The University Sciences Building

Proposal – 12.12.2011

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Executive Summary

The main purpose of this proposal is to identify issues and challenges with the existing design and to propose a solution to these issues. To assist these solutions, tasks, tools and a semester long schedule is 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. The building is constructed with concrete on the first 3 levels and steel the remaining 5 levels. The floor system 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 both braced frames and shear walls with varying heights.

As originally designed, the structural system has minimal flaws. An alternative design to obtain maximum efficiency is difficult to propose. After much research and investigations into alternative systems, I have proposed a solution to better the lateral systems as well as deep trusses to better assist the designed cantilevers. Currently, two solutions are to be further investigated. The first is the change the core lateral system from braced frames to shear walls, as well as introduce deep trusses to address the cantilevers. Second is to integrate both of the solutions together to form one rigid system, although this solution may prove to be infeasible.

As per the schedule, these proposed solutions will follow a logical schedule to help reach a final design as well as address the breadths. Two breadths will be of interest in the semester to come. First is a construction management breath. The primary focus of this breadth 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 breadth will pertain to the architecture. Both topics of the depth will incur altercations to the spatial layout and façade. The breath will investigate the changes needed to the spaces in the USB and the façade construction when applying the shear walls and trusses.

Building Introduction

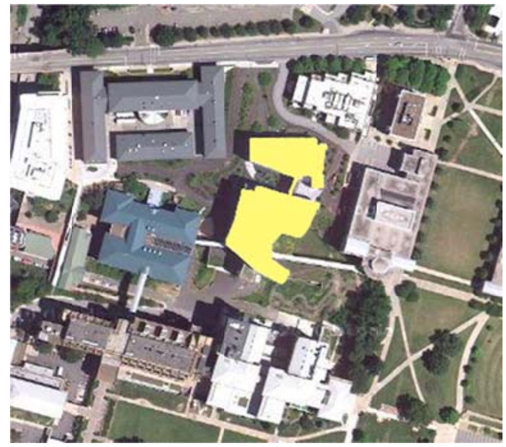


Figure 1 – Google Maps aerial view of site

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 2 – Helical ramp

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 3 – South Cantilever

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. 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.

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 use concrete beams and slabs with a combination of concrete columns and steel encased columns. The upper floors of both buildings use 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 assumpiton that the soil class was solid rock. The majority of the University's soil has been geologic lly tested to show this. As time proceeded and the geotechincal report was released, it was found that the site class was different than anticipated, was a site class C was determined appropreiate. This induced a complete redesign of Building 2's foundation along with using a new 'flowable fill' for backfill for Building 1. Flowable fill is entrained with fly ash, cement, and other agents to generate negliable lateral pressure on surrounding foundation walls but maintains a compressive strength of 500 psi (Calculations for this are not provided in this technical report).

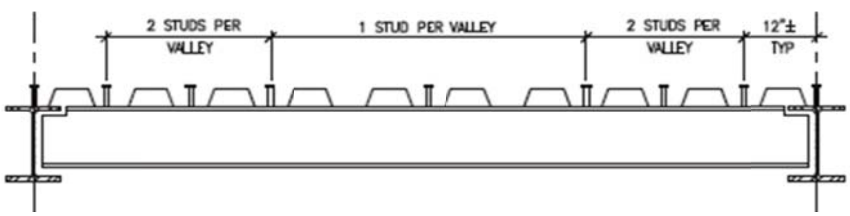
In has been concluded from the structural drawings that the allowable soil/rock bearing pressures for spread footings on weathered shale are 6000 psf. Likewise for siltstone/sandstone allowable pressures are 12000 psf. In addition, caissons socketed 5' into siltstone/sandy stone are to have an allowable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

The building load path initiated from the floor systems to columns and then to their respective caissons or interior column footings. For exterior perimeter caissons, they 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 withstand 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 dry density per ASTM D 1557. A vapor barrier is then required to be placed between the fill and the slab.

Expansion joints should be 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, typical 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".



