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{Structural Option}
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Virginia Commonwealth University School of Medicine
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Structural Thesis Proposal

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Executive Summary

The following report is a comprehensive proposed thesis that will not only investigate the structural implications of redesigned gravity and lateral systems for the James W. & Frances G. McGlothlin Medical Education Center, but will also explore the impacts made on cost of the project, time required for construction, and architectural features on both the inside and the outside. Located in Richmond, Virginia, the new Virginia Commonwealth University School of Medicine building rests on the previous site of the A.D. William's Building. The foundation system incorporates multiple, differing drilled piers and drilled pier-grade beam combinations to support the 13-story above ground structure. The framing system is all steel on composite steel/concrete decking. Lateral loads are resisted by steel concentrically braced frames, seven total in the building. A 65'-0" pedestrian bridge connects the new structure to the Main Hospital across East Marshall Street. The exterior façade was designed by internationally acclaimed architecture firm Pei Cobb Freed & Partners and is mainly glass and concrete panels. The VCU SOM (School of Medicine) had a vision for both this new building and its reinvented curriculum: open, honest collaboration.

To answer all building functions and program requirements, a rational design alternative of a non-composite system with bar joists and steel girders and a combination of moment and braced frames will be explored in the spring semester of 2014. All gravity members will be redesigned using hand calculations, utilizing computer modeling only to verify assumptions. The lateral system will also be redesigned using self-performed calculations; computer modeling will be applied to assist with editing of existing braced frames and to verify all wind/seismic load cases. The redesigned systems will then be properly vetted to determine if they are economical solutions.

The first breadth will focus on increases/decreases to both the cost and schedule for the VCU SOM project. While the redesign will remain steel construction, many factors will change both the theoretical cost and schedule for the project. An in-depth cost analysis will be completed for the new system and the altered project as a whole; this will then be compared to the original. A schedule analysis will also be completed, focusing solely on the structural system, and will be compared to the original to evaluate if the redesigned system is economical.

The redesigned gravity and lateral systems will also have major impacts on architectural features throughout the project. Changes to the gravity system could result in higher floor vibrations, larger members, and increased floor-to-floor height. The addition of moment frames and editing of braced frames will greatly affect the exterior skin on two faces of the building while also opening up floor space on several floors. All of these impacts will be further considered to ensure the VCU SOM project is not significantly altered and still meets all owner/project requirements.

Building Introduction

The James W. & Frances G. McGlothlin Medical Education Center, also known as the new Virginia Commonwealth University School of Medicine Education Center, is located in Richmond, Virginia. The 13 story, 220,000 square foot building was completed in early 2013. The project was constructed following the demolition of the A.D. Williams Building, which previously housed the VCU School of Medicine faculty offices, outpatient clinics, and laboratories. The new construction, as shown in Figure 1, encompasses all of these program requirements, along with various collaborative spaces, classrooms, and a 300-seat auditorium accessible via the second and third floors.

The building rests atop approximately 60 drilled piers of varying capacities and a 10" thick slab-on-grade. As the building progresses skyward, the structural lateral load resisting system is composed of steel concentrically braced frames, structural steel members, and composite concrete slabs on metal decking. The exterior of the building, designed by internationally acclaimed architecture firm Pei Cobb Freed & Partners, does not contribute to the structural strength of the building, but is intended for aesthetic and environmental purposes. The project is currently under review by the U.S. Green Building Council in hopes of achieving a LEED (Leadership in Energy & Environmental Design) Silver status.

Figure 1 – James W. & Frances G. McGlothlin Medical Education Center when approaching on E. Marshall Street

Structural System Overview

The James W. & Frances G. McGlothlin Medical Education Center, known as the Virginia Commonwealth University School of Medicine (VCU SOM) project during development and construction, is a 13-story building that has both a basement and small sub-basement located below ground level, which is at an elevation of 153 feet. Since the VCU SOM project was constructed following the demolition of the A.D. Williams Building, the foundation system is designed to accommodate existing conditions. The superstructure of the building is composed of a composite concrete/steel deck with steel members and steel concentrically braced frames. Both the 13th Floor and the rooftop house mechanical equipment, requiring added strength. All of these systems are further explained below.

Foundation System

All site investigation and tests drillings, six borings total, were completed by Geotech Inc.; their professional recommendations were then reported in April of 2009. Of the four schemes suggested, an arrangement using three differently sized piers extending 54' below the sub-basement level was applied. The different drilled piers used were intended to account for three variations of loadings: those loads considered "small" (≤ 450 kips), "medium" (730 to 1640 kips), and "heavy" (1640 up to roughly 3300 kips). To support all "small" loads, straight shaft drilled piers ranging in diameter from 3' to 8' were used. When loads were considered "medium", single-belled drilled piers with shaft diameters from 3' to 6' were used, under the condition that the bell diameters were not to exceed 3 times the shaft diameters. For all "heavy" loads, double-belled drilled piers were utilized, with shaft diameters between 3' and 6' and bell diameters between 9' and 13.5'.

During Geotech Inc.'s thorough site investigation, it was concluded that some existing piers would in fact conflict with piers necessary for support of columns in the new construction. To avoid removal of existing piers, a caisson and grade beam system was used where conflicts existed. The grade beams used in this configuration are all 48" deep and range in width, from 24" to 60". The sub-basement floor and portions of the basement floor are slab-on-grade – there are two different slab-on-grades, but the differences are only minor. The slab-on-grade located at the sub-basement level is 6" concrete slab on 4" crushed stone and the slab-on-grade located at the basement level is 5" concrete slab on 5" crushed stone.

