Technical Report 1

University of Virginia's College at Wise New Library

Image Courtesy of Cannon Design

Macenzie Ceglar
Structural Option
Advisor: Heather Sustersic
13 September 2013

Executive Summary

The New Library at the University of Virginia's College at Wise will serve as a main link between the upper and lower campus areas, which are currently divided by a steep 60 foot hill. The new 6 story, 68,000 ft^2, library will be integrated into the hillside, and will provide students with an easier and safer path across campus. The architectural design of the façade incorporates traditional materials found on campus, such as brick and stone. Construction on the New Library began in August 2012 and will be completed in August 2015.

Soil loads caused the foundation system for the New Library to be unique in its design. The foundation system utilizes a temporary leave-in-place soil retention system and foundation walls which are designed to resist future lateral soil loads. Other parts of the foundation system include piers, footings, and slabs-on-grade.

All six stories of the building have composite floor framing involving both composite steel wide flange members and composite decking. Framing layout in the building is fairly typical with bay sizes ranging between 25'-4" x 25'4" and 31'-0" x 25'-4". Steel wide flange columns are used as the vertical framing system and shear walls make up the building's lateral system.

Loading conditions considered in the building's design include live loads, gravity loads, snow loads, wind loads, seismic loads, and lateral soil loads.

The Virginia Uniform Statewide Building Code (USBC), along with "Facility Design Guidelines", governs the design of all buildings on the campus. The USBC adopts chapters 2-35 of International Building Code (IBC) 2009, which references codes and standards which include American Society of Civil Engineers (ASCE) 7-05, American Concrete Institute (ACI) 318-08, and the 13th edition of the Steel Construction Manual.

The following report will cover these topics in more detail.

Table of Contents

Purpose and Scope

The purpose of this technical report is to describe the physical existing conditions of the structure of the New Library at the University of Virginia's College at Wise, located in Wise, Virginia.

The scope of this technical report includes detailed descriptions of building materials, structural systems, joint details,applicable design codes, design loads, and load paths.The main focusis to provide a thorough description of the building's structural system. This will includedescriptions of the foundation; including slab-on-grade, piers, footings, and foundation walls. It will also contain details of systems such as typical floor framing, lateral, and roof. Other special factors influencing the design will be addressed, such as the large lateral soil loads which act on the foundation walls.

A full analysis of the New Library's structural design will be covered in the subsequent technical report.

General Description of Building

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

Figure 1: Site Location (Courtesy of Cannon Design)

Currently, there is a steep 60 foot hill dividing 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. The current hillside has a long winding staircase that provides limited access. Students will now be able to access the building from the first, second, third, fourth, and fifth levels. Also, a 24 hour access zone will allow students to travel across campus more easily and safely after normal operating hours.

Figure 2: New Library (Courtesy of Cannon Design)

Structurally, the design includes a 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 existing buildings 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.

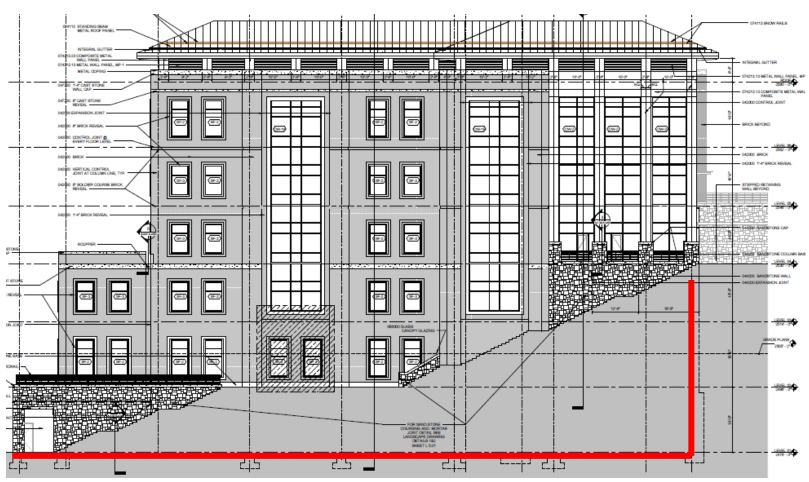

Figure 3: South Elevation Showing Building's Depth into Hillside (Sheet A-3.01)

Structural Overview

Brief Description of the 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 is comprised of 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 are located at the base of the column 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.

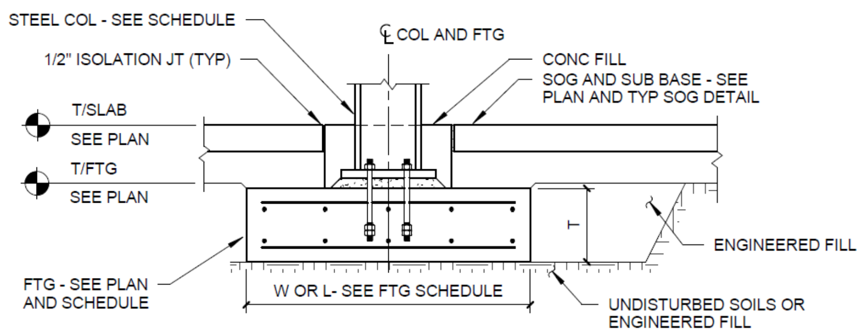

Figure 6: Typical Column Footing withoutPier (Sheet S-3.01, Detail 2)

