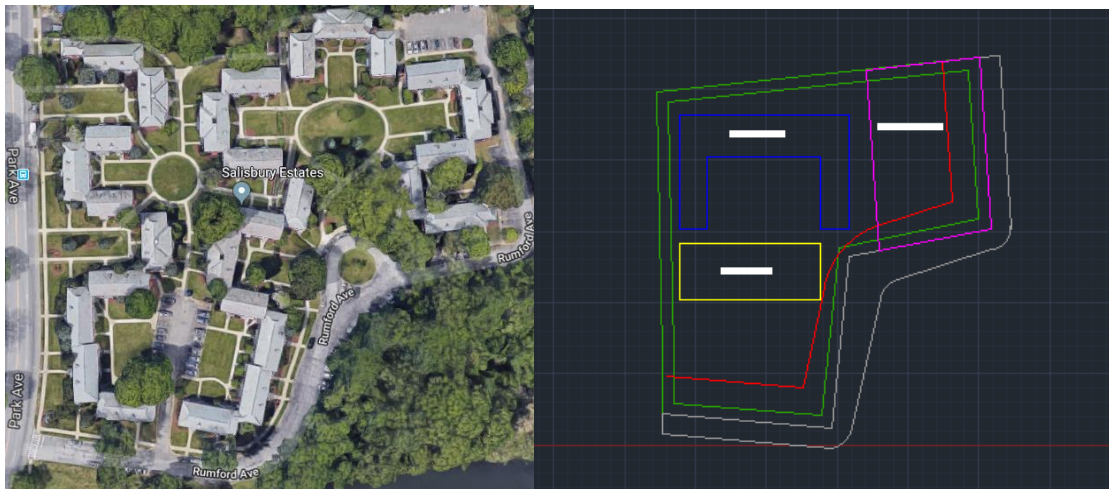




Redesign of Salisbury Estates



Major Qualifying Project

Presented by:

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Presented to:

Professor Leonard Albano and the Worcester Polytechnic Institute Civil & Environmental Engineering Department in partial fulfillment of the requirements of the Degree of Bachelor of Science

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This is a student project, submitted for academic credit. WPI typically publishes MQP Reports without peer review. For more information about the project program, please visit: <https://www.wpi.edu/academics/undergraduate/major-qualifying-project>

Abstract

With the Worcester Polytechnic Institute student body increasing, campus space must be expanded. Salisbury Estates presents an opportunity for redevelopment. Through interviews and research, multiple building layouts were considered, and preliminary designs for a residential and an academic building were finalized. Floor plans, life safety, and cost analysis were conducted. A complete framing plan with structural analysis of beams, columns, and footings was created for the academic building. Deliverables include a report, structural calculations, AutoCAD drawings, and a cost estimate.

Authorship

Due to the nature of the team's project, the paper was continuously being written as the design work was completed. Every member contributed to the overall writing. The primary authors for each of the major detailed sections was the person who led the primary design work on that topic. These sections were broken up as follows:

Zachary Abbott:

Floor Layout Design, Beam and Girder Design, Cost estimating, Preliminary author in tandem with others design

Mark DellaCroce:

Floor Layout Design in AutoCAD, Building egress design and analysis, Determined building occupant loads, Fire Sprinkler layouts in AutoCAD

Dylan Felty:

Interview Coordinator, Spreadsheet manufacturer, Column design, RISA 2D design, Lateral Bracing design, Cost estimating

Tyler Kornacki:

Site layout design, Floor Layout design, Beam design, Stairway and Elevator design, Lateral Bracing Design, Foundation Design

Capstone Design Statement

To satisfy the requirements of the Accreditation Board for Engineering and Technology (ABET) for Capstone Design Projects, the team considered realistic constraints. This section details how the project work addressed these constraints.

Constructability

It is important constructability throughout the design of a project. The design process can be followed correctly, and a structure may work on paper, but if the structural components cannot be integrated successfully then the work done is inadequate. The team continuously consulted outside sources, such as the *Massachusetts State Building Code (9th edition)* to address factors such as zoning, regulations, design aspects, and structural analysis. Steel sections were taken from the *Manual of Steel Construction*, published by The American Institute of Steel Construction.

Social

The social impact of a project must be considered to ensure it is actually feasible and successful for the region in which it is being completed. The new facilities will alter the landscape of WPI. Adding the academic facility will provide more classroom and laboratory space for the growing undergraduate class to collaborate and work as well as offices for the additional administration needed to facilitate this learning. The residential facility will also contribute to the support of the growing undergraduate student body by providing much needed dormitory space. The addition of these functional facilities will promote a more integrated campus that expands beyond just the hill on which most activities take place.

Economic

To evaluate the economic feasibility of this project, material and labor cost estimates were prepared. Given that this project will be funded by a private institution, every aspect from design through construction was evaluated.

Healthy and Safety

Health and safety should be considered for all phases of a project's life. In this case, the construction and occupancy were considered. The team ensured the safety of the construction process, the structure, and its occupants by designing in accordance with the *Massachusetts State Building Code 9th edition* and American Society of Civil Engineers (ASCE). The structures will be accessible and safe for all its occupants. The location of the facilities subjects them various environmental factors such as earthquake, snow, and wind loads which were accounted for in design.

Ethics

The American Society of Civil Engineers (ASCE) says that "Ethics is integral to all decisions, designs, and services performed by civil engineers." There are ethical specifications

that must be addressed for every project: designing the project in the best interest of the client, being truthful in the cost and timeline for the project, and not using substandard materials or techniques to save money. By adhering to these procedures, in addition to ASCE's assertion that "engineers uphold and advance the integrity, honor, and dignity of the engineering profession by using their knowledge and skill for the enhancement of human welfare and the environment, being honest and impartial and serving with fidelity the public, their employers and clients, striving to increase the competence and prestige of the engineering profession, and supporting the professional and technical societies of their disciplines" (ASCE, 2017), this project was completed ethically and appropriately.

Professional Licensure Statement

In the state of Massachusetts, as well as the rest of the United States, any construction designs must have the stamp of approval from a licensed Professional Engineer (PE). Because of the necessity to have these stamps of approval obtaining a PE certification is a major step for any engineer looking to further their career. Not only will this licensure open up the possibility for promotions within one's company but will also invite the opportunity for pay raises.

Due to the importance of a PE licensure, and the repercussions that may come with being held responsible for one's designs, they are both difficult and time consuming to obtain. There are three major steps in becoming a PE: receiving your college degree, becoming an EIT, and passing the Principles and Practice of Engineering exam. While this might not sound like much at first glance, they all have their own stipulations attached. The first step of obtaining your college degree must come from a 4-year ABET accredited institution. When nearing graduation from this program, or after graduation, one must register for and pass a Fundamentals of Engineering Exam to become an EIT. This is a 110 question computerized test that lasts a total of 5 hours and 20 minutes. These 110 questions are broken down into 18 sections ranging from basic overarching topics like mathematics, statistics, and ethics, to more discipline specific topics of materials, fluids mechanics, and structural design. Upon earning an EIT licensure one must then complete 4 years of professional practice under the supervision of a PE (3 years if having completed a Master's degree). Once this time has been completed then one can register to take a Principles and Practice of Engineering exam to become a PE. While the FE exam is a nationwide standard that can be taken and accepted throughout the US, a PE is only permitted to work in the state the pass their exam in, and others that accept that states test.

The structures designed in this project would need multiple PE stamps to be erected. While the design drawings shown in the Appendix would need to be stamped by a Civil/Structural PE, all of the nonstructural components would need stamps of approval from a PE in that field (i.e. Architectural, Electrical, Environmental, Fire Protection, and Mechanical).

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Executive Summary

This Major Qualifying Project (MQP) centered around the acknowledgement that as Worcester Polytechnic Institute (WPI) student body continues to grow, the need for more residential, academic, and collaborative spaces is present. This report offers a solution to the current housing and classroom space shortages that will only become more of a concern as incoming class sizes continue to increase. The comprehensive redesign of the Salisbury Estates property has involved the demolition of all existing buildings, roadways, paths, and landscape to allow for a new complex of large residential and academic buildings as well as an additional dining facility. This report includes AutoCAD drawings of a proposed academic building and a residential building as well as a site plan for the entire Salisbury Estates property, and a cost estimate for the undertaking of this project. These proposed buildings offer a significant addition of classrooms, common areas, dormitories, and parking spaces needed to accommodate the growing undergraduate population. Areas of depth have included structural design and analysis as well as life safety and fire protection, all of which have been addressed in accordance with applicable codes, standards, and Worcester City Ordinances.

Through multiple conducted interviews, as many interests and needs were included based on WPI employee feedback. The following functionalities have been incorporated in the design of the residential and academic buildings. For the residential building design, meeting spaces, large common areas and tech suites are provided. These functional spaces will promote collaboration and increase the appeal of the all new redesigned complex. The design incorporates housing for several hundred students within a two resident per unit style dormitory facility reaching a total of three stories. The first floor includes a dining area and a connecting lounge area available to members of the WPI community. The residential building forms a U-shape and has a total make up of 104,100 square feet.

The academic building design includes a combination of lecture halls, classrooms, offices, and tech suites in order to appeal to the several needs of the institution and create a greater draw to the development to complete work and collaborate. This building was designed to be three stories and has a total make up of 75,000 square feet.

The parking arrangement has been kept similar to the existing Salisbury Estates layout including street and flat lot style parking. Salisbury Estates occupies a substantial amount of land, some of which has been left for development outside of the building construction. A balance has been determined regarding what is to be developed into parking and what is to be set aside to form an open, green space that connects the facilities, similar to the current Quadrangle on campus. In addition to providing students a safe place to go outside and enjoy leisurely activities, this open space will also provide opportunity for further development in the future if necessary.

The architectural layouts were completed for both buildings while a complete structural design and analysis was completed for the academic building with similar properties and methods used for cost estimates of the residential building as time did not allow for a complete structural analysis of both buildings. Upon completing the floor layout for the academic building, the columns were placed as accurately and most desirable as possible while fitting the floor layout. Using beam and girder sizing design aids, the allowable distance separating the columns was determined and member lengths were chosen. Once the bay sizes were determined, ASCE 7 was used to determine design loads for sizing of members. A top-down approach to size members was taken, starting with the roof bays, followed by the third floor, then second floor, and ending with the first floor. With beams and girders sized and self-weights determined, the columns supporting these bays were then designed. The framing plan was finalized with the design of lateral bracing in the corner bays. When the framing designs were completed, foundation design began. Due to the lack of a basement in this building, the foundation design involved simple baseplates and footings for each column.

Simultaneously to the structural design, a life safety analysis was conducted while the architectural drawings were being finalized for both buildings. The egress analysis ensured there was enough space present in the architectural drawings for building occupants to safely egress as well as proper door swing with respect to occupant load in each room of the building. Following this, fire protection plans were made in the form of AutoCAD plans for the installation of full automatic sprinkler systems for both buildings.

An accurate cost estimate for first the academic building was assessed using cost data from RSMeans publications. Following the completion of the structural design, cost data from RSMeans publications was consulted for costs per linear foot of all structural members. In addition to these linear foot values, all nonstructural elements were estimated with cost per square foot values. Using these same methods the cost estimate for the residential building was also developed. Fire protection costs were estimated on a square foot basis for both buildings with respect to sprinkler and fire alarm costs.

Future recommendations have been included as to how this project can be continued with future MQP teams. This completed project includes enough information and drawings to demonstrate that a new academic and residential building is a useful way to repurpose the existing Salisbury Estates property while filling a great need to the WPI campus with the addition of dormitory, classroom, lecture hall, office, tech suite, dining, and collaborative spaces for students to live and grow as individuals.

1. Introduction

The following has been derived from what Worcester Polytechnic Institute (WPI) lacks most in terms of infrastructure on campus. This report offers a solution to the current housing and classroom space shortages that will only become more of a concern as incoming class sizes continue to increase. The comprehensive redesign of the Salisbury Estates property has involved the demolition of all existing buildings, roadways, paths, and landscaping to allow for a new complex of large residential and academic buildings as well as an additional dining facility. This report includes a digital model of the proposed buildings, a site plan for the entire site, and a cost estimate. This will also demonstrate the significant addition of classrooms, common areas, dormitories, and parking spaces provided to accommodate the growing undergraduate population. Areas of depth have included structural design and analysis as well as life safety and fire protection, all of which will have been addressed in accordance with applicable codes and standards.

The residential building design includes meeting spaces and large common areas as well as tech suites. These functional spaces will promote collaboration and increase the appeal of the complex. The design incorporates housing for several hundred students within a two-resident-per-unit style dormitory facility. The first floor also includes a dining area and a connecting lounge area available to members of the WPI community. The separate academic building design includes a mixture of lecture halls, classrooms, offices, and tech suites in order to appeal to the several needs of the institution and create a greater draw to the development.

More parking is necessary to accommodate the new users of the facilities including faculty, staff, and students. It has been deemed undesirable to erect an entire parking garage for this purpose. Therefore, the parking has been kept similar to its current style with street and lot parking. Salisbury Estates occupies approximately 9 acres, some of which has been left for development outside of the building construction. A balance has been determined regarding what is to be developed into parking and what is to be set aside to form an open, green space that connects the facilities, similar to the current Quadrangle on campus. In addition to providing students a safe place to go outside and enjoy leisurely activities, this open space will also provide opportunity for further development in the future if necessary.

2.0 Background

This project aimed to provide more residential space to account for the growing WPI student body, as well as an academic facility to further support this growing community and promote more integration of the Salisbury Estates area with the rest of campus. To effectively deliver this project, certain background knowledge was required. Several factors were considered for the design of these new structures. The site was first assessed to determine property lines and land conditions that would restrict the scope of work. Design ideas were then developed with input from WPI faculty and staff to ensure that the wants and needs of the University were considered. Building code research was conducted to ensure that the proposed buildings have been designed in accordance with applicable codes and standards. The project's impact on the community was also considered to ensure that the new development would fit well into the area and not cause issues with surrounding properties. Designs are only accepted if they are economically feasible; therefore, the cost of the proposed development has been assessed. Decisions were also made ethically, and items were addressed in a correct, professional manner throughout the project.

2.1 Site Information

The proposed buildings have been situated within the lot of WPI's Salisbury Estates. This area is located along Massachusetts Route 122A (Park Avenue), between Salisbury Pond and the Worcester Center for Crafts as seen in Figure 1. For students to access this complex by foot, they must either walk along an indirect sidewalk or an unpaved and unlit path along Salisbury Pond. Alternatively, access by car is only possible through a single entrance and exit on Park Avenue (Rumford Avenue). The plot of land is quite expansive and has primarily level topography. According to flood maps from the FEMA Flood Map Service Center, this land is in an area of minimal flood risk despite its close proximity to Salisbury Pond; therefore, flooding is of no issue.

In addition to the plot of land Salisbury Estates is currently on, WPI owns some additional neighboring property. The large building located between the Worcester Center for Crafts and Avis Car Rental belongs to WPI and is currently being used to store equipment for WPI Facilities. Aside from this building, all of the land between the Worcester Center for Crafts and Grove Street is under WPI control. This includes a small parking area to the north that has been expanded southward to provide additional parking and a through way for an extra access point to the Salisbury Estates property.

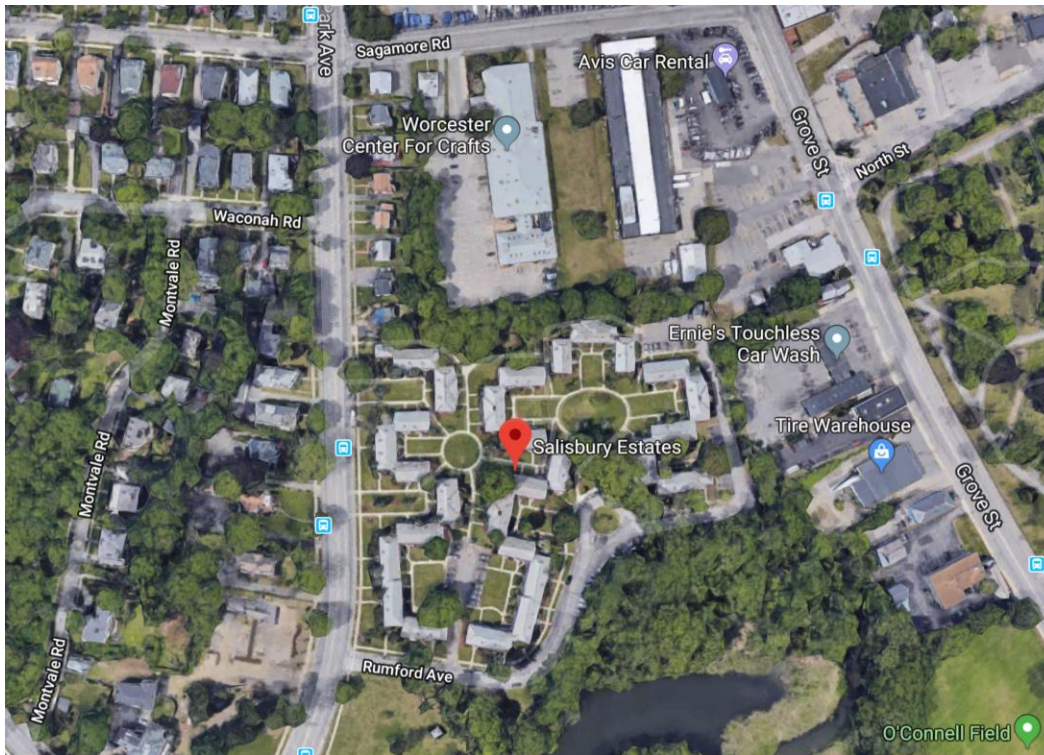


Figure 1: Aerial view of Salisbury Estates site – (Google, n.d.)

2.2 Community Impact

The redesign of the Salisbury Estates property will affect the surrounding Worcester community. From the demolition of the existing property to the active construction of the buildings, the proposed development will impact not only the WPI community, but also the community of Worcester.

2.2.1 Impact on the WPI Community

With student populations at WPI growing every year, on-campus residential space has reached its capacity; all available rooms have been filled and some students are even on housing waitlists. WPI administrators and staff from across the institution agree that additional housing for undergraduates is the top priority moving forward. Without access to on-campus housing, students are forced to move to off-campus alternatives which can vary in quality and safety. In extreme cases, some students may even resort to lengthy or inconvenient commutes from neighboring communities if they are unable to secure housing on campus.

Although residential space has been identified as the top priority for future development according to interviews, the need for additional academic space is also present. As the size of the student body grows, so does the amount of classes offered. With only so many hours in a day,

WPI has begun to encounter scheduling difficulties due to a lack of available classrooms for professors to instruct courses. The growing student body will only intensify this issue in coming years if additional classroom space is not added to campus.

2.2.2 Impact on the Greater Worcester Community

The new construction on Salisbury Estates has significant potential to impact the greater Worcester community. In order to begin the construction for the project, all existing structures will be demolished and landscape cleared. From this initial step, this project will impact the greater Worcester area. With demolition and new construction comes loud noise, displacement of existing residents, and potential impediment of public utilities for surrounding buildings, all of which will affect residents of the community for the duration of the project. Additionally, once built, the new structures will themselves become part of the community. The structures have been designed to fit into the theme of the surrounding area and not stick out as loud additions to the pre-existing neighborhood.

2.3 Design Parameters

The following sections discuss the technical aspects of the team's final building designs and what has been incorporated with respect to fire code requirements and occupancy classifications. The limiting factor for the design of the building lies in the codes, standards, and ordinances put forth by the City of Worcester and the Commonwealth of Massachusetts. The building has been designed according to the *2015 Edition of the International Building Code* (IBC) which Massachusetts currently adopts, the *9th edition of the Massachusetts State Building Code* (MSBC), which Massachusetts currently sets in place to amend certain sections of the 2015 IBC, all National Fire Protection Association (NFPA) codes and their respective editions adopted by Massachusetts, and all zoning and ordinances for Worcester.

2.3.1 Zoning Requirements

Across Massachusetts, cities and towns are divided into different zoning districts that serve to regulate the use of specific plots of land and govern building characteristics across different neighborhoods and usage areas. Although the entirety of WPI's main campus is zoned as Institutional (IN-S), it was discovered that the Salisbury Estates property has been zoned as Limited Residential (RL-7) which presented several design restrictions that do not apply to WPI's campus on the hill. Of significant relevance to this project are the restrictions on permitted land use, permitted dimensions, and off-street accessory parking requirements. These regulations can all be found within Tables 4.1, 4.2, and 4.4 respectively of the City of Worcester Zoning Ordinance. Table 1 shows the major considerations associated with each regulation that were taken into account during the preliminary discussion of design alternatives.

Table 1: Design Parameters/Regulatory Considerations

Ordinance Table Number	Regulation	Consideration
4.1	Permitted Uses by Zoning District	<ul style="list-style-type: none"> ● <u>Dormitory Space</u>: Permitted under “Special Permit” ● <u>Schools Non-Profit</u>: Permitted
4.2	Permitted Dimensions by Zoning District	<ul style="list-style-type: none"> ● Maximum of three stories ● Maximum overall height of 45 feet
4.4	Off-Street Accessory Parking Requirements	<ul style="list-style-type: none"> ● 0.33 parking spaces required per dwelling unit ● Ten parking spaces required per classroom

Referring to these regulations impacted the scope of alternative designs discussed. Initially, the design was to incorporate a building height of five stories; however, the Worcester Ordinances identified that the maximum height restriction for the specified zone was limited to three stories. This research also provided a clearer picture of the amount of parking required based on the number and types of occupants.

Further investigation revealed that there exists a 100-foot buffer zone from the waterline of Institute Pond which meant that all new construction must be set back 100 feet from the pond. If construction was desired beyond the 100-foot buffer zone, then a variance must be requested to receive permission.

2.3.2 Occupancy Classification for Residential Building and Academic Building

The team decided to propose a three-story residential hall with bedrooms, common spaces, and tech suites. The academic building design has incorporated classrooms, laboratories, lecture halls, offices, and tech suites. A dining facility was also implemented on the 1st floor connecting the two halls in the center. Table 2 shows the code requirements and restrictions that were taken into account for the proposed building designs. These occupancy classifications were important to determine the appropriate occupant load of the various spaces in the buildings once final layouts and areas were discussed and agreed upon.

Table 2: Minimum Building Code Requirements for Building Design

Occupancy in Question	Code Requirement	Code Reference
Residential Hall Occupancy Classification	Residential Group R-2: sleeping spaces of more than two dwelling units where occupants are primarily in nature, which includes dormitories.	MSBC Section 310.4.
Occupancy Separation	Group R-2 occupancies shall be separated from other accessory occupancies.	MSBC Section 508.2.4
Need for Automatic Sprinkler System	Group R occupancies shall be equipped throughout with an automatic sprinkler system.	MSBC Section [F] 420.5
Entry common space occupancy classification	Assembly Group A, a portion of a building used for gathering of persons for purposes including recreation shall be classified as Assembly.	MSBC Section 303.1
Dining hall occupancy classification	Assembly Group A-2, use of cafeterias and similar dining facilities.	MSBC Section 303.3
Commercial kitchen occupancy classification	Assembly Group A-2, associated commercial kitchens attached to a dining facility.	MSBC Section 303.3
Offices	Business Group B Occupancy	MSBC Section 302

Tech Suites	Group B Occupancy because Tech Suites are intended to hold less than 50 people	MSBC Section 302
Classrooms and lecture halls	Assembly Group A	MSBC Section 303.1

The residential spaces have remained separate from the main entryway with the attached dining facility; furthermore, for security reasons, double door vestibules with key card access from the ingress side of the building entryway to the residential areas have been incorporated to prevent unwanted persons from entering the residential halls. The occupancy classifications were used to calculate the occupant loads which can be present at any given time in the residential space, entryway common space, dining space, and commercial kitchen space. The determined occupant loads are set forth by the code to ensure the buildings can support a safe evacuation in the event of a fire. If the total number of building occupants exceed the occupant load of the building, staircases and doorways will become overcrowded inhibiting a safe egress for all building occupants.

2.3.2.1 Building Construction Type

Type I and Type II construction were considered for the residential building, ideally including a full steel structural frame with brick facade. Type II construction was decided upon due to the primary focus of the project being on the design of the structural frame, that being of steel. The construction type and occupancy classifications were then used to calculate the maximum allowable building footprint per the MSBC. Type I construction is defined by the use of steel, and Type II construction is defined by the use of brick or masonry with steel structural member elements. Types III, IV, and V construction include the use of combustible materials and are therefore undesirable for use in a residential dormitory building.

2.3.2.2 Building Size Limitations

Table 3 shows the building size limits with respect to construction type. Since the proposed buildings are to be comprised of mainly steel structural elements, the steel is required to have a certain level of fire resistance in an hour rating system. Table 3 shows the requirements per the MSBC.

Table 3: Building Code Requirements for Fire Safety

Occupancy in Question	Code Requirement	Code Reference
Building Height allowance	85 feet for residential occupancies of Type II construction when equipped with an automatic sprinkler system	MSBC Table 504.3
Stories permissible	5 stories under Type II construction when equipped with an automatic sprinkler system	MSBC Table 504.4
Building area allowance	Unlimited under residential occupancies of Type II construction, provided the building is equipped with an automatic sprinkler system	MSBC Table 506.2
Type II structural elements	1-hour fire resistance rating for all structural members of the building frame	MSBC Table 601
Bearing walls	1-hour fire resistance rating	MSBC Table 601
Roof Structure	1-hour fire resistance	MSBC Table 601

2.3.2 Fire Requirements with Respect to Site Plan

The following sections contain the limits to the site plan design with respect to fire requirements including the fire access road, the location of the entrances to the buildings, and the fire department connections to the buildings. These requirements assisted in shaping the landscape of the site plan and identifying locations of parking spaces.

2.3.2.1 Fire Department Connections

The design of both the residential and academic buildings had to account for the location of fire department connections. MSBC Section [F] 912: Fire Department Connections states that with respect to hydrants, driveways, buildings and landscaping, these fire department

connections shall be located so that fire apparatus and hoses connected to supply the system will not obstruct access to the buildings for other fire apparatus. The fire department connections shall be located on the street side of buildings, fully visible, and recognizable from the street or nearest point of fire department vehicle access. The section continues to acknowledge that the fire department connections shall be maintained at all times and shall never be obstructed by fences, bushes, trees, walls or any other fixed or moveable object.

2.3.2.2 Fire Access Road

According to MSBC Section 503.1.1, approved fire apparatus access roads shall be provided for every facility, building, or portion of a building hereafter constructed or moved into or within the jurisdiction of the project. The section further explains that the fire access road shall extend to within 150 feet of all portions of the facilities and all portions of the exterior walls of the first stories as measured by an approved route around the exterior of the buildings. It is also noted that the fire access road shall have an unobstructed width of no less than 20 feet, and an unobstructed vertical clearance of no less than 13 feet-6 inches.

2.3.3 Fire Requirements with Respect to Building Design

Table 4 addresses design codes and specifications regarding occupancy loading, egress plans, sprinkler systems, as well as the materials and furnishings that the team had to abide by in designing specific components of the buildings.

Table 4: Building Code Requirements for Life Safety Considerations

Category of Consideration	Code Requirement	Code Reference
Occupancy Load Calculations	Occupant load placards shall be provided for each space of the buildings.	MSBC 1607.1
Egress Plan	Evacuation plans shall be provided for each level of the buildings demonstrating primary and secondary means of egress	NFPA 101 2013 Edition
Sprinkler Design	Building shall be sprinklered throughout	NFPA 13
Building Entrance Access	Building entrance access shall be within certain distance of the fire access road, through which the main fire alarm panel shall be accessible	MSBC 504.1

2.5 Sustainability

Projects aiming to improve infrastructure must be effective not only today but also for their impact in the future. In order to accomplish this, sustainability must be addressed in design. It was important to assess the conditions of the site itself and design to minimize the project's impact on the plot of land due to environmental concerns such as flooding and erosion. The proposed redesign of Salisbury Estates is environmentally friendly and sustainable to accommodate for future generations as the WPI community continues to grow. The sustainability of the building materials and construction processes used were addressed along with the design itself.

2.6 Ethics

Throughout this project several ethical considerations were kept in mind. The American Society of Civil Engineers (ASCE) says that "Ethics is integral to all decisions, designs, and services performed by civil engineers." There are ethical specifications that must be addressed for every project: designing the project in the best interest of the client, being truthful in the cost and timeline for the project, and not using substandard materials or techniques to save money. Worcester residents of Salisbury Estates who would have to be relocated upon construction were also considered. These residents would be alerted at the beginning of the planning process to provide them with ample time to find a new residence; assistance for these residents will also be

provided by WPI. This affected the decision of the construction method. Design-bid-build was used instead of design-build to give the residents more time to relocate under less pressure. By adhering to these procedures, in addition to ASCE's assertion that "engineers uphold and advance the integrity, honor, and dignity of the engineering profession by using their knowledge and skill for the enhancement of human welfare and the environment, being honest and impartial and serving with fidelity the public, their employers and clients, striving to increase the competence and prestige of the engineering profession, and supporting the professional and technical societies of their disciplines" (ASCE, 2017), this project was completed ethically and appropriately.

3.0 Methodology

3.1 Preliminary Information

The first primary objective of the project was to determine what structural design was to be undertaken. A discussion with project advisor Professor Leonard Albano addressed design projects that could be continued upon and new projects that WPI has actually been considering. This gave rise to the idea of redesigning the apartments of Salisbury Estates. In order to collect further information regarding this on-campus complex, meetings were held with Residential Services and Facilities staff.

Meetings were first held with Matthew Foster and Amy Beth Laythe from Residential Services. These two individuals were sought out because of their roles in Residential Services and the knowledge their roles provided regarding life on campus. They both spoke heavily of the current conditions and issues regarding Salisbury Estates, which would later be affirmed by visiting a student resident at the complex. Additionally, these discussions exposed more undergraduate housing as being WPI's current greatest need. The WPI Residential staff shared potential means of developing and improving the complex in order to address these concerns. The details of these potential avenues of pursuit were discussed in order to better define what the school would want with this Major Qualifying Project and what could actually be produced within the span of one academic year. This allowed for the identification of a project topic that would be both feasible and effective.

Another meeting held with Bill Spratt of Facilities affirmed the information gathered from Residential Services. It was agreed upon that residential space is currently the greatest need at WPI. The poor state of Salisbury Estates was discussed from the facilities perspective as well. It was shared that the complex was nearing the point of being dysfunctional due to its deferred maintenance. This has been a recurring issue since less than 50 percent of the occupants are WPI residents and the school technically does not need to provide regular maintenance as they do for other facilities on campus that are strictly occupied by WPI. Mr. Spratt also shared the idea of implementing the addition of more dining space into the redesign of the complex. Table 5 lists the key points taken from each interview.

As stated above, in order to further understand the current conditions of Salisbury Estates, the team also visited the site and toured the apartment of a WPI resident. This allowed for the collection of first-hand observations of the interior spaces as well as the overall layout of the complex and potential for development. The lack of maintenance mentioned through the previous interviews was certainly noticed and the need for renovation and improvement was shared by the WPI resident visited by the team.

Table 5: Interview Takeaways

Interviewee	WPI Department	Key Points
Matthew Foster	Residential Services	<ul style="list-style-type: none"> ● Focus on undergrad ● Residential/academic mixed-use ● Open meeting space
Amy Beth Laythe	Residential Services	<ul style="list-style-type: none"> ● More dining ● Separate residential & academic ● Integrated with rest of campus/community
William Spratt	Facilities	<ul style="list-style-type: none"> ● Need for improvement affirmed ● Not top priority since majority of tenants non-WPI

3.2 Defining Site Plan

For the residential facilities there will be one U-shape building with a wedge/dining area in the middle, similar to Morgan and Daniels Hall. The wings of the U-shape will be mirror images of each other, each having an L shape and being connected by the wedge on the first floor center. Opposite the resulting U shape will stand a rectangular academic facility, somewhat forming an open space similar to the Quadrangle on campus today.

After the completion of the site layout design it was decided by the team to dedicate time and resources to the academic building initially. The reason for this was due to the complexity in the layout of the residential building. It was realized early on that connecting the wings of the U-Shape to the main body was a problem the team had not encountered before and therefore design of this structure would prove far more time consuming. Due to the limited time to work on the design of these facilities, the team’s time would be better used on the academic building instead of researching this problem. At the conclusion of the academic building design, the gathered information was extrapolated to determine an estimated cost for the residential building.

3.3 Evaluation of Alternatives

Prior to deciding upon a final site layout for the Salisbury Estates property, many alternative options were investigated as shown in Appendices B-E. Appendix B shows a sketch with three separate facilities, all of which were deemed too large after consulting maps of the site and appropriate distance scales. The building drawn in Appendix C was decided against due to

the awkward connection angles which would cause unnecessary complications in design later on. The northerly facing U-shape building was decided upon as shown in Appendix D. This demonstrates the desire to use the academic and residential buildings to make an enclosed open area similar to the Quadrangle. Further investigation into the boundary requirements led to the change of the academic building from a U-shape to a normal rectangle, which also opens up additional space to further develop in the future if necessary.

Through the evaluation of design options and consideration of limiting design specifications, the scope of the project regarding the structures to be designed and layout of the complex was decided upon. It was determined that the setback on the property line to the North was closer than thought, so the dining area was moved into the wedge. In the end the team decided to design one residential facility joined by a new wedge/dining space on the first floor along with a separate academic facility across an open space similar to the Quadrangle currently on campus. The layout of these buildings can be seen in Figure 2 in which blue and yellow represent the residential halls and academic facility, respectively.

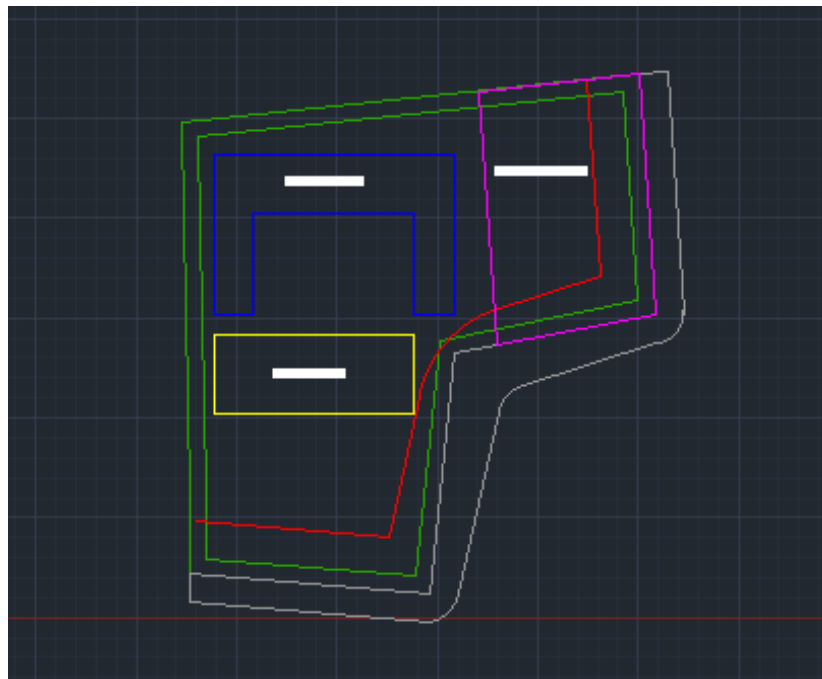


Figure 2: Final Site Plan

4.0 Architectural Floor Plans

When developing the floor plans for the academic and residential buildings a similar design method was followed. Each began with an initial idea of what was desired for the building, then as they were modeled around those ideas, the layouts were adapted to accommodate what was required based on fire safety and commercial building needs. The buildings were drawn in AutoCAD using different line colors for ease of viewability. A section of the residential building plans can be seen in Figure 3.