Floor System

The typical slab-on-deck found on floors 2 through 12 is a composite concrete/steel system. Most floors utilize 3", 20 gauge composite galvanized steel decking with a 3 ½" lightweight concrete topping. ½" diameter steel rebars placed at 12" on center provide reinforcement for the concrete. Shear studs, placed along the beams and girders, provide for composite behavior between the members and floor system.

Framing System

The VCU SOM framing system is composed of steel members: columns, beams, and girders.

Since a variety of loads are applied, the columns range anywhere in size from W10x88 to W14x455, with the majority of the columns closer in size to W14x145. Beams and girders throughout the structure are also composite steel construction; the beams are typically W18x35 and the girders are typically W24x76, excluding areas where extra strength is required.

Due to the irregularity of the structure's shape, a single typical bay is not common throughout the entire building. However, the 4th thru 13th Floors are closer in design and function, and therefore are more ordered. There are two bay sizes that make up the majority of these floors: a 30'x20' bay and a 30'x40' bay. A typical floor plan showing the 30'x20' size bay can be seen in Figure 2 below. To allow for open classroom space on several floors, the 30'x40' bay is necessary, explaining the variant bay sizes.

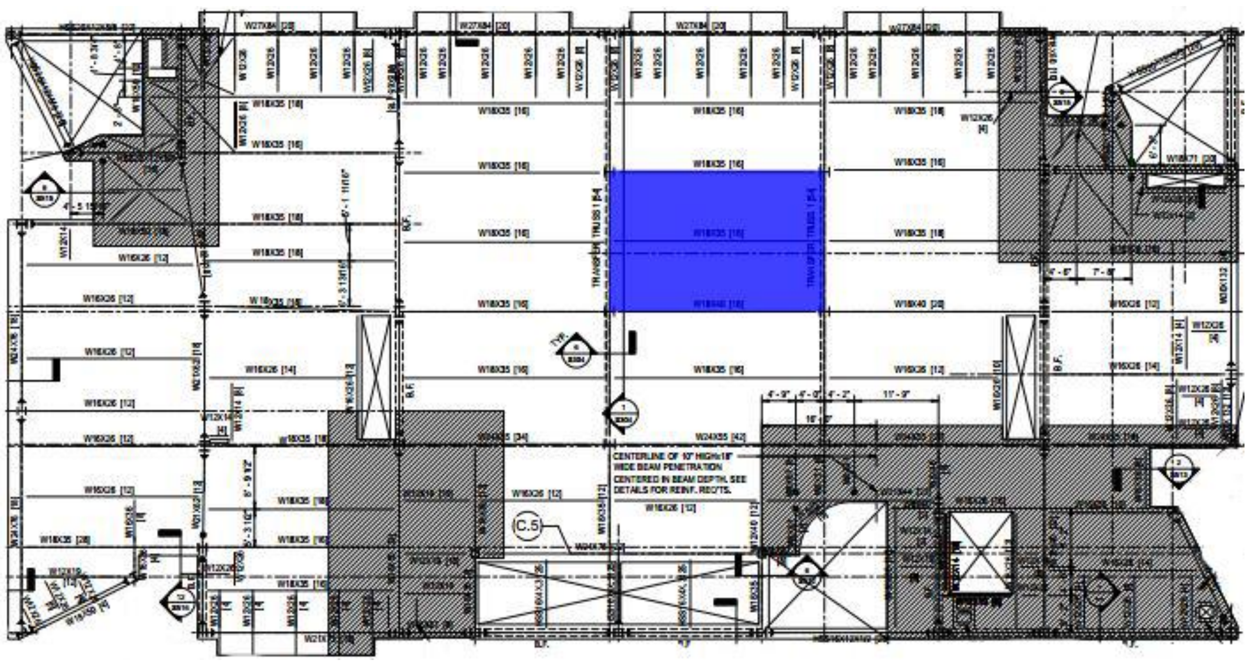


Figure 2 – Typical Floor Plan with Smaller Bay Size Emphasized

Lateral Force Resisting System

The VCU SOM's main lateral resisting system is a combination of braced frames and moment connections throughout the structure. There are seven steel concentrically braced frames, six traveling in one direction, with one frame contributing to the strength in the other path. The braced frames can be found highlighted in Figure 3. The layout of the braced frames accounts for lateral loads that could be applied from any of the possible directions. All of the frames are concentric, but each frame differs in size and levels included. Detailed drawings of the seven braced frames can be found in the supplemental drawings in Appendix A. A basic description of the applied lateral loads can be found below.

