THE PARALLAX

A Major Qualifying Project

Submitted to the Faculty

Of the

WORCESTER POLYTECHNIC INSTITUTE
in partial fulfillment of the requirements for the
Degree of Bachelor of Science in Architectural Engineering

By:

Dylan Roche

Bruno Scherrer

Approved:

Professor L.D. Albano, Advisor

Professor Mohamad Farzinmoghadam, Advisor

Abstract

The Parallax, an 118,000 square foot, dual-purpose facility, consisting of two academic floors and three residence floors, was designed to meet the challenges of WPI's growing community, in accordance with the *International Building Code 12 and 15.* Reference design specifications ACI 318, AISC 360-10, and the NDS were also used as guides. An energy-usage analysis was conducted to size, roughly, the building's mechanical system. The project's focus is the building design process, with emphasis on the architectural-structural relationship and design.

Acknowledgments

In completing this Major Qualifying Project, a few faculty members were invaluable to the process. We would like to especially thank our advisors, Professors Leonard Albano and Mohamad Farzinmoghadam for their support and guidance through the architectural and structural design of the project. We would also like to extend thanks to Professor Leffi Cewe-Malloy for her guidance in the initial steps of the architectural design process. Additionally, Professor and Director of the Robotics Engineering Program Michael A. Gennert for his cooperation and interview that provided insight into the needs and desire of the robotics program.

Authorship

Every sentence of this major qualifying project report was either written or edited by one of the project team members; however, specifics on major contributions are as follows:

Dylan Roche:

Executive Summary

Chapter 1: Introduction

Chapter 2: Background

Chapter 3: Architectural Design

3.1: The Program

3.2: Background

3.3: The Parallax Residence Hall

3.4: The Parallax Academic Center

3.5: Conclusion

Chapter 4: Structural Design

4.1: Introduction

4.2.4: Column and Load Bearing Walls [Concrete Design]

4.2.5: Foundation and Foundation Walls [Concrete Design]

4.2.6: Lateral Loads [Concrete Design]

4.3.3: Shear Loads [Wood Design]

4.4.1: Background [Pratt Truss]

4.4.2: General Design [Pratt Truss]

Chapter 5: Energy Conservation

Chapter 6: Conclusions & Recommendations

Bruno Scherrer:

Executive Summary

Chapter 1: Introduction

Chapter 2: Background

Chapter 3: Architectural Design

- 3.1: The Program
- 3.2: Background
- 3.5: Conclusion

Chapter 4: Structural Design

- 4.2.1: Load Transfer/Types of Load [Concrete Design]
- 4.2.2: Assumptions/Givens of the System [Concrete Design]
- 4.2.3: Slab Design [Concrete Design]
- 4.2.6: Lateral Loads [Concrete Design]
- 4.3.1: Background [Wood Design]
- 4.3.2: Wall Framing [Wood Design]
- 4.3.3: Shear Loads [Wood Design]
- 4.4.3: Sizing Members [Pratt Truss]

Chapter 6: Conclusions & Recommendations

Dylan Roche

Bruno Scherrer

Executive Summary

As Worcester Polytechnic Institute's student population continues to grow, there are two challenges to face: limited residential space and an increase in the number of course sections required to accommodate a higher volume of students. Also, due to WPI's project-based curriculum, there becomes a rising need for project team workspace. In addition, the spreading interest in WPI's Robotics Engineering program yields motive to provide space to expand the program.

The purpose of this MQP is to investigate the design process, with emphasis on architecture and structure, and to solve the aforementioned challenges rooted in WPI's growing community.

The Parallax is a building engineered to address these challenges. Its structure is a combination of two substructures: an academic facility with a residence hall above, three floors each. The residence hall provides student housing for the increasing population. The purpose of the academic facility is to address the remaining challenges through providing additional teaching spaces, project workspaces, and space for the RBE program. An egress design and an energy analysis were also conducted, as supplementary content for the architectural program. The energy analysis utilizes energy usage intensity (EUI) to estimate mechanical system size requirements for heating and cooling. All architectural design work was conducted in Revit.

The focus of the structural design was to explore the concepts of "podium construction". Therefore, the design requires the use of two construction materials: reinforced concrete and wood. However, due to an overhang feature in the architectural design, there was also some steel design, allowing the project to cover all three major construction materials. Risa 2D was used to assist in the preparation of the steel calculations.

Table of Contents

List of Figures

List of Tables

Chapter 1: Introduction

Worcester Polytechnic Institute expects growth in its student population. As such, there is a constant need for more space; both academic and residential. WPI's campus lacks a building dedicated to group project work, a pillar of WPI's academic philosophy. Similarly, although half of the Robotics Engineering program is centralized in Gateway, the other half of the program is disseminated across the main campus and could use consolidation. The Parallax building is a proposal to fulfill the needs and desires of the WPI community.

WPI is currently constructing the Foisie Innovation Studio and Messenger Residence Hall to address some of these concerns. The building will be located in place of the old Alumni Gym, adjacent to Harrington Auditorium, with a footprint of roughly 150 feet by 150 feet. Within the innovation studio portion there are several larger areas dedicated to makerspaces and robotics but all the smaller workspaces, for individuals or project teams, are distributed throughout the hallways, corners, and between other spaces. This building is entirely of steel construction and is made up of two academic floors, topped with three residential floors.

The Parallax utilizes "podium" style construction; concrete for the academic floors with wood construction for the residential floors. The motivations for this design are the low cost and speed of wood construction, and the increased building size allowances for reinforced concrete construction. The Parallax considers multiple architectural engineering systems in the overall architectural and structural designs. The academic center is designed to accommodate for some of WPI's growth, focusing on project collaboration space and the Robotics Engineering (RBE) program. The residence hall is designed for efficiency of space and to continue the modernization of on-campus housing. The project is modeled in Revit and recognizes applicable codes and standards. WPI's sustainability criteria of being a "100 year building" has also been considered.

Chapter 2: Background

A key challenge posed by the needs of WPI is the growing community. Since 1996, WPI's freshman class has increased, on average, by 25 students each year. When this growth adds up, it has an effect on both class sizes and housing availability. Figure 1 shows the increasing volume of applications and numbers of students admitted; these values represent *potential* for growth. Figure 2 plots the increasing volume of freshmen enrolled each year: *actual* growth. For this reason, the top three residential floors of The Parallax will allow WPI to meet the increasing number of students for years to come.

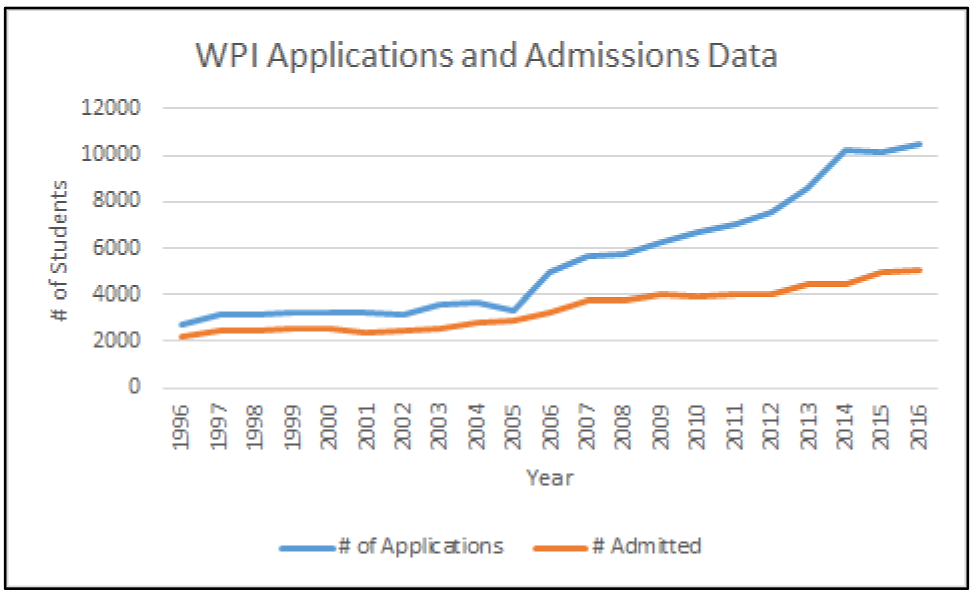


Figure 1: WPI Applications and Admissions Data, 1996-2016

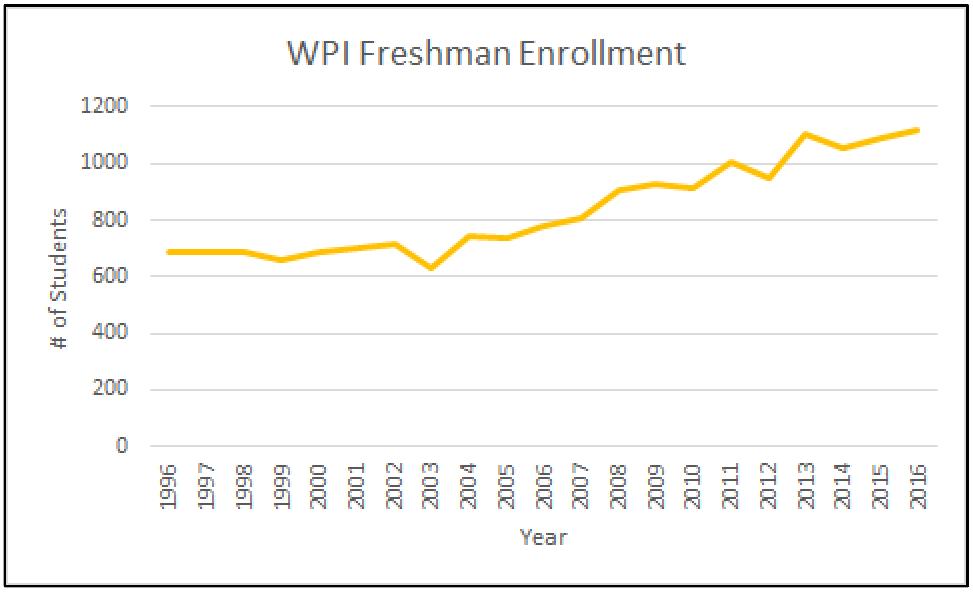


Figure 2: WPI Freshman Enrollment, 1996-2016

A further challenge stems from WPI's project-based curriculum. Whether students are working on qualifying projects (I.e. humanities seminar, IQP, or MQP) or they are working on projects for a class, they need dedicated project workspace. One such course is the Global Problems Seminar (GPS), which impacts a large number of freshmen, roughly four hundred each year. Unfortunately, however, WPI currently has limited means to fulfill the need for project workspace. Options are mainly limited to tech suites in the Gordon Library and the general practice of reserving rooms in other academic buildings.

Another key challenge is space for the Robotics Engineering (RBE) program. Currently half of the RBE program (14,000 square feet) is based in Gateway Park at 85 Prescott St. The other half of the program is dispersed across campus: at least one lab and one faculty office in each of six other buildings.

Table 1: RBE Labs and Offices

Academic Building	Space Allocated to RBE Program
Alden Memorial	Musical Robotics Lab, academic office
Atwater Kent Labs	Undergrad Teaching Labs (4), academic offices (4)
Fuller Labs	Interaction Lab, academic offices (3)
Higgins Labs	Soft Robotics Lab, academic offices (4)
Olin Hall	Robotics Lab, academic office
The Washburn Shops	Humanoid Robotics Lab, academic offices (2)

A podium design was chosen for The Parallax in order to reduce construction costs by making the residential floors wood frame and the academic floors reinforced concrete; offering a lower cost than making the whole building reinforced concrete. In short, podium buildings include multiple stories of wood over a concrete or steel "podium". A basic example would be multiple floors of a hotel or condo (wood construction) atop one or two floors of a casino, mercantile occupancy, or parking (concrete). Some benefits of wood construction include: speed of construction, design flexibility, and reduced environmental impact. The benefit of using concrete construction on the lower floors allows for larger bay areas, yielding spaces less restricted by vertical structural members. There is also a level of fire protection associated with non-combustible construction that allows concrete buildings to be less restricted by building code. As a whole, the concrete design is favorable for the academic portion of the building because it will perform better in reducing any noise or vibrations from work in the RBE labs. Furthermore, the concrete will also perform better with noise reduction for the classes and offices throughout the building. However, the wood design will be conducive for the repetitive, compartmentalized residence floors. For The Parallax, wood construction will be used for the residence floors and reinforced concrete for the academic facility, below. Figure 3 illustrates an exterior rendering of The Parallax.

Figure 3: Exterior Rendering of the Parallax with Podium Design

The function of any structure is to transfer the loads, or forces, acting upon it. The fundamental loads considered include dead loads, live loads, snow loads, wind loads, and seismic loads. Dead loads are considered constant; including the structure's self-weight and weight of permanent non-structural components, and other finishes. Dead loads are simple to calculate as they are derived from sizes and quantities of materials. Live loads consist of all movable objects, i.e. people and furniture, which may fluctuate throughout the day in each space, resulting in variable intensity. Allowable live loads are dictated by the building code and are different depending on the building's use and room type. Snow load depends on a building's geographic location and is derived from ASCE 7-10, provided by the Applied Technology Council's ATC website. Wind and seismic loads are lateral forces, for which a structure must be braced to resist. The structure must also be anchored to the ground in order to resist being overturned, if the structure's self-weight is not sufficient to hold it down.

The structural concept of a podium contains several aspects of design to consider. Although wood construction is generally prescriptive, the lateral load needed more consideration due to its position on top of the podium. One point of analysis is how the wood structure transfers the loading through itself and into the concrete structure; the other, the overturning moment of the wood structure results in tie-down forces required to keep the wood structure attached to the concrete structure, specifically the roof slab of The Parallax. The concrete structure is inherently responsible for supporting and transferring loads, including those from the wood structure, to the ground through the foundation. The slabs are designed carry all of the moment caused by dead loads, live loads, and in some cases snow loads acting on the slab. Consequently, the columns and load bearing walls are responsible for vertically supporting loads carried by the slab and the weight of the slab itself. Thicknesses of slabs and sizing of columns and walls, and their reinforcement, will be dictated by both the loads each member carries and code requirements. Table 2 describes some of the key equations used in the design calculations.

Table 2: Key Equations for Concrete Design Calculations

Equation	Use
$A_c = \frac{P}{0.85(1-\rho)f'_c} + \rho f_y$	This equation determines the area of concrete (A_c) of a column given: the load (P), the reinforcement ratio (ρ), the compressive strength of concrete (f'_c), and the yield strength of steel (f_y).
$a = \frac{A_s f_y}{0.85 f'_c b}$	This equation determines the depth (a) of the compression block for the cross section of the slab. There are different design approaches depending on whether or not the compression block goes into the web. The equation is based on the area of reinforcing steel (A_s), the yield strength of steel (f_y), the compressive strength of concrete (f'_c), and the width of the beam-equivalent of the slab (b).
$W_u = 1.2DL + 1.6LL + 0.5SL$	This is the equation for flexure load, based on the dead load (DL), live load (LL), and the snow load (SL).
$M_u = \frac{1}{8} W_u L^2$	This is the equation for the moment developed in a simply supported beam, given the load (W_u) and the span (L).
$M_u = f_y \varphi \rho b d^2 (1 - 0.59\rho \frac{f_y}{f'_c})$	This moment equation is used to solve for the steel reinforcement ratio (ρ), given the moment (M_u), the safety factor (ϕ), the yield strength of steel (f_y), the slab's beam-equivalent width (b), the distance from the slab surface to the reinforcement (d), and the compressive strength of concrete (f'_c).
$A_s = \rho b d$	This equation uses the steel reinforcement ratio (ρ), and the cross-sectional area of the beam-equivalent of the slab (bd) to find the area of steel reinforcement (A_s).

The field of building construction has an interest in reducing projects' carbon footprints in an attempt to preserve the earth. Because of this, "green" buildings have become more desirable. Accreditations, such as LEED, set a certain standard to essentially rank a buildings environmental impact and efficiency. Due to the different occupancy types of The Parallax, there are different energy requirements throughout the building. Energy use intensity (EUI) is a value expressed as energy per square foot per year, found from dividing the total energy consumption of a building in one year by its gross floor area. Statistical data on occupancy types and their associated EUIs, as well as energy requirements to achieve LEED certification, sets up a guideline for target EUI measurements for The Parallax. The target EUI value is used to determine a preliminary size for the mechanical system for the building. Also, due to the variety of construction materials in podium construction, there will be different heat gains and heat losses associated with each space based on the wall construction, glazing, and orientation. Heat gain and loss calculations are used to validate decisions made about the building's envelope and construction details.

The goal of The Parallax is to provide a harmonious solution to the challenges of providing both residential and academic spaces while promoting sustainability. Architectural, structural, and energy challenges are analyzed and addressed through the use of relevant engineering calculations and design, as well as addressing code requirements.

Chapter 3: Architectural Design

3.1: The Program

The intent of The Parallax is to directly address the challenges previously discussed: WPI's growing community, a lack of project workspace, and accommodating the RBE program. The residential floors afford a variety of housing, including views of both the quadrangle and center of campus. The goal for these residence floors is maximizing the number of occupants while providing the most for each individual room. The academic facility comprises a solution to all three challenges. In general, there is a floor assigned to meet each challenge; though, there is some intermingling between each of the floors and the challenges they address. The RBE labs are organized in the basement, their size requirements were determined from conversation with the program director: Professor Gennert. The first floor provides rooms and an open area for project workspace. The second floor has teaching rooms to accommodate additional classes resulting from increased student population. As a whole, The Parallax is meant to have a distinguishable atmosphere, yet simultaneously blend with the existing culture and architecture of WPI's campus.

3.2: Background

In order to begin an architectural design, zoning ordinances must be observed. Figure 4 illustrates the district location of The Parallax, indicated by the red circle.

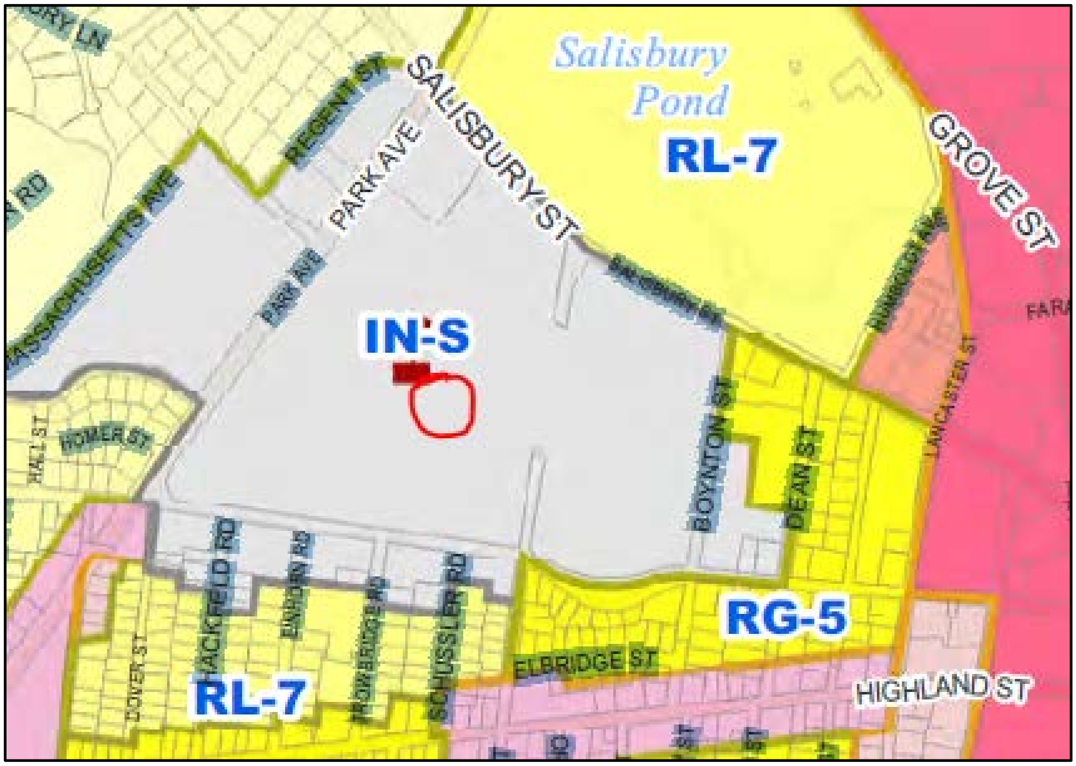


Figure 4: City of Worcester Zoning Map

The zoning map indicates that The Parallax lies in an "IN-S", or institutional-educational, district. After the district is determined, permitted uses for said district are indicated in Table 3; abridged from Table 4.1 of the City of Worcester Zoning Ordinance, as amended through February 3, 2015.

Table 3: Permitted Use Based on Zone District

Use	Permitted or Not
Dormitory	Permitted
University	Permitted
Food Service – excludes alcohol consumption/sale	With Special Permit
Research Lab - w/o manufacturing abilities	Permitted
Retail Food Sales	With Special Permit
Research Lab – w/ manufacturing abilities	Permitted

In addition, Table 4 details permitted dimensions for the IN-S district; abridged from Table 4.2 of the City of Worcester Zoning Ordinance, as amended through February 3, 2015. The pertinent information obtained from this table is the depth of each setback as these values impact the site plan. Because the building is located on the quadrangle, these setbacks will be used as the minimum distances required between The Parallax and adjacent buildings.

Table 4: Permitted Dimensions Based on Zone District

District	Use	Lot Area (Min SF)	Lot Frontage (Min ft)	Front Setback	Side Setback	Rear Setback	Max. Height (Stories)	Max. Height (ft)	Max. Floor to Area Ratio
IN-S	All	N/A	N/A	15 ft.	10 ft.	10 ft.	N/A	N/A	N/A

After review of the zoning ordinances, it is evident that The Parallax is permitted for construction as far as building use is concerned; with few limitations on dimensions.

Following zoning ordinances are the building code requirements. The requirements and limitations set in the building code create the mold for shaping the building. Table 5, below, lists the relevant building codes and their implications for The Parallax.

Table 5: IBC Code Implications

Code	Description	Result
IBC 2015: 602.2	Construction Type	Floors B, 1, 2 = **Type II (B)**
IBC 2015: 602.3	Construction Type	Floors 3, 4, 5 = **Type III (B)**
IBC 2015: 306.2	Occupancy Classification	Basement = **Group F-1**
IBC 2015: 310.4	Occupancy Classification	Floors 3, 4, 5 = **Group R-2**
IBC 2015: 304.1	Occupancy Classification	Floors 1, 2 = **Group B**
IBC 2015: Table 504.3	Max Building Height (ft)	*Groups B, F/Type II (B) = **75'**
IBC 2015: Table 504.3	Max Building Height (ft)	*Group R/Type III (B) = **75'**
IBC 2015: Table 504.4	Max Building Height (stories)	*Group B/Type II (B) = **4**
IBC 2015: Table 504.4	Max Building Height (stories)	*Group R-2/Type III (B) = **5**
IBC 2015: Table 506.2	Max Building Area (SF)	*Group B/Type II (B) = **69,000 SF**
IBC 2015: Table 506.2	Max Building Area (SF)	*Group F-1/Type II (B) = **46,500 SF**
IBC 2015: Table 506.2	Max Building Area (SF)	*Group R-2/Type III (B) = **48,000 SF**

*Buildings equipped throughout with an automatic sprinkler system installed in accordance with IBC 2015, Section 903.3.1.1.

Based on the results from the IBC, because The Parallax will comply with the sprinkler note (*) from Table 5, the building is approved for an academic facility with a basement and two floors above grade. In order to maximize the residential occupancy, the maximum number of Group R-2 floors will be used; however, because there are already two above-grade floors, the R-2 occupancy is limited to at most three floors and the total building height must not exceed 75 feet. Due to existing structures, the building footprint will remain at 150' x 150', 22,500 square feet; well under code allowances.

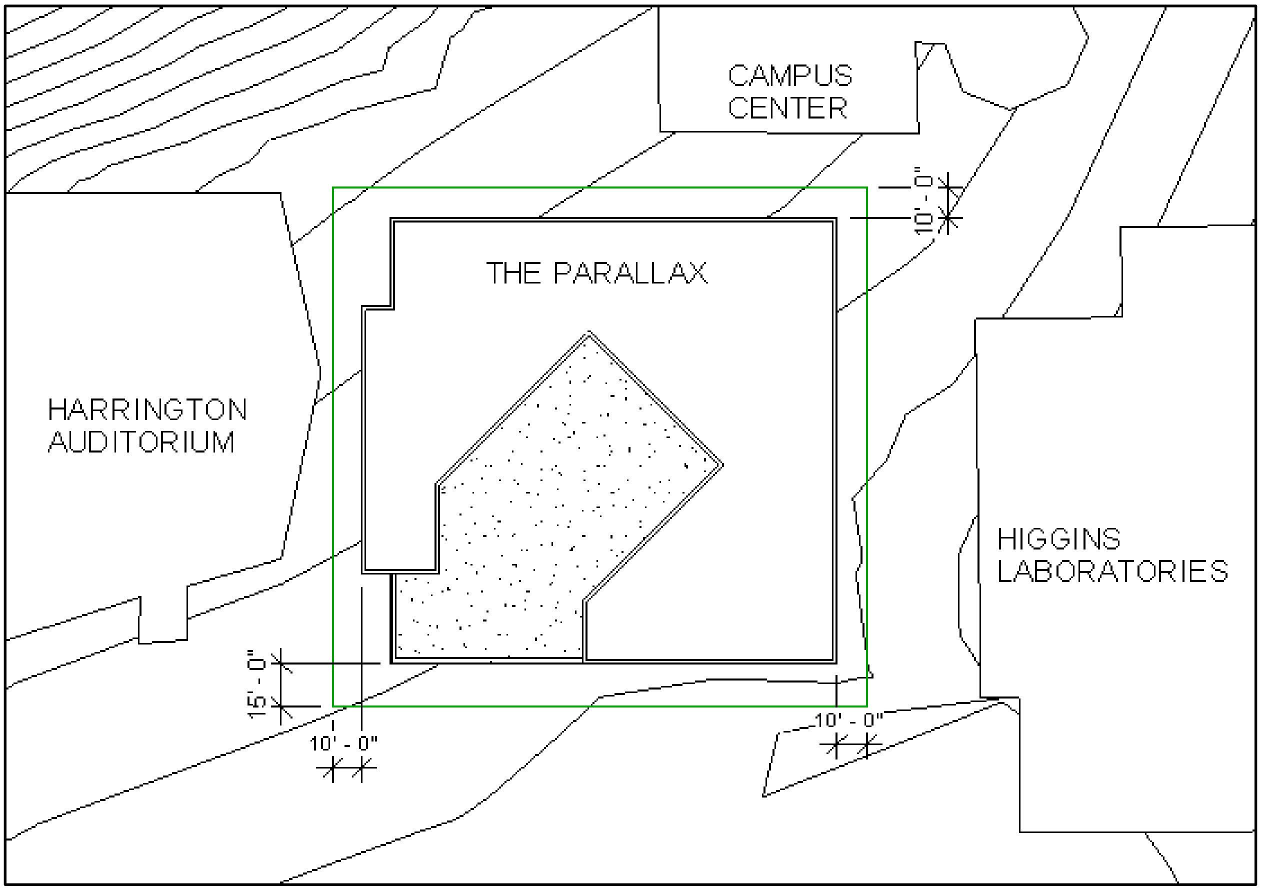


Figure 5: The Parallax Site Plan

In regard to egress capacity requirements, Table 6 is a condensed version of Table 1004.1.2 of the IBC, specific to The Parallax. It shows the minimum square foot per person requirement, occupant load factor (OLF), based on the function of a space. The size of each space in The Parallax was designed based on a target occupancy and these minimum square foot requirements. The target occupancies of each space were based on the occupancy loads of similar, existing spaces on WPI's campus. Table 7 contains design occupant load (DOL) data of each floor and space of The Parallax, based on Table 6. The term "gross" means that this requirement includes the entire area, all occupiable and non-occupiable spaces. The term "net" means that this requirement includes contribution from occupiable spaces only.

Table 6: Minimum Square Foot Requirements by Space

Function of Space	Minimum SF/Person
Mechanical Equipment Room	300 gross
Assembly – Concentrated	7 net
Assembly – Standing Space	5 net
Assembly – Unconcentrated	15 net
Assembly – Fixed Seats	Occupant Load = # of seats
Business Areas	100 gross
Dormitories	50 gross
Classrooms	20 net
Shops/Vocational Room/Lab	50 net

Table 7: Occupant Load Data of the Parallax

Level	Room	Area (SQF)	OLF	Occupant Load	Design OL
Basement	Labs	12073	50 net	241	234
	Innovation Chambers	715	15 net	48	30
	Makerspace	871	50 net	17	17
	Mechanical Room	1833	300 gross	23	20
	Unoccupied Space	5145			
			Total	**329**	**301**
First Floor	Offices	1170	100 gross	24	18
	Innovation Chambers	390	15 net	26	18
	Conference Rooms	1482	15 net	99	90
	Open Collaboration Space	13730	15 net	915	526
	Stair Seating	468	Fixed Seats	128	128
	Unoccupied Space	1231			
			Total	**1192**	**780**

Second Floor	North Classroom	1218	20 net	61	60
	South Classroom	971	20 net	49	48
	North Lecture Hall	1952	15 net	130	100
	South Lecture Hall	2450	15 net	163	100
	Offices	780	100 gross	18	12
	Innovation Chambers	390	15 net	26	18
	Conference Room	405	15 net	27	25
	Open Collaboration Space	10719	15 net	715	417
	Unoccupied Space	987			
			Total	**1188**	**780**
Third Floor	Dorms	N/A	Fixed Beds	59	59
	Common Room	820	15	55	55
	Terrace Rooftop	7093	15	473	444
			Total	**587**	**558**
Fourth Floor	Dorms	N/A	Fixed Beds	59	59
	Common Room	820	15	55	55
			Total	**116**	**116**
Fifth Floor	Dorms	N/A	Fixed Beds	59	59
	Common Room	820	15	55	55
			Total	**116**	**116**

In short, the discussed codes set base parameters. These parameters, coupled with the solutions discussed in the architectural program, begin to fill in the contours of the architectural design.

3.3: The Parallax Academic Center

The academic center can be accessed at ground level through either of two entrances; one facing the quadrangle in the southwest direction, the other facing the campus center in the northeast direction. There is a central stair that goes only from the ground floor to the second floor; however, two other stairs run all the way from the basement to the top-most residential floor. Only residents of the residence hall will have access to the residential floors, but all students will be able to access all three floors of the academic center. The floor-to-floor height of each academic floor is thirteen feet, to allow space for mechanical systems beneath the slabs, allowing eleven foot floor-to-ceiling heights. There are also bathrooms on each floor as per IBC Table 2902.1 Minimum Number of Required Plumbing Fixtures.

