THESIS PROPOSAL

THE HEALTH CENTRE

LOCATION | SOUTHEASTERN US

Hannah N Valentine

STRUCTURAL OPTION | ADVISOR: DR. HANAGAN

1 | Executive Summary

The Health Centre is a 750,000 square foot university hospital expansion project located in the southeastern United States. Located adjacent to existing hospital facility 'Clinic B,' this ten-story L-shaped building is connected by two bridges to the surrounding campus. Demand for new, state-of-the-art medical technology, additional research space, and extra hospital beds prompted the design and construction the Health Centre. At a height of 163 feet, the Health Centre will be by far the tallest building in the surrounding area when its construction is complete in 2016.

As a nod to the heritage and character of the surrounding university campus, The Health Centre takes its architectural cues from classical Italian and contemporary sources. Façade materials used on the building include stucco, metal panels, and a glass curtain wall. A green roof and four story underground parking garage contribute towards its goal of LEED silver certification. This building was designed as a "core-and shell," necessitating a structural consideration for flexibility of spaces and future expansion.

The existing structure of the Health Centre is mainly cast-in-place concrete on drilled piers and spread footings. Its floor system in the hospital bed tower consists of cast-in-place one-way concrete slabs and beams. Concrete moment frames spread throughout the structure resist the building's lateral loads. Below grade is a four-story parking garage. The parking garage floor slabs consist of two-way post-tensioned concrete slabs. The parking garage has its own lateral system of concrete shear walls.

The spring 2016 semester will propose alternative concrete gravity and lateral systems for the Health Centre. Overall, the redesign aims to reduce slab thickness for a more efficient use of materials and a reduction in floor-to-floor heights. The proposed thesis work will meet requirements for the Schreyer Honors College and the integrated Master's of Architectural Engineering program. Additional research and three-dimensional modeling will study floor vibrations of the redesigned structure and the current criteria for vibration sensitive research equipment.

In addition to an in-depth structural analysis, impact of the redesign and vibration criteria on construction cost and schedule will be studied. Results of this study will determine the feasibility of the design alternative. Relocation of a piece of mechanical equipment and its impact on the building's HVAC system will also be considered.

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2 | Introduction

2.1 Purpose

The primary objective of this proposal is to explore the existing building conditions of The Health Centre and establish the basis for the proposed redesigned structural system. Documentation of the existing structural systems and relevant building codes, will provide the foundation for the proposal. This report will also detail the alternative structural system chosen, and establish the methods and schedule that will be used to complete future work in the Spring 2016 semester.

2.2 General Building Overview

The Health Centre is a university hospital expansion project consisting of a nine-story hospital bed tower with a mechanical penthouse and four-story underground parking garage. Located in the southeastern United States in the middle of a university campus, this L-shaped concrete building is built alongside existing hospital facilities referred to as 'Clinic B.' It features a lower green roof and new state-of-the-art technical facilities – including an ICU, emergency department, clinical facilities, and med-surg patient rooms. Upon completion in 2016, the building will become certified LEED Silver.

With an estimated cost of $203 million dollars, the new building will add approximately 450,000 square feet and 210 new hospital beds to the existing hospital complex. The building is designed to be a "core-and-shell" building with adaptable spaces and the possibility for future expansion. SmithGroupJJR was responsible for the architectural design of the building, while Walter P. Moore was responsible for the building's structural design.

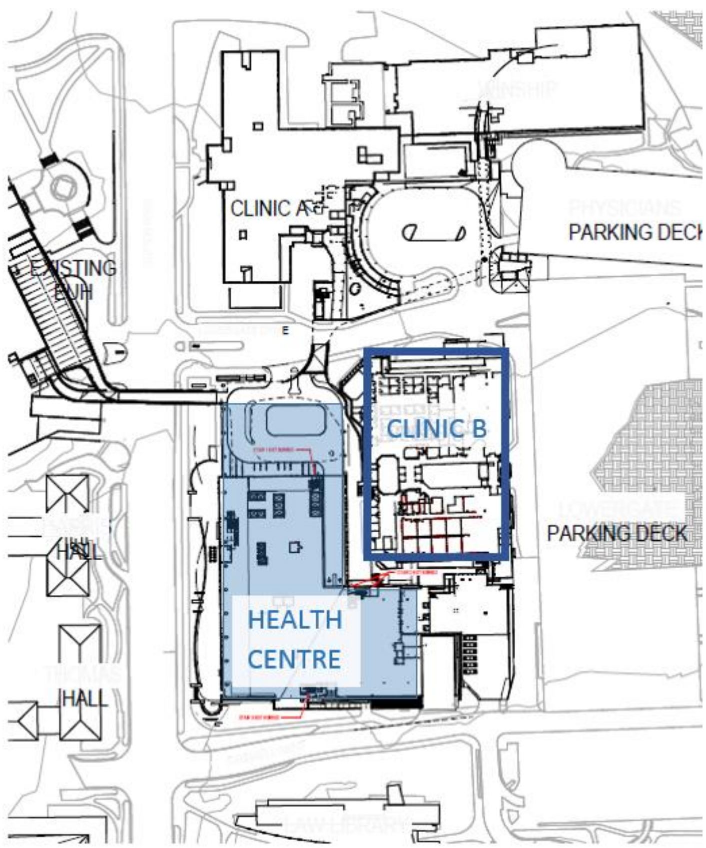


Figure 1 | Site Plan (Courtesy of SmithGroupJJR)

Figure 2 | East Elevation (Left) and South Façade (Right) with Metal Panel System (Courtesy of SmithGroupJJR)

The tallest building in the immediate area, the building stands out architecturally with a glass and metal façade system as depicted in Figure 2. In addition to the new technical facilities, the building site features a new entry drive for easier patient access and sustainable initiatives such as bioswales.

As the building increases in height, its floor plan becomes restricted to the rectangular bed tower area. Elevators are located in the northern end of the tower, and extend the full height of the building. The three main building footprints are shown in Figure 3.

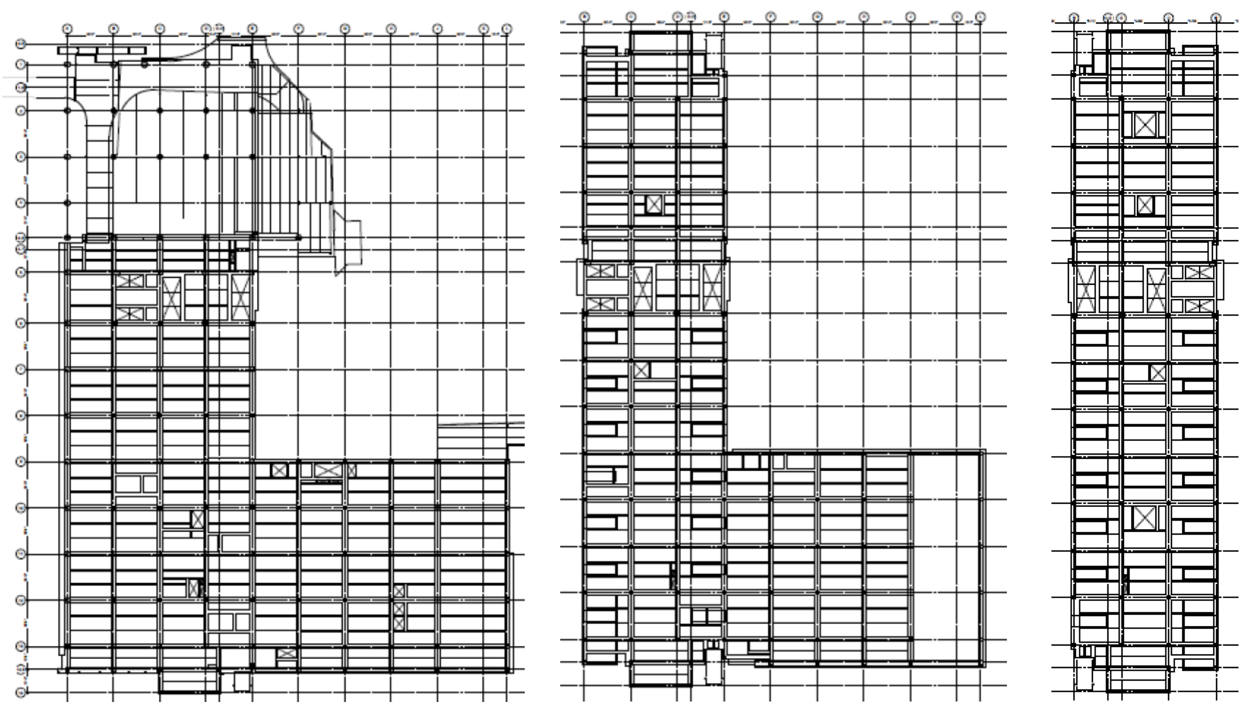


Figure 3 | Typical Building Floor Plans (Courtesy of Walter P. Moore)

2.3 Structural System Overview

Above ground, The Health Centre is mainly a cast-in-place concrete frame structure, as shown in Figure 4. The structural material used for the building was a choice driven by the contractors from McCarthy Building Construction, who noted the availability of concrete over steel in the building's southeastern location. Cast-in-place floors are one-way slabs that connect the building's diaphragm. Bays are 30'x30' squares wherever possible.