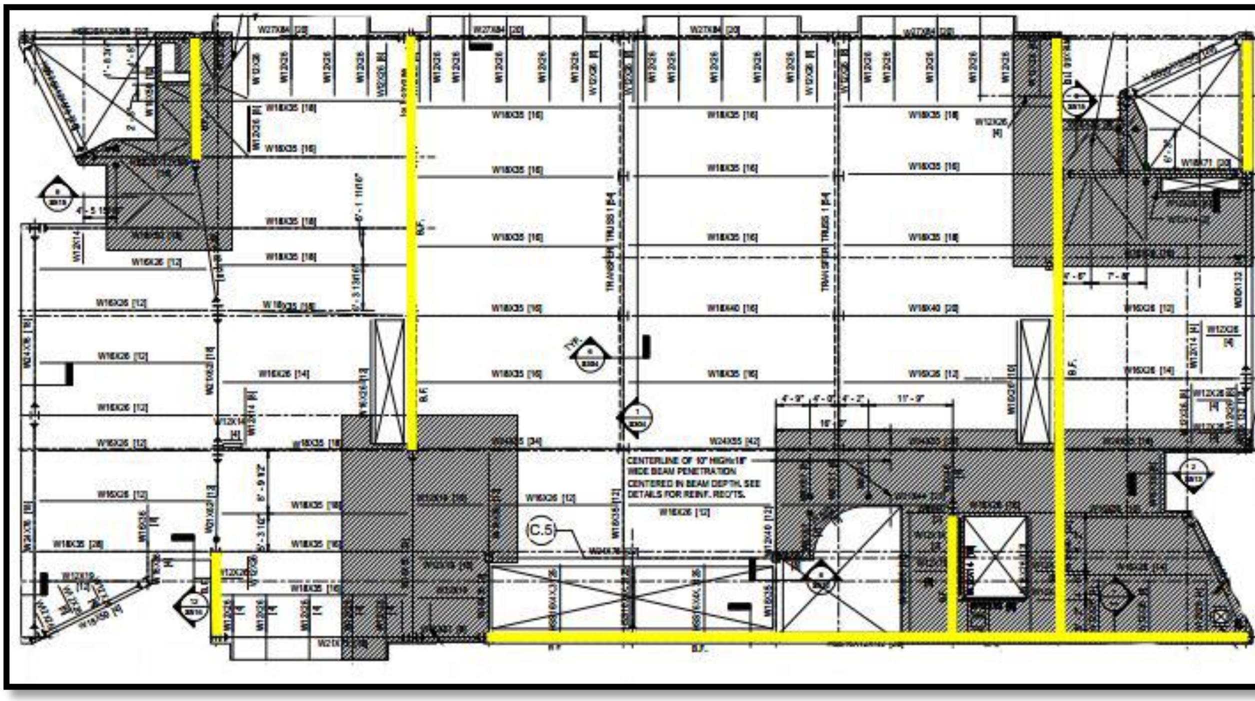


Figure 3 – Framing Typical to Floors 4th thru 12th with Braced Frames Highlighted

As seen in Figure 3, the braced frames throughout the structure span both directions, with the majority of the strength running North to South. Due to the positioning of the building, the anticipated loads are difficult to determine without a full investigation. The VCU SOM project is surrounded by equally tall buildings, but the wind tunnel effect cannot be discounted. The basic idea behind the lateral resisting system used in this project is that all "roads" will lead to the braced frames. Lateral loads hitting the building from any direction with traverse perpendicularly from their original direction across the floor through the beam and girder system. These loads will then be applied to the braced frames, which have been designed to withstand these pressures.

Roof System

The roofing system found in the VCU SOM project consists of 1 1/2", 18 gage wide-rib steel roof deck covered with a rubber roofing membrane (EPDM). This Ethylene-Propylene-Diene-Monomor (EPDM) rubber roofing is fully adhered on top of tapered insulation. Often referred to as white roofing for its coloring, EPDM installed in this building was required to have a specific solar reflectance to contribute to LEED certification. The roof deck is supported from below by W16x26 beams spaced at 5'-0" and W27x84 girders every 30'-0".

Bridge to Main Hospital

One of the most complicated structural elements found in the VCU SOM project is the bridge that connects the 2nd Floor to the existing Main Hospital 1st Floor, crossing E. Marshall Street. Approximately 65 ' in length, the bridge exits the VCU SOM building at an angle and travels on a diagonal towards the Main Hospital, as shown in Figure 4 below. The bridge also slopes 2" towards the Main Hospital, starting at an elevation of 169'-2" and ending at an elevation of 169'-0". The bridge has a height of roughly 14'-6" from the surface of the bridge floor to the bottom of the roof deck (at the intersection with VCU SOM project).

