Thesis Proposal

University of Virginia's College at Wise New Library


Image Courtesy of Cannon Design

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Structural Option
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Executive Summary

The New Library at the University of Virginia's College at Wise, is 6 stories, 102 feet tall, 68,000 SF, and is located in Wise, Virginia. The existing structural system is composite steel with composite metal deck. The framing system consists of steel wide flange members, and the lateral system consists of ordinary reinforced concrete shear walls. The building is also being integrated into a 60 foot hillsideand utilizes a temporary retaining wall system and foundation walls that are designed to take the full lateral soil forces in the future.

The existing structural system of the New Library is adequate to meet both strength and serviceability requirements. Therefore, a scenario has been proposed in which the University would like to investigate the option of a concrete system instead of the current steel system. The University would also like to investigate the option of a post-tensioned floor system.

A solution to this scenario will be provided through the proposed structural depth in which the building's structural system is redesigned using a mild-steel reinforced concrete flat slab with drop panels and analyzed using RAM Concept. The existing lateral system will be integrated with the concrete floor system and analyzed using ETABs.Concrete columns will be designed using the existing layout per the request of the architect in order to limit the redesigns impact on the building's interior layout.

In order to determine the feasibility of changing the building's structural system to concrete, the impact on the cost and construction schedule will be compared to that of the current steel system as the proposed construction breadth.

Due to the large retained soil depth at the building foundation walls, the proposed mechanical breadth will investigate the fluid at the base of the walls to determine an adequate drainage system.

In addition, MAE coursework will be incorporated into the proposed redesign through the use of computer modeling (AE530) and the design of miscellaneous metal façade supports (AE534).

Purpose and Scope

The purpose of this proposal is to present an overview of the work that will be completed during spring semester 2014. Included are a proposed problem scenario and structural depth involving the redesign of the New Library's structural system using reinforced concrete. Two individual breadth studies, along with proposed MAE course work are also presented. The first breadth will involve an analysis of the impact of this redesign on the cost and construction schedule, while the second will involve and an investigation of the drainage system at the base of the foundation wall to determine a system that is adequate. The MAE course work will include computer modeling and the design of miscellaneous metal façade supports. A detailed task outline and schedule for the work to be completed is also provided.

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General Description of Building

The New Library at the University of Virginia's College at Wisewill be located directly between the existing lower and upper parts of the campus, as seen in Figure 1. The new 68,000 ft^2 building will be 6 stories tall and will cost approximately $43 million.

Figure1: Site Location (Courtesy of Cannon Design)

Currently, there is a steep 60 foot hilldividing the UVA Wise campus. This had a large impact on the building's overall design. The New Library will be integrated into the hillside, shown in Figures 2 and 3, and will serve as a significant physical and architectural link between the two parts of campus. A long winding staircase is built into the existing hillside, and provides limited access for students. Students will be able to access the building from the first, second, third, fourth, and fifth levels and a 24 hour access zone will allow students to travel across campus more easily and safely after normal operating hours.

Figure2: New Library (Courtesy of Cannon Design)

Structurally, the design includesa temporary retaining wall system and foundation walls which extend up to 68 feet below grade on the eastern corner of the building.

The University Architect wanted the New Library to bring a sense of cohesion to the existingbuildings on campus. The design team was required to create a visual effect in which it would appear as if the surrounding buildings had been designed based on the New Library, thus creating an architectural link between the new building and the existing buildings. Architectural materials such as brick, stone, and cast stone, were chosen for the library's façade, as these are common to the existing buildings on campus. Along with numerous books and reference materials, the library will offer several other amenities to students including study rooms, conference rooms, smart workstations, and a café.

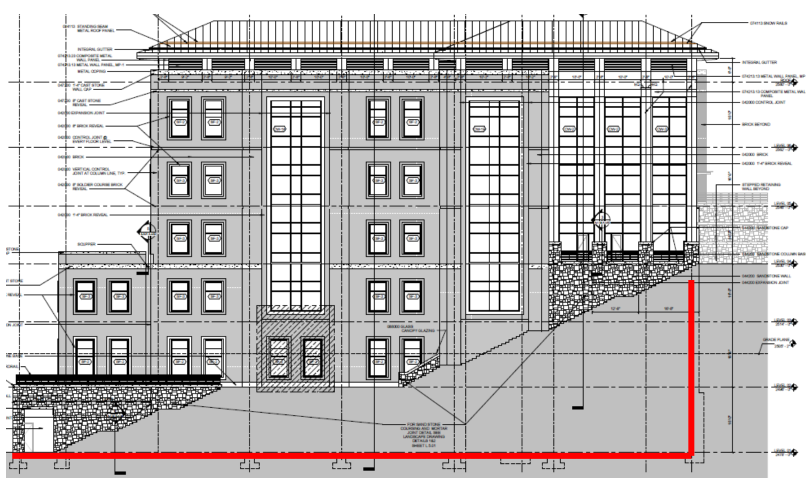


Figure 3: South Elevation Showing Building's Depth into Hillside(Sheet A-3.01)

Structural Overview of Existing System

Brief Description of the Existing Structural System

The New Library at the University of Virginia's College at Wise sits on a foundation system that consists of column piers, spread and strip footings, and foundation walls. Each floor of the 6 story building is framed using a composite system consisting of composite steel wide flange members and composite decking. Concrete shear walls make up the building's lateral system, along with several foundation walls that aid in resisting lateral soil loads. The upper roof system iscomprisedof pre-engineered cold formed metal trusses and a separate lateral system consisting of cold formed shear walls. The followingsection explains these components in moredetail.

Building Materials

Structural building materials used in the New Library's design, along with their specifications,are listed below in Figures 4 and 5.

Structural Steel		
Member	Grade	Fy (ksi)
Wide Flange Shapes and WT Sections	ASTM A992	50
Channels and Angles	ASTM A36	36
Pipe	ASTM A53, Grade B	30
Hollow Structural Sections	ASTM A500, Grade B	46
Base Plates	ASTM A36	36
All Other Steel Members	ASTM A36	36
High Strength Bolts, Nuts, and Washers	ASTM A-325 or A4-490 (Min. ¾" ϕ)	

Figure 4: Structural Steel Materials Specifications

Concrete and Reinforcing		
Use	Strength (psi)	Weight (pcf)
Footings	3000	150
Building Foundation Walls	5000	150
Slabs-On-Grade	3000	150
Slabs-On-Steel Deck	3000	150
All Other Concrete	4000	150
Use	Grade	
Typical Bars	ASTM A-615, Grade 60	
Welded Bars	ASTM A-706, Grade 60	
Welded Wire Fabric	ASTM A-185	

Figure 5: Concrete and Reinforcing Specifications

Foundation System

S&ME, Inc. performed a geotechnical exploration of the proposed site for the New Library in January 2012. They recommended that the main library structure be supported on spread foundations bearing on bedrock with 8 kip per square foot (ksf) allowable bearing pressure. Due to the high bearing pressure, there was no need for soil improvements. It was also determined that the retaining walls need to be capable of resisting an equivalent fluid pressure of 47 pounds per cubic foot (pcf). See the lateral soil loads section for more details.

The final design for the building's foundation followed the recommendations provided in the geotechnical report. The New Library will be supported on a shallow foundation whichwill consist of individual spread footings and continuousstrip footings, both of which will bear on bedrock.