The academic facility of The Parallax is a three tier space, each tier targeting a key objective; nevertheless, there is overlap between floors. The basement focus is placed on WPI's award winning robotics program, and accommodating some of its space requirements. The first floor is based on providing flexible project collaboration space, to stimulate innovation and creativity. A massive, central stair connects the first and second floors, and is fully integrated with the project collaboration functions of both floors. The second floor is geared toward growth; providing ancillary academic spaces, not necessarily designated to any single department. The academic center is equipped throughout with appropriate restroom accommodations and egress requirements as per the IBC. See Table 8, below. The Parallax's academic facility is a solution that comprehensively meets the challenges based on the needs of the WPI community.

Table 8: IBC Code Implications for Egress and Restroom Accommodations

IBC Code	Description	Calculation	Implication
1005.3.1	Minimum stairway width	Calculated by multiplying the occupant load of the floor by an egress capacity factor of 0.2 in/occupant, in buildings equipped with an automatic sprinkler system. Not less than 44 in.	Controlling occupancy is the 1st or 2nd floor with 780 persons. 780 persons x 0.2"/person = 156" of total stair width (clear width) Two 6.5' clear width stairs will work.
1005.3.2	Minimum width of non-stair egress components	Calculated by multiplying the occupant load of the floor by an egress capacity factor of 0.2 in/occupant.	Controlling occupancy is the 1st or 2nd floor with 780 persons. 780 persons x 0.2"/person = 156" of total door width (clear width)
1010.1.1	Minimum clear width of doors	Minimum clear width: 32 in	Must have enough doors to meet 156" of total clear width but each door must have a minimum 32" clear width.
Table 2902.1	Minimum number of required plumbing fixtures	This table lists the minimum number of plumbing fixtures required by occupancy.	Basement – 3 water closets and 3 lavatories First Floor – 16 water closets and 11 lavatories Second Floor – 16 water closets and 11 lavatories

WPI's Robotics Program is ranked second in the country and is the first to offer a Bachelor degree, Master degree, as well as a PhD. The Robotics Program hosts competitions throughout the year, with awards of over a million dollars and scouts like NASA and SpaceX. With increasing interest in the robotics field and its growth at WPI, a consolidated space is ideal for further development of the program. The basement is optimal for this purpose due to the nature of lab work. Considering the noise of testing, building, and manufacturing robots, the RBE program needs a space without noise restrictions.

The basement level of The Parallax centralizes the existing RBE labs from Table 2, which are currently scattered across campus. Table 9, below, lists the labs housed within The Parallax, the building they transferred from, and their size in the new facility. Figure 6 is the basement floor plan of The Parallax, illustrating the spacing of the labs.

Table 9: Parallax RBE Lab Data

New Lab	Current Building	Size (Square Footage)
Humanoid Robotics Lab 01	The Washburn Shops	Large (1500 SF)
Undergraduate Teaching Lab 02	Atwater Kent Labs	Large (1575 SF)
Undergraduate Teaching Lab 03	Atwater Kent Labs	Large (1550 SF)
Soft Robotics Lab 04	Higgins Labs	Small (775 SF)
Foisie Lab 05	N/A	Medium (1000 SF)
Undergraduate Teaching Lab 06	Atwater Kent Labs	Small (820 SF)
Lab 07	Olin Hall	Medium (1100)
Interaction Lab 08	Fuller Labs	Large (1600 SF)
Musical Robotics Lab 09	Alden Memorial	Medium (1240 SF)
Undergraduate Teaching Lab 10	Atwater Kent Labs	Medium (950 SF)

Figure 6: Basement Floor Plan

In addition to the RBE labs, the basement also houses five innovation chambers, a makerspace and the building's mechanical equipment. A crucial component, key to the cultivation of creativity and project collaboration, for this program, is the *innovation chamber*. Innovation chambers are 130 to 150 square feet, capable of accommodating teams as large as six. These rooms are equipped with an array of options for a multitude of brainstorming styles, as detailed in Table 10.

Table 10: Innovation Chamber Details

Variables	Options May Include
Seating Style	Rocking chairs, yoga balls, rolling chairs, standard chair, standing mat, ground seating, bean bags, hammocks, rotating stools
Desk Height	Adjust height all the way from sitting on the ground to standing
Media Options	Floor-to-ceiling whiteboards, magnets, computer display, projector, laptop hook-up, lots of outlets, whiteboard surface tables
Ambiance Settings	Light dimming, ambient music, retractable partitions b/w some units, coat rack, cubbies
Fidget Tools	Mini basketball and hoop, stress balls

The makerspace has approximately 1,000 square feet, as to occupy up to twenty students at one time. The makerspace has work surfaces at varying heights, to account for seated or standing working conditions. There is an equipment room from where students may check out tools and/or materials from the equipment manager/makerspace supervisor. There is also a 3D printer available, with supervised use.

And because one of WPI's goals for the building is to have a certain capacity for modification, in the event of future expansion, the mechanical equipment room is oversized for the potential addition of larger system.

Project work is the core of WPI's curriculum. Starting freshman year, students have the opportunity to enroll in the Great Problems Seminars (GPS); multidisciplinary teams of students and faculty collaborate to solve problems of global importance. Although participation in a GPS is optional, students MUST complete both an Interdisciplinary Qualifying Project (IQP) and a Major Qualifying Project (MQP) in order to graduate. Furthermore, most departments incorporate group work into their courses. Because there is so much project-based learning taking place on campus, with no concentrated project workspace, the first floor of The Parallax is dedicated to project development.

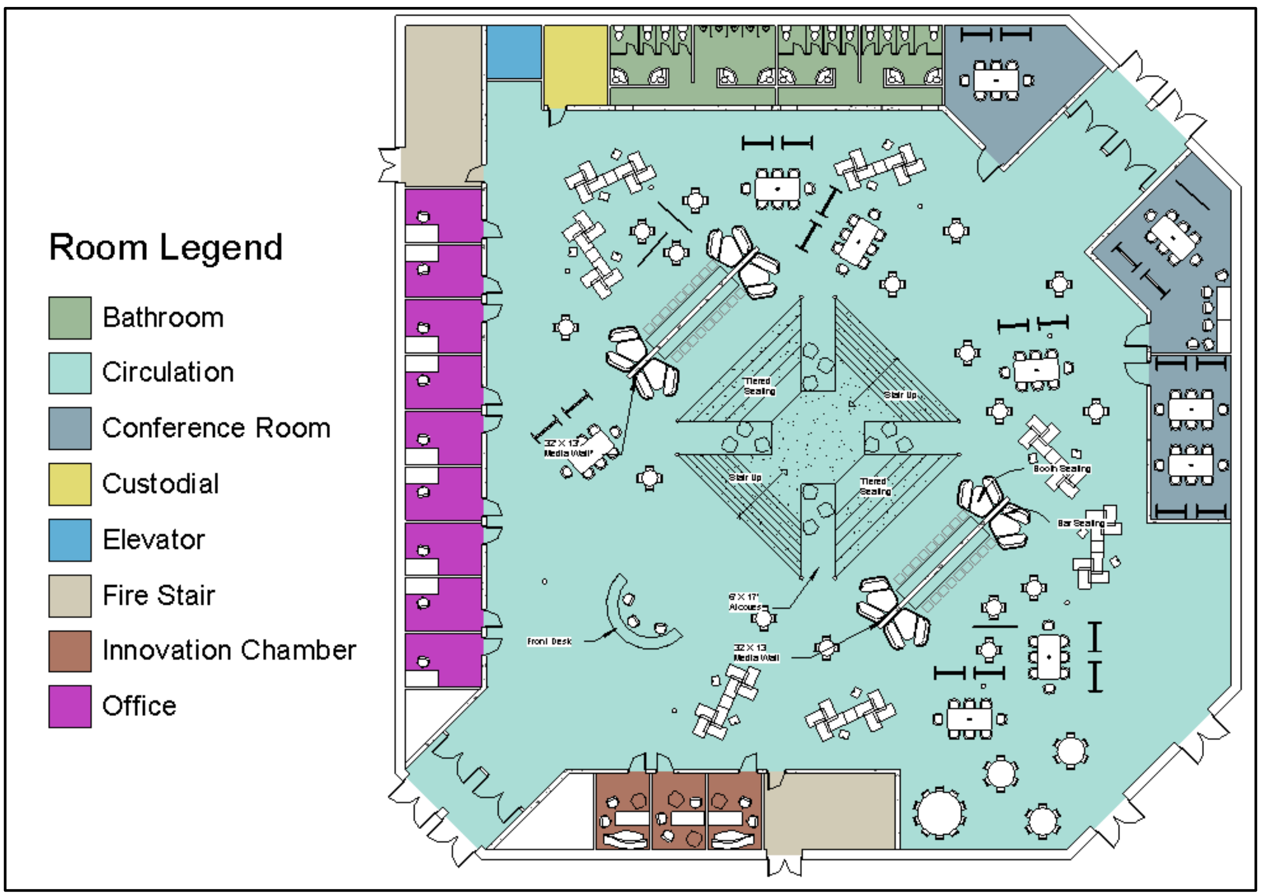


Figure 7: First Floor Plan

The first floor of The Parallax, see Figure 7 above, provides three innovation chambers, where student groups have access to various media resources and modes of brainstorming. The goal of the innovation chamber design is to provide a space that is conducive to both focusing on the problem at hand as well as fostering creativity and collaboration between group members. There are three conference rooms where groups can have a more formal meeting and/or host presentations. Nine offices on this level will account for a portion of relocated RBE faculty and staff, sixteen offices total. There is also a cafe, where purchase food and beverage will be available to the WPI community, as well as an adjacent patio. Because students often work on projects for hours at a time, the café will allow project teams to continue collaboration, or take a break, while they eat, without having to relocate.

The architectural highlight of The Parallax is the massive, central stair, connecting the first and second floors, see Figure 8. There are two paths of stairs from the first floor to the landing and four paths from the landing to the second floor. The stair is integrated into the project workspace theme of the first floor through two key features: tiered seating, facing media walls, and study alcoves, tucked in between the tiered seating and the usable stairs, see Figure 9. The two sets of tiered seating run between the first floor stairs and each set faces a 400 square foot media wall.

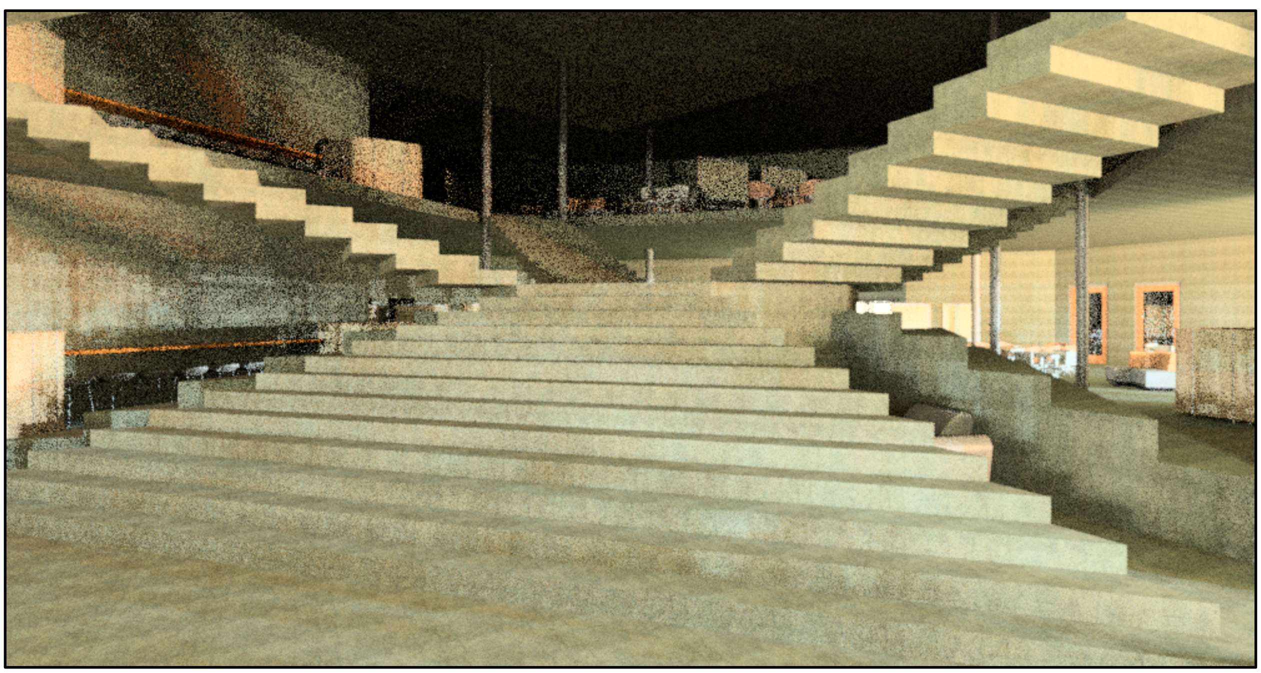


Figure 8: Interior Render Showcasing the Central Stair

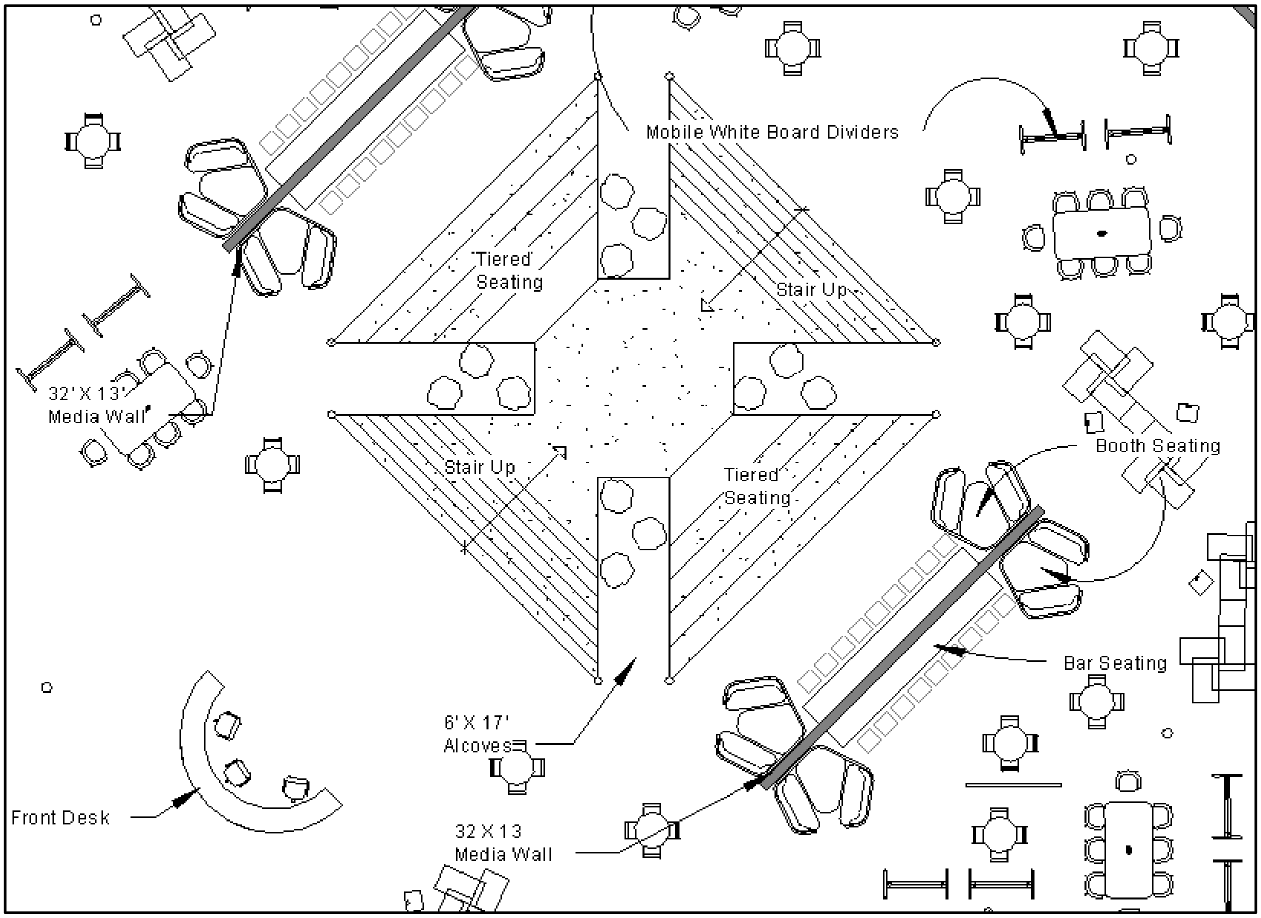


Figure 9: Central Stair in Plan-View

The media walls are a part of the structural solution; they double as load-bearing walls, which follow all the way through the building. There will be additional seating along both sides of the media wall. On the side of the walls opposite the tiered seating will be dry-erase boards and other modes of graphic display so that students also have the option of doing work in an open environment. The study alcoves, between the stairs and tiered seating, will serve as small, private work areas which, unlike innovation chambers and conference rooms, won't require a reservation. The reception desk, located directly between the quad-facing entrance and the central stair, is where students can ask questions about any of the project programs, and reserve innovation chambers or conference rooms.

The primary focus of the second floor, see Figure 10 below, is to provide spaces for academic overflow, with no particular field-of-study designation. In other words, as the WPI student body continues to grow and there is a continued increase in need for basic courses, required by all majors, this floor will help facilitate additional courses. WPI is over 150 years old and many of the departments have overgrown the means of their respective buildings, which were designed for class sizes from decades ago. There are two classrooms, two lecture halls, and an additional, quad-facing conference room. The classrooms and lecture halls will double function as spaces where academic departments and programs can host seminars, guest lectures, and information sessions for their various programs. There are also six additional RBE faculty offices and three more innovation chambers. Aside from these functions, and as an addition to the solution for increased project workspace, roughly 10,000 square feet of the second floor is an open collaboration space. It very nearly represents a large scale innovation chamber. There will be a range of seating available and many group configurations to form. Nearly all the elements of the work space will be mobile; therefore, it will be an ever-changing environment.

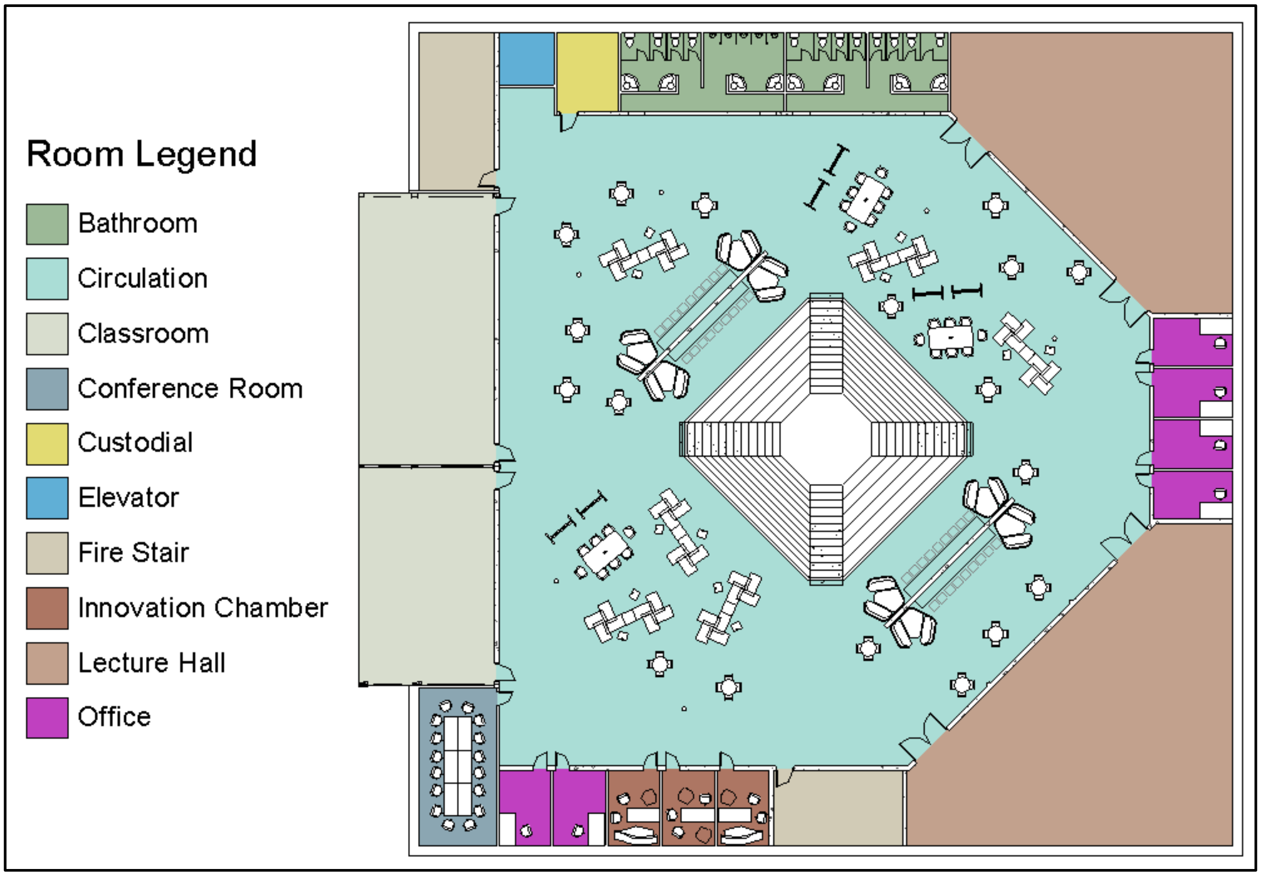


Figure 10: Second Floor Plan

3.4: The Parallax Residence Hall

The Parallax Residence Hall is designed to provide the most efficient use of space; to maximize the number of residents without sacrificing comfort. The unique "U" shape of the residence hall is critical because the long, bent corridor increases the exterior wall perimeter, from that of a simple rectangle. This allows for more windows, maximizing natural lighting, and effectively results in more rooms. Table 11 displays the dorm/suite schedule, as well as a brief description of each type of room.

The variety of room options stems from WPI's room and board payment structure. Unlike other schools which charge every student a standard room and board fee independent of their housing, the room and board cost at WPI is variable to where you live. The benefit of variety allows students willing to pay more for a more desirable room to do so.

Table 11: Dorm Schedule

Room Type	Area (Square Feet)	QTY	# of Residents/Room	# of Residents/Room Type
Double	170	14	2	28
Triple	395	2	3	6
Triple Suite	535	2	3	6
Quad Suite	725 - 775	2	4	8
Hex Suite	1050 - 1100	2	6	12
RA Single	125	1	1	1
Total Residents/Floor				61

*This schedule is consistent with the fourth and fifth floors; however, the third floor triples are 295 square feet due to the terrace access. See Appendix D.

The residence hall consists of three floors, each with the same floor plan; the only difference being the terrace access on the third floor and, subsequently, a 100 square foot decrease for the triples. In addition to the dorms and suites from Table 11, each floor has a large, 825 square foot, common room for residents to hang out, watch movies, hold meetings, and carry out any other group functions.

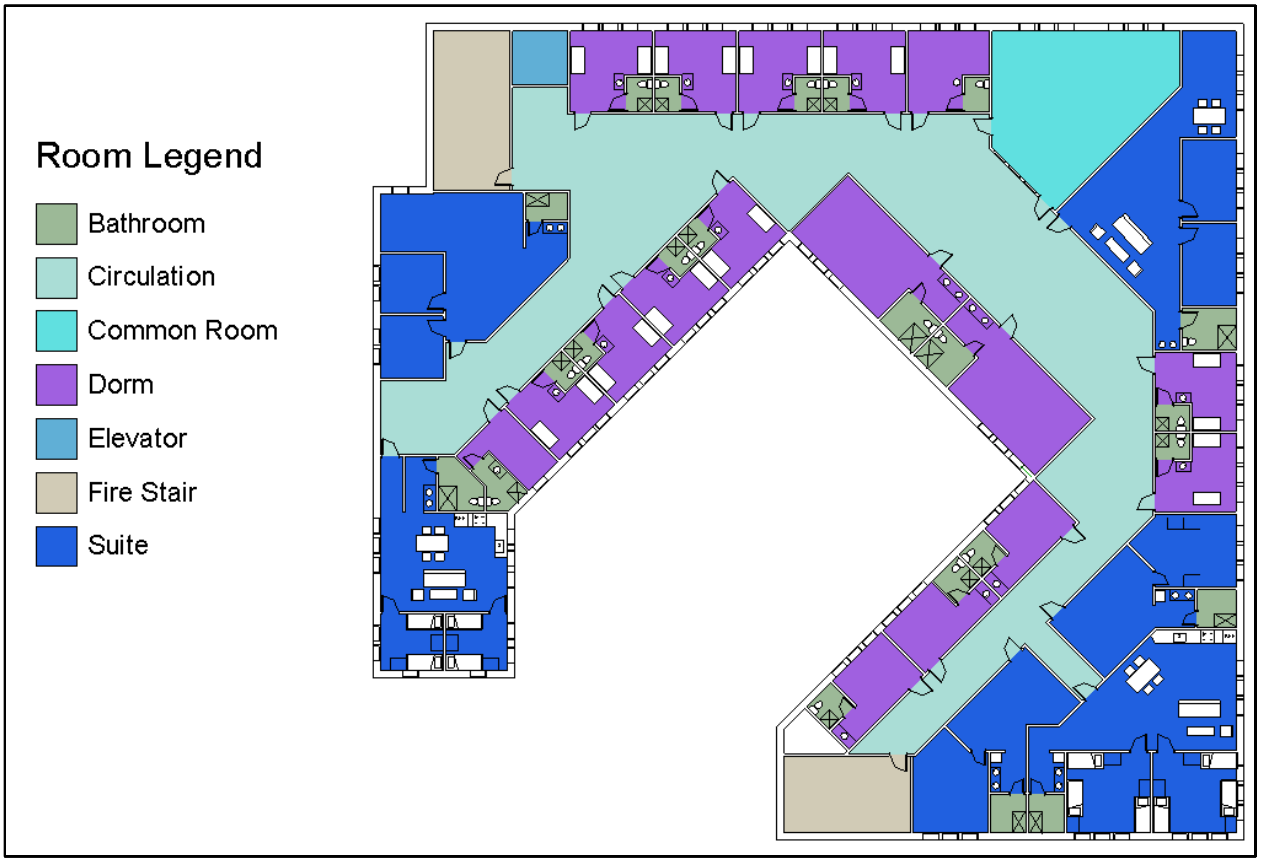


Figure 11: Fourth and Fifth Floor Plan

Each room has its own bathroom; equipped with both a shower and a water closet. The sinks and linen closets have all been mounted outside the bathroom; allowing roommates to access the sink or linen closet while the bathroom is occupied. All quad and hex suites are divided so that they contain two doubles or two triples, respectfully, which open into a common living space, kitchen, and bathroom as detailed in Figure 12 and Figure 13. Triple suites have a living space, separated from the bedroom, but no kitchen.