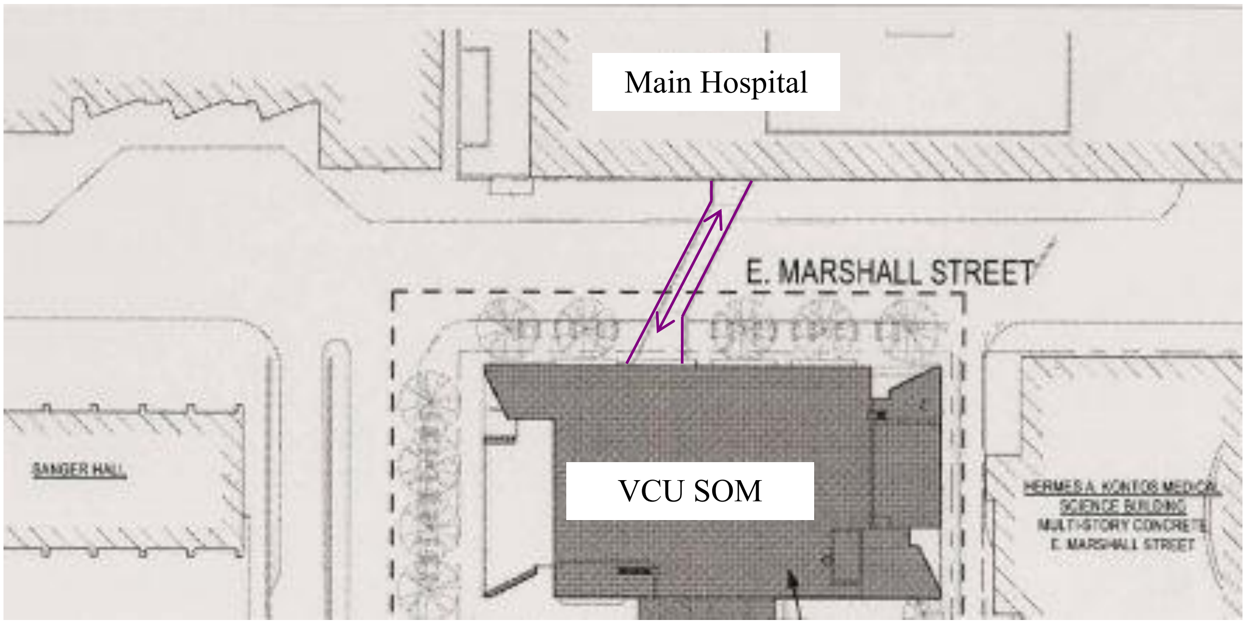


Figure 4 – Bridge Connecting VCU SOM to Main Hospital

Structural Design Alternative

Objective

As mentioned in the Structural System Overview, the VCU SOM building is composed of steel structural members, a composite concrete/steel floor system, and steel concentrically braced frames. While investigating alternate systems in Structural Technical Report III, it was determined that steel was the most economical option for the gravity system. Steel is moderately easy to construct, reasonably priced, and lightweight. While a composite deck and beam/girder system is used in the project, the possibility exists that using alternative steel systems could help reduce costs, decrease the schedule, and allow for larger spans and bay sizes.

The Lateral Load Resisting System for the VCU SOM building could also be altered to ultimately improve the building as a whole. The current system, seven concentrically braced frames, limits the layout for classrooms, offices, and open learning spaces on each level. With the addition of moment frames traveling in the East-West direction of the structure, the opportunity exists to edit and/or eliminate the braced frames traveling in the North-South direction.

Proposed Solution

In order to ensure the most efficient gravity system is being used, an alternative steel system will be designed and compared to the original. From Structural Technical Report III, it was determined that a gravity system consisting of non-composite decking with K-series bar joists and steel girders could be feasible. The use of bar joists has the potential for a decreased schedule, but the question does exist if bar joists really are less expensive in the "big picture" of the building. The validity of the alternative steel system will be analyzed not only for its structural strength, but also its feasibility and serviceability.

The lateral load resisting system will also be altered to ensure the most effective system is in place; both moment and braced frames will be used in conjunction in hopes of creating a more efficient, open building. Braced frames will remain in the North-South direction, but moment frames will be designed to travel in the East-West direction of the structure. With the addition of the moment frames, some of the current braced frames will either be edited or removed entirely. The editing of the braced frames, to occur after preliminary design of the moment frames, will be based on the strength required to carry the lateral loads and resist applicable torsional effects.

Solution Method

The redesign of the steel gravity system will be completed with the assistance of Steel Design Guide 11, AISC Steel Construction Manual, and Vulcraft Steel Roof & Floor Deck Catalog. Non-composite flooring, steel floor framing members, and columns will be designed by hand. Once member sizes are found, they will be compared to RAM design output utilizing the same loadings to ensure both hand calculations and RAM output is accurate for given conditions.

The redesign of the lateral load resisting system will require more iteration, especially since the braced frames will involve editing or elimination. The AISC Steel Construction Manual will again be referenced, along with specific design examples found on the AISC website. Once a preliminary design is found using hand calculations and application of basic wind & seismic loadings, a RAM model will be created and verified. Utilizing RAM, all other wind & seismic loadings will be completed to ensure no extreme torsional effects exist.

Breadth Topic 1 – Cost & Schedule Analysis

While the new structure (both gravity and lateral load resisting systems) will remain steel construction, both the cost and schedule need to be further analyzed to fully understand the effects of the redesign. It is misleading to state that the cost will decrease due to the gravity system change – K-series joists are typically less expensive in comparison to rolled beams when only considering the amount of steel required and installation. However, K-series joists result in higher floor vibrations, larger floor-to-floor heights, and additional fireproofing measures. All of these consequences have an associated price that affects the total cost of the project. An in-depth cost analysis will need to be completed for the entire project and then compared to the original to have an accurate comparison. A schedule analysis will also be completed, focusing solely on the structural system, since the redesign will change lead times, installation, and fireproofing required. The new schedule will then be compared to the structural system schedule for the original project.

Breadth Topic 2 – Architectural Considerations

The VCU SOM project was intended to create an environment conducive to a redesigned curriculum for the school – open floor plans that provide spaces for team meetings, faculty consultations, and large group classes. While the original design achieved this on several floors, the opportunity exists to create more open spaces with the redesign of the lateral system. With addition of moment frames traveling in the East-West direction, some of the braced frames traveling North-South could be eliminated or removed entirely. The editing or removal of braced frames could produce a more open environment, void of cumbersome steel bracing members. However, the addition of moment frames on the exterior of two sides of the building could affect the skin designed by internationally acclaimed architecture firm Pei Cobb Freed & Partners. Another architectural impact caused by the redesign stems from the gravity system: K-series joists typically are deeper than rolled beams when supporting the same floor. The added height would result in larger floor-to-floor heights, affecting the building immensely. All of the architectural impacts will need to be considered to validate if the structural design alternative is truly feasible.

