Mercy Health Muskegon

Mercy Campus Consolidation
Muskegon, MI

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Structural Existing Conditions & Proposal

Executive Summary

Located in Muskegon, MI, the Mercy Health Muskegon Medical Center is currently undergoing renovations and a new construction expansion. The goal of the Mercy Campus Consolidation project is to create a full-service hospital campus that embodies a patient-centered healing environment. Construction has been underway since September 2016 and will be completed in 2019.

Architecture

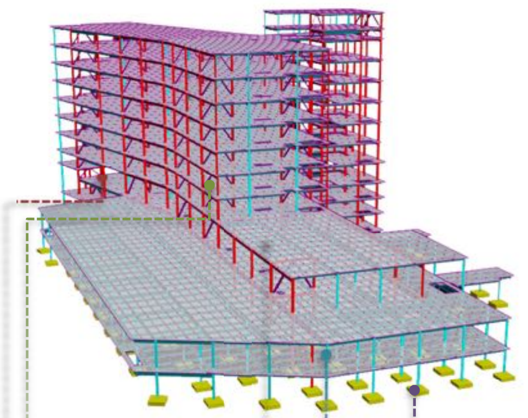
Focusing on the new addition, the 10-story structure is composed of two levels with a large footprint that support an eight-story tower with a smaller footprint.

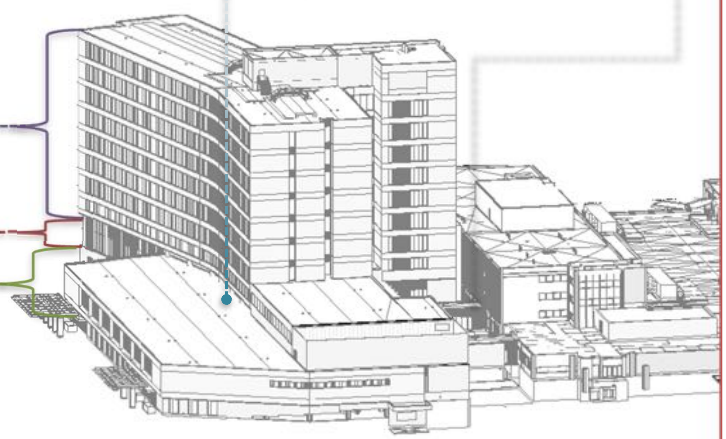
- The tower accommodates seven levels dedicated to inpatient care above a mechanical level.
- The two levels at the base include emergency and surgical departments along with public spaces and courtyard access.

Considerations

Since the new building is connected to the existing building at three locations where expansion joints are present, it will be necessary to make assumptions regarding whether it shall be treated as an independent structure and how this will affect its exposure to lateral loads.

The change in stiffness at the bed tower setback will also need to be considered. This geometry also poses several challenges and opportunities for alterations in future structural analysis and design reports.





Structure

Gravity system:

- Composite concrete slab and steel deck
- Composite wide flange beams and girders
- W14 columns
- Shallow concrete spread footings

Lateral system:

- Steel braced frames with wide flange beams and hollow structural section (HSS) braces (N-S)
- Steel moment frames with wide flange beams (E-W)
- W14 columns

Loads

While the weight of the structure and other permanent components determine the dead load, the source for determining live, snow, wind, and seismic loads is ASCE 7-10. In addition to these standard load types, it is necessary to consider several other design loads for future analysis and design. These cases include:

- Wind uplift at canopies
- Component and cladding wind loads
- Seismic loads for non-architectural components
- Lateral loads due to soil at foundation walls

The project is designed with the 2012 Michigan Building Code, which is based on the 2012 International Building Code with Michigan amendments. Frequently referenced design codes and standards include the American Concrete Institute (ACI), the American Institute of Steel Construction (AISC), and the American Society of Civil Engineers (ASCE).

The proposed thesis will investigate a redesigned composite steel structure, modified lateral system for a wind-controlled site location, vibration analyses, acoustic and prefabrication studies, and an analysis of the decision-making process involved in selecting structural systems for healthcare facilities.

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1.0 Introduction

1.1 Purpose and Scope

While the scope of the Mercy Campus Consolidation involves both renovations to existing facilities and new construction, this report and future structural analyses will focus primarily on the new addition to the campus. This report contains technical information on the application of design codes and standards for the addition as well as the designed existing structural systems. The impacts of architectural and mechanical features on the structural system are discussed further. A proposed thesis will explore modifications to the structural system and investigations of prefabrication, acoustics, vibration, and decision-making methods.

1.2 Mercy Campus Consolidation Overview

The Mercy Campus Consolidation consists of both renovations to existing facilities alongside a new addition. The renovations involve changes to the existing five-story hospital facility, which consists of four stories and a full basement. The 10-story addition is to occupy a total of approximately 380,000 square feet and reach a height of 167 feet. A diagram of the functional programs of the new building and its relation to the existing building can be seen in Figures 1 and 2. Construction on the project began in September 2016 and is expected to be complete in November 2019.

Figure 1: Mercy Health Muskegon Campus (original image provided by HGA)

Figure 2: Section of Existing Facility and Addition (original image provided by HGA)

The basement level, also referred to as the garden level, of the new building is partially exposed and is at the same elevation as the lowest level of the existing building. The garden level and a second story occupy a large footprint in order to incorporate multiple hospital departments and public areas. The two stories at the base contain emergency and surgical departments, also known as Diagnostic and Treatment (D&T). The public areas include a café, chapel, gift shop, healing garden, lobbies, lounges, and courtyards. Canopies make the entrances at these levels easily recognizable. A view of the main entrance on the west side of the new building is shown in Figure 3. As seen in the key plan (Figure 4), areas A, B, and C form the footprint of the new building.

Figure 3: View 1 - Main Entrance / Drop-off Area

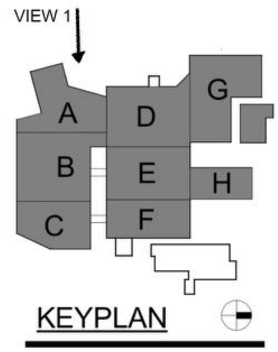

Figure 4: Key Plan (provided by HGA)

A mechanical level separates D&T and the seven-story inpatient bed tower, which occupies a smaller footprint. Single-occupancy patient rooms (Figures 5 and 6) line the perimeter along the long sides of the bed tower. The central spaces of the tower are dedicated to circulation and work areas for the medical staff. Figure 7 displays the architectural layout of a typical inpatient floor.

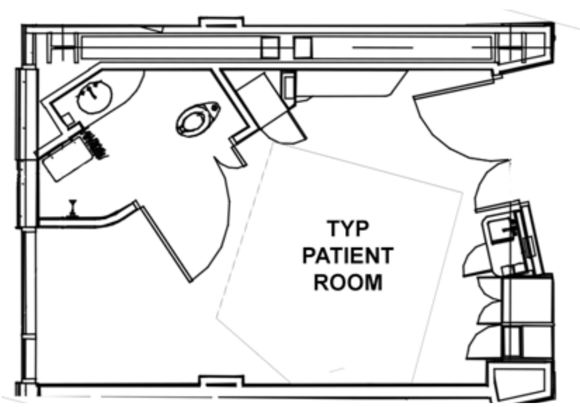

Figure 5: Typical Patient Room Plan (provided by HGA)

Figure 6: Typical Patient Room

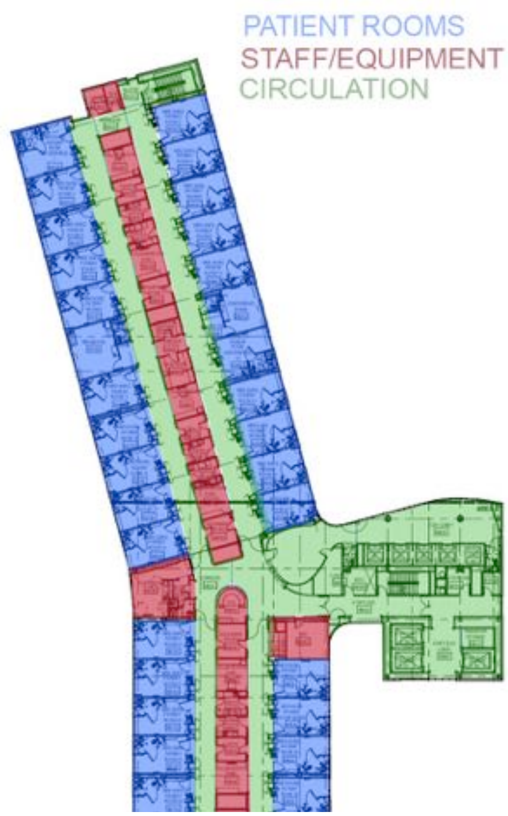

Figure 7: Typical Inpatient Floor (original image provided by HGA)

The façade of the bed tower is mostly comprised of aluminum metal panels and aluminum curtain wall systems. The aluminum metal panels are mounted to insulated metal panels, which are attached to a stud back-up wall. The studs transfer lateral loads on the wall to the structure. Wall sections displaying the composition and attachment are shown in Figure 8.