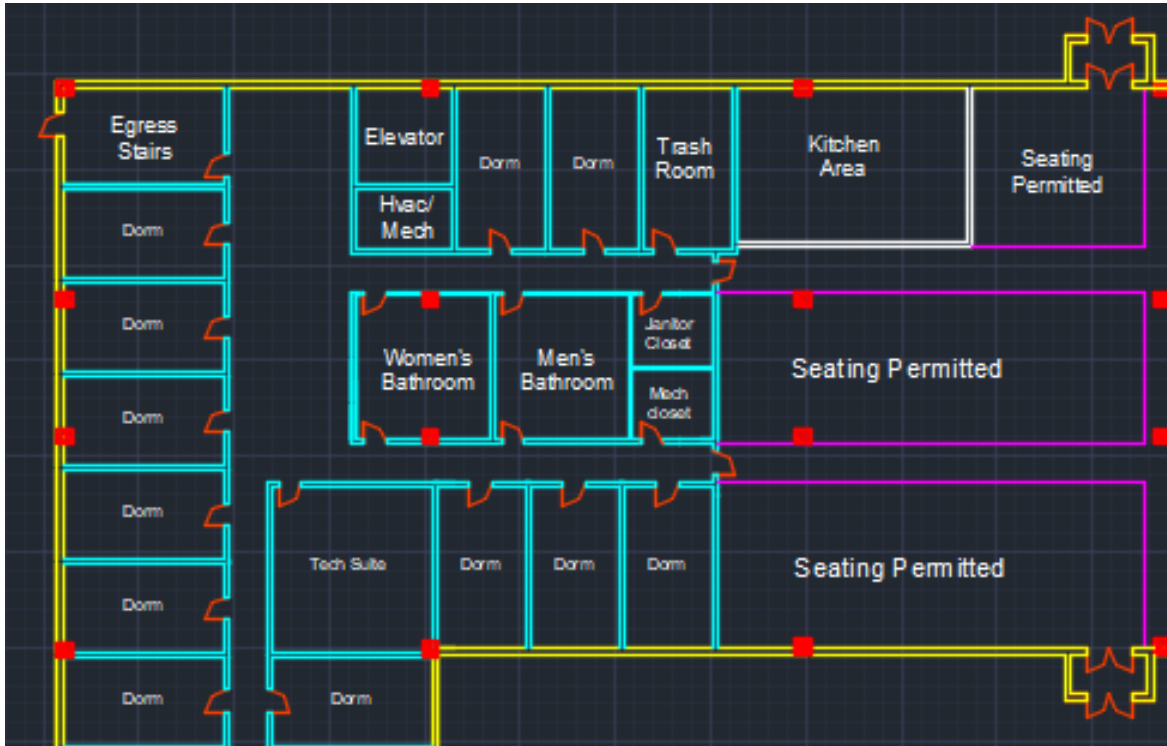


Figure 3: Sample of Residential Building Plans

Aside from these more detail-oriented changes there were some large adaptations that were necessary to make the limited spatial layouts and floor plans in both buildings. The residential building was the first to be looked through and finalized due to its unique style. One of the areas this building needs to house is some form of dining. This was originally designed to be located in an extension off the back end of the building. However, further investigation of the setback requirements of the lot showed that this extension would be outside of the permissible construction zone. As a result the dining portion of the building was moved into the wedge of the first floor connecting the two wings. The wedge was the location of the second major change in the residential building. When looking into dividing out the wedge into its different sections it was realized that the area allocated to this sole space that could be better utilized for more dorm rooms. This realization led to the shrinking of the wedge lengthwise on both sides, allowing for five more dorm rooms, along with a trash room, in each first floor wing. The final major change that was made in the residential building was a result of the fire safety analysis. When the floor

layouts were originally completed an occupancy rating was calculated. This showed that a second egress stair had to be added at the end of each wing next to the common rooms. These stairs were placed in the spaces previously assigned to dorm rooms, therefore resulting in the loss of two rooms.

After the finalization of the residential building floor layout the team moved to finalizing the floor plans for the academic building. The large changes to the academic building include revising the architectural drawings to eliminate dead-end corridors from the building, and adding egress doors that lead directly to the exterior of the building from the four large lecture hall spaces. The overall design of the building was completely changed to minimize any wasted spaces to incorporate as many areas for students to study and collaborate with one another as possible. A central main staircase was added to the building which is accessible from the entrances at either end of the building for an open concept feel. Four elevators are proposed throughout the building for ease and convenience of mobility. Both final architectural drawings can be found in Appendix E.

5.0 Fire Safety

The fire safety section involves the quantification of life safety elements including how long it will take building occupants to escape the building in the event of a fire, how many people can be in each building at any given time, and how wide the escape paths have to be for building occupants. Finally, fire protection systems have been designed to increase life safety and to proactively suppress fires.

5.1 Egress Analysis

A full egress analysis was conducted upon completion of the architectural drawings of both buildings for the purpose of ensuring that all occupants could safely escape in a fire event.

5.1.1 Occupant Load

To conduct an egress analysis, first the occupants loads for each room and each floor had to be developed to determine the number of enclosed fire rated egress stairwells that were needed to be incorporated into both buildings. Table 6 shows the occupant load of each floor for both the academic and residential buildings.

Table 6: Occupant Loads

Building and Floor Level	Maximum Occupant Load
Academic Building First Floor	926 Occupants
Academic Building Second Floor	762 Occupants
Academic Building Third Floor	451 Occupants
Residential Building First Floor	678 Occupants
Residential Building Second Floor	270 Occupants
Residential Building Third Floor	270 Occupants

5.1.2 Egress Width Requirements

The MSBC requires that each occupant within a building is provided with 0.3 inches of clear width for egress staircases. This factor is used to determine how many staircases are needed and how wide each of these staircases must be. Table 7 shows the total width of egress that must be provided per floor of each building using the multiplier of 0.3 inches per occupant. Further all other components of egress such as the clear width of doorways must be provided with 0.2 inches of clearance per occupant in accordance with the MSBC. The architectural building design layouts offer more space in width than code requires as seen in Table 7.

Table 7: Calculated Egress Width

Building and Floor Level	Egress Width Required	Number of Staircases or Egress exits provided	Egress widths supported by proposed design
Academic Building First Floor	277.8 Inches	4 Egress Stairwells	280 Inches
Academic Building Second Floor	228.6 Inches	4 Egress Stairwells	280 Inches
Academic Building Third Floor	135.3 Inches	4 Egress Stairwells	280 Inches
Residential Building First Floor	203.4 Inches	4 Egress Stairwells	280 Inches
Residential Building Second Floor	81 Inches	4 Egress Stairwells	280 Inches
Residential Building Third Floor	81 Inches	4 Egress Stairwells	280 Inches

5.2 Fire Protection Systems

Automatic sprinkler systems were designed in accordance with NFPA 13, the sprinkler installation code, to ensure full sprinkler coverage of both the Academic and Residential buildings. Appendix F shows detailed layouts of the sprinkler system including head locations, riser locations, branch pipe locations, and pipe sizing.

The buildings will be equipped with concealed pendant style sprinkler heads to offer the cleanest finish to each room and to give an optimally modern aesthetic. Sidewall sprinkler heads were used strategically in closets and in the entry vestibules to minimize excessive placement of sprinkler piping. A section of the sprinkler piping layout can be seen in Figure 4. The full sprinkler layout including head placement, piping arrangement and sizing, as well as riser locations can be seen for both buildings in Appendix F.

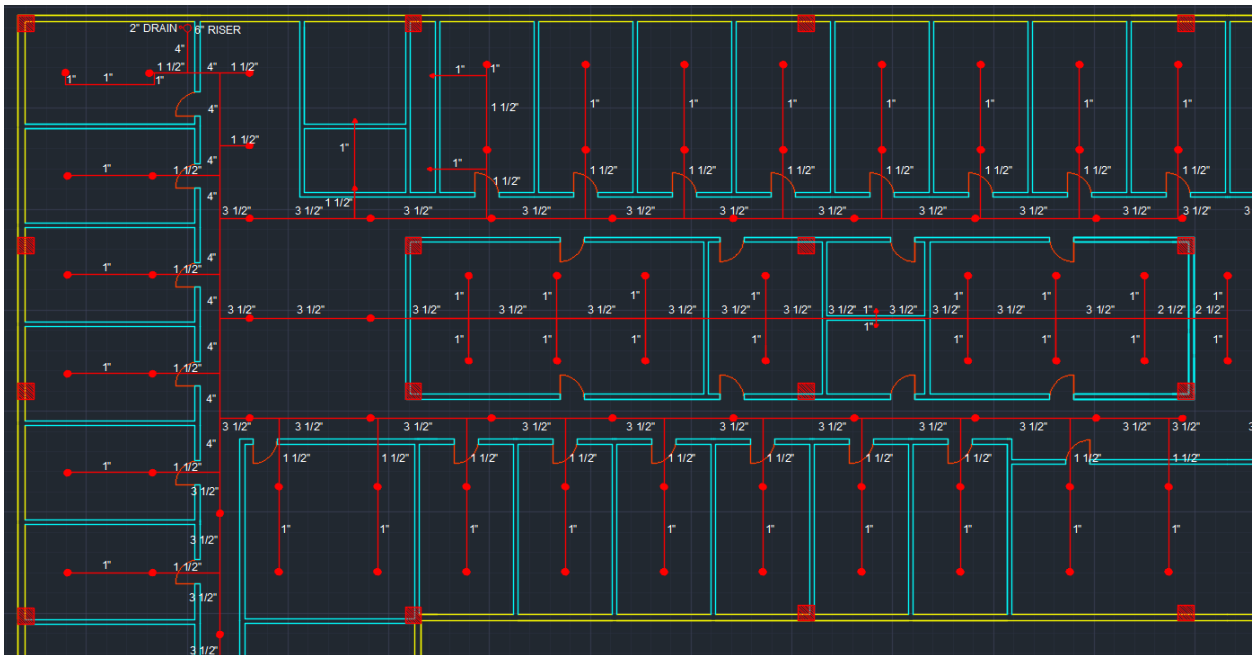


Figure 4: Sample of Sprinkler Design Drawings

6.0 Structural Design for Gravity Loads

The following section discusses the decision-making processes that went into the selection of governing load values for the structural design of the academic building. Applicable loads were extracted from Chapter 16 Section 1607 (Live Loads) of the 2015 IBC. Based on the types of spaces incorporated into the building, several different live load values were gathered leading to a lot of variation throughout the system. In order to simplify the design process in a conservative manner, it was decided to design members based on the governing live load for each level. These loads can be seen in Table 8.

Table 8: Governing Live Load Values

System Component	Governing Live Load	Load Value (psf)
Roof	Snow	55
Third/Second Floors	Above Corridor	80
First Floor	First Floor Corridor	100

As prescribed in ASCE 7, a reduction to the uniformly distributed live load was applicable for members supporting substantial tributary area. This applied, however, to only the floor elements. It was noticed that although the applied loads for the floors were greater in magnitude than those for the roof, this live load reduction for the floors actually led to the beam sizes for the roof matching some of those for the floors when looking at the outer 35-foot span sections.

Moving to dead loads, research was conducted to determine the values to be used for the essential slab and deck elements. When calculating the load for the concrete slab the standard 4-inch thickness was used (Concrete Construction, 2018). It was decided to use three-inch metal deck for both the roof and floors. The Vulcraft Steel Deck Catalog was referenced in order to determine which specific type of deck to use for each. 3-inch decking was used for floors and applied to the roof design as well for consistency. This is supported by Figure 5 from *The Architect's Studio Companion* which shows that a 3-inch deck suffices for a span range of about 8 to 16 feet, encompassing the beam spacing of the designed roof system (9.33ft-11.50ft). Specific decking was selected based on member spacing and loading parameters. The spacing selected to determine the decking was the greatest beam spacing in the structural system (11'-6") for both the roof and floors. For the roof, the 3N19 deck was selected since it had an allowable load of 59 psf for one span with spacing of 11'-6" as it sufficed when compared to the governing load of 55 psf as seen in Figure 6. For the floors, the 3VLI22 composite deck was selected based on the superimposed live load of 97 psf for the 3-inch thickness and 11'-6" spacing as shown in Figure 7. Although the greatest floor live load was 100 psf, the concrete used for floor slabs was

115 pcf rather than the 145 pcf the Vulcraft values correspond to which provided sufficient conservativity.

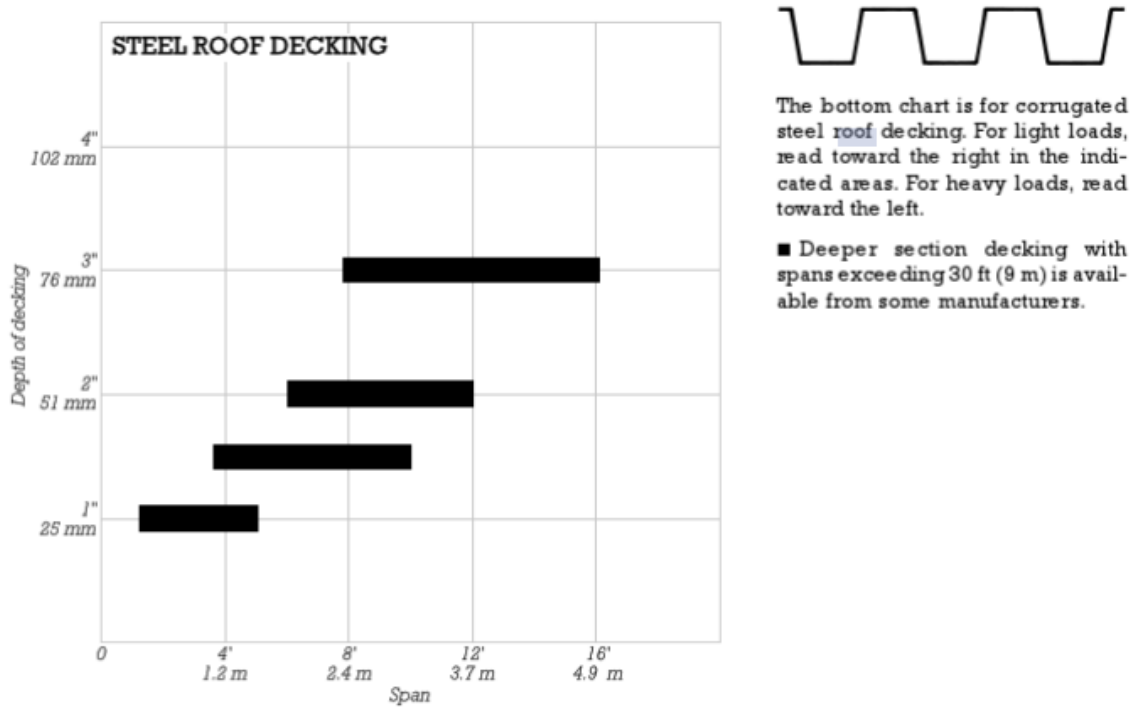


Figure 5: Typical Span-based Depths for Steel Roof Decking, The Architect's Studio Companion

VERTICAL LOADS FOR TYPE 3N

No. of Spans	Deck Type	Max. SDI Const. Span	Allowable Total Load (psf) / Load Causing Deflection of L/240 or 1 inch (psf)										
			Span (ft.-in.) ctr to ctr of supports										
			10-0	10-6	11-0	11-6	12-0	12-6	13-0	13-6	14-0	14-6	15-0
1	N22	11'-7"	50 / 43	46 / 37	42 / 32	38 / 28	35 / 25	32 / 22	30 / 20	28 / 18	26 / 16	24 / 14	22 / 13
	N20	13'-2"	66 / 56	60 / 48	55 / 42	50 / 37	46 / 32	42 / 28	39 / 25	36 / 23	34 / 20	31 / 18	29 / 16
	N19	14'-7"	79 / 69	71 / 59	65 / 51	59 / 45	55 / 40	50 / 35	47 / 31	43 / 28	40 / 25	37 / 22	35 / 20
	N18	15'-11"	91 / 81	82 / 70	75 / 61	69 / 53	63 / 47	58 / 42	54 / 37	50 / 33	46 / 30	43 / 27	40 / 24
2	N16	18'-6"	118 / 110	107 / 95	97 / 83	89 / 73	82 / 64	75 / 56	70 / 50	65 / 45	60 / 40	56 / 36	52 / 33
	N22	13'-8"	56 / 122	51 / 105	47 / 92	43 / 80	39 / 71	36 / 62	34 / 55	31 / 50	29 / 44	27 / 40	25 / 36
	N20	15'-6"	72 / 152	65 / 131	60 / 114	55 / 100	50 / 88	46 / 78	43 / 69	40 / 62	37 / 55	34 / 50	32 / 45
	N19	16'-11"	86 / 182	78 / 157	71 / 137	65 / 120	60 / 105	55 / 93	51 / 83	47 / 74	44 / 66	41 / 60	38 / 54
3	N18	18'-1"	98 / 211	89 / 182	81 / 158	74 / 139	68 / 122	63 / 108	58 / 96	54 / 86	50 / 77	47 / 69	44 / 62
	N16	20'-4"	123 / 276	112 / 238	102 / 207	93 / 181	86 / 159	79 / 141	73 / 125	68 / 112	63 / 100	59 / 90	55 / 82
	N22	13'-8"	69 / 95	64 / 82	58 / 72	53 / 63	49 / 55	45 / 49	42 / 43	39 / 39	36 / 35	34 / 31	31 / 28
	N20	15'-6"	90 / 119	81 / 103	74 / 90	68 / 78	63 / 69	58 / 61	53 / 54	50 / 48	46 / 43	43 / 39	40 / 35
	N19	16'-11"	107 / 143	97 / 123	89 / 107	81 / 94	75 / 83	69 / 73	64 / 65	59 / 58	55 / 52	51 / 47	48 / 42
	N18	18'-1"	122 / 165	111 / 143	101 / 124	92 / 109	85 / 96	78 / 84	72 / 75	67 / 67	63 / 60	58 / 54	55 / 49
	N16	20'-4"	154 / 216	139 / 186	127 / 162	116 / 142	107 / 125	99 / 111	91 / 98	85 / 88	79 / 79	74 / 71	69 / 64

Figure 6: Selection of Metal Roof Deck, Vulcraft Steel Deck Catalog

(N = 9.35) NORMAL WEIGHT CONCRETE (145 PCF)

TOTAL SLAB DEPTH	DECK TYPE	SDI Max. Unshored Clear Span			Superimposed Live Load (PSF) Clear Span (ft-in.)														
		1	2	3	7'-0	7'-6	8'-0	8'-6	9'-0	9'-6	10'-0	10'-6	11'-0	11'-6	12'-0	12'-6	13'-0	13'-6	14'-0
		SPAN	SPAN	SPAN															
5.00 (t=2.00) 45 psf	3VLI22	10'-0	10'-9	11'-1	216	195	176	161	148	137	127	90	83	76	70	64	59	54	50
	3VLI20	11'-8	12'-5	12'-10	241	216	196	178	163	150	139	129	121	113	78	72	66	61	57
	3VLI19	12'-3	13'-11	14'-4	265	237	214	194	178	163	151	140	131	122	115	79	73	68	62
	3VLI18	12'-7	15'-2	14'-9	289	261	238	218	201	186	173	161	151	142	134	127	92	86	80
5.50 (t=2.50) 51 psf	3VLI16	13'-4	15'-3	15'-7	327	294	267	243	223	206	191	178	167	156	147	139	132	96	89
	3VLI22	9'-6	9'-11	10'-7	247	222	201	184	169	156	113	103	94	87	80	73	67	62	57
	3VLI20	11'-3	11'-11	12'-4	275	247	223	203	186	171	159	148	138	97	89	82	76	70	65
	3VLI19	11'-10	13'-4	13'-9	302	270	244	222	203	186	172	160	149	139	98	91	84	77	71
6.00 (t=3.00) 57 psf	3VLI18	12'-3	14'-6	14'-4	330	298	271	248	229	212	197	184	173	162	153	112	105	98	92
	3VLI16	12'-11	14'-7	15'-1	373	335	304	277	255	235	218	203	190	178	168	159	117	109	102
	3VLI22	9'-2	9'-2	10'-2	277	249	226	206	190	140	127	116	106	97	89	82	76	70	65
	3VLI20	10'-9	11'-5	11'-10	309	277	250	228	209	193	178	166	119	109	100	92	85	79	73
6.00 (t=3.00) 57 psf	3VLI19	11'-7	12'-9	13'-2	339	304	274	249	227	209	193	179	167	156	111	102	94	87	80
	3VLI18	11'-11	13'-11	14'-0	370	334	304	279	257	238	221	207	194	182	136	126	118	110	103
	3VLI16	12'-7	14'-0	14'-6	400	376	341	311	286	264	245	228	213	200	189	178	132	123	115

Figure 7: Selection of Composite Floor Deck, Vulcraft Steel Deck Catalog

The exterior enclosure was another element that had to be addressed for the design of the exterior beams and girders. It was determined the exterior facade would be composed of brick to comply with the standard design of campus buildings. The team referred to *The Design of Wood Structures - Appendix B: Weight of Building Materials* (Breyer, 2015) which provided a value of 38 psf. This was factored by an average wall height of 15 ft for each floor of the structure to get an exterior enclosure value of 570 lb/ft.

Stairways and elevators were unique live loads that required extended research and calculations to determine the resultant loading. Once the new framing plans were set so the beams would no longer interfere, it had to be determined what the implications of the beam loading would be. The bays containing the egress stairs contained two components. First was the distributed loads on the new north-south spanning beams. The design of these beams was the same process as the standard vertical beams. Complications arose when it came time to look at the vertical beams the horizontal ones were connected to. These were unique because on one side was the connected beams from the stairway and on the other was the uniform floor loading. While the situation as a whole was unique, when broken down it was two scenarios that had already been analyzed. Figure 8 shows an example illustration of the altered framing of one of these bays.

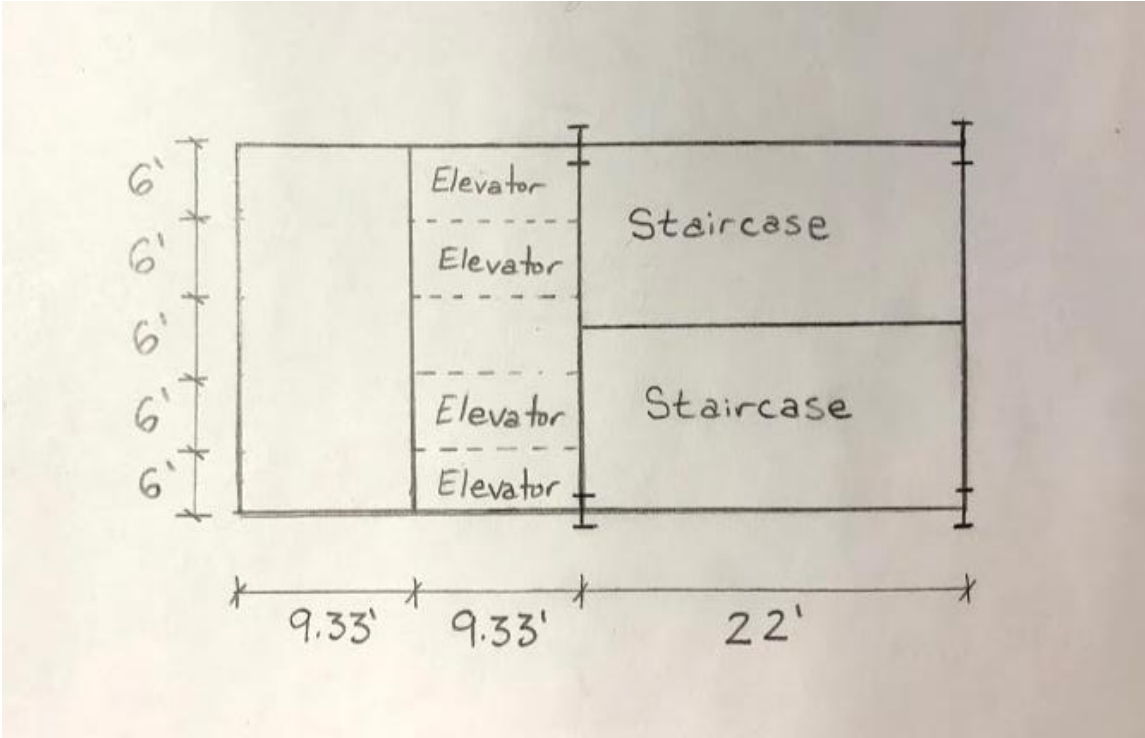


Figure 8: Example Framing Plan Around Staircase and Elevators

After the completion of the bays for the egress stairwells, design moved to the main stairway. While the main stairway only utilized one E-W beam, making its design more simple than the egress stair, the N-S beams it was connected to posed many questions to be answered. On the other side of these beams were the building elevators along with a small HVAC closet. Elevators are a design topic the team had little experience with. An illustration of this frame can be seen in Figure 9. IBC does not give details on the loading from elevators, but directs readers to the use of ASME A17.1/CSA B44 (ASME, 2016). Consulting with this resource led to the finding of Figure 10 which gives a graph for design concentrated load vs. area. While the original floor plan had the elevators as approximately an 12.5ft by 12 ft area, this graph only gives loads up to a 54 sq. ft. area. Beam spacing in this section of the building was set to be 9.33 ft, so the additional 3.5 ft of elevator was cut back to allow for an entryway to the elevators. Additionally, in order to comply with the 54 sq. ft. max area found in ASME the elevator was cut in half to form two elevators with 9 ft by 6 ft dimensions.

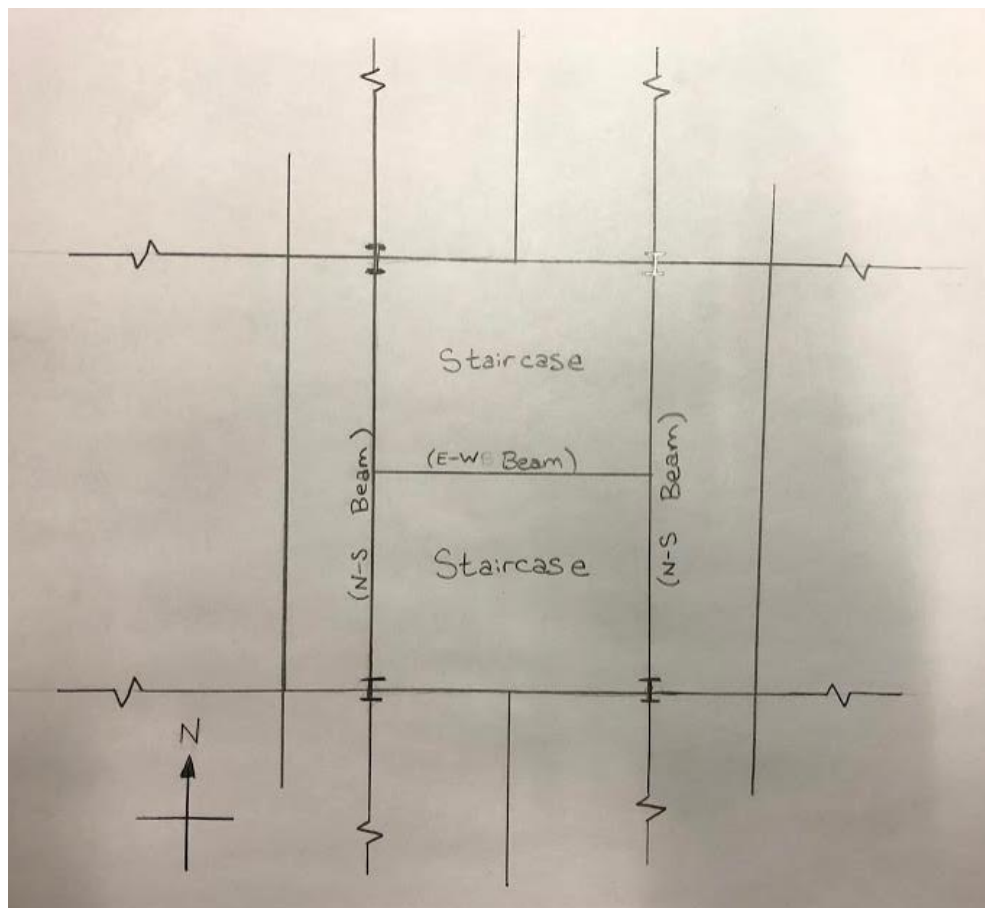


Figure 9: Main Staircase Framing Plan

With the loads of the elevators determined it had to be considered how to apply them. All other loads in the building were used as distributed loading per foot of beam, now the elevators are a concentrated live load. In order to be conservative with the beam design it was decided to place the concentrated loads at the points that would cause the greatest moment and deflection in the beams. Along with these concentrated loads from the elevators and the supporting beam from the main staircase there was a small partially distributed load from the HVAC closet. Once all of the loads and deflections on this beam had been determined and combined, the final deflection was arrived at. While typical deflection limits are $L/240$ or $L/360$, depending on load types, for beams supporting elevators the maximum allowable deflection is considered $L/1666$ (Tornquist, 2014). This led to the need to increase the beam size beyond that needed for bending strength due to the need for a greatly increased major axis moment of inertia I_x value.

ASME A17.1-2007/CSA B44-07

Fig. 8.2.1.2 Minimum Rated Load for Passenger Elevators

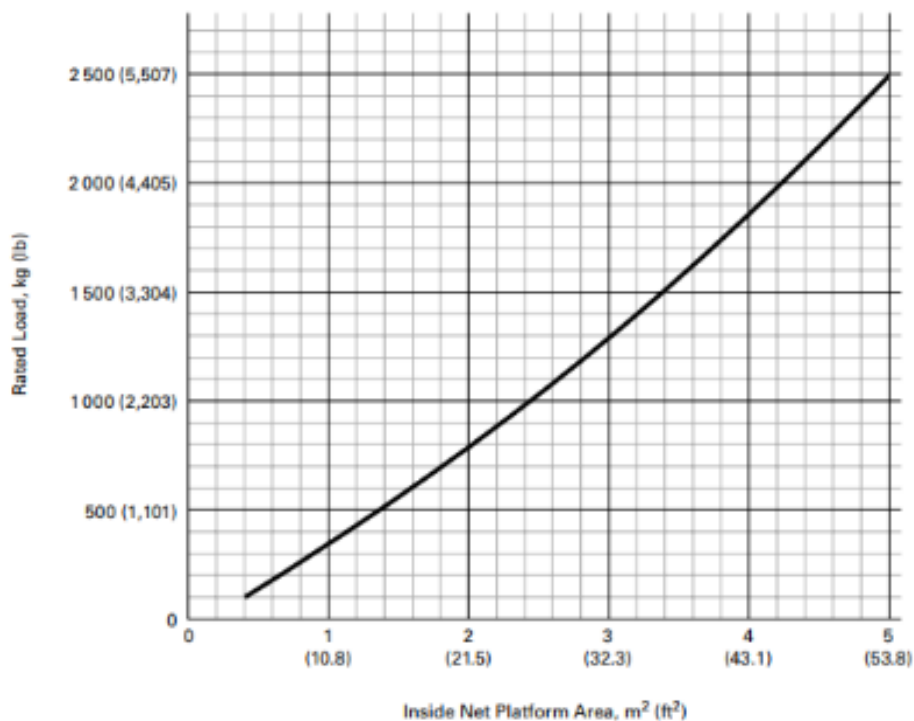


Figure 10: Safety Code for Elevators and Escalators, ASME A17.1-2007 pg 242

7.0 Design of Academic Facility

The major focus of this project was the structural design of the new buildings to be erected on the Salisbury Estates property. This chapter details the structural designs the team completed for this part of the project.

7.1 Roof/Floor Beam and Girder Design

In order to understand where to begin for the sizing of members, *The Architect's Studio Companion* (Allen, 2005) was referred to for typical member sizes based on system characteristics. The design was carried out from the top-down, directing attention to the roof first. Load Resistance Factor Design (LRFD) was used to design the members, and an Excel spreadsheet was designed to assist in this iterative process for most members. A copy of the Excel spreadsheet used and hand calculations showing specific steps during the design process can be found in Appendix G.

A truss system was considered initially due to it being a more structurally efficient design than a beam-and-girder system. Referring to Figure 11 – the Structural Steel Truss) guidelines within the *Companion* – exposed the need for deep truss systems in order to span the large buildings proposed. This would cause issues with the zonal height restrictions discovered in preliminary research; therefore, it was decided to design the roof with beams and girders similar to the floors.

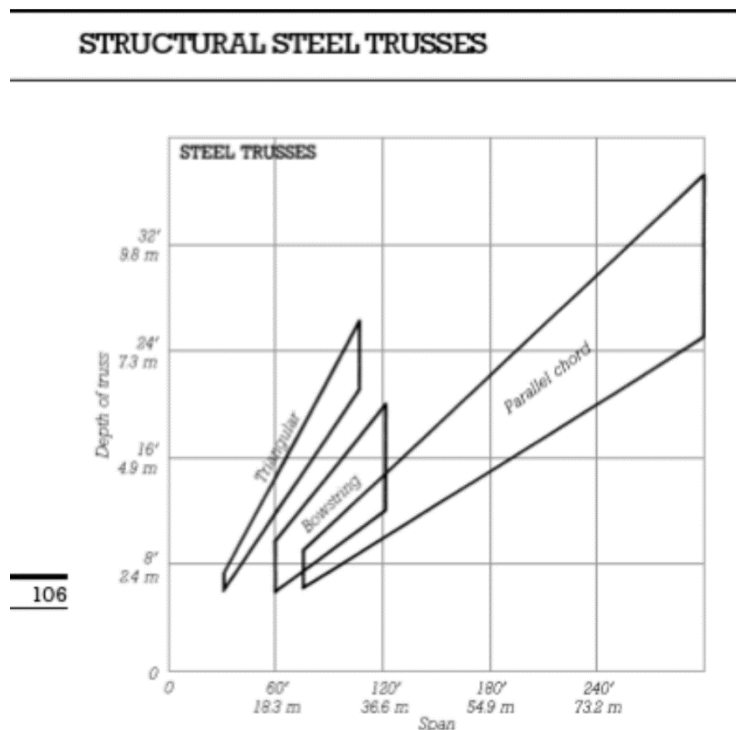


Figure 11: Typical Span-based Depth for Steel Trusses, *The Architect's Studio Companion*

The approach for design of the floor members was considered next. The team referred to Figure 12 specifying typical span ranges for different types of structural systems. This provided a basis for the limitations on span lengths, which aided in the placement of columns and connecting elements in the systems.