The below-grade parking garage consists of two-way post-tensioned flat slabs. Foundations are typically cast-in-place spread footings, with some deep drilled piers on competent rock. CMU walls in the building are non-load bearing. A steel bridge connects the structure to other campus buildings. Further details regarding the building's structural system will be explored throughout this report.

Due to the life-safety concerns for hospital structures, The Health Centre is Building Category IV under ASCE 7-05. The building was designed for basic wind speeds of 90 MPH and Seismic Design Category C.

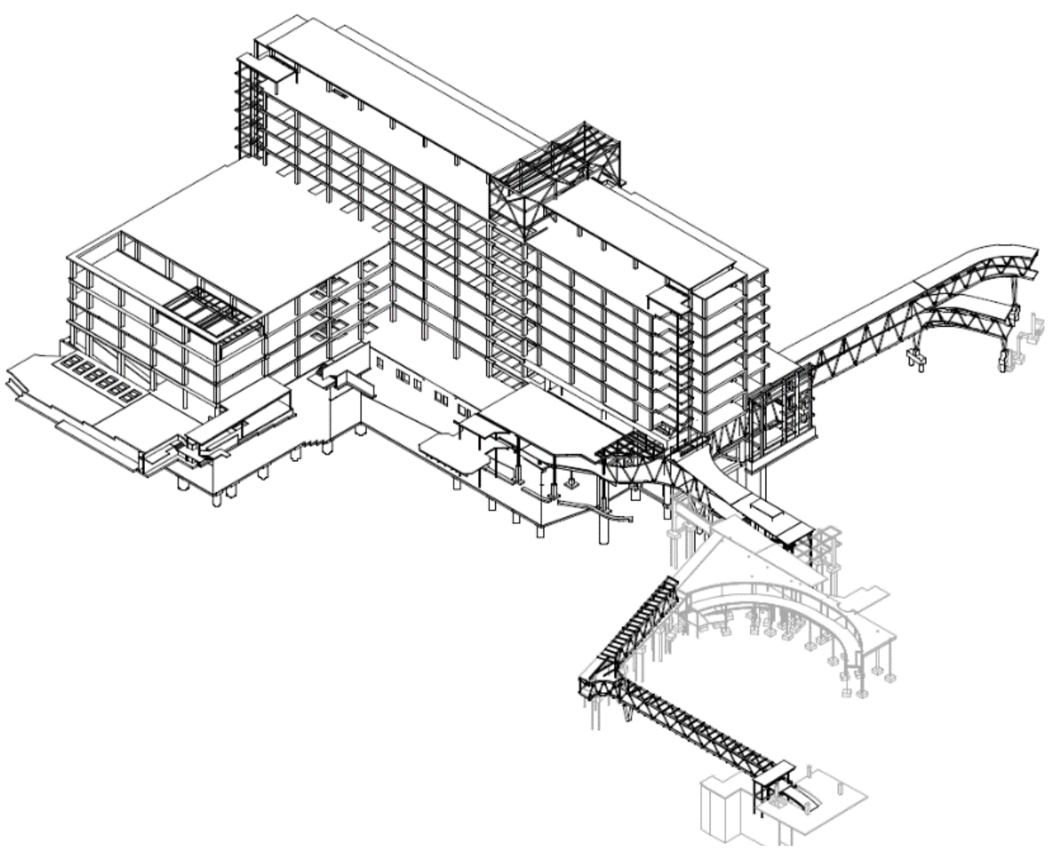


Figure 4 | Overall Building Structure (Courtesy of Walter P. Moore)

3 | Structural Systems

3.1 Foundations

The two primary foundation types used in this building are drilled piers and spread footings. All foundations were designed to be 4,000 psi normal weight concrete and are spaced the width of a typical 30'x30' bay in most locations.

Drilled piers are used mainly underneath the parking structure and the western side of the building. They were designed for 80 ksf net end bearing pressure on competent rock. There are 14 types of drilled piers with pier diameters ranging from 36" to 96". The piers use both #3 and #4 ties spaced at 12" and typically have #11 bars for vertical reinforcement. Typical details for drilled piers are provided in Figure 5. In some locations, drilled piers are embedded into the rock a depth of 5'-0".

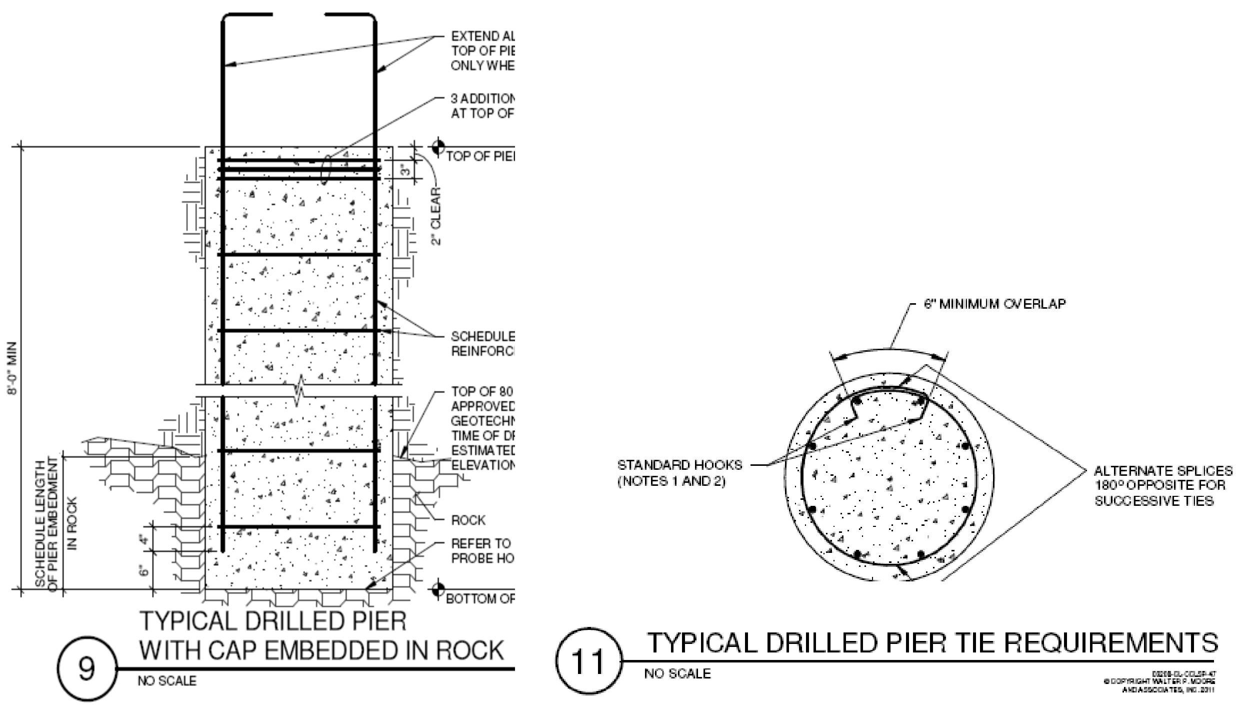


Figure 5 | Typical Drilled Pier Details (Courtesy of Walter P. Moore)

Rectangular spread footings range in size from 4'x6'x18" with #6 rebar to 12'x12'x82" with #9 rebar. They were designed for 30 ksf net pressure on competent rock or 2 ksf net pressure on compacted soil depending on their location in the building. Some spread footings have an equivalent drilled pier that the contractor may choose to use instead. Typical details for spread footings are shown in Figure 6, while a partial foundation layout is provided in Figure 7.

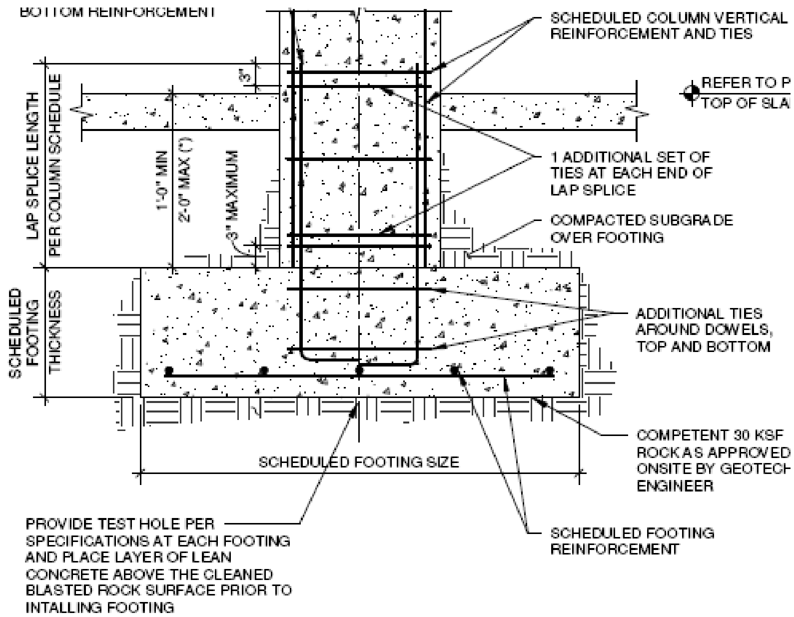


Figure 6 | Typical Foundation Detail (Courtesy of Walter P. Moore)