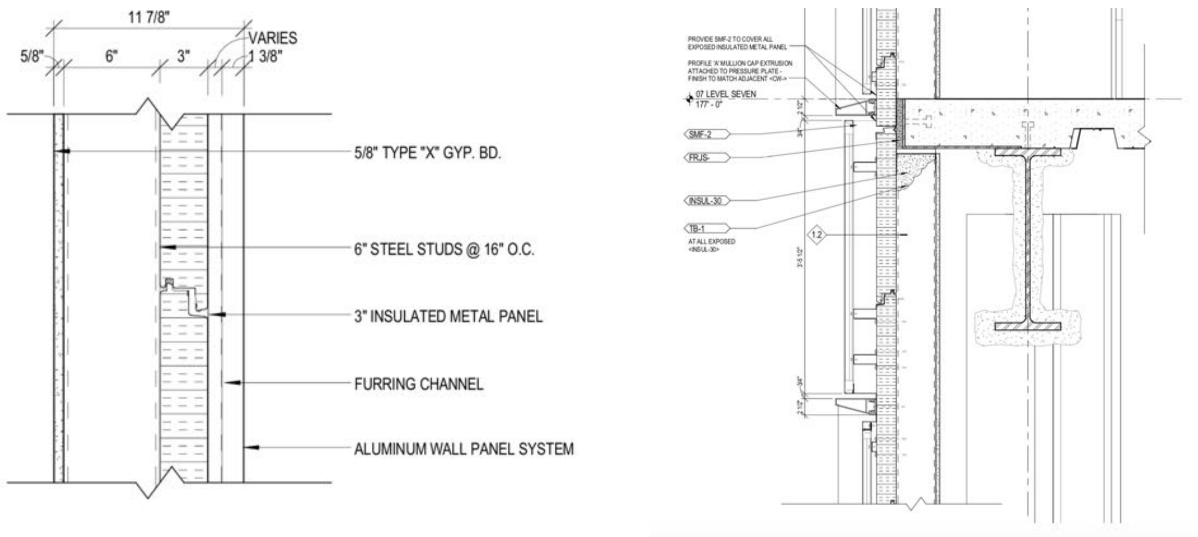

Figure 8: Exterior Metal Panel Wall Sections (provided by HGA)

The mechanical system is critical for the operation and daily use of the Mercy Health Muskegon medical center. The addition will be served by a variable air volume (VAV) system that is responsible for the heating and cooling ventilation distribution systems. The plumbing system is also important for fully sprinklered design requirements and medical gas supply throughout the hospital. Integration of the structural system with ductwork and piping of the mechanical system will be a significant consideration in future analysis reports and designs. The location of a full mechanical level below the bed tower is also a concern for acoustic performance.

1.3 Structural Framing System Overview

Structurally, the addition is steel framed. A composite concrete slab and steel deck system transfers gravity loads to composite wide flange beams and girders that are supported by W14 columns. The columns then transfer vertical loads to shallow concrete spread footings. In the lateral system, the composite slab and deck system acts as a diaphragm to transfer loads to the lateral force-resisting elements. Steel moment frames with wide flange beams run along the east-west direction, and steel braced frames with wide flange beams and hollow structural section (HSS) braces resist loads in the north-south direction. W14 columns also support these frames and distribute loads to the shallow foundation system.

2.0 Loads and Codes

Discussed here are the load types that are applicable to the construction of the new Mercy Health Muskegon hospital building. Codes used for load calculations and structural designs are also detailed.

2.1 Design Codes and Standards

The Mercy Health Muskegon addition is designed in accordance with the 2012 Michigan Building Code, which utilizes the 2012 International Building Code with Michigan amendments. Reference codes and standards, as referenced by the Michigan Building Code, and areas of use in the project design are as follows:

- ACI 318-05: concrete slabs, footings, and foundation walls
- ACI 530-05: masonry design and construction
- AISC 360-10: structural steel
- AISI: steel floor and roof decks
- ASCE 7-10: dead, live, snow, wind, and seismic loads; components and cladding wind loads; seismic restraint requirements for nonstructural (architectural, mechanical, and electrical) components
- AWS: structural welds for steel framing
- SDI: steel decking

2.2 Gravity Loads

Dead loads used for structural design included the weight of the structure (slabs, beams, columns, etc.) and all other permanent elements supported by or attached to the structure. Examples of these elements include walls, finish materials, and equipment. Since Mercy Health Muskegon is a hospital, large pieces of equipment such as surgical lights and anesthesia booms add a significant amount of dead load and had to be given special consideration as additional support structures are needed. Dead loads are determined from weights of materials found in ASCE 7-10 requirements for minimum design dead loads or from manufacturer data. For more detail, see section 2.1 in Notebook Submission A: Building Codes, Specifications, and Loads.

Minimum design live loads are determined from ASCE7-10 Chapter 4. As seen in Figure 9, floor live loads in this project fall into several different categories, including reducible with partitions, reducible, and non-reducible. Reducible live loads are permitted to be reduced per IBC 1607.10. See section 2.2 in Notebook Submission A for detailed live load classifications.

Live Load Allowances / Requirements	Floor Location
Reducible with partitions	Patient rooms, offices, operating rooms, labs, library reading rooms
Reducible (without partitions)	Lobbies, level one corridors,level one retail, corridors above level one, rehab gymnasiums, kitchen and dining
Non-reducible	Stairs and exits, storage, mechanical and electrical rooms

Figure 9: Classification of Minimum Live Load Reduction Allowance by Floor Location

Flat roof snow loads and drift loads are critical due to Mercy Health Muskegon being in Risk Category IV. These loads are calculated per ASCE 7-10 Chapter 7. A separate snow load calculation must be performed for canopies (see section 5.1), which are designed with a higher thermal factor applicable to unheated and open-air structures.

2.3 Lateral Loads

The source for determining wind loads for the main wind-force resisting system is ASCE 7-10 Chapter 27. The wind loads on components and cladding are determined from ASCE 7-10 Chapter 30. The determination of these loads incorporates factors relative to Risk Category IV and Exposure Category B.

Seismic loads for the building structure shall be determined from ASCE 7-10 Chapter 12. Seismic restraints for nonstructural components will use seismic design loads calculated per ASCE 7-10 Chapter 13. Load determinations will utilize the seismic importance factor that applies to Risk Category IV. Some parameters in the calculation of seismic loads are adjusted for site class effects. The new building is considered Site Class D. The building structure seismic design load calculation will utilize a response modification coefficient that corresponds to the appropriate seismic force-resisting system described in the Lateral System portion of this report (section 3.2). The seismic load resisting system will be classified as either steel or concrete moment frames or steel braced frames, depending on the direction in which loads are being applied.

3.0 Structural Framing Systems

Here is a detailed description of the elements that compose the gravity and lateral systems for the Mercy Health Muskegon medical center. Applicable reference codes and standards used for determining loads and designing the structure are also detailed.

3.1 Gravity System

3.1.1 Typical Bay

Typical bays are used to represent common or repetitive bays for the floor framing. They are useful for displaying main framing characteristics such as overall bay size, framing layout, and typical member sizes.

While the inpatient bed tower has floors that are all very similar, the first two floors of the new building are more irregular due to the many different functions that are contained within the large footprint. Therefore, it is difficult to define a typical bay for the emergency and surgical department levels that is representative of the entire framing system at the base levels. Due to this, there are two typical bays, one for the bed tower and one for D&T. Figures 10 and 11 depict the bed tower floor framing layout and typical bay.