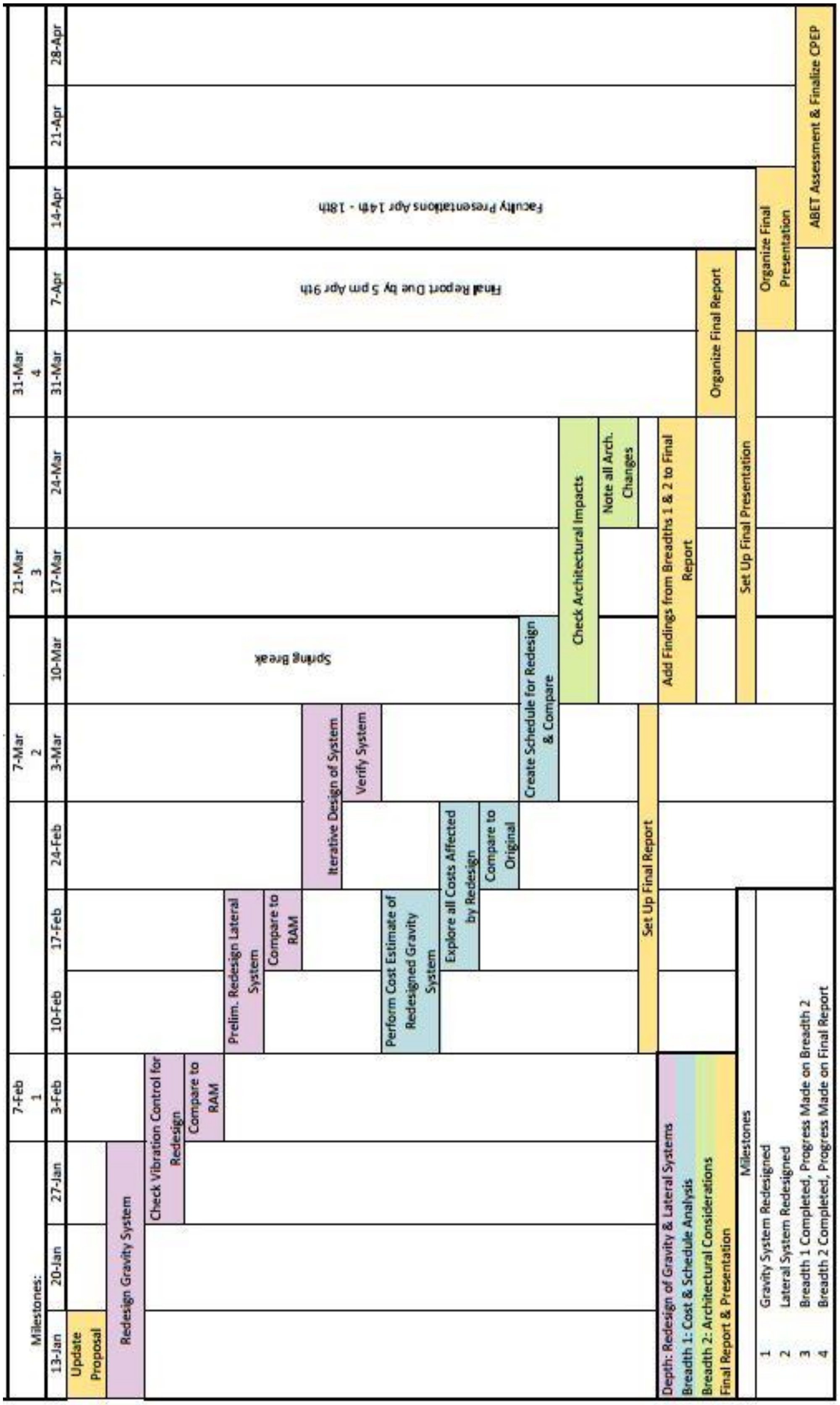
Tasks

1) Redesign Gravity System
    a) Design non-composite flooring
    b) Design horizontal steel framing members (K-series joists & girders)
    c) Check vibration control for floors
    d) Design vertical steel framing members (columns)
    e) Apply design loadings used in hand calculations to RAM
    f) Compare RAM design to hand calculations to ensure accuracy of both
2) Redesign Lateral System
    a) Determine all gravity loadings
    b) Determine wind & seismic loadings
    c) Design initial moment frames in East-West direction
    d) Verify validity of moment frames by comparing to RAM output
    e) Complete multiple iteration of lateral system redesign in RAM, editing braced frames when possible
    f) Once satisfied with redesign, complete all wind & seismic loadings on RAM model to verify acceptable
3) Perform Cost & Schedule Analysis
    a) Using RSMeans, completed detailed cost analysis of redesigned gravity system (just structural implications)
    b) Theoretically adjust all costs affected by redesign (entire project)
    c) Compare redesigned system to original system (just structural costs)
    d) Compare redesigned system to original system (considering all possible cost implications)
    e) Create schedule for redesigned gravity system
    f) Compare construction/installation times required for redesigned and original system
4) Research Architectural Possibilities due to Redesign
    a) Adjust floor-to-floor height for gravity system redesign
    b) Ensure vibration control is achieved in accordance with code requirements
    c) Examine effects of lateral system redesign on exterior skin
    d) Either model or hand sketch any necessary changes to exterior skin

   e) Explore additional implications from structural redesign
   f) Verify all changes are in-line with VCU standards/program

5) Final Report & Presentation
   a) Set up final report
   b) Set up final presentation
   c) Add to final report & presentation as progress is made
   d) Finalize final report & submit
   e) Finalize final presentation & practice
   f) Present findings for evaluation