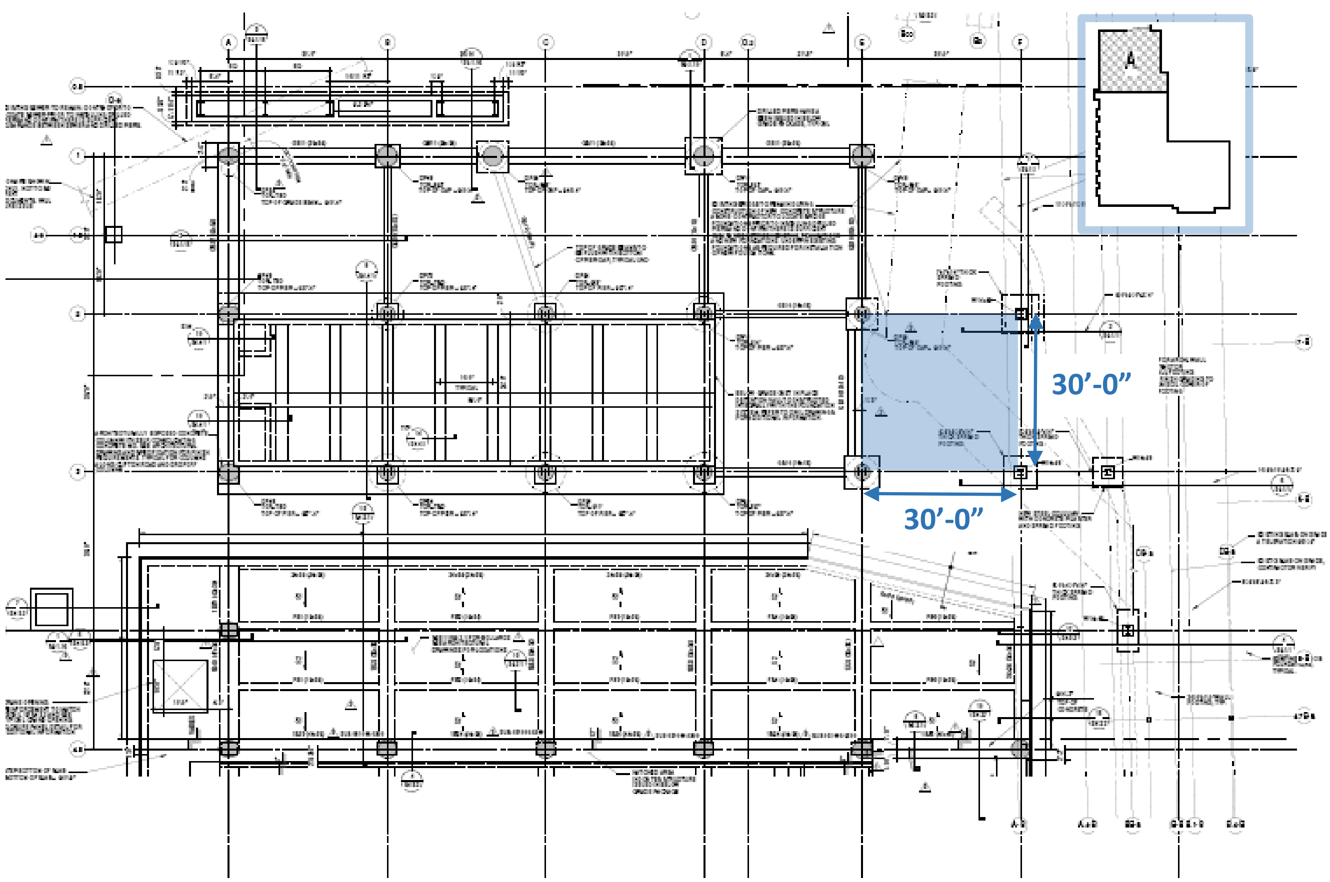


Figure 7 | Partial Foundation Plan (Courtesy of Walter P. Moore)

3.2 Gravity System

3.2.1 Typical Bay

A typical bay size of 30'x30' is used throughout the building, as depicted in Figure 8. Overall, the floor system consists of a cast-in-place one-way skip-pan joists. Typical girders are 36"x25" and typical purlins are 9"x25" with #8 top and bottom bars. A typical section detail for the floor system is provided in Figure 9. In some locations – usually near floor openings or slab depressions – there is variation in beam width and depth. The flat floor slab depth ranges from 5" to 14" thick, with a typical depth of 5" and 7". Top and bottom bars vary in size and spacing depending on the slab location, but are typically #3 or #4 spaced at 12". Some depressions in the slab occur for medical equipment and other hospital technology. All floor system components for the hospital bed tower and parking garage are 5,000 psi normal weight concrete.

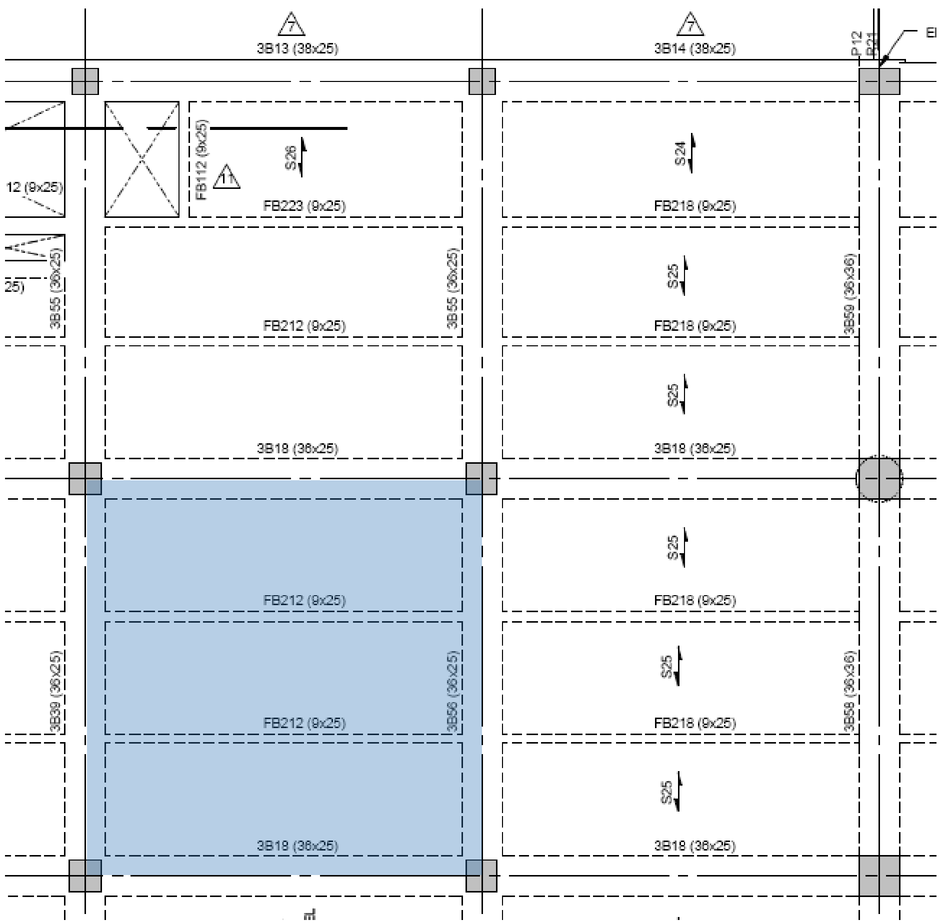


Figure 8 | Typical Bay from Third Floor Area D Floor Plan (Courtesy of Walter P. Moore)

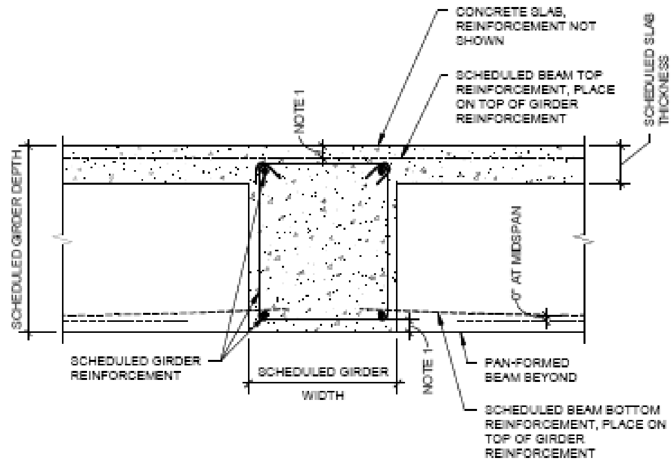


Figure 9 | Typical Floor Section (Courtesy of Walter P. Moore)

3.2.2 Columns

For the bed tower, column size decreases as floor level increases. Parking garage columns are typically 28”x44” with 22 #9 rebar for vertical reinforcement. From the ground floor of the bed tower to the bottom of the fourth level, most columns are 28”x32” with vertical reinforcement consisting of 12 #8 rebar. Floors above the fourth floor, including the penthouse, typically have 24”x24” square columns with 8 #8 vertical reinforcement. A column splice is used when these size changes occur (Figure 10). Some columns have also been sized for future steel expansion. 7000 psi normal weight concrete is used for all cast-in-place columns.