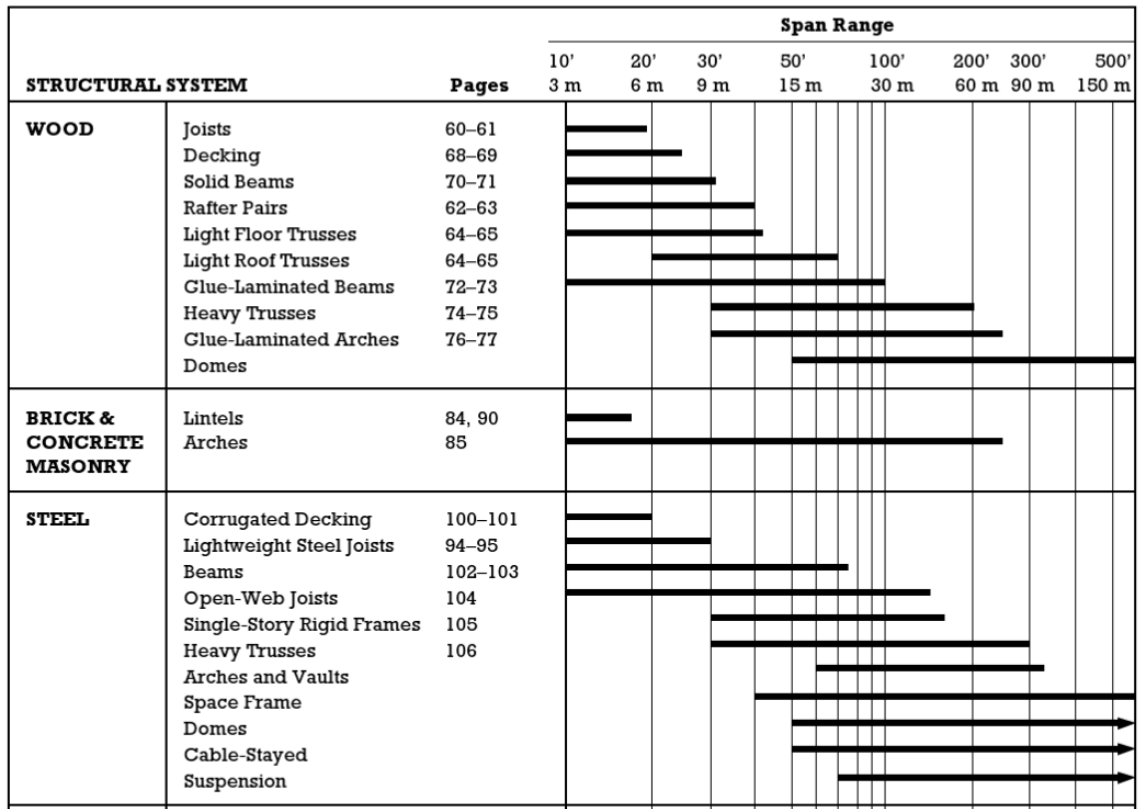


Figure 12: Span Ranges for Structural Systems, *The Architect's Studio Companion*

The greatest difficulty when designing the framing plans came in the bays containing staircases and elevators. In these bays the beam spacings and layouts had to be adapted so as not to interfere with the stairs and elevators. A boxing in approach to the stairwells was decided upon after consulting framing plans from Gateway as shown in Figure 13.

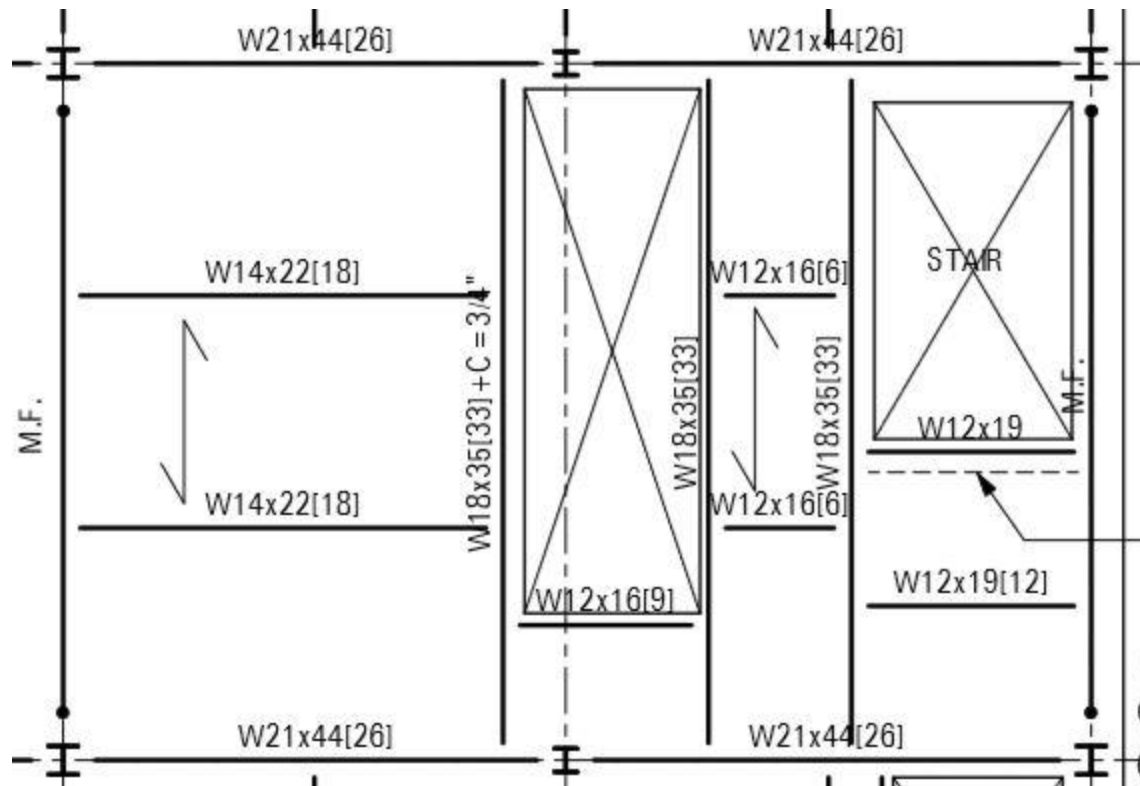


Figure 13: Level Two Framing of WPI Gateway Park, Gateway Building Plans

Doing this raised the need to adapt the Excel spreadsheets used in the assistance of the member sizing to reflect the loading differences. While the elevators themselves did not cause the need to adjust any framing plans, they were looked at carefully and determined to not be in the path of any desired beam locations. Bays with staircases however required an adjustment of beam location. These adapted framing plans can be seen in Figures 14 and 15.

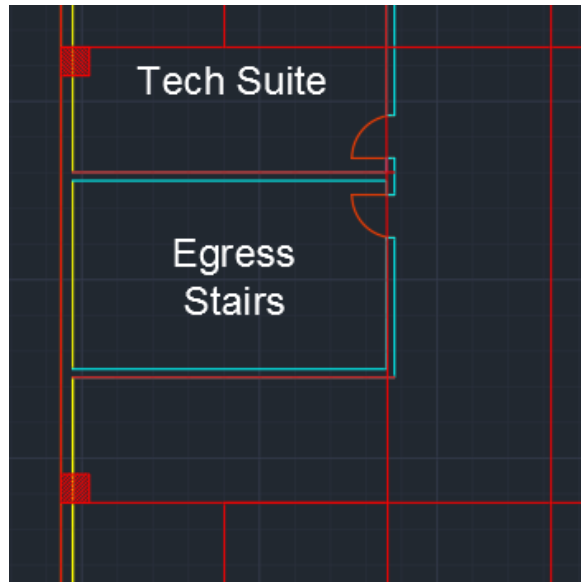


Figure 14: Special Framing Around Egress Staircase

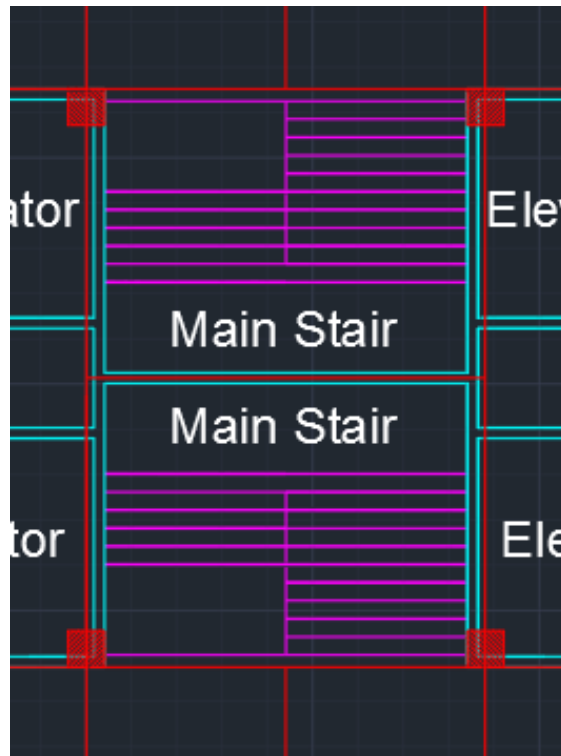


Figure 15: Special Framing Around Main Staircase

During design it was decided to cope the beam flanges for necessary connections. One final consideration when choosing the final member sizes was the debate between efficiency versus ease of construction. There were many different size members that were deemed usable in

certain areas of the building. In cases where the beam sizes changed frequently it was decided to size up some of the members in order to provide a more repetitive construction. This could also lower costs in some cases, even though more steel is being used, because there are less uniquely sized members being ordered. However, instances where there were many of the same size beam before a change it was determined not to size up the smaller members due to great increase in weight and lack of cost benefit.

7.2 Columns

Following the design of the beams and girders, the sizing of columns was addressed. Prior to the start of calculations, design considerations about the loading acting on the column had to be confronted. These considerations consisted of two primary components: the selection of the governing loading combination and the selection of the specific column to be used for design. Various loading cases from ASCE 7 were evaluated to determine which combination resulted in the greatest load. Additionally, due to the inconsistent column placement throughout the building, eight different bays consisting of varying tributary areas were investigated. Design loads acting on each bay were conservatively deemed consistent for ease of calculations, however bays along the exterior of the structure included the weight of the exterior enclosure. It was determined that Bay D, shown in Figure 16, with the largest tributary area resulted in the largest axial load, despite the lack of exterior enclosure and its added weight.

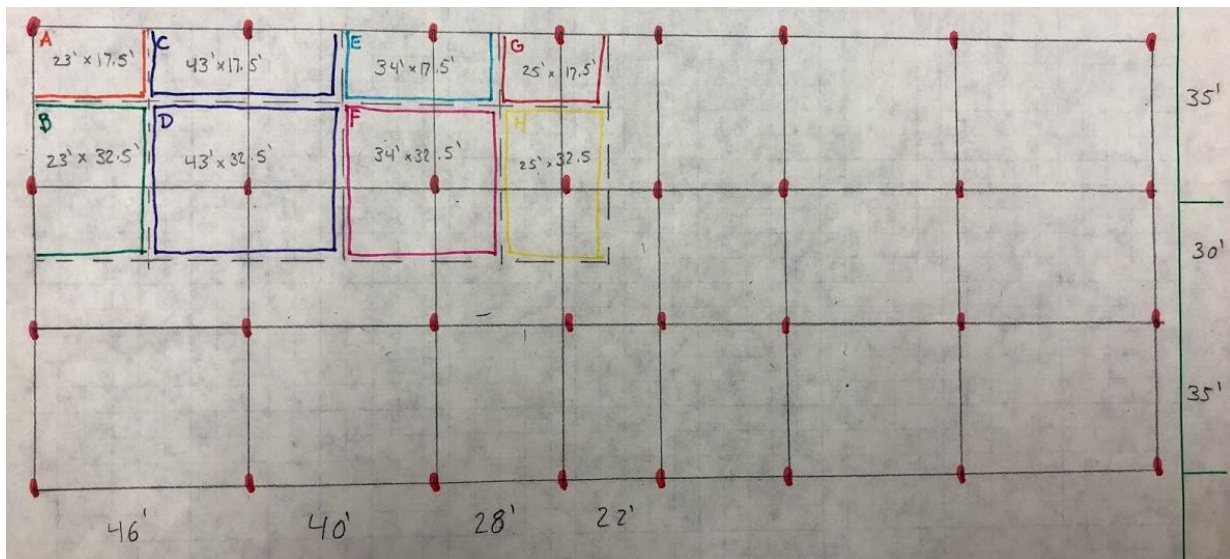


Figure 16: Column Bays Investigated for Design

Column sizing was carried out for the column located on the first floor of Bay D. The first-floor column within the largest bay was chosen to represent the highest amount of loading acting on a column anywhere within the structure. Once sized, it was decided that the selected section was to be used for every column within the entire building for ease of construction.

Design calculations and an accompanying Excel document utilized in design can be found in Appendix H.

7.3 Design of the Lateral-Load Resisting System

In order to design the lateral-load resisting systems of the structure, both seismic and wind loads were addressed. The seismic design rating was initiated. Beginning with the determination of the mapped spectral acceleration for short periods (S_s) and the mapped spectral accelerations for 1-second intervals (S_1) values for the City of Worcester. The S_s and S_1 values for all towns and cities in Massachusetts can be found in the 9th Edition Amendment to the *Massachusetts State Building Code*. The seismic design categories and site classifications were defined based on equations found in ASCE 7, from there, the risk category was determined as risk category IV, site class C, which is the most detrimental scenario of seismic activity that the Salisbury Estates geographical location can be exposed to.

Lateral reinforcement was designed for the corner bays of the structure as they are composed of the largest N-S and E-W members and will brace the largest deflection points. The N-S face of the structure was addressed first. Design for seismic loading was carried out initially. Data that was determined through the methods described above were input into a seismic base shear and vertical shear distribution Excel spreadsheet formed based on ASCE 7 requirements, seen in Appendix I, that was used to organize and evaluate seismic base shear and vertical shear distribution. The expected seismic forces for each level of the structure were identified and input into a RISA 2D model representing the three-story steel frame. Images of the final RISA 2D model can be found in Appendix L. The thought process used was that the psf force values calculated using the Excel document could be applied to applicable areas of the wall faces of the structure.

The team tested the loading case that resulted in the greatest stresses and deflections on the structure. This same process of evaluating the resulting deflections was executed for wind loads to determine whether seismic or wind would be the governing lateral force condition. The accompanying Excel document used to aid in the determination of wind loads can be found in Appendix J. Greater deflections were noticed under seismic loading conditions, therefore the bracing was designed for these cases. Bracing was then added and iteratively adjusted until deflections were within tolerable values according to the drift analysis Excel document as seen in Appendix K. This same process was carried out for the E-W section. The final bracing member sizes can be seen in Table 9.

Table 9: Lateral Reinforcement Member Sizes

Structure Face/Section	Lateral Reinforcement Member Size
N-S (35-foot) section	W12x14
E-W (46-foot) section	W10x12

7.4 Footings

The first step in designing the footings for the foundations system was to design the steel baseplates to transfer loads from the structural steel columns to the supporting concrete elements. In order to determine how much force was to be supported, the column axial loads had to be addressed. These were determined by referencing the Excel spreadsheet used for column design and identifying the greatest resultant vertical axial force. This was simplified since the columns were designed to be the same size (W12x72) throughout the structural system. Since the proposed building did not include the design of a basement level, it was decided that the use of pedestals between the baseplates and footings was unnecessary.

The area of the baseplates had to be designed to assure the concrete footing can withstand the forces being transmitted through the baseplate. Bearing pressure for normal weight concrete was used in these calculations as that will be used for the footings. Once the baseplate area required based on this maximum bearing pressure was determined, dimensions were chosen to meet this requirement while minimizing and normalizing the moments created by them. Moments resulting from the pressure on the edges of the baseplate determine the thickness required for the baseplates. For this reason minimizing the moments will result in a thinner baseplate and a lower-cost structure.

The connections between the baseplates and footings then had to be designed. To determine the required area of the connecting bolts, 0.5% of the baseplate area was calculated, based on the parameters of the *Design of Concrete Structures* (Darwin, 2016). Due to OSHA requirements there will be four anchoring bolts, one in each corner. Therefore, required area of bolts was divided by the minimum of four bolts to determine bolt sizes. From here, Table J3.4 of the AISC Steel Manual was referenced to identify the minimum required spacing between the center of the connecting bolts and edge of baseplate.

The final component to design was footings. Based on column placement throughout the framing system, the maximum footing size allowed to avoid overlap 30'x22'. To determine the area of footing actually required, the soil bearing pressure of the Salisbury Estates site had to be assessed. The soil type was found to be silty sand with a corresponding soil bearing capacity of 3000 psf (NRCS) (Concrete Network, 2015). Assuming a footing depth of five ft, the effective

bearing capacity then had to be addressed taking into account the depth and density of the concrete. Required footing area was then determined using the loads and effective bearing capacity. With the baseplate and footing dimensions determined the footing's effective depth was calculated using the nominal punching-shear strength along with the factored shear force. After ensuring that the footing withstands beam-shear and bearing, the bending moment was used to determine the reinforcement required by for the footings. Final sizes and reinforcement values can be seen in Table 10. Due to dimensional constraints from the bar diameters, required spacing, steel cover width, and concrete casing the number of reinforcing bars was increased to allow for a uniform distribution. Detailed drawings of the baseplate and footing designs, accompanied by their calculations, can be located in Appendix M.

Table 10: Baseplate and Footing Dimensions and Reinforcement

	Base Plate	Footing
Size	16"x12"x1.5"	20'x20'x5' ⁽¹⁾
Reinforcement		
Size	No. 5	No. 18
Quantity	4	192 (6 layers of 32)
Spacing	1" in from corners	5.25" between 1" between layers

⁽¹⁾ : 5 foot thickness was based on a conservative assumption

8.0 Cost Analysis

Although the structural design was the focus of the project, assessing cost was an important addition. Cost estimates were calculated for both the demolition of the existing Salisbury Estates and the construction of the new proposed facilities. All estimates for cost were executed using data taken from RSMeans; specifically the *RSMeans Building Construction Costs* data and the *RSMeans Square Foot Costs* data (Gordian, 2018).

8.1 Demolition of Existing Site

The cost of developing the Salisbury Estates complex involves not only the construction of the facilities, but also the demolition of the existing site beforehand. The team was supplied with information on the existing Salisbury Estates by The WPI Facilities Department. Through referencing these documents, it was found that the complex consists of 108 units, each about 850 square feet. Using an assumed average height of 25 feet to each unit (gathered from previously visiting the site), a cost per cubic foot of space was taken from *RSMeans Building Construction Costs* data to estimate the demolition cost of the site to be about \$800,000 (Gordian, 2018).

8.2 Construction of New Site

A cost estimate for the designed structures was developed in three parts. First, an estimate for the structural system of the building was developed by calculating the cost based on unit cost values per linear footage of each member section in the building. Certain member sizes used within the building were not listed in the RSMeans data. When this was the case, the next largest section listed in the data was selected and costs for the larger section were used in place of the missing data. Specific members for which this occurred are listed in Table 11. A comprehensive list of all section sizes and associated costs can be found in Appendix N.

Table 11: RSMeans Upscaled Member Sizes

Structural Sections			
Structural Element	Specific Section	Section Data Used from RS Means	Unit Cost per L.F.
Beam	W14x22	W14x26	42.86
Beam	W16x31	W16x31	50.34
Beam	W16x40	W16x40	64.01
Beam	W18x31	W18x35	57.53
Beam	W18x40	W18x40	64.53
Beam	W18x55	W18x55	86.87
Beam	W21x44	W21x44	69.89
Beam	W21x50	W21x50	78.39
Beam	W21x55	W21x62	96.04
Beam	W24x84	W24x84	127.8
Beam	W30x90	W30x99	149.21
Girder	W18x40	W18x40	64.53
Girder	W18x55	W18x55	86.87
Girder	W21x50	W21x50	78.39
Girder	W21x62	W21x62	96.04
Girder	W24x62	W24x62	95.65
Girder	W24x68	W24x68	104.65
Girder	W24x84	W24x84	127.8
Girder	W30x90	W30x99	149.21
Girder	W30x108	W30x108	162.21
Girder	W33x99	W33x118	177.33
Girder	W33x130	W33x130	194.52
Girder	W36x135	W36x135	201.35
Girder	W36x182	W36x194	287.56
Girder	W40x149	W36x150	223.35
Gider	W40x167	W36x170	252.45
Column	W12x72	W12x87	130.89
Lateral Brace	W12x16	W12x16	28.96
Lateral Brace	W12x22	W12x22	37.46

The sprinkler system cost estimate was calculated on a square foot basis at \$3.00 per square foot for brand new construction. The fire alarm system cost estimate was calculated on a square foot basis at \$2.00 per square foot for brand new construction (Tyco, 2017). The fire protection costs were determined for both the academic and residential buildings based on the same cost per square foot basis. Table 12 shows this cost breakdown.

Table 12: Fire Protection Costs

Academic Building	Residential Building
Total Square Footage 75000	Total Square Footage 104100
Sprinkler system cost \$225,000.00	Sprinkler system cost \$312,300.00
Fire alarm cost \$150,000.00	Fire alarm cost \$208,200.00

Following the cost estimate for the structural system and fire protection system, costs for various finishes to the building were calculated through the use of *RSMMeans Square Foot Costs* data. A list of all non-structural specific line items that were investigated can be found in Appendix O.

8.3 Final Cost

After summing both structural and non-structural elements of the academic building, two final costs for the construction of the building were found. Throughout calculations, costs for each element were found for the cost of material plus labor. In addition to this, the cost of overhead and profit that the contractors would likely charge for their services was added in to the total cost for a second estimate. For each of these estimates, a cost per square foot was calculated as well. Table 13 shows these final cost estimates.

Table 13: Total Academic Building Cost Estimate

Total Cost	Total Cost + O&P
\$19,550,151	\$19,953,118
\$260.67 per S.F.	\$266.04 per S.F.

9.0 Conclusions and Recommendations

This section will discuss what was completed throughout the course of this project in order to satisfy the team's capstone design requirements. This will include the process to go from our initial ideas of the project, through the research required, and to the final design, fire protection and life-safety analysis, and cost estimations. Following this conclusion will be recommendations on what could have been done differently for the project along with what future teams could look at for a continuation of our project.

9.1 Academic Building Conclusion

Upon completion of preliminary research and site layout design, the team moved forward with the floor layout design, structural design (using LRFD design), fire protection and life safety design, and cost estimation for the academic building. The floor layout design was finished first as it allowed for an accurate and desirable placement of columns to minimize interference within the floor space. Using beam and girder sizing design aids, the allowable distance separating the columns was determined and member lengths were chosen.

The life safety analysis was conducted while the architectural drawings were being finalized to ensure there was sufficient egress space from the building as well as proper door swing with respect to occupant load in each room of the building. Following this, fire protection plans were made in the form of AutoCAD plans for the installation of a fully automatic sprinkler system.

Once the bay sizes were determined, ASCE 7 was used to determine design loads for sizing of members. The team took a top-down approach to size members, starting with the roof bays, followed by the second and third floors, and ending with the first floor. With beams and girders sized and self-weights determined, the columns supporting these bays were then designed. The final part of developing the framing plan was the design of lateral bracing in the corner bays. With the framing designs completed, the team moved to foundation design. Due to the lack of a basement in this building, the foundation design involved simple baseplates and footings for each column. While the team completed the structural design of member sizes for this building, there was not enough time to design all of the system connections. Given more time, the team would have carried out typical connection design for the academic building.

In order to develop an accurate cost estimate for the building, cost data from RSMeans publications was used along with estimated fire protection costs. Following the completion of the structural design, cost data from RSMeans publications was consulted for costs per linear foot of all structural members. In addition to these linear foot values, all nonstructural elements were estimated with cost per square foot values. The final cost added was a standard cost per square foot value for the sprinkler system.

9.2 Residential Building Extrapolation

The team used their findings from the design of the academic structure to extrapolate an estimated cost for the construction of the residential building. The extrapolation of cost was calculated by multiplying the cost per square foot of the academic building by the total square footage of the residential building. Table 14 shows these estimates.

Table 14: Total Residential Building Cost Estimate

Total Cost	Total Cost + O&P
\$27,135,747	\$27,694,764

It should be noted that these cost estimates are based off the calculations of an academic facility and adjustments should be made to these figures to reflect a more accurate cost of a residential facility. Within the construction of a residential space, certain costs exist that would not be present in an academic setting. Included in these are additional plumbing fixtures such as shower stalls and a greater number of toilets to meet increased demand. Furthermore, added security features would like be included in the construction of a residential facility such as optical sensors in the hallways. Additionally, in the preliminary design for the residential building, there was the inclusion of a dining facility located on the first floor of the structure. This facility would likely raise the overall cost of the proposed residential building.

The elements included in the final cost for each building are structural, life safety, and occupancy code necessities. The cost estimate does not include furnishings for either building. It should be noted that due to the difference in use of each of these buildings, costs associated with these furnishings would likely create a further disparity in cost.

9.3 Recommendations

Based on the team's finishing point for this project, it is recommended that a future team continue this project further focusing on the aspects to be discussed herein. A future team should spend the time to research the connection design for the framing in the residential building. With framing connections designed, the team could then go forward to complete the structural and fire protection design of the residential building and not have to rely on extrapolation. Aside from the structural design of the buildings, there could be more in-depth fire protection design throughout. The main focus for the fire protection was the sprinkler systems and egress design requirements. A future team could go further with this by completing life safety plans including emergency light, exit signage, evacuation plans, fire alarm drawings (including location of smoke detectors), horn/strobe devices, manual fire alarm pull station locations, and fire extinguisher placement. The last recommendation is to develop a LEED certification plan for the buildings' construction and fixtures. Sustainable development is becoming a very important aspect for new structures in

today's industry. WPI has also focused on this for its new buildings, so this could be a relevant aspect to look more into.

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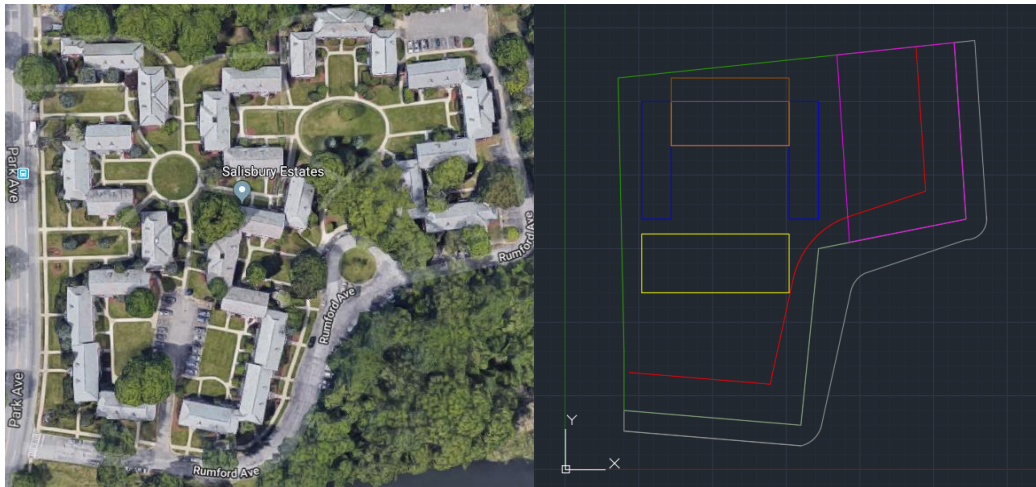
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Appendix A: Final Proposal



Redesign of Salisbury Estates



Major Qualifying Project Proposal

Presented by:

Zachary Abbott, Mark DellaCroce, Dylan Felty, & Tyler Kornacki

Presented to:

Professor Leonard Albano and the Worcester Polytechnic Institute Civil Engineering Department in partial fulfillment of the requirements of the Degree of Bachelor of Science

2018-2019

Abstract

With the Worcester Polytechnic Institute (WPI) undergraduate student body growing every year, there is a need for expansion of on-campus space. The apartment complex of Salisbury Estates serves as an outlet to help provide this necessary accommodation, but the poor conditions of the site have become recognized more-so, presenting the need for development of the site. Through interviews with WPI staff and preliminary research on site restrictions and design criteria, alternatives will be assessed and a layout will be decided upon. The floor plan and framing plan composing the proposed facilities will then be developed and structural design and analysis of the required beams, columns, and footings will be performed in accordance with relevant specifications. A life safety analysis addressing egress will also be performed before a cost analysis is executed to estimate demolition, construction, and labor costs. Deliverables will include the structural calculations carried out for design, models of plans and renderings, and a cost estimate, all of which will be presented with a final report and poster.

1. Introduction:

The following proposal is derived from what Worcester Polytechnic Institute (WPI) lacks most in terms of infrastructure on campus. This proposal offers a solution to the current housing and classroom space shortages that will only become more of a concern as incoming class sizes continue to increase. The comprehensive redesign of the Salisbury Estates property will involve the demolition of all existing buildings, roadways, paths, and landscape to allow for a new complex of large residential and academic buildings as well as an additional dining facility. A report will include a digital model of the proposed buildings, a site plan for the entire site, and a full cost estimate. This will also demonstrate the significant addition of classrooms, common areas, dormitories, and parking spaces provided to accommodate the growing undergraduate population. Areas of depth will include structural design and analysis as well as life safety and fire protection, all of which will be addressed in accordance with applicable codes and standards.

The residential building design will include meeting spaces and large common areas as well as tech suites. These functional spaces will promote collaboration and increase the appeal of the complex. The design will incorporate housing for several hundred students within a two resident per unit style dormitory facility. The first floor will also include a dining area and a connecting lounge area available to WPI members. The separate academic building design will include a mixture of lecture halls, classrooms, and offices in order to appeal to the several needs of the institution and create a greater draw to the development.

More parking will be required to accommodate the new users of the facilities. It will be undesirable to erect an entire parking garage for this purpose. Therefore, the parking will be kept similar to its current style with street and lot parking. Salisbury Estates occupies a substantial amount of land, some of which will remain available for development outside of the building construction. A balance will be determined regarding what is developed into parking and what is left alone so as to form an open, green space that connects the facilities similar to the Quadrangle on campus currently. In addition to providing students a safe place to go outside and enjoy leisurely activities, this open space will also provide opportunity for further development in the future if necessary.

2.0 Background:

Several factors must be considered for the design of a new structure. The current site will be assessed to determine property lines and land conditions. The design will be developed with input from WPI faculty and staff to ensure that the wants and needs of the University are considered. Code research will be conducted to ensure that the proposed buildings will be designed in accordance with applicable codes and standards. The project's impact on the community will be considered to ensure that the new development will fit well into the area and not cause issues with surrounding properties. Designs are only accepted if they are economically feasible; therefore, the cost of the proposed development will be assessed. Ethics is also a topic to be constantly aware of in order to ensure that items are being addressed in a correct, professional manner throughout the project.

2.1 Current Site Information

The proposed buildings will be situated within the lot of WPI's Salisbury Estates. This area is located along Massachusetts Route 122A (Park Avenue), between Salisbury Pond and the Worcester Center For Crafts as seen in Figure 1 below. For students to access this complex by foot, they must either walk along an indirect sidewalk or an unpaved and unlit path along Salisbury Pond. Alternatively, access by car is only possible through a single entrance and exit on Park Avenue (Rumford Avenue). The plot of land is quite expansive and has primarily level topography. According to flood maps from the FEMA Flood Map Service Center, this land is in an area of minimal flood risk despite its close proximity to Salisbury Pond; therefore, flooding should not be an issue.



Figure 1: Aerial view of Salisbury Estates site

In addition to the plot of land Salisbury Estates is currently on, WPI owns some additional neighboring property. The large building located between the Worcester Center for Crafts and Avis Car Rental belongs to WPI and is currently being used to store equipment for WPI Facilities. Aside from this building, all of the land between the Worcester Center for Crafts and Grove Street is under WPI control. This includes a small parking area to the north that could be expanded southward to provide additional parking and a through way for an extra access point to the property.

2.3 Design Parameters

The following sections demonstrate the technical aspects of our final building designs and what must be incorporated with respect to fire code requirements and occupancy classifications. The limiting factor for the design of the building lies in the codes, standards, and

ordinances put forth by the City of Worcester and the Commonwealth of Massachusetts. The building is to be designed according to the *2015 Edition of the International Building Code* (IBC), the *9th edition of the Massachusetts State Building Code* (MSBC), all National Fire Protection Association (NFPA) codes and their respective editions adopted by Massachusetts, and all zoning and ordinances for Worcester.

2.3.1 Zoning Requirements

Across Massachusetts, cities and towns are divided into different zoning districts that serve to regulate the use of specific plots of land and govern building characteristics across different neighborhoods and usage areas. Although the entirety of WPI’s main campus is currently zoned as Institutional (IN-S), the Salisbury Estates property is currently zoned as Limited Residential (RL-7) which presents several design restrictions that do not apply to WPI’s campus on the hill. Of significant relevance to this project are the restrictions on permitted land use, permitted dimensions, and off-street accessory parking requirements. These regulations can all be found within the City of Worcester Zoning Ordinance in Tables 4.1, 4.2, and 4.4 respectively. Table 1 below shows the major considerations associated with each regulation that were taken into account during the preliminary discussion of design alternatives.

Table 1: Design Parameters/Regulatory Considerations

Ordinance Table Number	Regulation	Consideration
4.1	Permitted Uses by Zoning District	<ul style="list-style-type: none"> ● <u>Dormitory Space</u>: Permitted under “Special Permit” ● <u>Schools Non-Profit</u>: Permitted
4.2	Permitted Dimensions by Zoning District	<ul style="list-style-type: none"> ● Maximum of three stories ● Maximum overall height of 45 feet
4.4	Off-Street Accessory Parking Requirements	<ul style="list-style-type: none"> ● 0.33 parking spaces required per dwelling unit ● Ten parking spaces required per classroom

Referring to these regulations impacted the scope of alternative designs discussed by the team. Initially, the design was to incorporate a building height of five stories; however, the

Worcester Ordinances identified that the maximum height requirement for the specified zone was only three stories. This research also provided a clearer picture of how much parking will be required based on the number and types of occupants.

Further investigation revealed that there exists a 100-foot buffer zone from the waterline of Institute Pond which means that all new construction must be set back 100 feet from the pond. If construction is desired beyond the 100-foot buffer zone, then a variance must be requested to receive permission.

2.3.2 Occupancy Classification for Residential Building and Academic Building

The team has decided to propose a three-story residential hall that will include bedrooms, common spaces, and tech suites. A dining facility will also be implemented on the 1st floor connecting the two halls in the center and extending beyond the back of the building to include a full commercial kitchen. The academic building design will incorporate offices, tech suites, classrooms, and lecture halls. The table below shows the code requirements and restrictions that must be taken into account of the proposed building designs. These occupancy classifications (shown in Table 2 below) will be important to determine the final occupant load of every space in the report of this project after final areas of the building are discussed and agreed upon.