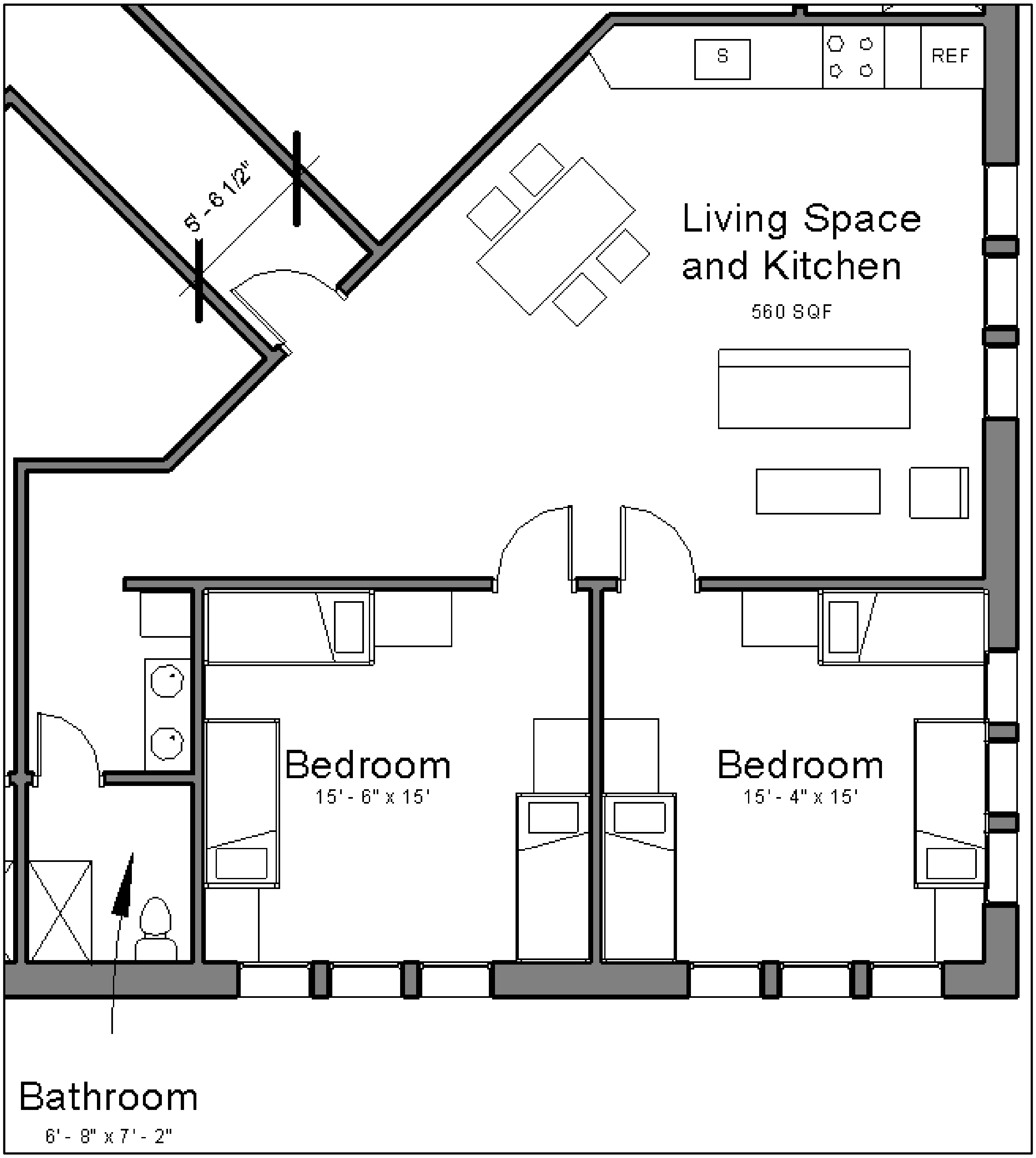


Figure 12: Hex Suite Floor Plan

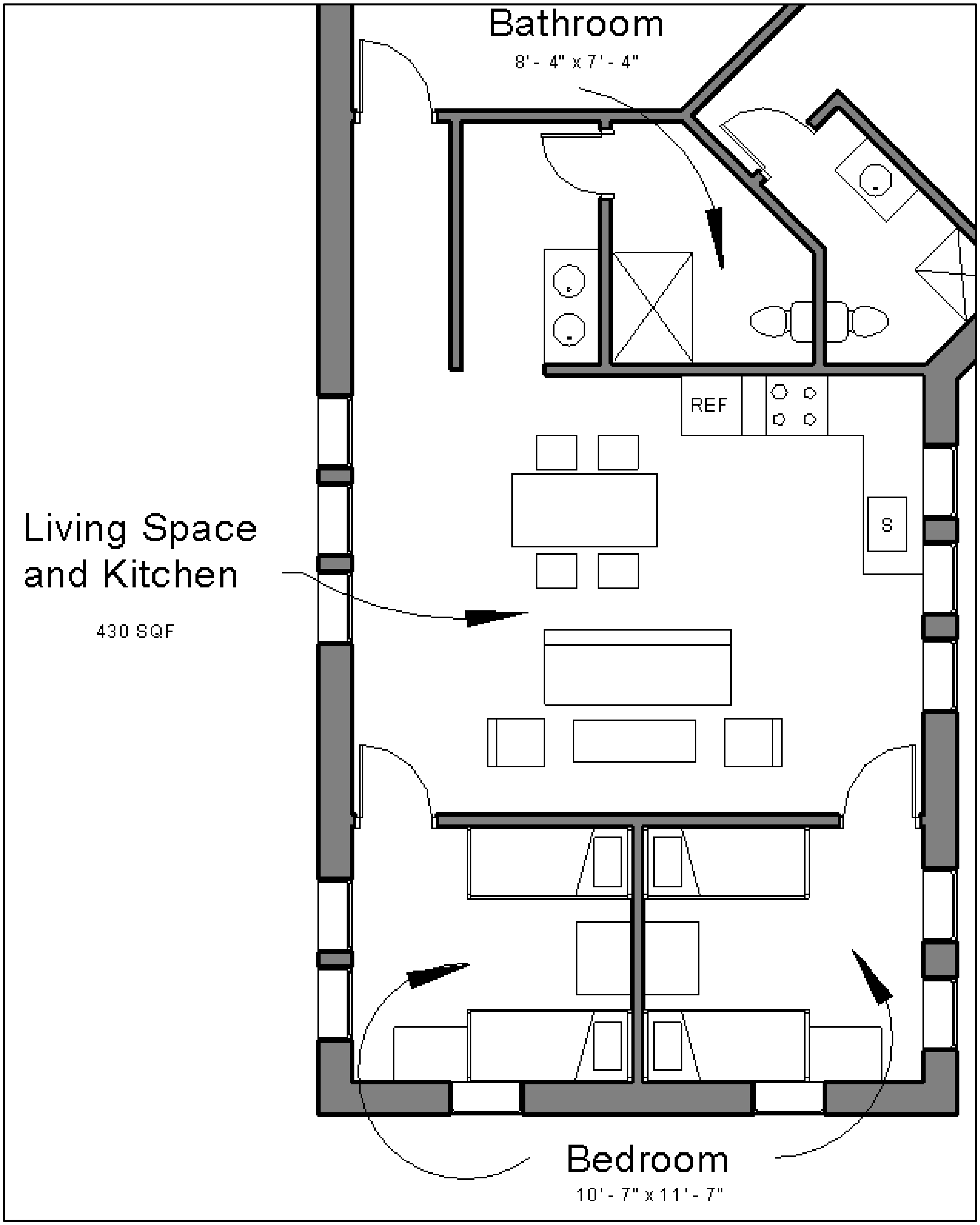


Figure 13: Quad Suite Floor Plan

Figure 12 and Figure 13 also showcase the furnishings for each resident: a lofted, twin-size bed with a desk underneath, and a dresser.

The third floor terrace is an intended product of geometry from the "U" shaped residence hall. In order to make efficient use of space, this terrace is accessible to Parallax residents and their guests via the third floor residence hall. However, key card access will be required for admittance, which will only be granted to Parallax residents. In providing terrace access to Parallax residents, which cannot be found at any other residence hall on WPI's campus, The Parallax may gain favor when it comes time for housing selection. Along with a prime view of the quadrangle, the terrace features an array of seating and workspaces.

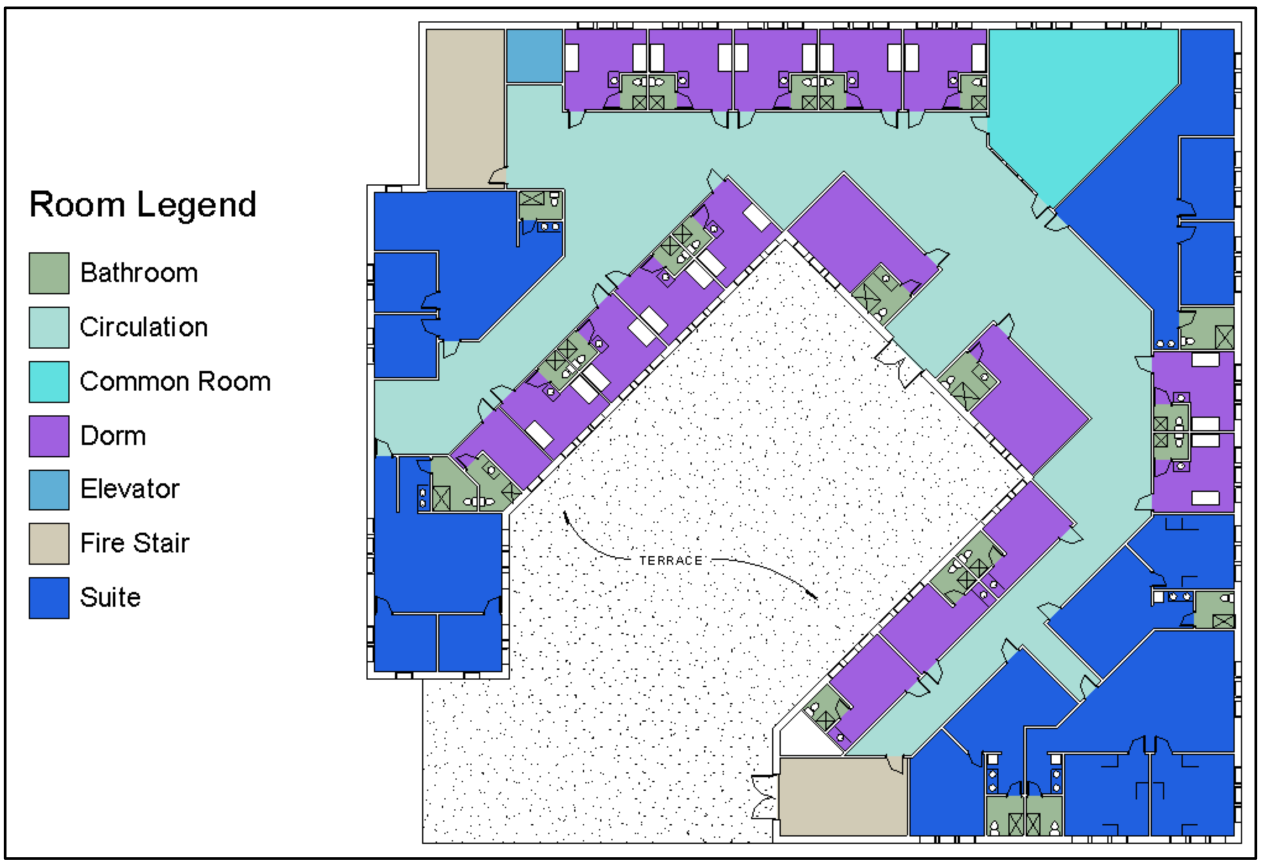


Figure 14: Third Floor Plan

3.5: Conclusion

The WPI community faces several challenges: academic and residential growth, increasing project workspace, and housing the diffused portions of the RBE program. The Parallax utilizes the "divide and conquer" philosophy by addressing each challenge on one of the academic levels and providing a residence hall to specifically address student admissions increases. When all the pieces come together and The Parallax becomes whole, the sum of the challenges is solved.

Chapter 4: Structural Design

4.1: Introduction

A building's structural system is designed to transfer loads, both laterally and vertically, through structural members from the top of the building down to its foundation where the loads are essentially transferred to the ground. This is accomplished through the use of load-bearing walls, floor systems (slabs, beams, joists, and etc.), and columns. For the three known structural materials - concrete, steel, and wood, beams transfer their load onto girders which support those transferred loads and then laterally transfer them to the columns to which they are connected to. The floor system is designed to be responsible for carrying the moment forces caused by any live, dead, snow loads acting on it. Furthermore, floor systems act as diaphragms to transfer wind and seismic loads. This decision on the floor system simplifies the design process of the vertical members because now these are considered to only carry gravity loads, or loads acting vertically. This includes those members' self-weight along with the weight of any members attached to it i.e. girders.

In order to minimize costs and production time, members are often standardized for the worst case scenario presented in the building. If a steel structure were to have every member designed for its unique case, the design process would have to be lengthened an absurd amount and the manufacturing process would take much longer as well in order to produce every single member separately; However, if members are standardized, the design process takes a fraction of the time and members can be produced in bulk. The same process goes for wood and concrete design.

4.2: Concrete Design

The Parallax's academic facility consists of the basement and first two floors that are designed with reinforced concrete. This base will serve as a podium for the three residential floors above. This type of construction is simply termed, "podium construction." The structural design of the academic facility utilizes load-bearing walls and two-way slabs, in order to limit the number of columns and provide a larger, more open floor plan. The load bearing walls are all located near the perimeter of The Parallax which allowed the center of the building to be open with minimal restrictions. Furthermore, they are carried up through the residential part of the building and essentially guided the architectural layout of each floor.

4.2.1 Load Transfer/Types of Load

The loads acting on the building are initially carried by the floor system and are then transferred laterally to its supporting columns. These columns carry the load down to the foundation and eventually into the ground, see Figure 15 below. For The Parallax, the residential columns transfer the loads down to the concrete podium. The podium then carries the load down into the foundation and eventually into the ground.

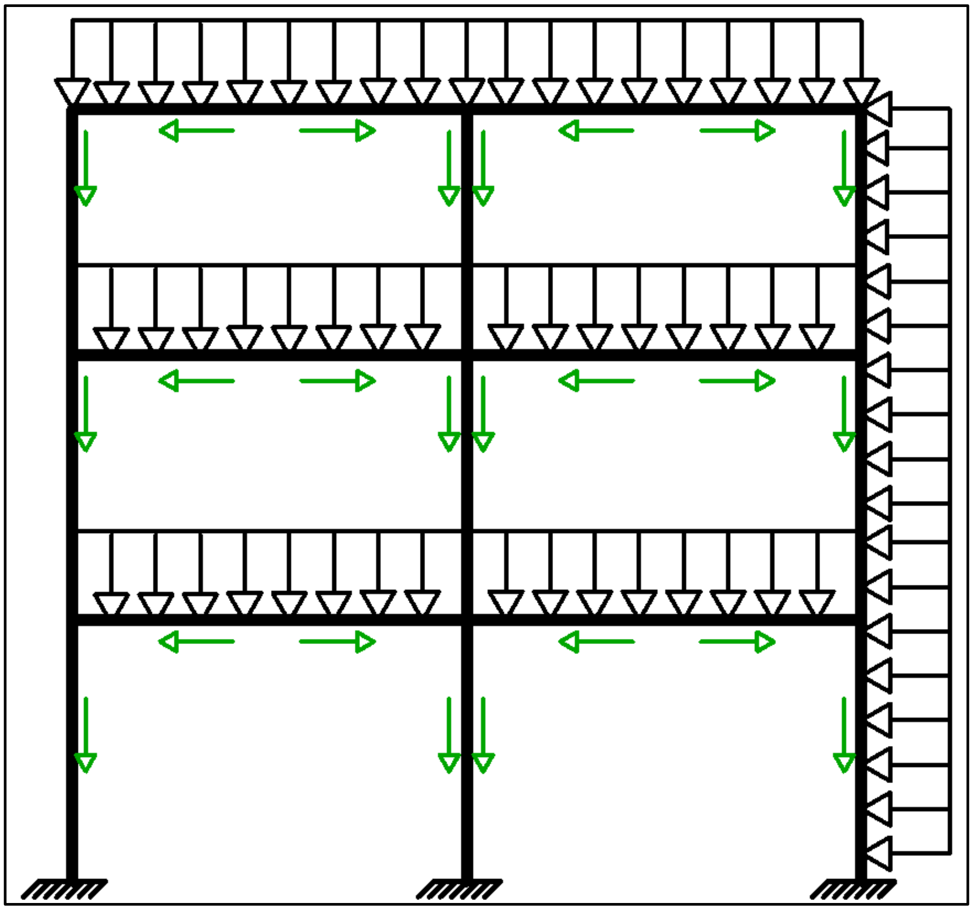


Figure 15: Load Path

When designing the concrete structural system, the first piece that was designed was the slab system because the loads acting on it could be calculated. The columns and load bearing walls were then calculated using their tributary areas. The Parallax's academic facility is supporting three floors of student dormitories and any snow accumulation on its roof; therefore, the largest and most important slab is the top most concrete slab. Consequently, this slab carries the residential dead load and live load along with the snow loads and transfers those loads to its supporting columns and load bearing walls. However, before commencing the design process, a few assumptions were made:

4.2.2 Assumptions/Givens of the System

1. The rebar strength will be 60,000 psi.
2. The concrete strength will be 4,000 psi.

3. The transfer of unbalanced moments from the slabs to the supporting columns and bearing walls was neglected for the preliminary sizing.
4. The residential building creates a total, superimposed dead load of 90 psf, 40 psf for bedrooms and 80 psf for hallways.

4.2.3 Slab Design

The moments that act on a slab are what dictate its design. The moment diagram on a slab is parabolic with the top of the parabola being considered a positive moment and the negative moments occurring at the edge of the slab; the tips of the parabola, see Figure 16.

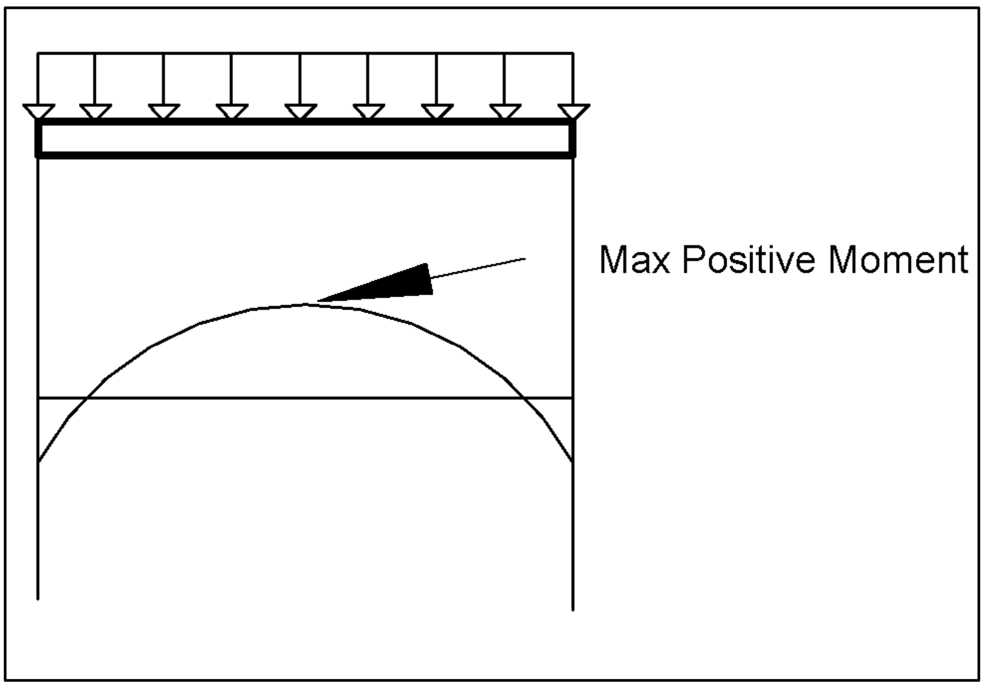


Figure 16: Positive Bending Moment Diagram

A positive moment means that the top of the slab is in compression and the bottom is in tension. For this reason the reinforcing steel is designed for the tension portion of the slab. A negative moment means the opposite and therefore, the rebar will be placed within the upper portion of the slab. The moment forces are calculated through the ultimate weight which is given by the factored associated loads acting on the building. These loads were 100 psf for the live load, 35 psf for the snow load, and the dead load was a combination of the slab's self-weight in addition to the 90 psf for the residential building sitting on top of the podium.

Table 12: Concrete Slab Systems

Concrete Slab System	Key Parameters
One-Way Slab	Flat rectangular slab with reinforcement
One-Way Joist Slab	Minimizes concrete footprint of the one-way by inserting joists where rebar is needed
Waffle Slab	Utilizes same technique the one-way joist does but now the joists span all directions of the slab, creating the waffle look.

The first slab system designed was a *one-way slab system*. A one-way slab system is designed to only have reinforcement in one direction. These types of slabs must be used in bays that have a length ratio larger than three, as in the length of the bay must exceed three times the width of the bay. The reinforcement will span across the short length (width) of the slab. After calculating the one way slab, a thickness of 20 inches was obtained. This is non-ideal: both the cost and weight would be immense for a 20-inch concrete slab, spanning a 22,500 square feet. Also, the depth of this slab will subtract usable vertical space, lowering the plenum, which would force the building to increase its ultimate height in order to ensure the specified ceiling heights by the architect. Increasing the building's height could cause implications with the construction type of the building. Standard concrete slab thicknesses for commercial projects is between six and ten inches.

The next step was to then design a *one-way joist slab system*. The purpose of the joist is to minimize the amount of concrete being used. This will lower the cost of construction and the thickness of the slab, ultimately lowering the slab’s self-weight. With a joist system, the rebar is placed in the joists that extend down from the thinner slab and there are voids between the joists where no concrete is present. However, even with the one-way joist system, the total depth of the joist was too long.

Therefore, a *two-way slab system* must be considered because it will be less costly, less massive, and allow larger bay sizes, giving the building a more open floor plan.

Two-way slabs allow for larger bay sizes because there is reinforcement running in both directions of the slab. The positive and negative moments still dictate how much reinforcing steel is required and the bay sizes are limited to a length/width ratio of three. When designing any two way slab system, there are nine different cases, or combinations, of slabs, in which the edges of the slab are either continuous or discontinuous. A continuous edge is one that will continue to span into the next bay. A discontinuous one is an edge that stops at its support (i.e. an edge that is fixed to an exterior wall).

The coefficient method uses the nine cases previously mentioned. The coefficients that are used to calculate the moments in the slab are controlled by the case and whether the moment is positive or negative. When considering the worst case scenario of the roof slab, the calculations yielded a thickness of 14 inches. This thickness is still too thick and expensive; therefore, a *waffle slab*, the joist system for a two-way slab, was designed.

To begin waffle slab calculations, a few assumptions about the initial waffle dimensions were made: the flange width is 42 inches, the web is 12 inches wide, and the slab is 3 inches thick. However, ACI 9.5.3.3 calls for a minimum slab thickness of 5 inches. With the assumptions made, the design process was repeated for the multiple cases presented in the building. For the slab determined to be the worst case scenario, see Figure 17 below. Six separate moments were identified due to the geometry of the slab.

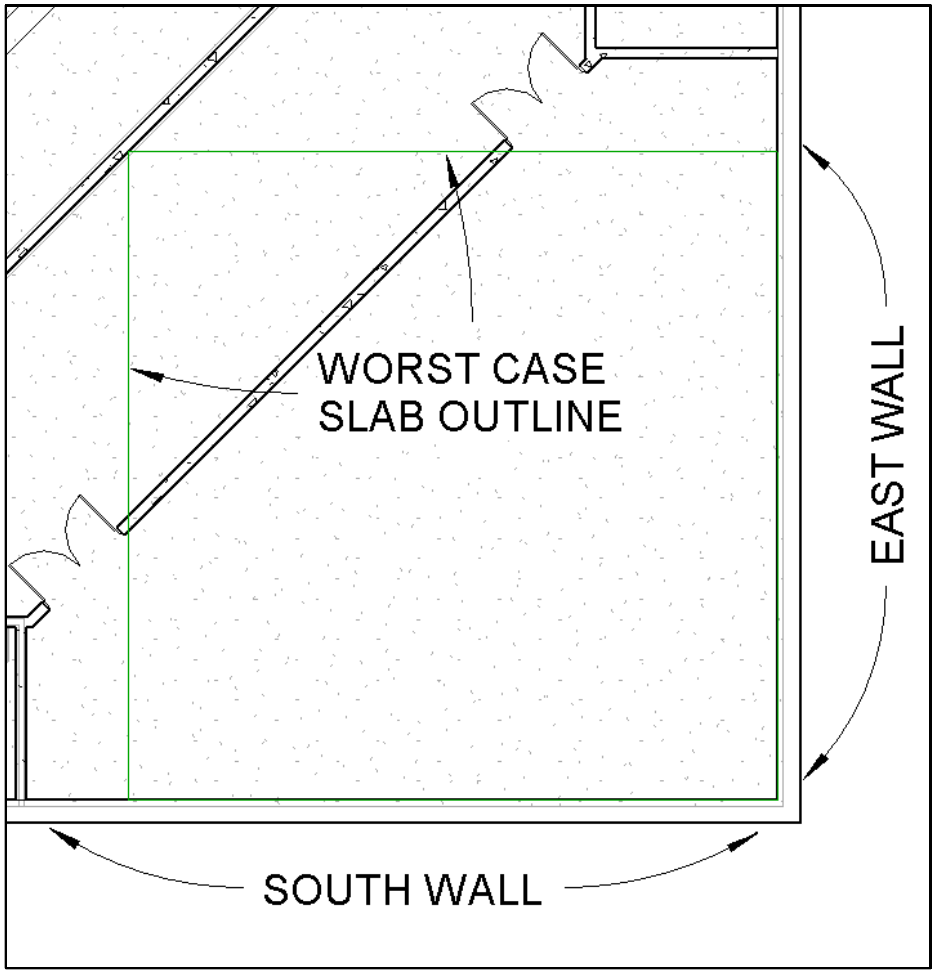


Figure 17: Worst-case Slab

Therefore, the design process was completed for each moment in order to determine the necessary rebar. In order to minimize costs, rebar was restricted to be no larger than a #8. The final size of the rebar was found to be a number #8 which has a diameter of one inch.

Initially, the designed waffle slab system shortened the depth of the total slab to ten inches, three inches of slab with a seven-inch web, web width of twelve inches with thirty-inch spacing between webs, five No. 8 reinforcing bars in the short direction, and six of the same in the long direction.

4.2.4 Column and Load Bearing Walls

The exterior load bearing walls are responsible for gravity and lateral forces. However, as explained in section 4.2.5, the walls are sufficiently thick that the lateral loads are negligible. Gravity loads include loads carried by the slab, the weight of the slab, and the column/bearing wall's self-weight. Therefore, the sizing of these members was not as complex. The axial loading was determined in order to design the required area of the concrete and steel reinforcement to sustain the load. Based on these methods, the large columns were found to be ten inches in diameter with four No. 4 bars, the small columns were calculated to be eight inches in diameter with five No. 3 bars, and the bearing walls were determined to be ten inches thick with two No. 8 bars every twelve inches.

4.2.5 Lateral Loads

Interpolation of Table 27.6-1 from the ASCE 7-10 yields a wind pressure value of fifteen pounds per square foot, acting at twenty-six feet; the top of the concrete construction. With a compressive strength of 4,000 pounds per square inch, the walls of the concrete structure are inherently strong enough to render these standard wind loads negligible.

4.2.6 Foundation and Foundation walls

In general, foundation walls carry vertical load from the superstructure and lateral load from both soil pressure and seismic activity. The foundation slab acts as a diaphragm in terms of lateral support. The Parallax foundation walls are ten inches thick, poured on site, with two No. 8 reinforcing bars every twelve inches, as to be consistent with the load-bearing walls above. The foundation slab design was conducted using the one-way slab design method. The 150' x 150' footprint was divided into thirty-six 25' x 25' slabs: yielding a slab length, L, of 25 feet. Because the whole slab is continuously supported by the earth, the ground will act as the subdividing joists. An initial slab thickness (h) of 10 inches was also assumed. Table 13 walks through the design process.

Table 13: Foundation Slab Design Procedure

Step 1: Calculate Flexure Load	W_u = 1.2DL + 1.6LL + 0.5SL	W_u = 1305.9 psf
Step 2: Calculate Moments	Interior/Exterior: $M_u = (-1/11)WL^2$	M_u = -74.2 k-ft
	Midspan: $M_u = (1/16)WL^2$	M_u = 51 k-ft
Step 3: Calculate the depth of the reinforcement, d	$M_u = \phi\rho f_y bd^2[1 - 0.59\rho(f_y/f'_c)]$	d ≥ 9.52 in
Step 4: Check minimum cover for actual d and recalculate	d = h - 0.75 in - 0.25 in	d = 9 in, not ≥ 9.62
	New h = 12 in	W_u = 1335.9 psf M_u = -75.9 k-ft (Int/Ext) M_u = 52.2 k-ft (Midspan) d ≥ 9.62 in (calculated d) d = 11 in, ≥ 9.62 (actual d)
Step 5: Calculate reinforcement requirement with interpolation	$A_s = M_u/[\phi f_y(d - 0.5a)]$ $a = (A_s f_y)/(0.85f'_c b)$	A_s = 1.193 in^2 (Midspan)
Solution Checks	2 #7 bars, A_s = 1.20 in^2 <u>2 #8 bars, A_s = 1.57 in^2</u> A_s,min = 0.003bh = 0.48 in^2 A_s,max = 0.021bh = 2.97 in^2	0.48 in^2 ≤ 1.57 in^2 ≤ 2.97 in^2

The table shows that the initial thickness assumption was incorrect and the actual slab thickness will be 12 inches. Although two No. 7 bars will suffice, two No. 8 bars will be used for standardization of materials, as the load-bearing walls and other slabs are also using No. 8 reinforcing bars. These two No. 8 bars will be placed at every twelve inches.

4.3 Wood Design

4.3.1 Background

Wood design follows the basic principles of load transferring introduced in the beginning of the chapter. The floor joists are considered beams that can connect to a girder that transfers the load to a load bearing wall or column; these floor joists can also be directly attached to load bearing walls. The load-bearing walls of the residential building transfer loads down into the roof slab of the podium.

4.3.2 Wall Framing

Wood framing is generally prescriptive. However, in order for the residential structure to qualify as Type III (B) construction, the exterior walls are to be framed using fire-retardant-treated lumber. The exterior wall frame is composed of 2X6 nominal wood studs, spaced at 16" on center. The interior partitions are also comprised of 2x6 studs at 16" O.C. However, the interior walls have no requirement for fire rating due to the construction type. Despite the lack of a requirement, the interior walls are finished with 5/8" drywall, yielding a 1 hour fire rating.

4.3.3 Shear loads

The design of the shear wall was crucial due to the building's elevation. Because the three-story building is located on top of a podium, it experiences higher wind velocities than if it were level with the ground. The design process for a wood frame shear wall is outlined by the Code Master that references ASCE 7-10 and the 2012 IBC. The Code Master breaks the process down in seven steps; some of which, have multiple considerations. The steps are listed below in Table 14:

Table 14: Code Master Steps for Shear

Step	Description	Answer
1	Determine Risk Category	Category III
2	Determine Basic Wind Speed	124 MPH
3	Determine Mean Roof Height	56 ft.
4	Determine Exposure Category	Category B
5	Determine Enclosure Classification of Building	Enclosed
6	Determine Directionality Factor K_d, Topographic Factor K_{zt}, and Gust Effect Factor G or G_t	K_d = .85 K_{zt} = 1 G_f = .85
7	Determine Wind Design Method for MWFRS	Method 5: Wind Tunnel Procedure

Due to the residential building's "U" shaped geometry, there is no simplified method to determine the design wind pressures for the design of the shear wall and diaphragm. The only way to design this building would be to produce a scaled model of the building and test it in a wind tunnel. Putting the model in a wind tunnel would allow the design process to be extremely accurate due to the fact that all the results would be computerized based on how the model reacts in the tunnel. The results would be produced for each individual wall. The wind tunnel would essentially note how much load is acting on the wall and then based on this value, the amount of shear that the wall is experiencing would be determined. This shear value guides the design of the sheathing, structural tie downs and diaphragm sheathing as well.

However, for the sake of time and to provide a learning experience with the wind load provisions of ASCE 7, the building was treated as a simple case, and the shear walls and diaphragms were standardized from the design for the worst-case scenario. Therefore, for Step 7 in the table above, Method 2 was chosen. Method 2 requires a building to be an enclosed simple diaphragm with a height of less than 160 feet. It's also described as a simplified version of method 1 assuming the requirements are met.

Method 2 is presented in chapter 27 part 2 of the ASCE 7-10. Taking into account the parapet roof and the height locations of the building, the wind pressures at key heights on the wall were obtained from Table 15. The building's height, the geographic wind speed given by the ATC's website and the L/B value, found by dividing the shear wall's length by the length of the perpendicular wall that directly faces the wind, were the guiding parameters when using the table. The required wind pressure was then found by interpolating the table values corresponding to the parameters, see Appendix C for calculations.