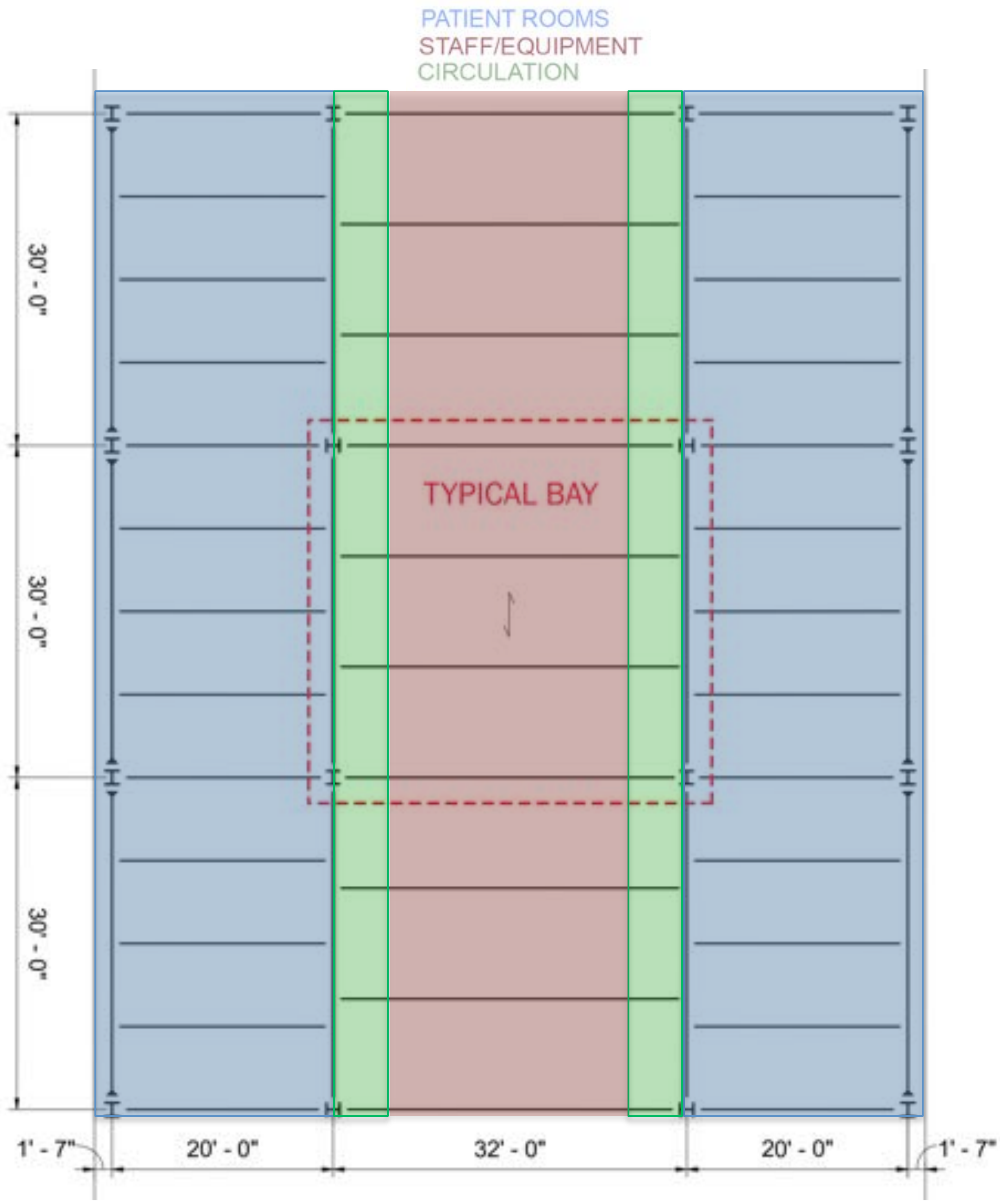

Figure 10: Typical Bed Tower Partial Floor Plan

There are two typical bays defined by the extents of the patient rooms. The 30' x 32' central bay is the larger of the two and will therefore be chosen for the typical bay at these floors.

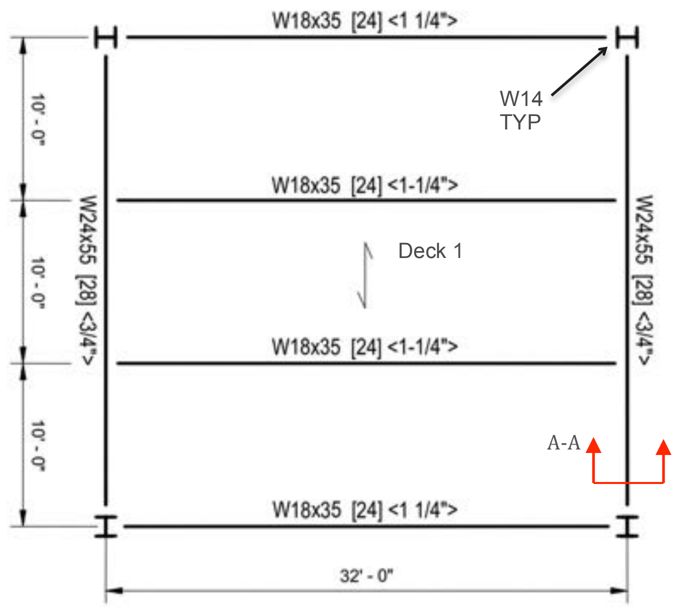

Figure 11: Typical Bed Tower Bay Framing Plan

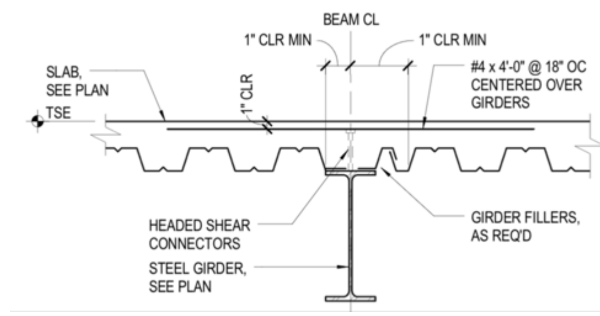

Figure 12: Section A-A (provided by HGA)

At above grade levels, Deck 1 represents a typical composite floor system (Figure 12). It is constructed with an 18 gage, 3" composite galvanized steel deck and a 4½" normal weight concrete topping, reaching a total thickness of 7½". The deck is typically oriented perpendicular to the beams. Composite steel beams and girders are connected to the deck and slab with ¾" diameter and 5" long headed shear studs. In the typical bed tower bay, 24 studs along the W18x35 beams and 28 studs along the W24x55 girders are evenly distributed. Beams are spaced at 10' o.c. and span the long direction of the bay. With this 32' span, the beams are cambered 1 ¼" to avoid excessive deflection issues. The girders are cambered ¾".

In the typical D&T bay (Figure 13), the layout is similar to the typical bed tower bay, but there are a few differences. The typical D&T bay is smaller at a size of 24'x30', and smaller section W16x26 beams spanning the short direction are not required to have camber. Beams maintain a 10' o.c. spacing but have only 22 evenly distributed studs along the 24' length. The 30' girders are again W24x55 and cambered ¾", but they have three sections of shear studs. There are sections of 16, 6, and 16 studs. The higher quantities of shear studs are located near the columns where the beam is more heavily loaded in shear.

Figure 13: Typical D&T Bay Framing Plan (original image provided by HGA)

Both typical bays contain wide flange columns with a nominal column size of 14”. Columns range in size from W14x43 to W14x342. They are typically spliced every two floors using bolted or welded column splices.

An example of an irregular D&T bay is shown in Figure 14. This layout is different due to the additional framing required for medical equipment support in a procedure room.

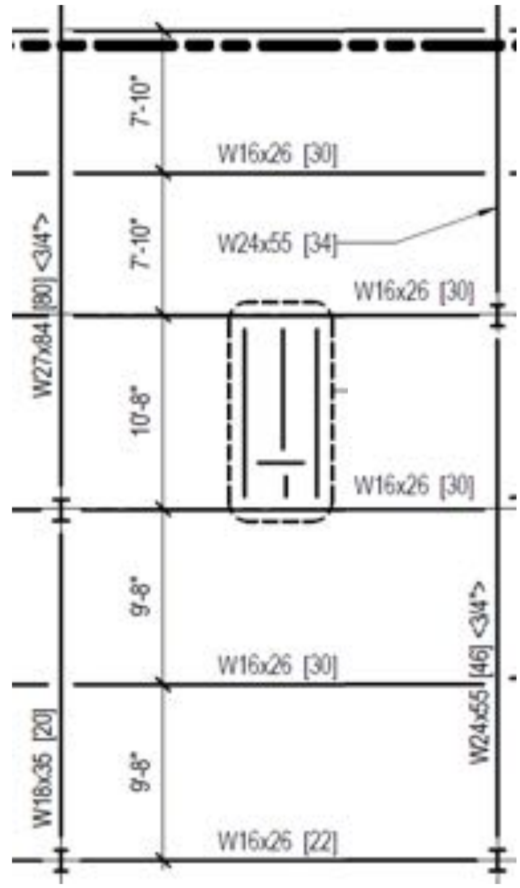

Figure 14: Example of Irregular D&T Bay (original image provided by HGA)

3.1.2 Slab-on-Grade

At the lowest floor, the partially exposed garden level has a slab on grade, which differs from the typical slab at an elevated floor. At this level, there are two typical types of slab-on-grade (S.O.G), both of which are at the same elevation as the lowest level of the existing hospital campus facilities. The standard concrete S.O.G is 5” thick and typically reinforced with 6x6-W2.9xW2.9 welded wire fabric (WWF). All slabs in the project have a specified compressive strength of 3500 psi. At mechanical and electrical areas, the S.O.G is increased to 6” thick.

3.1.3 Foundation System

The geotechnical report for the new building states that the soil is classified as poorly graded sand and recommends a maximum net allowable bearing pressure of 12,000 psf on new spread footings. The footings are designed with a minimum depth below adjacent grade of four feet in order to meet the required 42” minimum embedment depth for frost protection.

Like the existing building, the new building is supported on a shallow foundation system consisting of spread footings with a specified concrete compressive strength of 4000 psi. Figure 15 shows the foundation plan. Dimensions of the spread footings range from three feet to 40 feet, and the depths range from 1’-6” to 5’-6”. The larger spread footings are used to tie together and support braced frames. These spread footings will have an impact on future analysis as they will need to be checked not only for gravity loads but also for overturning due to uplift at one side of the braced frame. Columns are typically centered on the footings. Figure 16 and Table 1 show the footing layout and schedule for typical bed tower bays. A typical interior column footing detail is shown in Figure 17.