Table 2: Design Parameters Code Implications

Occupancy in Question	Code Requirement	Code Reference
Residential Hall Occupancy Classification	Residential Group R-2: sleeping spaces of more than two dwelling units where occupants are primarily in nature, which includes dormitories.	MSBC Section 310.4.
Occupancy Separation	Group R-2 occupancies shall be separated from other accessory occupancies.	MSBC Section 508.2.4
Need for Automatic Sprinkler System	Group R occupancies shall be equipped throughout with an automatic sprinkler system.	MSBC Section [F] 420.5

Entry common space occupancy classification	Assembly Group A, a portion of a building used for gathering of persons for purposes including recreation shall be classified as Assembly.	MSBC Section 303.1
Dining hall occupancy classification	Assembly Group A-2, use of cafeterias and similar dining facilities.	MSBC Section 303.3
Commercial kitchen occupancy classification	Assembly Group A-2, associated commercial kitchens attached to a dining facility.	MSBC Section 303.3
Offices	Business Group B Occupancy	MSBC Section 302
Tech Suites	Group B Occupancy because they will be intended to hold less than 50 people	MSBC Section 302
Classrooms and lecture halls	Assembly Group A	MSBC Section 303.1

The residential spaces shall remain separate from the main entryway with the attached dining facility; furthermore, for security reasons, there must be double door vestibules with key card access from the ingress side of the building entryway to the residential areas. This is to prevent unwanted persons from entering the residential halls. The occupancy classifications will be used to calculate the occupant loads which can be present at any given time in the residential space, entryway common space, dining space, and commercial kitchen space.

2.3.2.1 Building Construction Type

The residential building can be designed with Type I or Type II construction which will ideally include a full steel structural frame with brick facade. The construction type and occupancy classifications can then be used to calculate the maximum allowable building footprint per the MSBC. Worcester Ordinances have stricter restrictions than those found in the MSBC; therefore, the Worcester Ordinances take precedence. Type I construction is defined by the use of steel, and Type II construction is defined by the use of brick or masonry. Types III, IV, and V construction includes the use of combustible materials and are therefore undesirable for use in a residential dormitory building.

2.3.2.2 Building Size Limitations

The table below shows the building size limits with respect to construction type. Since the buildings will be comprised of mainly steel structural elements, the steel is required to have a certain level of fire resistance in an hour rating system. Table 3 below shows the requirements per the MSBC; however, as previously stated, Worcester Zoning Ordinances take precedence over the MSBC.

Table 3: Design Parameters Construction Considerations

Occupancy in Question	Code Requirement	Code Reference
Building Height allowance	Unlimited for residential occupancies of Type I construction when equipped with an automatic sprinkler system	MSBC Table 504.3
Stories permissible	Unlimited under Type I construction when equipped with an automatic sprinkler system	MSBC Table 504.4
Building area allowance	Unlimited under residential occupancies of Type I construction provided the building is equipped with an automatic sprinkler system	MSBC Table 506.2

Type IA structural elements	Three-hour fire resistance rating for all structural members of the building frame	MSBC Table 601
Bearing walls	Shall have a three-hour fire resistance rating	MSBC Table 601
Roof Structure	Shall have a one-and-a-half-hour fire resistance	MSBC Table 601

2.3.2 Fire Requirements with Respect to Site Plan

The following sections contain the limits to the site plan design with respect to fire requirements including the fire access road, the location of the entrances to the buildings, and the fire department connections to the buildings. These requirements will assist in shaping the landscape of the site plan and identifying where parking spaces will be located.

2.3.2.1 Fire Department Connections

The design of both the residential and academic buildings must take into account the location of fire department connections. MSBC Section [F] 912: Fire Department Connections states that with respect to hydrants, driveways, buildings and landscaping, these fire department connections shall be located so that fire apparatus and hoses connected to supply the system will not obstruct access to the buildings for other fire apparatus. The fire department connections shall be located on the street side of buildings, fully visible and recognizable from the street or nearest point of fire department vehicle access. The section continues to acknowledge that the fire department connections shall be maintained at all times and shall never be obstructed by fences, bushes, trees, walls or any other fixed or moveable object.

2.3.2.2 Fire Access Road

According to MSBC Section 503.1.1, approved fire apparatus access roads shall be provided for every facility, building, or portion of a building hereafter constructed or moved into or within the jurisdiction of the project. The section further explains that the fire access road shall extend to within 150 feet of all portions of the facilities and all portions of the exterior walls of the first stories as measured by an approved route around the exterior of the buildings. It is also noted that the fire access road shall have an unobstructed width of no less than 20 feet, and an unobstructed vertical clearance of no less than 13 feet-6 inches.

2.3.3 Fire Requirements with Respect to Building Design

The following table addresses design codes and specifications regarding occupancy loading, egress plans, sprinkler systems, as well as the materials and furnishings that the team will have to abide by in designing specific components of the buildings.

Table 4: Design Parameters for Life Safety Considerations

Category of Consideration	Code Requirement	Code Reference
Occupancy Load Calculations	Occupant load placards shall be provided for each space of the buildings.	MSBC 1607.1
Egress Plan	Evacuation plans shall be provided for each level of the buildings demonstrating primary and secondary means of egress	NFPA 101 2013 Edition
Sprinkler Design	Building shall be sprinklered throughout	NFPA 13
Building Entrance Access	Building entrance access shall be within certain distance of the fire access road, through which the main fire alarm panel shall be accessible	MSBC 504.1

2.4 Community Impact

The redesign of the Salisbury Estates property will affect the surrounding Worcester community. From the demolition of the existing property to the active construction of the buildings, the proposed buildings will impact not only the WPI community but also the community of Worcester.

2.4.1 Impact on the WPI Community

With student populations at WPI growing every year, on-campus residential space has reached its capacity; all available rooms have been filled and some students are even on waitlists.

Departments across the institution agree that additional housing for undergraduates is the top priority moving forward. Without access to on-campus housing, students are forced to move to off-campus alternatives which can vary in quality and safety. In extreme cases, some students may even resort to lengthy or inconvenient commutes from neighboring communities if they are unable to secure housing on campus.

Although residential space has been identified as the top priority for future development, the need for additional academic space is also present. As the size of the student body grows, so does the amount of classes offered. With only so many hours in a day, WPI has begun to encounter scheduling difficulties due to a lack of available classrooms for professors to instruct courses. The growing student body will only intensify this issue in coming years if additional classroom space is not added to campus.

The new and improved Salisbury Estates property will offer a solution to this lack of adequate residential housing and classroom space at WPI.

2.4.2 Impact on the Greater Worcester Community

The new construction on Salisbury Estates has significant potential to impact the greater Worcester community. In order to begin the construction for the project, all existing structures must be demolished and landscape cleared. From this initial step, this project will impact the greater Worcester area. With demolition and new construction comes loud noise, displacement of existing residents, and potential impediment of public utilities for surrounding buildings, all of which will affect residents of the community for the duration of the project. Additionally, once built, the new structures will themselves become part of the community. The structures will be designed to fit into the theme of the surrounding area and not stick out as loud additions to the pre-existing neighborhood.

2.5 Sustainability

Projects aiming to improve infrastructure must be effective not only today but also in the future. In order to accomplish this, sustainability must be addressed in design. The proposed redesign of Salisbury Estates will need to be environmentally friendly and sustainable to accommodate for future generations as the WPI community continues to grow. It is important to assess the conditions of the site itself and design so as to minimize the project's impact on the plot of land due to environmental concerns such as flooding and erosion. The team will need to be conscious of the building materials and construction processes used along with the design itself.

2.6 Ethics

Throughout this project several ethical considerations must be kept in mind. The American Society of Civil Engineers (ASCE) says that “Ethics is integral to all decisions, designs, and services performed by civil engineers.” There are ethical specifications that must be addressed for every project: designing the project in the best interest of the client, being truthful in the cost and timeline for the project, and not using substandard materials or techniques to save money. In addition to these, the team must address the current Worcester residents of Salisbury Estates that will have to be relocated upon construction. These residents will be alerted early in the planning process to provide them with ample time to find a new residence; assistance for these residents will also be provided by WPI. By adhering to these procedures, in addition to ASCE’s assertion that “engineers uphold and advance the integrity, honor, and dignity of the engineering profession by using their knowledge and skill for the enhancement of human welfare and the environment, being honest and impartial and serving with fidelity the public, their employers and clients, striving to increase the competence and prestige of the engineering profession, and supporting the professional and technical societies of their disciplines” (ASCE, 2017), this project will be completed ethically and appropriately.

3.0 Methodology

Table 5: Methodology Breakdown

Project Methodology Summary
Establish Design Goals
Conduct interviews with Residential Services and Facilities
Investigate site layout options and evaluate alternatives
Structural Analysis and Design of Residential Facility, Dining Facility, and Academic Facility
Determine required use of space and develop floor plan
Develop a framing plan
Perform design calculations for structural system members including beams, columns, and footings
Life Safety Analysis
Configure egress plan
Develop architectural drawings
Cost Analysis
Estimate demolition costs
Estimate total material quantities and associated costs
Estimate architectural and construction labor costs
Deliverables
Final report and poster
Structural calculations
Computer models including Revit renderings and AutoCAD floor plans and cross sections
Total project cost estimate

3.1 Establish Design Goals and Develop Site Plan

Although the redesign of Salisbury Estates is the objective of the team, it was agreed that the perspectives of the school’s staff should provide insight towards the actual wants and needs regarding the development of this complex and contribute to a more feasible, desirable design. While there exist many codes and regulations that will influence and inform the design of the

proposed structures, an important consideration is the University's vision for the property. With proposed aspects of residential space included in the team's building design, representatives from Residential Services will be interviewed to gain a better understanding of this department's wants and needs for future residential structures. Additionally, the team plans to conduct interviews with representatives of the WPI Facilities Department to gain more information about the current site layout.

A solid baseline of information regarding Salisbury Estates will be gathered from these various meetings, a final consensus will be agreed upon and the scope of work outlined. Understanding that the entirety of Salisbury Estates will be demolished and leveled, a new proposal for the site layout of the property will be developed. Before coming to a final decision, different site plans and ideas will be considered. The final decision will incorporate shared points gathered from the interviews as well as engineering judgement used by the team.

After demolition, a parking lot will be added to account for the new residential and academic facilities while also forming a northward connection to Sagamore Road to provide an additional entrance/exit. In addition to the parking lot, both our designed residential and academic structures will need to be placed on the existing site. An iterative approach will be taken to design a site plan that will incorporate all aspects of the team's design in an ideal manner.

3.2 Structural Design and Analysis

Structural design calculations will be conducted for both the academic and residential facilities. These calculations will be carried out starting with the top of the structure and then working downward. The roof will be designed to service design loads prescribed in ASCE 7-10 and *the Massachusetts State Building Code*, including snow, rain, earthquake, and dead loads. With the roof designed, the top floor members can be designed to carry this overhead loading along with its own applicable dead and live loads. This process will be applied to all additional floors before designing the foundation. LRFD design will be used throughout.

Structural analysis software, such as Risa 2D, will be used to analyze the integrated structural system selected through the previous design calculations. This will allow for the identification of errors and potential need for more design iterations until deflections and stresses are within allowable values.

3.3 Life Safety Analysis

Upon completion of the architectural drawings for both the residential and academic buildings, a comprehensive life safety analysis will be completed which will address evacuation plans, emergency lighting locations, exit sign placement, fire alarm pull stations, and occupant load calculations. Utilizing the requirements and specifications found from code research, AutoCAD drawings will be developed to show evacuations routes, and placement of emergency lighting, exit signs, and manual fire alarm pull stations. A sprinkler layout will be overlaid on the architectural drawings, for both the academic and residential buildings. Finally, occupant load placards will be developed for each room of both buildings based on occupancy classification and square footage.

3.4 Cost analysis

A comprehensive cost analysis shall be conducted for the demolition of the current buildings on the Salisbury Estates lot, the construction of the new buildings, and the projected return from the dining facility and the residential hall spaces.

3.4.1 Demolition

The demolition of the current apartments within Salisbury Estates, along with the leveling of the property, will contribute significantly to the cost of the project. Due to the focus of this project being on the structural design and life safety of the buildings, the specifics of the demolition process are not essential for the purpose of this project. Therefore, the cost estimate for this demolition will be calculated using an average cost per unit area of the property.

3.4.2 New Building

The construction of the new residential and academic buildings will comprise the majority of the cost for the project. The cost of the materials used will be researched and applied to the total amount of such materials used to determine this total material cost. Time to complete the construction will also be estimated to allow for a reasonable value for the cost of labor. Summing these values will provide an estimate for the cost of the project.

3.4.2.1 Materials

Once all of the structural members have been designed, the cost of the material used will be calculated using R.S. Means. Additionally, a list of interior materials used shall be provided upon completion of the building design. This list will contribute to the cost analysis portion of the report. Some examples of materials to be included are gypsum wall-board, carpeted flooring, and suspended ceiling tiles.

3.4.2.2 Labor Cost

The final component of the cost estimate of the building will be the labor cost of erection. It will be difficult to ascertain an accurate estimate of this cost due to unpredictable nature of the component costs. A time estimate will be made based on recently completed projects of a similar nature to this project. This time will be used to estimate the overhead cost of the construction with base values found from R.S. Means.

3.4.3 Return on Investment

With one of these buildings being residential with a small dining option, WPI will attain a source of income by investing in this property. The large increase in beds accompanied by the additional meal plans of the undergraduate students will greatly increase the revenue of this site. After a given amount of time, this development will provide WPI with profits which can then be used for further expansions.

4. Deliverables

One of the major deliverables provided will be the calculations carried out for the design of the structural members. The deliverables with respect to fire and life safety shall include AutoCAD drawings of the architectural floor plans to be overlaid with a sprinkler layout, stairwells, fire doors, and fire barrier locations. An occupancy load table for the buildings, a fire resistance material rating for the buildings, and site plan view displaying building entrances, pathways, fire access roads, as well as fire department connections will also be provided. AutoCAD and Revit models will also be produced to visually show the iterations and final designs of the proposed buildings. A cost estimate will supplement the design work to present the financial assessments for each necessary component of the project. A final report will be developed to demonstrate the actual methods used as well as corresponding results and conclusions made by the team. The entirety of this information will be organized visually in a clear and concise manner on a final poster. A schedule showing tasks to be completed throughout the three terms can be seen in Figure 2 below:

Figure 2: Gantt Chart of Three-Term Schedule

WBS NUMBER	TASK TITLE	A-TERM							B-TERM							C-TERM										
		WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7	WEEK 1	WEEK 2	WEEK 3	WEEK 4	WEEK 5	WEEK 6	WEEK 7				
0	Preliminary Information																									
0.0	Decide on Project	■																								
0.1	Meet with Residential Services		■	■																						
0.2	Meet with Facilities			■	■																					
0.3	Outside Research		■	■	■																					
1	Proposal																									
1.1	Introduction					■																				
1.2	Background					■	■																			
1.3	Methodology					■	■																			
1.4	Deliverables					■	■																			
1.5	Bibliography						■																			
1.6	End-of-term Submittal							■																		
2	Building Design																									
2.0	Demolition							■																		
2.1	Floor Plan					■	■																			
2.2	Design Roof							■	■																	
2.3	Framing Plan								■	■																
2.4	Sizing Members									■	■	■														
2.5	Foundation										■	■	■													
2.6	Parking											■	■	■												
2.7	Cost												■	■												
2.8	End-of-term Submittal													■												
3	Final Report																									
3.1	Introduction																					■				
3.2	Background																					■	■			
3.3	Methodology																						■	■	■	
3.4	Cost Analysis																							■	■	
3.5	Conclusion & Recommendations																							■	■	
3.6	End-of-term Submittal																								■	■
4	Final Presentation																									
4.1	Poster																									■

5. Bibliography

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“FEMA Flood Map Service Center” FEMA, [msc.fema.gov/](https://www.fema.gov/).

City of Worcester Zoning Ordinance 2018 Edition

International Building Code (IBC) 2015 Edition

Massachusetts State Building Code (MSBC) 9th Edition

National Fire Protection Association NFPA 13 2013 Edition

National Fire Protection Association NFPA 101 2015 Edition

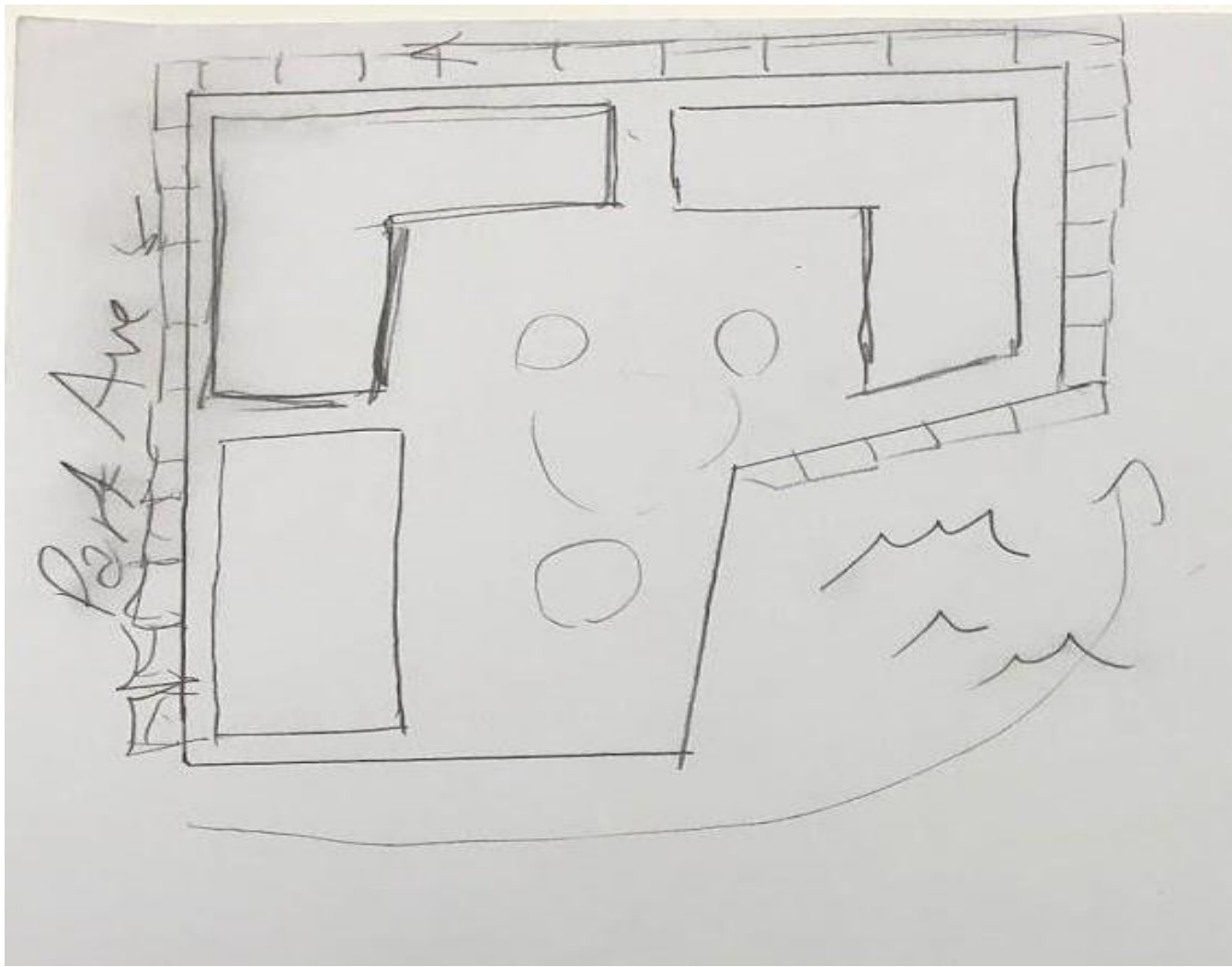
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National Fire Protection Association NFPA 221 2015 Edition

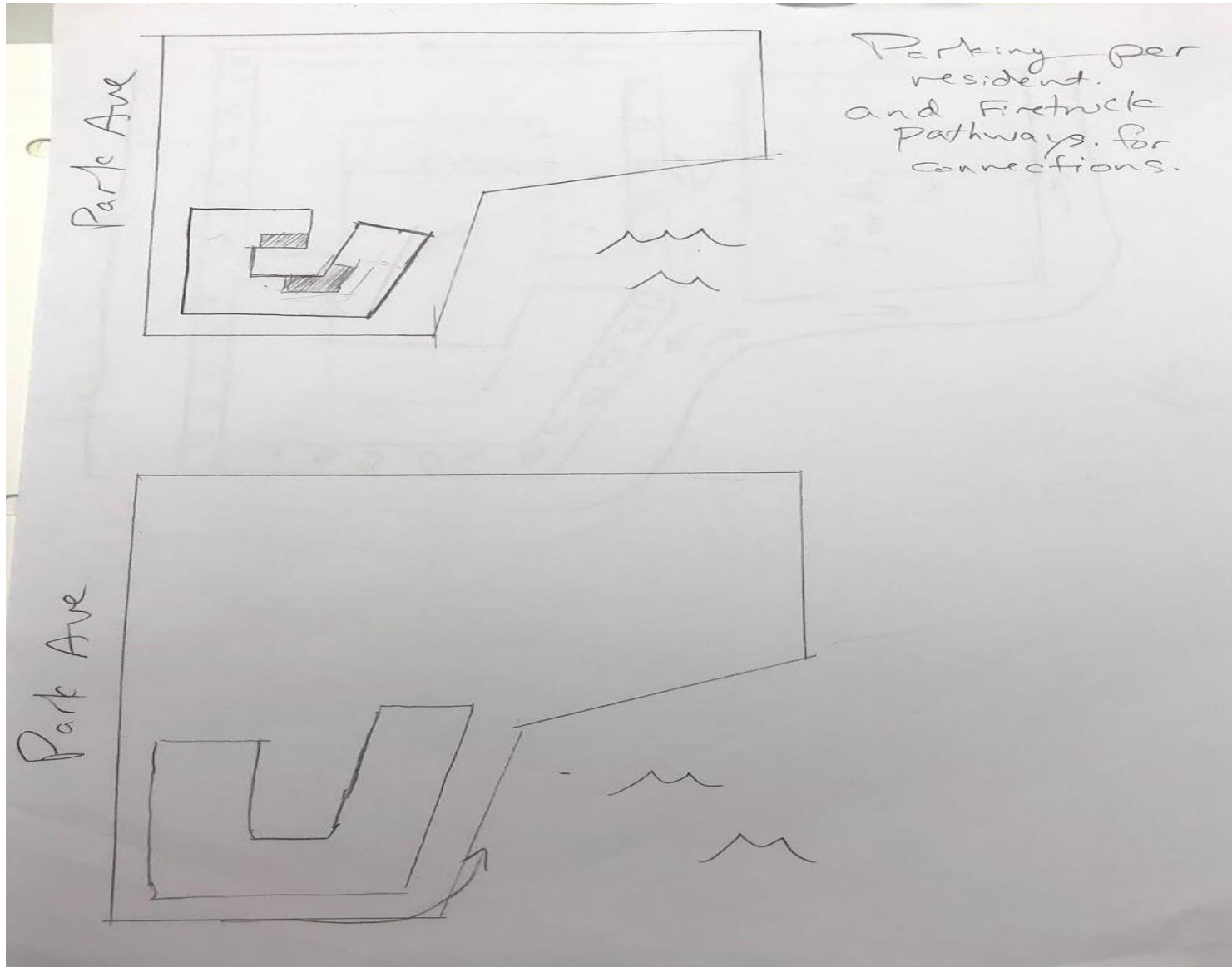
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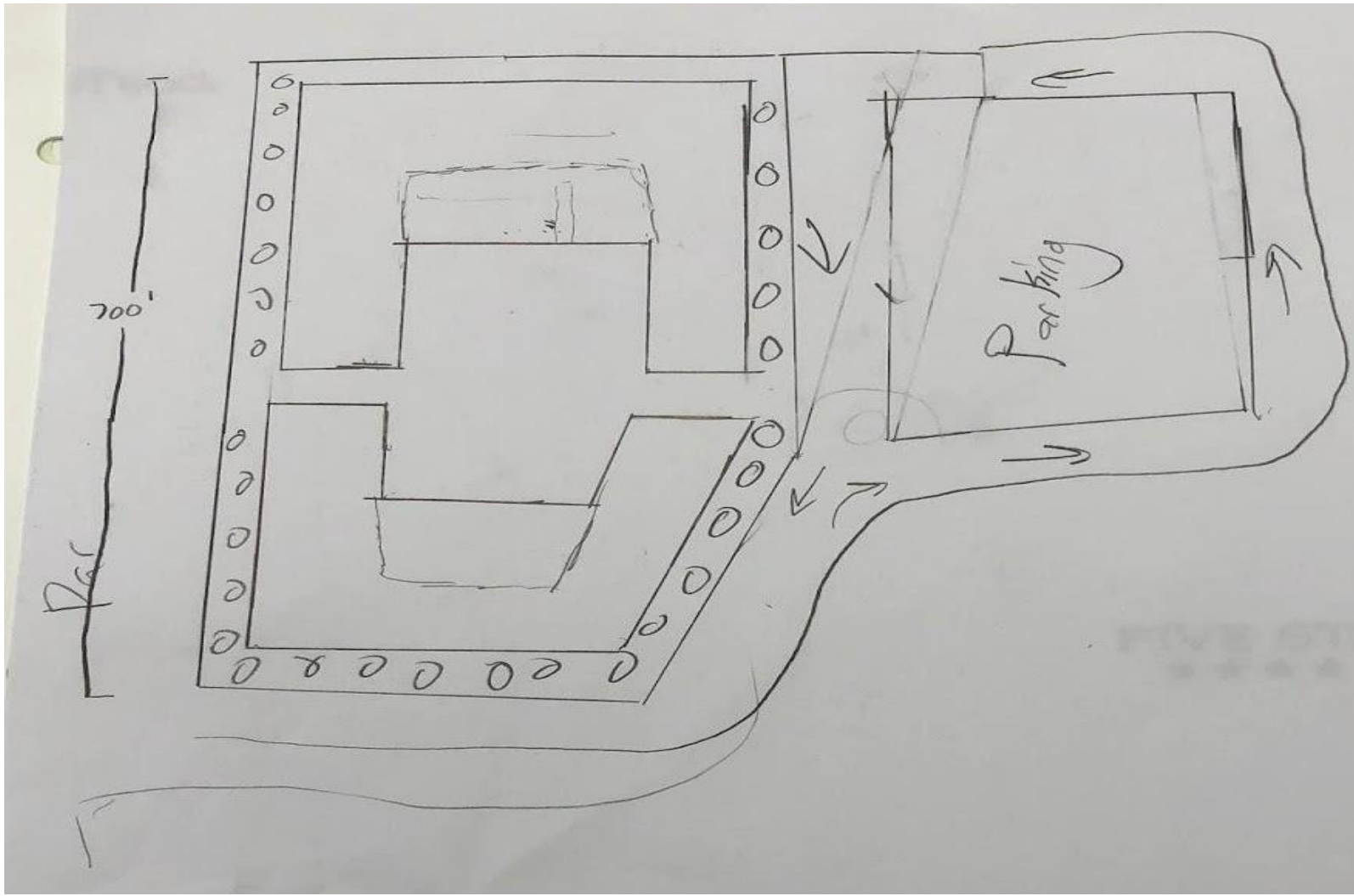
Appendix B: Site Plan Brainstorm 1



Appendix C: Site Plan Brainstorm 2

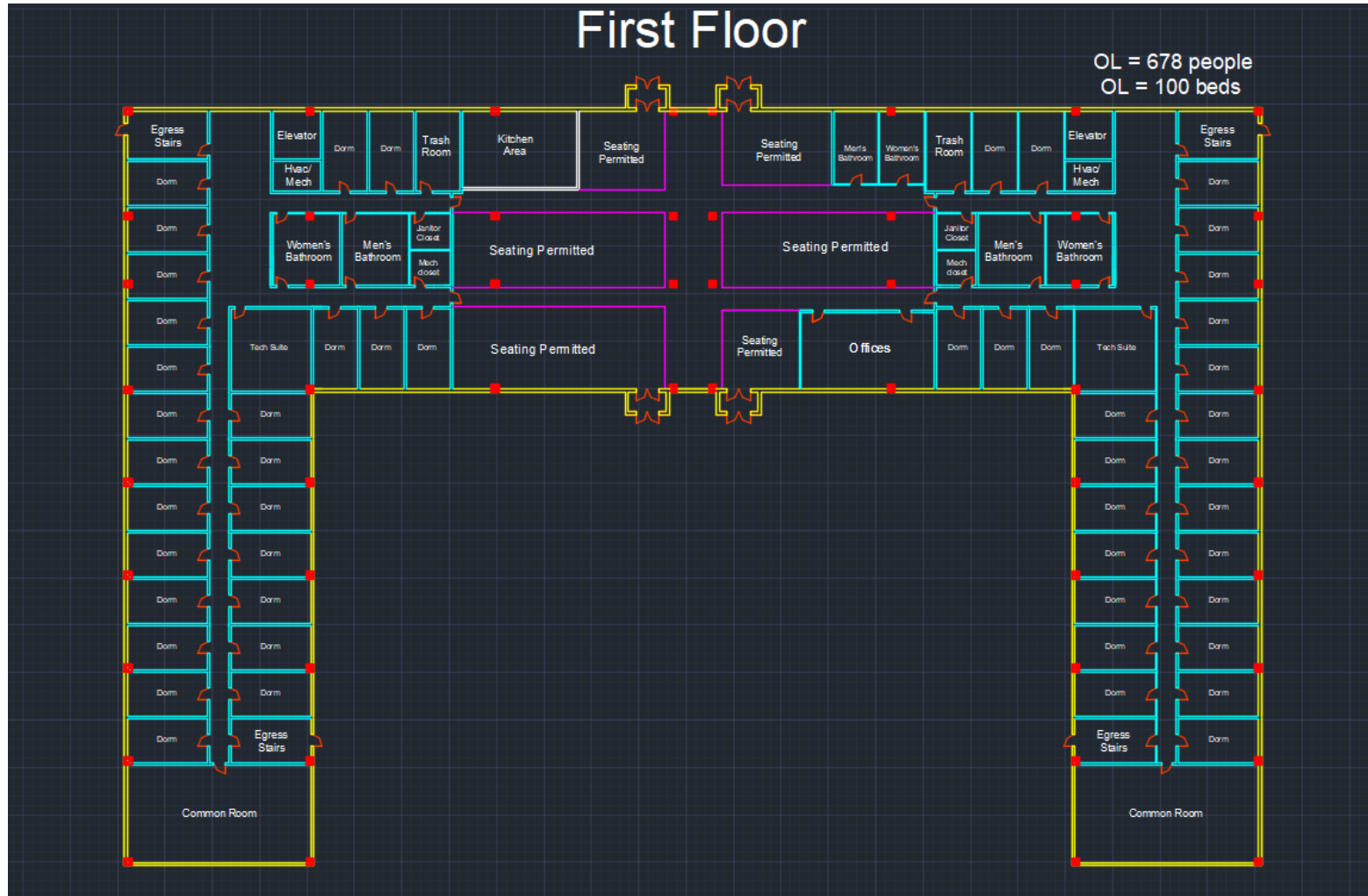


Appendix D: Site Plan Brainstorm 3



Appendix E: Architectural Drawings

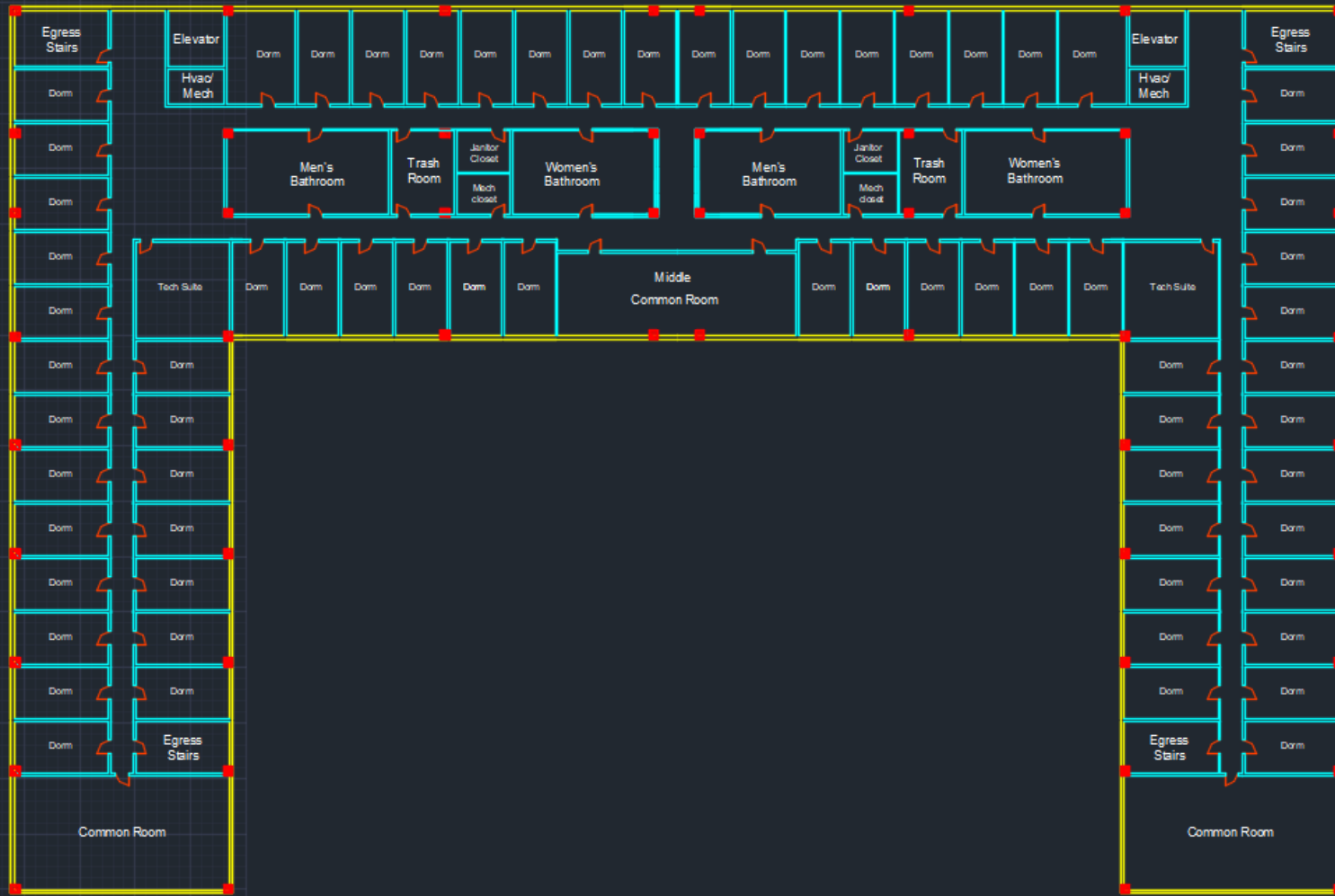
Appendix E.1: Residential Architectural Drawings