Schedule

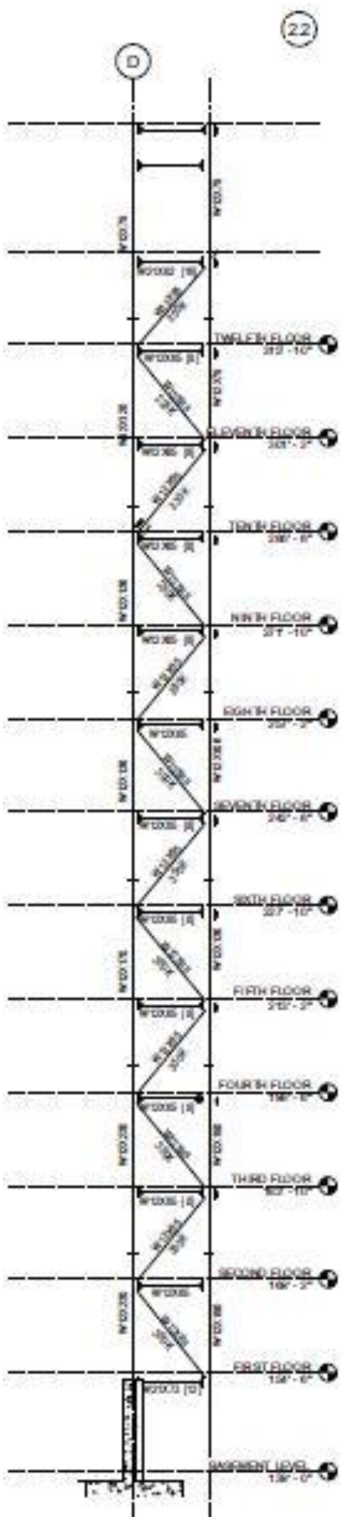

Milestones:
7-Feb
1
7-Mar
2
21-Mar
3
31-Mar
4
13-Jan
20-Jan
27-Jan
3-Feb
10-Feb
17-Feb
24-Feb
3-Mar
10-Mar
17-Mar
24-Mar
31-Mar
7-Apr
14-Apr
21-Apr
28-Apr
Update Proposal
Redesign Gravity System
Check Vibration Control for Redesign
Compare to RAM
Prelim. Redesign Lateral System
Compare to RAM
Iterative Design of System
Verify System
Perform Cost Estimate of Redesigned Gravity System
Explore all Costs Affected by Redesign
Compare to Original
Create Schedule for Redesign & Compare
Spring Break
Check Architectural Impacts
Note all Arch. Changes
Set Up Final Report
Add Findings from Breadths 1 & 2 to Final Report
Organize Final Report
Set Up Final Presentation
Final Report Due by 5 pm Apr 9th
Faculty Presentations Apr 14th - 18th
Organize Final Presentation
ABET Assessment & Finalize CPEP
Depth: Redesign of Gravity & Lateral Systems
Breadth 1: Cost & Schedule Analysis
Breadth 2: Architectural Considerations
Final Report & Presentation
Milestones
1 Gravity System Redesigned
2 Lateral System Redesigned
3 Breadth 1 Completed, Progress Made on Breadth 2
4 Breadth 2 Completed, Progress Made on Final Report

Closing

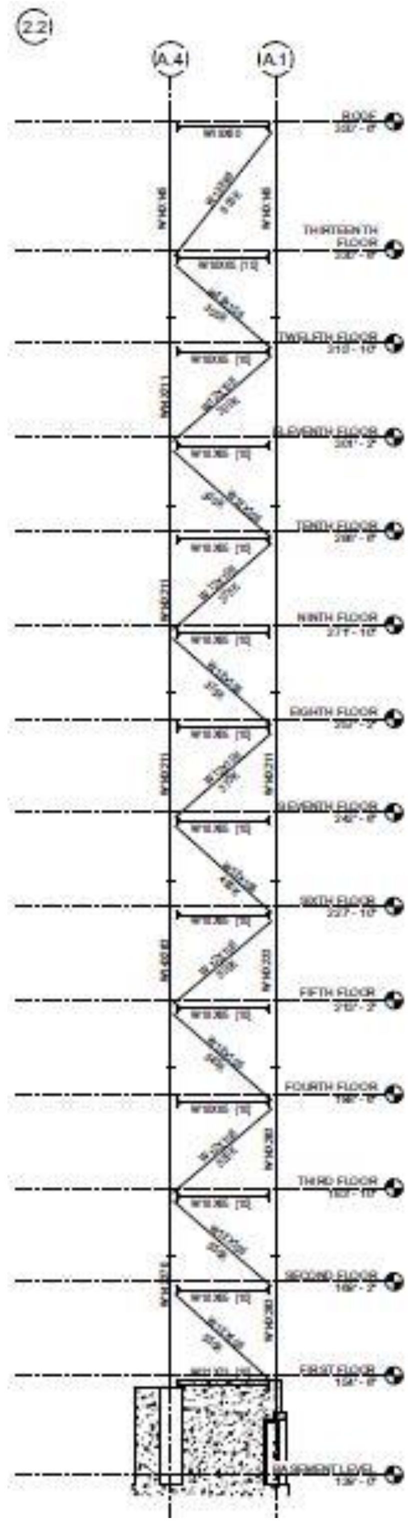
As mentioned prior to this report and demonstrated throughout the text, rational alternatives exist for both the gravity and lateral systems found in the James W. & Frances G. McGlothlin Medical Education Center. While the original composite steel/concrete system with braced frames meets all requirements, a non-composite system with bar joists and a combination of moment and braced frames could provide additional strength and removal of cumbersome bracing. To prove the validity of this redesign, both hand calculations and computer modeling will be completed during the spring semester.