Figure 15: Foundation Plan (original image provided by HGA)

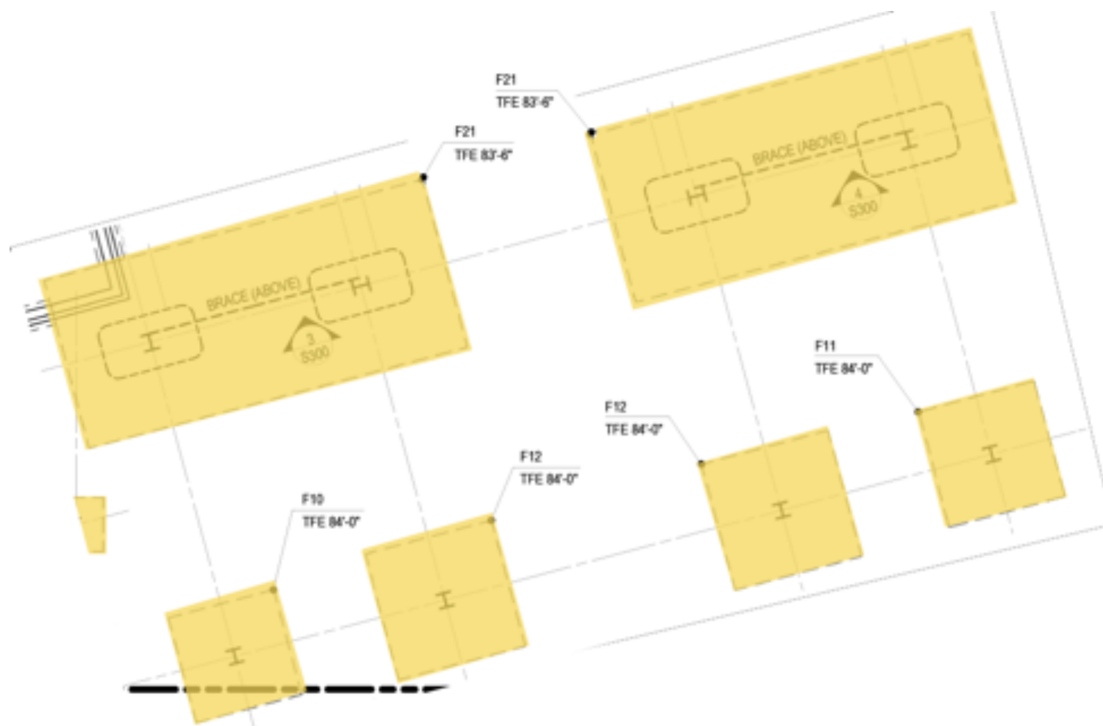

Figure 16: Typical Bed Tower Bay Foundation Plan (original image provided by HGA)

Table 1: Footing Schedule for Typical Bed Tower Bays				
Type	**Length**	**Width**	**Depth**	**Reinforcing**
F10	10'-0"	10'-0"	3'-6"	(11) #9 EW
F11	11'-0"	11'-0"	4'-0"	(12) #9 EW
F12	12'-0"	12'-0"	4'-0"	(13) #10 EW
F21	36'-0"	16'-0	5'-6"	(44) #8 TOP (Short Way) (22) #8 TOP (Long Way) (44) #10 BOT (Short Way) (22) #10 BOT (Long Way)

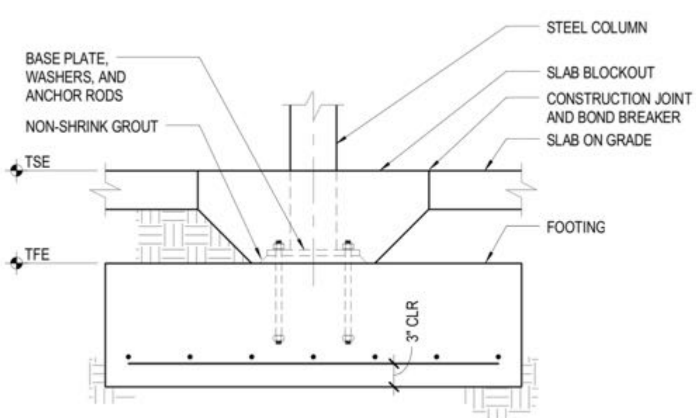

Figure 17: Typical Interior Column Footing Detail (provided by HGA)

3.2 Lateral System

The composite steel and concrete slab system acts as a diaphragm to transfer lateral loads to the lateral load resisting elements. The main lateral force resisting system consists of steel braced frames in the north-south direction and steel moment frames in the east-west direction. Figure 18 shows the locations of the moment frames (blue) and braced frames (red) that extend from the base through the entire height of the building. Both types of frames use wide flange beams and W14 columns. The braced frames are typically concentrically braced with HSS diagonal braces that range in size from HSS6x6x5/16 to HSS14x14x5/8. An elevation of a typical braced frame in the D&T area is shown in Figure 19. While this frame does not extend the full height of the building, the bracing layout is typical.

Figure 18: Lateral System Layout
(original image provided by HGA)

The braced frames and moment frames deliver lateral loads from the diaphragms to the foundation system and are typically supported directly by concrete spread footings. There is an exception at three steel moment frames that span between the central and viewing courtyards. In these instances, concrete moment frames at the garden level support the steel moment frames. A 3D view of the lateral system modeled in ETABS is shown in Figure 20.

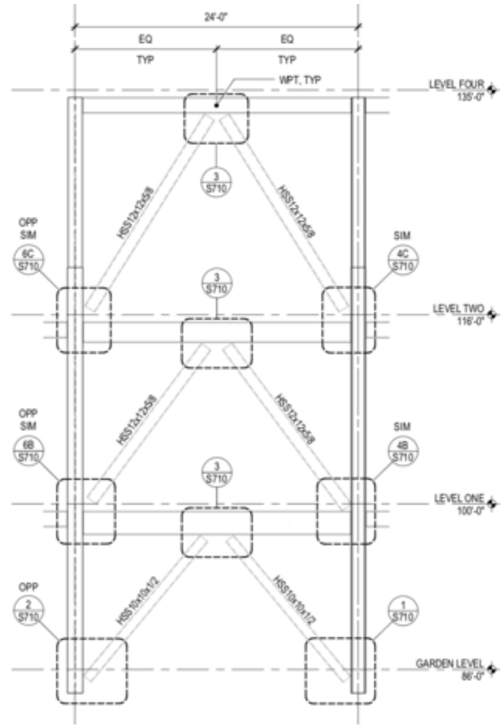

Figure 19: Typical Braced Frame Layout (provided by HGA)

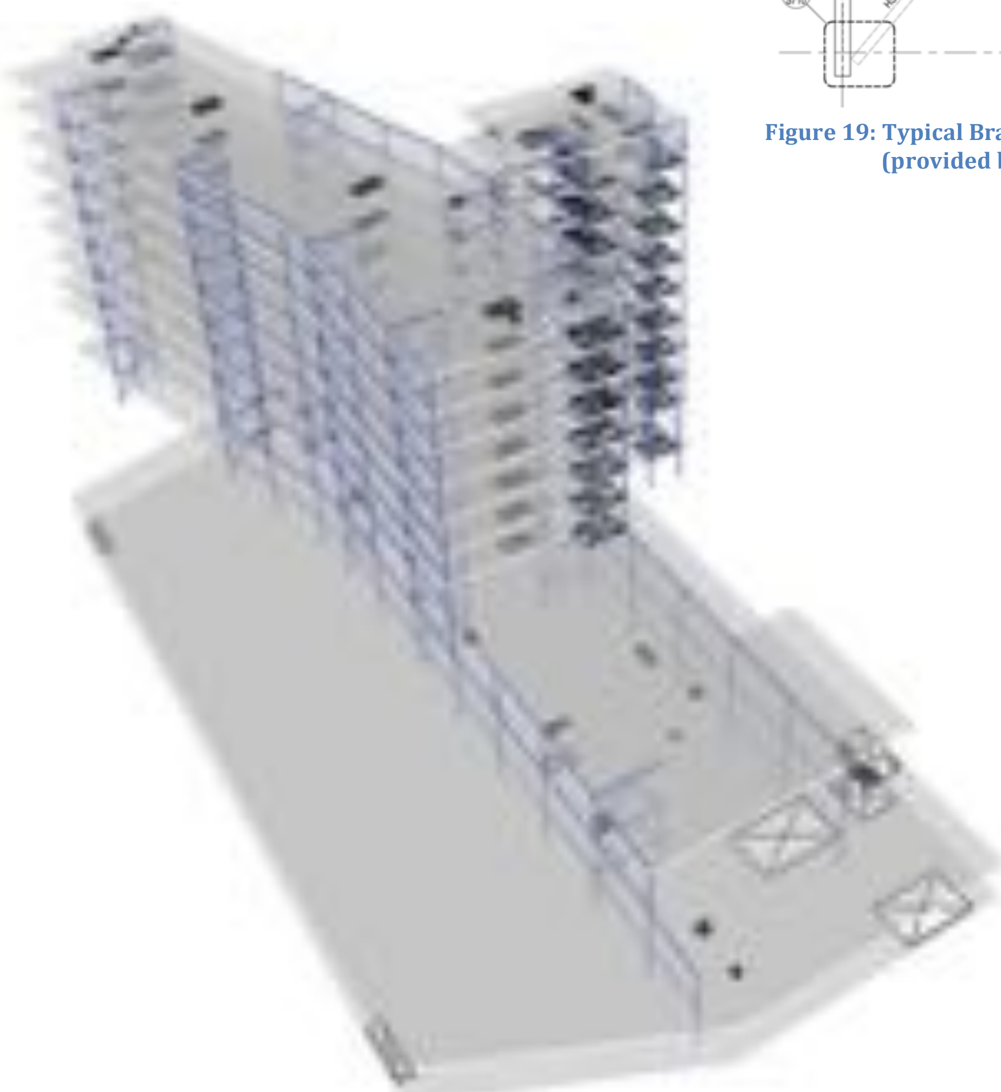

Figure 20: 3D View of Lateral System

4.0 Load Paths

Gravity loads on the structure follow a load path from the floor slab or roof deck to structural beams, followed by the girders and the columns. Finally, the columns transfer the vertical loads to the foundation system. A diagram of the load path for a gravity load applied at the roof is shown in Figure 21. The gravity loads, which are discussed in further detail in section 2.0 of Notebook Submission A, include dead, live, and snow loads.