Second Floor

OL = 270 people

OL = 136 beds

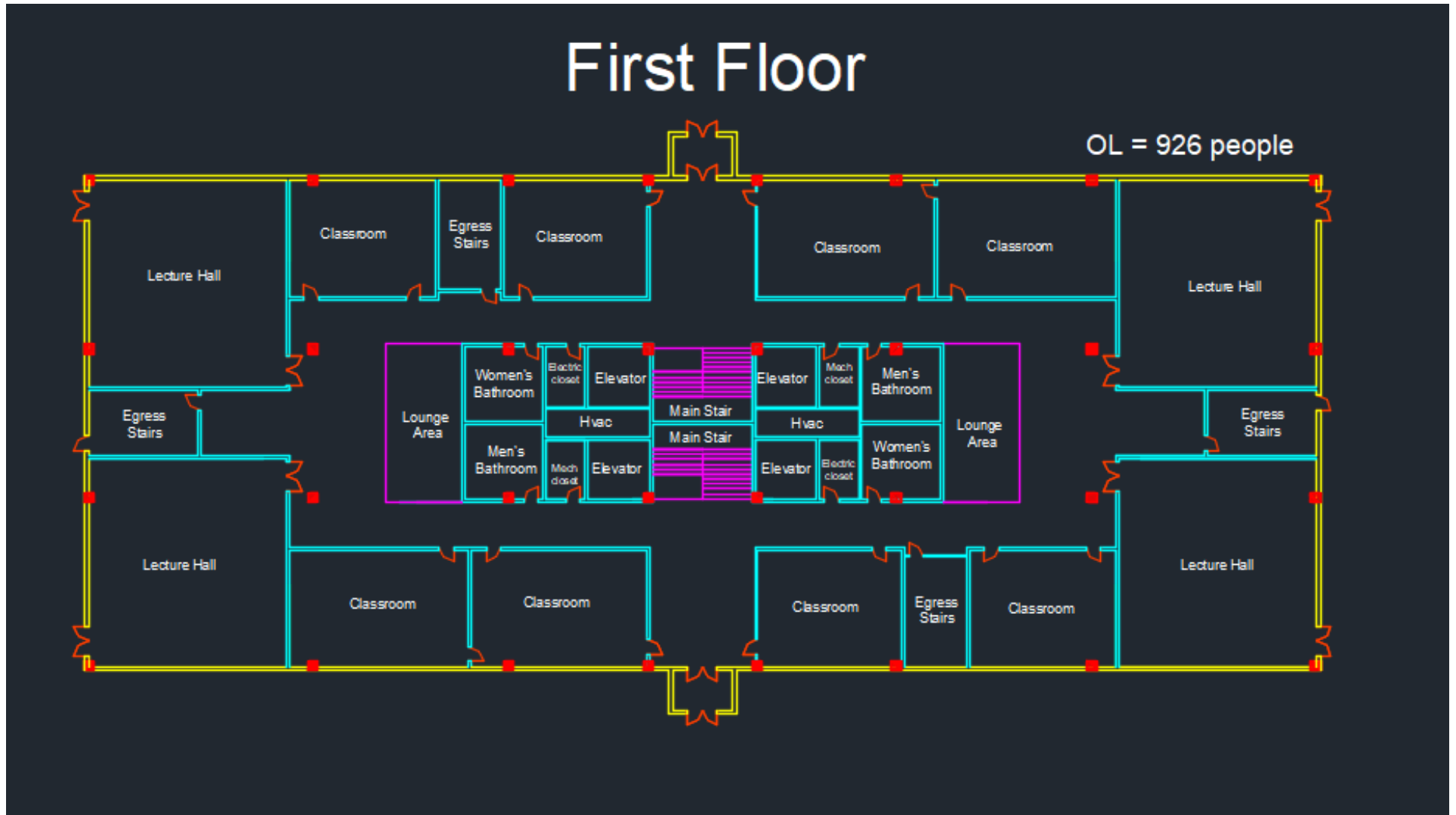


Third Floor

OL = 270 people
OL = 136 beds

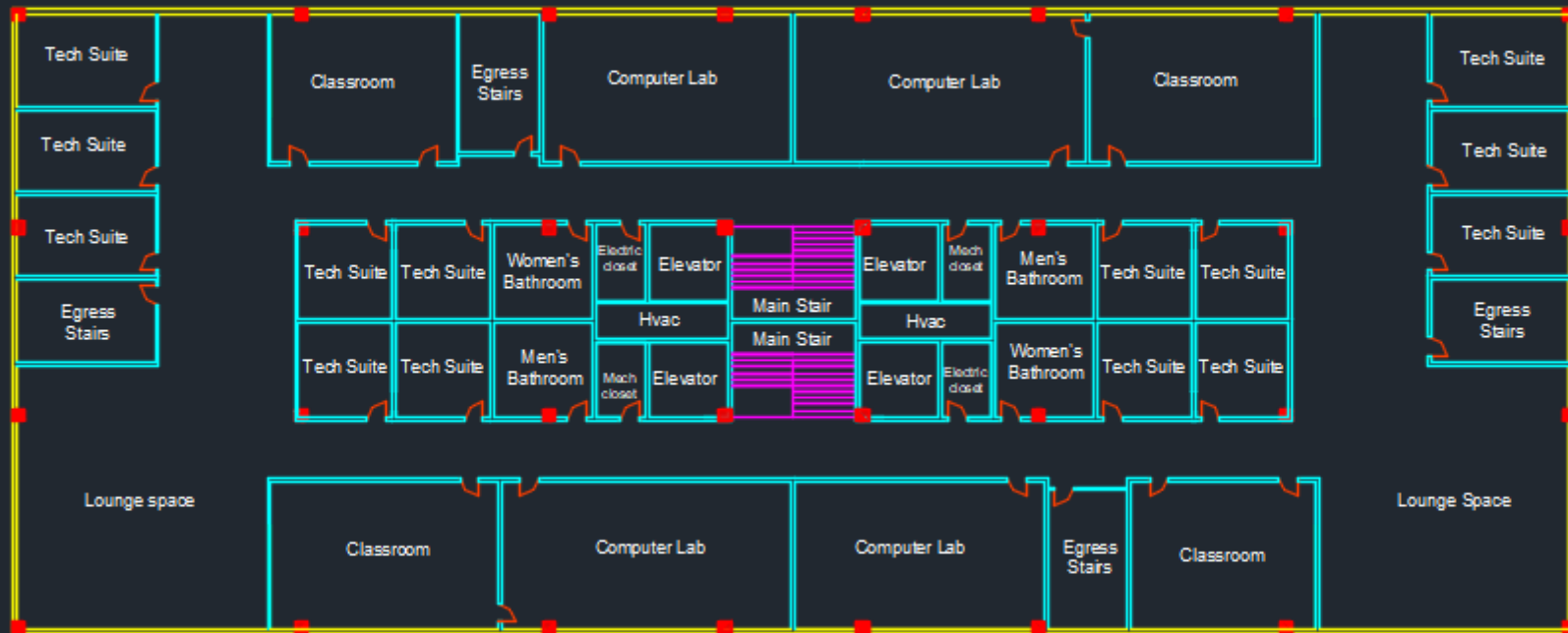


Appendix E.2: Academic Architectural Drawings



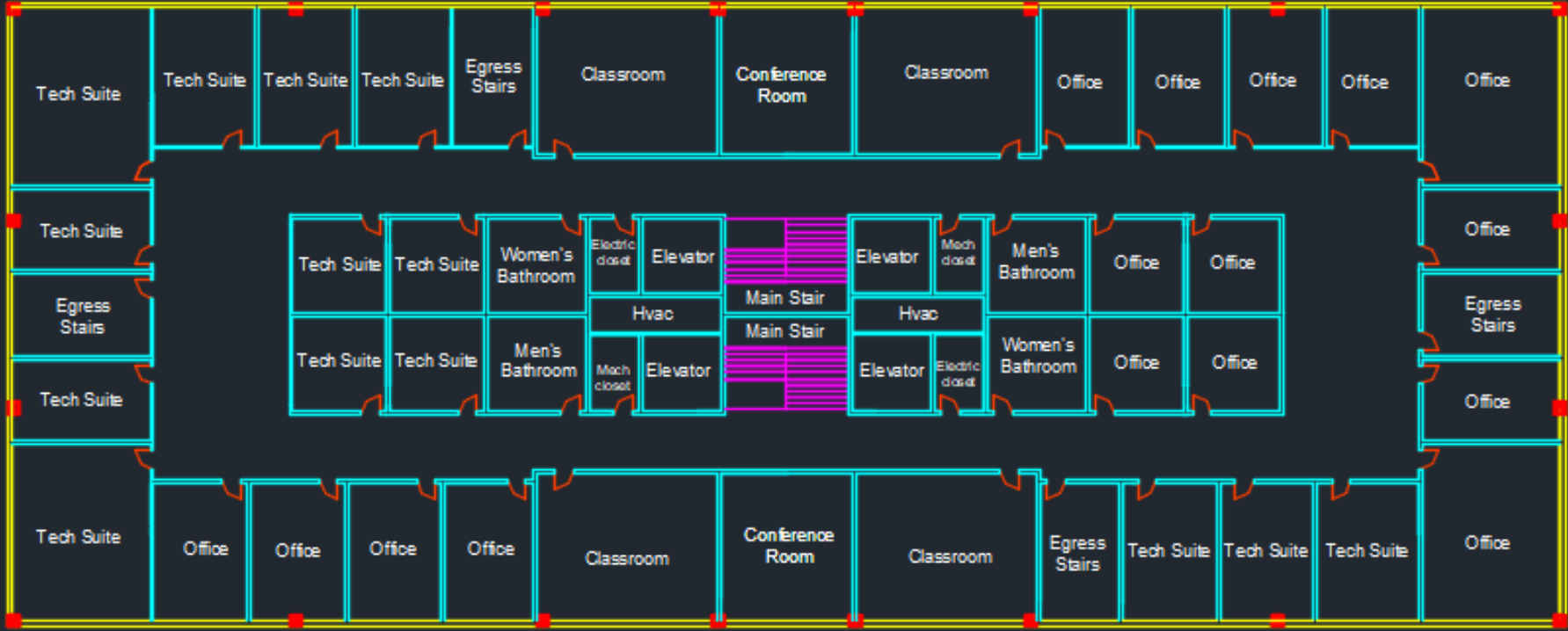
Second Floor

OL = 762 people



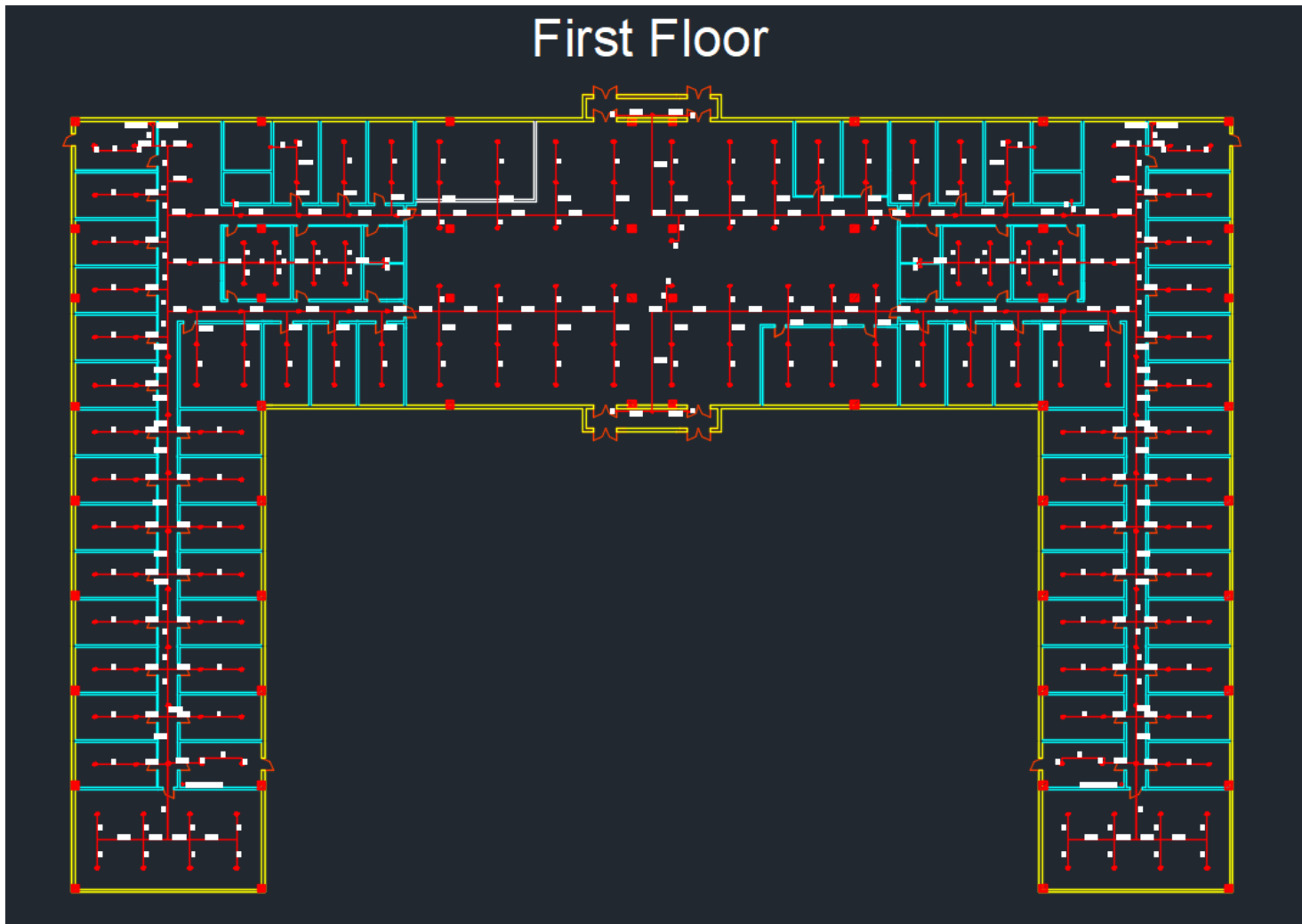
Third Floor

OL = 451 people

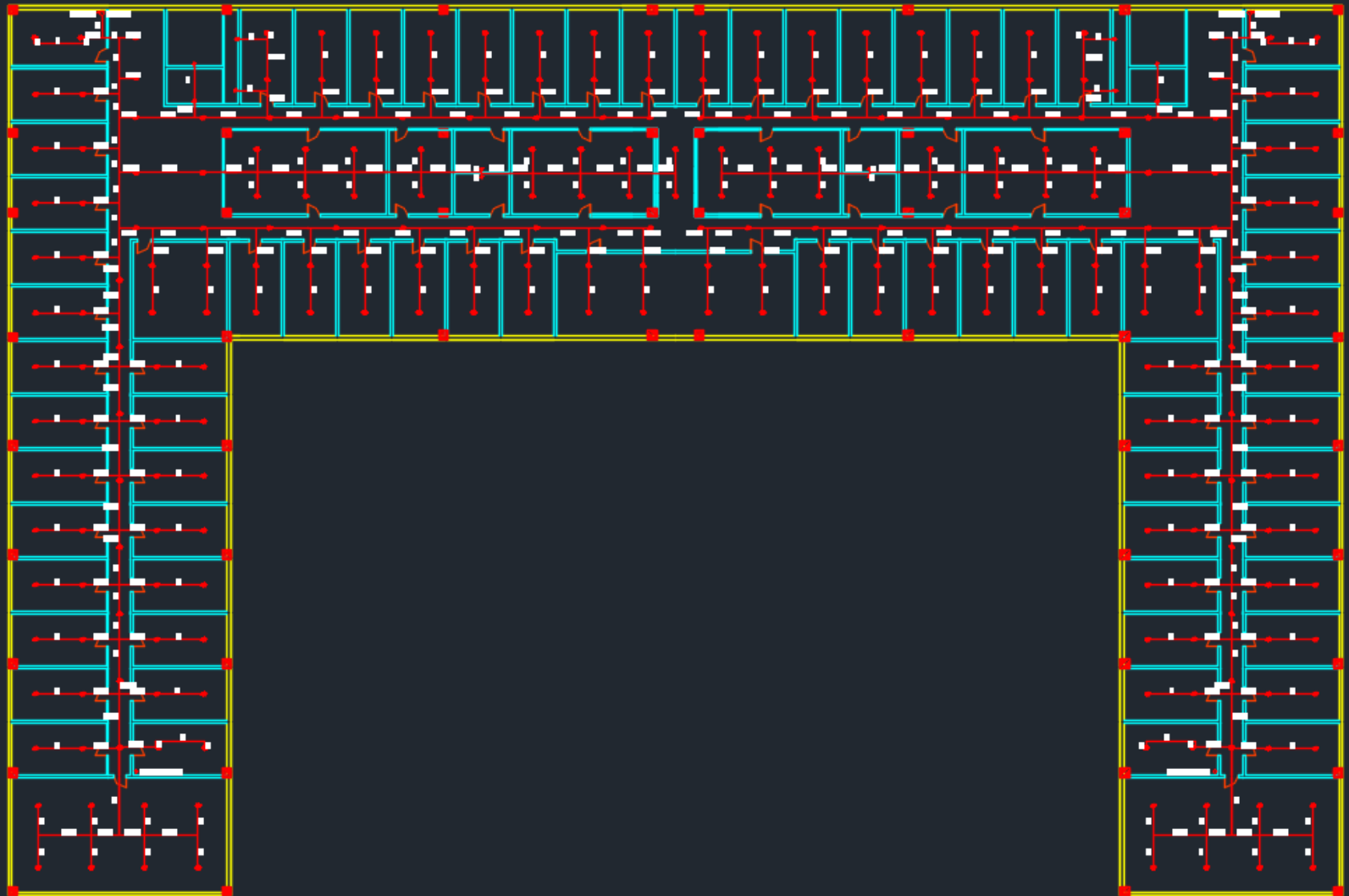


Appendix F: Academic and Residential Sprinkler Design Drawings

Appendix F.1: Residential Sprinkler Design Drawings



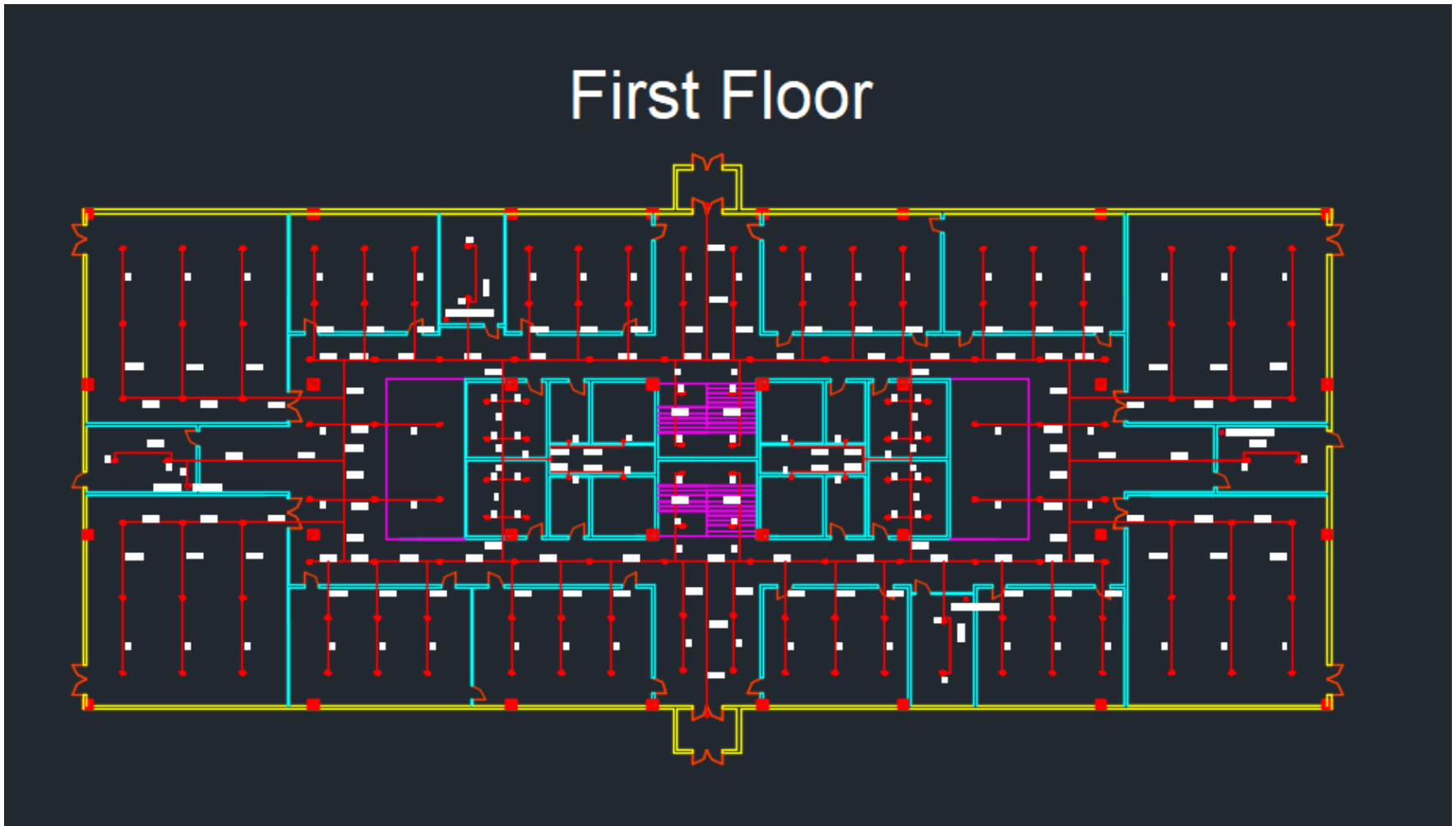
Second Floor



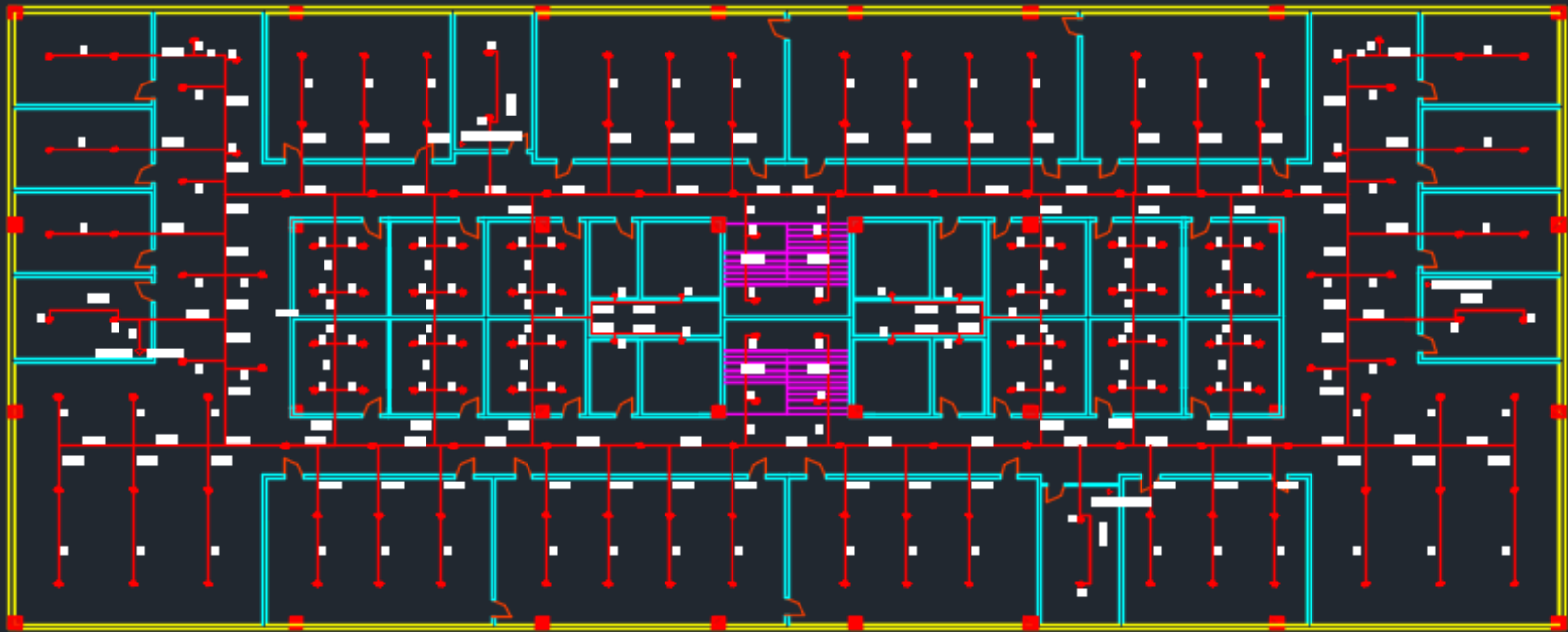
Third Floor



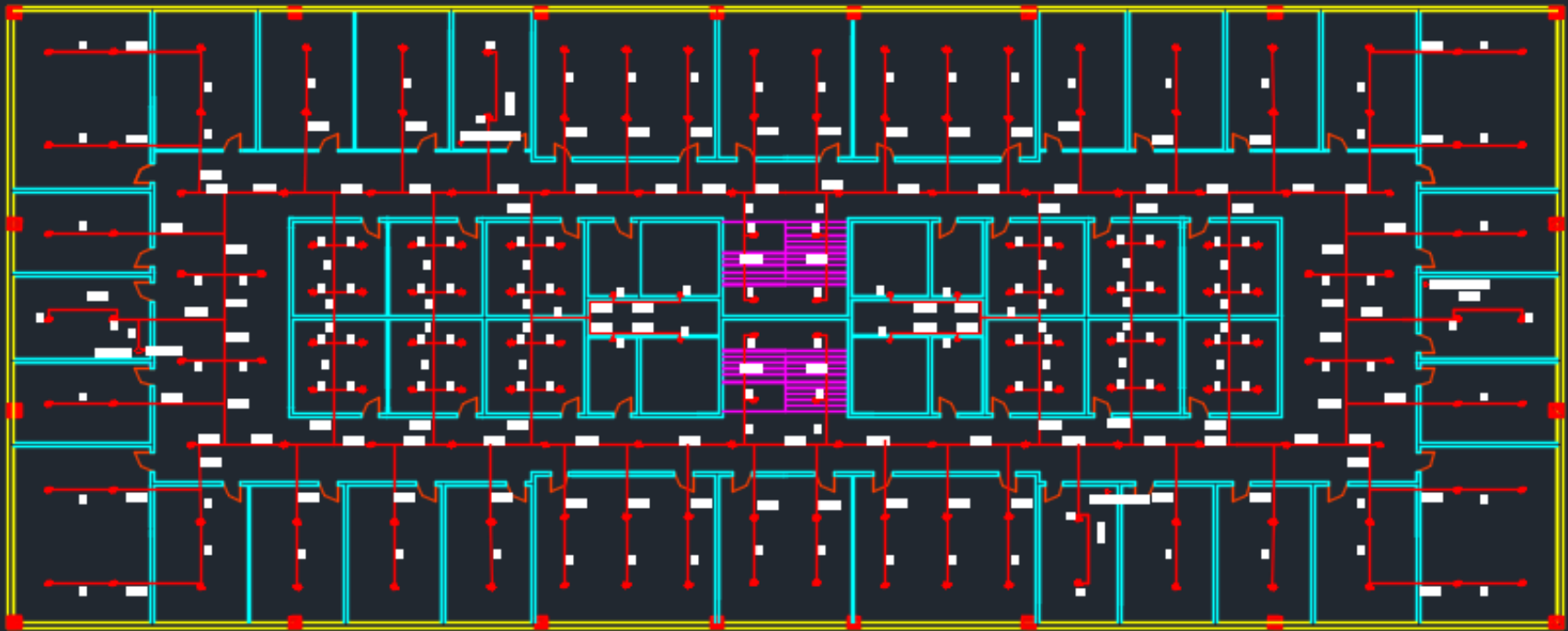
Appendix F.2: Academic Sprinkler Design Drawings



Second Floor



Third Floor



Appendix G: Academic Building Beam and Girder Design

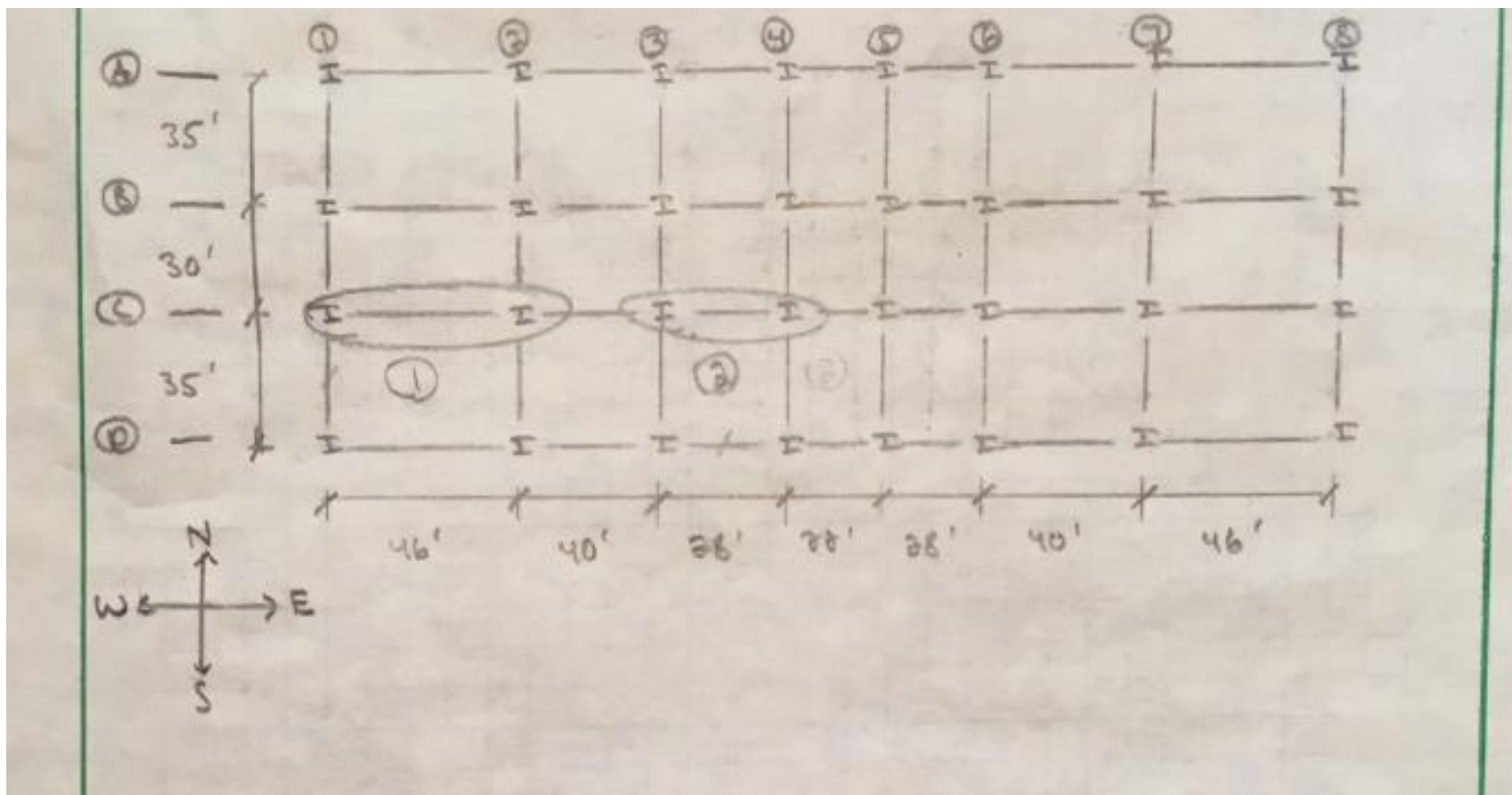
Appendix G.1: Beam Design Aid

Initial Assumptions:		Units			
Es	29000	ksi		Acceptable Zx Value >	5.506666667 in ³
Fy	50	ksi			
Bay Properties:		Units		Selected Section Properties:	Units
Section Length	10	ft		Section	W2x4
Section Spacing	10	ft		Self Weight	10 lb/ft
Is Interior? (1=No, 2=Yes)	1			Section Z _x Value	10 in ³
				Section I _x Value	1140 in ⁴
				Adjusted Load Combination (Wu)	1664.000 lb/ft
Dead Loads:		Units		Adjusted Max Moment	249.600 k-in
MEP	10	psf		New Acceptable Zx	5.55 in ³
Ceiling	10	psf			
Concrete Slab+Decking	10	psf			
Exterior Enclosure (DL)	10	lb/ft		Deflection Checks:	Units
				L/360	0.333333333 in
Total Dead Load	310	lb/ft		L/240	0.5 in
Live Loads:		Units		0.5LL	400.000 lb/ft
Above Corridors	80	psf		DL+0.5LL	720.000 lb/ft
Reduced Live Load	140.000	psf			
				$\Delta_{max} LL$	0.0027 in
Total Live Load	80.000	psf		$\Delta_{max} DL+LL$	0.0049 in
Total Live Load	800.000	lb/ft			
Load Combinations:		Units			
1.4(DL)	434	lb/ft			
1.2(DL) + 1.6(LL) + 0.5(Lr or S or	1652	lb/ft			
Used Combination (Wu)	1652	lb/ft			
Max Moment	247.8	k-in			