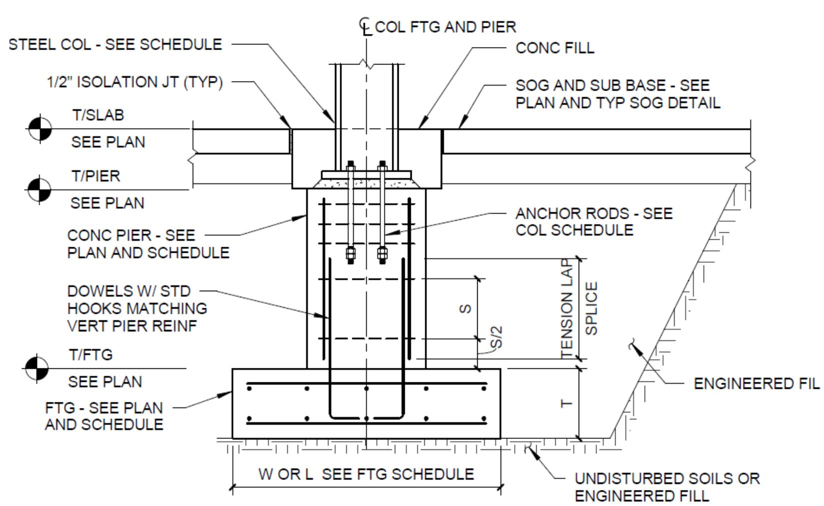

Figure 7: Typical Colum Footing with Pier (S-3.01, Detail 1)

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 shotcrete then 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 deteriorate over time. Thus the foundation walls are designed to resist the full soil once the superstructure is complete. This was most likely 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. This concept will be further explored in later technical reports. The foundation wall and this design concept can be seen in Figures 8 and 9.

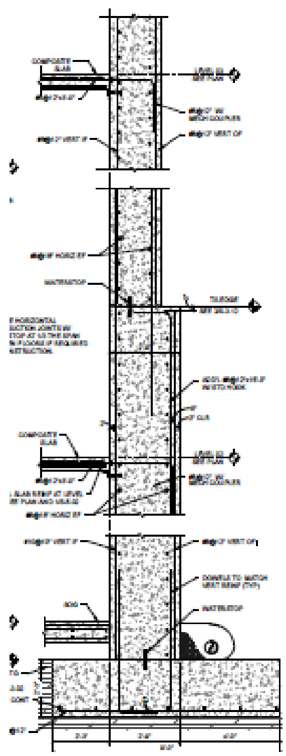

Figure 8: Foundation Wall (S-3.11, Detail 1)

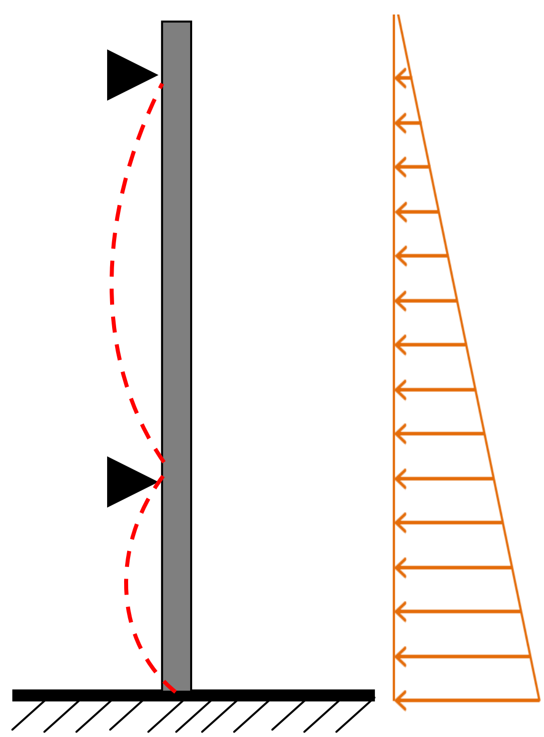

Figure 9: Foundation Wall with Design Concepts

Slab Thicknesses

Two different slab-on-grade thicknesses are used in the building. A 5” slab-on-grade, reinforced with 6x6-W2.9xW2.9 welded-wire-fabric, is located at Levels 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 is located 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.