The individual spread footings arelocated under the steel columns. At interior columns, the spread footingsare located directly at the base of the column (see Figure 6). At exterior columns the spread footings arelocated at the base of thecolumn piers (see Figure 7). In both of these cases, the connection is most likely pinned due to the use of the minimum number of required anchor bolts (4), and the fact that no moment frames are used in the structure.

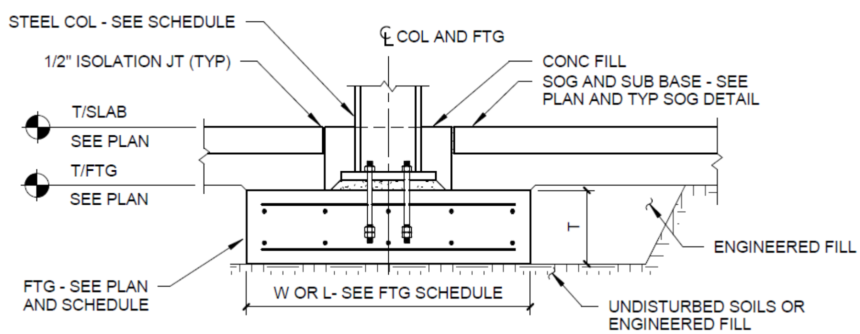


Figure 6: Typical Column Footing withoutPier (Sheet S-3.01, Detail 2)

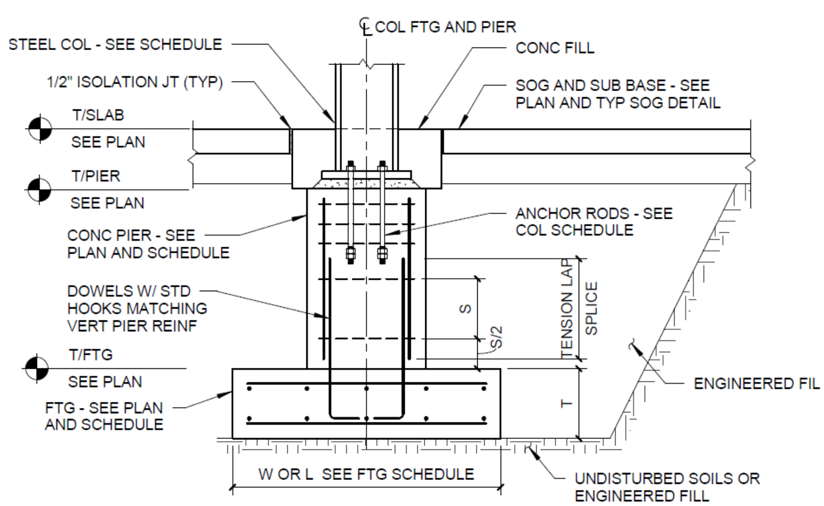


Figure 7: Typical Colum Footing with Pier (S-3.01, Detail 1)

Continuous strip footings are located under the perimeter foundations walls. Many of the footings are stepped in order to limit the amount of excavation required.

One of the biggest challenges with the project was designing a way to resist the lateral soil forces on the building's structure. After discussing several options, the team chose to use a temporary leave-in-place soil retention system (which includes the use of soil nails and shotcrete covering). This system was determined to be the most cost effective and efficient solution. The temporary system allows the soil to be excavated down to the bearing grade and the shotcretethen doubles as one side of the formwork for the foundation walls, thus decreasing the cost of formwork for the project.

It is expected that the rock anchors will deteriorateover time. Thus, the foundation walls aredesigned to resist the full soil load once the superstructure is complete. This was done by designing the foundation walls with a fixed-base condition, providing sufficient rebar to resist flexure, eccentric footings, and lateral support at upper floor levels.The foundation wall and this design concept can be seen in Figures 8 and 9.

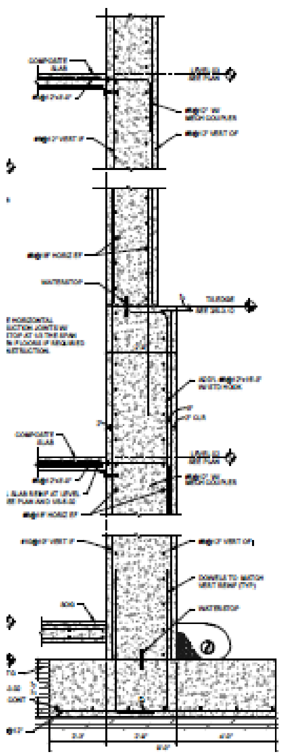


Figure 8: Foundation Wall(S-3.11, Detail 1)

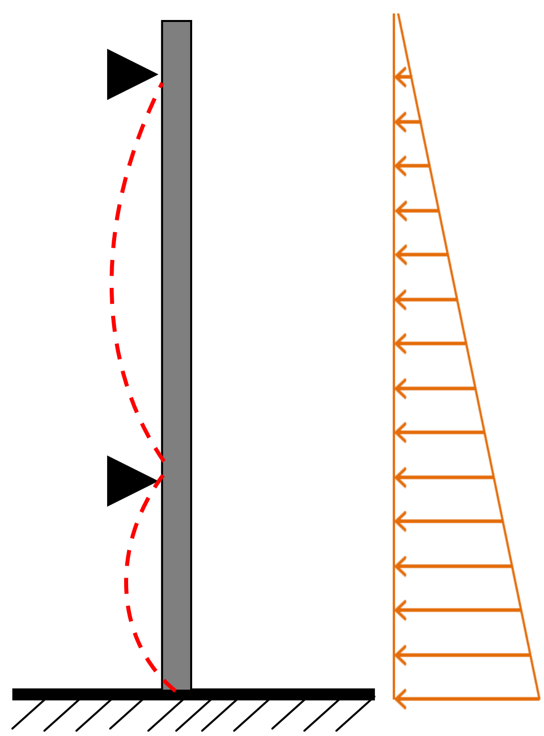


Figure 9: Foundation Wall with Design Concepts

Slab Thicknesses

Two different slab-on-gradethicknesses are used in the building. A 5” slab-on-grade, reinforced with 6x6-W2.9xW2.9 welded-wire-fabric,islocated atLevels 1 and 2. On level 1, these slabs are located in the 24-hour access zone, which is an area of moderate student traffic. On Level 2, there is also a small section in the south corner of the building that is on grade and utilizes a 5” S.O.G. An 8” slab-on-grade, reinforced with #5@18” each-way on both the top and the bottom islocated on Level 1. It is supporting areas of high density storage where specialty compact shelving will be located. Figure 10 and 11 show the extents of each slab thicknesson Levels 1 and 2.