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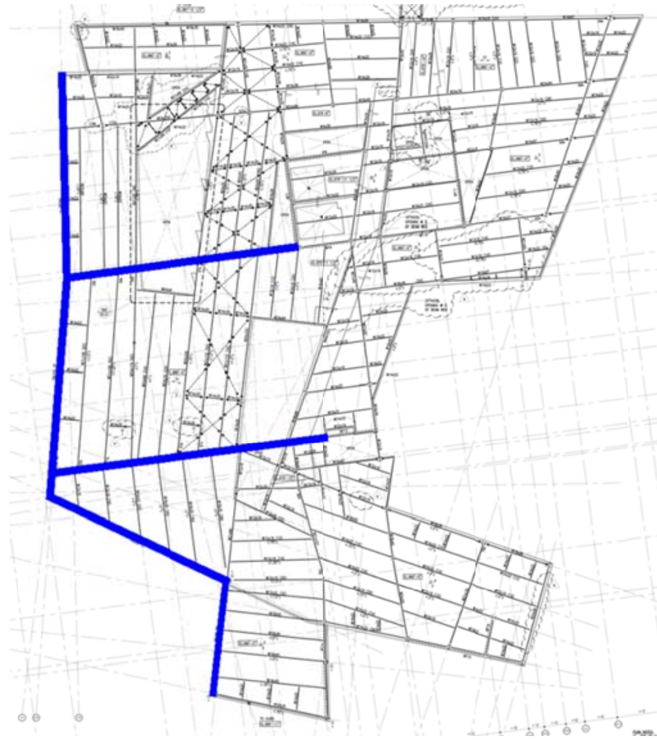
The composite and non-composite decks are placed with the ribs of the deck perpendicular to the infill beams to maintain the rigidity of the system. This proved to be a conflict to construct with the placement of shear studs. Where it is efficient to place studs along the length of the beam uniformly normal to the valley and peaks of the deck, it was extremely difficult 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 doesn't hold true 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. .



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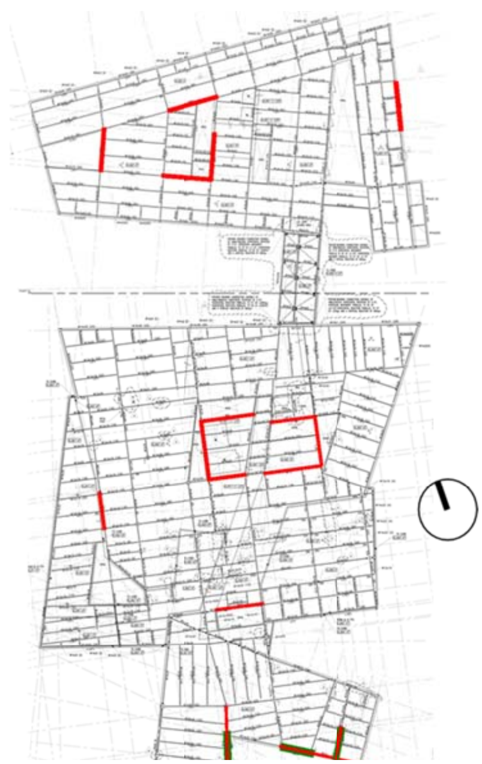
An intricate and vital part of this structural framing system is the truss system in Building 1 which varies in height from Level 6 to the roof (Figure 5). These trusses are comprised of chord sizes as big as W30x292 and intermediate bracing elements as small as W14x53. Due to the complex cantilevers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

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



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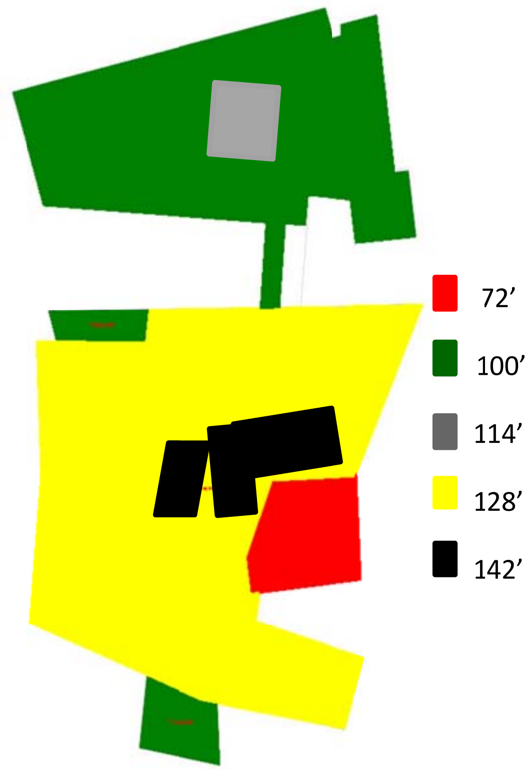
building are kept on the lower floors, which has been assumed to

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 for adaquacy.



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

Technical Reports 1 and 3 have confirmed and displayed the structural strength and serviceability adequacy requirements. Due to the complexity of the building the construction efficiency was comprised with respect to the lateral and supplemental systems. 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 will be utilized to adequately resist lateral loads. The complexity of connections within these braced frames caused much delay and confusion during construction. The decision of 16 braced frames can either be attributed to the design professional's preference or many other reasons. Proposing a shear wall lateral system at the core that, as designed, consists of 6 braced frames may help reduce the complexity of connections therefore helping the construction efficiency.