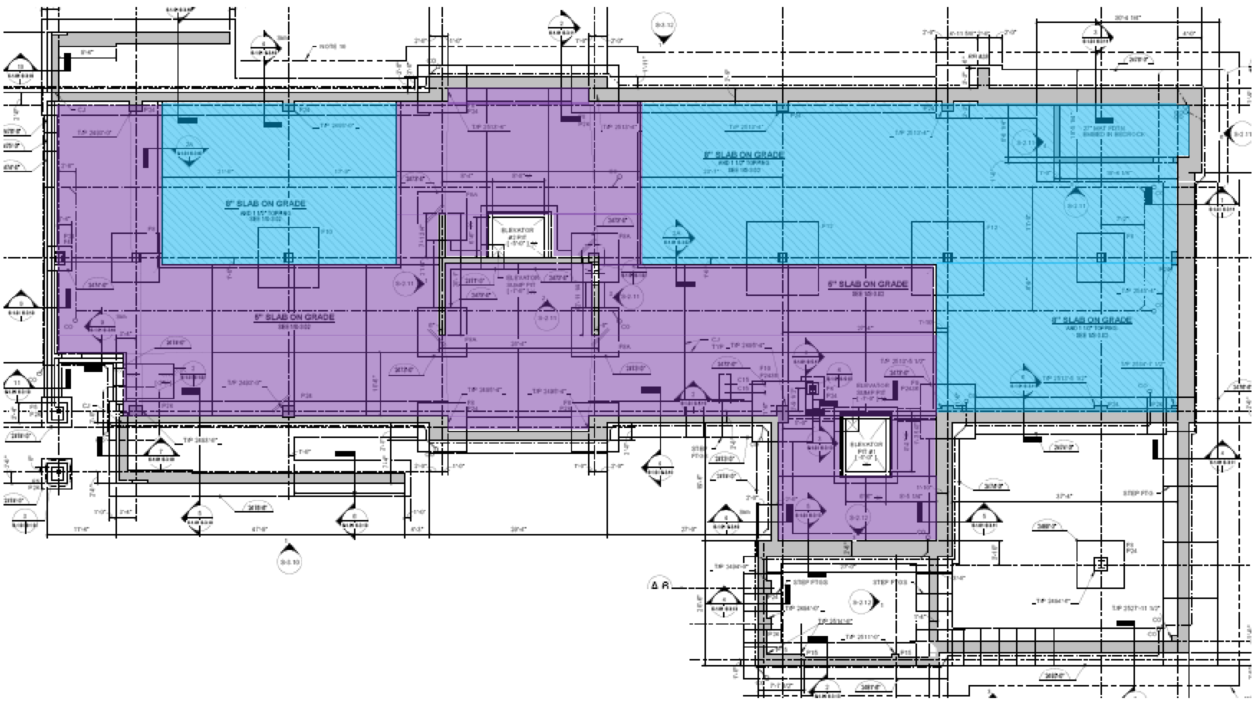

Figure 10: Level 1 Slab-On-Grade Thicknesses (S-1.01)

5”
8”

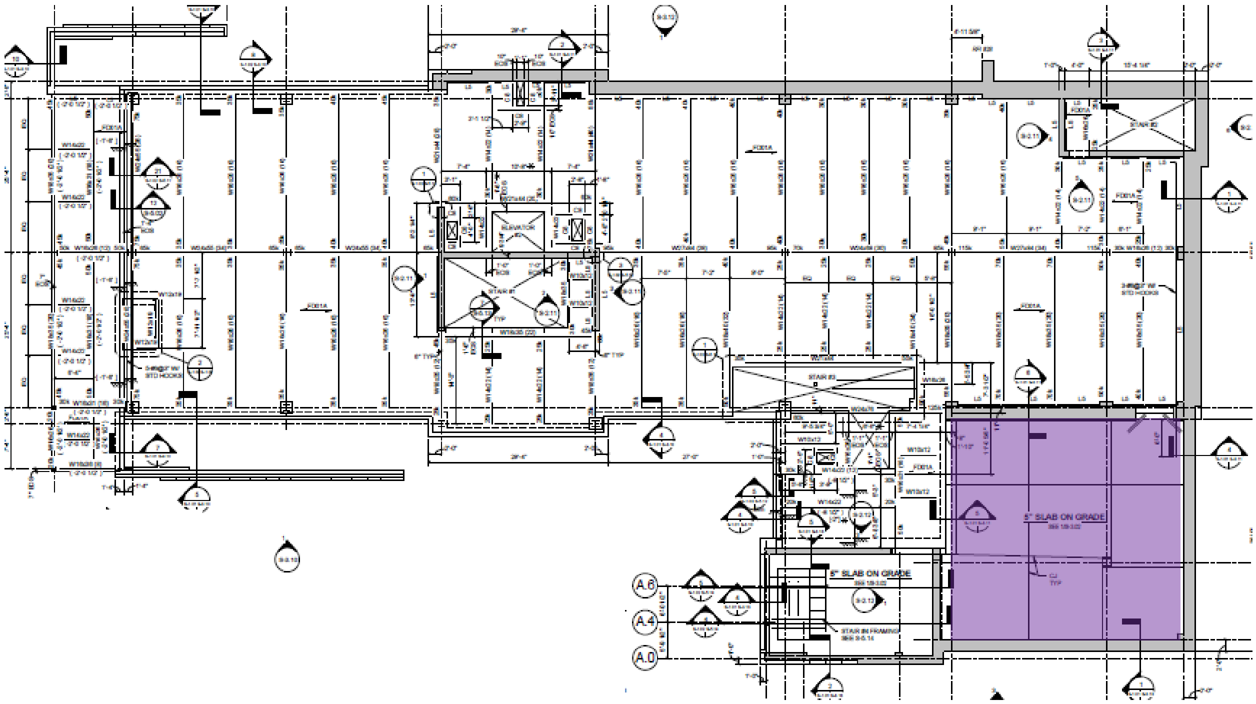

Figure 11: Level 2 Slab-On-Grade Thicknesses (S-1.02)

5”

Floor System

The New Library's floor system is a composite steel system comprised of 4 ½" normal weight concrete reinforced with 6x6-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 typically runs 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.