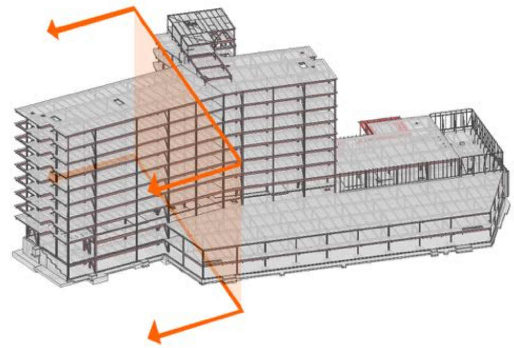

Figure 21A: Structure with Section Cut for Figure 21

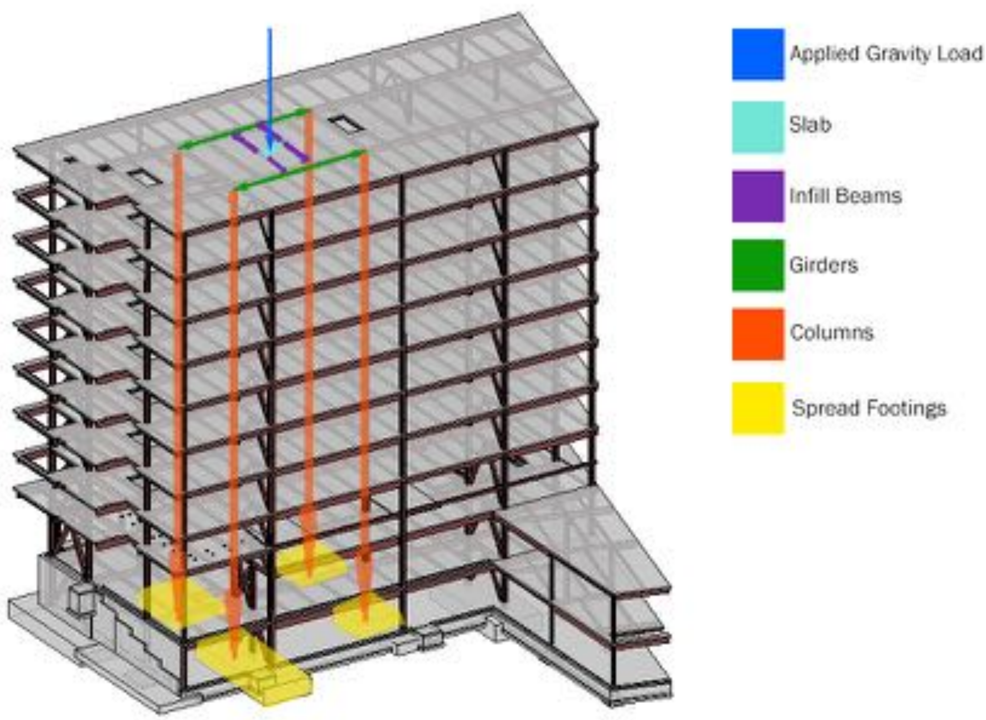

Figure 21: Gravity Load Path 3D Diagram

Lateral loads follow a different load path in which the composite steel and concrete slab system acts as a diaphragm to transfer loads. In the case of wind loads, the exterior wall is subjected to wind pressure and transfers the load to the slab. The slab then acts as a diaphragm and transfers the load to the lateral resisting elements, which then transfer loads to the foundations. When the slab is acting as a diaphragm, it acts similarly to a beam that is subjected to shear stress from the lateral loads and supported at the locations of the lateral frames. The slab also acts as a diaphragm to transfer seismic loads.

Figure 22 shows a sample lateral load path in the North-South direction where lateral loads are resisted primarily by braced frames. The load follows a path from the diaphragm to the beam and braces, then the columns, and spread footings.

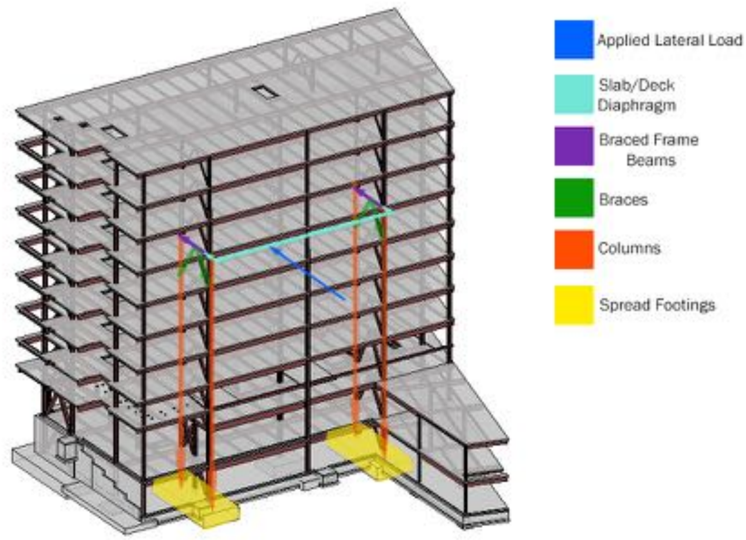

Figure 22: N-S Lateral Load Path 3D Diagram

5.0 Additional Structural Design Considerations

5.1 Canopy Framing

Canopies are present at the northwest (Figure 23), southwest, and southeast (Figure 24) entrances of the new building. The structural steel framing of the canopies consists primarily of wide flange beams supported by HSS columns that are attached to the bottom of beams in the main structural framing system. The wide flange beams span between two HSS supports above and are cantilevered at one end.

Figure 23: Northwest Entrance

These canopies pose structural challenges due to uplift from wind loads. Per architectural requirements, the exposed structural steel present in the canopies must meet the requirements for Architecturally Exposed Structural Steel (AESS).

Figure 24: Southeast Entrance

5.2 Additional Support Structures

There are many types of hospital equipment within the Mercy Health Muskegon diagnostic and treatment center. Surgical lights, anesthesia booms, and other equipment booms are predominantly located on the second floor of the D&T center. Based on weight and manufacturer requirements, additional support structure is necessary. A schematic support structure layout for a surgical equipment boom is illustrated in Figures 25 and 26.

Figure 25: Plan of Equipment Support Structure

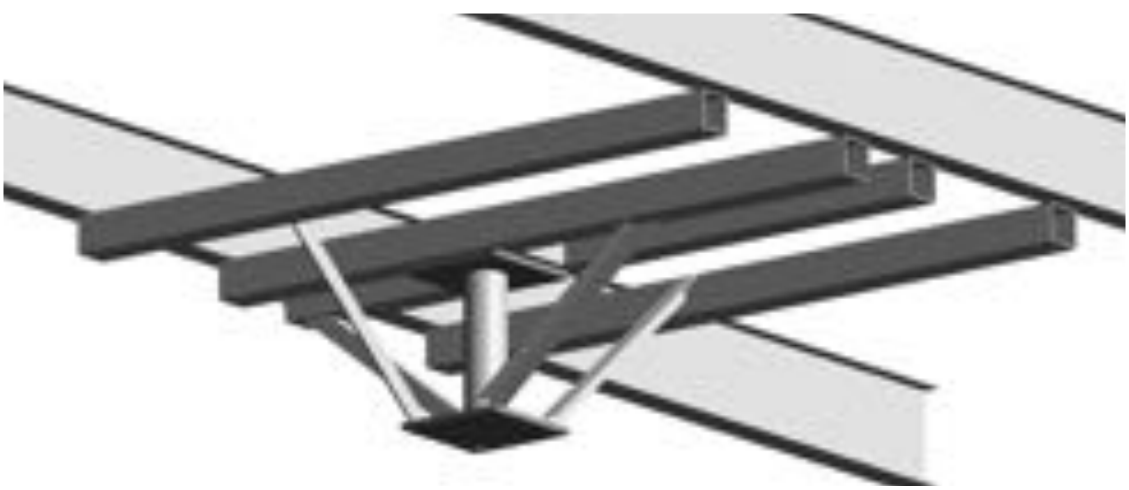

Figure 26: 3D View from Underside of Equipment Support Structure

5.3 Slab Depressions

Patient rooms in the bed tower contain a typical 1½” slab depression in bathroom showers to create a sloped floor so water is directed into the drain. This may need to be considered in future analyses or designs with calculations that involve slab thickness. The slab depression location in a typical patient room is illustrated in Figures 27 – 29.