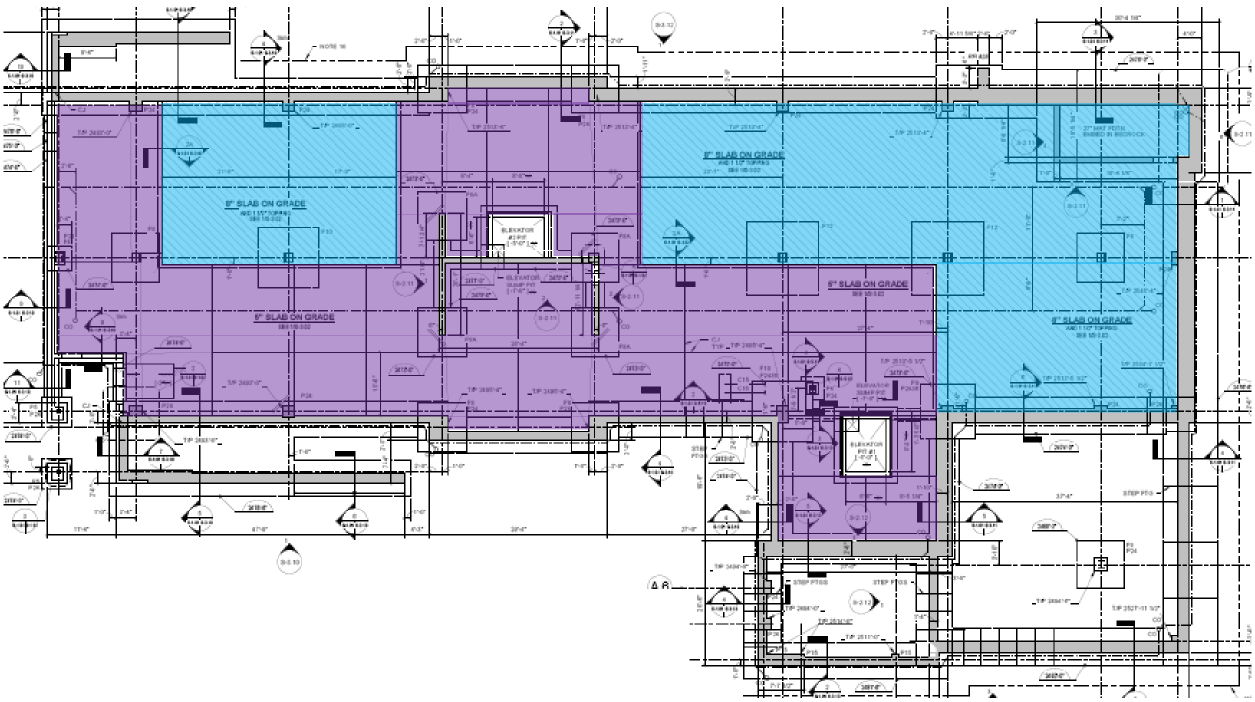


Figure 10: Level 1 Slab-On-Grade Thicknesses (S-1.01)

5”
8”

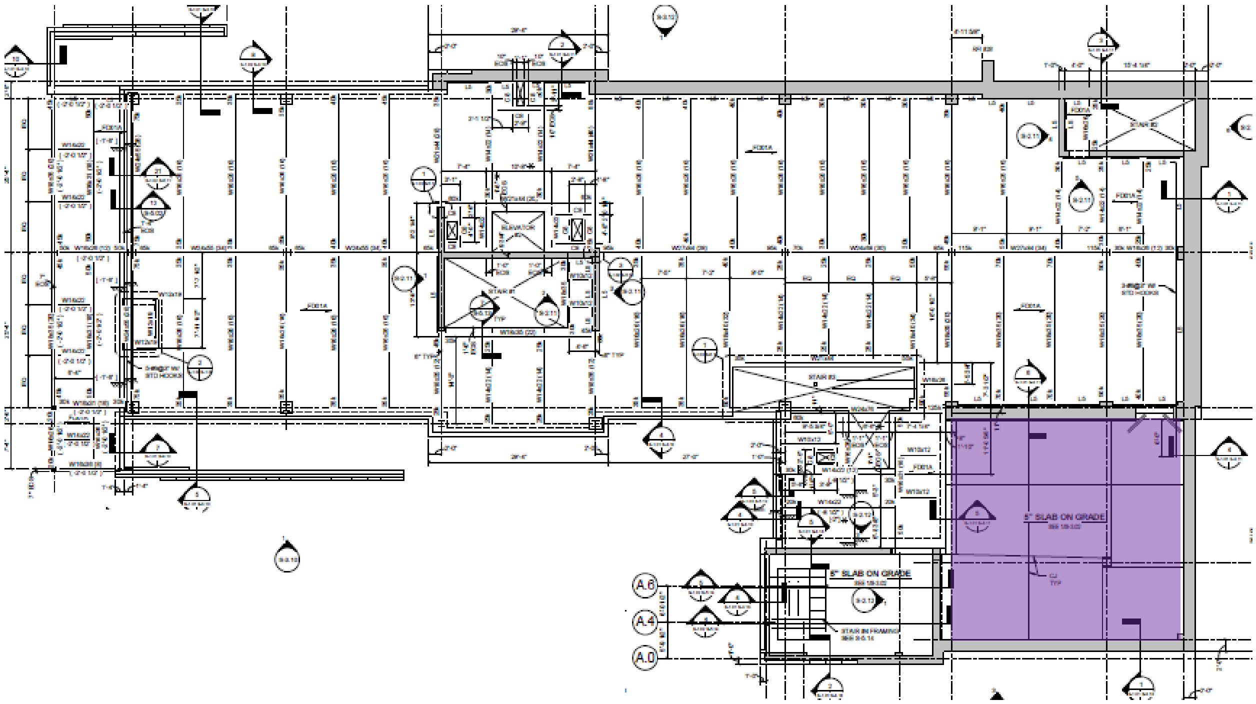


Figure 11: Level 2 Slab-On-Grade Thicknesses (S-1.02)

5”

Floor System

The New Library's floor system is a composite steel systemcomprised of 4 ½" normal weight concretereinforced with6x6-W2.9xW2.9 welded-wire-fabric on 2" 18 gage steel deck (6 ½" total thickness). The 4 ½" topping provides the required 2 hour fire rating without the additional cost of spray-on fire proofing. The deck typicallyruns perpendicular to wide flange steel members, and in cases where the deck runs parallel to the members, #4 x 4'-0" rebar is placed at 18" on center to decrease cracking due to tensile forces in the concrete slab. Composite action is achieved by transfer of the load from the slab to the members by ¾" diameter x 3 ½" long shear studs.

Typical Bay: Floor

Multiple sized bays are used in the New Library. The typical beam span is 25'-4" and typical bay sizes range from 25'-4" to 31'-0". Typical members used to frame Level 2 up through Level 6 are primarily W16x26 beams. Smaller beams, such as W14x22, are used in areas around the stairwells and larger beams, such as W18x35, are used in areas supporting general collections along with areas of high student traffic. Typical interior girders supporting these beams are W25x55 and spandrel girders vary in size depending on location. Figure 12 below shows a 27'-4" bay with W16x26 beams.