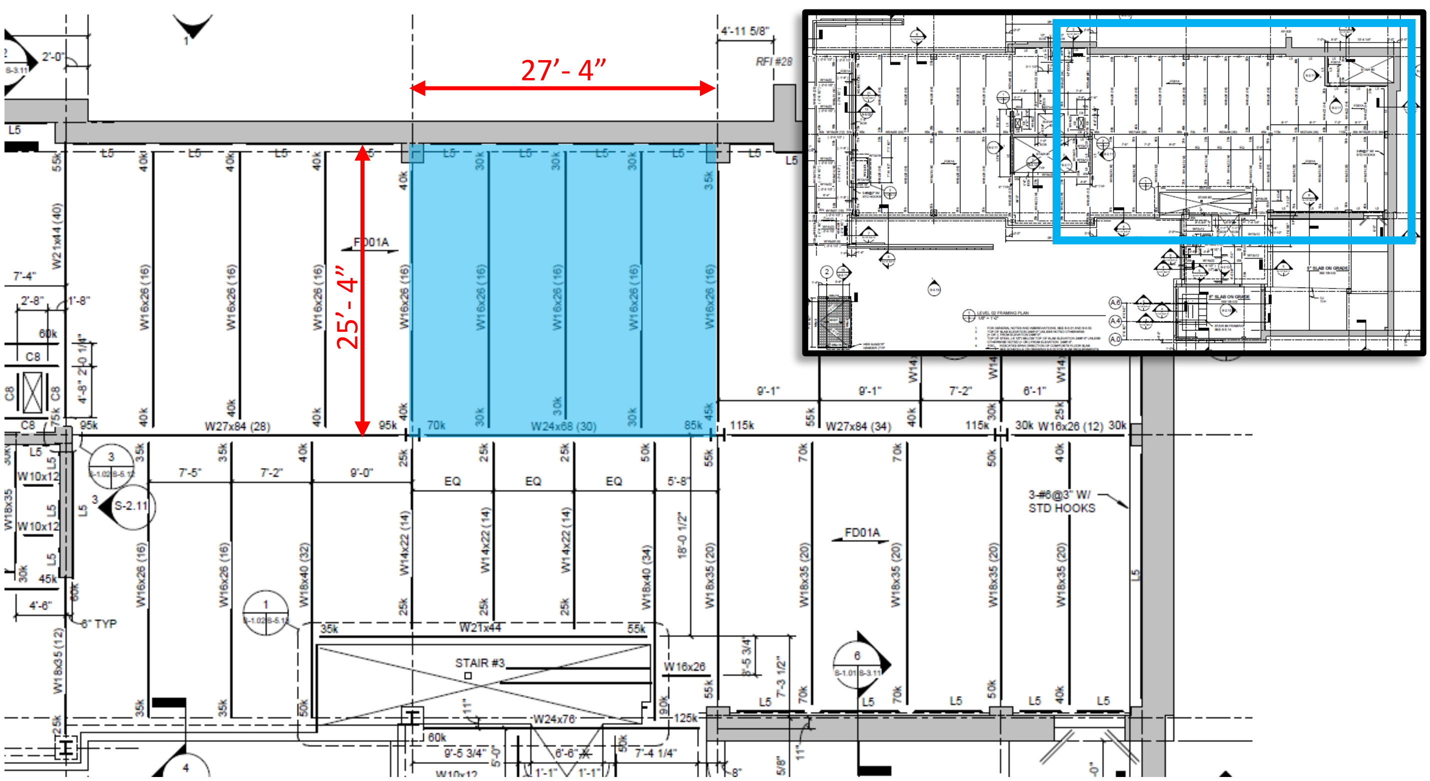

Figure 12: Level 2 Framing Plan Showing Typical Bay (Sheet S-1.02)

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 extend between Level 1 and Level 3. The need for these larger columns is due to the increased tributary area, as compared to typical bays, and larger design loads from general collections on all upper floors. Figure 13 shows the location of the W12x170 columns.