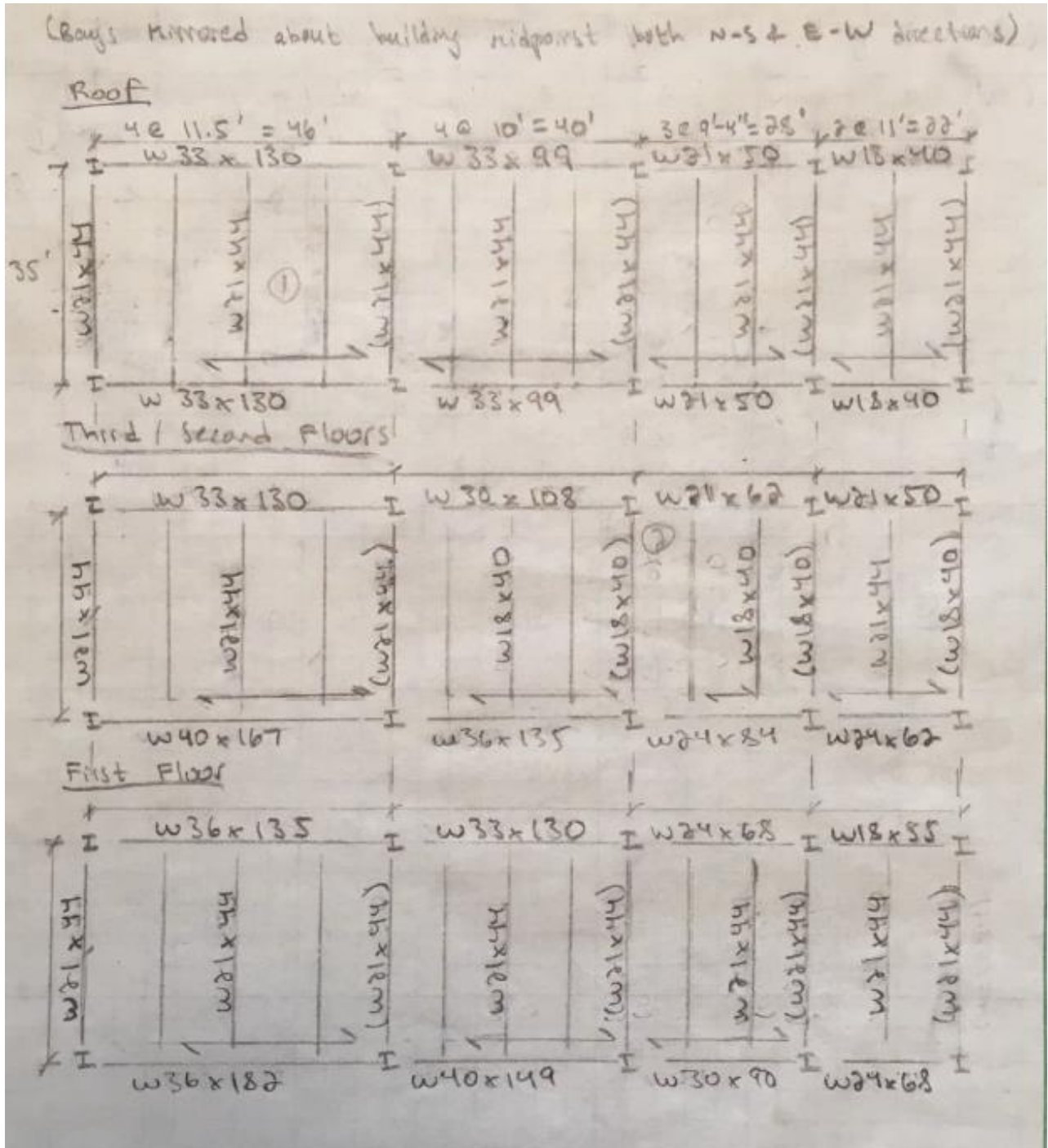
Appendix G.2: Girder Design Aid

Initial Assumptions:		Units			
Es	29000	ksi		Acceptable Zx Value >	204.6380935 in ³
Fy	50	ksi			
Beams within Bay Properties:		Units		Selected Section Properties:	Units
Beam Length	35	ft		Section	W2x4
Beam Spacing	11.5	ft		Self Weight	100 lb/ft
Beam Self Weight	10	lb/ft		Section Z _x Value	10 in ³
Is Interior? (1=No, 2=Yes)	1			Section I _x Value	1140 in ⁴
Girders within Bay Properties:		Units		Self Weight Distributed Load Factored (Wu)	120.000 lb/ft
Girder Length	46	ft		Adjusted Max Moment	9589.594 k-in
				New Acceptable Zx	213.10 in ³
Dead Loads:		Units			
MEP	10	psf		Deflection Checks:	Units
Ceiling	10	psf		L/360	1 in
Concrete Slab+Decking	10	psf		L/240	2.3 in
Exterior Enclosure (DL)	10	lb/ft		0.5LL (Into Concentrated Load)	16.062 k
				DL+0.5LL (Into Concentrated Load)	37.452 k
Total Dead Load	365	lb/ft		Δ _{max} LL	1.7025 in
				Δ _{max} DL+LL	3.9697 in
Live Loads:		Units			
Above Corridors	80	psf			
Reduced Live Load	79.813	psf			
Total Live Load	79.813	psf			
Total Live Load	917.854	lb/ft			
Load Combinations:		Units			
1.4(DL)	511	lb/ft			
1.2(DL) + 1.6(LL) + 0.5(Lr or S or R)	1906.57	lb/ft			
Used Combination (Wu) (acting on Bea	1906.57	lb/ft			
Concentrated load on Girder from Bear	66729.8	lb			
Max Moment	9208.71	k-in			

Appendix G.3: Academic Building Structural Bay Layout



Appendix G.4: Academic Building Final Member Sizes



Appendix G.5: Academic Building Roof Member Design

Bay 1

Interior Beam - Strength Performance

Loads

Roof	20 psf (Lr)	
Deck	3.15 psf	} (W)
Shingles/ins.	16 psf	
CMEP	8.85 psf	
Snow	55 psf (S)	

Steel Properties

$E_s = 29,000 \text{ ksi}$
 $F_y = 50 \text{ ksi}$

Load Combinations

- $w_u = 1.4D = [1.4(3.15 \text{ psf} + 16 \text{ psf} + 8.85 \text{ psf})] 11.5 \text{ ft}$
 $w_u = 450.8 \text{ lb/ft}$
- $w_u = 1.2D + 1.6(Lr \text{ or } S \text{ or } R) + 1.6W + 1.6(W \text{ or } 0.5W)$
 $w_u = [1.7(28 \text{ psf}) + 1.6(55 \text{ psf})] 11.5 \text{ ft}$
 $w_u = 1398.4 \text{ lb/ft} \rightarrow \text{governs}$

Calculate M_u

$$M_u = \frac{w_u L^2}{8} = \frac{(1398.4 \text{ lb/ft})(35 \text{ ft})^2}{8} \rightarrow M_u = 2569.56 \text{ k-in}$$

Determine Z_x using $Z_x \geq \frac{M_u}{\phi F_y}$

$$Z_x \geq \frac{(2569.56 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 57.0 \text{ in}^3$$

Use Table 3-2 to find beam size

From Table 3-2 \rightarrow $w \geq 1 \times 44$ ($Z_x = 95.4 \text{ in}^3$)

Update w_u w/ self-weight

$$w_u = (1398.4 \text{ lb/ft}) + 1.7(44 \text{ lb/ft}) \rightarrow w_u = 1451.20 \text{ lb/ft}$$

Calculate New M_u

$$M_u = \frac{w_u L^2}{8} = \frac{(1451.20 \text{ lb/ft})(35 \text{ ft})^2}{8} = 2666.58 \text{ k-in}$$

Check Z_x

$$Z_x \geq \frac{M_u}{\phi F_y} = \frac{(2666.58 \text{ k-in})}{(0.9)(50 \text{ ksi})}$$

$$Z_x \geq 59.3 \text{ in}^3 \rightarrow Z_x \text{ w/ } 1 \times 44 = 95.4 \text{ in}^3 \quad \checkmark$$

Interior Beam - Deflection Performance

Live Loads

$$\Delta L \leq \frac{L}{360} \text{ or } 1'' \text{ max}$$

$$\Delta L = \frac{5 w_L L^4}{384 E I_x} \quad w_L = \text{roof live load (snow since governs)}$$

$$w_L = (55 \text{ psf}) (11.5 \text{ ft}) = 632.500 \text{ lb/ft}$$

$$\Delta L = \frac{5 (632.500 \text{ lb/ft}) (35 \text{ ft})^4 (12 \text{ in/ft})^3}{384 (29 \cdot 10^6 \text{ psi}) (843 \text{ in}^4)}$$

$$\Delta L = 0.87 \text{ in}$$

$$\frac{L}{360} = \frac{35 \text{ ft} \cdot (12 \text{ in/ft})}{360} = 1.17 \text{ m} \rightarrow \text{use } 1 \text{ in}$$

$$\Delta L = 0.87 \text{ in} < 1 \text{ in} = \frac{L}{360} \leftarrow$$

Dead & Live Loads

$$\Delta T \leq \frac{L}{240}$$

$$\Delta T = \frac{5 w_T L^4}{384 E I_x} \quad w_T = \text{dead + live load}$$

$$w_T = 1.322 \text{ lb/ft} + 44 \text{ lb/ft} + 632.5 \text{ lb/ft} = 998.5 \text{ lb/ft}$$

$$\Delta T = \frac{5 (998.5 \text{ lb/ft}) (35 \text{ ft})^4 (12 \text{ in/ft})^3}{384 (29 \cdot 10^6 \text{ psi}) (843 \text{ in}^4)}$$

$$\Delta T = 1.38 \text{ in}$$

$$\frac{L}{240} = \frac{35 \text{ ft} \cdot (12 \text{ in/ft})}{240} = 1.75 \text{ m}$$

$$\Delta T = 1.38 \text{ in} < 1.75 \text{ in} = \frac{L}{240} \leftarrow$$

Use W21x44

Interior Girder - Strength Performance

$$A_u = \frac{w_u L}{2}$$

$$A_u = \frac{(145.20 \text{ lb/ft})(35 \text{ ft})}{2} \rightarrow A_u = 25.396 \text{ k}$$

$$2A_u = 2(25.396 \text{ k}) \rightarrow 2A_u = 50.792 \text{ k}$$

Calculate M_u

$$M_u = \frac{P_L}{4} + P_a = \left[\frac{(50.792 \text{ k})(46 \text{ ft})}{4} + (150.792 \text{ k})(11.5 \text{ ft}) \right] \frac{12 \text{ in}}{1 \text{ ft}}$$

$$M_u = 14018.59 \text{ k-in}$$

Determine Z_x using $Z_x \geq \frac{M_u}{\phi F_y}$

$$Z_x \geq \frac{(14018.59 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 311.5 \text{ in}^3$$

Use Table 3-2 to find girder size

$$\text{From Table 3-2} \rightarrow W 33 \times 130 \quad (Z_x = 467 \text{ in}^3)$$

$$w_{u \text{ self}} = 127 \text{ lb/ft} \rightarrow w_{u \text{ self}} = 156 \text{ lb/ft}$$

$$M_{u \text{ self}} = \frac{w_{u \text{ self}} L^2}{8} = \frac{(156 \text{ lb/ft})(46 \text{ ft})^2}{8} \rightarrow M_{u \text{ self}} = 495.144 \text{ k-in}$$

$$M_u = (14018.590 \text{ k-in}) + (495.144 \text{ k-in}) \rightarrow M_u = 14513.736 \text{ k-in}$$

Check Z_x

$$Z_x \geq \frac{(14513.736 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 322.5 \text{ in}^3$$

$$Z_x \text{ required} = 322.5 \text{ in}^3 < 467.0 \text{ in}^3 = Z_x \text{ } W 33 \times 130 \quad \leftarrow$$

Interior Girder - Deflection Performance

Live Loads (LL), no 0.5 since roof

$$\Delta L \leq \frac{L}{360} \text{ or } 1'' \text{ max}$$

$$\Delta L = \left(\frac{PL^3}{48EI_x} + \frac{Pa}{24EI_x} (3L^2 - 4a^2) \right)$$

$$\Delta L = \left(\frac{(32.138^k)(46\text{ft})^3}{48(29 \cdot 10^6 \text{ psi})(3610 \text{ in}^4)} + \frac{(32.138^k)(11.5\text{ft})}{24(29 \cdot 10^6 \text{ psi})(3610 \text{ in}^4)} (3(46\text{ft})^2 - 4(11.5\text{ft})^2) \right) \frac{1728 \text{ in}^3}{1\text{ft}^3}$$

$$\Delta L = 0.95 \text{ in}$$

$$\frac{L}{360} = \frac{46 \text{ ft} (12 \text{ in/ft})}{360} = 1.51 \text{ in} \rightarrow \text{use } 1 \text{ in}$$

$$\Delta L = 0.95 \text{ in} < 1 \text{ in} = \frac{L}{360} \checkmark$$

Dead & Live Loads ($\Delta L + LL$), no 0.5 since roof

$$\Delta T \leq \frac{L}{240}$$

$$\Delta T = \left(\frac{PL^3}{48EI_x} + \frac{Pa}{24EI_x} (3L^2 - 4a^2) \right), \quad P = (w_D + w_{\text{self}} + w_L) \cdot \frac{L_{\text{beam}}}{2}$$

$$\Delta T = \left(\frac{(44.954^k)(46\text{ft})^3}{48(29 \cdot 10^6 \text{ psi})(3610 \text{ in}^4)} + \frac{(44.954^k)(11.5\text{ft})}{24(29 \cdot 10^6 \text{ psi})(3610 \text{ in}^4)} (3(46\text{ft})^2 - 4(11.5\text{ft})^2) \right) \frac{1728 \text{ in}^3}{1\text{ft}^3}$$

$$\Delta T = 1.92 \text{ in}$$

$$\frac{L}{240} = \frac{46 \text{ ft} \cdot (12 \text{ in/ft})}{240} = 2.30 \text{ in}$$

$$\Delta T = 1.92 \text{ in} < 2.30 \text{ in} = \frac{L}{240} \checkmark$$

Use W 33 x 130

Exterior Beam / Girder

Followed same processes

Exterior enclosure WA

Beam \rightarrow W21x44
Girder \rightarrow W33x130

Academic Building

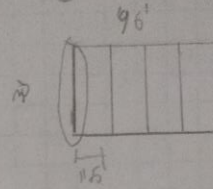
Interior ^{Roof} Edge Bay

Exterior Beam

1/2

$$E_s = 29,000 \text{ ksi}, \quad F_y = 50 \text{ ksi}$$

$$\text{Beam length} = 30 \text{ ft} \quad \text{Spacing} = 11.5 \text{ ft}$$



<u>DL</u>	<u>Lr</u>	<u>S</u>
28 psf	20 psf	55 psf

$$\text{Tributary Area} = \frac{11.5 \text{ ft}}{2} = 5.75 \text{ ft}$$

Loads

$$DL = (28)(5.75) = 161 \text{ lb/ft}$$

$$S = (55)(5.75) = 316.25 \text{ lb/ft}$$

Load Combination

$$1.2 DL + 1.6 S = 1.2(161.25) + 1.6(316.25) = 193.2 + 506 = 699.2 \text{ lb/ft}$$

$$W_o = 699.2 \text{ lb/ft}$$

$$M_o = \frac{699.2(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 943.92 \text{ k-in}$$

$$z_x = \frac{943.92}{(0.9)(50)} = 20.98 \text{ in}^3 \quad \text{--- } 12 \times 16 \quad z_x = 20.1$$

$$W_{12 \times 19} \quad z_x = 24.7 \text{ in}^3 \quad I_x = 130 \text{ in}^4$$

$$DL = 161.25 + 19 = 180.25 \text{ lb/ft}$$

$$1.2 DL + 1.6 S = 1.2(180.25) + 1.6(316.25) = 216.3 + 506 = 722 \text{ lb/ft}$$

$$M_o = \frac{722(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 974.7 \text{ k-in}$$

$$z_x = \frac{974.7}{(0.9)(50)} = 21.66 \text{ in}^3 \quad 24.7 \text{ in}^3 \geq 21.66 \text{ in}^3 \quad \checkmark$$

Academic Building

Interior ^{Roof} Edge Bay

Exterior Beam

3/2

$$\Delta T \leq \frac{1}{2} \times 3 = 1.5 \text{ in}$$

$$w_T = (28+55)(5.75) + 19 = 496.25 \text{ lb/ft}$$

$$\Delta T = \frac{5w_T L^4}{384 E I_x} = \frac{5(496.25)(30)^4}{384(29000)(130)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 2.455 \not\leq 1.5$$

$$I_{\text{required}} = 130 \left(\frac{2.455}{1.5}\right) = 207.91 \text{ in}^4 \Rightarrow \text{W14} \times 26 \quad I_x = 245 \text{ in}^4$$

$$w_T = (28+55)(5.75) + 26 = 503.25 \text{ lb/ft}$$

$$\Delta T = \frac{5(503.25)(30)^4}{384(29000)(245)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 1.291 \leq 1.5 \quad \checkmark$$

$$\Delta S \leq \frac{1}{360} \text{ or } 1" = 1"$$

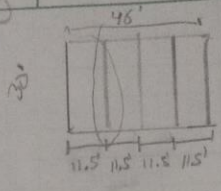
$$w_S = 55(5.75) = 316.25$$

$$\Delta S = \frac{5(316.25)(30)^4}{384(29000)(245)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 0.8117 \leq 1" \quad \checkmark$$

Use W14x26 ✓

Academic Building | Interior ^{Roof} Edge Bay | Interior Beam | 1/2

$E_s = 29,000 \text{ ksi}$ $F_y = 50 \text{ ksi}$



Beam length = 30 ft Spacing = 11.5 ft

- | | | |
|--|---------------|--------------------|
| <u>DL</u> | <u>Lr</u> | <u>S</u> |
| MEP = 8.85 psf
Insulation = 1 psf
Rubber Membrane = 15 psf
Decking = 3.15 psf | Roof = 20 psf | Snow Load = 55 psf |

Tributary Width = $\frac{11.5 \text{ ft} (2)}{2} = 11.5 \text{ ft}$

Loads
 $DL = (8.85 + 1 + 15 + 3.15) 11.5 = 322 \text{ lb/ft}$

$L_r = 20 \times 11.5 = 230 \text{ lb/ft}$

$S = 55 \times 11.5 = 632.5 \text{ lb/ft}$

Load Combinations

$1.4 DL = 1.4 (322) = 450.8 \text{ lb/ft}$

$1.2 DL + 1.6 (L_r \text{ or } S) = 1.2 (322) + 1.6 (230) = 386.4 + 368 = 754.4 \text{ lb/ft}$
 $= 1.2 (322) + 1.6 (632.5) = 386.4 + 1012 = 1398.4 \text{ lb/ft}$

$W_u = 1,398.4 \text{ lb/ft}$

$M_u = \frac{W_u L^2}{8} = \frac{1,398.4 (30)^2}{8} = 155,295 \text{ lb}\cdot\text{ft} \times \frac{1 \text{ kip}}{1000 \text{ lb}} \times \frac{12 \text{ in}}{1 \text{ ft}} = 1863.54 \text{ k}\cdot\text{in}$

$M_u = 1645.68 \text{ k}\cdot\text{in}$

$Z_x \geq \frac{M_u}{\phi F_y} = \frac{1863.54 \text{ k}\cdot\text{in}}{(0.9)(50 \text{ ksi})} = 41.41 \text{ in}^3$

Academic Building

Interior Edge Bay

Interior Beam

3/2

Checks AISC Manual Table 3-2 for min Z_x value greater than 41.47 in^3
(Bdd W shape has lowest weight)

Use W14x30 $Z_x = 47.3 \text{ in}^3$ $I_x = 291 \text{ in}^4$

Add 30 lb/ft to DL

$$DL = 322 + 30 = 352 \text{ lb/ft}$$

$$1.2 DL + 1.6 S = 1.2(352) + 1.6(632.5) = 422.4 + 1012 = 1434.4 \text{ lb/ft}$$

$$w_b = 1434.4 \text{ lb/ft}$$

$$M_u = \frac{w_b L^2}{8} \left(\frac{12}{1000} \right) = \frac{1434.4 (30)^2}{8} \left(\frac{12}{1000} \right) = 1936.44 \text{ k-in}$$

$$Z_x \geq \frac{1936.44}{0.9(50)} = 43.03 \text{ in}^3 \quad 47.3 > 43.03 \quad \checkmark$$

Deflection Checks

$$\Delta T \leq \frac{L}{240}$$

$$w_T = D + S = (28 + 55) 11.5 + 30 = 984.5 \text{ lb/ft}$$

$$\Delta T = \frac{5 w_T L^4}{384 E I_x} = \frac{5 (984.5) (30)^4}{384 (29000) (291)} \left(\frac{\text{lb/ft}}{\text{ksi}} \right) \left(\frac{\text{ft}^4}{\text{in}^4} \right) = 1.23 \text{ in}; \quad \frac{\text{lb/ft}^3}{\text{kip/in}^2} \frac{1 \text{ kip}}{1000 \text{ lb}} \left(\frac{12 \text{ in}}{1 \text{ ft}} \right)^3$$

$$\Delta T = 2.126 \text{ in} \quad L/240 = \frac{30 \text{ ft}}{240} \left(\frac{12 \text{ in}}{1 \text{ ft}} \right) = 1.5 \text{ in} \quad 2.126 \neq 1.5$$

$$\text{Required } I_x = 291 \left(\frac{2.126}{1.5} \right)^4 = 412.47 \text{ in}^4 \rightarrow \text{W18x35} \quad I_x = 510 \text{ in}^4$$

$$w_T = 984.5 + 35 - 30 = 989.5 \text{ lb/ft}$$

$$\Delta T = \frac{5 (989.5) (30)^4}{384 (29000) (510)} \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3 = 1.22 \text{ in} \leq 1.5 \text{ in} \quad \checkmark$$

$$\Delta S \leq \frac{L}{360} \text{ or } 1"$$

$$w_S = 55 (11.5) = 632.5$$

$$\Delta S = \frac{5 (632.5) (30)^4}{384 (29000) (90)} \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3 = 0.78 \quad \frac{L}{360} = \frac{30 (12)}{360} = 1 \quad 0.78 \leq 1 \quad \checkmark$$

$$\text{Use } \text{W18x35} \quad I_x = 510 \text{ in}^4$$

Appendix G.6: Academic Building Third/Second Floor Member Design

Bay 2

Interior Beam - Strength Performance

Loads

Deck	7 psf	} (D)
Slab	38 psf	
CMF	10 psf	
Corridors	60 psf (L)	

Reduced live load: $L = L_0 \left(0.25 + \frac{15}{\sqrt{K_{LL} A_T}} \right)$

$L_0 = 7, A_T = 9.35' \times 35' = 326.55 \text{ ft}^2$

$L = 66.956 \text{ lb}$

Load combinations

- $w_u = 1.40 = [1.4(7 \text{ psf} + 38 \text{ psf} + 10 \text{ psf})] 7.83 \text{ ft}$
 $w_u = 653.1 \text{ lb/ft}$
- $w_u = 1.2D + 1.6L + 0.5(L_r \text{ or } S \text{ or } R)$
 $w_u = [1.2(50 \text{ psf}) + 1.6(66.956 \text{ psf})] 9.33 \text{ ft}$
 $w_u = 1559.32 \text{ lb/ft} \rightarrow \text{governs}$

Calculate M_u

$$M_u = \frac{w_u L^2}{8} = \frac{(1559.32 \text{ lb/ft})(35 \text{ ft})^2}{8} \rightarrow M_u = 2865.25 \text{ k-in}$$

Determine Z_x using, $Z_x \geq \frac{M_u}{\phi F_y}$

$$Z_x \geq \frac{(2865.25 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 63.7 \text{ in}^3$$

Use Table 3-2 to find beam size

From Table 3-2 \rightarrow W18x40 ($Z_x = 78.4 \text{ in}^3$)

Update w_u w/ self-weight

$$w_u = (1559.32 \text{ lb/ft}) + 1.2(40 \text{ lb/ft}) \rightarrow w_u = 1607.32 \text{ lb/ft}$$

Calculate new M_u

$$M_u = \frac{w_u L^2}{8} = \frac{(1607.32 \text{ lb/ft})(35 \text{ ft})^2}{8} \rightarrow M_u = 2453.45 \text{ k-in}$$

check Z_x

$$Z_x \geq \frac{M_u}{\phi F_y} = \frac{(2453.45 \text{ k-in})}{(0.9)(50 \text{ ksi})}$$

$$Z_x \geq 65.6 \text{ in}^3, \quad Z_x \text{ w/ } h=40 = 78.4 \text{ in}^3 \quad \leftarrow$$

W18x40 is OK, but check with all

the possibility of instability of the system

Interior Beam - Deflection Performance

Live Loads

$$\Delta L \leq \frac{L}{360} \text{ or } 1" \text{ max}$$

$$\Delta L = \frac{5 w_L L^4}{384 E I \pi} \quad w_L = \text{corridor load since governs}$$

$$w_L = 0.5(624.70 \text{ lb/ft}) \rightarrow w_L = 312.35 \text{ lb/ft}$$

$$\Delta L = \left(\frac{5(312.35 \text{ lb/ft})(35 \text{ ft})^4 (12 \text{ in/ft})^3}{384(29 \cdot 10^6 \text{ psi})(612 \text{ in}^4)} \right) \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta L = 0.59 \text{ in}$$

$$\frac{L}{360} = \frac{35 \text{ ft} \cdot (12 \text{ in/ft})}{360} = 1.17 \text{ in} \rightarrow \text{use } 1 \text{ in}$$

$$\Delta L = 0.59 \text{ in} < 1 \text{ in} = \frac{L}{360} \quad \checkmark$$

Dead & Live Loads

$$\Delta T \leq \frac{L}{240}$$

$$\Delta T = \frac{5 w_T L^4}{384 E I \pi} \quad w_T = \text{dead \& live load!}$$

$$w_T = 2466.5 \text{ lb/ft} + 40 \text{ lb/ft} + (312.35 \text{ lb/ft}) \rightarrow w_T = 818.85 \text{ lb/ft}$$

$$\Delta T = \left(\frac{5(818.85 \text{ lb/ft})(35 \text{ ft})^4 (12 \text{ in/ft})^3}{384(29 \cdot 10^6 \text{ psi})(612 \text{ in}^4)} \right) \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta T = 1.56 \text{ in}$$

$$\frac{L}{240} = \frac{35 \text{ ft} \cdot (12 \text{ in/ft})}{240} = 1.75 \text{ in}$$

$$\Delta T = 1.56 \text{ in} < 1.75 \text{ in} = \frac{L}{240} \quad \checkmark$$

Use W18x40

Interior Girder - strength Performance

$$A_u = \frac{w_u L}{2}$$

$$A_u = \frac{(1607.32 \text{ lb/ft})(35 \text{ ft})}{2} \rightarrow A_u = 28.128 \text{ k}$$

$$2A_u = 2(28.128 \text{ k}) \rightarrow 2A_u = 56.256 \text{ k}$$

Calculate M_u

$$M_u = P_u = [(56.256 \text{ k})(9.33 \text{ ft})] \frac{\text{ft} \cdot \text{lb}}{\text{ft}}$$

$$M_u = 6298.433 \text{ k-in}$$

Determine Z_x using $Z_x \geq \frac{M_u}{\phi F_y}$

$$Z_x \geq \frac{(6298.433 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 140.0 \text{ in}^3$$

Use Table 3-2 to find girder size

From Table 3-2 \rightarrow W21x62 ($Z_x = 149 \text{ in}^3$)

$$w_{\text{self}} = 1.2(62 \text{ lb/ft}) \rightarrow w_{\text{self}} = 74.4 \text{ lb/ft}$$

$$M_{\text{self}} = \frac{w_{\text{self}} L^2}{8} = \frac{(74.4 \text{ lb/ft})(35 \text{ ft})^2}{8} \rightarrow M_{\text{self}} = 87.494 \text{ k-in}$$

$$M_u = (6298.433 \text{ k-in}) + (87.494 \text{ k-in}) \rightarrow M_u = 6385.927 \text{ k-in}$$

Check Z_x

$$Z_x \geq \frac{(6385.927 \text{ k-in})}{(0.9)(50 \text{ ksi})} \rightarrow Z_x \geq 141.2 \text{ in}^3$$

$$Z_x \text{ required} = 141.2 \text{ in}^3 < 149 \text{ in}^3 = Z_x \quad \text{W21x62}$$

Interior Girder - Deflection Performance

Live Loads (0.5LL)

$$\Delta L \leq \frac{L}{360} \text{ or } 1" \text{ max}$$

$$\Delta L = \left(\frac{P_a}{24EI_x} (3L^2 - 4a^2) \right) \cdot \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta L = \left(\frac{(10.932^k)(9.33 \text{ ft})}{24(29.0 \times 10^6 \text{ psi})(1330 \text{ in}^4)} (3(28 \text{ ft})^2 - 4(9.33 \text{ ft})^2) \right) \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta L = 0.38 \text{ in}$$

$$\frac{L}{360} = \frac{28 \text{ ft} \cdot (12 \text{ in/ft})}{360} = 0.93 \text{ in}$$

$$\Delta L = 0.38 \text{ in} < 0.93 \text{ in} = \frac{L}{360} \quad \checkmark$$

Dead & Live Loads (DL + 0.5LL)

$$\Delta T \leq \frac{L}{240}$$

$$\Delta T = \left(\frac{P_a}{24EI_x} (3L^2 - 4a^2) \right) \cdot \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta T = \left(\frac{(26.85^k)(9.33 \text{ ft})}{24(29.0 \times 10^6 \text{ psi})(1330 \text{ in}^4)} (3(28 \text{ ft})^2 - 4(9.33 \text{ ft})^2) \right) \frac{1728 \text{ in}^3}{1 \text{ ft}^3}$$

$$\Delta T = 0.94 \text{ in}$$

$$\frac{L}{240} = \frac{(28 \text{ ft}) \cdot (12 \text{ in/ft})}{240} = 1.40 \text{ in}$$

$$\Delta T = 0.94 \text{ in} < 1.40 \text{ in} = \frac{L}{240} \quad \checkmark$$

Use W21 x 62

Exterior Girder

Followed same process!

Added exterior enclosure weight:

$$38 \text{ psf (brick veneer)} \cdot 15 \text{ ft (story height)} = 570 \text{ lb/ft}$$

Girder \rightarrow W24 x 84

Appendix G.7: Member Design Around Main Staircase

1/10

Academic Building | Main Stair Beam System

$E_s = 29,000 \text{ ksi}$ $F_y = 50 \text{ ksi}$
 $n_m = 2$ (Interior Beam)

DL **LL**

MEP = 8.85 psf Stairway = 100 psf
 Insulation = 1 psf
 ceiling = 2 psf
 Deck = 5 psf = 40 psf

Tributary width = 30 ft

Loads

$DL = (8.85 + 1 + 2 + 40) (30) = 1555.5 \text{ lb/ft}$
 $LL = (100) (30) = 3000 \text{ lb/ft}$
 Do not use Live Load Reduction for stairways

Load Combinations

$1.4 DL = 1.4 (1555.5) = 2177.7 \text{ lb/ft}$
 $1.2 DL + 1.6 LL = 1.2 (1555.5) + 1.6 (3,000) = 6,666.6 \text{ lb/ft}$
 $w_u = 5,042.89 \text{ lb/ft}$

$M_u = \frac{w_u L^2}{8} = \frac{(6,666.6) (22)^2}{8} \left(\frac{1 \text{ k}}{1000 \text{ lb}} \right) \left(\frac{12 \text{ in}}{1 \text{ ft}} \right) = 4,839.95 \text{ k-in}$
 $M_u = 4,839.95 \text{ k-in}$

$Z_x \geq \frac{M_u}{\phi F_y} = \frac{(4,839.95)}{(0.9) (50)} = 107.55 \text{ in}^3$

$22'$
 $15'$ $15'$
 $30'$
 $11'$ $11'$

Academic Building

Main Stair Beam System

2/10/0

Check AISI Table 3-2 for min Z_x value greater than 107.55 in^3
(Bold WShape has lowest weight)

Use W21x50 $Z_x = 110 \text{ in}^3$ $I_x = 984 \text{ in}^4$

Add 50 lb/ft to DL

$$DL = (1555.5 + 50) = 1605.5 \text{ lb/ft}$$

$$1.2DL + 1.6LL = 1.2(1605.5) + 1.6(3000) = 1926.6 + 4800 = 6726.6 \text{ lb/ft}$$

$$M_o = \frac{6726.6 (22)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 4883.51 \text{ ft}\cdot\text{in}$$

$$Z_x = \frac{4883.51}{(0.9)(50)} = 108.52 \text{ in}^3 \quad 110 \text{ in}^3 > 108.52 \text{ in}^3 \quad \checkmark$$

Deflection Checks

$$\Delta_T \leq \frac{L}{240} = \frac{22(12)}{240} = 1.1 \text{ in}$$

$$W_T = D + 0.5L = (1605.5) + 0.5(3000) \\ W_T = (1605.5) + (1500) = 3105.5 \text{ lb/ft}$$

$$\Delta_{max} = \frac{5W_T L^4}{384EI_x} = \frac{5(3105.5)(22)^4}{384(29000)(984)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 0.574 \text{ in} \leq 1.1 \text{ in} \quad \checkmark$$

$$\Delta_L \leq \frac{L}{360} = \frac{22(12)}{360} = 0.733 \text{ in}$$

$$W_L = 0.5L = 1500 \text{ lb/ft}$$

$$\Delta_{max} = \frac{5(1500)(22)^4}{384(29000)(984)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 0.277 \text{ in} \leq 0.733 \text{ in} \quad \checkmark$$

Use W21x50 member for the horizontal beam

Academic Building

Main Stair Beam System

w/ Elevators

3/10

W2-bx12

$4 \times 6 = 56 \text{ sq}$

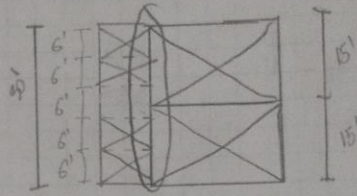
$E_s = 29,000 \text{ ksi}$ $F_y = 50 \text{ ksi}$

$K_{Lz} = 2$ (Interior Beam)

Beam Length = 30'

Tributary width = $\frac{9.33}{2} = 4.665'$

1 point load at midpoint



Right Side

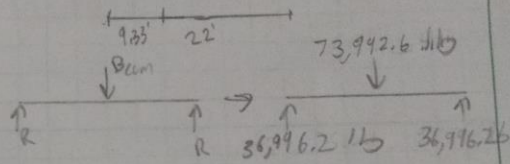
Concentrated Load

$W_o = 6726.6 \text{ lb/ft}$

Beam = $6726.6 \left(\frac{22}{2}\right) = 73,992.6 \text{ lb}$

$R = \frac{\text{Beam}}{2} = \frac{73,992.6}{2} = 36,996.3 \text{ lb}$

$M_u = \frac{PL}{4} = \frac{73,992.6 (30)}{4} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 6,659.33 \text{ k-in}$



Left Side

Distributed Load

- DL
- MEP = 8.85 psf
- Insulation = 1 psf
- Ceiling = 2 psf
- Decking + Slab = 40 psf

- 1st floor corridor = 100 psf
- 2nd floor corridor = 80 psf

$DL = (8.85 + 1 + 2 + 40) (4.665) = 241.88 \text{ lb/ft}$

$LL_{1st} = 100 (4.665) = 466.5 \text{ lb/ft}$

$LL_{2nd} = 80 (4.665) = 373.2 \text{ lb/ft}$

Load Combinations

$1.2 DL + 1.6 LL_{1st} = 1.2(241.88) + 1.6(466.5) = 290.26 + 746.4 = 1036.66 \text{ lb/ft}$

$1.2 DL + 1.6 LL_{2nd} = 1.2(241.88) + 1.6(373.2) = 290.26 + 597.12 = 887.38 \text{ lb/ft}$

Academic Building

Main Stair Beam System

w/Elevators

4/10

Design Elevator Cars as 9' x 6'