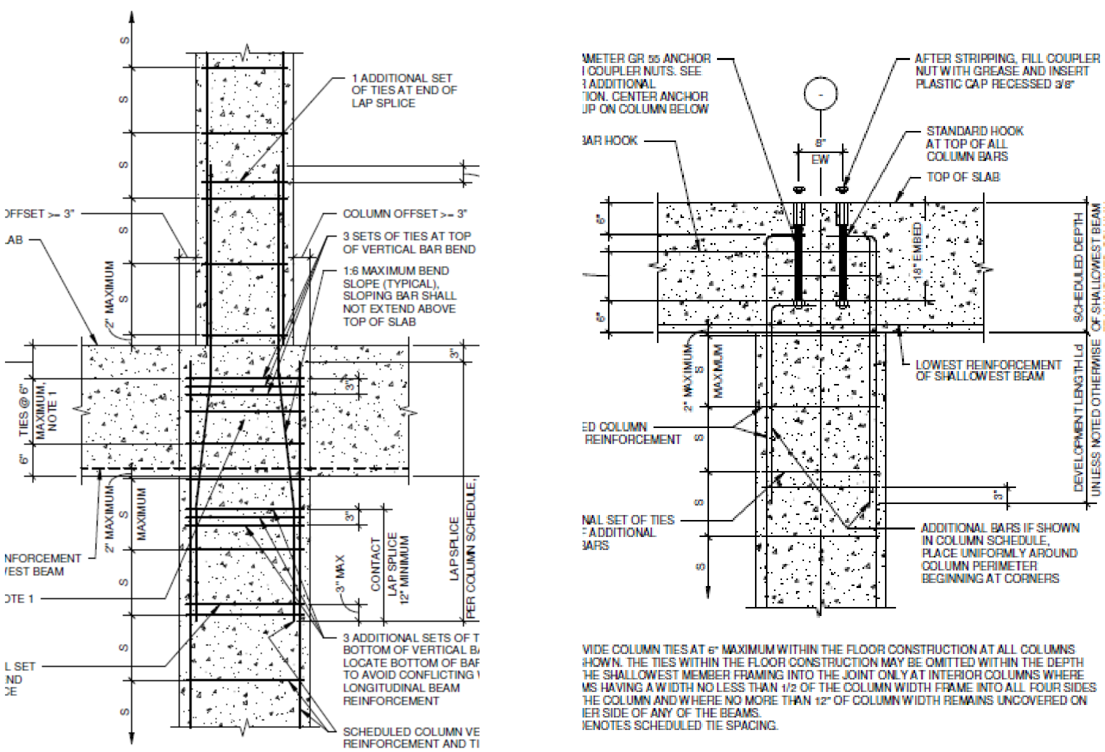


Figure 10 | Typical Column Splice and Steel Expansion Details

Ellipse concrete columns are used in some locations, including underneath the bridge structure, and are detailed in Figure 11. Additionally, W14 structural steel encased in concrete is used in some locations between the ground and fourth levels when columns do not continue below grade to the underground parking garage.

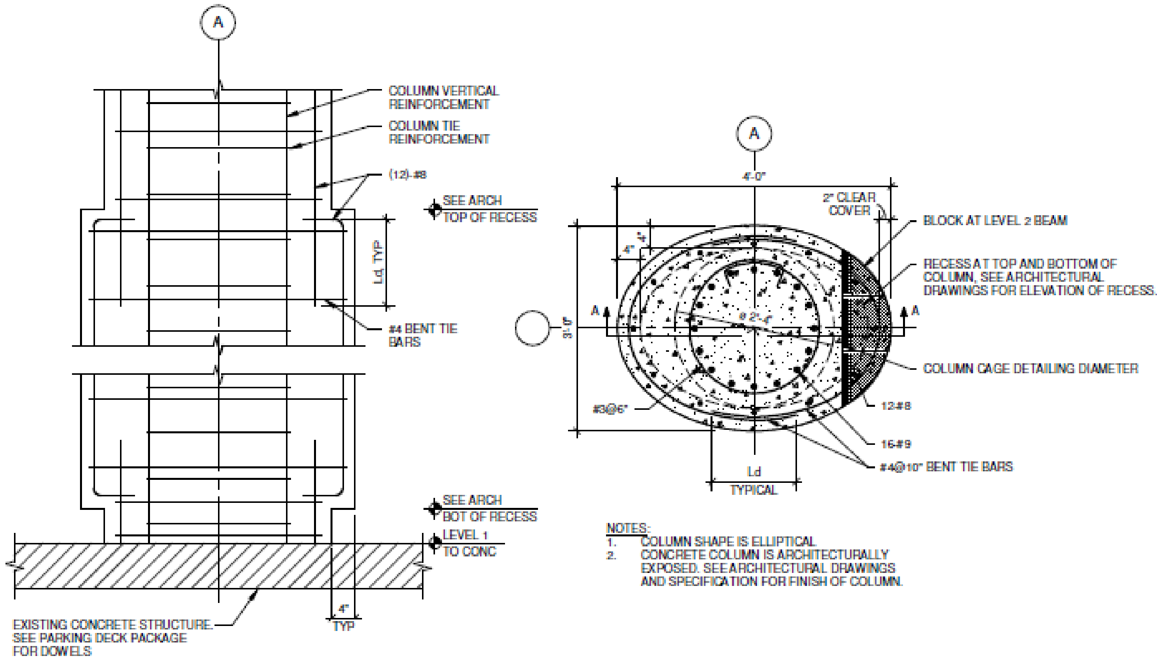


Figure 11 | Ellipse Column Detail

3.3 Lateral System

3.3.1 System Overview

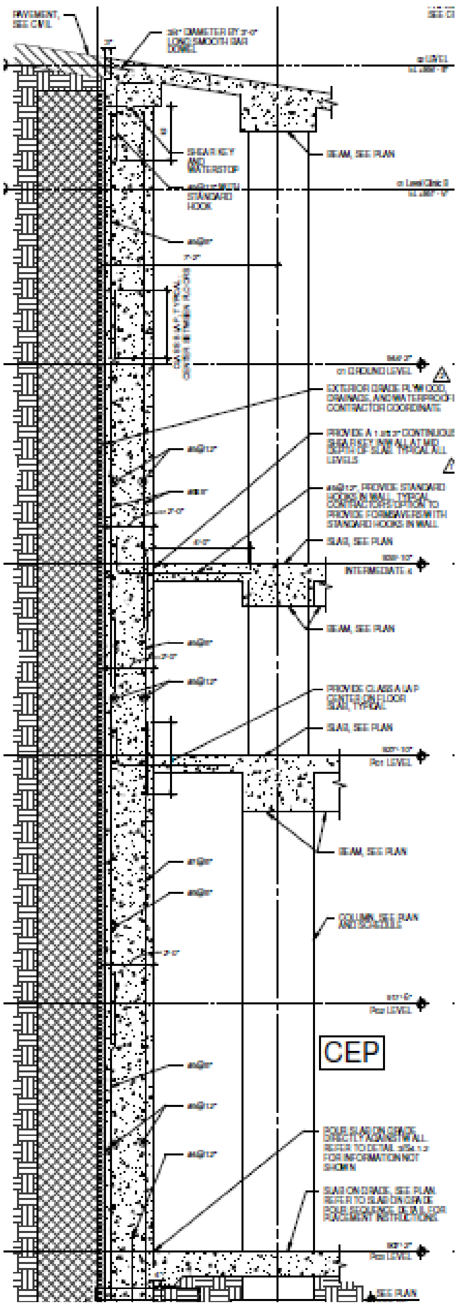
Above grade, concrete moment frames are used to resist lateral loads in both the north-south and east-west directions (Figure 12). All beams and columns above grade are detailed to resist gravity and lateral loads. Below grade, exterior shear walls resist soil and potential seismic forces. 7000 psi normal weight concrete is used for all lateral system vertical elements. Lateral load is transferred into the moment frames and shear walls through the floor diaphragm

Basement shear walls in the parking garage begin at the bottommost level and end at grade, as shown in Figure 13. Typically 2' thick and approximately 50' high, they extend around the exterior of the parking structure. A 1.5"x3" continuous shear key and standard hooks connect the walls to the post-tensioned floor diaphragm.

Lateral load resistance in the bed tower structure takes advantage of the fact that all concrete framing provides a certain level of moment resistance. Large girder sizes on the exterior, typically 50"x48", indicate that particular attention was paid to lateral resistance on the exterior of the structure. A typical deep beam cross section is provided in Figure 14.

A concrete floor diaphragm consisting of a 5” one-way flat slab and 25” deep beams (in most locations) transfers the lateral load throughout the building (Figure 14). Due to the nature of this lateral system, concrete moment frames extend the full height of the building with some stopping at the fourth floor green roof.

Design for service requirements take into consideration the lateral deflection of wind. Wind loads with a 10-year mean recurrence interval were considered for a lateral deflection of the typical floor height/400.