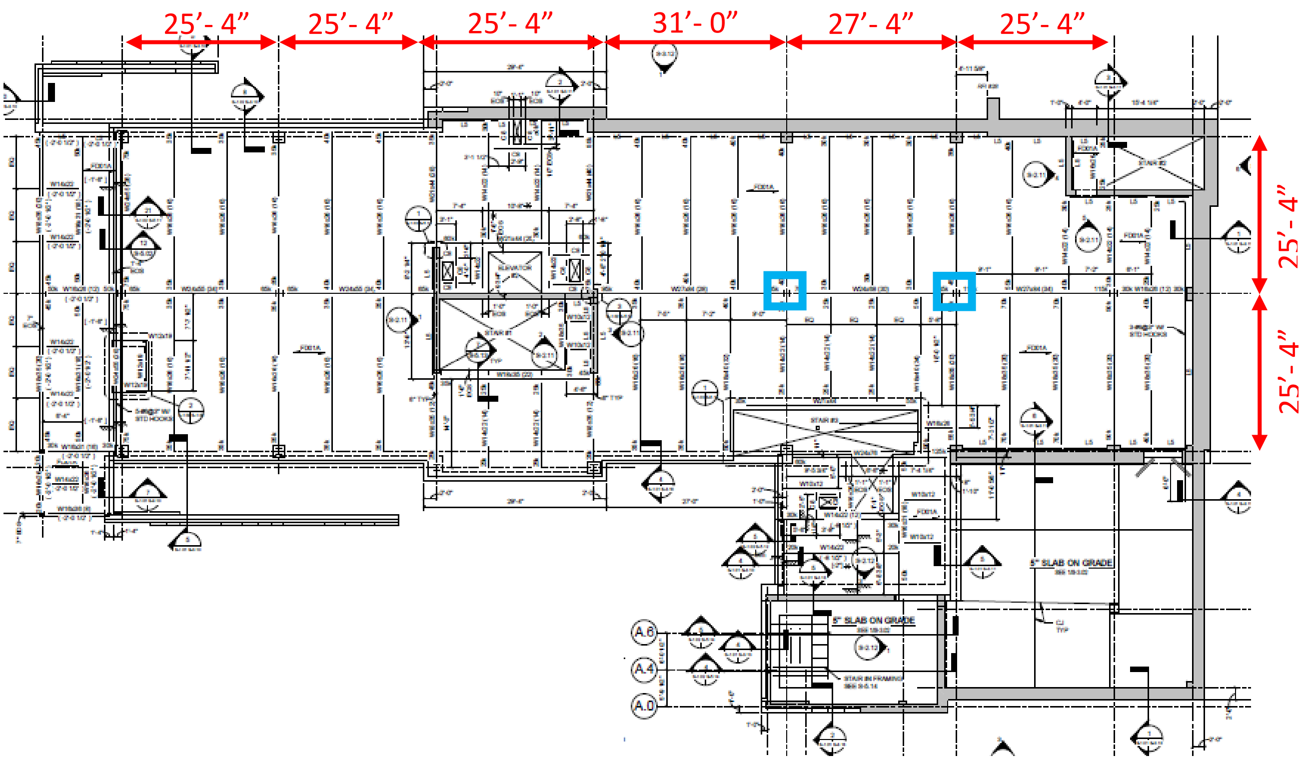

Figure 13: Level 2 Showing Location of W12x170 Columns (Sheet S-1.02)

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" NWC slab. The upper 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 larger beam size is due to increased design loads based on the HVAC system. Figure 14 below shows a 27'-4" bay with W18x35 beams.

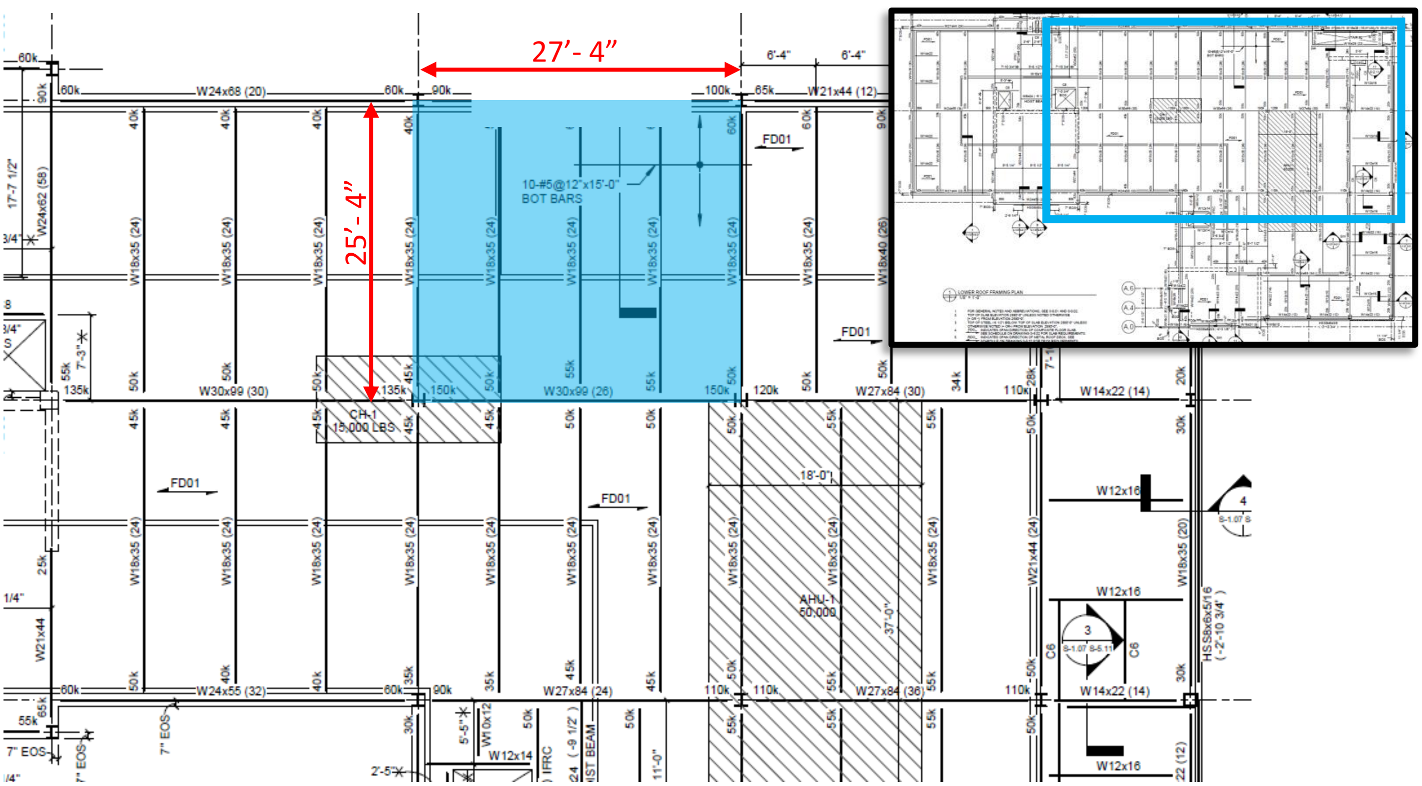

Figure 14: Lower Roof Framing Plan Showing Typical Bay (Sheet S-1.07)

Upper Roof

The upper roof is a raised false mansard consisting of 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.