Furthermore, the cantilevers of the USB were a challenge in the design process and will be a point of interest in this proposal. Implementing trusses to account for these cantilevers may prove a more efficient structural system. The intent is to have these trusses tie into the core of the building and to have portion of the truss cantilever out. Initially it is thought that this could decrease structural dead load in the cantilevered areas. The floor system may be altered slightly from the original design but for the most part remain the same.

Solution Statement

Two main solutions for the USB have been proposed. These solutions also include other minor solutions independently that will be explored separately throughout the design process. They will be compared to find the most efficient system. The following are the two proposed solutions.

1. Core shear wall lateral system and deep trusses on cantilevers
2. Core shear wall lateral system integrated with deep trusses.

The reason for two different solutions is because an adequate design of the trusses will perform well in gravity conditions but may not against lateral loads. Integrating the deep trusses with the core shear walls may allow the whole system to resist lateral loads more efficiently. The intent will be to design will be to design the trusses to resist gravity loads with a focus on the cantilevers, while considering the interaction with the rest of the gravity system. Next the deep trusses will be integrated with the core lateral system to not only determine its individual lateral adequacy but also as a lateral system as a whole.

With the consideration of two academic breadths, construction management and architecture, this proposals schedule, tasks and tools will help outline an efficient process to achieve an alternative design.

Breadth Topics

Construction Management — Phased Construction, Schedule, and Cost

The main purpose of the construction management breadth is to construct a phased construction schedule. If the system chosen is the deep trusses integrated with the shear walls, then the pouring and erecting of both systems will be a main focus. The order in which these tasks are completed will be paramount to the other tasks falling in place. In addition, the construction of two buildings and the complexity of floor plans can be constructed with more accuracy and efficiently after an implemented phased construction plan. Also due to the size of the deep trusses, the staging and picking of members will need to be strategically placed. These tasks will inherently affect the rest of the construction project.

Furthermore, the change of shear walls from braced frames will induce more concrete and formwork cost. The complexity of the system may also cause increased labor hours. Detailed estimates of structural members will be of most interest. These changes may also affect architectural aesthetics, which will also have a need for detailed estimates.

Architecture — Spatial Layout and Façade

Since the primary use of the deep trusses is to provide adequate structural strength, the layout of architectural spaces may be compromised. Certain spaces may need to be rearranged because most areas will be impenetrable due to the diagonals of the trusses. Furthermore, the trusses may be visible in some areas through the windows that are currently designed. An alternative design and location of the windows and other elements of the façade may be necessary.