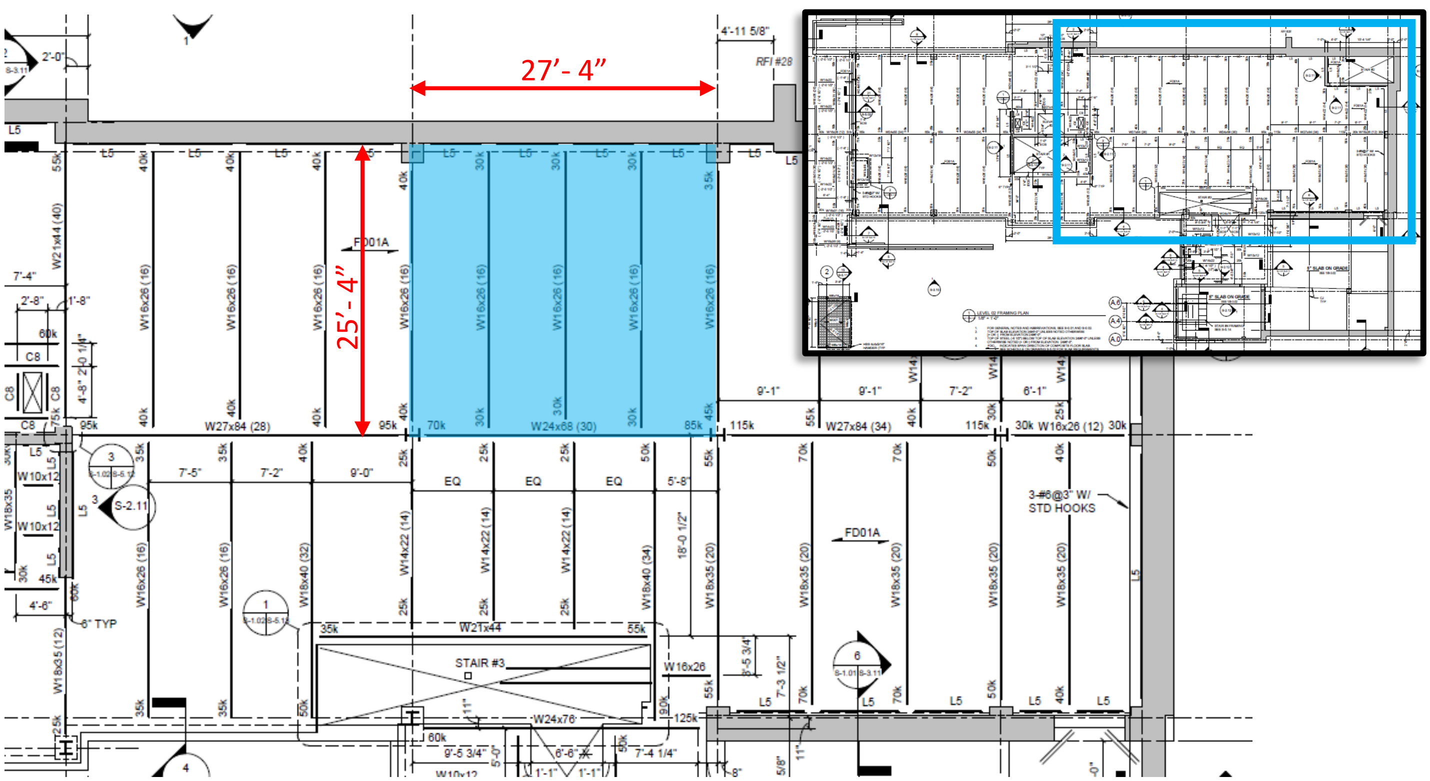


Figure 12: Level 2 Framing Plan Showing Typical Bay (Sheet S-1.02)

Framing System

All of the main structural columns in the New Library are wide flange steel members. Other columns found in the building are hollow structural steel, which are used in vestibules and in entrance areas. Most of the columns have a 12” depthand vary in weight; with the majority ranging between W12x45 and W12x65.The largest columns in the building are W12x170 and they extendbetween Level 1 and Level 3. The need for these larger columns is due to the increased tributary area, ascompared to typical bays, and larger design loads from general collections on all upper floors. Figure 13 shows the location of the W12x170 columns.

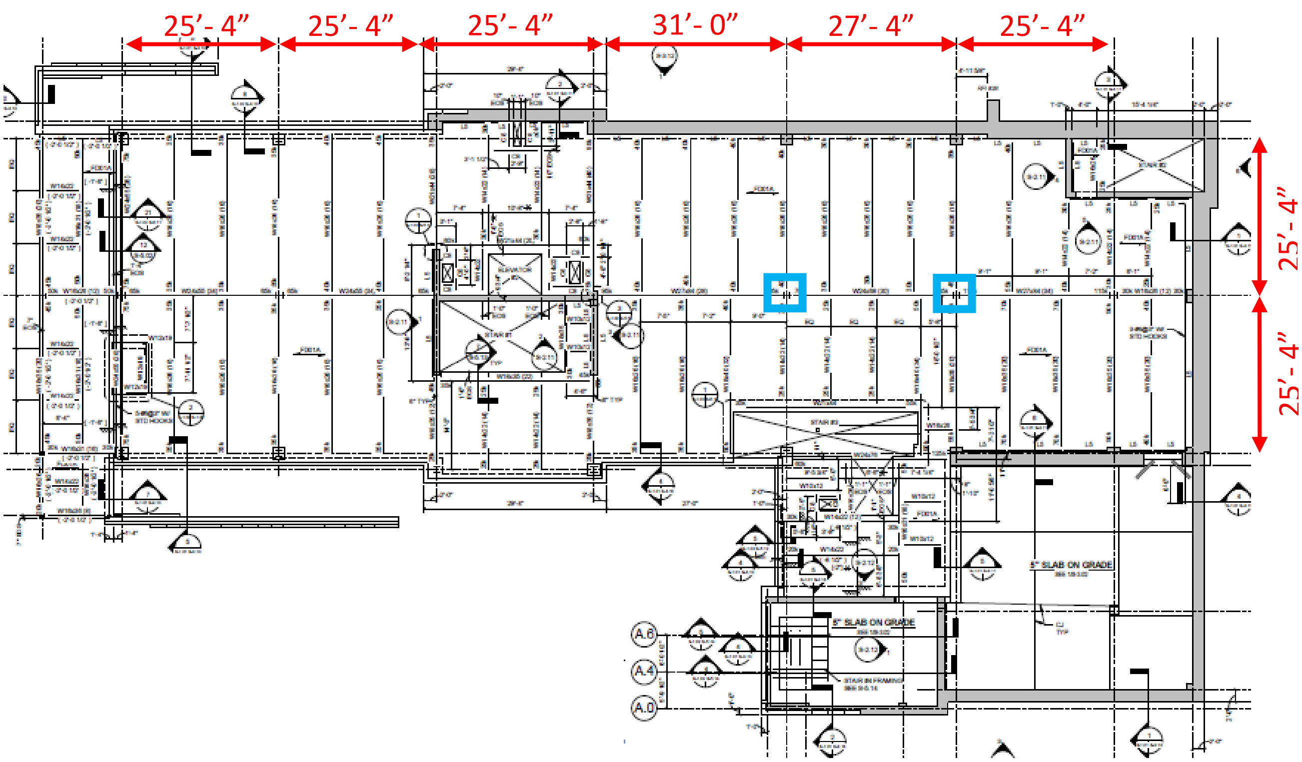


Figure 13: Level 2 Showing Location of W12x170 Columns (Sheet S-1.02)

Roof System

Two separate roof systems were used to complete the New Library. A lower roof covers the majority of the building between column lines 3-9 and A-E and supports an air handling unit and a chiller (mechanical well area). The framing is composite wide flange steel beamsand a 6 ½” NWCslab. Theupper roof is designed to mimic the existing campus buildings and also serves to conceal the building’s air handling unit and chiller.

Lower Roof

Bay sizes used in the lower roof framing of the New Library are the same as those used in the framing of the lower floors. The typical beam span is 25’-4” and typical bay sizes range from 25’ 4” to 31’-0”. Beams used to frame the lower roof are typically W18x35. This largerbeam size is due to increased design loads based on the HVAC system. Figure 14 below shows a 27’-4” bay with W18x35 beams.