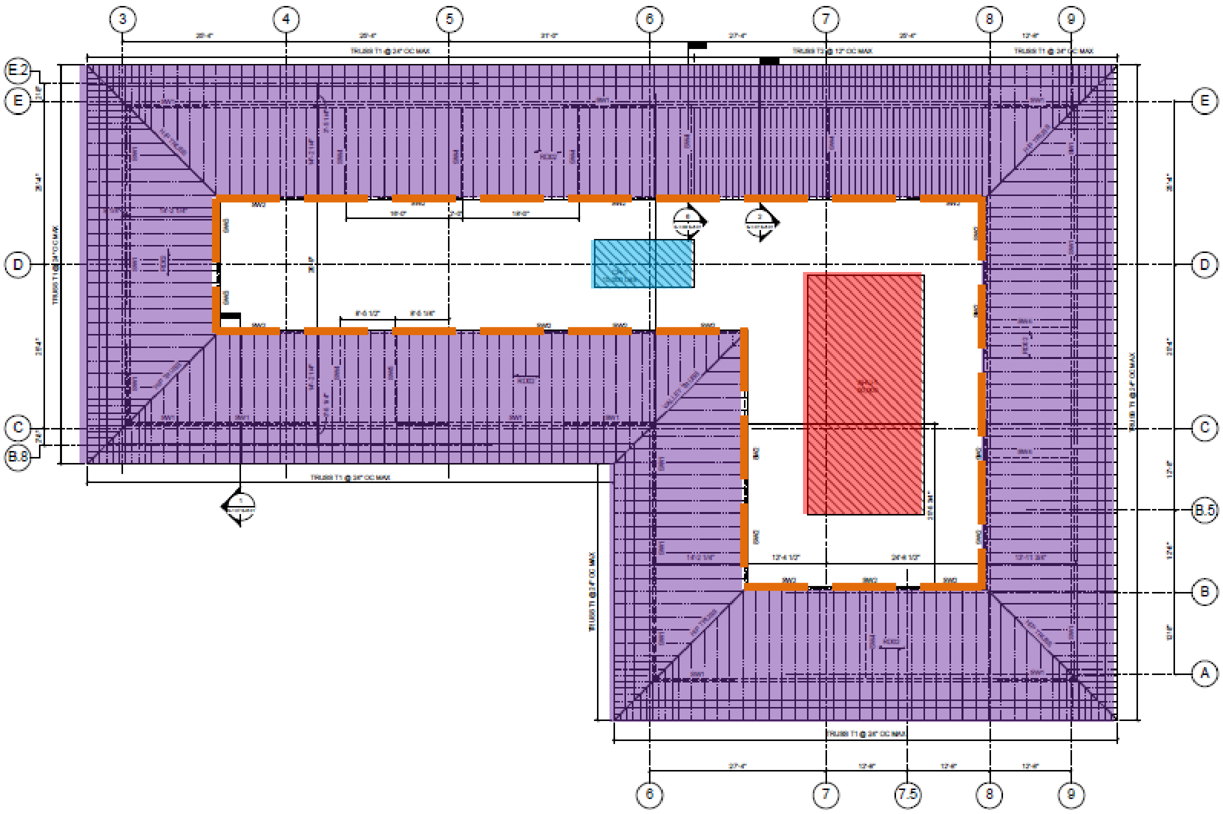

Figure 15: Upper Roof Framing Plan Showing Pre-engineered Trusses (Sheet S-1.08)

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

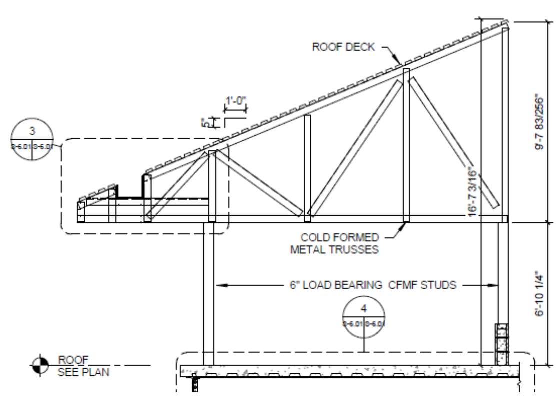

Figure 16: Cold Formed Metal Truss (S-6.01)

Lateral System

The lateral force resisting system for the New Library consists of ordinary reinforced concrete shear walls. There are nine 12” thick shear walls of varying length 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 most likely 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.