Table 15: ASCE 7-10 Table 27.6-1

Table 27.6-1
MWFRS – Part 2: Wind Loads – Walls
Exposure B

V(mph)	110			115			120			130			140			160			180			200		
h(ft.), L/B	0.5	1	2	0.5	1	2	0.5	1	2	0.5	1	2	0.5	1	2	0.5	1	2	0.5	1	2	0.5	1	2
160	38.1	37.7	34.1	42.1	41.7	37.8	46.4	45.9	41.7	55.8	55.1	50.2	66.3	65.4	59.7	91.0	89.4	81.8	120.8	118.3	108.5	156.2	152.4	140.0
	25.6	25.4	21.0	28.3	28.1	23.3	31.2	30.9	25.7	37.5	37.1	30.9	44.6	44.0	36.8	61.2	60.1	50.4	81.3	79.6	66.9	105.2	102.6	86.2
150	36.9	36.6	33.0	40.7	40.4	36.5	44.9	44.4	40.3	53.9	53.3	48.5	63.9	63.1	57.6	87.5	86.1	78.9	116.1	113.8	104.5	149.9	146.5	134.7
	25.1	24.9	20.6	27.7	27.5	22.8	30.5	30.2	25.2	36.7	36.2	30.3	43.5	43.0	36.0	59.6	58.6	49.3	79.0	77.4	65.3	102.0	99.7	84.2
140	35.6	35.4	31.9	39.3	39.1	35.3	43.3	42.9	38.9	51.9	51.4	46.7	61.5	60.8	55.5	84.0	82.8	75.9	111.2	109.2	100.4	143.5	140.5	129.3
	24.5	24.4	20.2	27.1	26.9	22.4	29.8	29.6	24.6	35.7	35.4	29.6	42.4	41.9	35.2	57.9	57.0	48.1	76.6	75.2	63.7	98.8	96.7	82.0
130	34.4	34.2	30.8	37.9	37.7	34.0	41.7	41.4	37.4	49.9	49.5	44.9	59.1	58.5	53.3	80.5	79.5	72.8	106.3	104.6	96.2	136.9	134.3	123.8
	24.0	23.9	19.8	26.5	26.3	21.9	29.1	28.9	24.1	34.8	34.5	28.9	41.2	40.8	34.3	56.2	55.4	46.9	74.2	73.0	62.0	95.5	93.7	79.8
120	33.1	33.0	29.6	36.5	36.3	32.7	40.1	39.9	35.9	47.9	47.6	43.1	56.6	56.2	51.0	76.9	76.1	69.6	101.3	99.9	91.8	130.2	128.0	118.0
	23.4	23.3	19.4	25.8	25.7	21.4	28.4	28.2	23.6	33.9	33.7	28.3	40.1	39.7	33.5	54.4	53.8	45.6	71.7	70.7	60.2	92.2	90.6	77.4
110	31.8	31.7	28.4	35.1	34.9	31.3	38.5	38.3	34.4	45.9	45.6	41.2	54.1	53.8	48.8	73.3	72.6	66.3	96.3	95.1	87.4	123.5	121.6	112.1
	22.9	22.8	19.0	25.2	25.1	20.9	27.7	27.5	23.0	33.0	32.8	27.6	38.9	38.7	32.6	52.7	52.2	44.4	69.2	68.4	58.4	88.8	87.4	75.0
100	30.5	30.4	27.1	33.6	33.5	29.9	36.8	36.7	32.9	43.8	43.6	39.3	51.6	51.3	46.4	69.6	69.1	62.9	91.2	90.3	82.8	116.6	115.1	106.0
	22.3	22.3	18.5	24.6	24.5	20.4	26.9	26.8	22.5	32.1	31.9	26.8	37.8	37.6	31.7	50.9	50.5	43.0	66.7	66.0	56.6	85.3	84.2	72.5
90	29.2	29.1	25.9	32.1	32.0	28.5	35.1	35.0	31.2	44.7	41.6	37.3	49.1	48.8	44.0	65.9	65.5	59.5	86.0	85.3	78.0	109.6	108.5	99.8
	21.8	21.7	18.1	23.9	23.9	19.9	26.2	26.1	21.9	31.1	31.0	26.1	36.6	36.4	30.8	49.2	48.9	41.7	64.2	63.6	54.6	81.8	80.9	69.9
80	27.8	27.7	24.5	30.5	30.5	27.0	33.4	33.3	29.6	39.6	39.5	35.2	46.4	46.3	41.5	62.2	61.9	55.9	80.8	80.3	73.1	102.6	101.7	93.3
	21.2	21.2	17.7	23.3	23.2	19.4	25.5	25.4	21.3	30.2	30.1	25.4	35.4	35.3	29.9	47.4	47.2	40.3	61.6	61.2	52.6	78.3	77.6	67.2
70	26.3	26.3	23.1	28.9	28.8	25.4	31.6	31.5	27.9	37.4	37.3	33.1	43.7	43.6	38.9	58.3	58.1	52.2	75.5	75.1	68.1	95.5	94.9	86.6
	20.6	20.6	17.2	22.6	22.6	18.9	24.7	24.7	20.7	29.3	29.2	24.6	34.2	34.2	28.9	45.6	45.5	38.8	59.1	58.8	50.6	74.7	74.3	64.3
60	24.8	24.8	21.7	27.2	27.1	23.8	29.7	29.6	26.1	35.1	35.0	30.9	41.0	40.9	36.2	54.4	54.2	48.4	70.1	69.8	62.8	88.2	87.9	79.6
	20.0	20.0	16.7	21.9	21.9	18.4	23.9	23.9	20.1	28.3	28.2	23.6	33.0	33.0	27.9	43.9	43.8	37.3	56.5	56.3	48.5	71.2	70.9	61.4
50	23.1	23.1	20.2	25.3	25.3	22.1	27.6	27.6	24.2	32.6	32.6	28.6	38.0	38.0	33.4	50.3	50.2	44.5	64.5	64.4	57.4	80.9	80.7	72.5
	19.3	19.3	16.3	21.2	21.2	17.8	23.1	23.1	19.5	27.3	27.3	23.0	31.8	31.8	26.9	42.0	42.0	35.8	54.0	53.8	46.3	67.6	67.5	58.4
40	21.5	21.5	18.6	23.5	23.5	20.4	25.6	25.6	22.3	30.2	30.2	26.3	35.1	35.1	30.7	46.3	46.2	40.7	59.2	59.1	52.3	73.9	73.8	65.7
	18.8	18.7	15.8	20.5	20.5	17.4	22.4	22.4	18.9	26.4	26.4	22.4	30.7	30.7	26.1	40.5	40.4	34.6	51.7	51.7	44.5	64.6	64.5	55.8
30	19.6	19.6	16.9	21.4	21.4	18.5	23.3	23.3	20.2	27.5	27.4	23.8	31.9	31.9	27.7	41.9	41.9	36.6	53.4	53.4	46.8	66.5	66.4	58.5
	18.1	18.1	15.4	19.8	19.8	16.8	21.5	21.5	18.4	25.3	25.3	21.6	29.5	29.5	25.2	38.7	38.7	33.2	49.3	49.3	42.5	61.4	61.3	53.1
20	17.5	17.5	15.1	19.2	19.2	16.6	20.9	20.9	18.1	24.5	24.5	21.2	28.5	28.5	24.7	37.3	37.3	32.4	47.4	47.4	41.3	58.8	58.8	51.4
	17.2	17.2	14.8	18.8	18.8	16.2	20.5	20.5	17.7	24.1	24.1	20.8	28.0	28.0	24.2	36.7	36.7	31.7	46.6	46.6	40.4	57.8	57.7	50.3
15	16.7	16.7	14.5	18.2	18.2	15.8	19.9	19.9	17.3	23.3	23.3	20.3	27.1	27.1	23.6	35.4	35.4	30.9	44.9	44.9	39.3	55.6	55.6	48.7
	16.7	16.7	14.5	18.2	18.2	15.8	19.9	19.9	17.3	23.3	23.3	20.3	27.1	27.1	23.6	35.4	35.4	30.9	44.9	44.9	39.3	55.6	55.6	48.7

The design process compared the two largest walls because they were perpendicular to the two smallest walls that would be receiving the shear load. Therefore, the two worst case scenario walls are pointed out below in Figure 18 and Figure 19.

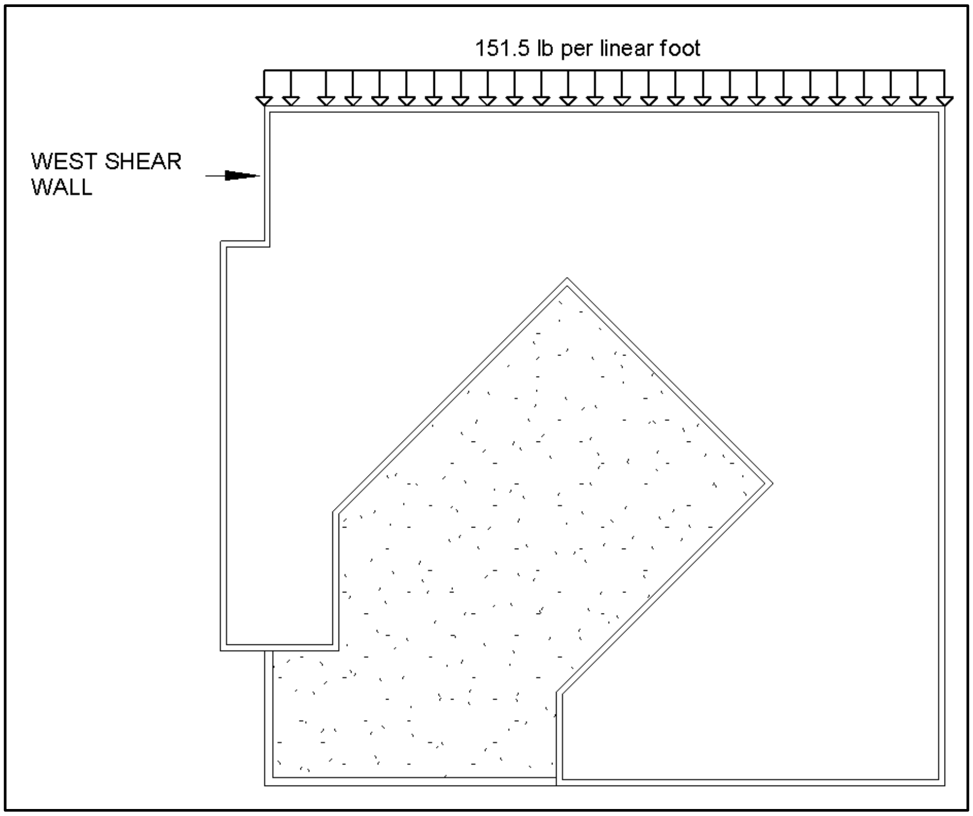


Figure 18: West Shear Wall

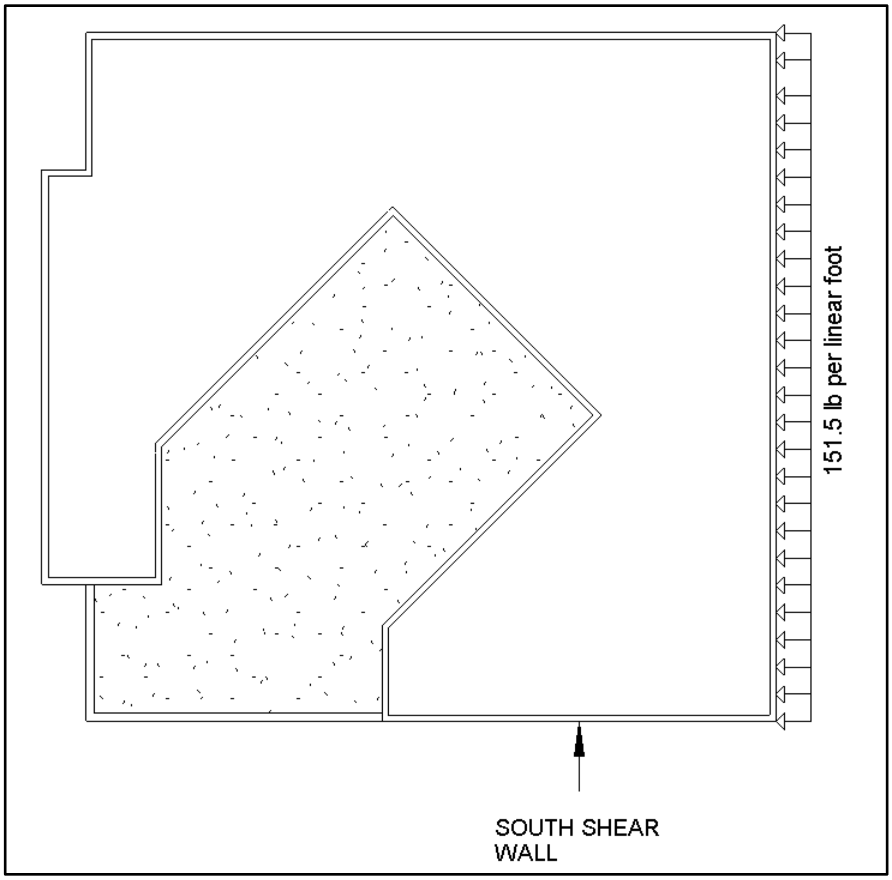


Figure 19: South Shear Wall

Through analysis, the west wall was deemed to be the governing for the worst case scenario. This is because the west wall is responsible to carry the same amount of load as the south wall but the west wall's distance is shorter; therefore, putting a higher strain on it. The loads for this wall were then distributed to each floor according to the tributary width of each diaphragm. Using Table 4.2C in the *Wind and Seismic Special Design Provisions for Wind and Seismic* (SDPWS) code, the initial sheathing grade was determined to be a 5/16" Sheathing and Single-Floor with 6d nail size. However, Table 5503.1 in the 780 CMR Massachusetts building code calls for a minimum of 11/16" thick sheathing when floor joists are spaced 16" on center.

Using LRFD combined with the Segmented Wood shear Wall Design method, Section 4.3.5.1 of the SDPWS, the West wall was separated into segments with heights of 10' and varying widths, See

Figure 20 below. The large white panels represent the sheathing and the shade areas represent the brick veneer of the building.

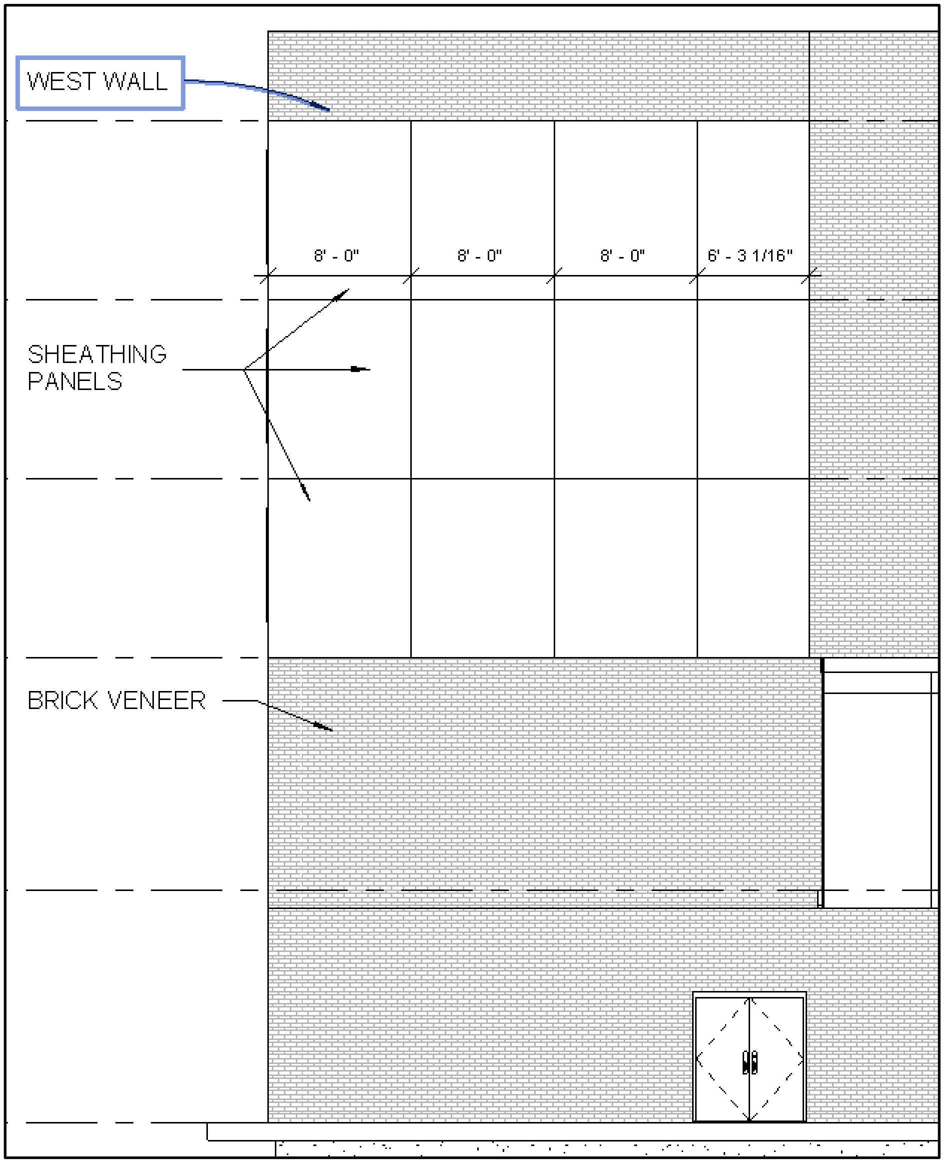


Figure 20: West Shear Wall Elevation

These panels represent the sheathing for the shear walls that were sized in accordance with Table 4.3.4 "Maximum Shear Wall Aspect Ratios." Because the sheathing was pre-determined to be structural with blocking, the acceptable ratio of height to base, H/b_s, was 3.5:1. In order to size the sheathing, the lateral load acting on the second floor needed to be divided by the length of the West wall and then multiplied by the factor $\phi = .8$. Using Table 4.3 in the SDPWS, the selected sheathing was chosen as 7/16" Structural Panel I with 8d nails 6" o.c. Table 4.3 lists different types of sheathing materials, their thickness, fastener penetration, and fastener type and size. Each combination of these parameters have a corresponding seismic and wind resistance.

To finish the design of the shear wall, the required tie-down forces for the wall needed to be determined. To begin, this wall was designed to be treated as a whole unit rather than having each panel of sheathing act as its own system. Section C4.3.7 of the SDPWS specifies that this can be accomplished by screwing 2-2x6 members together where sheathing panels meet. This connection allows for the transfer of load through the panels, simplifying the tie-down calculations. The tie-down calculations are relatively straightforward: a function of the wall's height and length, and the force of the wind acting on the wall in pounds per linear foot. Table 16 walks through the tie-down calculations for the North-facing wall, illustrated in Figure 21.

Table 16: Tie-down Forces, North Wall

Panel	Width (ft)	Ratio of Panel Width to Total Width	Shear Load (lb)	Tie-Down Force @ 3rd Floor (lb)	Tie-Down Force @ 4th Floor (lb)	Tie-Down Force @ 5th Floor (lb)
A	14.83	0.1827	5,295	10,711	7,141	3,570
B	6.5	0.0801	2,321	10,711	7,141	3,570
C	8.33	0.1026	2,974	10,711	7,141	3,570
D	5.33	0.0657	1,903	10,711	7,141	3,570
E	5.67	0.0699	2,024	10,711	7,141	3,570
F	5.67	0.0699	2,024	10,711	7,141	3,570
G	5.67	0.0699	2,024	10,711	7,141	3,570
H	29.17	0.3594	10,415	10,711	7,141	3,570
Total	81.17	1	28,980	10,711	7,141	3,570

As can be seen in Table 16, the tie-down forces of the panels are equivalent at each floor. This is because the load acting on each panel is a function of the ratio of the panel's width to the total width. In other words, the load acting on a panel is proportional to its width. A more involved analysis could show

how some of the shear load is actually carried by the lateral struts, the sections of wall above and below the windows and between panels.

Figure 21: North Shear Wall Elevation

4.4 Pratt Truss

4.4.1 Background

The second floor of the academic facility features two classrooms, on the west side of The Parallax, that overhang the first floor exterior wall by ten feet, see Figure 22 below.

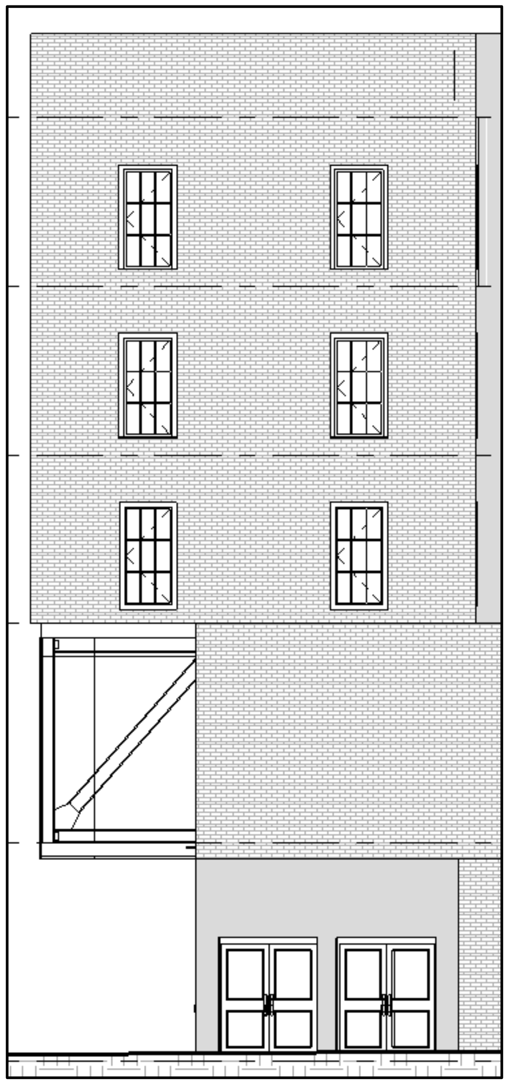


Figure 22: Overhang Elevation

The three stories of residential construction, above, also overhang. A Pratt truss is the ideal structural solution; essentially tying back all the loads, acting on the overhang, to the load-bearing walls in the main structure. Initially, a Vierendeel was considered but because of load-path knowledge it was predetermined that for the truss to be acceptable, the members would've been substantially larger. The Pratt truss offers bracing members which consequently decreased the size of the members. To architecturally enhance the overhang, the steel members will be exposed and put on display with a glazed curtain wall: the envelope for the two classrooms.

4.4.2 General Design

To more efficiently explain the design process, Table 17 details the procedure, step by step.

Table 17: Truss Design Procedure

Step	Description
1 – Spacing	Determine how many trusses are to be used, and their orientation, based on the architecture and design goals.
2 – Tributary Area	Based on the spacing, calculate the tributary areas each truss is responsible for supporting.
3 – External Load Calculations	Based on the tributary areas, calculate the magnitude and location of the external loads (dead load, live load, and snow load) acting on the truss.
4 – Member Orientation	Based on the external loading, geometry of the truss, and anticipated load path, make an educated assumption of the truss members' orientations.
5 – Reactionary Forces	Based on the external loading and support locations, calculate the reactionary forces acting on the truss.
6 – Member Forces/Influence Lines	Using both external loads and reactionary forces, calculate the forces in each member of the truss using influence lines.
7 – Member Sizing	With the forces of all the truss members calculated, member sizing can begin.

In the case of the second floor overhang, three trusses are used: one at each end and a third, illustrated as the wall dividing the two classrooms. The middle truss was selected for design because it has the largest tributary area; therefore, its final solution can be used for the other trusses, for standardization purposes. After calculating the external loads, the member spacing and orientation was assumed from the cantilever geometry of the truss. See Figure 23.

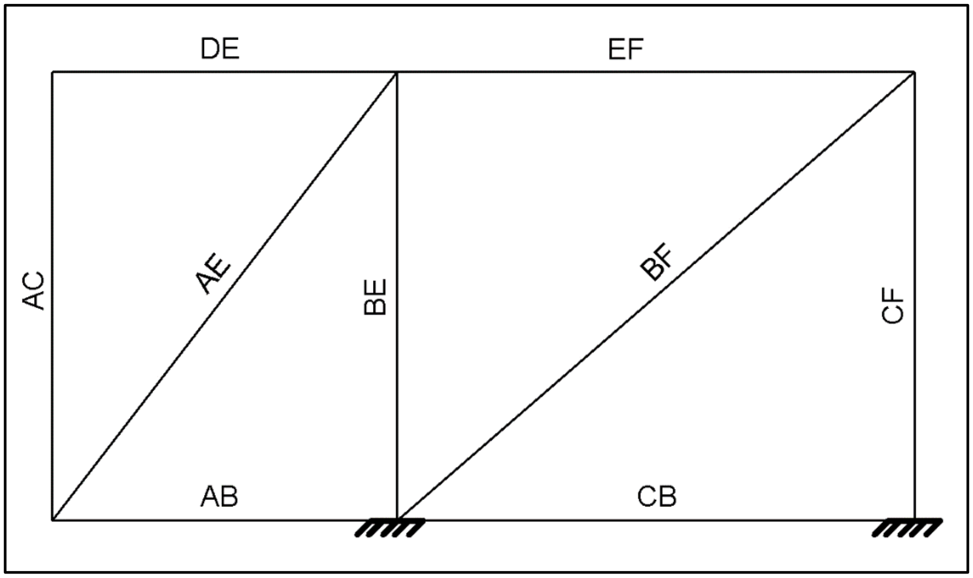


Figure 23: Simple Pratt Truss Sketch

4.4.3 Sizing Members

Similar to the concrete and wood members, the steel members were also designed based on the worst-case scenario for tension and combined axial and flexure. To confirm the completed hand calculations, the truss was put into the structural software *RISA 2D*. The software produced the member forces acting on each member of the truss. Refer to Appendix D for the results on all members. The results for the critical members are presented in Table 18 below.

Table 18: Truss Member Forces

Member label	Section	Axial (K)	Shear (K)	Moment (K-ft)
Member EF	1	-3.26	204.966	377.68
	2	-3.26	26.266	-144.129
	3	-3.26	-11.234	-172.313
	4	-3.26	-48.734	-59.872
	5	-3.26	-86.234	193.194
Member EB	1	299.761	-10.39	-93.194
	2	299.761	-10.39	-59.426
	3	299.761	-10.39	-25.658
	4	299.761	-10.39	8.109
	5	299.761	-10.39	41.877
Member CF	1	64.501	12.603	112.967
	2	64.501	12.603	72.008
	3	64.501	12.603	31.049
	4	64.501	12.603	-9.91
	5	64.501	12.603	-50.868
Member AE	1	-25.736	-4.689	-10.776
	2	-25.736	-4.689	8.448
	3	-25.736	-4.689	27.673
	4	-25.736	-4.689	46.898
	5	-25.736	-4.689	66.123