The changes to the gravity and lateral systems will not only affect the structure of the building – there will also be significant impacts on the floor height, exterior skin, cost, and schedule for the VCU SOM project. The first breadth of this proposed thesis will explore cost and schedule changes caused by the structural system redesign. The second breadth will focus on the architectural impacts caused by the redesign, namely exterior skin issues, increased floor-to-floor height, and removal of unnecessary bracing. Both areas will be analyzed in-depth and compared to the original system – this comparison will also serve to validate if the redesign is the more economical option.

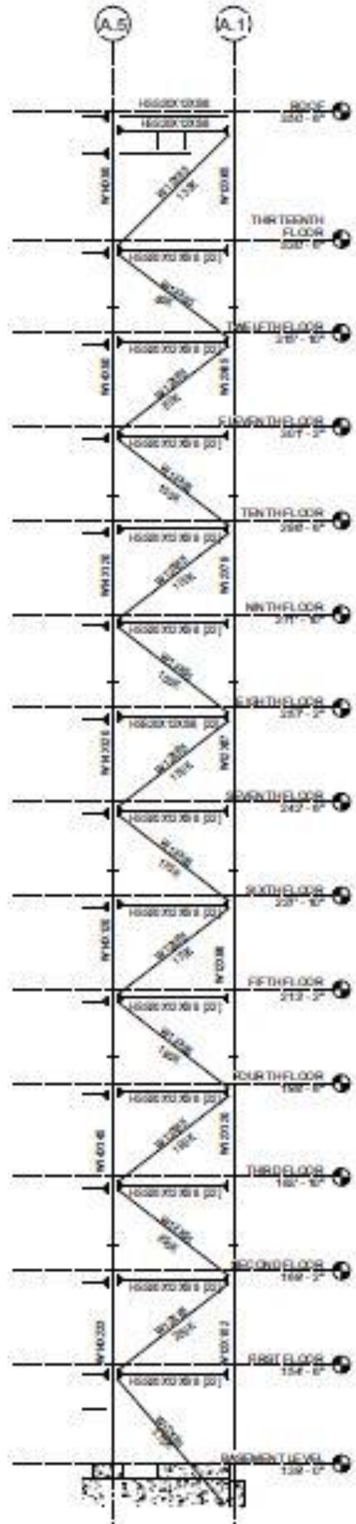
Appendix A – Braced Frame Supplemental Drawings



