. Others are ‘Chevron’ braced frames between two bays and a few span through 3 or more bays.

In Building 1 these braced frames are connected to shear walls were the load is taken from steel elements to concrete elements. These concrete elements are generated from the formed concrete walls lining the 147 parking spot garage. This adds a considerable weight to the building. All shear/retaining walls employed in

Figure 6. Level 6 Braced Frames and Shear walls

building are kept on the lower floors, which has been assumed to level 6. Refer to Figure 6 for the layout of brace frames (red) and shear walls (green) on Level 6. The challenge for Technical Report 3 will be to figure out how these lateral force resisting systems receive force on all floors of the building.

Roof System

This dual building system has 5 different roof heights which take into account mechanical penthouses. Figure 7 gives a discription of these varying heights in reference to grade elevation of 0'-0" (+880'). The framing of the roof is composed of wide flange framing with a 3" x 18 GA metal roof deck. The construction of the roof includes a modified bituminous roof system. This systems ranges in size from 3" to 12". This system is to undergo a flood test with 2" of ponding water for 24 hours to test leakage.

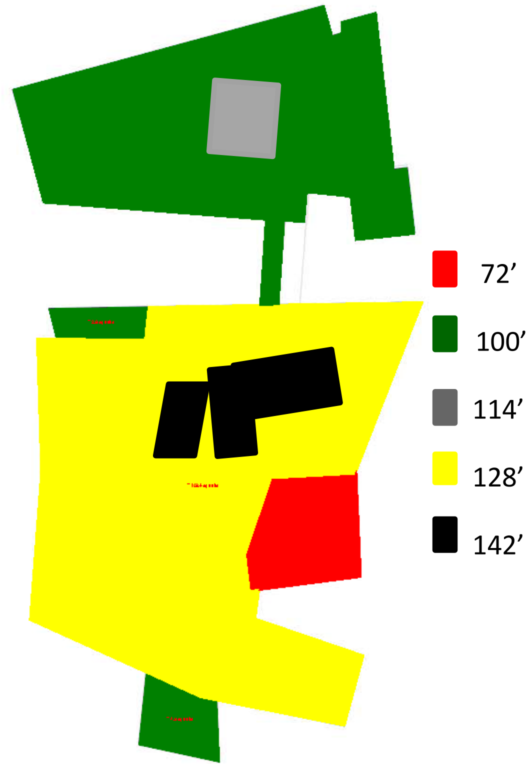


Figure 7. Roof elevations

Design Codes

In accordance with the specifications of structural drawing S0.01 the original design is to comply with the following codes:

- 2006 International Building Code with local amendments (IBC 2006)
- 2006 International Fire Code with local amendments (IFC 2006)
- Minimum Design Loads for Building and other structures (ASCE 7-05)
- Building Code Requirements for Structural Concrete (ACI 318)
- AISC Manual of Steel Construction LRFD 3rd Edition

These codes were also used in hand calculations and verifications in this Technical Report and those forthcoming.

Problem Statement

Figure 8 – South cantilever of the 6th and 7th floors.

Technical Reports 1 and 3 have confirmed and displayed the structural strength and serviceability of the existing structural system. Although this existing system has proven to perform well under all gravity and lateral loads, the cost and construction efficiency were compromised due to the steel construction with the building's geometric complexity.

Currently, the lateral system design is a combination of steel braced frames and concrete shear walls. In both buildings, a total of 16 different braced frames are utilized to adequately resist lateral loads and three shear walls used on the south cantilever shown in Figure 8. For the braced frames, the complexity of connections caused much delay and confusion during construction. These delays have been noted as a contribution of poor performance by the steel erector as well as the challenging task of erecting multiple complex frames. Secondly, the composite floor system consists of many different sized and angled beams. Many instances occur where beams connect to girders at non orthogonal directions (Figure 9). This presented a challenge to the manufactures and erectors. Precision was paramount and this consequently increased the price of the whole system. In addition, much of the projects delay of schedule has been attributed to the erection of steel.