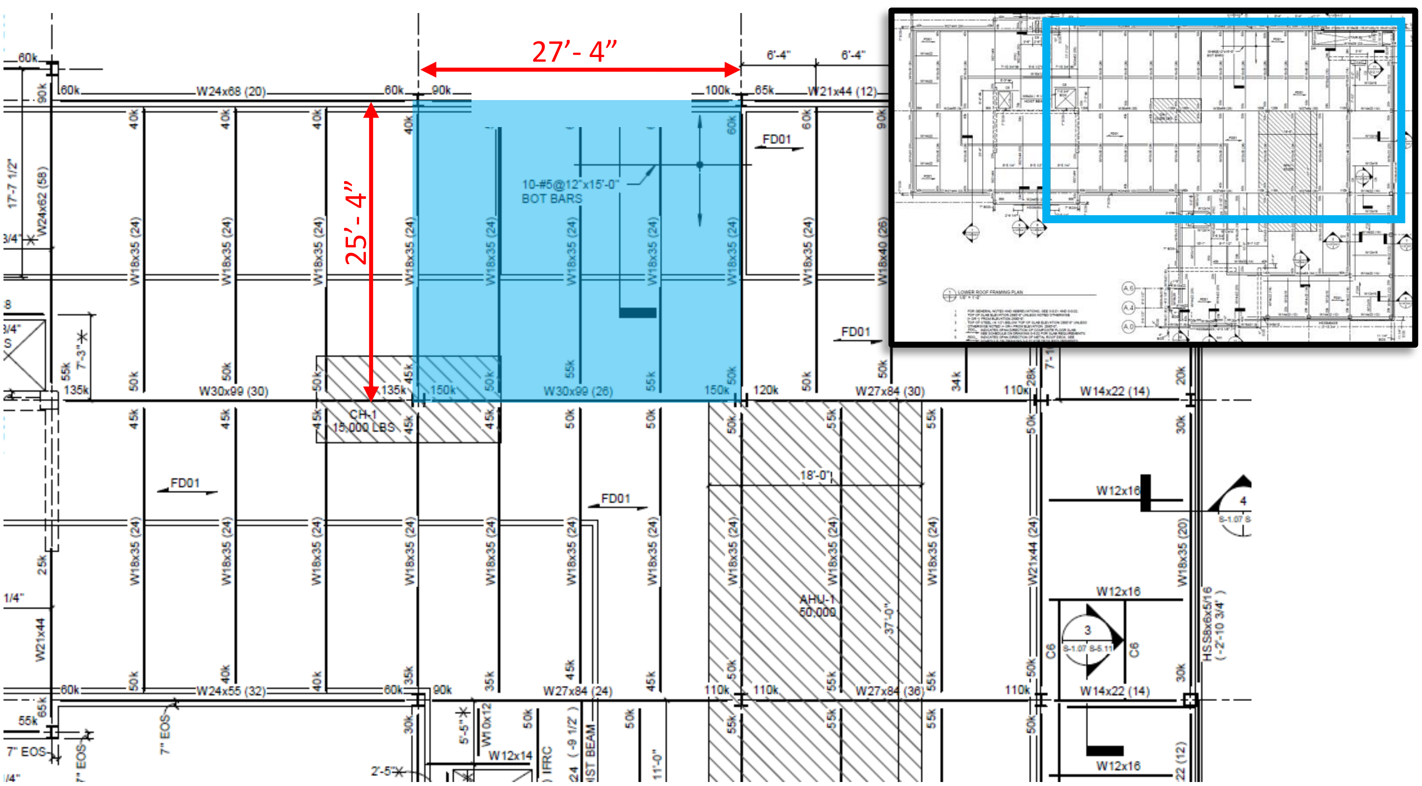


Figure 14: Lower Roof Framing Plan Showing Typical Bay (Sheet S-1.07)

Upper Roof

Theupper roof is a raised false mansard consistingof pre-engineered cold formed metal trusses and cold formed shear walls. This layout can be seen below in Figure 15.These trusses are triangular in shape and approximately 9’-7” tall,are covered by 1 ½” type B roof deck, and sit on 6” load bearing CFMF studs. This can be seen below in Figure 16.

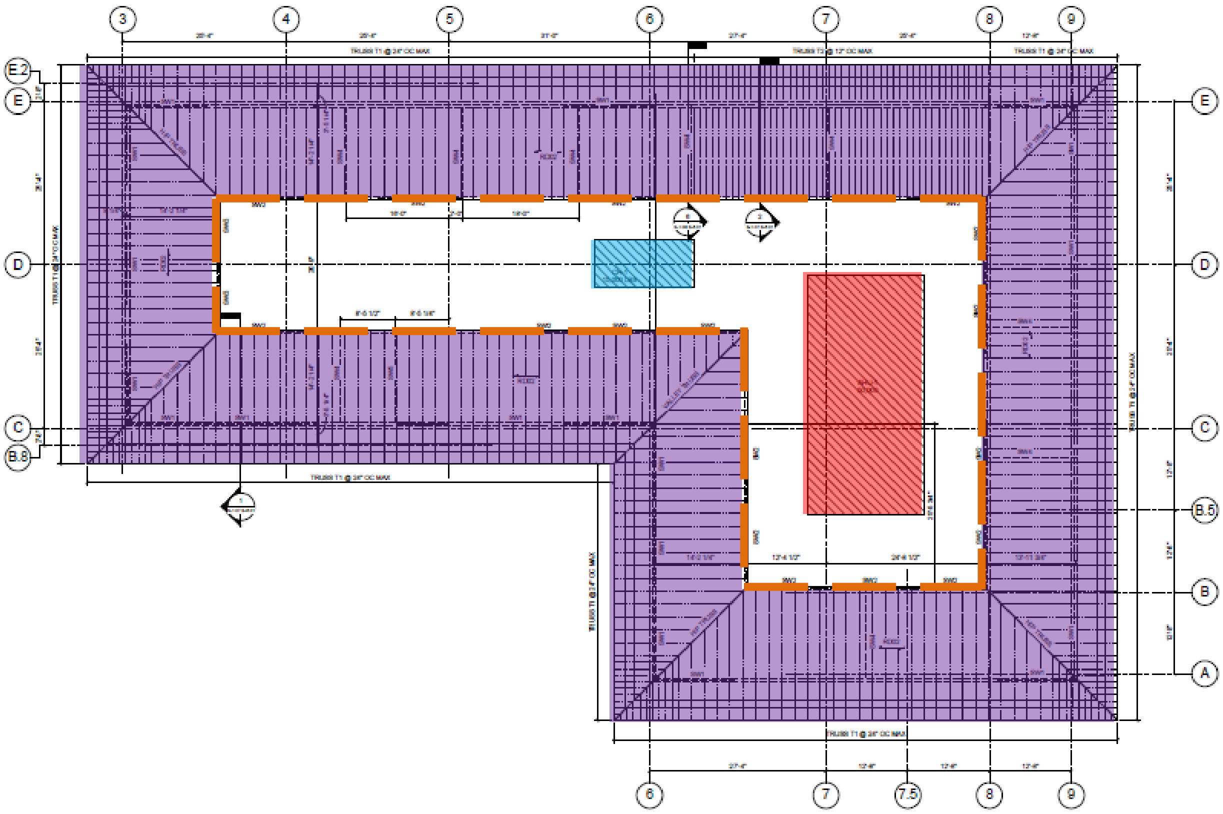


Figure 15: Upper Roof Framing Plan Showing Pre-engineered Trusses (Sheet S-1.08)