Task and Tools

Depth- Deep Trusses with New Shear Walls

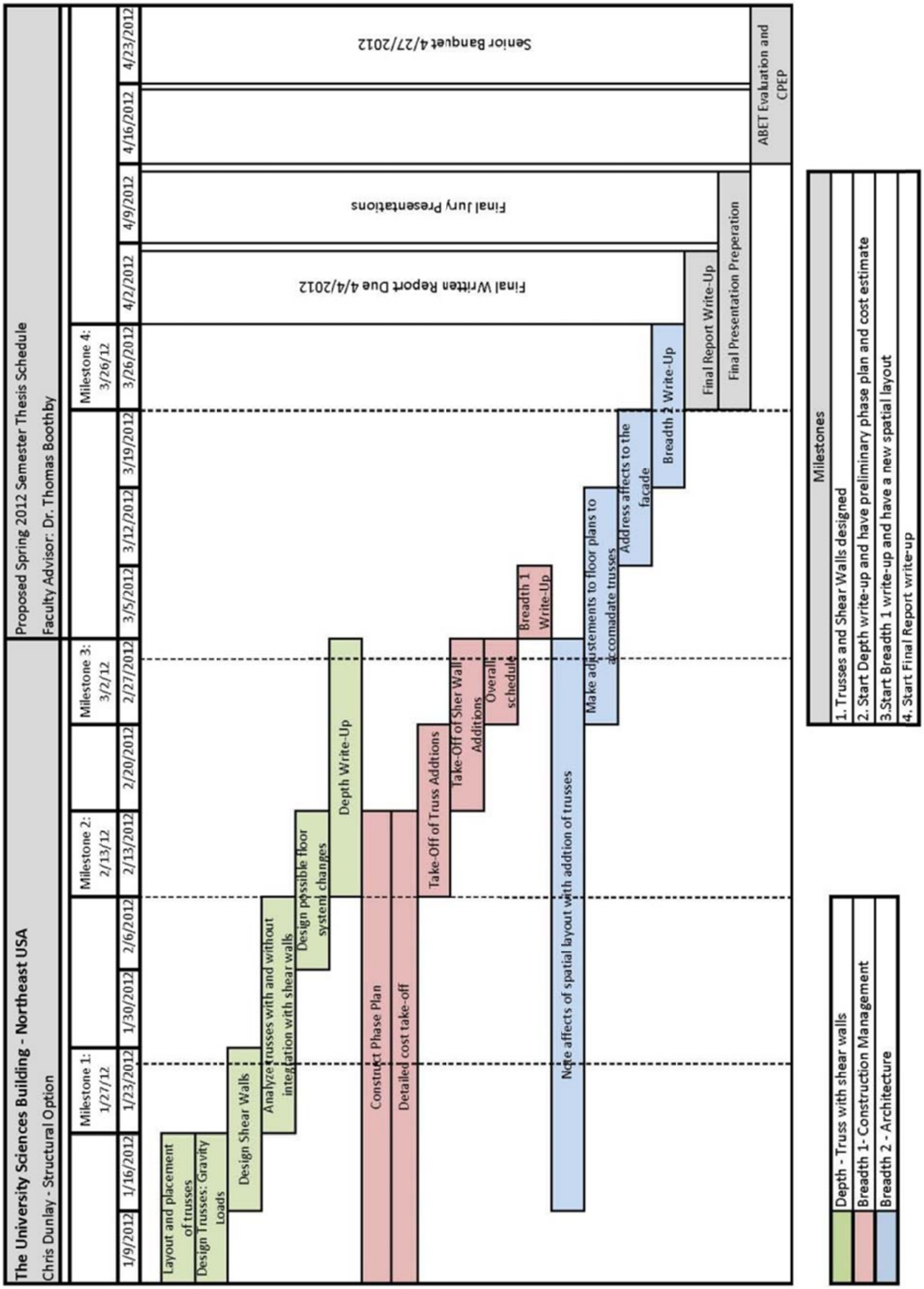
1. **Task 1: Make a proposed layout of trusses**
   a. Where is the most efficient placement
2. **Task 2: Design the trusses under gravity loads.**
   a. Determine member sizes
   b. Determine truss configuration
   c. Determine member connections
   d. Construct a computer model of the truss
3. **Task 3: Design the shear walls at the core**
   a. Determine material properties
   b. Design the shear wall per the lateral loads
   c. Construct a computer model of the system
4. **Task 4: Determine how much lateral load the trusses receive**
   a. Perform hand and computer model calculations
5. **Task 5: Explore the option of trusses integrated with shear walls**
   a. Determine the difference in layout
   b. Design the connection of steel trusses with respect to shear walls
6. **Task 6: Consider needed altercations in floor system with trusses**
   a. Design Composite floor system for the affected areas
7. **Compare designs, methods, pros and cons.**

Breadth 1 – Construction Management

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

Breadth 2 – Architecture

1. **Identify areas where trusses will affect spatial layout**
    a. Match trusses with wall construction
    b. Do not obstruct life safety plan
2. **Identify areas where trusses may affect the façade**
    a. Do they obstruct windows?
    b. New façade construction?


The University Sciences Building - Northeast USA
Chris Dunlay - Structural Option
Proposed Spring 2012 Semester Thesis Schedule
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 of trusses
Design Trusses: Gravity Loads
Design Shear Walls
Analyze trusses with and without integration with shear walls
Design possible floor system changes
Depth Write-Up
Construct Phase Plan
Detailed cost take-off
Take-Off of Truss Addtions
Take-Off of Sher Wall Additions
Overall schedule
Breadth 1 Write-Up
Note affects of spatial layout with addtion of trusses
Make adjustements to floor plans to accomadate trusses
Address affects to the facade
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 - Architecture
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 lateral system and an introduction of deep trusses to help increase the structural efficiency and constructability. With an unknown layout and design of the proposed trusses, many viable options for its construction and use are still available. Currently two different options are being considered. First is the redesign of the core lateral system from steel braced frames to concrete shear walls to help reduce the constructability issue. In addition, deep trusses will be designed to help resist the gravity loads for the building's complex cantilevers. Secondly, the two concepts of the first option will be investigated as an integrated system. This will help achieve a more efficient system to resist lateral loads.

In introducing different structural systems, other features and systems of the building will be affected. This proposal addresses two breadths; construction management and architecture. The construction management breadth will focus on a phased construction plan. As there are 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 architecture. This breadth will focus on the spatial layout of spaces affected by the addition of trusses. Also, the redesign may affect the façade. The trusses may be visible through the windows and relocating these windows may be of interest.

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