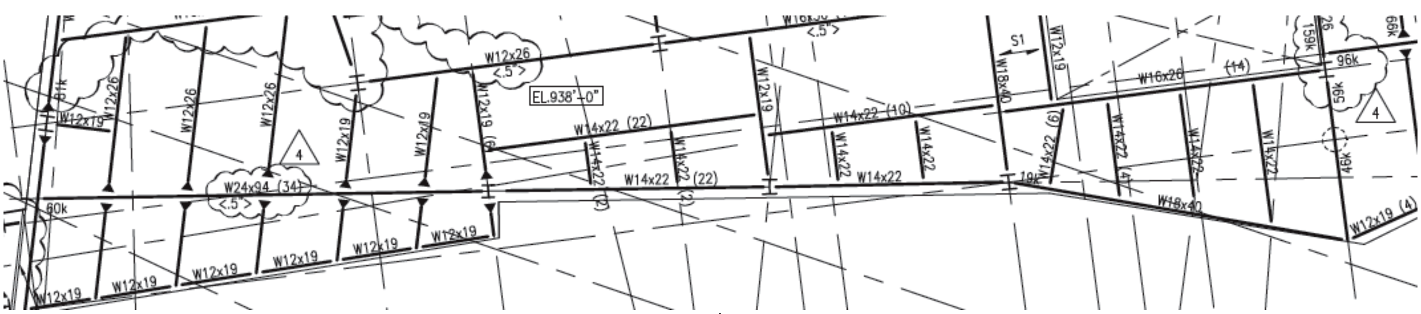


Figure 9 – South Portion of 5th floor framing plan.

Solution Statement

Figure 10 – Braced Frames and Shear Wall Locations floor framing plan.

The proposed structural redesign consists of changes to two major structural systems within the USB. First will be the lateral system; changing the system to all shear walls with supplemental moment frames. As currently designed, the lateral system consists of both shear walls and braced frames; 16 braced frames and 3 shear walls. The design process will include determining the locations and sizing of the walls. Initially, the location of the existing braced frames will serve as a first trial location of the shear walls, as shown in Figure 10. From there moment frames will be placed to help reduce torsion due to the torsional irregularities of the structure. This will most likely be an iterative process. Secondly, the existing composite steel deck floor system will be redesigned as a two way reinforced flat slab concrete floor. Both systems will be designed and verified by hand calculations and computer software and finally analyzed as a whole structure in ETABS.

Per Technical Report 2, the two way flat plate system, without drop panels, was analyzed and compared to other floor systems; composite deck, one way slab with beams, and precast hollow core planks. As initially designed, a 12” deep slab is the cheapest system at $16.35/SF but also the heaviest at 150 psf. Other factors such as the foundation design and construction schedule will be affected. Further detailed information can be found in Technical Report 2. See Figure 11 for a tentative cross section of the slab through a column/drop panel.

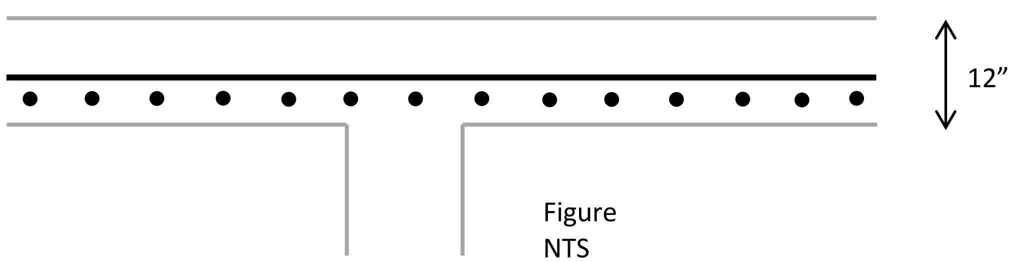


Figure 11 – General cross section of two way flat slab through column

Due to the complexity and odd angles of the floor construction, pouring concrete into these shapes will be easier than framing steel and deck into these shapes. As previously noted, the lay out and connections of the framing members was very time consuming which consequently lost money. The introduction of concrete is intended to help illuminate these problems.

With the structural system changing to predominately concrete, the use of form work and other materials will be of interest when considering its construction. Due to the irregular floor plans, the reuse of constructed formwork will not be readily available. It is suspected that the original cost of $16.35/SF will increase because of the need to construct new formwork on almost every level. Although the preliminary research of technical report 2 indicates these specific details of this floor system, a thorough redesign will be necessary, along with revised cost estimates and system specifications.

Breadth Topics

Construction Management

The main focus of the construction management breadth is to construct a phased construction schedule with more attention on the structural construction. The USB has essentially two different buildings that are vital to be constructed in the most economical sequence. The change of the structural system from steel to concrete will induce a different schedule and sequence for construction. Tasks such as setting formwork and the curing of concrete will all need to be phased to allow for the quickest and cheapest construction.

In addition, the construction of the shear walls will be planned and scheduled with respect to the construction to the floor systems. Factors such as weather and availability of the concrete on days of pouring will all have a vital impact on the phased schedule.