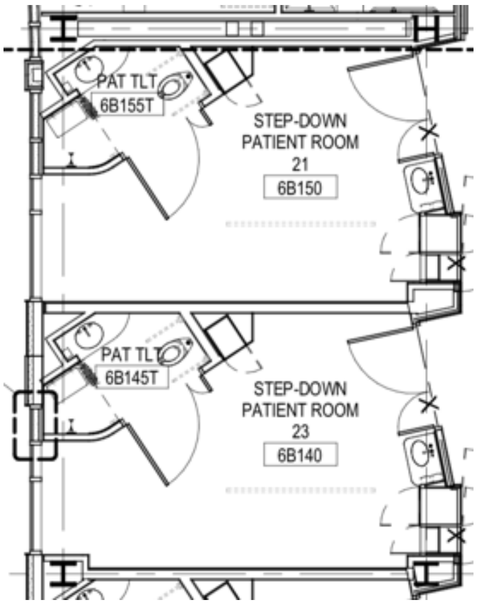

Figure 27: Typical Patient Rooms (provided by HGA)

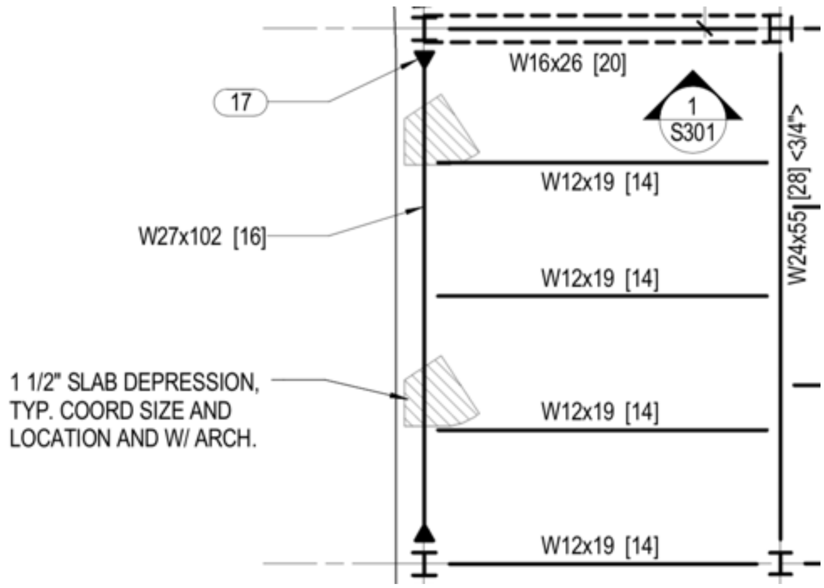

Figure 28: Typical Patient Room Framing (provided by HGA)

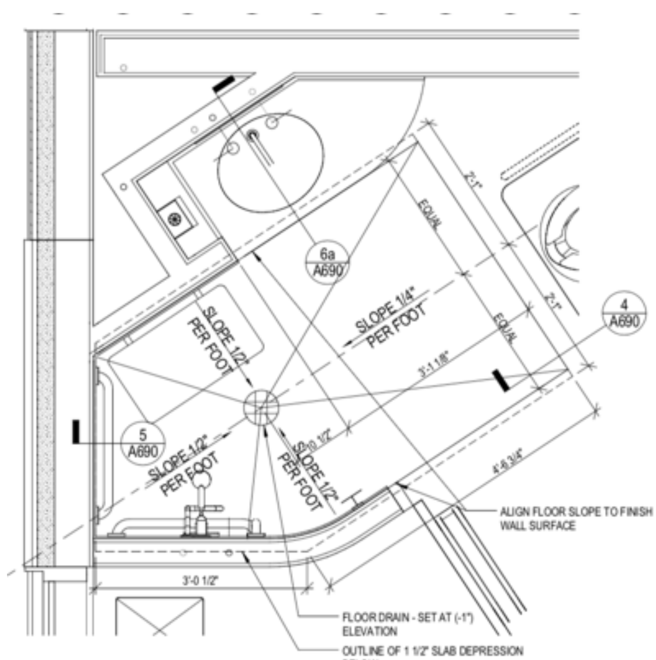

Figure 29: Slab Depression Diagram (provided by HGA)

5.4 Connections

While there are a variety of connections used throughout the project, there are three typical connections. These include gravity beam to girder and column bolted double angle connections, double-sided moment frame connections, and welded gusset plate braced frame connections.

Typical Connection 1 (Figure 30) is a bolted double angle connection for gravity beam to girder framing. This connection type is also used for gravity beams and girders framing into wide flange columns. Where a beam frames into a column web, stiffener plates are typically required because the column web is less stiff than the flanges. Another common gravity connection is a bolted single angle connection used where wide flange beams frame into other wide flange beams.

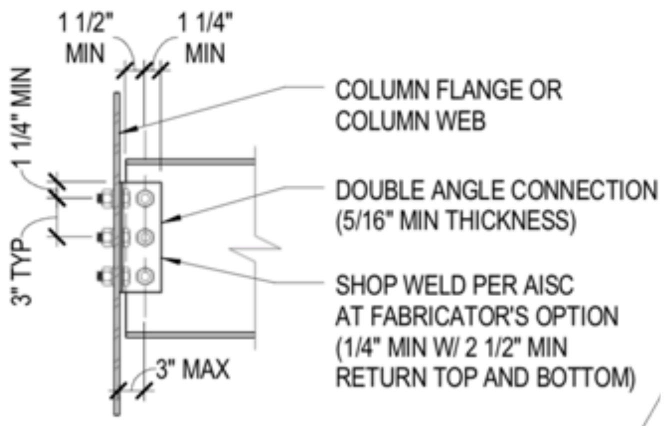

Figure 30: Typical Connection 1 (provided by HGA)

Critical connections also occur at the lateral frames where connections are required to transfer lateral loads. Typical Connection 2 (Figure 31) is a double-sided moment connection that is typical of the moment frames along the bed tower perimeter. This connection uses A490 slip-critical bolts rather than the standard A325 bolts used for shear connections in the project. Figure 32 shows Typical Connection 3, a welded gusset plate connection for concentrically braced frames.

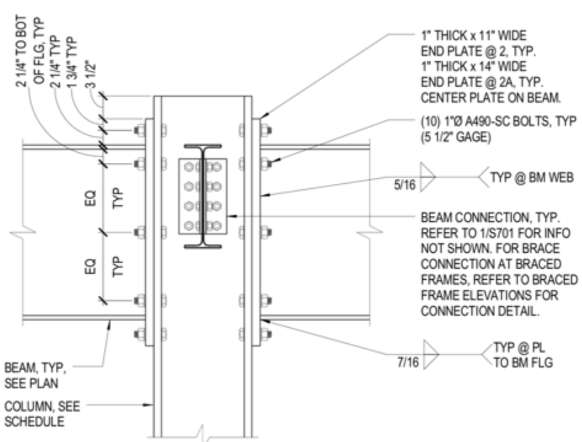

Figure 31: Typical Connection 2 (provided by HGA)

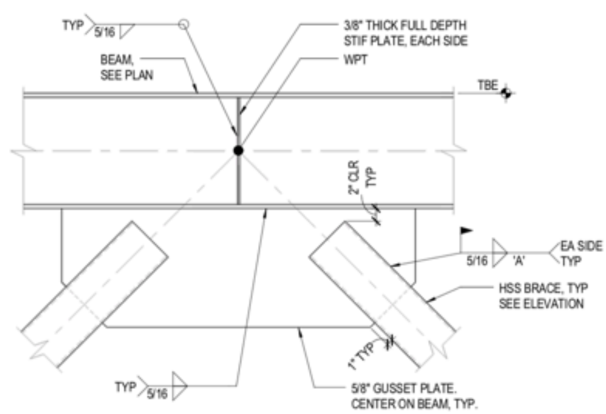

Figure 32: Typical Connection 3 (provided by HGA)

5.5 Expansion Joints

The Mercy Campus Consolidation consists of an addition to the existing hospital facility. While the new and existing buildings are connected, they have separate gravity and lateral systems. Expansion joints are required to provide a connection that allows movement of the two structures without them colliding or becoming separated.

2" expansions joints (Figure 33) are used to connect the new and existing buildings. The purpose of the expansion joints is to connect the two structures while allowing for movement due to thermal expansion or lateral forces. The expansion joint filler is flexible, compressible polyethylene foam that permits movement.