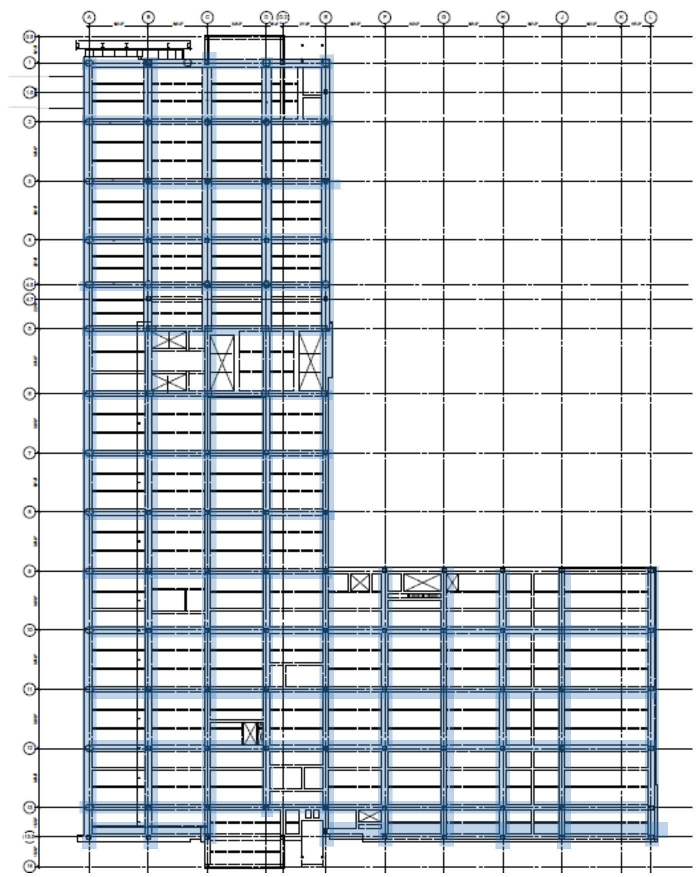


Figure 12 | Fourth Floor Concrete Moment Frames (WPM)

Figure 13 | Exterior Concrete Shear Wall Detail (WPM)

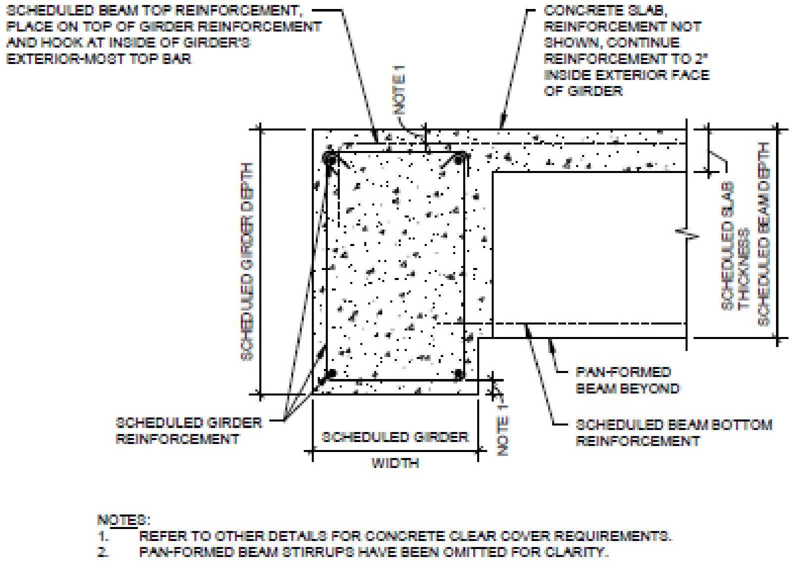


Figure 14 | Typical Deep Beam Cross-Section (WPM)

3.3.1 Load Path

The two load paths under consideration for this report are gravity and lateral load paths.

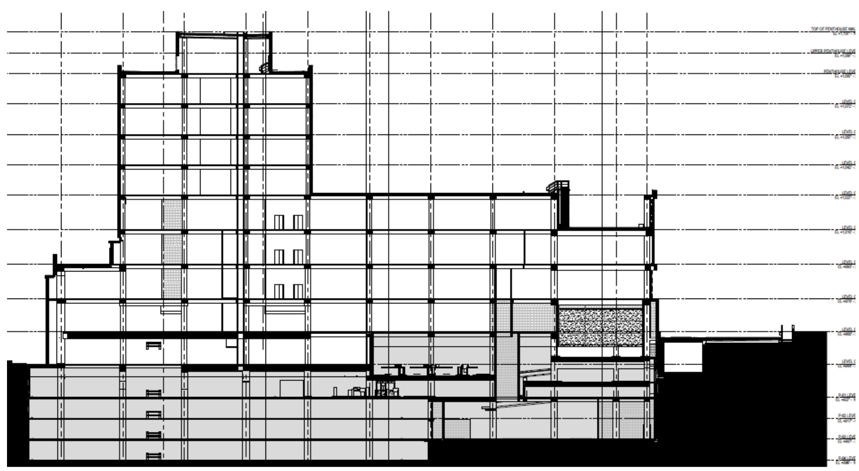


Figure 22 | Building Section Looking North (Courtesy of SmithGroupJJR)

For gravity loads, the load path begins at the penthouse roof. Roof live and dead loads are carried by columns to the floor below. On the penthouse level, mechanical equipment and cooling tower loads are carried by the concrete floor diaphragm and distributed to the columns. This process of load distribution continues throughout the remaining levels, noting the additional green roof loads on the fourth level. At grade, dead and live loads on the floor are distributed onto slab on grade and cast-in-place grade beams. Eventually, all building gravity loads are carried by the columns to the drilled pier and spread footing foundations. Depending on the foundation location, these loads are either distributed into surrounding compact soil or competent rock.

Wind loads place a lateral pressure on the bed tower façade. Pressure generates a force on the exterior façade that is distributed along its surface. This force is distributed based on stiffness to building elements. Exterior moment frames will take some of the lateral load, and the floor diaphragm will distribute the remaining lateral force to the other concrete moment frames. The columns of the moment frames will carry the lateral force and its foundation will resist overturning moment created by the lateral force.

Seismic loads are due to ground acceleration during a seismic event. Ground acceleration causes building acceleration, which is based on the building mass and is quantified during design as story forces. The forces caused by acceleration are distributed on each floor according to stiffness of building framing elements. Above grade, seismic story forces are distributed by the diaphragm to concrete moment frames and carried by the columns down to the foundations. Below grade, seismic story forces are taken to the foundations by the exterior shear walls. The diaphragm will not distribute seismic forces as much due to the exterior location of the walls and their similarity in stiffness in each direction.

3.4 Structural Details

3.4.1 Secondary Structural Elements

An architecturally exposed structural steel (AESS) canopy is a major architectural feature on the western side of the building. The canopy consists of double steel plate fins welded to AESS 4"x2"x ½" HSS. The canopy is connected to and supported by a 2x3 steel plates and 4x4x5/16 double angle kicker. These steel supports are welded to embed plates to connect the canopy to the concrete framing as seen in Figure 15.

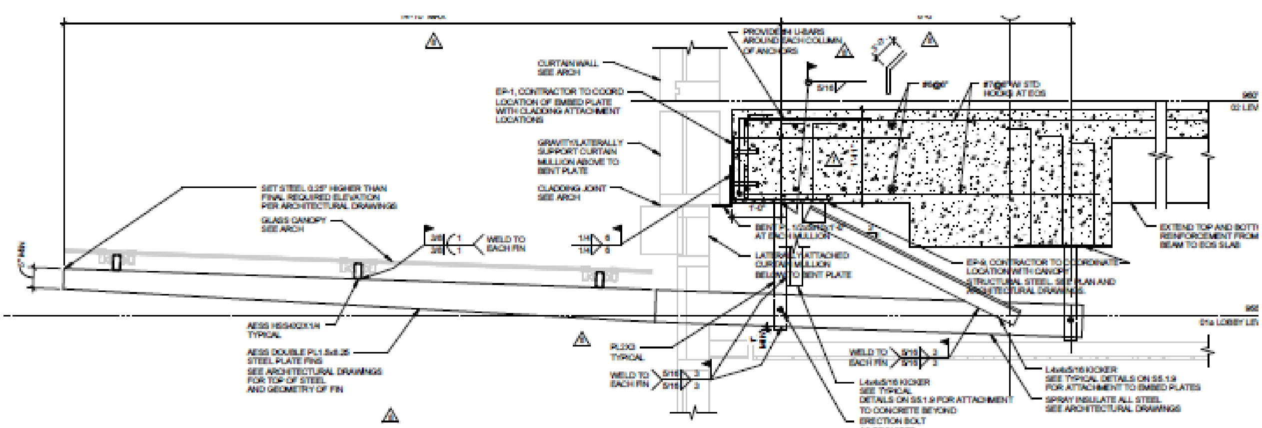


Figure 15 | West HSS Canopy Connection to Concrete Framing (Courtesy of Walter P. Moore)

An 8" non-load bearing CMU wall surrounds all elevator and stair shafts on the parking garage level. For these 8" interior CMU walls, vertical reinforcing is typically #5 or #6 rebar depending on wall height. The concrete strength of these masonry units at minimum 1,900 psi. Typical details for masonry connection to structural framing are shown in Figure 16.