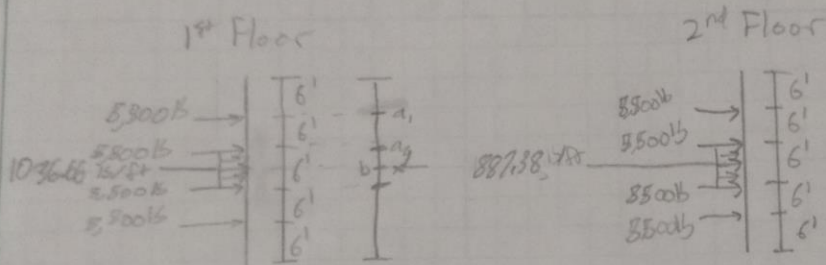
Area
 $9 \times 6 = 54 \text{ sq ft}$

Using ASME A17.1-2007/CSA B74-07 Figure 8.2.1.2

Minimum Rated Load for Passenger Elevators

$54 \text{ sq ft} \rightarrow (5,500 \text{ lbs}) \quad LL = 1.6(5500) = 8800$

Placing loads at location causing Max Moment and Deflection



First Floor Moment

$$M_{max} = P_{a1} + P_{a2} + R_1 \left(a_2 + \frac{R_1}{2w} \right) (5,500)(6) + (8,800)(6+6) + \left(\frac{10,366(6)}{2} \right) \left((6+6) + \frac{R_1}{2(10,366)} \right)$$

$$M_{max} = 52,800 + 105,600 + 3109.98 (12+1.5) = 158,400 + 41,984.73$$

$$M_{max} = 200,384.73 \text{ lb}\cdot\text{ft} \left(\frac{1 \text{ ft}}{1000 \text{ lb}} \right) \left(\frac{12 \text{ in}}{1 \text{ ft}} \right) = 2,404.62 \text{ k}\cdot\text{in}$$

Second Floor Moment

$$M_{max} = 158,400 + \left(\frac{88,738(6)}{2} \right) \left((6+6) + \frac{R_1}{2w} \right) = 158,400 + (2662.14)(12+1.5)$$

$$M_{max} = 158,400 + 35,938.89 = 194,338.89 \text{ lb}\cdot\text{ft} \left(\frac{1 \text{ ft}}{1000} \right) \left(\frac{12}{1} \right) = 2,332.07 \text{ k}\cdot\text{in}$$

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Main Stair Beam system w/ Elevators

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Total Moment

1st Floor

$$M = 6,659.33 + 2,404.62$$

$$M = 9,063.95 \text{ k-in}$$

$$z_x = \frac{M_u}{\phi F_y} = \frac{9,063.95}{0.9(50)} = 201.42$$

$$\underline{W24 \times 84} \quad z_x = 224 \text{ in}^3$$

$$I_x = 2370 \text{ in}^4$$

2nd Floor

$$M = 6,659.33 + 2,332.07$$

$$M = 8,991.4 \text{ k-in}$$

$$z_x = \frac{8,991.4}{0.9(50)} = 199.81 \text{ in}^3$$

$$\underline{W24 \times 84} \quad z_x = 224 \text{ in}^3$$

$$I_x = 2370 \text{ in}^4$$

Add 84 lb-ft DL

$$DL = 1/2(84) = 42 \text{ lb-ft}$$

$$M_u = \frac{100.8(50)}{8} = 11,340 \text{ lb-ft}$$

$$= 136.08 \text{ k-in}$$

1st Floor

$$M = 9,063.95 + 136.08 = 9,200.03 \text{ k-in}$$

$$z_x = \frac{9,200.03}{0.9(50)} = 204.44 \leq 224 \text{ in}^3$$

2nd Floor

$$M = 8,991.4 + 136.08 = 9,127.48 \text{ k-in}$$

$$z_x = \frac{9,127.48}{0.9(50)} = 202.81 \leq 224 \text{ in}^3$$

Deflection

From Elevators for Tall Buildings by Tomquist $\Delta_{max} = L/1666$

$$\Delta_{max} = \frac{30}{1666} \left(\frac{12}{1}\right) = 0.2161 \text{ in}$$

$$\Delta_{max} = \frac{5w_u L^4}{384EI} + \frac{w_b}{384EI} (8L^3 - 4b^2L + b^3) + \frac{P_1 a_1}{6EI} (3Lx - 3x^2 - a_1^2)$$

$$+ \frac{P_2 a_2}{6EI} (3Lx - 3x^2 - a_2^2) + \frac{P_2 L^3}{48EI}$$

1st Floor

$$w_T = 84 \text{ lb-ft}$$

$$U = 241.88 + 0.5(116.5) = 475.13 \text{ lb-ft}$$

$$P_1 = 0.5(5500) = 2750 \text{ lb}$$

$$P_2 = \frac{3105.5(22)}{2} = 34160.5 \text{ lb}$$

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$$\Delta_{max} = \frac{5(84)(30)^4}{384(29000)(2370)} + \frac{(475.13)(6)}{384(29000)(2370)} (8(30)^3 - 4(6)^2(30) + 6^3) +$$

$$\frac{(2750)(6)}{6(29000)(2370)} (3(30)(15) - 3(15)^2 - (6)^2) +$$

$$\frac{(2750)(12)}{6(29000)(2370)} (3(30)(15) - 3(15)^2 - (12)^2) + \frac{(34,160.5)(30)^3}{48(29000)(2370)}$$

$$\left(\frac{1728 \text{ in}^3}{1 \text{ kip}} \right) \left(\frac{1 \text{ kip}}{1000 \text{ lb}} \right)$$

$$\Delta_{max} = (0.01289 + 0.02289 + 0.02557 + 0.04249 + 0.2796) (1728) \left(\frac{1}{1000} \right)$$

$$\Delta_{max} = (0.3834) \left(\frac{1728}{1000} \right) = 0.6626 \text{ in} > 0.2161$$

$$I_x \text{ needed} = 2370 \left(\frac{0.6626}{0.2161} \right) = 7266.66 \text{ in}^4 \rightarrow \text{W36} \times 135 \quad I_x = 7800 \text{ in}^4$$

$$w_f = 135 \text{ lb}$$

$$\Delta_{max} = \left(\frac{5(135)(30)^4}{384(29000)(7800)} + 0.02289 \left(\frac{2370}{7800} \right) + 0.02557 \left(\frac{2370}{7800} \right) + \right.$$

$$\left. 0.04249 \left(\frac{2370}{7800} \right) + 0.2796 \left(\frac{2370}{7800} \right) \right) \left(\frac{1728}{1000} \right)$$

$$\Delta_{max} = (6.29 \times 10^{-4} + 0.00696 + 0.00777 + 0.01291 + 0.08496) (1.728)$$

$$\Delta_{max} = 0.1957 \text{ in} \leq 0.2161 \text{ in} \checkmark$$

Use W36 x 135

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Second Floor

$$w_T = 84 \text{ lb/ft}$$

$$w = 241.88 + 0.5(373.2) = 428.48$$

$$\Delta_{max} = \left(\frac{5(84)(30)^4}{384(29000)(2370)} + \frac{(428.48)(6)(8(30)^3 - 4(6)^2(30) + (6)^3)}{384(29000)(2370)} \right) +$$

$$\frac{(2750)(6)(3(30)(15) - 3(15)^2 - (6)^2)}{6(29000)(2370)}$$

$$\frac{(2750)(12)(3(30)(15) - 3(15)^2 - (12)^2)}{6(29000)(2370)} + \frac{(34,160.5)(30)^3}{48(29000)(2370)}$$

$$\left(\frac{1728 \text{ in}^3}{1553} \right) \left(\frac{1 \text{ kip}}{1000 \text{ lb}} \right)$$

$$A_{max} = (0.01289 + 0.02064 + 0.02557 + 0.04249 + 0.2796)(1.728)$$

$$\Delta_{max} = 0.6587 \text{ in} > 0.2161 \text{ in}^s$$

$$I_x \text{ needed} = 2370 \left(\frac{0.6587}{0.2161} \right) = 7224.06 \text{ in}^4 \Rightarrow \underline{W36 \times 135} \quad I_x = 7800$$

$$\Delta_{max} = (6.29e^{-1} + 0.00627 + 0.00777 + 0.01291 + 0.08496)(1.728)$$

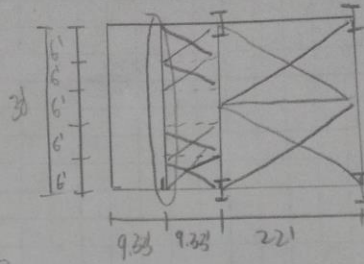
$$\Delta_{max} = (0.12523)(1.728) = 0.1945 \text{ in} < 0.2161 \text{ in} \checkmark$$

$$E_s = 29,000 \text{ ksi} \quad F_y = 50 \text{ ksi}$$

$$K_{LZ} = 2 \text{ (Girder Beam)}$$

$$\text{Beam Length} = 30'$$

$$\text{Tributary width (left side)} = \frac{9.33'}{2} = 4.665'$$



Right side same as left side from previous beam

Left side

Distributed Loads

DL

$$\begin{aligned} \text{MEP} &= 8.85 \text{ psf} \\ \text{Insulation} &= 1 \text{ psf} \\ \text{Ceiling} &= 2 \text{ psf} \\ \text{Decking + Slab} &= 40 \text{ psf} \end{aligned}$$

LL

$$\begin{aligned} 1^{\text{st}} \text{ Floor} &= 100 \text{ psf} \\ 2^{\text{nd}} \& 3^{\text{rd}} \text{ Floor} &= 80 \text{ psf} \end{aligned}$$

$$DL = (8.85 + 1 + 2 + 40)(4.665) = 241.86 \text{ lb/ft}$$

$$LL_{1st} = 100(4.665) = 466.5 \text{ lb/ft}$$

$$LL_{2nd} = 80(4.665) = 373.2 \text{ lb/ft}$$

Load Combinations

$$1.2DL + 1.6LL_{1st} = 1036.66 \text{ lb/ft}$$

$$1.2DL + 1.6LL_{2nd} = 687.38 \text{ lb/ft}$$

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Main Stair Beam System w/Elevators

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First Floor Moment

$$M_{max} = \frac{w_0 L^2}{8} = \frac{(1036.66)(30^2)}{8} \left(\frac{12}{1000} \right) = 1399.991 \text{ k}\cdot\text{in}$$

2nd Floor Moment

$$M_{max} = \frac{(887.38)(30^2)}{8} \left(\frac{12}{1000} \right) = 1197.963 \text{ k}\cdot\text{in}$$

Total Moment

1st Floor

$$M = 1399.991 + 2404.62$$

$$M = 3804.61 \text{ k}\cdot\text{in}$$

$$z_x \geq \frac{3804.61}{0.9(50)} = 84.54 \text{ in}^3$$

2nd Floor

$$M = 1197.963 + 2332.07$$

$$M = 3530.03 \text{ k}\cdot\text{in}$$

$$z_x \geq \frac{3530.03}{0.9(50)} = 78.45 \text{ in}^3$$

USE W 21x44 $z_x = 95.4 \text{ in}^3$ $I_x = 893 \text{ in}^4$

$$DL = 12(44) = 52.8 \text{ W}\cdot\text{ft}$$

$$w_0 = 1036.66 + 52.8 = 1089.46 \text{ lb}\cdot\text{ft}$$

$$M_{max} = 1470.77 \text{ k}\cdot\text{in}$$

$$M = 1470.77 + 2404.62 = 3875.39$$

$$z_x \geq \frac{3875.39}{0.9(50)} = 86.12 \text{ in}^3 \leq 95.4 \text{ in}^3 \checkmark$$

$$w_0 = 887.38 + 52.8 = 940.18 \text{ lb}\cdot\text{ft}$$

$$M_{max} = 1269.24 \text{ k}\cdot\text{in}$$

$$M = 1269.24 + 2332.07 = 3601.31$$

$$z_x \geq \frac{3601.31}{0.9(50)} = 80.03 \leq 95.4 \checkmark$$

$$\Delta_{max} = L/1666 = 0.2161 \text{ in}$$

1st Floor

$$w_T = 241.88 + 44 + 0.5(466.5) = 519.13 \text{ lb}\cdot\text{ft}$$

2nd Floor

$$w_T = 241.88 + 44 + 0.5(373.2) = 472.48$$

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Main Stair Beam System w/ Elevators

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1st Floor

$$\Delta_{max} = \left(\frac{5(519.13)(30^4)}{384(29000)(843)} + (0.02964 + 0.03311 + 0.05504) \left(\frac{1830}{843} \right) \right) \left(\frac{1}{1000} \right) \left(\frac{1728}{1} \right)$$

$$\Delta_{max} = (0.224 + (0.1178)(2.171)) (1.728) = (0.224 + 0.2557)(1.728)$$

$$\Delta_{max} = (0.4797)(1.728) = 0.829 \text{ in} \geq 0.2161 \text{ in}$$

$$I_x \text{ needed} = 843 \left(\frac{0.829}{0.2161} \right) = 3233.75 \text{ in}^4 \rightarrow W 30 \times 99 \quad I_x = 3990 \text{ in}^4$$

$$w_T = 519.13 - 44 + 99 = 574.13 \text{ lb/ft}$$

$$\Delta_{max} = \left(\frac{5(574.13)(30^4)}{384(29000)(3990)} + (0.2557) \left(\frac{843}{3990} \right) \right) (1.728)$$

$$\Delta_{max} = (0.0523 + 0.054) (1.728) = (0.10632) (1.728)$$

$$\Delta_{max} = 0.18373 \leq 0.2161 \quad \checkmark \quad \text{Use } W 30 \times 99$$

2nd Floor

$$\Delta_{max} = \left(\frac{5(472.48)(30^4)}{384(29000)(843)} + (0.02673 + 0.03311 + 0.06503) \left(\frac{1830}{843} \right) \right) \left(\frac{1}{1000} \right) \left(\frac{1728}{1} \right)$$

$$\Delta_{max} = (0.20384 + (0.11487)(2.171)) (1.728) = (0.20384 + 0.24936)(1.728)$$

$$\Delta_{max} = (0.4532)(1.728) = 0.7831 \text{ in} \geq 0.2161 \text{ in} \quad \checkmark$$

$$I_x \text{ needed} = 843 \left(\frac{0.7831}{0.2161} \right) = 3054.98 \text{ in}^4 \rightarrow \underline{W 30 \times 99}$$

Appendix G.8: Member Design Around Egress Staircase

Academic Building | Egress Stair System | 1/8

$E_s = 29,000$ $F_y = 50 \text{ ksi}$
 $K_{LL} = 2$ (interior beam)
 Beam Length = 23 ft
 Tributary Width = $8.25' + \frac{13.5'}{2} = 15 \text{ ft}$

DL LL
 MEP = 8.85 psf Stairs = 100 psf
 Insulation = 1 psf
 Ceiling = 2 psf
 Decking + slab = 40 psf

$LL_{reduced} = LL \left(0.25 + \frac{15}{8 K_{LL} A_T} \right)$
 $K_{LL} = 2$ for interior beams
 $A_T = 23' \times 15'$

Loads

$DL = (8.85 + 1 + 2 + 40) \times (15) = 777.75 \text{ lb/ft}$
 $LL = (100) \times (15) = 1500 \text{ lb/ft}$
 Don't reduce live load due to stairs being egress path

Load Combinations

$1.4 DL = 1.4(777.75) = 1,088.85 \text{ lb/ft}$
 $1.2 DL + 1.6 LL = 1.2(777.75) + 1.6(1,500) = 933.3 + 2,400 = 3,333.3 \text{ lb/ft}$
 $W_u = 3,333.3 \text{ lb/ft}$

Max Moment

$M_u = \frac{W_u L^2}{8} = \frac{(3,333.3)(23^2)}{8} \left(\frac{1 \text{ k}}{1000 \text{ lb}} \right) \left(\frac{12 \text{ in}}{1 \text{ ft}} \right) = 2,644.97 \text{ k-in}$
 $z_x \geq \frac{M_u}{\phi F_y} = \frac{2,644.97}{(0.9)(50)} = 58.27 \text{ in}^3$

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Check AISC Manual Table 3-2 for min Z_x value greater than 58.77 in^3 (Add W shape has lowest weight)

Use W18x35 $Z_x = 66.5 \text{ in}^3$ $I_x = 510 \text{ in}^4$

Add 31 $\frac{1}{8}$ " DL

$$DL = 777.75 + 35 = 812.75 \text{ lb/ft}$$

$$12 \text{ DL} + 1.6 \text{ LL}_{\text{unfactored}} = 1.2(812.75) + 3400(1.16) = 3375.3 \text{ lb/ft}$$

$$M_U = \frac{3375.3(23)^2}{6} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 2678.3 \text{ kip}$$

$$Z_x \geq \frac{2678.3}{(0.9)(50)} = 59.52 \text{ in}^3 \leq 66.5 \text{ in}^3 \checkmark$$

Deflection Checks

$$\Delta T \leq \frac{L}{240} = \frac{23(12)}{240} = 1.15 \text{ in}$$

$$W_T = D + 0.5L = 812.75 + 0.5(1500) = 1562.75 \text{ lb/ft}$$

$$\Delta T = \frac{5W_T L^4}{384EI_x} = \frac{5(1562.75)(23)^4}{384(29000)(510)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 0.6653 \text{ in} \leq 1.15 \text{ in} \checkmark$$

$$\Delta LL \leq \frac{L}{360} = \frac{23(12)}{360} = 0.767 \text{ in}$$

$$W_L = 0.5(1500) = 750 \text{ lb/ft}$$

$$\Delta LL = \frac{5(750)(23)^4}{384(29000)(510)} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right)^3 = 0.3193 \text{ in} \leq 0.767 \text{ in} \checkmark$$

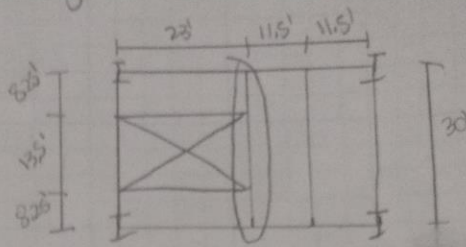
Use W18x35 member for these horizontal beams

Academic Building / Egress Stair System

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$E_s = 29,000 \text{ ksi}$ $F_y = 50 \text{ ksi}$
 $K_{L2} = 2$ (interior beam)

Beam length = 30'
 Tributary width = $\frac{115'}{2} = 5.75'$
 2 symmetrical point loads

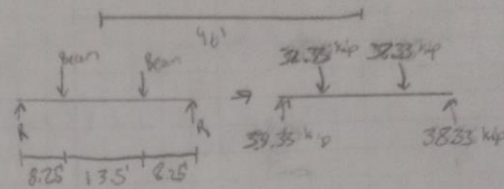


Concentrated Loads

$W_o = 3,833.3 \text{ lbs/ft}$

Beam = $W_o \cdot \frac{B_w}{2} = (3,833.3) \cdot \left(\frac{115'}{2}\right) = 38,332.95 \text{ lb}$

$M_o = P_o = 38.3 (8.25) \left(\frac{3}{2}\right) = 3,795 \text{ kip}$



$LL \text{ reduction} = LL \left(0.75 + \frac{15}{\sqrt{K_{L2} L_n}}\right)$

Distributed Load

DL
 MEP = 8.85 psf
 Finishes = 1 psf
 Ceiling = 2 psf
 Decking + Slab = 40 psf

LL
 1st floor corridor = 100 psf
 2nd & 3rd floor corridors = 80 psf

$K_{L2} = 2$ for interior beam

DL
 $DL = (8.85 + 1 + 2 + 40) (5.75) = 298.14 \text{ lb/ft}$

$LL_{1st} = (100) (5.75) = 575 \text{ lb/ft}$

Don't reduce first floor load due to it being an egress exit

$LL_{2nd} = (80) (5.75) = 460 \text{ lb/ft}$
 $LL_{2nd \text{ reduced}} = \left(0.75 + \frac{15}{\sqrt{10} (5.75) (30)}\right) (80) (5.75) = 466.48 \text{ lb/ft}$

Load Combinations

$1.2 DL + 1.6 LL_{1st} = 1.2 (298.14) + 1.6 (575) = (357.77) + (920) = 1277.77$

$1.2 DL + 1.6 LL_{2nd} = 1.2 (298.14) + 1.6 (460) = (357.77) + (736) = 1093.77$

$W_{1st} = 1277.77 \text{ lb/ft}$ $W_{2nd} = 1093.77 \text{ lb/ft}$

$$\Delta T \leq \frac{270}{240} = 1.125$$

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$$M_{U_{1st}} = \frac{(1227.77)(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 1,724.99 \text{ k-in}$$

$$M_{U_{2nd}} = \frac{(1,093.77)(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 1,476.59 \text{ k-in}$$

Total Moments

1st Floor
 $M_{U_{concentrated}} + M_{U_{distributed}} = 3,795.11 + 1,724.99 = 5,519.99 \text{ k-in}$

2nd Floor
 $M_{U_{concentrated}} + M_{U_{distributed}} = 3,795.11 + 1,476.59 = 5,271.59 \text{ k-in}$

$$Z_{x_1} = \frac{(5,519.99)}{(0.9)(50)} = 122.67 \text{ in}^3$$

$$Z_{x_{2nd}} = \frac{(5,271.59)}{(0.9)(50)} = 117.15 \text{ in}^3$$

1st Floor

Use W21x55 $Z_x = 126 \text{ in}^3$ $I_x = 1140 \text{ in}^4$

Add 55 lb/ft to DL

$$DL = 298.14 \text{ lb/ft} + 55 = 353.14 \text{ lb/ft}$$

$$1.2 DL + 1.6 LL = 1.2(353.14 \text{ lb/ft}) + (920) = (423.77) + (920) = 1343.77 \text{ lb/ft}$$

$$M_U = \frac{(1343.77)(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 1814.09 \text{ k-in}$$

$$M_{Total} = (1814.09) + (3,795.11) = 5,609.09 \text{ k-in}$$

$$Z_x = \frac{5,609.09}{(0.9)(50)} = 124.65 \quad 126 \geq 124.65 \text{ in}^3 \checkmark$$

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Egress Stair System

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$$\Delta T \leq \frac{L}{240} = \frac{30(12)}{240} = 1.5 \text{ in}$$

$$W_T = DL + 0.5LL = (353.14) + 0.5(575)$$

$$W_T = 640.64 \text{ lb/ft}$$

$$\Delta_{max} = \frac{P_a}{24EI} (3L^2 - 4a^2) + \frac{5W_T L^4}{384EI}$$

$$P = (212.75 + 0.5(1500)) \frac{23}{2} = 1797.6$$

$$\Delta_{max} = \left(\frac{(1797.6)(8.25)}{24(29000)(1140)} (3(30)^2 - 4(8.25)^2) \right) + \left(\frac{5(640.64)(30)^4}{384(29000)(1140)} \right) \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3$$

$$\Delta_{max} = 0.784 + 0.3517 = 1.137 \text{ in} \leq 1.5 \text{ in} \checkmark$$

$$\Delta L \leq \frac{L}{360} = \frac{30(12)}{360} = 1 \text{ in}$$

$$W_L = 0.5LL = 0.5(575) = 287.5 \text{ lb/ft}$$

$$P = 0.5(1500) \frac{23}{2} = 8625$$

$$\Delta_{max} = \left(\frac{(8625)(8.25)}{24(29000)(1140)} (3(30)^2 - 4(8.25)^2) \right) + \left(\frac{5(287.5)(30)^4}{384(29000)(1140)} \right) \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3$$

$$\Delta_{max} = 0.3761 + 0.159 = 0.535 \text{ in} \leq 1 \text{ in} \checkmark$$

Use W21x55 for vertical beam on 1st Floor

2nd Floor

Use W21x55 $z_x = 126 \text{ in}^3$ $I_x = 1140 \text{ in}^4$

Add 55 lb/ft to DL

$$DL = 298.14 + 55 = 353.14 \text{ lb/ft}$$

$$1.2DL + 1.6LL = 1.2(353.14) + (736) = (423.77) + (736) = 1159.77 \text{ lb/ft}$$

$$M_U = \frac{(1159.77)(30)^2}{8} \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right) = 1565.69 \text{ k-in}$$

$$M_{total} = (1565.69) + (3,795.15) = 5360.69 \text{ k-in}$$

$$z_x \geq \frac{5360.69}{(0.9)(50)} = 119.13 \text{ in}^3 \quad 126 \geq 119.13 \checkmark$$

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Egress Stair System

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$$\Delta_T \leq \frac{L}{240} = \frac{30(12)}{240} = 1.5 \text{ in}$$

$$W_T = 0L + 0.5LL = (353.14) + 0.5(460)$$

$$W_T = 583.14 \text{ lb/ft}$$

$$P = ((812.75) + 0.5(1500)) \frac{23}{2} = 17,971.6$$

$$\Delta_{max} = \left(\left(\frac{(17,971.6)(8.25)}{24(29,000)(1140)} (3(30)^2 - 4(8.25)^2) \right) + \left(\frac{5(583.14)(30)^4}{384(29,000)(1140)} \right) \right) \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3$$

$$\Delta_{max} = 0.784 + 0.3215 = 1.105 \text{ in} \leq 1.5 \text{ in} \checkmark$$

$$\Delta_{LL} \leq \frac{L}{360} = \frac{30(12)}{360} = 1 \text{ in}$$

$$W_{LL} = 0.5LL = 0.5(460) = 230 \text{ lb/ft}$$

$$P = 0.5(1500) \frac{23}{2} = 8625.17 \text{ lb}$$

$$\Delta_{max} = \left(\left(\frac{(8625)(8.25)}{24(29,000)(1140)} (3(30)^2 - 4(8.25)^2) \right) + \left(\frac{5(230)(30)^4}{384(29,000)(1140)} \right) \right) \left(\frac{1}{1000} \right) \left(\frac{12}{1} \right)^3$$

$$\Delta_{max} = 0.376 + 0.1265 = 0.502 \text{ in} \leq 1 \text{ in} \checkmark$$

Use W21x55 for vertical beam on 2nd & 3rd floors

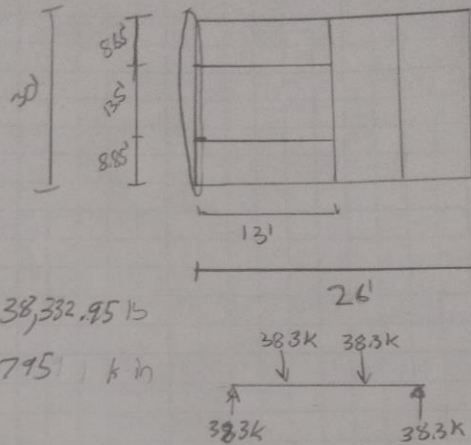
Academic Building | Egress Stair System

7/8

$E_s = 29,000 \text{ ksi}$ $F_y = 50 \text{ ksi}$

Beam Length = 30'

2 symmetrical point loads



Concentrated loads

$w_u = 3,333.3 \text{ lb/ft}$

Beam $P_u = w_u \frac{L}{2} = 13,333.3 \left(\frac{23}{2}\right) = 38,332.95 \text{ lb}$

$M_u = P_u = 38.3 (8.25) \left(\frac{12}{1}\right) = 3,795.1 \text{ k.in}$

Distributed Load

Enclosure = 38 psf \times height = 15 ft = 570 lb/ft

1.2 DL = 1.2(570) = 684 lb/ft

$M_u = \frac{(684)(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 923.4 \text{ k.in}$

$M_{Total} = 3,795.1 + 923.4 = 4,718.4 \text{ k.in}$

$Z_x \geq \frac{4,718.4}{(0.9)(50)} = 104.85 \text{ in}^3 \rightarrow W21 \times 50 \quad Z_x = 110 \text{ in}^3 \quad I_x = 984 \text{ in}^4$

Add 50 lb/ft DL

DL = 684 + 1.2(50) = 684 + 60 = 744 lb/ft

$M_u = \frac{744(30)^2}{8} \left(\frac{1}{1000}\right) \left(\frac{12}{1}\right) = 1004.4 \text{ k.in}$

$M_{Total} = 3,795.1 + 1004.4 = 4,799.4 \text{ k.in}$

$Z_x \geq \frac{4,799.4}{0.9(50)} = 106.65 \text{ in}^3 < 110 \text{ in}^3 \checkmark$

Academic Building | Egress Stair System

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$\Delta T \leq \frac{L}{240} = 1.5 \text{ in}$ $w_T = PL = 570 \times 50 = 620 \text{ lbs/ft}$

$\frac{P_u}{2.162} (3L^2 - 4a^2) \left(\frac{1}{1000}\right) \left(\frac{1728}{1}\right) = 0.908 P = ((12.75) + 0.5(1500)) \left(\frac{23}{2}\right) = 17,971.6 \text{ lb}$

$\Delta_{max} = (0.908) + \left(\frac{5(620)(30^3)}{384(29000)(989)} \right) \left(\frac{1}{1000} \right) \left(\frac{1728}{1} \right)$

$\Delta_{max} = (0.908) + (0.396) = 1.304 \text{ in} \leq 1.5 \text{ in} \checkmark$

$\Delta LL \leq \frac{L}{360} = 1 \text{ in}$

$P = 0.5(1500) \left(\frac{23}{2}\right) = 8625 \text{ lb}$

$\Delta_{max} = 0.436 \text{ in} \leq 1 \text{ in} \checkmark$ $\Delta LL = \frac{(8625)(8.25)}{24(29000)(989)} (3(30^2) - 4(8.25^2)) \left(\frac{1}{1000}\right) \left(\frac{1728}{1}\right)$

Use W21x50

$\Delta LL = 0.436$

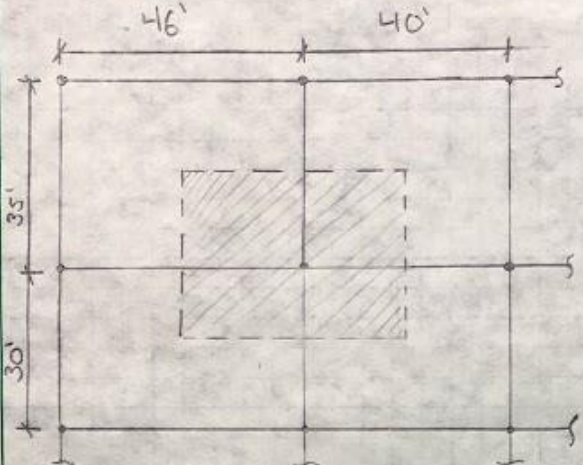
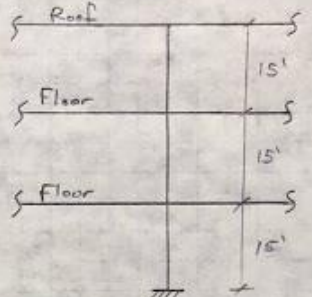
Appendix H: Column Design

Appendix H.1: Column Excel Document Design Aid

Column Bay Properties:	D	Units		Selected Section Properties:		Units
Tributary Width	43	ft		Column Height	15	ft
Tributary Length	32.5	ft		Section	W12x72	
Total beam length enclosed	162.5	ft		Self Weight	72	lb/ft
Total girder length enclosed	43	ft		ry	3.04	in
Beam self weight	99	lb/ft		rx	5.32	in
Girder self weight	135	lb/ft		Fy	50	ksi
Total exterior length	0	ft		Es	29000	ksi
				Ag	21.1	in ²
Dead Loads:		Units		Factored Pu w/ Self Weight	697.8246	kips
MEP	8.85	psf				
Concrete Slab+Decking	40	psf		KL/r Check		Units
Ceiling+Insulation	3	psf		Governing L/r Value	59.211	
Exterior Enclosure	570	lb/ft		4.71*sqrt(E/Fy)	113.432	
Roof Dead Load	15	psf		Long or Short Column?	Short	
TOTAL DEAD LOAD	248.12	kips		Fe	81.639	ksi
Live Loads:		Units		Short Calculation		Units
Service Load	80	psf		Fcr	38.694	ksi
TOTAL LIVE LOAD	223.6	kips		Pcr	734.7969867	kips
Other Loads:		Units		Long Calculation		Units
Snow	55	psf		Fcr	71.598	ksi
TOTAL SNOW LOAD	76.86	kips		Pcr	1359.639348	kips
Total Factored Pu (for 2 floors)	693.94	kips				
Consult Table 4-1a in AISC Manual						

Appendix H.2: Column Design Hand Calculations

Column Design
Bay D.
1/4

Tributary Width = 43 feet
 Tributary Length = 32.5 feet
 Total enclosed beam length = (5) (32.5') = 162.5 feet
 Total enclosed Girder length = (1) (43') = 43 feet
 Max enclosed beam self weight = 99 lb/ft
 Max enclosed girder self weight = 135 lb/ft

Loads:

<p><u>Dead Loads:</u></p> <ul style="list-style-type: none"> MEP = 8.85 psf Concrete slab + Decking = 40 psf Ceiling + Insulation = 3 psf Exterior Enclosure = 570 lb/ft Roof Dead Load = 15 psf 	<p><u>Live Loads:</u></p> <ul style="list-style-type: none"> Service Load = 80 psf <p><u>Other:</u></p> <ul style="list-style-type: none"> Snow Load = 55 psf
---	---

* Design will be carried out for the 1st Floor columns and the same member size will be used in each story for ease of design. *

Dead Load Calculation:

$$\begin{aligned}
 DL &= [(8.85 \text{ psf} + 3 \text{ psf}) (43 \text{ ft} \times 32.5 \text{ ft}) (3)] \\
 &\quad + [((162.5 \text{ ft} \times 99 \text{ lb/ft}) + (43 \text{ ft} \times 135 \text{ lb/ft})) (3)] \\
 &\quad + [(40 \text{ psf}) (43 \text{ ft} \times 32.5 \text{ ft}) (2)] \\
 &\quad + [(15 \text{ psf}) (43 \text{ ft} \times 32.5 \text{ ft})]
 \end{aligned}$$

$$DL = 248120 \text{ lb} = 248.12 \text{ K}$$

Live Load Calculation:

$$LL = (80 \text{ psf}) (43 \text{ ft} \times 32.5 \text{ ft}) (2)$$

$$LL = 223600 \text{ lb} = 223.6 \text{ K}$$

Snow Load Calculation:

$$S = (55 \text{ psf}) (43 \text{ ft} \times 32.5 \text{ ft})$$

$$S = 76862.5 \text{ lb} = 76.86 \text{ K}$$

Governing Load Combination: $1.2DL + 1.6LL + 0.5S$

$$P_u = 1.2(248.12 \text{ K}) + 1.6(223.6 \text{ K}) + 0.5(76.86 \text{ K})$$

$$\underline{\underline{P_u = 693.94 \text{ K}}}$$

Consult Table 4-1a in AISC Manual

Column Design | Bay D

3/4

Select W12x72

Section Properties:

$$\text{Self Weight} = 72 \text{ lb/ft}$$

$$r_y = 3.04 \text{ in}$$

$$r_x = 5.32 \text{ in}$$

$$F_y = 50 \text{ ksi}$$

$$E_s = 29000 \text{ ksi}$$

$$A_g = 21.1 \text{ in}^2$$

$$\Phi_c P_n @ 15 \text{ ft} = 735 \text{ k}$$

$$\text{New } P_u \text{ including Self Weight} = 693.9 \text{ k} + 1.2(72 \text{ lb/ft})(15 \text{ ft})(3)$$

$$\underline{P_u = 697.82 \text{ k}}$$

Strength Check:

$$\Phi_c P_n > P_u \rightarrow 735 \text{ k} > 697.82 \text{ k} \checkmark$$

KL/r Check:

Assuming $K = 1.0$

$$L_x/r_x = (15 \text{ ft})(12 \text{ in/ft}) / (5.32 \text{ in}) = 33.83$$

$$L_y/r_y = (15 \text{ ft})(12 \text{ in/ft}) / (3.04 \text{ in}) = 59.21 \rightarrow \text{Governs}$$

Long or Short Column?

$$4.71 \sqrt{E/F_y} = 4.71 \sqrt{\frac{29000 \text{ ksi}}{50 \text{ ksi}}} = 113.432$$

$$59.21 < 113.432 \quad \therefore \text{Short to Intermediate Column.}$$

Column Design

Bay D

4/4

$$F_e = \frac{\pi^2 E}{(L/r)^2} = 81.639 \text{ ksi}$$

$$F_{cr} = \left(0.658^{(F_y/F_e)}\right) F_y = \left(0.658^{(50\text{ksi}/81.64\text{ksi})}\right) 50\text{ksi}$$

$$F_{cr} = 38.694 \text{ ksi}$$

$$P_{cr} = \phi F_{cr} A_g = 0.9 (38.694 \text{ ksi})(21.1 \text{ in}^2)$$


$$P_{cr} = 734.8 \text{ k}$$

$$P_{cr} > P_u \rightarrow 734.8 \text{ k} > 634.22 \text{ k} \checkmark$$

\therefore W12x72 is acceptable for use.