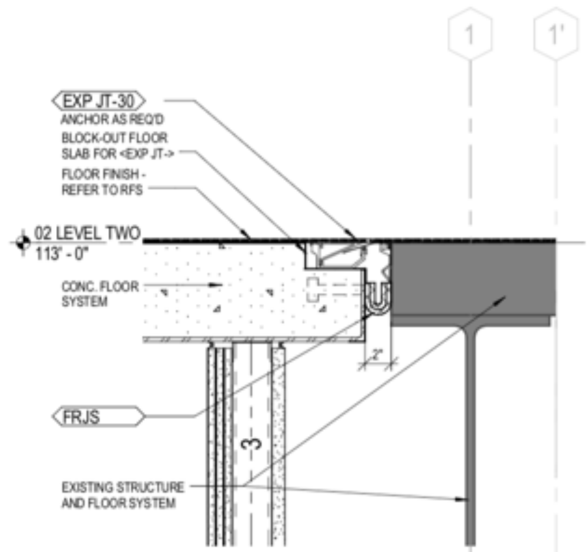

Figure 33: Typical Expansion Joint (provided by HGA)

6.0 Systems Summary

While the typical bays of the structural framing are relatively simple, there are design elements throughout the building that will impact future alternative analyses and designs to be studied. Due to a nonuniform footprint for the entire height of the structure, some of the braced and moment frames are present at only the lower floors. The setback resulting change in lateral stiffness will need to be carefully analyzed as it could cause a vertical stiffness irregularity and affect the response to lateral loads. Additionally, locating and accurately accounting for the weight of heavy hospital equipment for the gravity analysis may pose a challenge.

The mechanical system will also impact future designs because it is highly critical for hospital operation. Integration between the structural and mechanical systems will be a significant consideration. Due to its location directly below the bed tower, the mechanical level is also an area where acoustic performance issues could arise.

Some analysis procedures, especially those involving lateral loads, may require modification depending on if the structure is being analyzed as an independent building or an extension of the existing structure; therefore, assumptions on how the new building is being analyzed as a whole will have a significant impact.

7.0 Proposal

7.1 Background

Hospitals are complex facilities that require thorough consideration of the design impacts on patient care. The Mercy Health Muskegon addition was designed with a focus on patient-centered care, so it is critical to minimize negative performance effects on the occupants of the hospital. Vibration is a significant factor that falls into this category as it can affect patient comfort and vibration-sensitive hospital equipment. Similarly, acoustics play an important role in patient health and contentment. Another goal is providing design flexibility for any changes required by the owner over time. Hospital construction is also becoming faster paced, and the construction schedule is a key factor for hospital owners who have a firm deadline for facility operation. These considerations are the basis for this proposal, which outlines the procedures for meeting design goals of performance, flexibility, and scheduling.

7.2 Problem Statement

The existing gravity and lateral systems are to be redesigned to meet the design goals of the Mercy Health Muskegon addition. The redesigns and additional prefabrication, acoustic, vibration, and decision-making studies will strive to meet strength and performance requirements for the patient-centered hospital when moved to a theoretical new location along the coast of Florida.

7.3 Structural Depth

The gravity system will be redesigned as composite steel or non-composite with fewer infill beams. This choice is the most favorable result of the Notebook Submission B gravity load analysis and comparison for a typical bay. The different structural systems that were compared included the existing composite steel framing, modified composite steel framing that includes fewer infill beams, flat slab, and one-way pan joists. A more in-depth analysis and comparison of these systems will be performed to verify that the modified composite steel design is the best choice. The comparison will utilize several different decision-making techniques, including the Analytical Hierarchy Process (AHP), Choosing By Advantages (CBA), and the Pugh Matrix (PM). See Section 7.8 of this report for more information about the decision-making method study. The results of these comparisons will be analyzed to determine if the most beneficial system was chosen as a result of the original structural system comparisons performed in Notebook Submission B. Numerous iterations of the redesigned gravity system will also be used for a vibration analysis.

The lateral system will also undergo a redesign. Mercy Health is part of Trinity Health, which has hospital locations across the United States. The lateral system redesign will explore a theoretical location change of the Mercy Health Muskegon addition to Fort Lauderdale, Florida, an area where Trinity Health has an existing hospital. With this move to a hurricane region, the structure will be exposed to significantly higher wind loads, which will be calculated and compared to those of the existing location. While the existing structure is designed for a controlling seismic lateral load case, the lateral system will now be redesigned to accommodate increased wind loads. The redesign will consist of modifications to member sizes and to the quantity of braced and moment frames if necessary. The number of lateral frames will be evaluated to determine if any can be removed or if additional frames are required. The potential to reduce the amount of moment frames will be investigated to reduce the cost that accompanies the required moment connections.

7.4 Methodology

More detailed calculations are required for the composite steel and flat slab gravity systems. A long span deck will be considered for the composite steel design to reduce weight. The original hand calculations (Notebook B section 6.1) used for the system will be modified to compare the effects of using a long span deck. Several iterations of the composite steel system will then be designed and analyzed using a RAM model (see section 7.7), which will also be used to run vibration analyses for the systems. The RAM vibration analysis results will be verified with hand calculations that follow AISC Design Guide 11: Vibrations of Steel-Framed Structural Systems Due to Human Activity.

The flat slab design of a typical bay also requires further analysis as it was schematically designed for a slab depth that meets the ACI requirements that allow a deflection check to be bypassed. This calculation results in a conservative depth that overestimates the actual slab thickness required for strength and serviceability. It is important to accurately calculate the required slab depth as it has an impact on several factors used for system comparisons such as weight, structural depth, and cost estimate. A RAM Concept model will be created for the two-way flat slab system to design a thinner slab for deflection.

For the lateral system, new wind loads will be manually calculated using the ASCE 7-10 Chapter 27 MWFRS Directional Procedure as followed in Notebook A section 3.1. These loads will be compared to ETABS and RAM auto-generated wind loads for the structure in the assumed Ft. Lauderdale location. The lateral system will then be redesigned using RAM Structural System and verified with manual spot checks similar to those included in Notebook C section 8.5.

7.5 Construction Management Breadth: Prefabrication

Since it is becoming increasingly popular to use prefabricated elements in hospital projects, a construction management breadth with a focus on prefabrication will be investigated. This research will explore elements that have potential to be prefabricated and their feasibility based on integration with other building systems. Prefabricated components that will be investigated include but are not limited to bathrooms, patient room headwalls, and mechanical racks. After this analysis, detailed calculations will be performed to determine the effects of using prefabricated elements on the construction schedule and building cost. These results will then be compared to cost and scheduling of the current design to determine if prefabrication would be a beneficial approach. The cost of schedule will also be considered since changes in schedule length can have a significant impact on the overall cost. If there is a significant change in schedule length, the cost of schedule analysis will include general construction costs for equipment, operation, labor, and interest on loans as appropriate. Early or delayed hospital occupancy and operation will also be considered in this analysis.

7.6 Mechanical Breadth: Acoustics

The Mercy Health Muskegon hospital was designed for patient-centered care, and acoustics are a significant concern for the privacy and well-being of patients. As a mechanical breadth, an acoustic analysis will be executed for the floor, wall, and ceiling assemblies in a typical patient room to determine the sound characteristics and acoustical performance. One area of concern is the fourth level of the addition, which is a bed tower level that is directly above a full mechanical level. This area could pose significant acoustic challenges and will therefore be the focus of this investigation. Based on the acoustic analysis results, suggestions will be made for potential opportunities to improve the acoustical performance and determine the benefits and challenges associated with these changes. Acoustical performances of proposed new assemblies will be compared to those of the existing design to see how the changes affect the overall performance. If no considerable problems are found with the existing design, quality assurance and quality control will be discussed to ensure that the desired results are achieved through quality construction.

7.7 MAE Requirements

A detailed model of the gravity and lateral systems of the Mercy Health Muskegon addition will be created in RAM Structural System to fulfill the MAE requirements. The computer modeling with this software will build upon the modeling fundamentals discussed in AE 530: Computer Modeling of Building Structures. While this course focused on ETABS and SAP2000, the information and techniques learned will be used to become familiar with new structural modeling software. The RAM model will be used to analyze and optimize new designs for steel-framed gravity systems and lateral systems that may incorporate a combination of moment frames, braced frames, and shear walls. Additionally, the model will be used for vibration analysis of the system. As a check to ensure proper modeling and load generation for the lateral elements, the lateral loads generated in RAM will be compared to previous hand calculations and ETABS auto-generated wind and seismic loads.

7.8 Honors Requirements

Honors thesis requirements will be met through the research and application of several multi-criteria decision-making (MCDM) methods for determining an optimal structural system for use in healthcare facilities. These MCDM methods include the Analytical Hierarchy Process (AHP), Choosing By Advantages (CBA), and the Pugh Matrix (PM). A literature review will be conducted to identify the uses of these decision-making techniques within the architecture, engineering, and construction (AEC) industry. The research will also be used to identify the benefits and challenges associated with each method and how they may affect results. A survey and discussions with professionals in the AEC industry will be the basis for the criteria used for the AHP, CBA, and PM. These MCDM methods will then be utilized to compare the various gravity systems considered for use in the Mercy Health Muskegon addition. The results of each method will be compared and used to determine if the original decision to use a modified composite steel system in the redesign was the best decision based on the specified design goals.

Please see the document entitled "A Thesis Proposal for Decision-Making Methods in the Structural Design of Healthcare Facilities" for the full Honors Thesis Proposal.