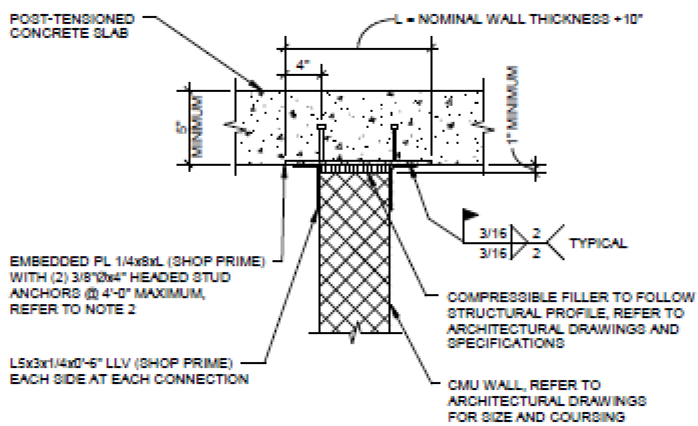


Figure 16 | Building Section Looking North (Courtesy of WPM)

3.4.2 Joint Details

With a variety of architectural and structural systems in The Health Centre, there are many different joint types to consider for construction and design. Due to this being a largely concrete structure, joints are particularly important to avoid cracking and other structural defects. Figure 17 depicts typical details for joints in concrete connections.

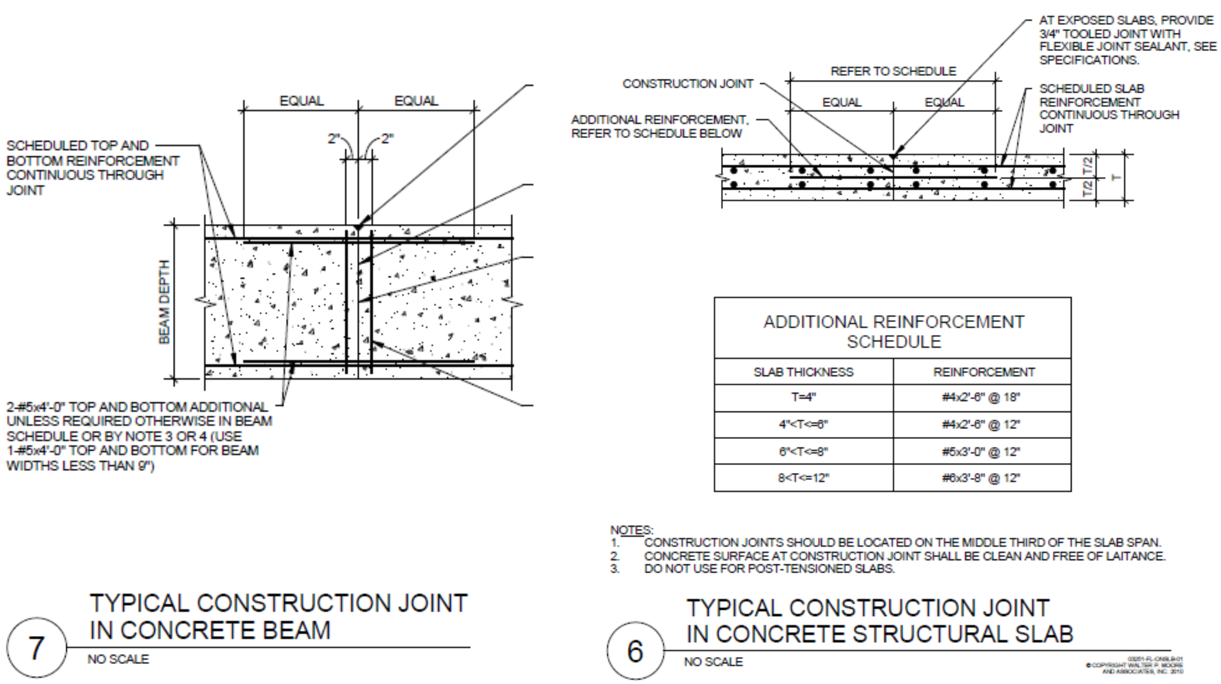


Figure 17 | Typical Construction Joints in Bed Tower Concrete Floor System (Courtesy of Walter P. Moore)

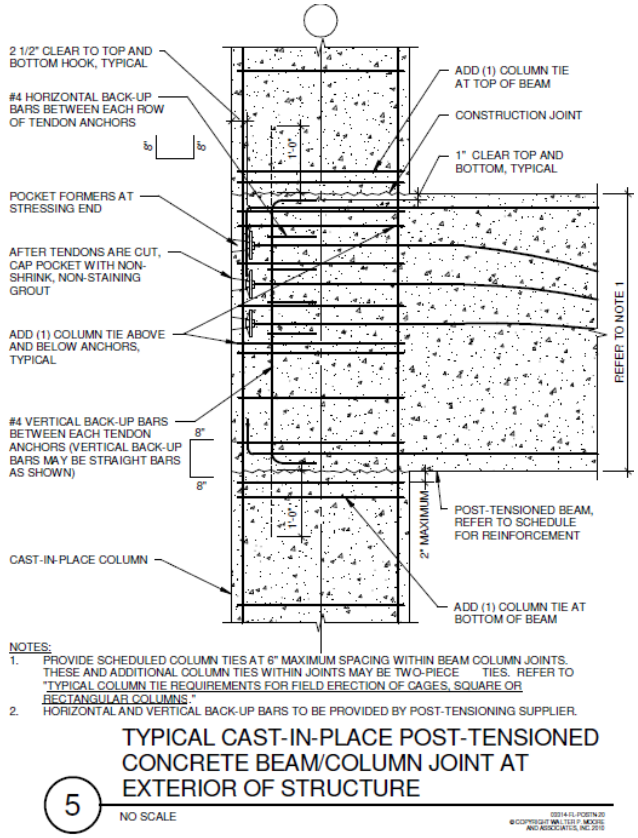


Figure 18 | Typical Cast-In-Place PT Exterior Beam/Column Joint in Parking Garage (Courtesy of WPM)

Figures 18-20 show typical joints for four story underground post-tensioned parking garage. Structures such as parking garages are often post-tensioned to prevent deflection and sagging due to car weight, and allow longer bay spans. At the exterior of the structure, the post-tension slab connects to a cast-in-place columns. 1" of clear cover for top and bottom of the slab is typical above and below anchors. #4 back-up bars are located between the tendon anchors. At the stressing end are pocket formers. Once the tendons are cut, the pocket is capped with non-shrink, non-staining grout. The reinforcing schedule for the two-way post-tensioned slab in Figure 18 shows the location of 90° and 180° hooks, as well as drop panels and reinforcing.

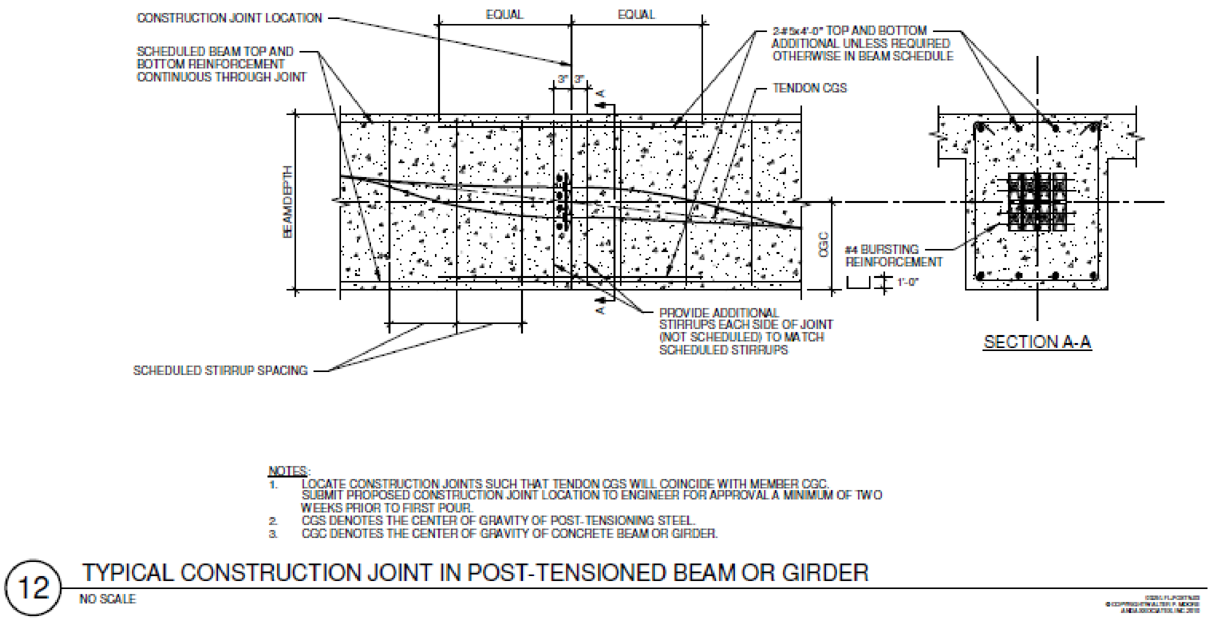


Figure 19 | Typical Cast-In-Place PT Exterior Beam/Column Joint in Parking Garage (Courtesy of WPM)