Finally, a thorough cost report will be determined. This report will focus on the change of the structural and mechanical system (breadth topic 2). This will be compared to the existing system and is anticipated to lower the overall project cost.

Mechanical

Due to the structural change of steel to concrete the behavior of the mechanical system will change as well. The focus of this breath will be to identify where and how the loads will have changed throughout the building. This will potentially change which system is most economical per the new conditions. In addition, the existing floor depth is 30.2” deep (steel beams and deck), whereas the new concrete floor system will be about 12” deep. This addition to the plenum space will provide more flexibility within this space, possibly allowing for a more efficient system.

Also, mechanical penetrations and connections will be considered with respect to a concrete structural system. Penetrations will be important for maintain the structural system’s integrity.

Task and Tools

Structural Depth - Shear Walls and Two Way Flat Slab

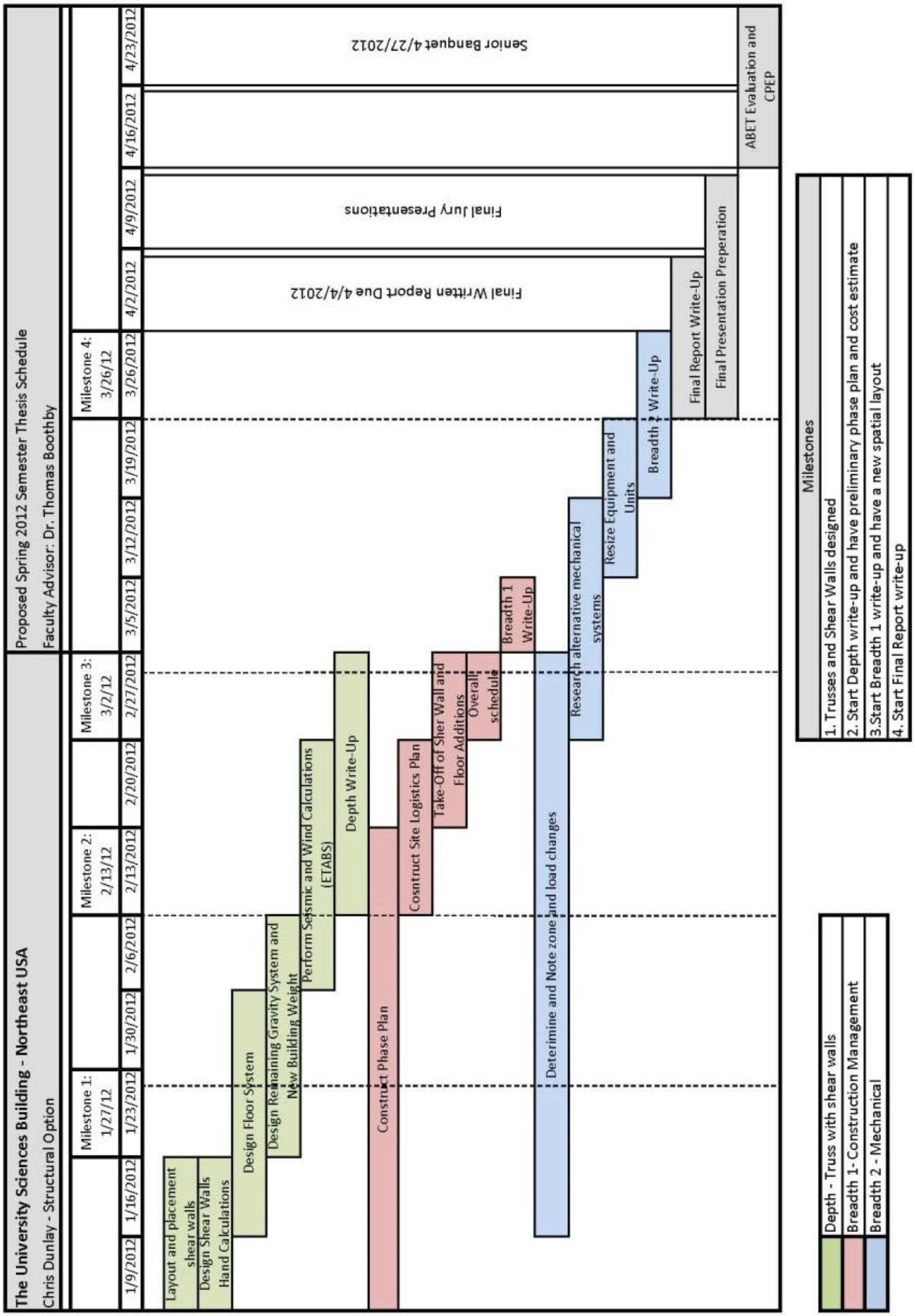
1. **Task 1: Determine Shear Wall Locations**
2. **Task 2: Determine Shear Wall and Moment Frame Properties and sizes**
    a. Relative Stiffness by hand calculations
    b. Portal Frame analysis for moment frames
3. **Task 3: Design Two Way Flat Slab System**
    a. Direct Design Method (By Hand)
    b. Equivalent Frame Method (By Hand)
    c. PC Slab Verification
4. **Task 4: Size Columns**
    a. Determine additional load per column. Design Columns
    b. PC Column Verification
5. **Task 5: Determine New Building Weight**
6. **Task 6: Redesign Per Seismic and Wind Conditions**
    a. Seismic hand calculations
    b. Wind hand calculations
7. **Task 7: Construct Computer Model**
    a. Analyze new design in ETABS
8. **Task 8: Revise Design**
9. **Task 9: Revise Proposal**