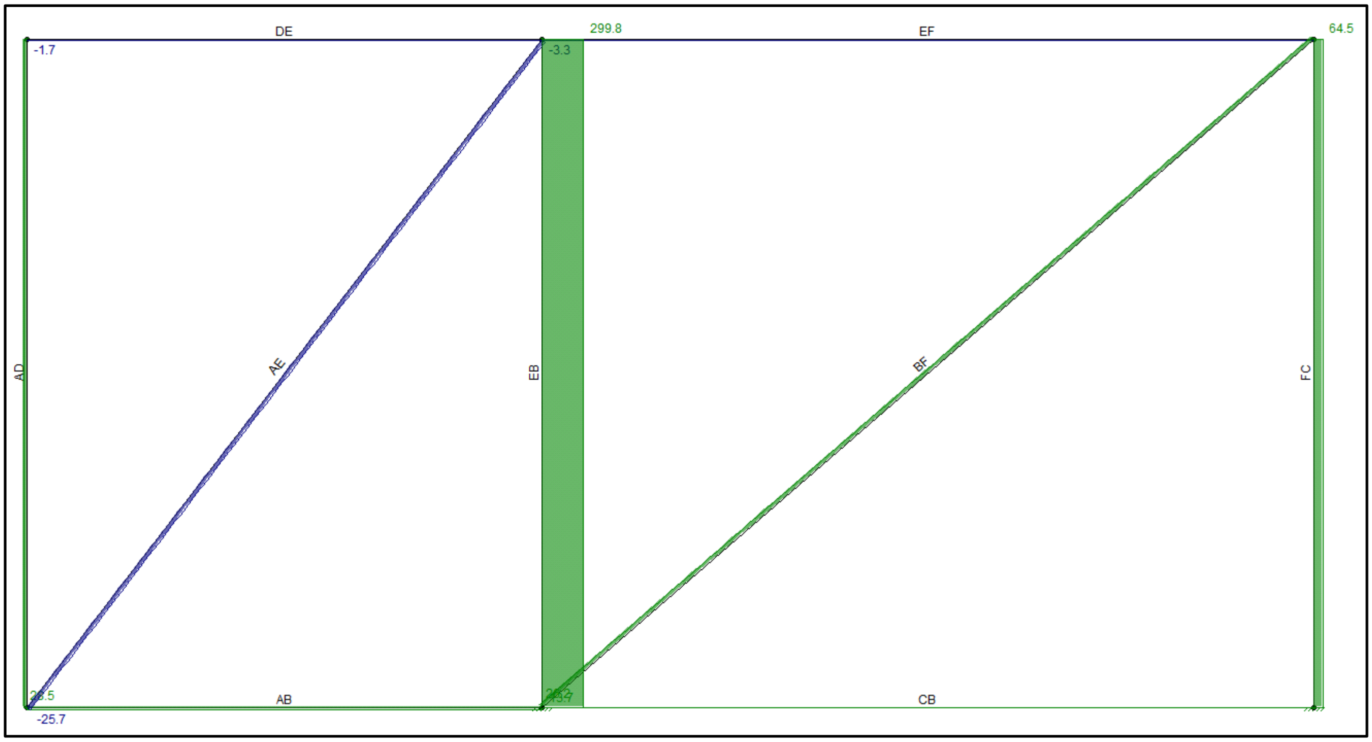


Figure 24: Pratt Truss Axial Loading Diagram

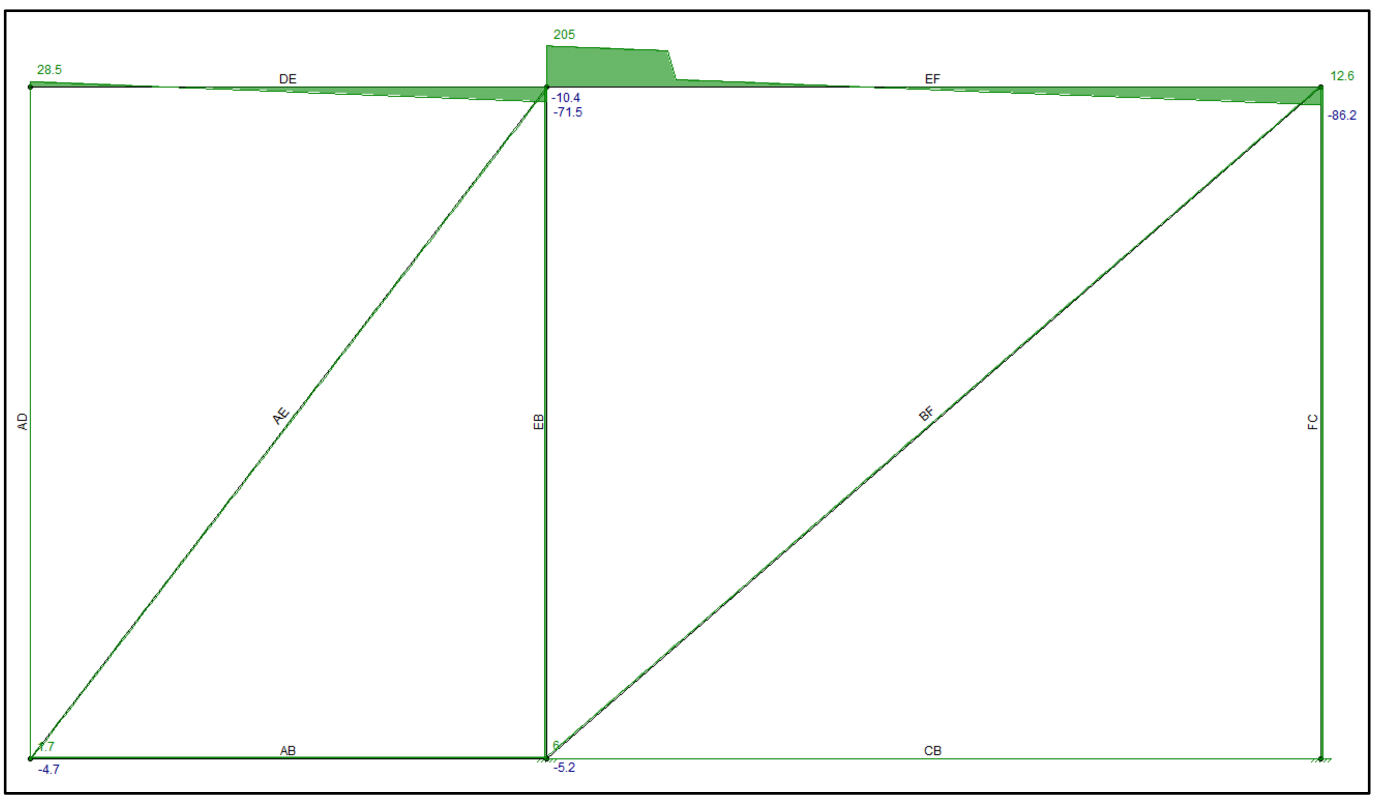


Figure 25: Pratt Truss Shear Diagram

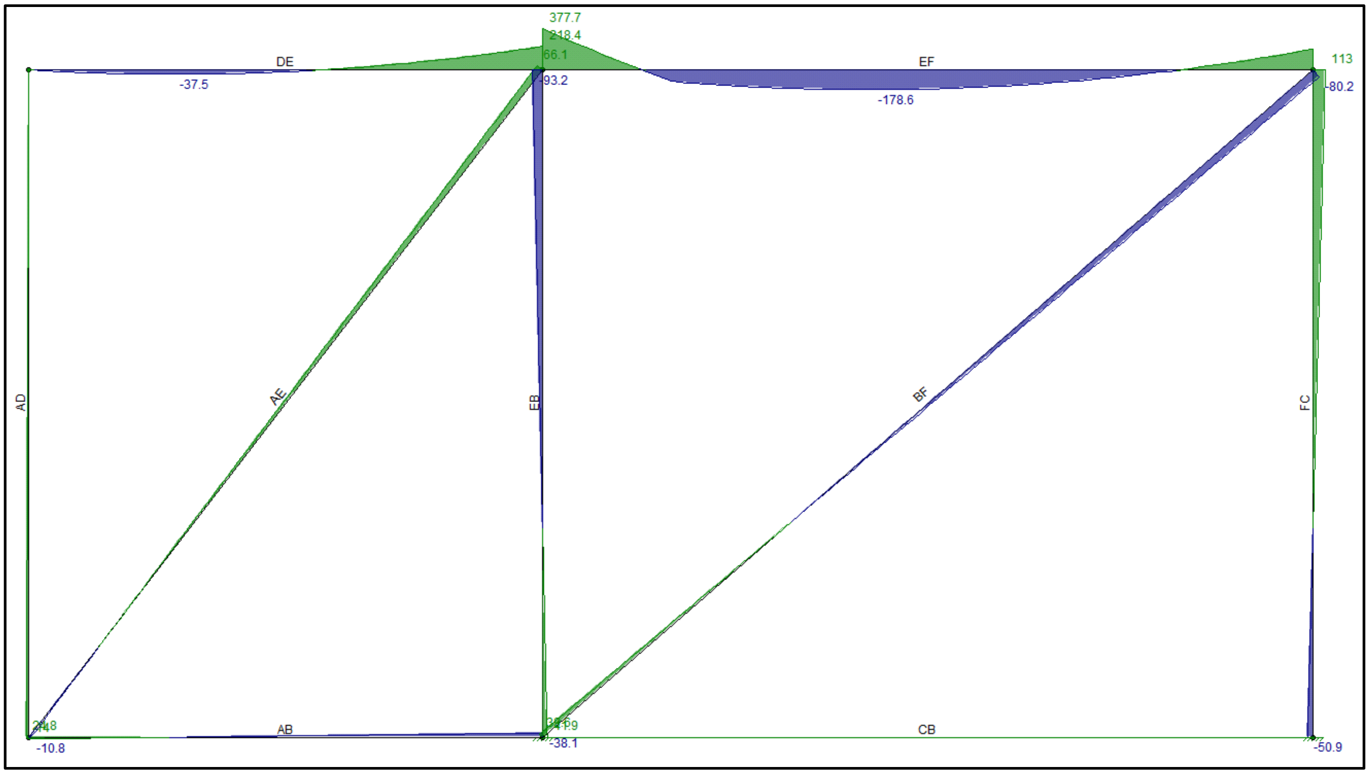


Figure 26: Pratt Truss Moment Diagram

The *American Institute of Steel Construction Manual* (AISCM) was essential in designing members for the truss. Table 1-1 provides all necessary dimensions of any given member, Table 3-2 organizes W shapes by their Z_x value but also provides the design moment capacity and the moment of inertia about the X-axis. These values are essential in determining the bending capacity and deflection of a selected member. Furthermore, Table 4-1 presents information on the available strength of W sections in axial compression. The AISC also presents the procedure for the design of tension members in Chapter D in the specification.

Sizing of the steel members was broken down into three separate calculations: one for members with combined axial compression and flexure, another for members experiencing combined axial tension and flexure, and finally shear calculations. Due to these combined forces, equations in H1-1a and H1-1b, presented below, from Chapter H in the Specification of the AISCM are the dictating equations for sizing the members.

(a) When $\frac{P_r}{P_c} \geq 0.2$

$$\frac{P_r}{P_c} + \frac{8}{9}\left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1a)}$$

(b) When $\frac{P_r}{P_c} < 0.2$

$$\frac{P_r}{2P_c} + \left(\frac{M_{rx}}{M_{cx}} + \frac{M_{ry}}{M_{cy}}\right) \leq 1.0 \qquad \text{(H1-1b)}$$

Figure 27: AISCM Chapter H Specification Equations

The moment portion of the calculations are identical with the goal of determining the flange local buckling force of the members: all members were found to have plastic bending. Plastic bending dictated the allowable moment value, which was equal to the nominal moment of the selected member, that the system called for. This value, along with the actual moment are both plugged into the appropriate equation.

Along with the moment values used in the equations, compression and tension values make up the other half of the equation. Compression members were all found have the Y-axis to govern the calculation. This required to use Table 4-1 in the AISCM to find the available axial strength of the selected member, P_c which is equal to PhiP_n. Tension members are a little more involved in the sense that there is more than one parameter to consider when choosing the appropriate value for P_c. Tension yield in the gross area and tension fracture in the net area produce the required minimum area that a member should have to resist the tensile load acting on it. PhiP_n is found for each case then the lower value the governing one for choosing $P_{c,}$ refer to Appendix D for calculations. Below, Figure 28 Figure 28: Final Truss Design is a drawing of the final Pratt truss with the labeled members.

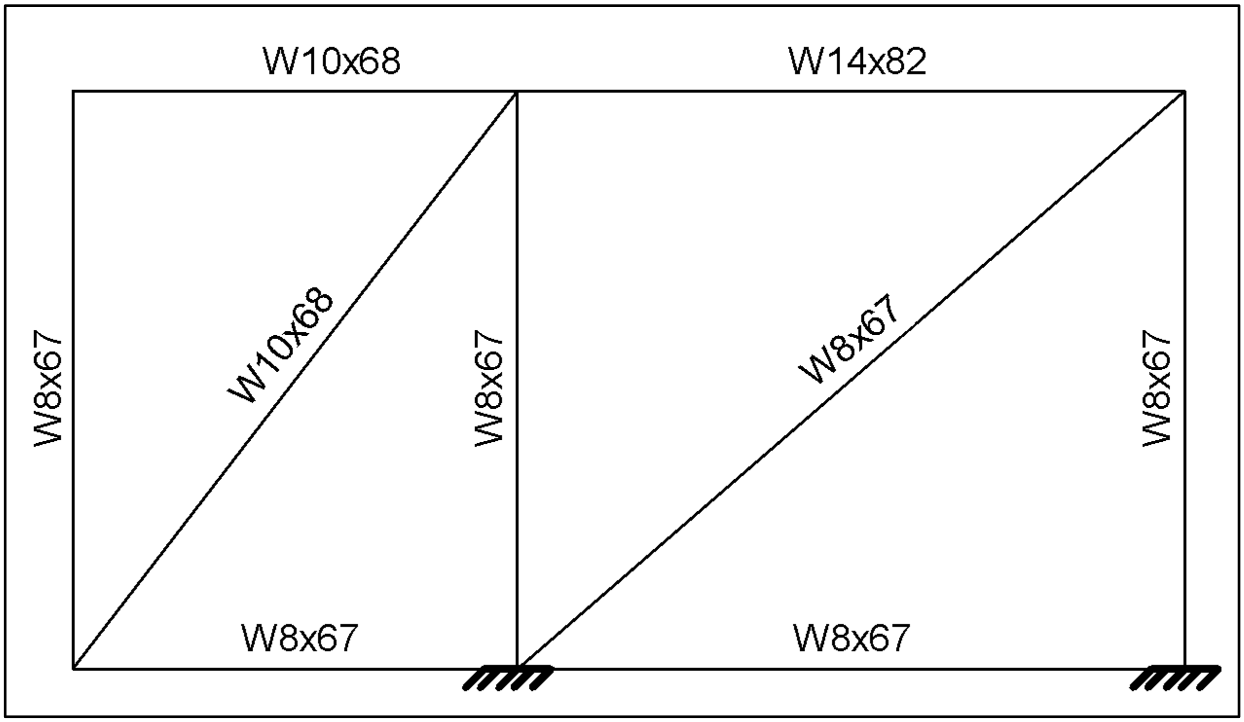


Figure 28: Final Truss Design

Chapter 5: Energy Conservation

An energy analysis was considered in the design of The Parallax. Energy Use Intensity (EUI) measurements were utilized in order to size mechanical systems. To find the reasonable ranges for EUI, a couple of sources were considered: the Energy Star Portfolio Manager tabulates EUI, the ASHRAE Standard 90.1-2007, and the *Energy Performance of LEED for New Construction Buildings*. The Parallax academic facility is considered an office-type building and the residential floors are dorm-type. Table 19 details EUI measurements from these sources.

Table 19: EUI Requirements

Reference	Office	Dorm	Site EUI
Energy Star PM	67.3	73.9	kBtu/SQF
ASHRAE	39-45	40.8	kBtu/SQF
Energy Perf. Of LEED for New Construction Buildings	86	80	kBtu/SQF

After researching some LEED report cards of business and dorm-type buildings, it was determined that maintaining a Site EUI of 60 kBtu/ft^2 in the office-type floors and 50 kBtu/ft^2 in the dorm-type floors, will result in a LEED Gold certification, considering that the building fulfill all other necessary LEED credits. Table 20 contains relevant data from the case studies.

Table 20: LEED Case References

Project	LEED	EAc1	% Improvement	kBtu/ft^2	Rating
College N. Res. Hall	LEED BD+C: New Construction v3 - LEED 2009	3/19	16	67	Silver
TraPac Admin Bldg	LEED BD+C: New Construction v2 - LEED 2.2	4/10	21	68	Gold
Smart Bldg Cntr WPIP	LEED BD+C: New Construction v3 - LEED 2009	19/19	48	45	Platinum
Tercero S. Student Hsg	LEED BD+C: New Construction v2 - LEED 2.2	6/10	28	58	Gold
UALR Student Srvc Cntr	LEED BD+C: New Construction v3 - LEED 2009	10/19	30	60	Gold
UALR West Hall	LEED BD+C: New Construction v3 - LEED 2009	10/19	30	56	Gold

It is estimated that only 50% of site EUI values are attributed to heating, and 20% to cooling; therefore, if the site EUI is adjusted, the heating or cooling system can then be sized. Figure 29 details the calculations for using EUI to determine rough system sizing.

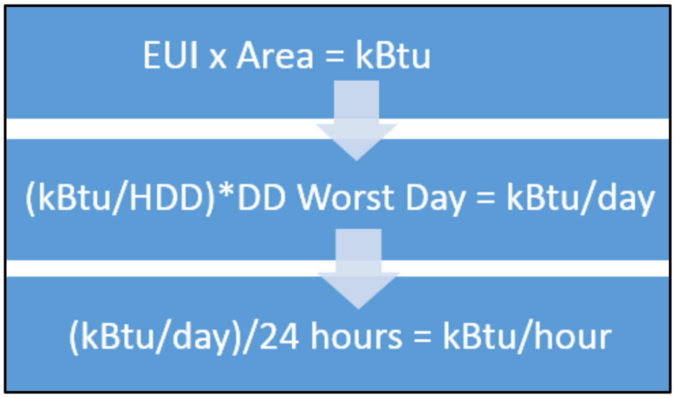


Figure 29: EUI System Sizing Flow Chart

Table 21 and Table 22, below, compile the relevant data necessary to complete these calculations: target EUI, floor area, heating degree days, and degree day worst day.

Table 21: Heating Load Data

Occupancy	Target EUI (kBtu/SQF)	Square Feet	50% EUI = Heating (kBtu/SQF)	Total kBtu	HDD	DD Worst Day (Feb. 20)	Heating Days	Heating Load (kBtu/hr)
Office	60	45,000	30	1,350,000	6031	58	12,983	541
Dorm	50	67,500	25	1,687,500	6031	58	16,229	676

Table 22: Cooling Load Data

Occupancy	Target EUI (kBtu/SQF)	Square Feet	20% EUI = Heating (kBtu/SQF)	Total kBtu	CDD	DD Worst Day (Feb. 20)	Cooling Days	Cooling Load (kBtu/hr)
Office	60	45,000	12	540,000	857	17	10,712	446
Dorm	50	67,500	10	675,000	857	17	13,390	558

After doing the calculations, there is an estimated 1217 kBtu/hour for total heating and 1004 kBtu/hour for total cooling. The implications of these loads call for a unit capable of 84 tons of refrigeration for cooling and 357 kW of heating. These results are reasonable as there are standard mechanical units capable of meeting these requirements.

Heating and cooling load calculations, using the CLTD/CLF method, were also conducted for four different rooms throughout The Parallax: the smaller of the two classrooms from the second floor, both hex suites on the fifth floor, and the smaller of the two lecture halls from the second floor. These rooms were selected for their differing exposures relative to the sun and their envelope. The heat gain and heat loss values are shown in Table 23.

Table 23: Heat Gain/Loss Calculation

Room	Orientation	Gross Wall Area SQF	Glazing Area SQF	Room Area SQF	Wall U-Value	Roof U-Value	Heat Gain (Btu/hr)	Heat Loss (Btu/hr)
Small Classroom	SW	643.5	643.5	973	0.19	N/A	1808	2050
SE Facing Hex Suite	SE	750	172	1160	0.0332	0.0122	1087	2063
NE Facing Hex Suite	NE	700	129	1133	0.0332	0.0122	968	742
Small Lecture Hall	NE	1,335	180	1966	0.0316	N/A	896	1494

It is clear from the comparison of Table 23 to Table 21 and Table 22 that the energy required to accommodate the actual heat gain and heat loss of the building, Table 23, will be well under the estimated energy required, Table 21 and Table 22.

Chapter 6: Conclusions & Recommendations

The objectives of The Parallax were to provide sufficient space for community growth, in both an academic and residential sense, provide an adaptable project collaboration environment, and to provide space for the consolidation of the Robotics Engineering labs and offices. The Parallax meets these objectives derived from the needs and desires of the WPI community as a multi-occupancy building. The academic center consists of three floors, each addressing one of the three challenges. The residence hall, above, addresses the growth from a residential perspective.

The academic and residential facilities act as a "one-two punch", providing housing for over 180 students, over 22,000 square feet of project collaboration space, and a whole floor almost entirely dedicated to relocating the RBE labs to a single building. A detailed structural analysis was conducted, as well as research into energy usage, to support the architectural design. In sum, The Parallax has an opportunity to be highly celebrated by WPI for its consideration of the Institute's unique culture, the solutions it poses to community challenges, as well as the opportunities it provides for innovation, collaboration, and idea development.

As a continuation to this project, the following concepts are recommended for areas of future work: more in-depth heating and cooling analysis of the entire building, the use of heavy timber construction versus traditional framing, or a fire code analysis I.e. sprinkler design, detection, notification and alarm systems, and smoke control.

References:

American Institute of Steel Construction. (2015). *Steel Construction Manual*. United States of America: American Institute of Steel Construction.

American Society of Civil Engineers. *Minimum Design Loads for Buildings and Other Structures*. Reston, US: ASCE 7-10, 2013. ProQuest ebrary. Web. 3 March 2017.

Boise Cascade: Engineered Wood Products. Weights of Building Materials – Pounds per Square Foot [PSF], Aug. 2016. Tinyhousescommunity.com

Building Code Requirements for Structural Concrete (ACI 318-08) and Commentary. Farmington Hills, MI: American Concrete Institute, 2009. Print.

Breyer, Donald E., Kenneth J. Fridley, David Garnet Pollock, and Kelly E. Cobeen.*Design of Wood Structures: ASD/LRFD*. New York: McGraw-Hill, 2015. Print.

Ching, Frank. *Building Construction Illustrated*. Hoboken: Wiley, 2008. Print.

Institute, Structural Engineering. *Minimum Design Loads for Buildings and Other Structures (ASCE Standard)*. N.p.: American Society of Civil Engineers / ASCE, 2005. Print.

International Code Council. (2012). *International Building Code*. United States of America: International Code Council.

International Code Council. (2015). *International Building Code*. United States of America: International Code Council.

Lockyear, Scott. "Austin, TX, USA." *Csengineermag.com*. N.p., 19 Feb. 2014. Web. 3 Mar. 2017.

NAHB Research Center Inc. Residential Design Guide: 2000 Edition. February 2000.

NDS: National Design Specification for Wood Construction. Leesburg, VA: American Wood Council, 2012. Print.

RISA 2D. Software.

"Snowload.atcouncil.org." *Snowload.atcouncil.org*. N.p., n.d. Web. 03 Mar. 2017.

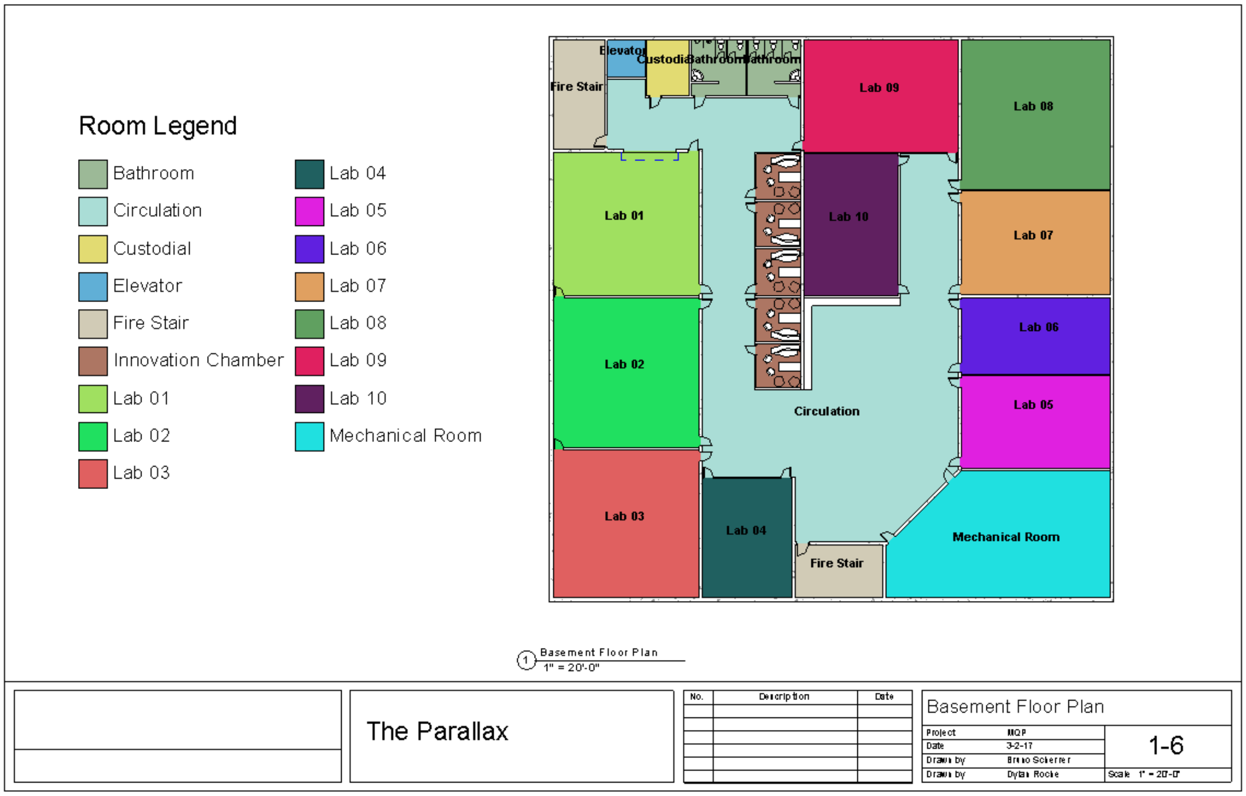
Structure and Codes Institute. (2014). *Code Master Wind Design Overview.* S.K. Ghosh Associates Inc. Print.

WoodWorks. *Wood Buildings Aim High*. *Woodworks.org*. N.p., 2011. Web. 3 Mar. 2017.

Appendices:

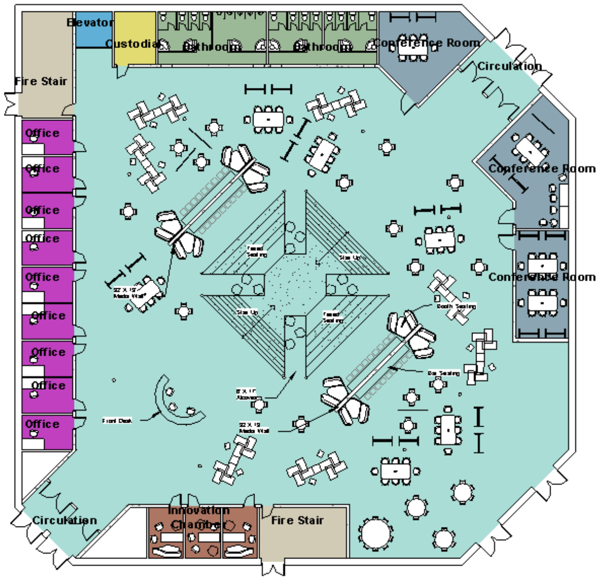
Appendix A: Drawing Package

A.1 Floor Plans and Site Plan



Room Legend

- Bathroom
- Circulation
- Conference Room
- Custodial
- Elevator
- Fire Stair
- Innovation Chamber
- Office



1 First Floor
1" = 20'-0"

The Parallax

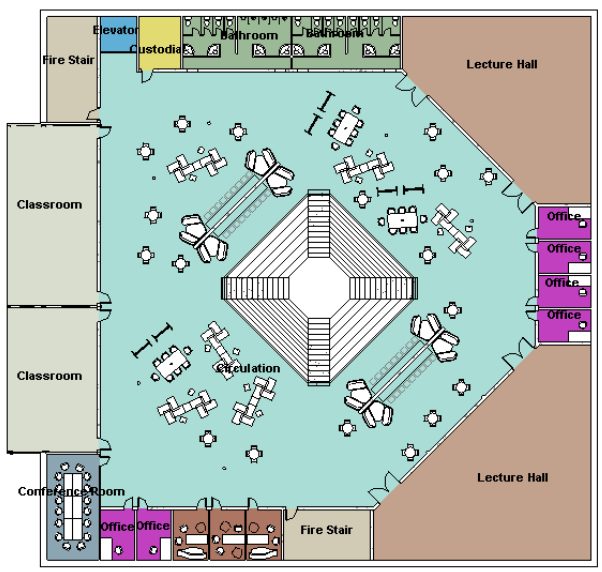
No.	Description	Date

First Floor Plan

Project	MQP	2-6
Date	3-2-17	
Drawn by	Bruno Scherrer	
Drawn by	Dylan Rocke	Scale 1" = 20'-0"

Room Legend

- Bathroom
- Circulation
- Classroom
- Conference Room
- Custodial
- Elevator
- Fire Stair
- Innovation Chamber
- Lecture Hall
- Office



1 Second Floor Plan
1" = 20'-0"

The Parallax

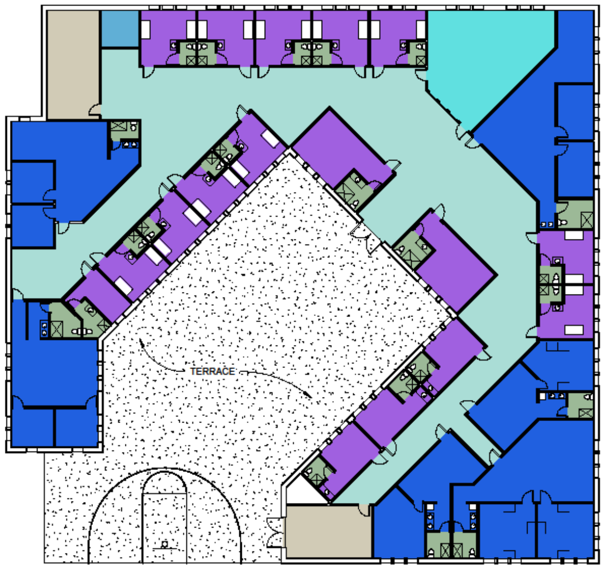
No.	Description	Date

Second Floor Plan

Project	MQP	3-6
Date	3-2-17	
Drawn by	Bruno Scherrer	
Drawn by	Dylan Rocke	Scale 1" = 20'-0"

Room Legend

- Bathroom
- Circulation
- Common Room
- Dorm
- Elevator
- Fire Stair
- Suite



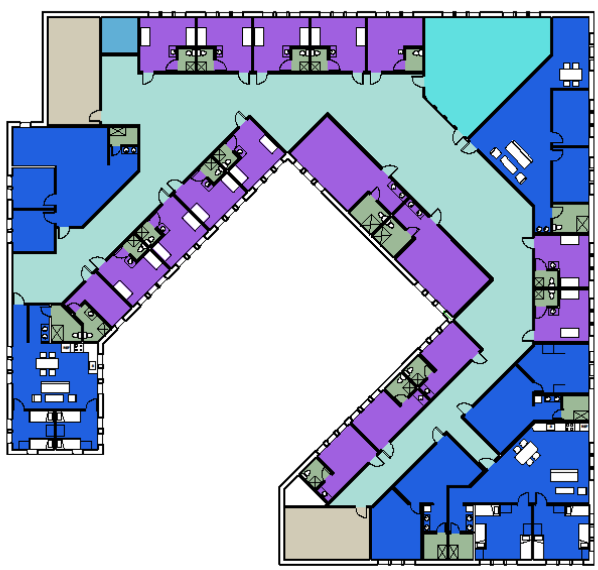
1 Third Floor Plan
1" = 20'-0"

The Parallax	No.	Description	Date	Third Floor Plan

Project	MQP	4-6
Date	3-2-17	
Drawn by	Bruno Scherrer	
Drawn by	Dylan Roche	Scale 1" = 20'-0"