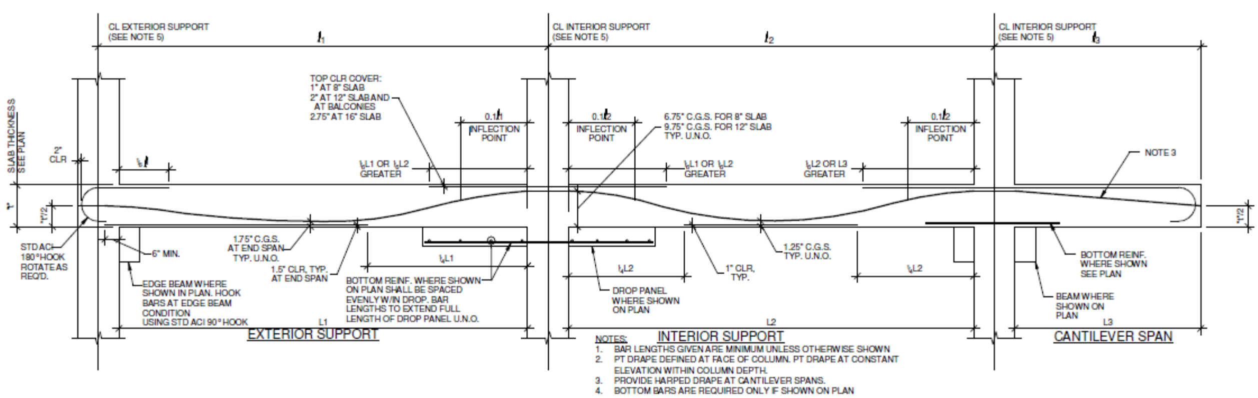


Figure 20 | Two Way PT Slab Reinforcing Diagram (Courtesy of WPM)

4 | Codes and Loading

4.1 Applicable Codes

All known building codes and standards used for The Health Centre are listed in Table 1. It is important to note that an exemption for the structural design permitted the use of 2006 ICC codes as amended by the state. The rest of the building components – including architecture, plumbing, and mechanical systems – use 2012 ICC codes as amended by the state. In order to build the hospital, a Special Land Use Permit was obtained from the county to build on land zoned for office-institutional use.

Category	Applicable Code
Building Code	2006 IBC | Structural Documentation Only 2012 International Building Code 2012 International Existing Building Code
Energy Code	2012 International Energy Conservation Code
Fire Code	2012 International Fire Code
Mechanical Code	2012 International Mechanical Code
Plumbing Code	2012 International Plumbing Code
Fire Protection	NFPA 10 | Standard for Portable Fire Extinguishers 2010 NFPA 13 | Installation of Sprinkler Systems 2010 NFPA 14 | Standard for the Installation of Standpipe and Hose Systems 2010 NFPA 70 | National Electrical Code 2011 NFPA 72 | National Fire Alarm and Signaling Code 2010 NFPA 101 | Life Safety Code 2000
Accessibility	ADA 2010 ICC/ANSI 117.1 Accessible and Usable Buildings and Facilities 2003
Elevators	ASME A17.1 Safety Code for Elevators and Escalators 2010
American Society of Civil Engineers	ASCE 7-05 | Minimum Design Loads for Buildings and Other Structures ASCE 7-10 | Non-Structural Requirements
American Concrete Institute	ACI 318 | Building Code Requirements for Structural Concrete
American Institute of Steel Construction	Steel Construction Manual, Edition Unknown

Table 1 | Applicable Codes

4.2 Gravity Loads

Design dead and live loads used for The Health Centre are tabulated in Table 2 below. Live loads for each occupancy/use category were taken from ASCE 7-05. Unless otherwise noted as NR, live loads are reducible. In particular, horizontal framing floor members in parking garages did not have reduced live loads.

Occupancy/Use	Superimposed Dead Load (psf)	Live Load - Uniform (psf)	Live Load – Concentrated (lbs)
Green Roof/Outdoor Area (RF2)	100	100 NR	-
Typical Hospital Areas (HOS3)	15	100	2000
Hospital Diagnostic Areas (HOS2)	75	350 NR	106,000
Mech./Elec. Rooms (MEC)	75	150 NR	2000
Penthouse Roof (RFPH)	50	20	-
Mixed Use Areas (MU1)	55	100	2000
Restroom (RR)	40	100	-
Patient Rooms (PAT)	15	80 + 15 psf (partitions)	1000
Lobbies and Corridors (PUB1)	15	100	2000
Parking Garage (PK1)	5	40 NR	3000
Storage (STO)	15	125 NR	2000
Kitchen (KIT)	95	150 NR	2000
Typical Roof (RF3)	25	20 NR	-
Insulated Roof (RF1)	50	20 NR	-

Table 2 | Design Loads

4.3 Snow Loads

Values for snow load are based on data from ASCE 7-05. In this location, ground snow load is 5 psf and flat-roof snow load is 4 psf. Due to the importance of a hospital structure, the snow load importance factor used in determining snow loads is 1.2. The snow exposure factor for this building is 0.9. For design, these small snow loads indicate that roof live with control in building load combinations.

4.4 Lateral Loads

4.4.1 Wind Loads

Wind loads were determined using ASCE 7-05 criteria. A basic wind speed of 90 mph was used for design. The Health Centre falls into building category IV and wind exposure category B. Other factors used to determine wind loads were a wind importance factor of 1.15 and the internal pressure coefficient of +0.18/-0.18.

Components and cladding wind loads for parapets, overhangs, and façade systems were also determined using ASCE 7-05 criteria. A minimum value of 10 psf was used for components and classing design.

4.4.2 Seismic Loads

All seismic loads were calculated using the equivalent lateral force procedure from ASCE 7-05. The building is Seismic Design Category C and has an importance factor of 1.5. Soil is considered to be Site Class C. No vertical irregularities were considered for seismic loading. For this building, seismic loads control design.

4.5 Soil Loads

Soil loads were considered for design of basement retaining walls. Lateral earth trapezoidal pressure due to soil loading was modeled as 0 psf at the bottom of the basement wall x 30 psf/ft of depth at 20 percent of the retained soil height. Surcharge loads on basement walls was also considered during design.

5 | Proposal

5.1 Problem Statement

The existing structure of the Health Centre bed tower meets all necessary strength, code, and serviceability requirements. Additionally, the building meets the contractor's request for a concrete structural system. To continue to fulfill this request and pursue a deeper knowledge of concrete design, further consideration will be given for alternative concrete gravity and lateral systems for the bed tower. The alternative systems will be selected to satisfy the client's desire to fit in more with the surrounding university campus buildings and decrease the Health Centre's overall height. Solutions will explore the feasibility of a thinner gravity system to decrease story heights above grade. The below grade parking garage gravity system will not be included in the scope of this redesign.

A scenario in which the client wishes to replace some patient beds with additional research areas that use vibration sensitive equipment will be introduced for the alternative structural system. Such areas will be designed for the appropriate vibration criteria.

5.2 Proposed Solution

In Notebook B, it was determined that a 10" thick concrete flat slab gravity system would yield the thinnest floor depth. This system will be explored further as a solution to the given problem statement for its ability to be cast-in-place and economical use of material. The 30'x30' typical bay size and existing column locations will be utilized for the redesigned structure. Incorporation of shear drops or drop panels to accommodate punching shear will likely be necessary. Edge beams will also be incorporated into the gravity system with a preliminary size of 25"x36". Preliminary redesign column sizes are will use the existing structure's typical column sizes. The lateral system will use shear walls in both the North-South and East-West directions around the elevator core as needed.

The 2006 International Building Code and minimum design loads from ASCE 7-05 will be referenced for the solution proposed above.

5.3 Solution Method

Gravity design of the flat slab system will use Chapter 13 of the ACI 318-11 Building Code Requirements for Reinforced Concrete and follow the Equivalent Frame Method. Computer analysis of gravity loads will utilize the programs SP Slab and SP Column. Analysis in these programs will use the trial sizes proposed as the initial input. Additionally, vibration analysis of the gravity system will be completed in the finite element analysis program SAP2000 in combination with AISC Design Guide 11. Precedent for use of Design Guide 11 for concrete structures can be found in existing buildings.

Design of the lateral system will follow Chapter 21 of ACI 318-11, and will be analyzed in the computer program Etabs. Throughout the gravity and lateral design process, notes from AE 431 and other architectural engineering courses will be used as a reference. AE faculty members with relevant expertise will also be a resource for the redesign and vibration analysis.

5.4 Breadth Topics

5.4.1 Construction

The impact of the alternative structural system on construction cost and schedule will be analyzed in a construction breadth. In general, changes to the structural system will alter the critical path of construction. The new critical path – in addition to the new cost of materials - will affect the overall project cost. Cost and schedule analysis will be used to determine the feasibility of the proposed structural system.

5.4.2 Mechanical

HVAC systems and large hospital equipment are sources of vibrations that can impact the performance of vibration sensitive equipment. Additionally, because the main mechanical room is located below grade, it is susceptible to the possibility of flooding in high rain conditions. In the mechanical breadth, the location of HVAC equipment will be studied for an instance in which it would be appropriate to consider an equipment location change. The effect of this relocation will be assessed for its impact on the overall mechanical system and construction cost. Structure-borne vibration created by the equipment relocation will be also be analyzed for its acoustical impact and effect on relevant vibration sensitive equipment.

5.5 Additional Requirements

5.5.1 Schreyer Honors College

Work for this thesis will meet requirements set by both the Schreyer Honors College and the Department of Architectural Engineering. To satisfy Honors College requirements, an investigation of current requirements, research, and design approaches for vibration sensitive equipment will be carried out. This investigation will focus on information relevant for equipment typically found in hospital and research laboratories, including microscopes and MRI equipment. Both steel and concrete structures will be considered, with a focus on the redesigned concrete structure of the Health Centre. Appropriate finite element analysis software, such as SAP2000, will be used to model a three-bay span of the Health Centre for vibration analysis. The results of this modeling and research will provide a better understanding of building stiffness and behavior under walking excitation. Overall, this investigation will provide experience for situations that may occur in the structural engineering industry and encourage professional development.