Braced Frame – Line 2.1

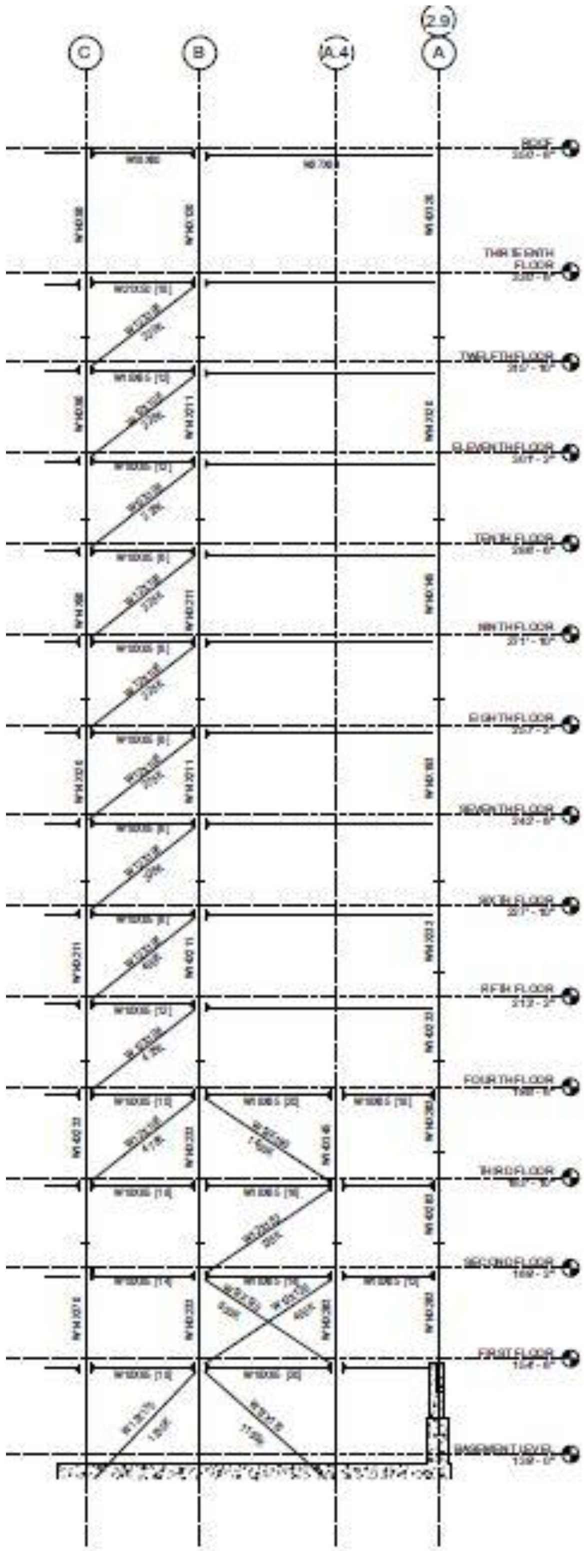


Braced Frame – Line 2

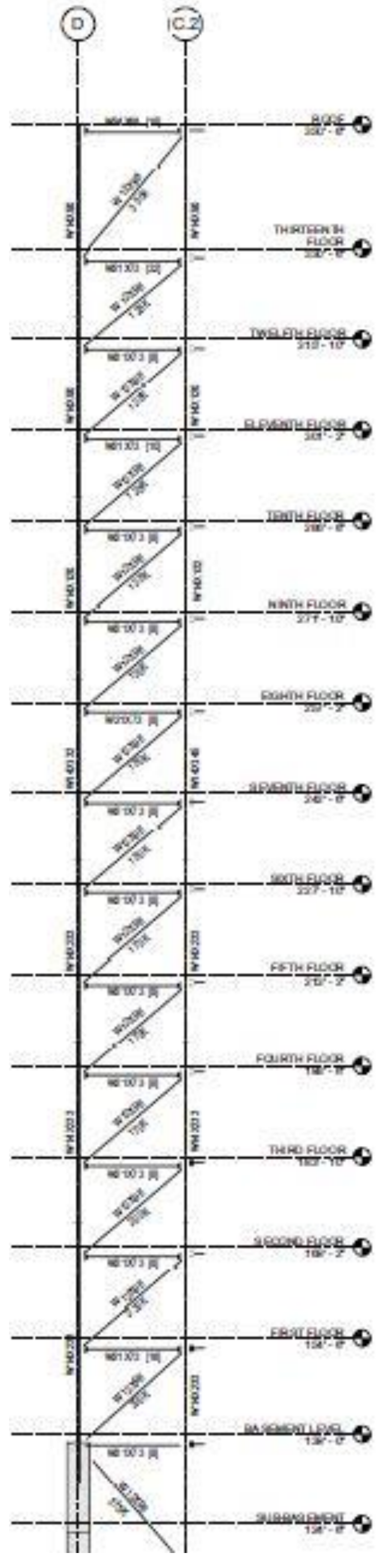


Braced Frame – Line 7

Appendix A – Braced Frame Supplemental Drawings

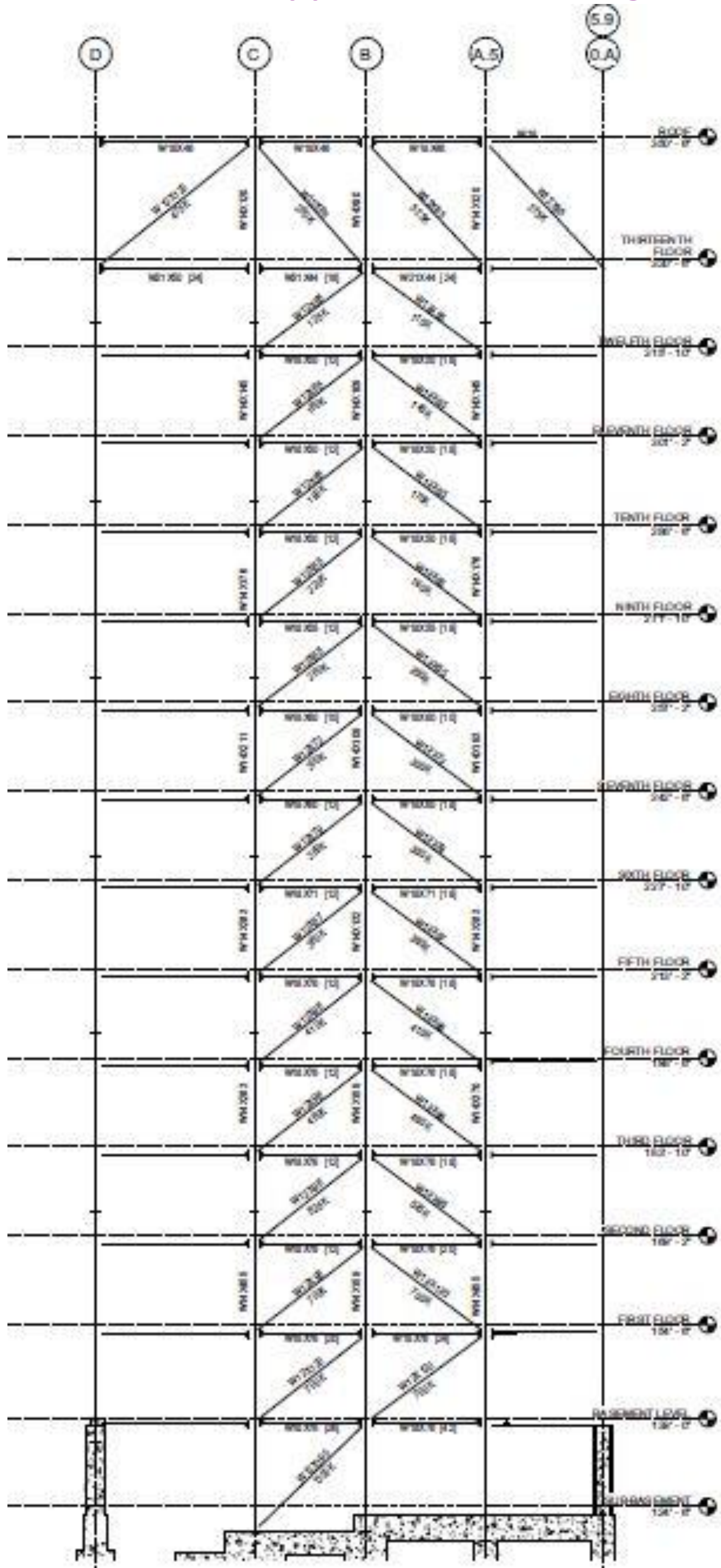


Braced Frame – Line 3



Braced Frame – Line 5.7

Appendix A – Braced Frame Supplemental Drawings



Braced Frame – Line 6

Appendix A – Braced Frame Supplemental Drawings

Braced Frame – Line D
(S202)