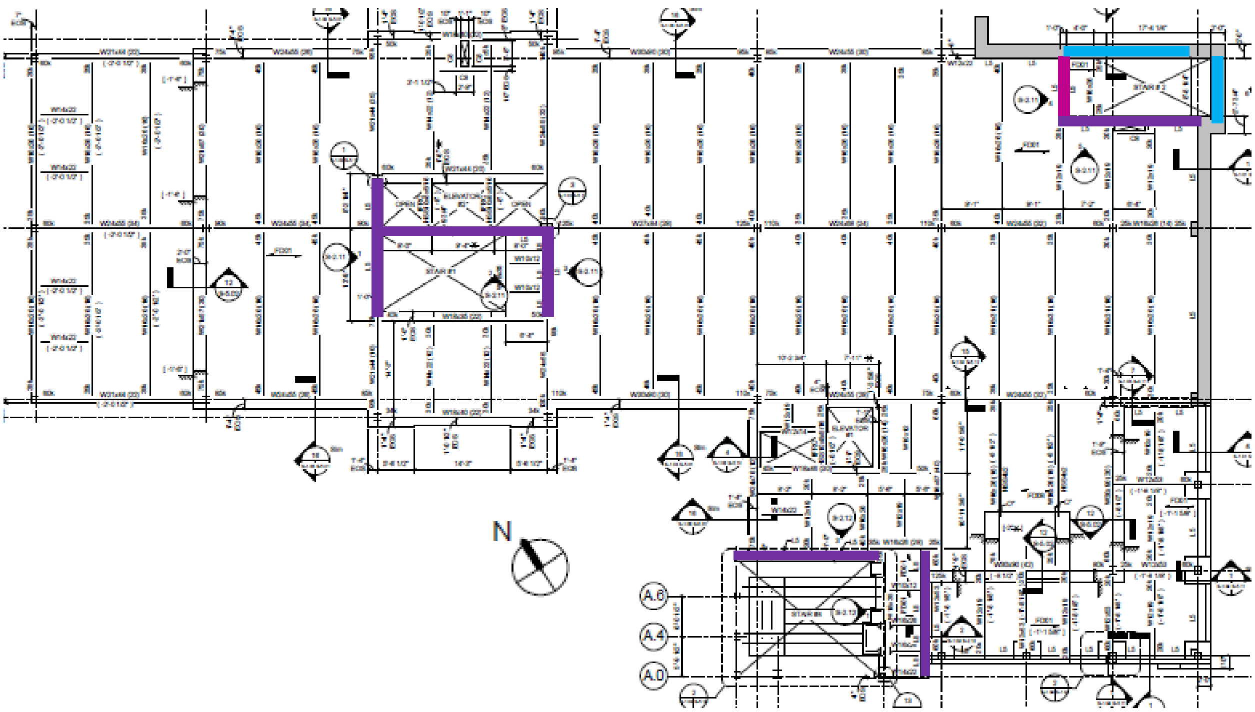

Figure 17: Floor Framing Plan Showing Shear Wall Locations (S-1.04)

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

Joint Details

In the New Library, the typical connections are beam-to-girder, beam-to-wall, slab-to-wall, and shear wall-to-foundation wall connections. A brief description of these various connections along with images taken from the construction documents are provided below.

Typical Beam-to-Girder Connection:

The wide flange beams used in the floor and lower roof systemsare connected to the wide flange girders using double angle connections (see Figure 18). The double angle creates a shear connection by not restricting the movement of the flanges (due toonly connecting the webs of the members).

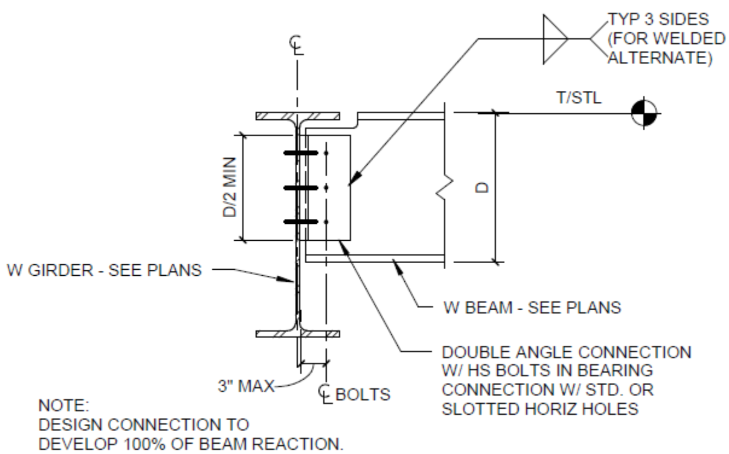

Figure 18: Beam-to-Girder Connection (Sheet S-5.01 Detail 5)

Typical Beam-to-Wall Connection

The wide flange beams used in the floor and lower roof systems are connected to the concrete walls by angles bolted to the wide flange web and welded to a plate that is embedded in the wall (see Figure 19). The angle creates a shear connection by only connecting the web of the member.

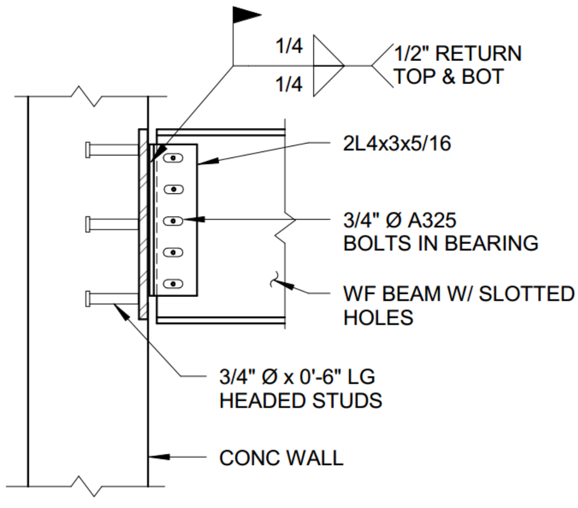

Figure 19: Beam –to-Wall Connection (Sheet S-1.05 Detail 12)

Typical Slab-to-Wall Connection

The composite deck used in the floor and lower roof systems rests on relief angles that are connected to shear walls by expansion bolts. A mechanical coupler is placed in the wall to allow for ease of construction when providing continuous rebar from the slab to the wall (see Figure 20). According to the specifications these couplers are capable of developing 125 percent of the specified yield strength of the bar in tension and compression.

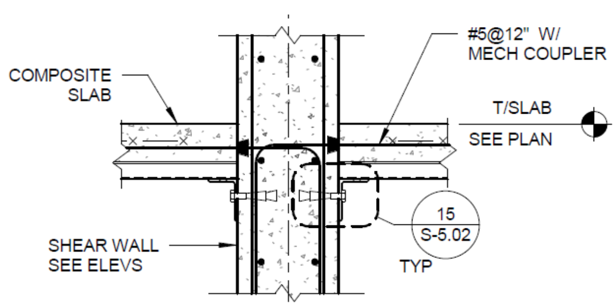

Figure 20: Slab-to-Wall Connection (Sheet S-2.11 Detail 10)

Typical Shear Wall-to-Foundation Wall Connection

The shear walls that rest on top of foundation walls are connected by a fully developed tension splice and the surface is intentionally roughened (see Figure 21). This allows the shear wall to behave monolithically with the lower foundation in transmitting lateral forces.