5.5.2 MAE Coursework

The proposed concrete redesign will fulfil requirements for the Graduate School of the Pennsylvania State University. Coursework from AE 530: Advanced Computer Modeling of Building Structures will be used to construct and verify a three-dimensional computer model of the redesigned building in Etabs. SAP2000 will also be utilized to verify Etabs output and analyze the fundamental period of several bays for vibration analysis. Modeling the building in three dimensions will promote a greater understanding of building behavior, stiffness, and various end and joint conditions. Additionally, coursework from AE 538: Earthquake Resistant Design of Buildings will be used to provide seismic reinforcing detailing for the shear wall design that increases ductility and strength in a seismic event.

5.6 Tasks and Tools

1. **Research Phase**
    - **a.** Research modeling approach for design of concrete flat slab
    - **b.** Research modeling approach for design of shear walls
    - **c.** Further research of vibration sensitive equipment
        - **i.** Determine equipment appropriate for hospital research labs
        - **ii.** Research typical manufacturer vibration criteria for hospital and MRI equipment
        - **iii.** Research more precedents for vibration criteria use in concrete structures
        - **iv.** Research modeling approach for vibration assessment of a three-bay span

2. **Structural Depth | Concrete Redesign**
    - **a.** Gravity System
        - **i.** Design
            1. Reassess structural gravity loads
            2. Design flat slab system and shear drops
            3. Design edge beams
            4. Design columns
        - **ii.** Model
            1. Verify design in SP slab and SP column
            2. Create three-dimensional Etabs model for lateral analysis
    - **b.** Lateral System
        - **i.** Design and Model
            1. Reassess structural lateral loads
            2. Design preliminary shear wall
            3. Determine shear wall locations based on building geometry/architecture
            4. Analyze seismic and wind loads in Etabs
            5. Verify and redesign shear wall reinforcing
        - **ii.** Validate Design
            1. Validate Etabs model with hand calculations
            2. Verify reinforcing detail with seismic detailing from AE 538

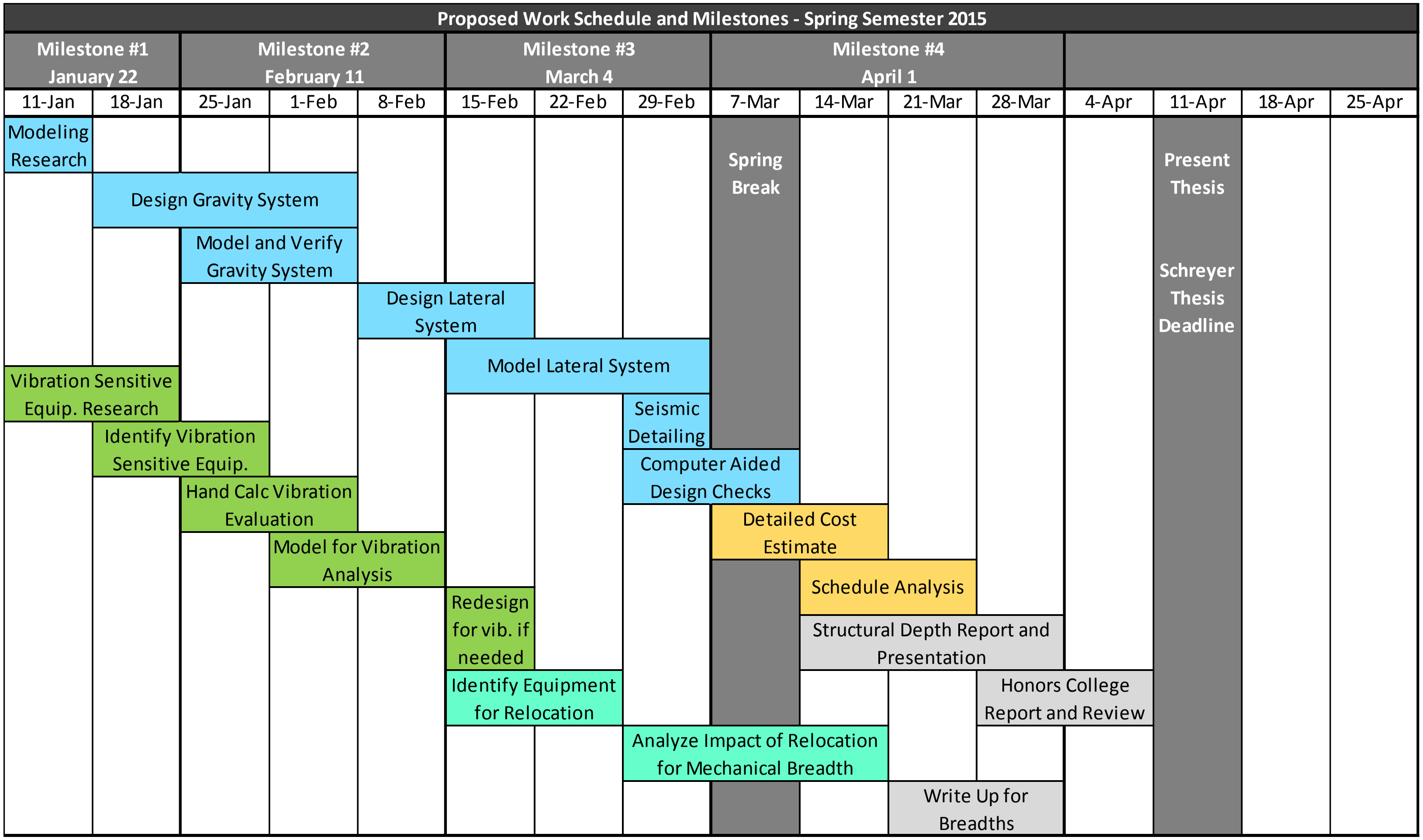
3. **MAE Vibration Analysis**
   a. Analyze
      i. Determine location of new vibration sensitive equipment
      ii. Determine possible sources of vibrations
      iii. Evaluate typical three-bay span for appropriate Design Guide 11 criteria by hand
      iv. Compare results to existing concrete buildings
   b. Model
      i. Create model in SAP2000 to assess bay stiffness, fundamental frequency, and other vibration criteria determined from research phase
      ii. Redesign gravity system for vibration sensitive areas as necessary
      iii. Verify redesign with SAP2000, SP slab and column

4. **Mechanical Breadth**
   a. Relocation of equipment
      i. Identify potential HVAC equipment for relocation based on function, flood risk
      ii. Determine new location of a single piece of HVAC equipment
   b. Analyze impact
      i. Study effect of relocation on function of building's mechanical system
      ii. Analyze possible acoustic impact
      iii. Determine if relocation follows appropriate building code
      iv. Assess if new location impacts vibration sensitive equipment

5. **Construction Breadth**
   a. Cost Analysis
      i. Calculate construction cost of existing structure
      ii. Calculate construction cost of redesign alternative
      iii. Analyze difference in cost of systems
   b. Schedule Analysis
      i. Determine schedule for existing structure
      ii. Determine schedule for redesign alternative
      iii. Analyze difference in schedule and impact on cost
   c. Assess feasibility of redesign based on cost and schedule impact

6. **Final Documentation**
   a. Outline final report for AE and Schreyer requirements
   b. Outline final presentation
   c. Refine and complete final report and presentation
   d. Submit final report for Schreyer review
   e. Submit and present final documentation to jury

5.7 Schedule



Key	
(blue)	Structural Depth
(yellow)	Construction Breadth
(aqua)	Mechanical Breadth
(green)	Vibration Analysis
(grey)	Course Documentation

Milestone Summary	
Milestone #1: Complete research phase of thesis and begin gravity design phase. Identify vibration sensitive equipment.	**Milestone #2:** Finish gravity system design and begin lateral system. Complete vibration computer modeling.
Milestone #3: Finish lateral system design. Begin final checks for structural system and groundwork for breadths.	**Milestone #4:** All breadths are finished. Both report and presentation are finished. Prepare Schreyer documents.

5 | Conclusion

The Health Centre is a 750,000 square foot hospital project located in the Southeastern US with 10 stories above grade and four stories below grade. Its existing structural system utilizes cast-in-place one-way slab and beams for gravity loads and concrete moment frames for lateral loads. The four stories below grade use a post-tensioned two-way parking garage structure with exterior shear walls. Upon completion, the hospital facility will be home to state-of-the-art medical technology, additional research space, and extra hospital beds.

An alternative concrete design aims to make a more efficient use of material and reduce floor-to-floor heights. The redesign proposed is a flat slab floor system with a shear wall core. The shear wall core will resist lateral loads and will utilize seismic detailing from previous graduate coursework. Considered in the proposed redesign is the additional client request for research areas with vibration sensitive equipment. Some bays will be modeled to satisfy this additional request, which will require in-depth research of existing precedents and criteria. Throughout the redesign process, advanced computer modeling techniques will be implemented.

Feasibility of the redesign will be evaluated by its impact on construction schedule and cost. The implications of relocation of mechanical equipment on mechanical and structural systems will be included in the proposed thesis work. Impact of this relocation on vibration sensitive equipment will be considered during the design process.