	A	B	C	D	E	F	G	H	I
49	Maximum Spectral Response Accelerations for Short and 1-Second Periods:								
50		SMS =	0.384	SMS = Fa*SS, ASCE Eqn. 11.4-1, page 65					
51		SM1 =	0.161	SM1 = Fv*S1, ASCE Eqn. 11.4-2, page 65					
52									
53	Design Spectral Response Accelerations for Short and 1-Second Periods :								
54		Sds =	0.256	Sds = 2*SMS/3, ASCE 7-10 Eqn. 11.4-3, page 65					
55		SD1 =	0.107	SD1 = 2*SM1/3, ASCE Eqn. 11.4-4, page 65					
56									(continued:)
57									
58	Seismic Design Category:								
59		Category(for Sds) =	B	ASCE 7-10 Table 11.6-1, page 67					
60		Category(for SD1) =	B	ASCE 7-10 Table 11.6-2, page 67					
61		Use Category =	B	Most critical of either category case above controls					
62									
63	Fundamental Period:								
64		Period Coefficient, CT =	0.030	ASCE 7-10 Table 12.8-2, page 90					
65		Period Exponent, x =	0.75	ASCE 7-10 Table 12.8-2, page 90					
66		Approx. Period, Ta =	0.521	sec., Ta = CT*hn^x, ASCE 7-10 Section 12.8.2.1, Eqn. 12.8-7					
67		Upper Limit Coef., Cu =	1.686	ASCE 7-10 Table 12.8-1, page 90					
68		Period max., T(max) =	0.879	sec., T(max) = Cu*Ta, ASCE 7-10 Section 12.8.2, page 90					
69		Fundamental Period, T =	0.521	sec., T = Ta <= Cu*Ta, ASCE 7-10 Section 12.8.2, page 90					
70									
71	Seismic Design Coefficients and Factors:								
72		Response Mod. Coef., R =	8	ASCE 7-10 Table 12.2-1, pages 73-75					
73		Overstrength Factor, Ωo =	2	ASCE 7-10 Table 12.2-1, pages 73-75					
74		Defl. Amplif. Factor, Cd =	4	ASCE 7-10 Table 12.2-1, pages 73-75					
75		Cs =	0.032	Cs = Sds/(R/I), ASCE 7-10 Section 12.8.1.1, Eqn. 12.8-2					
76		CS(max) =	0.026	For T<=TL, CS(max) = SD1/(T*(R/I)), ASCE 7-10 Eqn. 12.8-3					
77		CS(min) =	0.011	CS(min) = 0.044*Sds*I >= 0.01, ASCE 7-10 Eqn. 12.8-5					
78		Use: Cs =	0.026	CS(min) <= Cs <= CS(max)					
79									
80	Seismic Base Shear:								
81		V =	248.65	kips, V = Cs*W, ASCE 7-10 Section 12.8.1, Eqn. 12.8-1					
82									
83	Seismic Shear Vertical Distribution:								
84		Distribution Exponent, k =	1.01	k = 1 for T<=0.5 sec., k = 2 for T>=2.5 sec.					
85				k = (2-1)*(T-0.5)/(2.5-0.5)+1, for 0.5 sec. < T < 2.5 sec.					
86		Lateral Force at Any Level: Fx = Cv _x *V, ASCE 7-10 Section 12.8.3, Eqn. 12.8-11, page 91							
87		Vertical Distribution Factor: Cv _x = W _x *h _x ^k /(ΣW _i *h _i ^k), ASCE 7-10 Eqn. 12.8-12, page 91							
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Appendix J: Wind Load Excel Document Design Aid

		MWFRS Wind Loads		Job No: 11054																																												
		ASCE 7-10		Designer: DCB																																												
		Enclosed & Partially Enclosed Buildings of All Heights		Checker:																																												
Notes:		Grinding Building (+/- Z Direction)		Date: 2/13/2019																																												
Basic Parameters																																																
Risk Category	II			Table 1.5-1																																												
Basic Wind Speed, V	120 mph			Figure 26.5-1A																																												
Wind Directionality Factor, K_d	0.85			Table 26.6-1																																												
Exposure Category	C			Section 26.7																																												
Topographic Factor, K_{zt}	1.00			Section 26.8																																												
Gust Effect Factor, G or G_f	0.850			Section 26.9																																												
Enclosure Classification	Enclosed			Section 26.10																																												
Internal Pressure Coefficient, GC_{pi}	+/- 0.18			Table 26.11-1																																												
Terrain Exposure Constant, α	9.5			Table 26.9-1																																												
Terrain Exposure Constant, z_e	900 ft			Table 26.9-1																																												
Wall Pressure Coefficients																																																
Windward Wall Width, B	100 ft																																															
Side Wall Width, L	250 ft																																															
L/B Ratio	2.50																																															
Windward Wall Coefficient, C_p	0.80			Figure 27.4-1																																												
Leeward Wall Coefficient, C_p	-0.28			Figure 27.4-1																																												
Side Wall Coefficient, C_p	-0.70			Figure 27.4-1																																												
Roof Pressure Coefficients																																																
Roof Slope, θ	0.8°																																															
Median Roof Height, h	45 ft																																															
Velocity Pressure Exposure Coef., K_z	1.07			Table 27.3-1																																												
Velocity Pressure, q_s	33.5 psf			Equation 27.3-1																																												
h/L Ratio	0.18																																															
Windward Roof Area	0 ft ²																																															
Roof Area Within 23 ft of WW Edge	0 ft ²																																															
<table border="1"> <thead> <tr> <th rowspan="2">Location</th> <th rowspan="2">Min/Max</th> <th colspan="4">Horiz Distance From Windward Edge</th> </tr> <tr> <th>0 ft</th> <th>23 ft</th> <th>45 ft</th> <th>90 ft</th> </tr> </thead> <tbody> <tr> <td rowspan="2">Windward Roof Coefficient Normal to Ridge, C_{pr}</td> <td>Min</td> <td>-0.90</td> <td>-0.90</td> <td>-0.50</td> <td>-0.30</td> </tr> <tr> <td>Max</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> </tr> <tr> <td rowspan="2">Leeward Roof Coefficient Normal to Ridge, C_{pr}</td> <td>Min</td> <td>-0.90</td> <td>-0.90</td> <td>-0.50</td> <td>-0.30</td> </tr> <tr> <td>Max</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> </tr> <tr> <td rowspan="2">Roof Coefficient Parallel to Ridge, C_{pr}</td> <td>Min</td> <td>-0.90</td> <td>-0.90</td> <td>-0.50</td> <td>-0.30</td> </tr> <tr> <td>Max</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> <td>-0.18</td> </tr> </tbody> </table>						Location	Min/Max	Horiz Distance From Windward Edge				0 ft	23 ft	45 ft	90 ft	Windward Roof Coefficient Normal to Ridge, C_{pr}	Min	-0.90	-0.90	-0.50	-0.30	Max	-0.18	-0.18	-0.18	-0.18	Leeward Roof Coefficient Normal to Ridge, C_{pr}	Min	-0.90	-0.90	-0.50	-0.30	Max	-0.18	-0.18	-0.18	-0.18	Roof Coefficient Parallel to Ridge, C_{pr}	Min	-0.90	-0.90	-0.50	-0.30	Max	-0.18	-0.18	-0.18	-0.18
Location	Min/Max	Horiz Distance From Windward Edge																																														
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Leeward Roof Coefficient Normal to Ridge, C_{pr}	Min	-0.90	-0.90	-0.50	-0.30																																											
	Max	-0.18	-0.18	-0.18	-0.18																																											
Roof Coefficient Parallel to Ridge, C_{pr}	Min	-0.90	-0.90	-0.50	-0.30																																											
	Max	-0.18	-0.18	-0.18	-0.18																																											
Figure 27.4-1																																																
Structure Pressure Summary [Add Internal Pressure $q GC_{pi}$ or $q GC_{ps}$ as Necessary]																																																
Height, z	K_z	q_s	Walls				Roof			Internal																																						
			WW	LW	WW + LW	Side	Normal to Ridge WW	LW	Parallel to Ridge	Positive	Negative																																					
0 ft	0.85	26.6 psf	18.1 psf		25.9 psf					6.0 psf																																						
5 ft	0.85	26.6 psf	18.1 psf		25.9 psf					6.0 psf																																						
9 ft	0.85	26.6 psf	18.1 psf		25.9 psf					6.0 psf																																						
14 ft	0.85	26.6 psf	18.1 psf		25.9 psf					6.0 psf																																						
18 ft	0.88	27.6 psf	18.8 psf		26.6 psf					6.0 psf																																						
23 ft	0.92	29.0 psf	19.7 psf	-7.8 psf	27.5 psf	-19.9 psf				6.0 psf	-6.0 psf																																					
27 ft	0.96	30.1 psf	20.5 psf		28.3 psf					6.0 psf																																						
32 ft	0.99	31.1 psf	21.1 psf		29.0 psf					6.0 psf																																						
36 ft	1.02	32.0 psf	21.7 psf		29.6 psf					6.0 psf																																						
41 ft	1.05	32.8 psf	22.3 psf		30.1 psf					6.0 psf																																						
45 ft	1.07	33.5 psf	22.8 psf		30.6 psf					6.0 psf																																						

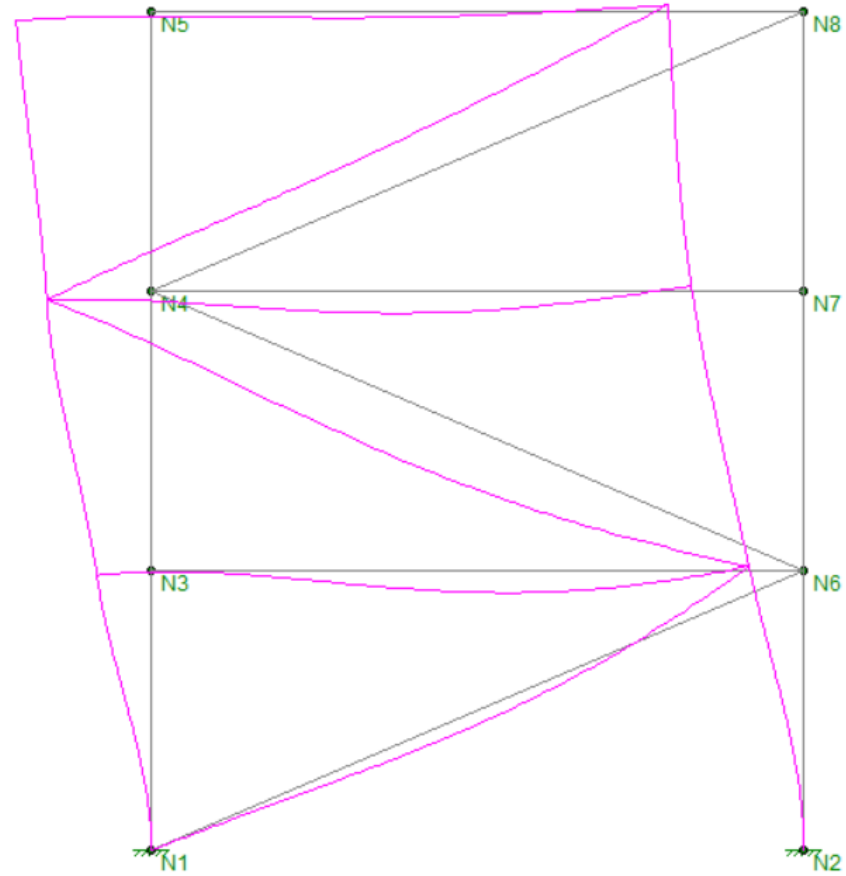
Appendix L: RISA 2D Building Models for Lateral Reinforcement Design



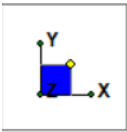
Demonstration Version

2D Joint Deflections (By Combination)

	L...	Joint Label	X [in]	Y [in]	Rotatio...
1	4	N1	0	0	0
2	4	N2	0	0	0
3	4	N3	-0.885	-0.069	3.282e-03
4	4	N4	-1.692	-0.131	1.366e-03
5	4	N5	-2.184	-0.133	2.039e-03
6	4	N6	-0.889	0.086	5.34e-03
7	4	N7	-1.819	0.099	3.762e-03
8	4	N8	-2.19	0.117	1.491e-03

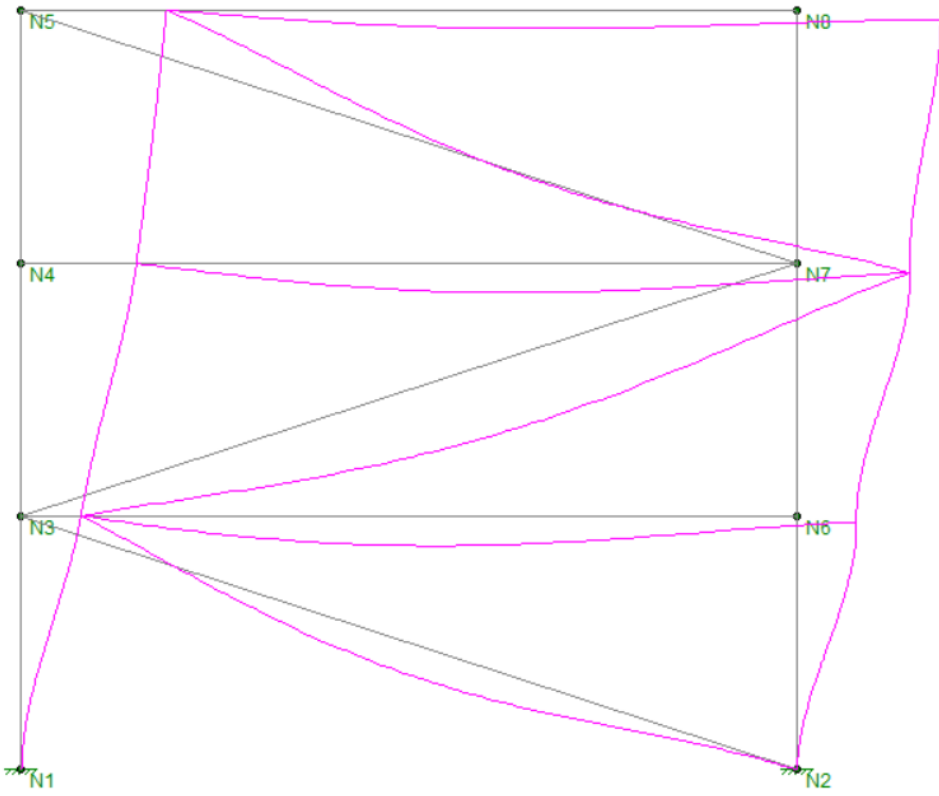


Results for LC 4, 1.2D + E + L + 0.2S



Demonstration Version

	L...	Joint Label	X [in]	Y [in]	Rotatio...
1	4	N1	0	0	0
2	4	N2	0	0	0
3	4	N3	1.058	.023	-3.851e-03
4	4	N4	2.047	.017	-3.312e-03
5	4	N5	2.577	.025	-2.231e-03
6	4	N6	1.056	-.089	9.704e-04
7	4	N7	2.007	-.152	1.135e-03
8	4	N8	2.561	-.157	-1.232e-04



Results for LC 4, 1.2D + E + L + 0.2S

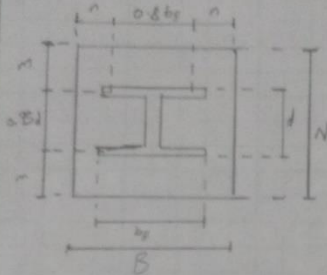
Appendix M: Baseplate and Footing Design Hand Calculations

Base Plate Design

Column $W12 \times 72 \rightarrow A_g = 21.1 \text{ in}^2$ $d = 12.3 \text{ in}$ (12.4 in) $b_f = 12.0 \text{ in}$

$P_u = 697.8 \text{ kips} + 1.3 \text{ kips} + 63.7 \text{ kips} = 762.8 \text{ kips}$

$F_c = 4 \text{ ksi}$



Use Area Footing (A_2) greater than Area Base Plate (A_1)

$P_u = \phi_c P_r$ $\phi_c = 0.65$

$P_r = (0.85 F_c A_1) \sqrt{A_2/A_1}$ $\sqrt{A_2/A_1} \leq 2$

$\therefore P_r = (0.85 F_c A_1) (2)$

$\therefore P_u = (0.65)(0.85(4) A_1) (2)$

$762.8 \text{ kips} = 4.92 \text{ ksi } A_1 \rightarrow A_1 = 172.58 \text{ in}^2$

$N \approx \sqrt{A_1} + \Delta$ $\Delta = 0.5(0.95d - 0.8b_f) = 0.5(0.95(12.3) - 0.8(12))$

$N = \sqrt{172.58} + 1.043$ $\Delta = 0.5(11.685 - 9.6) = 0.5(2.085) = 1.043 \text{ in}$

$N \approx 13.137 + 1.043 = 14.18 \text{ in}$ round to nearest even inch $\rightarrow 16 \text{ in}$

$B = \frac{A_1}{N} = \frac{172.58}{16} = 10.79 \text{ in} \rightarrow 12 \text{ in} < 11$

$A_1 = (16)(12) = 192 \text{ in}^2$

$m = \frac{N - 0.95d}{2} = \frac{16 - (11.685)}{2} = 2.1575 \text{ in}$

$n = \frac{B - 0.8b_f}{2} = \frac{12 - (9.6)}{2} = 1.2 \text{ in}$

$n' = \frac{\sqrt{d b_f}}{4} = \frac{\sqrt{12.3(12)}}{4} = \frac{\sqrt{147.6}}{4} = 3.037 \text{ in} \checkmark$

$n' > m > n$
 $\therefore n' = l$

$t_{\text{required}} = l \sqrt{\frac{2P_u}{\phi_b F_y B N}} = (3.037) \sqrt{\frac{2(762.8)}{(0.9)(50)(16)(12)}} = 1.276 \text{ in} \rightarrow 1.5 \text{ in}^*$

Base Plate is 16" x 12" x 1.5"

Base Plate Design

2/2

Minimum reinforcement connecting baseplate to footing

$$A_s \geq 0.005 A_1$$

OSHA requires minimum 4 reinforcement anchors (1 in each corner)

$$A_s \geq 0.005 (12" \times 16") = 0.96 \text{ in}^2$$

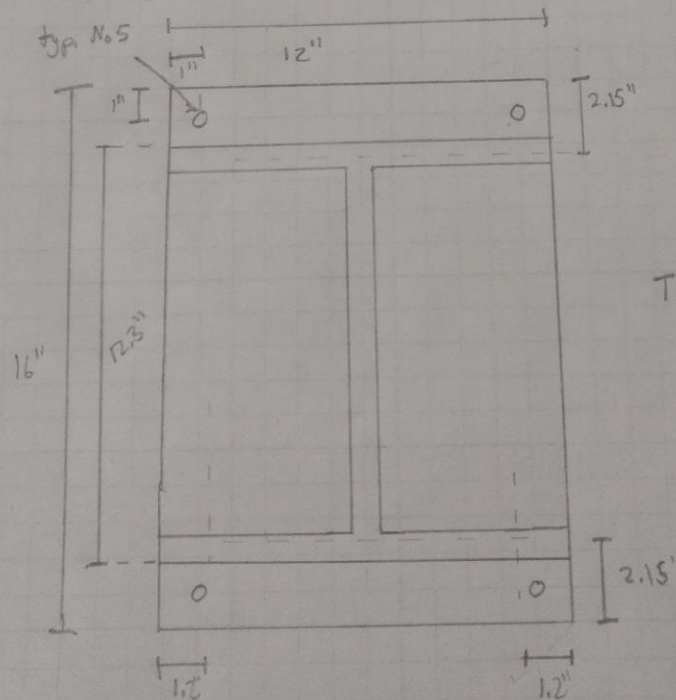
$$4A_b \geq A_s \rightarrow 4A_b \geq 0.96 \text{ in}^2 \rightarrow A_b \geq 0.24 \text{ in}^2$$

Use No 5 bolts ($A = 0.31 \text{ in}^2$)

Distance between center of holes $\geq 3d = 3(11/16) = 33/16"$

Minimum Edge distance from center of hole $= 7/8"$

Place holes 1" in from each edge (1 in each corner)



Concrete Footing

1/4

$$f'_c = 4 \text{ ksi} \quad q_a = 3 \text{ ksf} \quad \gamma_{\text{conc}} = 145 \text{ pcf} \quad \text{Assume 5' deep}$$

$$D+L = 593.75 \text{ kips} + \text{Self weight}$$

$$q_e = 3000 - 5(145) = 3000 - 725 = 2275 \text{ psf}$$

$$A_{\text{req}} = \frac{D+L}{q_e} = \frac{593.75}{2.275} = 260.99 \text{ ft}^2 \times 5' = 1305 \text{ ft}^3 \times 145 \text{ pcf} =$$

$$\text{Self weight} = 189 \text{ kips}$$

$$A_{\text{req}} = \frac{593.75 + 189.23}{2.275} = 314.16 \text{ ft}^2 \times 5' = 1720.8 \times 145 = 250 \text{ kips}$$

$$A_{\text{req}} = \frac{593.75 + 250}{2.275} = 370.67 \times 5 = 1853 \times 145 = 269 \text{ kips}$$

$$A_{\text{req}} = \frac{593.75 + 269}{2.275} = 379.11 \times 5 = 1895.6 \times 145 = 275 \text{ kips}$$

$$A_{\text{req}} = \frac{593.75 + 275}{2.275} = 381.81 \times 5 = 1909.02 \times 145 = 277 \text{ kips}$$

$$A_{\text{req}} = \frac{593.75 + 277}{2.275} = 382.75 \text{ ft}^2$$

Use 20' x 20' square footings

$$q_o = \frac{762.8 + 1.2(277)}{(20')^2} = \frac{762.8 + 332.4}{400} = 2.74 \text{ ksf}$$

Concrete Footing

2/4

Punching Shear $\beta = 4/3$

$$V_{c, min} \left\{ \frac{4}{2 + 4/\beta_1} = 5 \right\} \sqrt{f'_c} b_o d \quad b_o = 2(16+d) + 2(12+d) = 56 + 4d$$

$$\phi V_c = (0.75)(4) \left(\frac{\sqrt{4000}}{1000} \right) (56 + 4d)d = 10.63d + 0.76d^2$$

$$V_u = q_u \left[20^2 - \frac{(16+d)(12+d)}{144} \right] = 2.74 \left[400 - \frac{192 + 28d + d^2}{144} \right]$$

$$V_u = 2.74 \left[400 - \frac{4}{3} - \frac{7}{36}d - \frac{d^2}{144} \right] = 1092.35 - 0.533d - 0.19d^2$$

$$V_u = \phi V_c \rightarrow 1092.35 - 0.533d - 0.19d^2 = 10.63d + 0.76d^2$$

$$0 = -1092.35 + 11.163d + 0.95d^2$$

$$d = 29.54 \text{ in}$$

Beam Shear

$$\phi V_c = (0.75)(2) \sqrt{f'_c} b d = 0.75(2) \left(\frac{\sqrt{4000}}{1000} \right) (20 \times 12)(28.54)$$

$$\phi V_c = 649.81 \text{ kips}$$

$$V_u = q_u \left(\frac{20 - 12''}{2} - \frac{28.54''}{12} \right) (20') = 2.74 (9.5' - 2.378') (20')$$

$$V_u = 390.267 \text{ kips}$$

$$\phi V_c > V_u \quad 649.81 > 390.267 \quad \checkmark$$

Becking

$$\phi B_n = 0.65 (2) (0.85) (4 \text{ ksi}) (12'' \times 16'') = 848.64 \text{ kips} > 762.8 \text{ kips} \quad \checkmark$$

Find A_s

$$M_u = (q_u b) \frac{l^2}{2}$$

$$l = \frac{b-a}{2} = 9.5'$$

$$M_u = (2.74)(20) \frac{(9.5)^2}{2} = 2472.85 \text{ k-ft} \times 12 = 29674.2 \text{ k-in}$$

$$M_u = \phi \rho f_y b d^2 \left(1 - 0.59 \rho \frac{f_y}{f_c'}\right) \quad A_s = \rho b d$$

$$29674.2 = (0.9) \rho (60) (20 \times 12) (28.54)^2 \left(1 - 0.59 \rho \frac{(60)}{(4)}\right)$$

$$0 = -29674.2 + 10556329.54 \rho - 93423516.39 \rho^2$$

$$\rho = 0.1101$$

$$A_s = 0.1101 (20 \times 12) (28.54) = 754.209 \text{ in}^2$$

#18 bars have 4 in² area

$$\frac{754.209}{4} = 188.55 \text{ bars} \rightarrow 190 \text{ #18 bars (95 in each direction)}$$

Cover = 2.5"

$$\phi \text{ #18 bars} = 2.257 \text{ in}_{\text{bar}} \times 95 \text{ bars} = 214.415 \text{ in}$$

$$240' - 2.5 \times 2 = 235''$$

$$1.5 d_s \text{ spacing between bars} = 3.386''$$

$$235'' = 2.257(b) + (3.386)(b-1)$$

$$235'' = 5.6425b - 3.386 \rightarrow 238.386 = 5.6425b$$

$$42.25b \rightarrow 42 \text{ bars/layer}$$

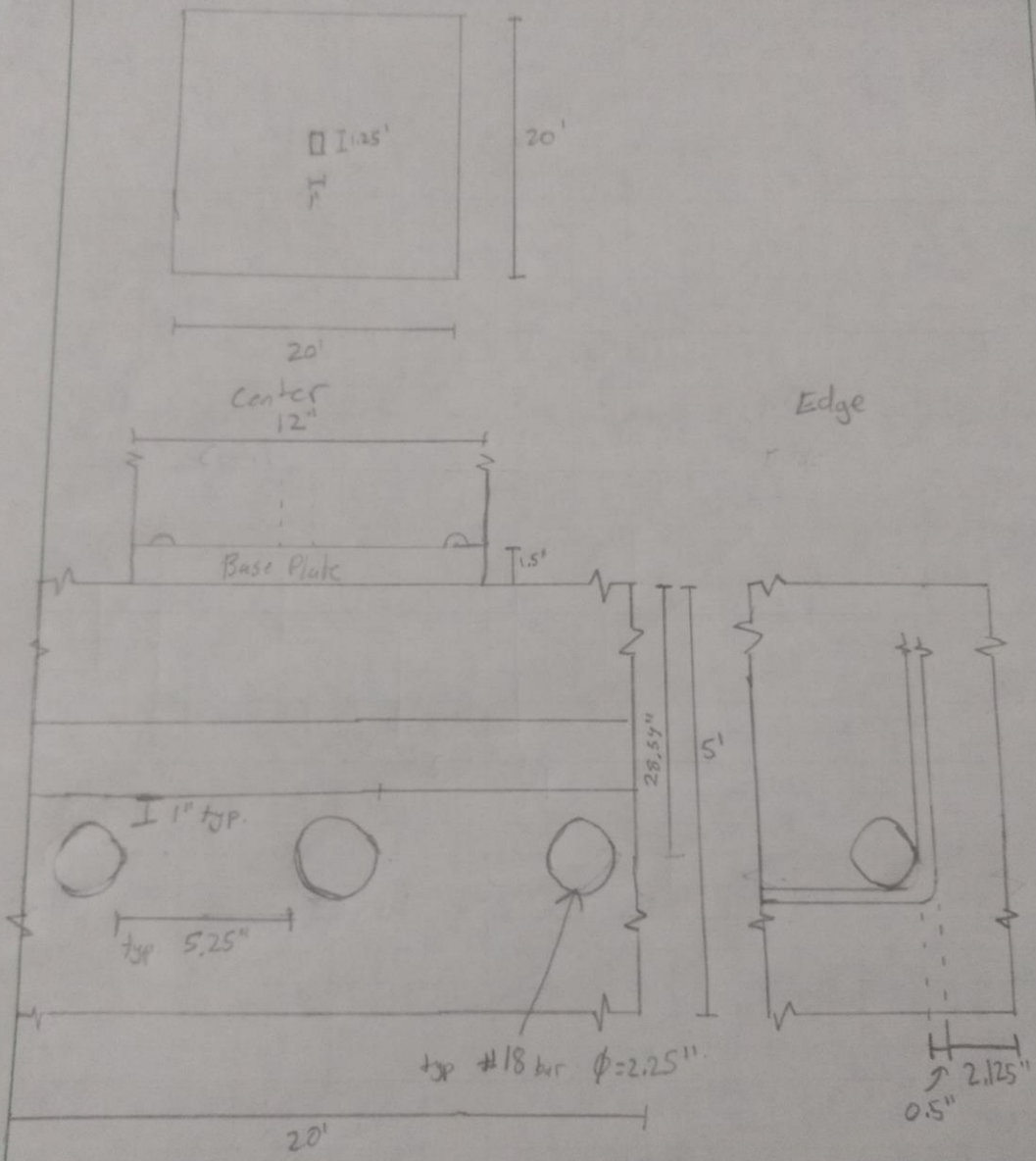
Use 32 bars/layer with 3 layers in each direction (alternating)

layers 1" above lower layer

5.25" spacing between bars

Concrete Footing

4/4



Appendix N: Cost Estimate of Academic Structural Frame

Structural Costs									
Item Type	Specific Item	Cost per Unit	Cost per Unit+OP	Units	Units/Roof	Units/2nd	Units/1st	Total Cost	Total Cost+OP
Beam	W14x22	42.86	48.5	\$/LF	60	0	0	2571.6	2910
Beam	W16x31	50.34	57	\$/LF	480	212	92	39466.56	44688
Beam	W16x40	64.01	72.5	\$/LF	0	0	60	3840.6	4350
Beam	W18x35	57.53	65.5	\$/LF	210	300	360	50051.1	56985
Beam	W18x40	64.53	73.5	\$/LF	0	980	0	63239.4	72030
Beam	W18x55	86.87	98	\$/LF	0	60	0	5212.2	5880
Beam	W21x44	69.89	79	\$/LF	1750	792	1772	301505.46	340806
Beam	W21x50	78.39	88.5	\$/LF	0	60	60	9406.8	10620
Beam	W21x55	96.04	108	\$/LF	0	0	60	5762.4	6480
Beam	W24x84	127.8	142	\$/LF	0	60	60	15336	17040
Beam	W30x99	149.21	166	\$/LF	0	60	60	17905.2	19920
Girder	W18x40	64.53	73.5	\$/LF	88	0	0	5678.64	6468
Girder	W18x55	86.87	98	\$/LF	0	0	44	3822.28	4312
Girder	W21x50	78.39	88.5	\$/LF	224	44	0	21008.52	23718
Girder	W21x62	96.04	108	\$/LF	0	112	0	10756.48	12096
Girder	W24x62	95.65	107	\$/LF	0	44	0	4208.6	4708
Girder	W24x68	104.65	117	\$/LF	0	0	156	16325.4	18252
Girder	W24x84	127.8	142	\$/LF	0	112	0	14313.6	15904
Girder	W30x90	149.21	166	\$/LF	0	0	112	16711.52	18592
Girder	W30x108	162.21	181	\$/LF	0	160	0	25953.6	28960
Girder	W33x99	177.33	197	\$/LF	320	0	0	56745.6	63040
Girder	W33x130	194.52	216	\$/LF	368	184	160	138498.24	153792
Girder	W36x135	201.35	224	\$/LF	0	160	184	69264.4	77056
Girder	W36x182	287.56	320	\$/LF	0	0	184	52911.04	58880
Girder	W40x149	223.35	248	\$/LF	0	0	160	35736	39680
Girder	W40x167	252.45	280	\$/LF	0	184	0	46450.8	51520
Column	W12x72	130.89	146	\$/LF	480	480	480	188481.6	210240
Lateral Brace	W12x16	28.96	33	\$/LF	48	48	48	4170.24	4752
Lateral Brace	W12x22	37.46	42.5	\$/LF	38	38	38	4270.44	4845
Concrete Slab	4" CIP	3.01	3.71	\$/SF	25000	25000	25000	225750	278250
Concrete Footin	Over 5CY, direct	17.54	26	\$/CY	74.07 per column	2370.24		41574.01	61626.24
Reinforcement	#18 Bars	1515	1875	Ton	835.58			1265903.7	1566712.5
Baseplate	1" Plate	54	59.5	\$/SF	1.33 per column	42.66		2303.64	2538.27

Appendix O: Cost Estimate of Academic Non-Structural Elements

Non-Structural Costs							
Item Type	Specific Item	Cost per Unit	Cost per Unit+OP	Units	Number of Units	Total Cost	Total Cost+OP
Demolition	Small/single bldg, no salvage - wood	0.31	0.39	\$/CF	2252500	698275	878475
Exterior Enclosure	Brick Veneer (on rigid steel)	162	162	\$/SF(floor)	75000	12150000	12150000
Interior	Interior partitions	9.54	10.6	\$/SF Partition	3750	35775	39750
Interior	Wall Finishes	1.81	4.02	\$/SF(surface)	8200	14842	32964
Interior	Floor Finishes	5.18	5.18	\$/SF(floor)	75000	388500	388500
Interior	Ceiling Finishes	0.64	0.64	\$/SF(ceiling)	75000	48000	48000
Elevators	3500# Capacity elevator	81000	81000	\$ per	4	324000	324000
Doors	Interior (1st Floor)	1245	1245	\$ per	35	43575	43575
Doors	Exterior (1st Floor)	7350	7350	\$ per double	9	66150	66150
Doors	Interior (2nd Floor)	1245	1245	\$ per	34	42330	42330
Doors	Interior (3rd Floor)	1245	1245	\$ per	48	59760	59760
Stairs	Stair Construction	18900	18900	\$ per flight	8	151200	151200
Plumbing	Plumbing Fixtures	2506	2506	\$ per	190	476140	476140
Plumbing	Domestic Water Distribution	3.21	3.2	\$/SF(floor)	75000	240750	240000
HVAC	Terminal & Package Units	21.8	21.8	\$/SF(floor)	75000	1635000	1635000
Electrical	Electrical Service/Distribution	3.82	3.82	\$/SF(floor)	75000	286500	286500
Electrical	Lighting & Branch Wiring	14.12	14.12	\$/SF(floor)	75000	1059000	1059000
Fire Protection	Sprinkler System	3	3	\$/SF(floor)	75000	225000	225000
Fire Protection	Fire Alarm System	2	2	\$/SF(floor)	75000	150000	150000