Breadth 1 – Construction Management

1. **Identify individual sections of construction to be phased**
    a. Schedule each phase
    b. Identify areas of overlap (efficiency)
2. **Identify change in project price**
    a. Structural and mechanical changes
        i. Material and hard costs
        ii. Labor costs
3. **Construct adjusted project schedule**

Breadth 2 – Mechanical

1. **Research effects of increased plenum space**
2. **Determine the change in loads**
    a. Identify current zones and loads
    b. Calculate new loads
3. **Research the most economical system**
    a. Compare existing with potential alternatives
    b. Configure new system or modify existing
4. **Coordinate clashes with mechanical equipment and concrete structure**


The University Sciences Building - Northeast USA
Proposed Spring 2012 Semester Thesis Schedule
Chris Dunlay - Structural Option
Faculty Advisor: Dr. Thomas Boothby
Milestone 1: 1/27/12
Milestone 2: 2/13/12
Milestone 3: 3/2/12
Milestone 4: 3/26/12
1/9/2012
1/16/2012
1/23/2012
1/30/2012
2/6/2012
2/13/2012
2/20/2012
2/27/2012
3/5/2012
3/12/2012
3/19/2012
3/26/2012
4/2/2012
4/9/2012
4/16/2012
4/23/2012
Layout and placement shear walls
Design Shear Walls Hand Calculations
Design Floor System
Design Remaining Gravity System and New Building Weight
Perform Seismic and Wind Calculatons (ETABS)
Depth Write-Up
Construct Phase Plan
Cosntruct Site Logistics Plan
Take-Off of Sher Wall and Floor Additions
Overall schedule
Breadth 1 Write-Up
Deterimine and Note zone and load changes
Research alternative mechanical systems
Resize Equipment and Units
Breadth 2 Write-Up
Final Report Write-Up
Final Presentation Preperation
ABET Evaluation and CPEP
Final Written Report Due 4/4/2012
Final Jury Presentations
Senior Banquet 4/27/2012
Depth - Truss with shear walls
Breadth 1- Construction Management
Breadth 2 - Mechanical
Milestones
1. Trusses and Shear Walls designed
2. Start Depth write-up and have preliminary phase plan and cost estimate
3.Start Breadth 1 write-up and have a new spatial layout
4. Start Final Report write-up

Conclusion

The proposed alternative design of the University Sciences Building focuses on the redesign of the existing steel structure to a two way concrete flat slab floor system with drop panel and concrete shear walls. This process will include research and multiple designs to find the most economical systems. The design will consist of hand calculations and the use of computer software. Both gravity and lateral loads will be analyzed to obtain the optimal structural design. The introduction of these systems are intended to maintain the acceptable structural capabilities and to also increase the efficiency of construction and lower the overall costs.

With introducing different structural systems, other features and systems of the building will be affected. Theses affects will be analyzed and addressed with two breadths; construction management and mechanical. The construction management breadth will focus on a phased construction plan. With essentially two buildings and complex floor plans, a phased plan will help maximize the construction schedule. In addition, incurred cost from the alternative structural system will be analyzed with an adjusted project schedule. The second breadth addresses the adjustments to the mechanical system. This breadth will focus on the change in the different loads induced by the new structural system, as well as the availability of more plenum space. Alternative systems will be researched and possibly implemented upon the completion of the research. The possibility of slightly adjusting the existing mechanical system may prove to be the most economical.

The redesign semester will follow the schedule provided in this proposal. Any changes, whether additions or omissions, will be noted in forthcoming revised proposals.