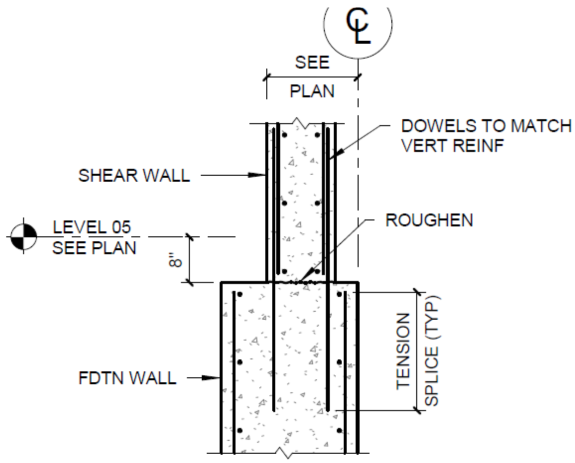

Figure 21: Shear Wall-to-Foundation Wall Connection (Sheet S-2.11 Detail 9)

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 on material 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 prescribes the 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.

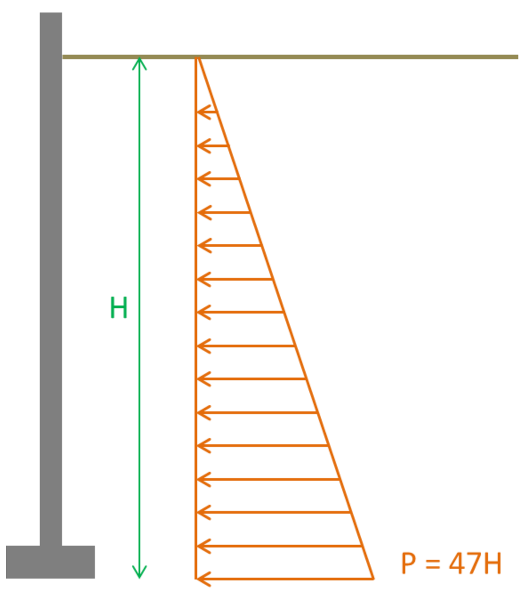

Figure 24: Equivalent Lateral Fluid Pressure

Load Paths

Gravity

Gravity loads in the New Library are first received by the composite floor slab which then transfers the load to steel infill beams. From there, the loads are then transferred to steel girders and then into steel columns. If the column is located at the building's interior, the loads will be transferred directly from the column base into a footing. If the column is located at the building's exterior, the loads will first be transferred to a concrete pier and then to a spread footing. Once the loads reach the footing they are then dissipated into bedrock.

Lateral

Wind

Wind loads on the New Library are first received by the exterior façade. The façade transfers the load into the floor diaphragm, which in turn transfers the loads into the concrete shear walls. Once in the shear walls, the loads are then transferred down into footings. Upon reaching the footings, the loadsare then dissipated into bedrock.

The upper roof system incorporates a separate lateral system which consists of cold formed shear walls. These are anchored to the lower roof diaphragm, which allows the lateral loads to be transferred in the concrete shear walls. The loads then follow the same path as wind loads on the building's façade.

Soil

Soil loads on the New Library are first received by the building's foundation walls. The walls then transfer the loads down into bedrock through several possible paths. In the first possible path, loads are transmitted directly into the footer from which the loads will be dissipated into bedrock. In the second possible path, loads are transmitted through the diaphragm at each floor level. Once into the diaphragm, the loads will be transferred into the shear walls and ultimately dissipated into bedrock. In the last load path, loads are transmitted directly into shear walls. Several shear walls are located directly perpendicular to foundation walls and may serve as a direct load path down to the foundation.

This topic will be further researched in later technical reports to determine the most accurate load path of the soil loads.

Conclusion

Technical Report 1 described the physical existing conditions of the New Library at University of Virginia's College at Wise. The contentconsisted of detailed descriptions of the foundations, composite floor system, framing systems, lateral systems, joint details, and design codes and loadings.

The architectural design of the building was dictated and constrained by the current buildings on campus. The building required a façade similar to the surrounding buildings. This design constraint will impact future assignments by restricting changes to the building's façade. During future structural thesis assignments, any changes made to the structural system will have to be constrained to the current architectural expression and carefully considered so the building's aesthetics will be preserved.

One of the major factors that affected the building's design wasits integration into the existing 60 foot hillside. The lateral soil loads associated with the hillside posed a unique design challenge for the foundation system. The design team's solution was to retain the hillside using a temporary leave-in-place soil retention system, along with designing the foundation walls to resist future soil loads. This design solution and the lateral soil loads will pose certain challenges in future analysis and design assignments.

In future analysis assignments, one challenge will be accurately modeling and analyzing the foundation walls. The foundation walls could be modeled as unbraced cantilevers, or could be modeled using the floor diaphragm as pin supports. The system will have to be carefully modeled and analyzed to determine if the floor diaphragm is aiding the foundation wall in resisting and distributing the load.An accurate load path for the soil loads will then have to be determined.

The soil retention system and foundation wall design will both pose possible difficulties in future design assignments. The current design was chosen based on a number of factors including ease of construction, surrounding structures, and cost. These factors will need to be considered if a structural redesign of the foundation and soil retention system is needed or desired.