Room Legend

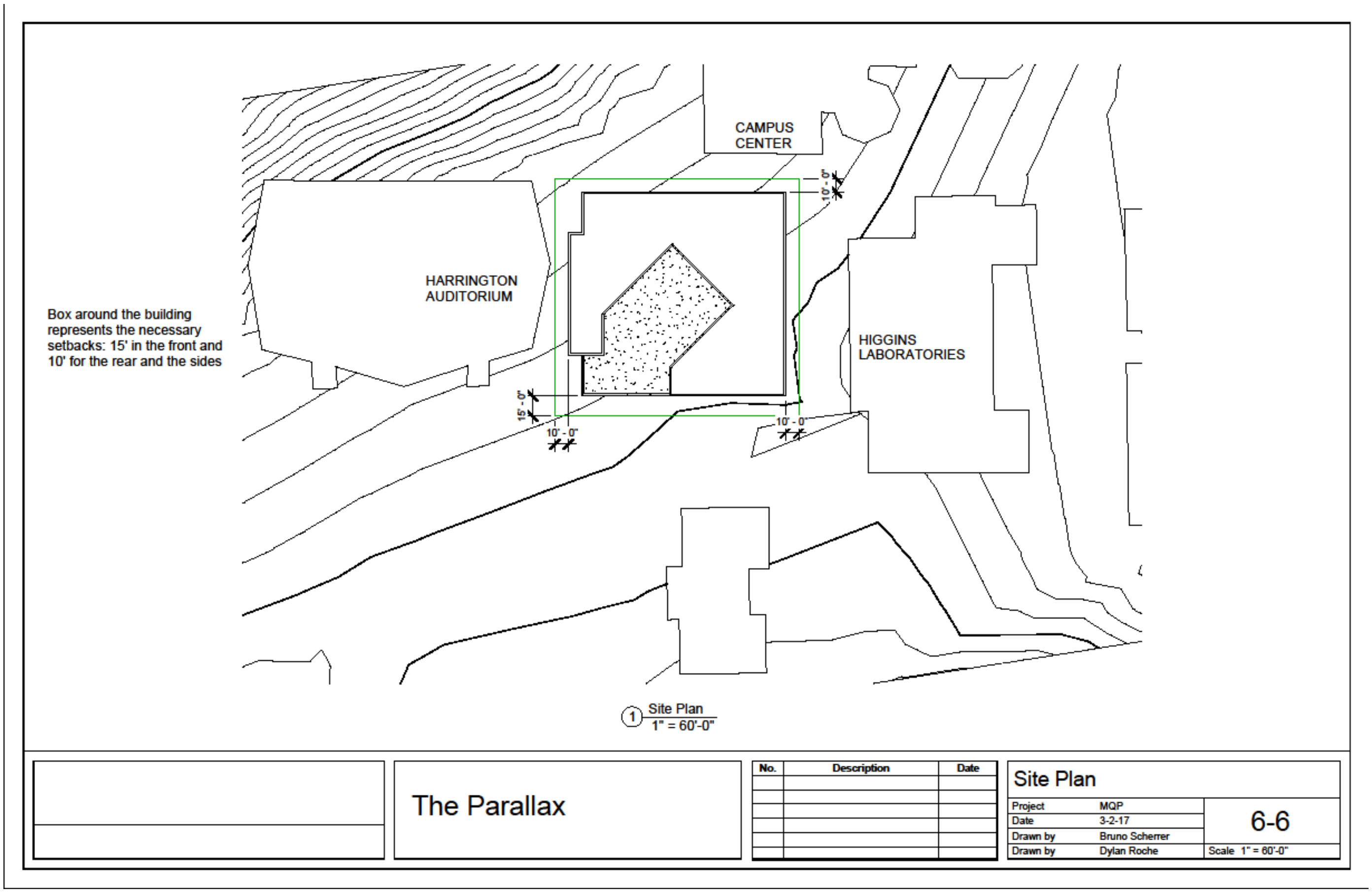
- Bathroom
- Circulation
- Common Room
- Dorm
- Elevator
- Fire Stair
- Suite



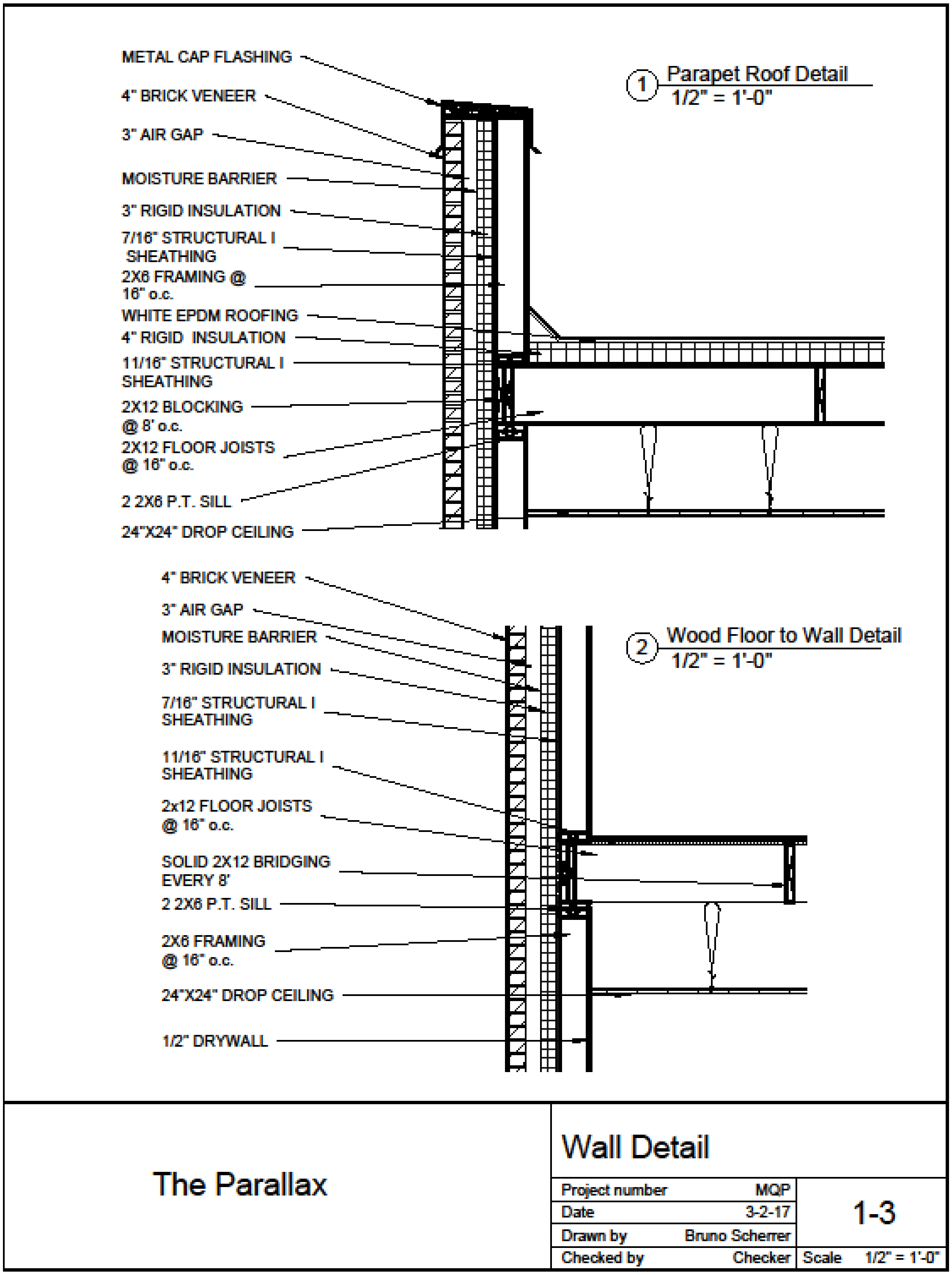
1 Fourth and Fifth Floor Plan
1" = 20'-0"

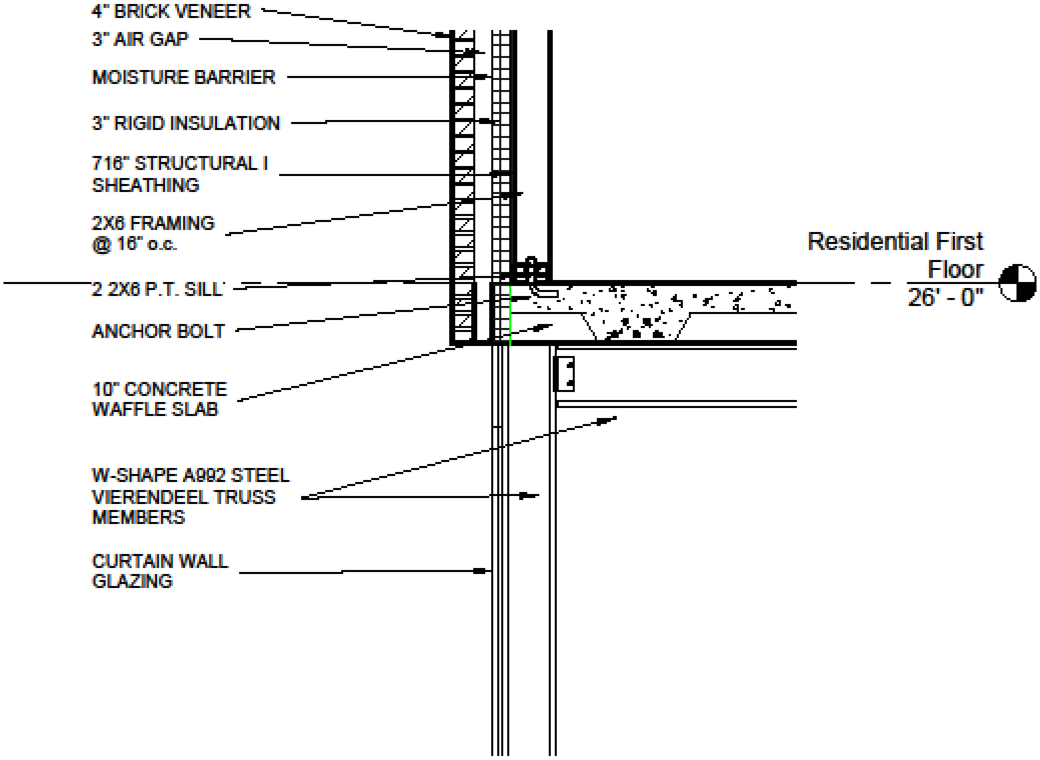
The Parallax	No.	Description	Date	Fourth and Fifth Floor Plan

Project	MQP	5-6
Date	3-2-17	
Drawn by	Bruno Scherrer	
Drawn by	Scherrer	Scale 1" = 20'-0"


CAMPUS CENTER
HARRINGTON AUDITORIUM
HIGGINS LABORATORIES
Box around the building represents the necessary setbacks: 15' in the front and 10' for the rear and the sides
10' - 0"
15' - 0"
10' - 0"
10' - 0"
1 Site Plan
1" = 60'-0"
The Parallax
No.
Description
Date
Site Plan
Project MQP
Date 3-2-17
Drawn by Bruno Scherrer
Drawn by Dylan Roche
6-6
Scale 1" = 60'-0"

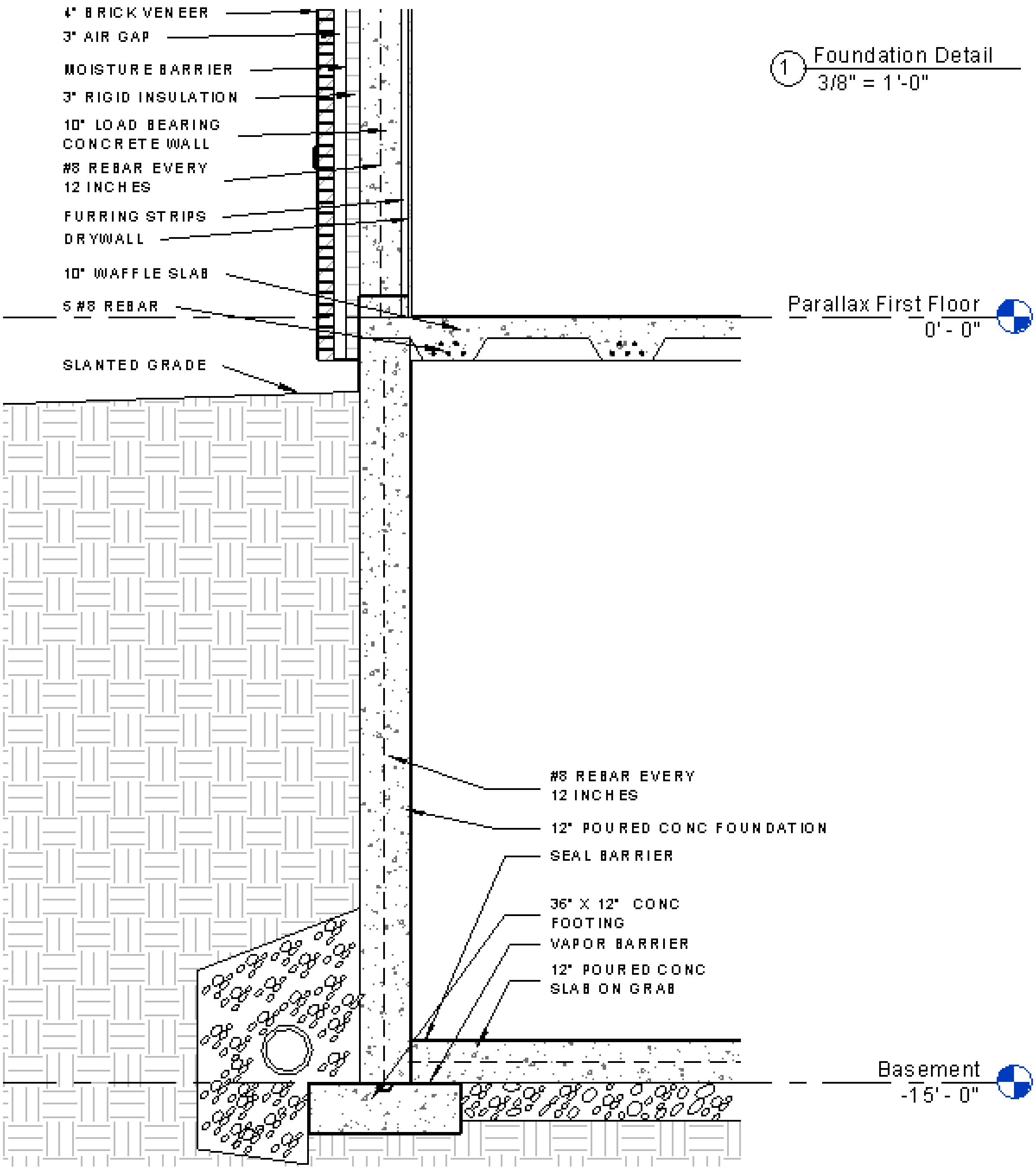
A.2 Wall Section Details





1 Residential Connection to Podium Roof
1/2" = 1'-0"

The Parallax	Wall Detail		
	Project number	MQP	2-3
	Date	3-2-17	
	Drawn by	Author	
	Checked by	Checker	Scale 1/2" = 1'-0"

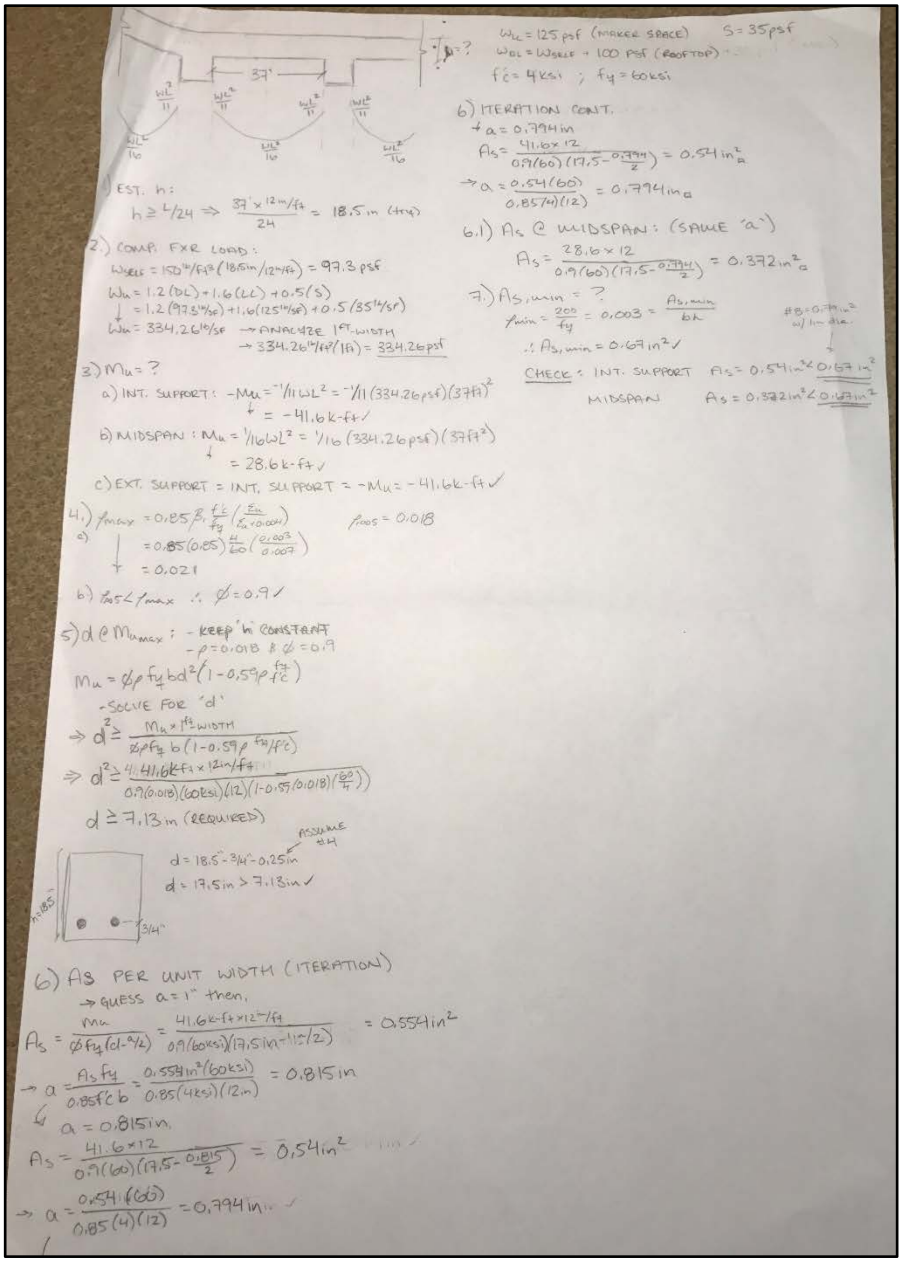


The Parallax	Wall Detail		
	Project number	MQP	3-3
	Date	3-2-17	
	Drawn by	Bruno Scherrer	
	Checked by	Checker	Scale 3/8" = 1'-0"

Appendix B: Concrete

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Estimate h				L =	37	ft						
2	h ≥ L/24				f'c =	4	ksi						
3	L =	444	in		fy =	60	ksi						
4	h ≥	18.5	in										
5													
6	Compute Flexure Load				ρmax = 0.85β(f'c/fy)(εu/(εu+0.004))					ρmin =	0.003		
7	Unit Weight	150	lb/ft^3		ρmax =	0.021							
8	Wself = (Unit Weight)(h/12in/ft)												
9	Wself =	231.25	psf		ρ0.005 = 0.85β(f'c/fy)(εu/(εu+0.005))								
10	LL =	100	psf		ρ0.005 =	0.018							
11	SL =	35	psf										
12					ρ0.005 < ρmax →		ϕ =	0.9					
13	Wu = 1.2(DL) + 1.6(LL) + 0.5(SL)												
14	Wu =	455	psf		d @ Mu,max		ρ =	0.018	ϕ =	0.9	Mu,max =	56.6	k-ft
15					Mu = ϕ*ρ*fy*b*d*d*(1 - 0.59ρ(fy/f'c))						Mu,mid =	38.9	k-ft
16	Mu = ?				d ≥	8.31	in						
17	a) Interior Support												
18	-Mu = (-1/11)WL^2				Check d								
19	-Mu =	-56626.8	lb-ft		d = h - 0.75in - 0.25in								
20					d =	17.5	>	8.31					
21	b) Midspan												
22	Mu = (1/16)WL^2				As/Unit Width (Iteration)								
23	Mu =	38931	lb-ft		As = Mu/(ϕfy(d-0.5a))			Guess a = 1in		a =	1.091	1	0.74
24					As =	0.742	in. sq.					1.088	0.742
25	c) Exterior Support											1.091	0.742
26	-Mu = (-1/11)WL^2				a = (As*fy)/(0.85*f'c*b)							1.091	
27	-Mu =	-56626.8	lb-ft		a =	1.091	in						
28													
29					As @ Midspan (same a)								
30					As =	0.510	in. sq.						
31													
32					As,min = ρmin*b*h			Check As	Interior Support		0.742	>	0.74
33					As,min =	0.74	in. sq.		Midspan		0.510	<	0.74

One-way Slab Design Calculations



$w_{LL} = 125$ psf (MAKER SPACE) $S = 35$ psf
$w_{DL} = w_{SELF} + 100$ psf (ROOFTOP)
$f'_c = 4$ ksi ; $f_y = 60$ ksi

1) EST. h:
$h \geq L/24 \Rightarrow \frac{37' \times 12 in/ft}{24} = 18.5$ in (try)

2.) COMP. FXR LOAD:
$w_{SELF} = 150 lb/ft^3 (18.5 in / 12 in/ft) = 97.3$ psf
$w_u = 1.2(DL) + 1.6(LL) + 0.5(S)$
$= 1.2(97.3 lb/sf) + 1.6(125 lb/sf) + 0.5(35 lb/sf)$
$w_u = 334.26$ lb/sf → ANALYZE 1 FT-WIDTH
→ $334.26 lb/ft^2 (1 ft) = 334.26$ psf

3) $M_u = ?$
a) INT. SUPPORT: $-M_u = -1/11 wL^2 = -1/11 (334.26 psf)(37 ft)^2$
$= -41.6$ k-ft ✓
b) MIDSPAN: $M_u = 1/16 wL^2 = 1/16 (334.26 psf)(37 ft^2)$
$= 28.6$ k-ft ✓
c) EXT. SUPPORT = INT. SUPPORT = $-M_u = -41.6$ k-ft ✓

4.) a) $\rho_{max} = 0.85 \beta_1 \frac{f'_c}{f_y} \left(\frac{\varepsilon_u}{\varepsilon_u + 0.004}\right)$ $\rho_{.005} = 0.018$
$= 0.85(0.85) \frac{4}{60} \left(\frac{0.003}{0.007}\right)$
$= 0.021$
b) $\rho_{.005} < \rho_{max}$ ∴ $\phi = 0.9$ ✓

5) d @ $M_{u,max}$: - KEEP 'h' CONSTANT
- $\rho = 0.018$ & $\phi = 0.9$
$M_u = \phi \rho f_y b d^2 \left(1 - 0.59 \rho \frac{f_y}{f'_c}\right)$
- SOLVE FOR 'd'
$\Rightarrow d^2 \geq \frac{M_u \times 1 ft\ WIDTH}{\phi \rho f_y b (1 - 0.59 \rho f_y / f'_c)}$
$\Rightarrow d^2 \geq \frac{41.6 k\text{-}ft \times 12 in/ft}{0.9(0.018)(60 ksi)(12)(1 - 0.59(0.018)(\frac{60}{4}))}$
$d \geq 7.13$ in (REQUIRED)

$h = 18.5$ 3/4"   ASSUME #4
$d = 18.5" - 3/4" - 0.25$ in
$d = 17.5$ in > 7.13 in ✓

6) AS PER UNIT WIDTH (ITERATION)
→ GUESS a = 1" then,
$A_s = \frac{M_u}{\phi f_y (d - a/2)} = \frac{41.6 k\text{-}ft \times 12 in/ft}{0.9(60 ksi)(17.5 in - 1 in/2)} = 0.554 in^2$
→ $a = \frac{A_s f_y}{0.85 f'_c b} = \frac{0.554 in^2 (60 ksi)}{0.85(4 ksi)(12 in)} = 0.815$ in
$a = 0.815$ in.
$A_s = \frac{41.6 \times 12}{0.9(60)(17.5 - \frac{0.815}{2})} = 0.54 in^2$
→ $a = \frac{0.54(60)}{0.85(4)(12)} = 0.794$ in ✓

6) ITERATION CONT.
$a = 0.794$ in
$A_s = \frac{41.6 \times 12}{0.9(60)(17.5 - \frac{0.794}{2})} = 0.54 in^2$
→ $a = \frac{0.54(60)}{0.85(4)(12)} = 0.794$ in

6.1) A_s @ MIDSPAN: (SAME 'a')
$A_s = \frac{28.6 \times 12}{0.9(60)(17.5 - \frac{0.794}{2})} = 0.372 in^2$

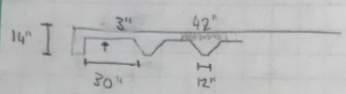
7.) $A_{s,min} = ?$
$\rho_{min} = \frac{200}{f_y} = 0.003 = \frac{A_{s,min}}{bh}$ #8 = 0.79 in² w/ 1 in dia.
∴ $A_{s,min} = 0.67 in^2$ ✓
CHECK: INT. SUPPORT $A_s = 0.54 in^2 < 0.67 in^2$
MIDSPAN $A_s = 0.372 in^2 < 0.67 in^2$

One-way T Joist Slab Design Calculations

Spacing: 30"

thickness: 30/12 → 2.5"
Use 3"

interior: L = .6L
exterior: L = .8L



2 #7 bars → 2(.6) = 1.2 = A_s

Short Direction
L = 50.1667'

$a = \frac{A_s f_y}{.85 f'_c b} \rightarrow \frac{1.2(60{,}000)}{.85(4000)42} = .504 < h_f = 3$ ✓

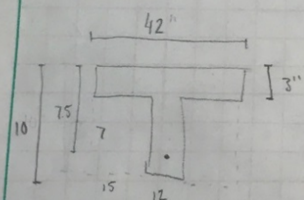
$\rho_{max} = .026759$

$M_u \le \phi \rho_{max} f_y b d^2 (1 - .59 \rho_{max} \frac{f_y}{f'_c}) \rightarrow bd^2 \ge 406.8 \text{ in}^3 \rightarrow b = 12 \therefore d = 5.8221$
$d = 6$

$h = d + 2.5$
$= 8.5 \rightarrow$ up to $h = 10"$ So real $d = 10 - 2.5 = 7.5"$

Beam $W_{self} = 150(\frac{42}{12} \cdot \frac{3}{12} + \frac{4.5}{12} \cdot 1) = 187.5 \rightarrow 187.5/3.5 = 53.57$ PSF

$W_u = 1.2(143.57) + 1.6(100) + .5(35) = 349.78$ PSF → 350

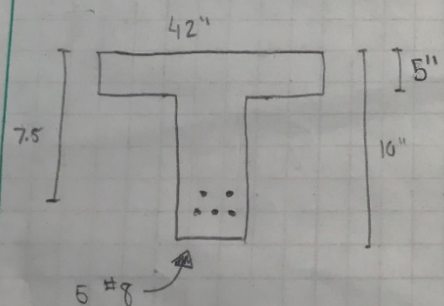


$M_u = \frac{1}{8}(349.78 \text{ lb/ft}^2)(50.1667 \text{ ft})^2 = 110{,}036 \times 12 = 1320436$

$M_u = f_y \phi \rho b d^2 (1 - .59 \rho \frac{f_y}{f'_c}) \rightarrow 127575000\rho(1 - 8.85\rho) = M_u$
$1129038750\rho^2 - 127575000\rho + 1320436 = 0$

$\rho = .0115 < \rho_{max}$

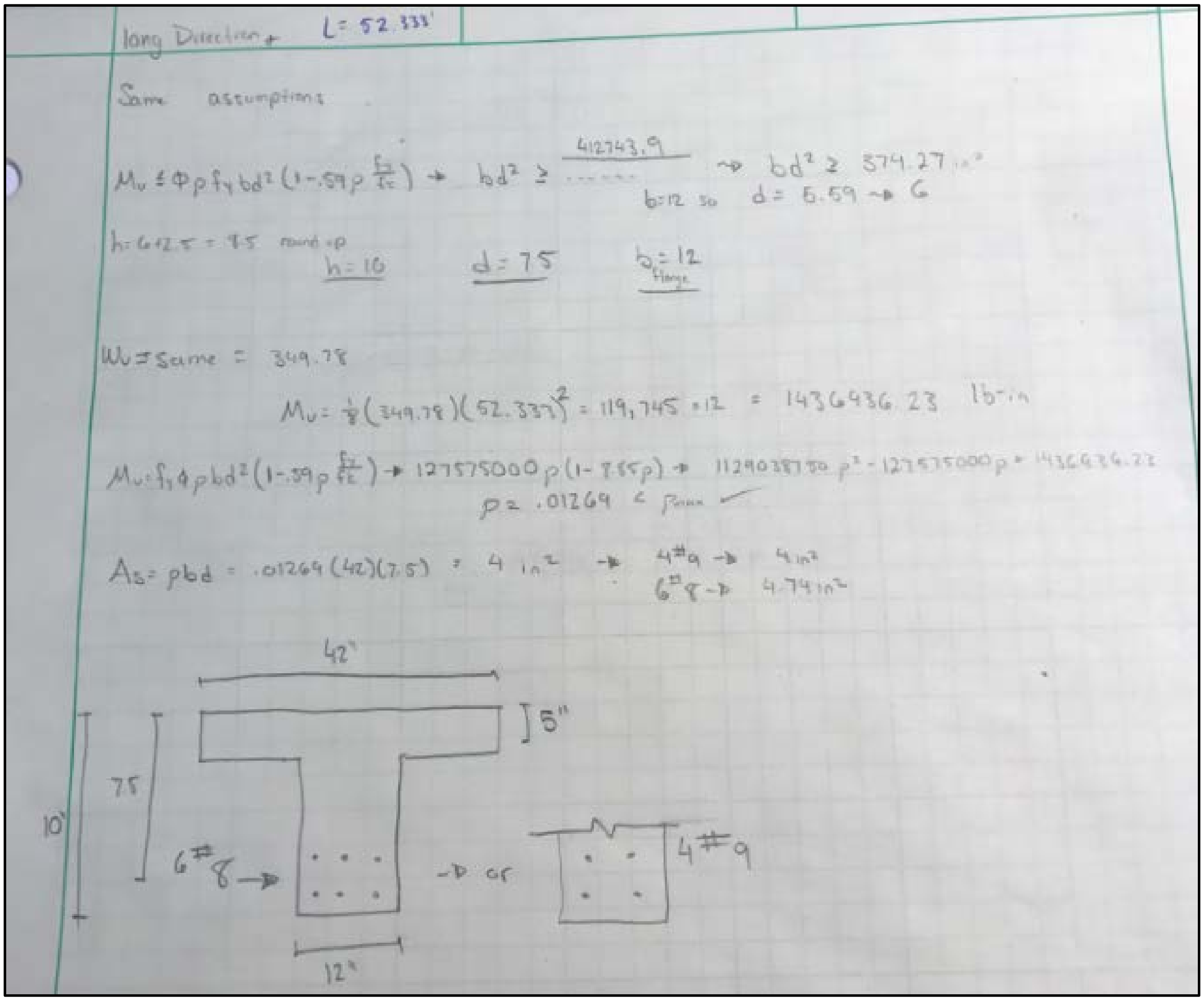
$A_s = \rho b d \rightarrow .0115(42)(7.5) = 3.62 \text{ in}^2$
5 #8 = 3.95



☆ ACI 9.5.3.3, thickness no less than 5"

- Does not affect calculations

Waffle Slab Design Calculations



long Direction+ $L = 52.333'$

Same assumptions

$M_u \le \Phi \rho f_y b d^2 (1 - .59 \rho \frac{f_y}{f'_c}) \rightarrow bd^2 \ge \frac{412743.9}{\cdots} \rightarrow bd^2 \ge 374.27 \text{ in}^3$