- Pre-engineered Light Gage Cold Formed Metal Trusses
- Mechanical Well Area
- Air Handling Unit
- Chiller

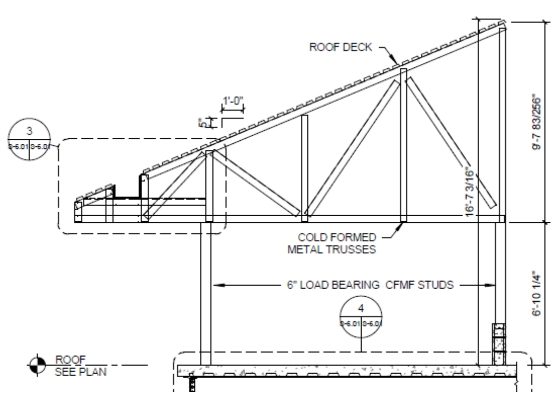


Figure 16: Cold Formed Metal Truss (S-6.01)

Lateral System

The lateral force resisting system for the New Library consists of ordinary reinforcedconcrete shear walls. There are nine 12” thick shear walls of varyinglength and height that make up this system. Figure 17 shows the location of these shear walls and categorizes them based on their heights.

Each shear wall is reinforced with #5 rebar at a code maximum spacing of 18” each-way on each-face of the wall. This layout ofreinforcing is typical with the exception of two walls that have condensed spacing in lower sections of the wall, especially in the horizontal direction. This condensed spacing is due to increased shear forces from soil loads.

Two of the walls located in the eastern corner of the building are introduced below grade as foundation walls. Levels 1 through 4 of this corner are located below grade at the location of the maximum retained soil. Once above-grade, soil loads no longer are the controlling load case and the walls are then designated as shear walls.

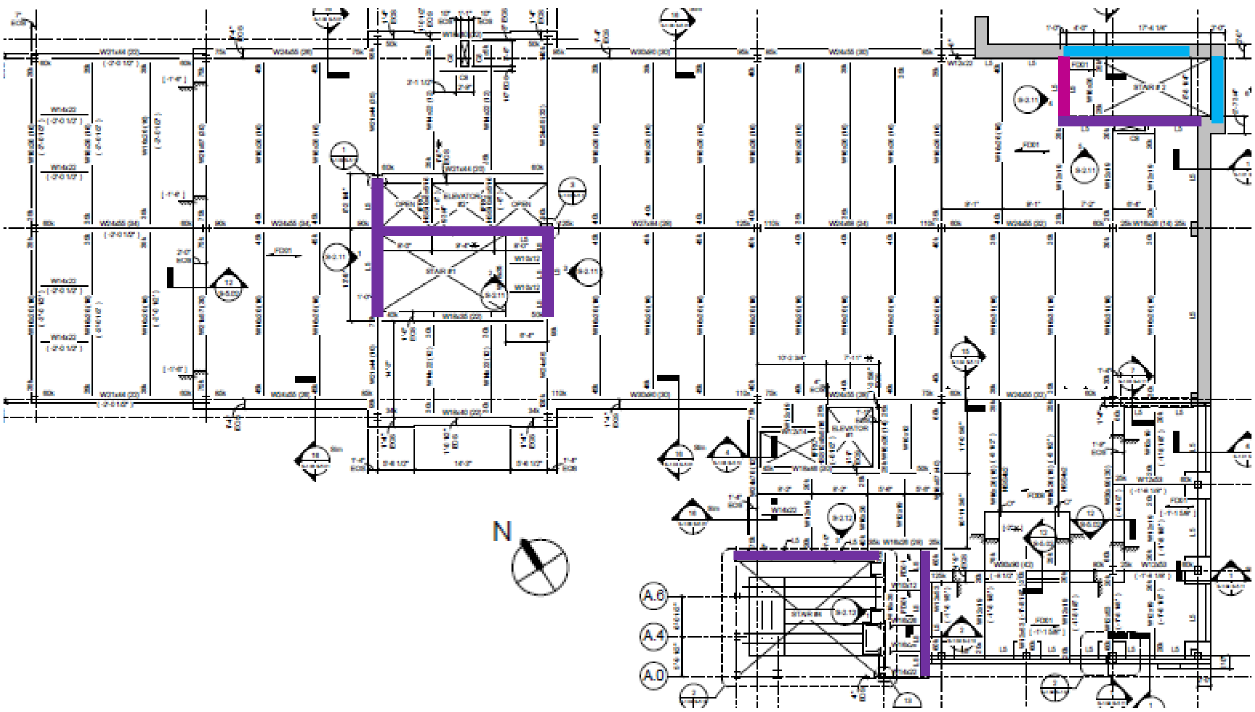


Figure 17: Floor Framing Plan Showing Shear Wall Locations (S-1.04)

Shear Walls From Level 1 to Roof Level
Shear Walls From Level 1 to Level 5
Shear Walls From Level 5 to Roof Level

Design Codes and Standards

Below is a list of the design codes and standards used in the structural design of the New Library at the University of Virginia's College at Wise:

- **International Code Council**
    - International Building Code 2009 (Chapters 2-35 Adopted by Virginia Uniform Statewide Building Code)
- **American Society of Civil Engineers**
    - ASCE 7-05: Minimum Design Loads for Buildings and Other Structures
- **American Concrete Institute**
    - ACI 318-08: Building Code Requirements for Structural Concrete
    - ACI 530-08: Building Code Requirements and Specifications for Masonry Structures
- **American Institute of Steel Construction**
    - AISC 360-05: Specifications for Structural Steel Buildings (Steel Construction Manual 13th Edition) - LRFD
- **University of Virginia Facilities Management and University Building Official**
    - Facility Design Guidelines

Design Loads

The following section focuses on topics concerning the loads used in the structural design of the New Library. These topics include national codes used for live and lateral loadings, the determination of the design loads used, and the load paths for different loading conditions.

National Code for Live Loads and Lateral Loadings

Load	National Code	Section
Live	ASCE 7-05 Chapter 6, and UVA Facility Design Guidelines	5
Lateral	ASCE 7-05 Chapter 12	8

Figure 22: National Code Chapter and Section for Live and Lateral Load

Gravity Loads

Live Loads

Design live load values are listed on sheet S-0.01 of the structural drawings. The majority of these loads were determined using Chapter 4 of ASCE7-05, with the exception of the design roof loads. The loads not found in ASCE 7-05 are listed in Figure 23 with an explanation of how they were determined.

Load	Determination of the Load
Roof area below sloped roof	The area below the sloped roof will most likely never see a live load, so the design team chose to simply provide a small allowance.
Roof mechanical area	The design team chose to blanket the roof with a live load instead of using the specific dead loads for the mechanical units. To determine a reasonable allowance the team used the largest PSF unit at the time and increased the load by 25%.
Minimum Roof Live Load	UVA Facility Design Guidelines specifies a minimum design roof live load.

Figure 23: Live Loads Not Found in ASCE7-05

Dead Loads

Design dead loads are listed on sheet S-0.01 of the structural drawings. These loads were based onmaterial weights and industry standards used at Cannon Design.