7.9 Approach

Task 1: Computer Modeling

- Create RAM Concept model for flat slab thickness calculation
- Create RAM Structural System model for use in gravity system vibration analyses and lateral system redesign

Task 2: Gravity Redesign

- Modify composite steel gravity design
  - Hand calculations for long span deck used in composite steel system
- Redesign composite steel gravity system using RAM model
  - Perform vibration analyses with four different design iterations and verify with Design Guide 11

Task 3: Lateral Redesign

- Recalculate wind loads for proposed Ft. Lauderdale location and compare with previously calculated lateral loads
- Redesign system with RAM model
  - Update member sizes in braced frames and moment frames
  - Modify quantity of lateral frames if necessary
  - Consider the use of shear walls or the removal of several moment frames while upsizing the remaining moment frames for efficiency
  - Update gravity system concurrently as changes to the lateral system design will likely affect some aspects of the gravity design
- Spot checks to verify lateral system redesign

Task 4: Prefabrication Breadth

- Research prefabricated components used in healthcare facilities
  - Consider the potential to use prefabricated elements, such as connections, in the gravity redesign
- Determine feasibility for use in the Mercy Health Muskegon addition
- Perform cost and schedule analyses

Task 5: Acoustics Breadth

- Analyze acoustic performance of existing floor, wall, and ceiling assemblies
- Research ways to improve acoustic performance and design new assemblies
  - Analyze acoustic performance of new assembles

- If no significant issues are found, research and discuss quality control and quality assurance of the construction process in relation to desired acoustic performance

Task 6: Gravity System Selection Comparison

- Modify gravity designs for typical bay
  - Update flat slab system design using new slab thickness from RAM Concept model
  - Update the decision matrix used in Notebook B considering modifications to composite steel and flat slab system
- Compare decision-making methods (in fulfillment of Schreyer Honors College thesis requirements)
  - Draft criteria-related survey questions; finalize survey and send to industry contacts
  - Complete data collection and sort data; create decision matrices
  - Apply CBA, AHP, and PM to Mercy Health Muskegon project gravity system comparisons

Task 7: Honors Thesis Documentation (throughout semester)

- Honors Thesis Formatting and Format Review
- Honors Thesis Final Submission

Task 8: AE Thesis Documentation (throughout semester)

- AE Thesis Report Finalization
- AE Thesis Presentation Finalization
- Presentation

7.10 Spring Semester Schedule

The proposed schedule is an anticipated plan of when tasks will be completed during the spring semester. This schedule may need to be modified throughout the course of the semester. Figure 34 provides a summary of the overall task start and end dates, and Figure 35 shows a detailed task schedule.

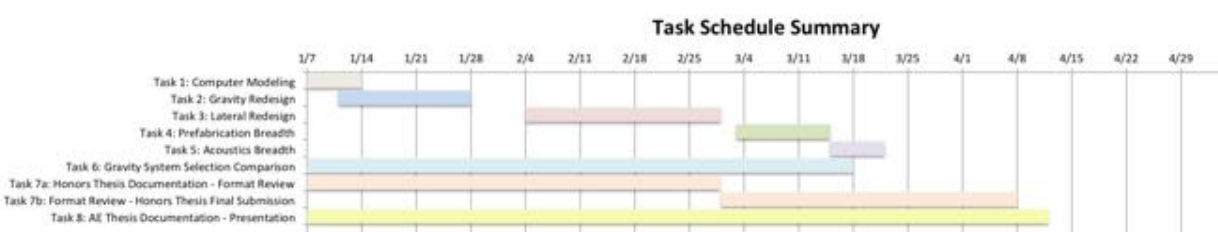

Figure 34: Spring Semester Task Schedule Summary

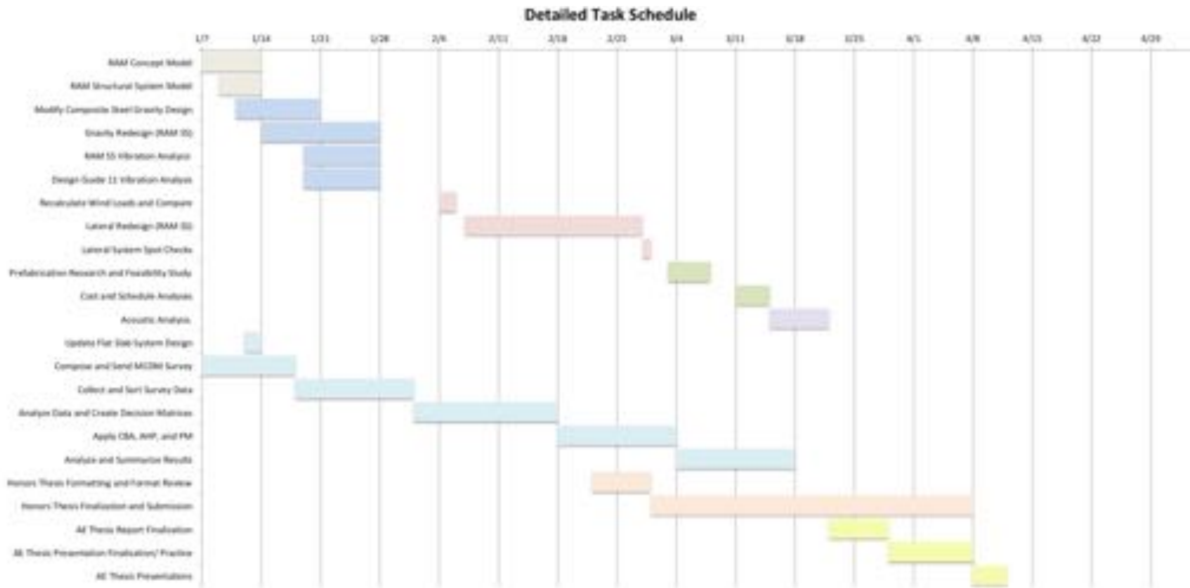

Figure 35: Detailed Spring Semester Task Schedule

7.11 Conclusion

Since hospitals are complex facilities that demand high performance, the Mercy Health Muskegon project requires thorough consideration of structural, mechanical, and construction optimization. The Mercy Health Muskegon hospital addition relies heavily on system integration and performance to provide a high quality, patient-centered healing environment. Like the original design, achieving these goals will be the focus of the proposed redesign. With many complex systems and features in the existing design, there are many opportunities to explore performance and maximize integration.

The proposed thesis will explore a redesigned structural system that is a modified version of the existing composite steel system. The choice to use this system will be further analyzed in a decision-making method study that is geared toward healthcare facilities. Using a detailed computer model, this design will also be optimized to enhance vibration performance. Since the addition, located in Michigan, is part of a healthcare system with many hospital locations, a lateral system redesign will be performed to consider use of the same system in a hurricane region. Prefabrication and acoustic performance will also be investigated.

The redesign will aim to maintain the existing architecture of the hospital and consider the impact on integration between the structural and mechanical systems. The prefabrication study will also seek to maintain or improve the construction schedule. Additionally, the proposed design solution will consider public health, safety, and welfare through vibration studies, acoustic analysis, and lateral drift limitations. Design decisions will also take economic and sustainability factors into consideration by reducing the number of structural members and costly connections, while also choosing economical structural sections. The overall goal of the proposed research and redesigns is to optimize the modified Mercy Health Muskegon addition to meet the high performance standards that healthcare facilities demand.

8.0 Appendix

A1 Proposed Task Start and End Dates

Task Name	Start	End
Task 1: Computer Modeling	1/7/19	1/14/19
Task 2: Gravity Redesign	1/11/19	1/28/19
Task 3: Lateral Redesign	2/4/19	3/1/19
Task 4: Prefabrication Breadth	3/3/19	3/15/19
Task 5: Acoustics Breadth	3/15/19	3/22/19
Task 6: Gravity System Selection Comparison	1/7/19	3/18/19
Task 7a: Honors Thesis Documentation - Format Review	1/7/19	3/1/19
Task 7b: Format Review - Honors Thesis Final Submission	3/1/19	4/8/19
Task 8: AE Thesis Documentation - Presentation	1/7/19	4/12/19

Task Name		Start	End
Task 1	RAM Concept Model	1/7/19	1/14/19
	RAM Structural System Model	1/9/19	1/14/19
Task 2	Modify Composite Steel Gravity Design	1/11/19	1/21/19
	Gravity Redesign (RAM SS)	1/14/19	1/28/19
	RAM SS Vibration Analysis	1/19/19	1/28/19
	Design Guide 11 Vibration Analysis	1/19/19	1/28/19
Task 3	Recalculate Wind Loads and Compare	2/4/19	2/6/19
	Lateral Redesign (RAM SS)	2/7/19	2/28/19
	Lateral System Spot Checks	2/28/19	3/1/19
Task 4	Prefabrication Research and Feasibility Study	3/3/19	3/8/19
	Cost and Schedule Analyses	3/11/19	3/15/19
Task 5	Acoustic Analysis	3/15/19	3/22/19
Task 6	Update Flat Slab System Design	1/12/19	1/14/19
	Compose and Send MCDM Survey	1/7/19	1/18/19
	Collect and Sort Survey Data	1/18/19	2/1/19
	Analyze Data and Create Decision Matrices	2/1/19	2/18/19
	Apply CBA, AHP, and PM	2/18/19	3/4/19
	Analyze and Summarize Results	3/4/19	3/18/19
Task 7a	Honors Thesis Formatting and Format Review	2/22/19	3/1/19
Task 7b	Honors Thesis Finalization and Submission	3/1/19	4/8/19
Task 8	AE Thesis Report Finalization	3/22/19	3/29/19
	AE Thesis Presentation Finalization/ Practice	3/29/19	4/8/19
	AE Thesis Presentations	4/8/19	4/12/19