$b = 12$ so $d = 5.59 \rightarrow 6$

$h = 6 + 2.5 = 8.5$ round up

$h = 10$ $d = 7.5$ $b_f = 12$ (flange)

W_u = same = 349.78

$M_u = \frac{1}{8}(349.78)(52.333)^2 = 119{,}745 \times 12 = 1436936.23$ lb-in

$M_u = f_y \phi \rho b d^2 (1 - .59 \rho \frac{f_y}{f'_c}) \rightarrow 127575000 \rho (1 - 8.85\rho) \rightarrow 1129038750 \rho^2 - 127575000 \rho = 1436936.23$

$\rho = .01269 < \rho_{max}$ ✓

$A_s = \rho b d = .01269(42)(7.5) = 4 \text{ in}^2 \rightarrow$ 4#9 → 4 in² ; 6#8 → 4.74 in²

Continued Waffle Slab Design Calculations

	A	B	C	D	E	F	G	H	I	J	K	L	M
1	Estimate h				L =	25	ft						
2	h ≥ L/24				f'c =	4	ksi						
3	L =	300	in		fy =	60	ksi						
4	h ≥	12	in										
5													
6	Compute Flexure Load				ρmax = 0.85β(f'c/fy)(εu/(εu+0.004))					ρmin =	0.003		
7	Unit Weight	150	lb/ft^3		ρmax =	0.021							
8	Wself = (Unit Weight)(h/12in/ft)												
9	Wself =	150	psf		ρ0.005 = 0.85β(f'c/fy)(εu/(εu+0.005))								
10	LL =	212	psf		ρ0.005 =	0.018							
11	SL =	35	psf										
12					ρ0.005 < ρmax →		ϕ =	0.9					
13	Wu = 1.2(DL) + 1.6(LL) + 0.5(SL)												
14	Wu =	1335.9	psf		d @ Mu,max		ρ =	0.018	ϕ =	0.9	Mu,max =	75.9	k-ft
15					Mu = ϕ*ρ*fy*b*d*d*(1 - 0.59ρ(fy/f'c))						Mu,mid =	52.2	k-ft
16	Mu = ?				d ≥	9.62	in						
17	a) Interior Support												
18	-Mu = (-1/11)WL^2				Check d								
19	-Mu =	-75903.4	lb-ft		d = h - 0.75in - 0.25in								
20					d =	11	>	9.62					
21	b) Midspan												
22	Mu = (1/16)WL^2				As/Unit Width (Iteration)								
23	Mu =	52184	lb-ft		As = Mu/(ϕfy(d-0.5a))			Guess a = 1in		a =	2.551	1	1.606
24					As =	1.734	in. sq.					2.362	1.718
25	c) Exterior Support											2.526	1.732
26	-Mu = (-1/11)WL^2				a = (As*fy)/(0.85*f'c*b)							2.547	1.734
27	-Mu =	-75903.4	lb-ft		a =	2.551	in					2.55	1.734
28												2.551	1.734
29					As @ Midspan (same a)								
30					As =	1.193	in. sq.						
31													
32					As,min = ρmin*b*h			Check As	Interior Support		1.734	>	0.48
33					As,min =	0.48	in. sq.		Midspan		1.193	>	0.48

Foundation Slab Design Calculations

	A	B	C	D	E	F	G	H
1	Given P, Solve for D							
2	Axial Loading				ϕ =	0.85	Compression	
3	Ac = P/(0.85*(1-ρ)*f'c)+ρ*fy				f'c =	4000	psi	
4	Ac =	75.16	sq. in		fy =	60000	psi	
5	D = sqrt((4*Ac)/pi)				ρ =	0.01		
6	D =	9.78	in		P =	298099	lb	
7	Actual D =	10	in					
8	Actual Ac =	78.54	sq. in					
9	Actual Ast =	0.79	sq. in					
10	Bar #	4	x	4	# of Bars	=	0.79	sq. in
11	Actual ρ =	0.0101	< 0.04					

Large (10”) Column Design Calculations

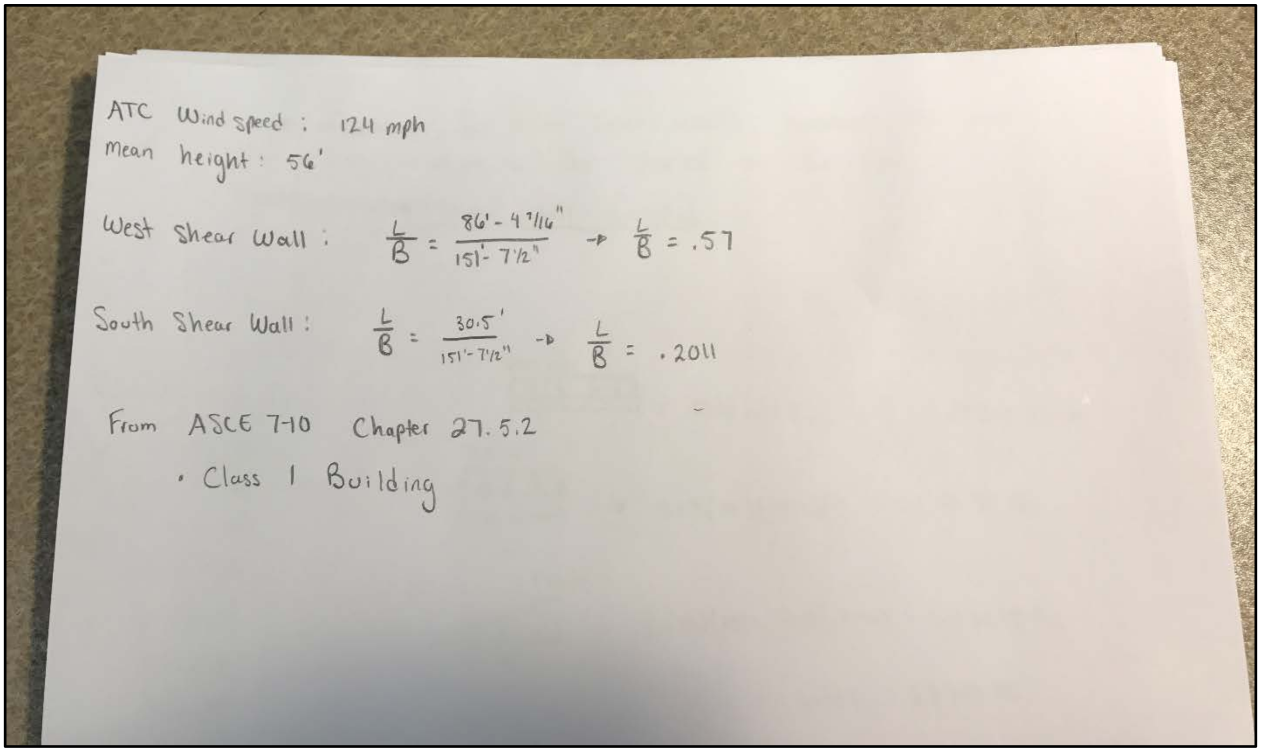
	A	B	C	D	E	F	G	H
1	Given P, Solve for D							
2	Axial Loading				ϕ =	0.85	Compression	
3	Ac = P/(0.85*(1-ρ)*f'c)+ρ*fy				f'c =	4000	psi	
4	Ac =	44.61	sq. in		fy =	60000	psi	
5	D = sqrt((4*Ac)/pi)				ρ =	0.01		
6	D =	7.54	in		P =	176943	lb	
7	Actual D =	8	in					
8	Actual Ac =	50.27	sq. in					
9	Actual Ast =	0.50	sq. in					
10	Bar #	3	x	5	# of Bars	=	0.55	sq. in
11	Actual ρ =	0.0109	< 0.04					

Small (8") Column Design Calculations

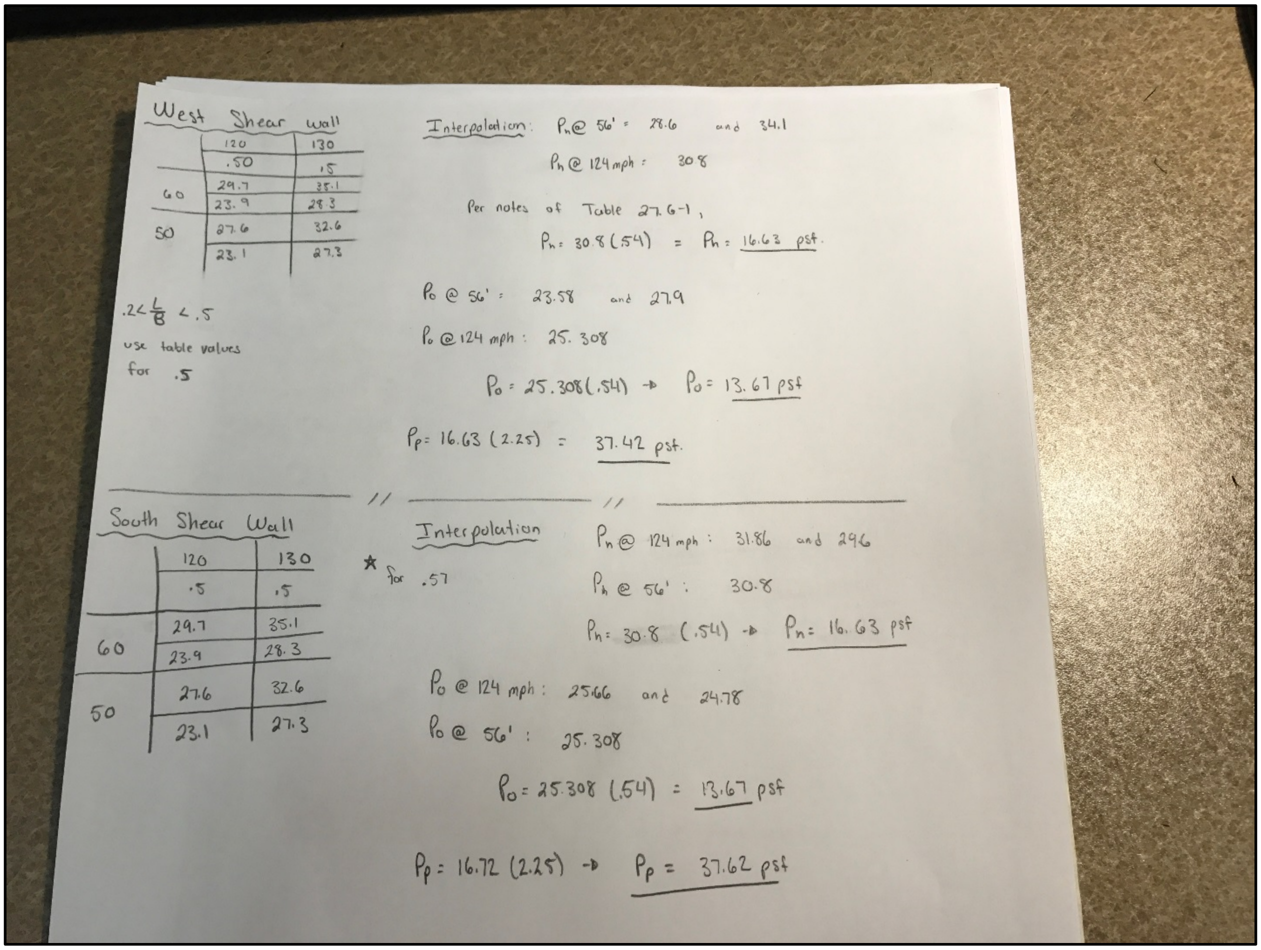
	A	B	C	D	E	F	G	H
1	Given P, Solve for D							
2	Axial Loading				ϕ =	0.7	Compression	
3	Ac = P/(0.85*(1-ρ)*f'c)+ρ*fy				f'c =	4000	psi	
4	Ac =	86.23	sq. in		fy =	60000	psi	
5	h = sqrt(Ac)				ρ =	0.01		
6	h =	9.29	in		P =	341986	lb	
7	Actual h =	10	in					
8	Actual Ac =	120.00	sq. in					
9	Actual Ast =	1.20	sq. in					
10	Bar #	8	x	2	# of Bars	=	1.57	sq. in
11	Actual ρ =	0.0131	< 0.04					

Load-Bearing Wall Design Calculations

Appendix C: Wood



Shear Design Pre-calculations



West Shear wall

	120	130
	.50	.5
60	29.7	35.1
	23.9	28.3
50	27.6	32.6
	23.1	27.3

.2 < L/B < .5

use table values for .5

Interpolation: Pn @ 56' = 28.6 and 34.1

Pn @ 124 mph = 30.8

Per notes of Table 27.6-1,

Pn = 30.8 (.54) = Pn = 16.63 psf.

Po @ 56' = 23.58 and 27.9

Po @ 124 mph : 25.308

Po = 25.308(.54) → Po = 13.67 psf

Pp = 16.63 (2.25) = 37.42 psf.

South Shear Wall

	120	130
	.5	.5
60	29.7	35.1
	23.9	28.3
50	27.6	32.6
	23.1	27.3

★ for .57

Interpolation Pn @ 124 mph : 31.86 and 29.6

Pn @ 56' : 30.8

Pn = 30.8 (.54) → Pn = 16.63 psf

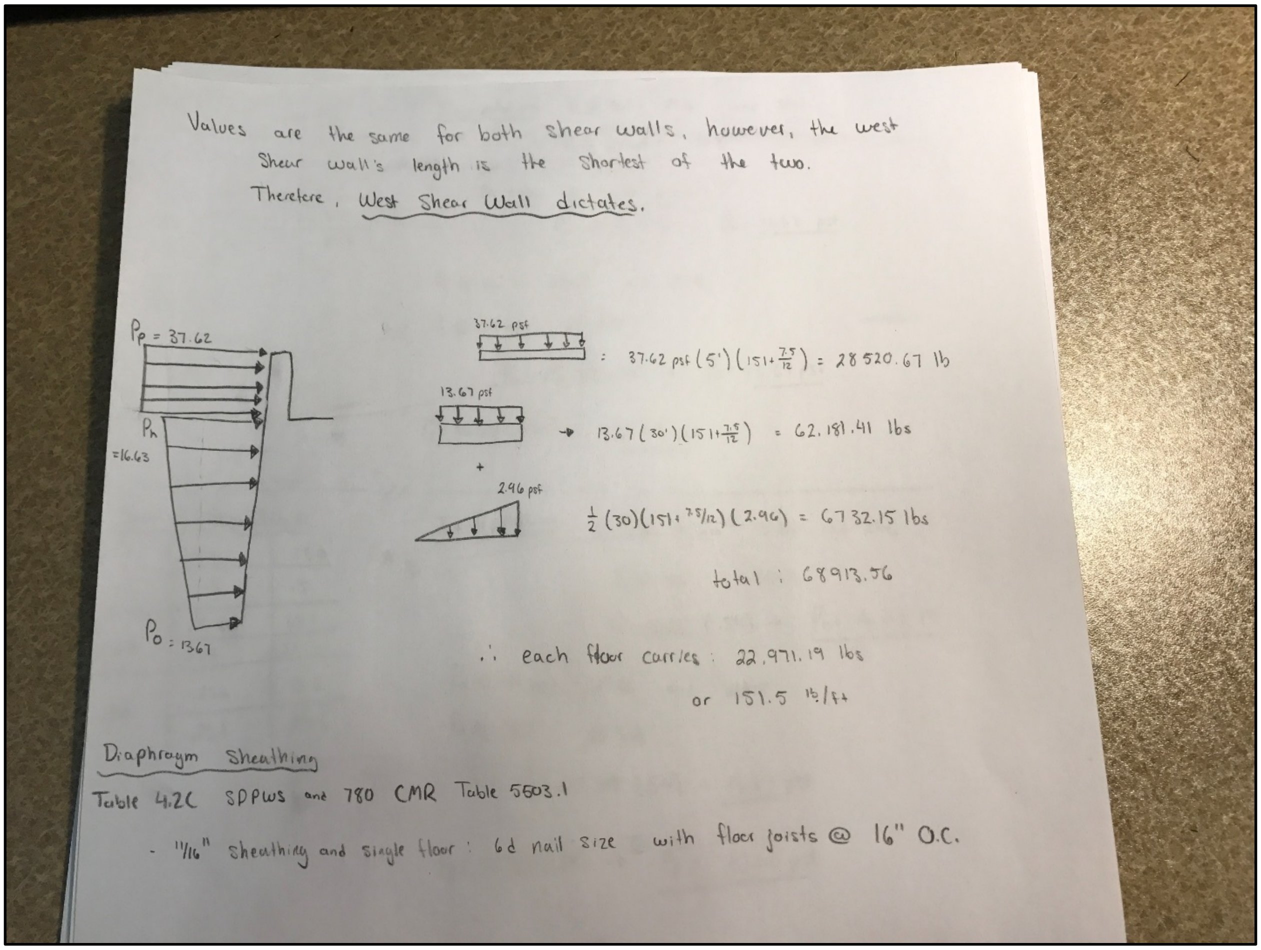
Po @ 124 mph : 25.66 and 24.78

Po @ 56' : 25.308

Po = 25.308 (.54) = 13.67 psf

Pp = 16.72 (2.25) → Pp = 37.62 psf

Interpolation of ASCE 7-10 Table 27.6-1



Values are the same for both shear walls, however, the west shear wall's length is the shortest of the two.
Therefore, West Shear Wall dictates.

= 37.62 psf (5') (151 + 7.5/12) = 28 520.67 lb

→ 13.67 (30') (151 + 7.5/12) = 62,181.41 lbs

\+

1/2 (30)(151 + 7.5/12) (2.96) = 6732.15 lbs

total : 68913.56

∴ each floor carries : 22,971.19 lbs
or 151.5 lb/ft

Diaphragm Sheathing

Table 4.2C SDPWS and 780 CMR Table 5503.1

- 11/16" sheathing and single floor : 6d nail size with floor joists @ 16" O.C.

Diaphragm Design Calculations

Shear Wall: LRFD, Segmented Wood Shear Wall (4.3.5.1)

- Max aspect Ratio: 3.5 : 1 → h/bs
- Douglas Fir-Larch: SG Factor = 1
- Wood Structural Panels with blocking
- Assuming min shear width is 2'-11" and max width is 10' (Table 4.3.4)

Sheathing panels for each floor have to carry:

22,971.19 lbs of force

$$\therefore \; V_s = \frac{22{,}971.19 \text{ lbs}}{8' + 8' + 8' + 6.25'} = 759.4 \text{ lb/ft}$$

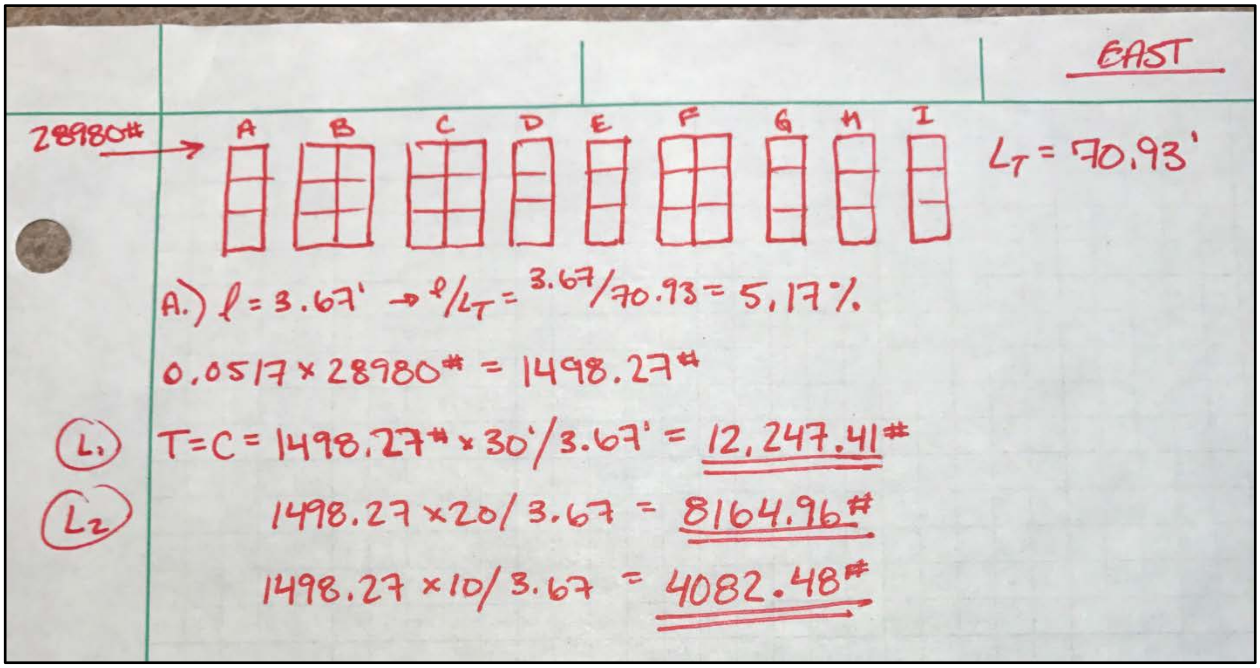
$$\phi V_s = .8(759.4) \rightarrow \phi V_s = 607.52 \text{ lb/ft}$$

Table 4.3 A

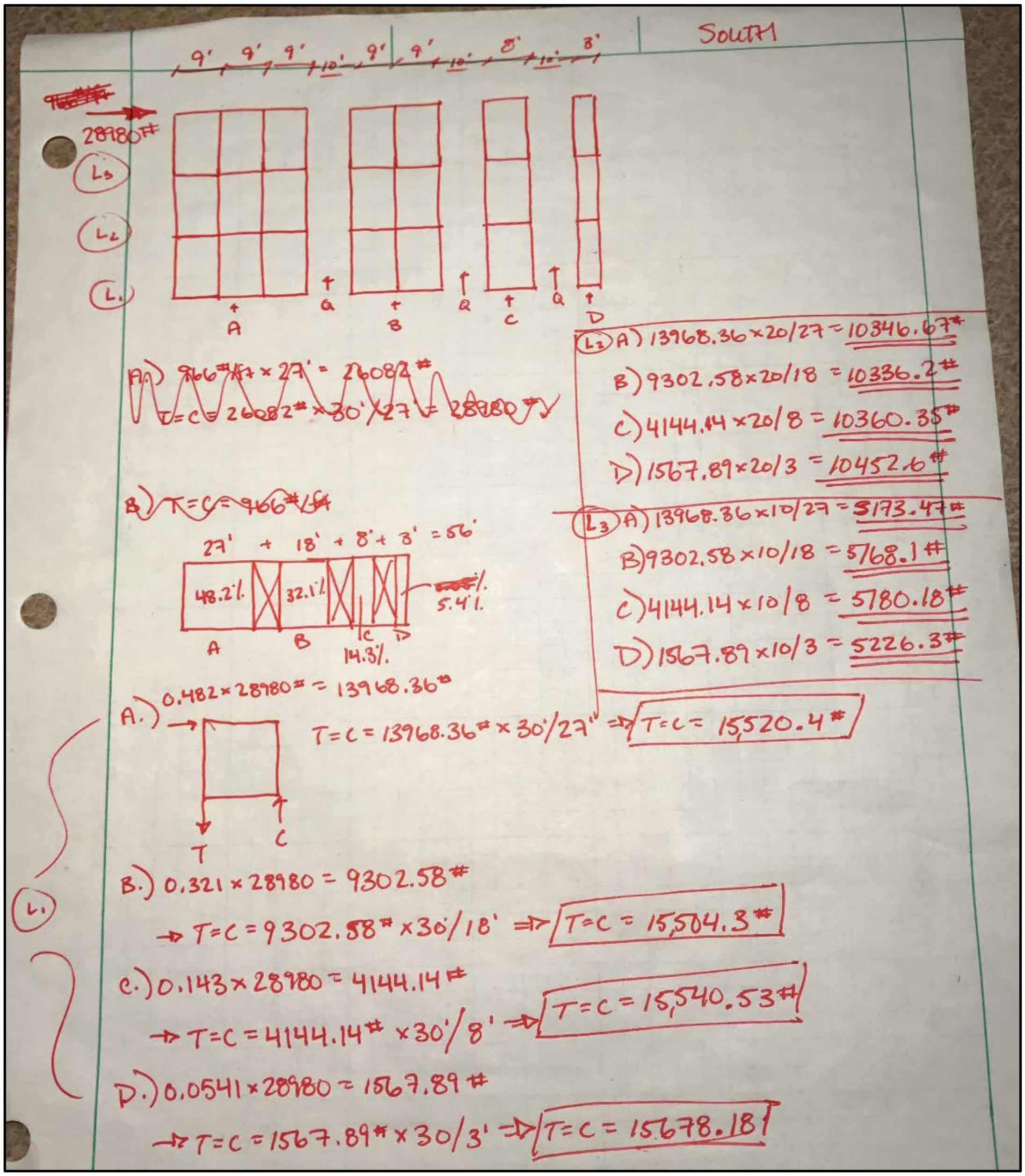
Structural Panel I 7/16" with 8d nails 6" o.c can carry up to 715 plf.

- Standardize all sheathing to this.

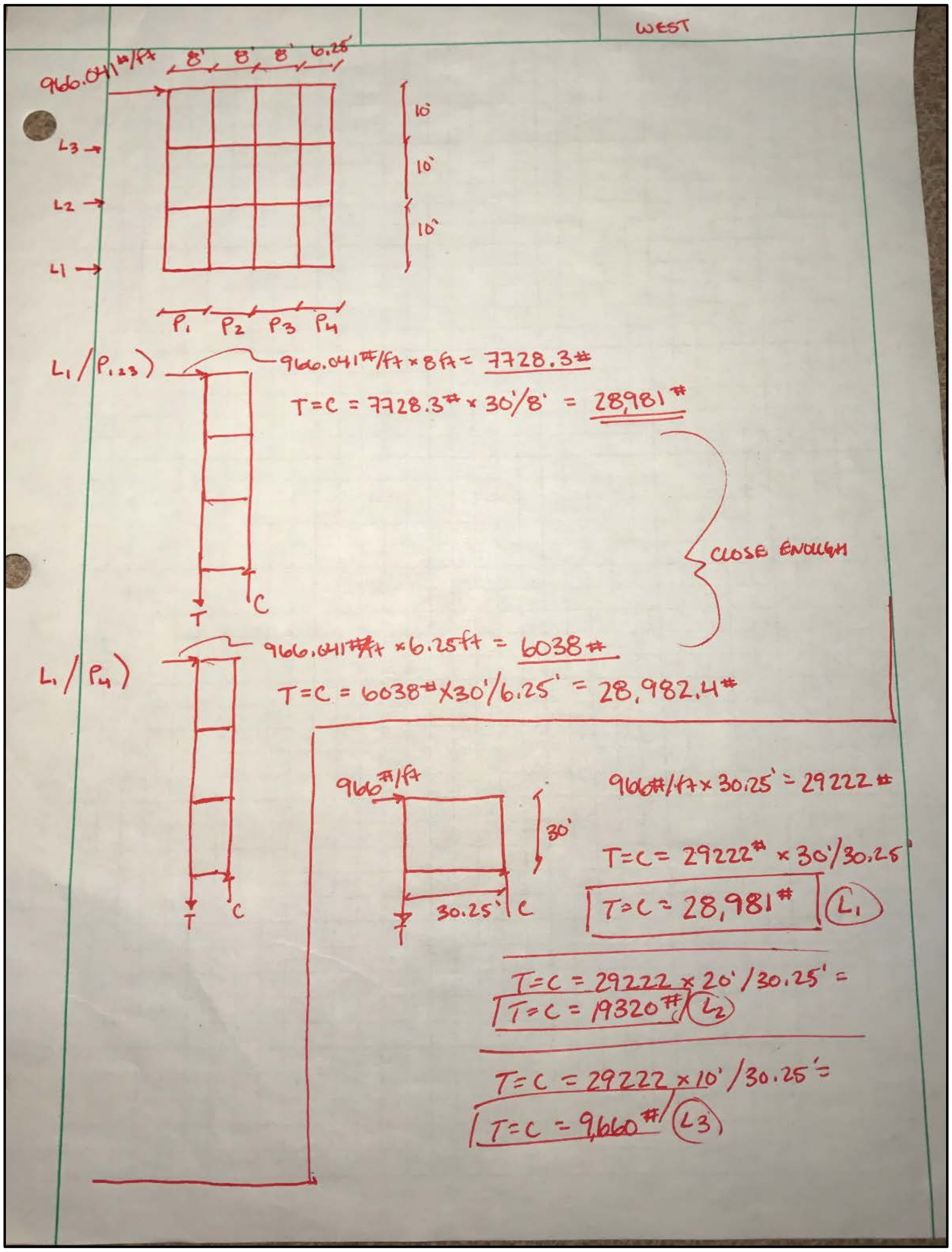
Shear Wall Design Calculations



Tie-down Forces for East Wall, Hand Calculations



Tie-down Forces for South Wall, Hand Calculations



Tie-down Forces for West Wall, Hand Calculations

	A	B	C	D	E	F	G
1	Tie-down Forces East Wall						
2	Panel	Width (ft)	Width Ratio	Load (lb)	30' T=C= (lb)	20' T=C= (lb)	10' T=C= (lb)
3	A	3.67	0.0517	1499	12257	8171	4086
4	B	9.5	0.1339	3881	12257	8171	4086
5	C	15	0.2115	6129	12257	8171	4086
6	D	4.5	0.0634	1839	12257	8171	4086
7	E	5.17	0.0729	2112	12257	8171	4086
8	F	13.5	0.1903	5516	12257	8171	4086
9	G	5.67	0.0799	2317	12257	8171	4086
10	H	8.17	0.1152	3338	12257	8171	4086
11	I	5.75	0.0811	2349	12257	8171	4086
12	Total	70.93	1	28980			