Snow Loads

Design snow loads must follow the UVA facility Design Guidelines. These guidelines state that ground snow loads are to be determined by case studies and other Virginia Unified Statewide Building Code requirements. The USBC adopts chapters 2-35 of IBC 2009 which references ASCE 7-05.

Lateral Loads

Wind Loads

Design wind loads were determined using Section 6.5 of ASCE 7-05.Section 6.5,Method 2, which is the analytical procedure for determining design wind loads for buildings of all heights.

Seismic Loads

Design seismic loads were determined using section 12.8 of ASCE 7-05. Section 12.8 prescribesthe Equivalent Lateral Force Procedure for determining seismic design loads.

Lateral Soil Loads

From the geotechnical report performed by S&ME, Inc. it was determined that the foundation walls should be designed for an at-rest equivalent fluid pressure of 47 pcf. The soil loads on the foundation walls are then dependent on the height of the wall. Figure 24 shows this distributed force on the foundation wall.

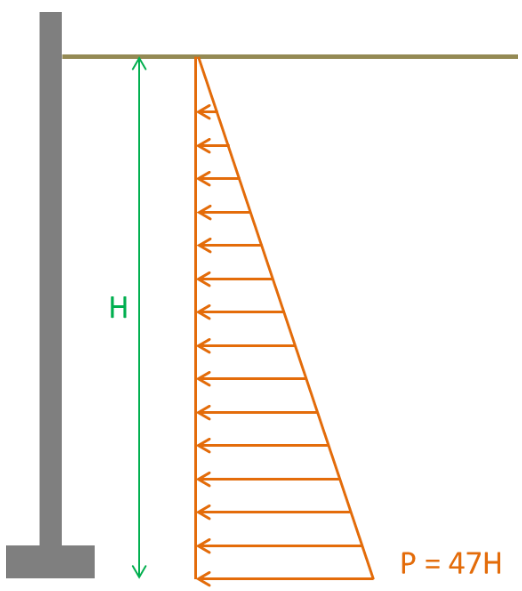


Figure 24: Equivalent Lateral Fluid Pressure

Problem Statement

As previously discussed, the New Library utilizes a composite steel framing system, and the lateral system involvesthe use of ordinary reinforced concrete shear walls. Previous technical reports have shown that the existing gravity system and lateral system for the New Library are adequate to meet both strength and serviceability requirements.

Since no significant problems exist with the current steel structural system, a scenario has been created in which it isdesired by the University to investigate the feasibility of a concrete framing system. As part of this investigation, the impact of the concrete system on the cost and construction schedule of the project should be compared to that of the existing steel system to allow the owner to make an informed decision. The architectural design of the New Library is based on the existing campus and surrounding buildings, so it is required that there is limited architectural impact with the system redesign.

Proposed Solution

The new structural system has been chosen to be a mild-steel reinforced two-way concrete slab with drop panels. This system will be analyzed using RAM Concept, which is one of the most efficient tools for designing concrete floor systems. It has already been determined that the existing shear walls are the most efficient lateral system and will be integrated with the new concrete system. ETABS will then be used to analyze the existing shear walls under anticipated increased seismic loads due to the increase in building mass. Columns will also be redesigned in concrete and will follow the existing column layout in order to minimize impact to the interior layout of the New Library.

The decision to use a two-way slab was based on several factors. In Technical Report 3, a two-way flat slab was found to be the least expensive of the alternative concrete systems that were studied due to decreased formwork and labor costs. Two-way systems with drop panels help to reduce the amount of negative reinforcement required at the columns and have become an industry standard unless excessive heavy loads are a concern (>200psf live load). The bay sizes of the New Library are of a moderate span, approximately 25 feet, and are relatively square, which is ideal for a two-way slab system.

The largest bay in the New Library spans 31 feet. It is recognized that excessive deflections in this bay will be an area of concern with the alternate system. To address this issue, both camber of the slab and alternative drop panelsizes will be investigated.

There is also an interest to investigate the option of a post-tensioned system. A schematic design of a portion of the floor system will be compared to the two-way concrete system in order to determine if a complete PT floor option would be beneficial.

Breadth Topics

Construction Breadth

A comparative cost analysis will be performed in which the cost of the existing composite steel system will be compared to that of the redesigned two-way concrete system. This cost analysis will include materials, erection/formwork, and labor. Cost information for the existing steel system will be provided by Cannon Design, while cost information for the redesigned concrete system will be determined using RS Means.

A schedule analysis will also be performed in which the impact of this system change on the critical path and construction schedule will also be considered. The construction schedule and the critical path required for the concrete system will be compared to that of the existing steel system, which will be provided by Cannon Design.

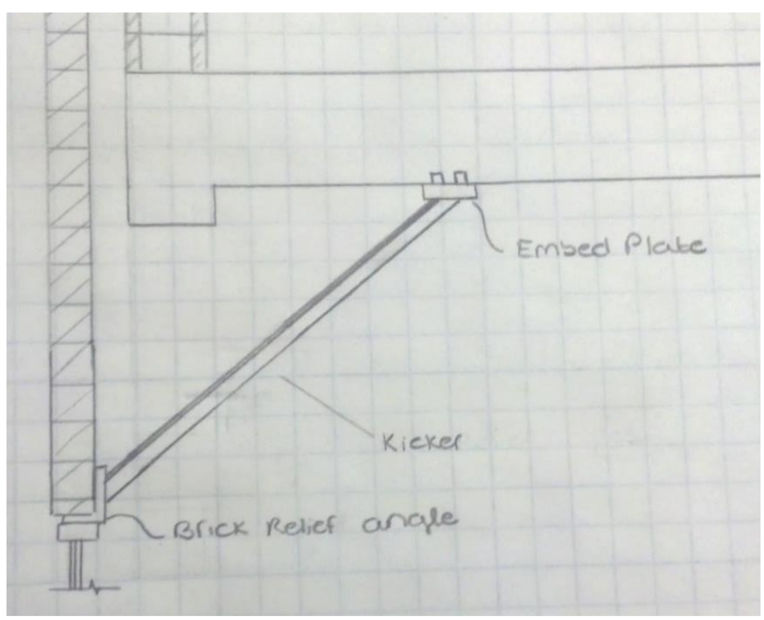
Mechanical Breadth

Drainage at the base of the foundation/basement walls will be investigated. The location of the water table will be determined and the head pressure at the base of the foundation walls will be calculated. It is assumed that a drainage system will be required. Thus, a drainage pipe and sump pump will be sized to keep water from rising above the height of the drainage pipe.

Waterproofing at the base of the foundation/basement walls and the effect of the water beneath the slab-on-grad will also be investigated.

MAE Requirement

Graduate level work will be incorporated into the structural system redesign. This will be done through the use of computer modeling and the design of steel connections. Material covered in AE530, *Computer Modeling of Building Structures*, will be used extensively throughout the redesign. RAM Concept will be learned through guided self-study, and will be used for the design of the floor system. ETABS will be used in the analysis of the lateral system. Material covered in AE534, *Advanced Steel Connections*, will be incorporated through the design of miscellaneous metal façade supports. These supports will be comprised of brick relief angles, kickers, and embedded steel connections.



Tasks and Tools

1. Winter Break Research
    a. Gain experience using RAM Concept through self-directed learning
    b. Obtain original construction schedule for the existing steel system

2. Design Concrete System
    a. Design gravity system including two-way slab, drop panels, and columns
        i. Calculate new loads considering increased dead load
        ii. Design reinforced two-way slab
            1. Determine trial slab thickness and trial column sizes
            2. Use RAM Concept to analyze slab
            3. Investigate need for drop panels
            4. Determine required reinforcement
            5. Check deflections and adjust slab thickness, drop panel arrangement, and amount of reinforcement to account for excessive deflections in problem areas
        iii. Design gravity columns and check using SP Column
        iv. Investigate the option of a post-tensioned system

    b. Check lateral system
        i. Adjust seismic loads for new building weight
        ii. Modify Technical Report 4 ETABS model to include adjusted loads
        iii. Analyze shear walls under increased seismic loads
        iv. Modify lateral elements as necessary

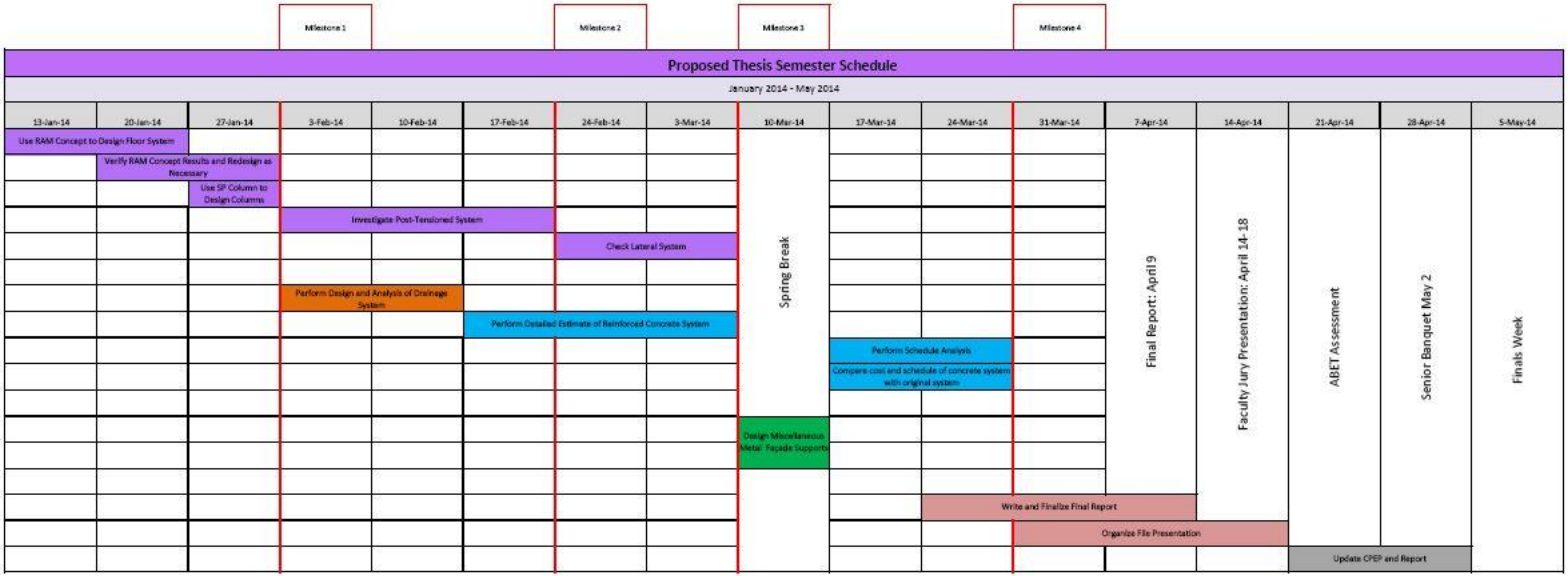
3. Perform cost and schedule comparison of existing system and new system
    a. Cost analysis
        i. Determine cost of materials, formwork, and labor using RS Means
        ii. Calculate overall cost of concrete system
        iii. Compare cost of existing steel system to redesigned concrete system
    b. Schedule analysis
        i. Adjust existing construction schedule to account for concrete system
        ii. Compare construction time of existing steel system to redesigned concrete system and determine impact of the critical path.
    c. Determine feasibility of concrete system.

4. Perform check on plumbing system
    a. Research current drainage system and drainage pipe location
    b. Determine location of the water table
    c. Determine head pressure at the base of the wall due to water
    d. Size drainage pipe and sump pump using geotechnical engineer's recommendations and industry standards
    e. Verify that water will not rise above the drainage pipe
    f. Investigate drainage system daylight outlet

5. Design Miscellaneous Metal Façade Supports
    a. Determine load path for brick supports
    b. Determine force in supports and on connections
    c. Design brick relief angles
    d. Design kickers
    e. Design embedded steel connection

6. Final Report and Presentation
    a. Outline final report
    b. Write and format final report
    c. Outline presentation
    d. Create presentation slide show
    e. Finalize report
    f. Practice presentation

Schedule



Structural Depth: Reinforced Concrete Redesign	
Breadth 1: Cost and Schedule Comparison	
Breadth 2: Design and Analysis of Drainage System	
MAE: Design of Miscellaneous Façade Support	
Report and Presentation	
Course/Semester Wrap Up	

Milestones	
1	Gravity System Redesign Complete
2	Post-tension System Complete, Mechanical Breadth Complete
3	Structural Depth Complete, Construction Breadth in Progress
4	Breadths and MAE Coursework Completed, Final Report Started

Conclusion

The structural system for the New Library at the University of Virginia's College at Wise was adequately designed for strength and serviceability requirements. As a result, a scenario has been proposed in which the University would like to investigate the option of a concrete system. The University would also like to investigate the option of a post-tensioned system.

The building's structural system will be redesigned using a mild-steel reinforced concrete flat slab with drop panels. This system is the least expensive of the alternative concrete systems considered in Technical Report 3, is an industry standard, and is ideal for the bay sizes commonly found in the New Library. To address excessive floor deflections, which will be a concern in the larger bays, camber and alternative drop panel sizes will be investigated.There is also an interest to investigate the option of a post-tensioned system, so a schematic design of a portion of the floor system will be completed and compared to the two-way slab system.

The existing lateral system will be integrated with the concrete floor system. Due to time constraints on the proposed work, and the interest to focus largely on the design and analysis of the concrete floor systems, the analysis of the lateral system will be limited to member checks under the increased shear forces and consideration of the effects the foundation walls on the torsion and drift of the structure. A more in depth study of the lateral system will be completed if time allows.

Concrete columns will be designed using the existing layout. This will minimize the impact of the system redesign on the building's interior layout.

Changing the structure to a concrete system will result in a difference in cost and construction time for the project. To determine how the concrete system will compare with the existing steel system,a detailed cost estimate of the concrete system will be compared to that of the existing system. Impacts on the construction schedule will also be investigated. This comparison will help determine the feasibility of designing the structural system in concrete.

Due to the large depth of the foundation walls, drainage at the base of the walls is a concern. Therefore, the drainage system at the base of the foundation walls will be designed to adequately prevent water buildup at the base of the walls.

MAE coursework will be incorporated into the redesign through the use of computer modeling of both the gravity and lateral systems and through the design of miscellaneous metal façade supports, required to resist components and cladding wind forces on the building's masonry façade.