Tie-down Forces for East Wall, Excel Calculations

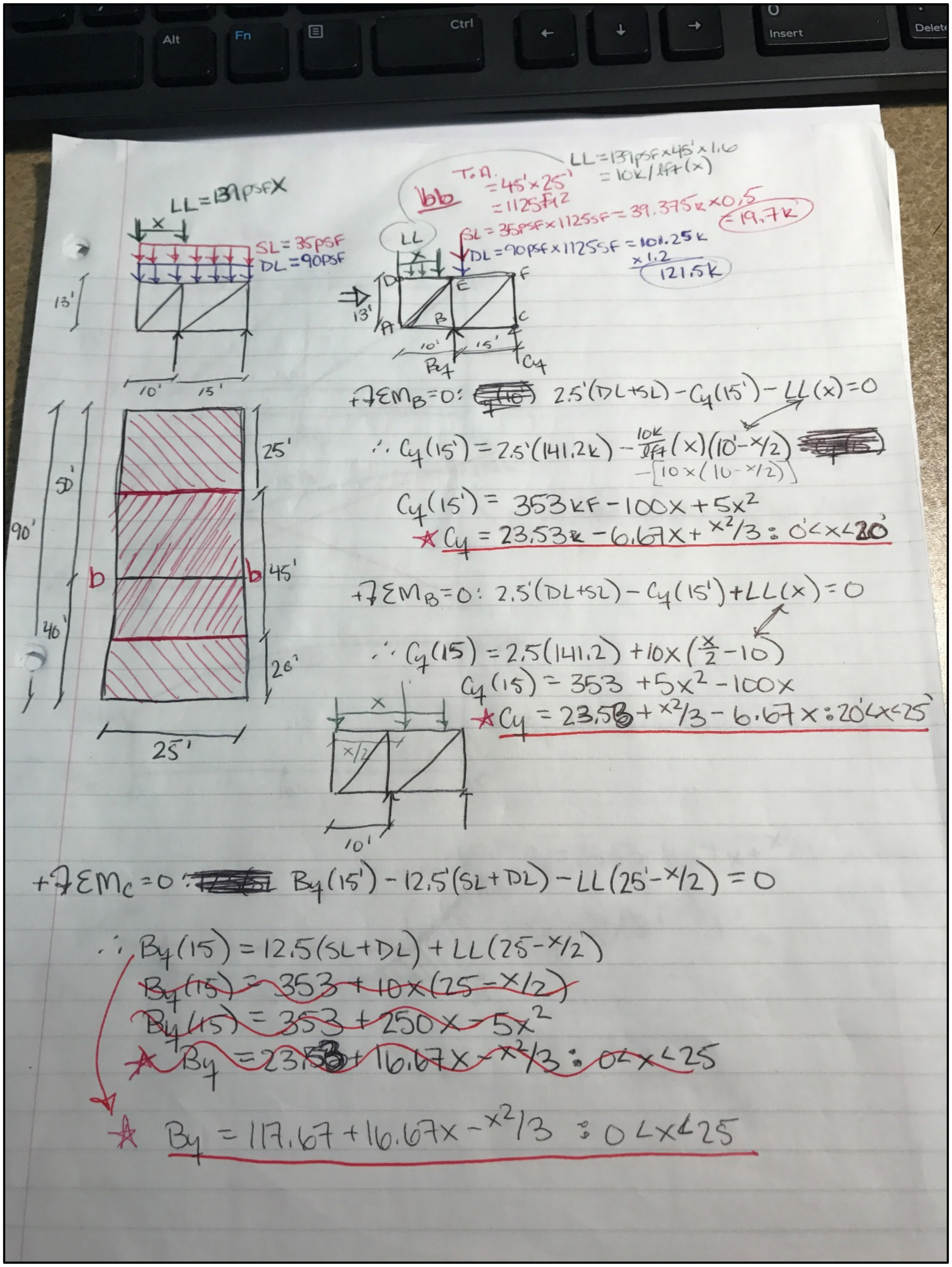
	A	B	C	D	E	F	G
1	Tie-down Forces South Wall						
2	Panel	Width (ft)	Width Ratio	Load (lb)	30' T=C= (lb)	20' T=C= (lb)	10' T=C= (lb)
3	A	27	0.4821	13973	15525	10350	5175
4	B	18	0.3214	9315	15525	10350	5175
5	C	8	0.1429	4140	15525	10350	5175
6	D	3	0.0536	1553	15525	10350	5175
7	Total	56	1	28980			

Tie-down Forces for South Wall, Excel Calculations

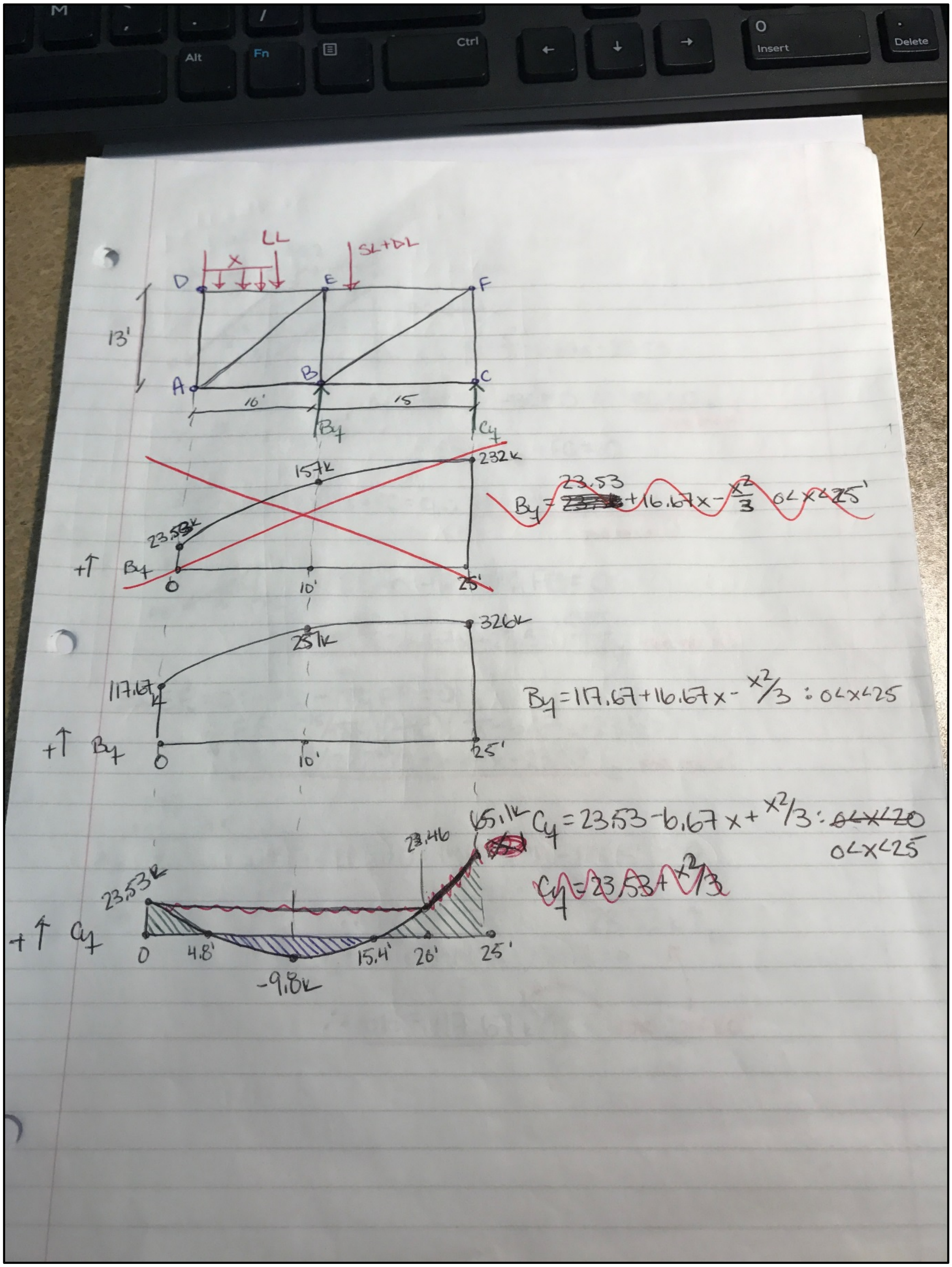
	A	B	C	D	E	F	G
1	Tie-down Forces West Wall						
2	Panel	Width (ft)	Width Ratio	Load (lb)	30' T=C= (lb)	20' T=C= (lb)	10' T=C= (lb)
3	A	30.25	1.0000	76689	76055	50703	25352

Tie-down Forces for West Wall, Excel Calculations

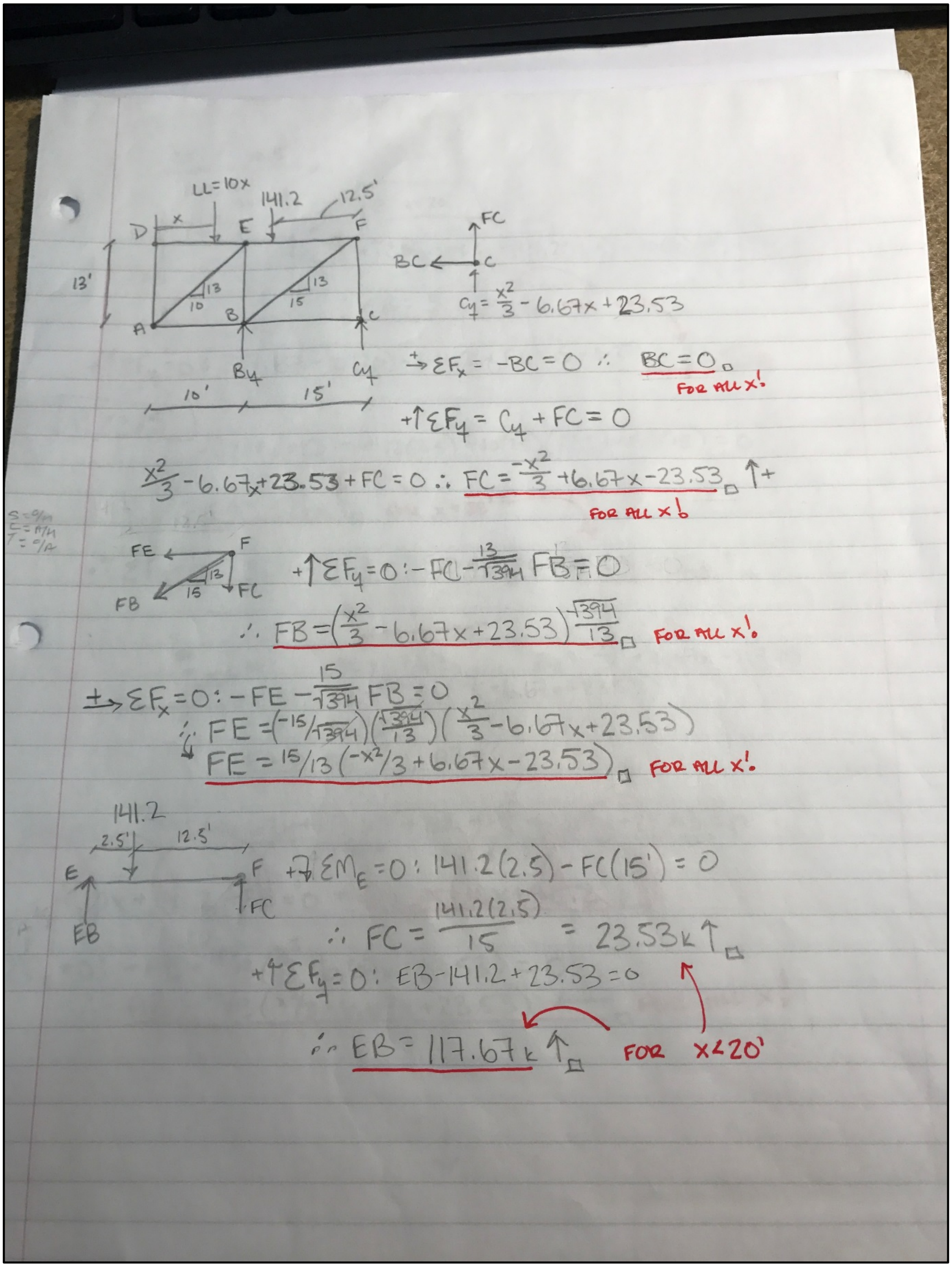
Appendix D: Pratt Truss



Reactionary Forces Calculations



Influence Line Diagrams



LL = 10x, 141.2, 12.5', x, D, E, F, 13', A, B, C, 10, 13, 15, B_y, C_y, 10', 15'

FC, BC, C

$C_y = \frac{x^2}{3} - 6.67x + 23.53$

$\overset{+}{\rightarrow} \Sigma F_x = -BC = 0 \therefore \underline{BC = 0}$ □ FOR ALL x!

$+\uparrow \Sigma F_y = C_y + FC = 0$

$\frac{x^2}{3} - 6.67x + 23.53 + FC = 0 \therefore \underline{FC = \frac{-x^2}{3} + 6.67x - 23.53}$ □ ↑+ FOR ALL x!

FE, F, FB, FC, 13, 15

$+\uparrow \Sigma F_y = 0: -FC - \frac{13}{\sqrt{394}} FB = 0$

$\therefore \underline{FB = \left(\frac{x^2}{3} - 6.67x + 23.53\right)\frac{-\sqrt{394}}{13}}$ □ FOR ALL x!

$\overset{+}{\rightarrow} \Sigma F_x = 0: -FE - \frac{15}{\sqrt{394}} FB = 0$

$\therefore FE = \left(-15/\sqrt{394}\right)\left(\frac{\sqrt{394}}{13}\right)\left(\frac{x^2}{3} - 6.67x + 23.53\right)$

$\underline{FE = 15/13\left(-x^2/3 + 6.67x - 23.53\right)}$ □ FOR ALL x!

141.2, 2.5', 12.5', E, F, EB, FC

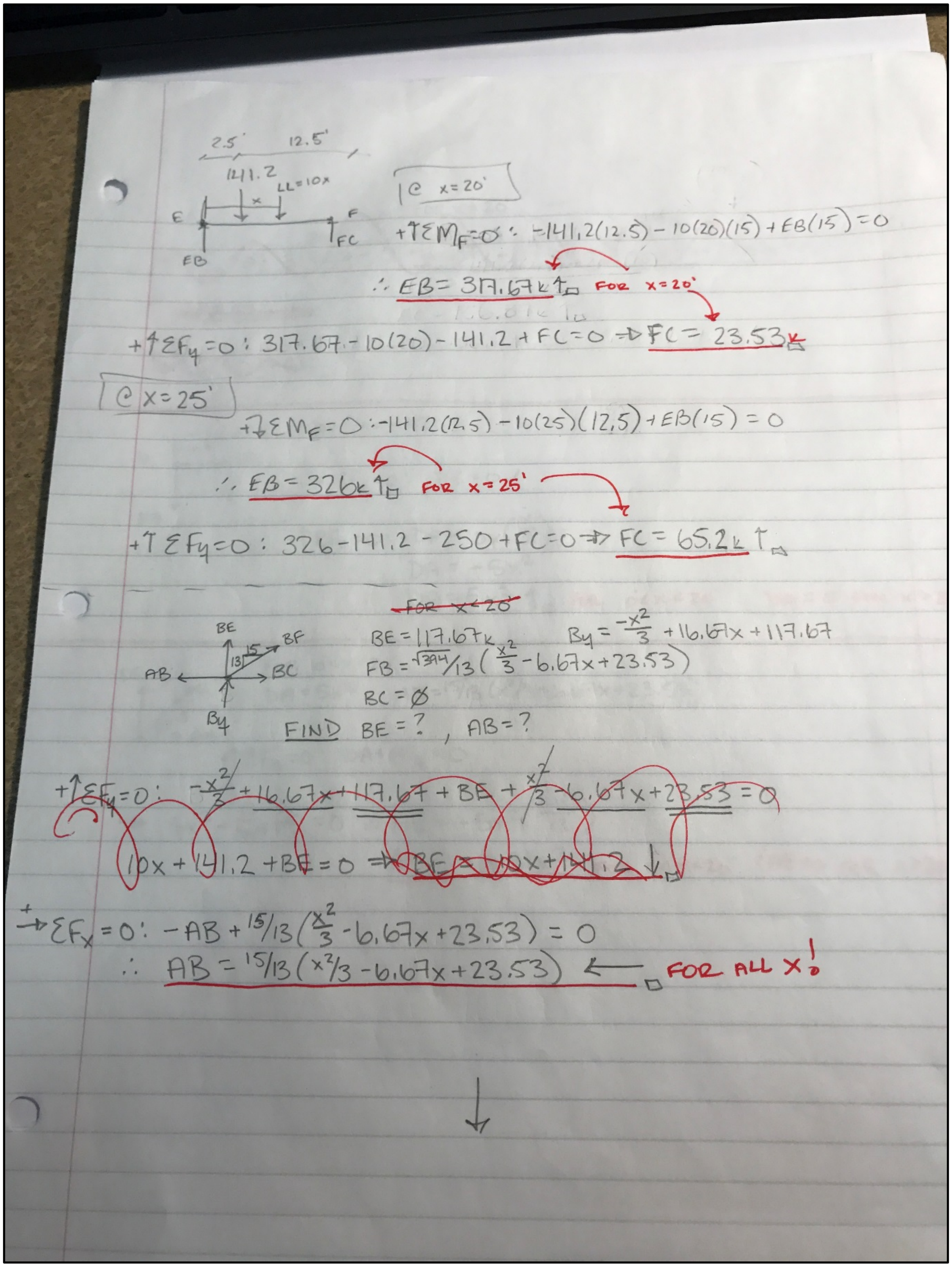
$+\circlearrowright \Sigma M_E = 0: 141.2(2.5) - FC(15') = 0$

$\therefore FC = \frac{141.2(2.5)}{15} = 23.53k \uparrow$ □

$+\uparrow \Sigma F_y = 0: EB - 141.2 + 23.53 = 0$

$\therefore \underline{EB = 117.67k} \uparrow$ □ FOR x<20'

Pratt Truss Member Force Hand Calculations



2.5' 12.5'

141.2 LL = 10x

E F EB FC

@ x = 20'

$+\circlearrowleft \Sigma M_F = 0: -141.2(12.5) - 10(20)(15) + EB(15) = 0$

$\therefore EB = 317.67k \uparrow$ FOR x = 20'

$+\uparrow \Sigma F_y = 0: 317.67 - 10(20) - 141.2 + FC = 0 \Rightarrow FC = 23.53k$

@ x = 25'

$+\circlearrowleft \Sigma M_F = 0: -141.2(12.5) - 10(25)(12.5) + EB(15) = 0$

$\therefore EB = 326k \uparrow$ FOR x = 25'

$+\uparrow \Sigma F_y = 0: 326 - 141.2 - 250 + FC = 0 \Rightarrow FC = 65.2k \uparrow$

~~FOR x < 20~~

BE BF 15 13 AB BC By

$BE = 117.67k$ $\quad B_y = -\frac{x^2}{3} + 16.67x + 117.67$

$FB = \sqrt{394}/13\left(\frac{x^2}{3} - 6.67x + 23.53\right)$

$BC = \varnothing$

FIND BE = ?, AB = ?

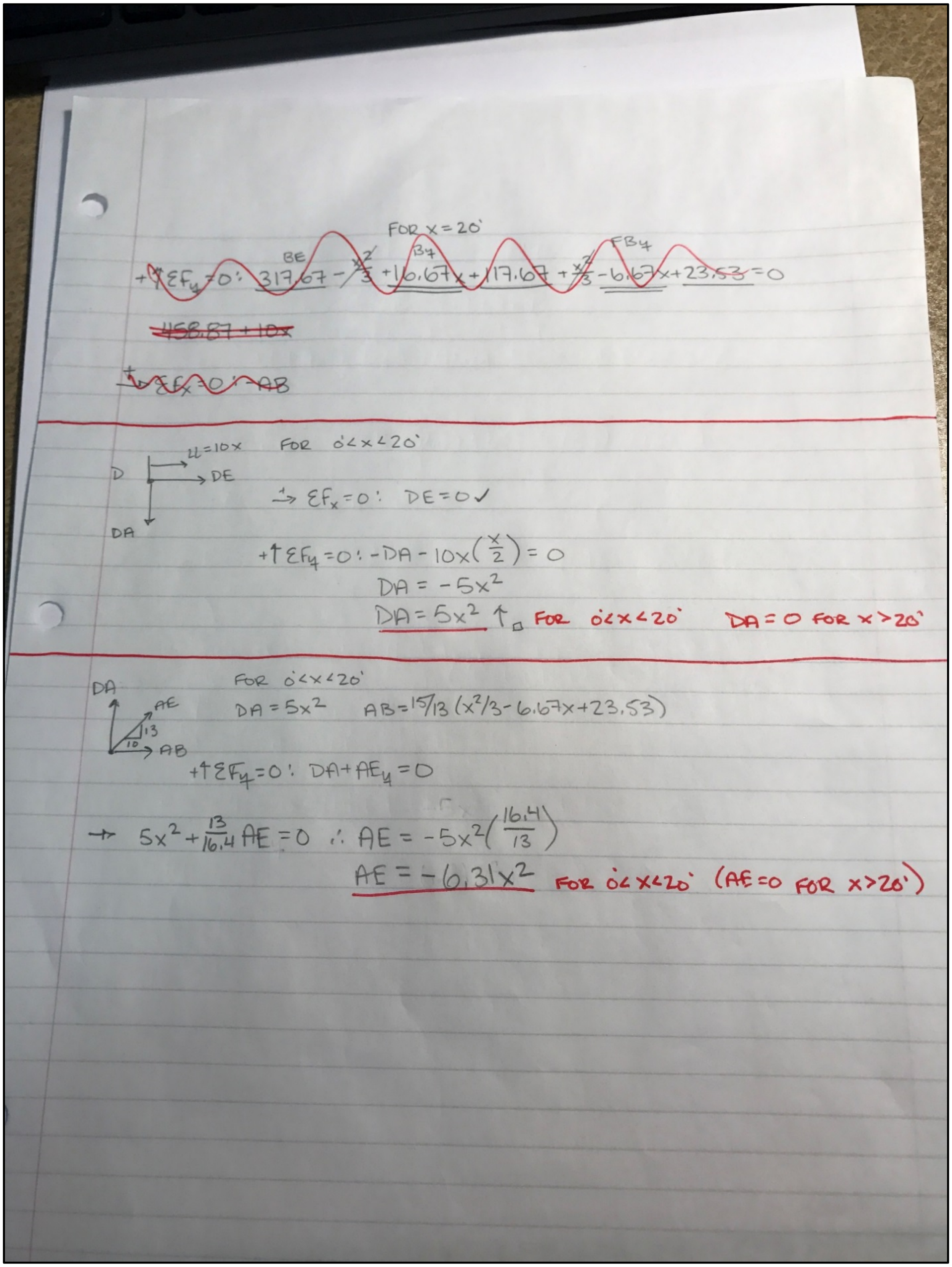
$+\uparrow \Sigma F_y = 0: -\frac{x^2}{3} + 16.67x + 117.67 + BE + \frac{x^2}{3} - 6.67x + 23.53 = 0$

$10x + 141.2 + BE = 0 \Rightarrow BE = 10x + 141.2 \downarrow$

$\xrightarrow{+} \Sigma F_x = 0: -AB + 15/13\left(\frac{x^2}{3} - 6.67x + 23.53\right) = 0$

$\therefore AB = 15/13(x^2/3 - 6.67x + 23.53)$ ← FOR ALL x!

Pratt Truss Member Force Hand Calculations Continued



~~FOR $x = 20'$~~

~~$+\uparrow \Sigma F_y = 0: 317.67 - \frac{x^2}{3} + 16.67x + 117.67 + \frac{x^2}{3} - 6.67x + 23.53 = 0$~~

~~$458.87 + 10x$~~

~~$\xrightarrow{+} \Sigma F_x = 0: AB$~~

FOR $0' < x < 20'$

$\xrightarrow{+} \Sigma F_x = 0: \quad DE = 0$ ✓

$+\uparrow \Sigma F_y = 0: -DA - 10x\left(\frac{x}{2}\right) = 0$

$DA = -5x^2$

$\underline{DA = 5x^2} \uparrow$ □ FOR $0' < x < 20'$ $\quad DA = 0$ FOR $x > 20'$

FOR $0' < x < 20'$

$DA = 5x^2 \quad AB = 15/13\,(x^2/3 - 6.67x + 23.53)$

$+\uparrow \Sigma F_y = 0: \quad DA + AE_y = 0$

$\rightarrow 5x^2 + \frac{13}{16.4} AE = 0 \quad \therefore AE = -5x^2\left(\frac{16.4}{13}\right)$

$\underline{AE = -6.31x^2}$ FOR $0' < x < 20'$ (AE = 0 FOR $x > 20'$)

Pratt Truss Member Force Hand Calculations Continued

GIVEN:

Size	W8X67						
E (Ksi)	29000	**Pc**	597	**bf (in)**	8.28	**d (in)**	9
I (in^4)	272	**ry (in)**	2.12	**tf (in(**	0.935	**Fy (ksi)**	50
L(in)	156	**rx (in)**	3.72	**tw (in)**	0.57		

COMBINED FLEXURE AND COMPRESSION

KyL/ry	73.58491	governs	Table 4-1
KxL/rx	41.93548		for Pc = ϕPn

Member	CF			
Pnt (K)	64.5	H1-1b	0.483678	acceptable
Mnt (ft-K)	113			

Pr/Pc	0.10804	USE	H1-1b

FLB				
Bf/2tf	4.427807	Plastic Bending Mp	ϕMn = ϕMp	263

SHEAR

Shear force	12.6	Kips
Aw (in^2)	5.13	
h/tw	11.1	Cv and ϕ = 1
ϕVn	153.9	acceptable

Member Sizing: Member CF

GIVEN:

Size	W8X67						
E (Ksi)	29000	**Pc**	597	**bf (in)**	8.28	**d (in)**	9
I (in^4)	272	**ry (in)**	2.12	**tf (in(**	0.935	**Fy (ksi)**	50
L(in)	156	**rx (in)**	3.72	**tw (in)**	0.57		

COMBINED FLEXURE AND COMPRESSION

KyL/ry	73.58491	governs	Table 4-1
KxL/rx	41.93548		for Pc = ϕPn

Member	EB
Pnt (K)	300
Mnt (ft-K)	93.2

H1-1a	0.81751	acceptable

Pr/Pc 0.502513 USE H1-1a

FLB

Bf/2tf 4.427807 Plastic Bending Mp ϕMn = ϕMp 263

SHEAR

Shear force 10.39 Kips

Aw (in^2)	5.13	
h/tw	11.1	Cv and ϕ = 1
ϕVn	153.9	acceptable

Member Sizing: Member EB

GIVEN:	Size	14x82					
E (Ksi)	29000	**Pc = ϕPn**	1024.87	**bf (in)**	10.1	**d (in)**	14.3
I (in^4)	881	**ry (in)**	2.48	**tf (in(**	0.855	**Fy (ksi)**	50
L(in)	180	**rx (in)**	6.05	**tw (in)**	0.51	**A (in^2)**	24
						Fu (ksi)	65

COMBINED FLEXURE AND TENSION

Member	EF		
Pnt (K)	3.26		
Mnt (ft-K)	377.68		
Yielding			
Min Ag	0.072444	acceptable	
ϕPn (k)	1080		
Rupture			
Ag	0.715552	acceptable	
An	23.35875		
Ae	21.02288		
ϕPn (k)	1024.865		
Pr/Pc	0.003181	USE	H1-1b

H1-1b	0.726504	acceptable

FLB					
Bf/2tf	5.906433	Plastic Bending Mp		ϕMn = ϕMp	521

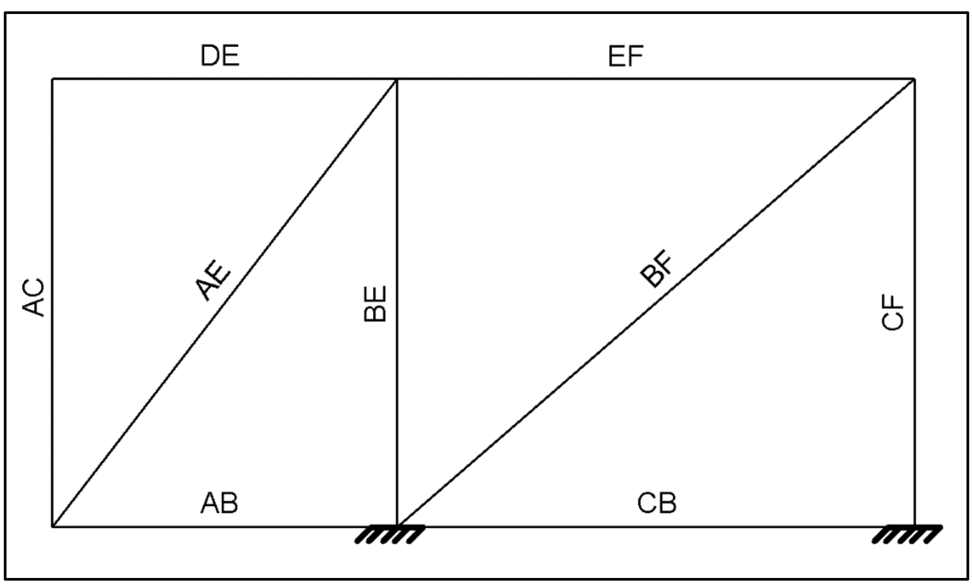
SHEAR

Shear force	204.97	Kips
Aw (in^2)	7.293	
h/tw	22.4	Cv and ϕ = 1
ϕVn	218.79	acceptable

Member Sizing: Member EF

GIVEN:	Size	W10x68								
E (Ksi)	29000		**Pc = ϕPn**	847.77		**bf (in)**	10.1		**d (in)**	10.4
I (in^4)	394		**ry (in)**	2.59		**tf (in(**	0.77		**Fy (ksi)**	50
L(in)	196.8		**rx (in)**	4.44		**tw (in)**	0.47		**A (in^2)**	19.9
									Fu (ksi)	65
COMBINED FLEXURE AND TENSION										
Member	AE									
Pnt (K)	25.74									
Mnt (ft-K)	66.12									
Yielding										
Min Ag	0.572	acceptable						H1-1b	0.221806	acceptable
ϕPn (k)	895.5									
Rupture										
Ag	1.164167	acceptable								
An	19.3225									
Ae	17.39025									
ϕPn (k)	847.7747									
Pr/Pc	0.030362	USE	H1-1b							
FLB										
Bf/2tf	6.558442		Plastic Bending Mp		ϕMn = ϕMp	320				
	SHEAR									
Shear force	4.689	Kips								
Aw (in^2)	4.888									
h/tw	16.7	Cv and ϕ = 1								
ϕVn	146.64	acceptable								

Member Sizing: Member AE



Risa Diagram

L...	Member Label	S...	Axial[k]	Shear[k]	Moment[k-ft]
1	AD	1	28.463	1.675	24.771
		2	28.463	1.675	19.325
		3	28.463	1.675	13.88
		4	28.463	1.675	8.435
		5	28.463	1.675	2.989
1	DE	1	-1.675	28.463	2.989
		2	-1.675	3.463	-36.917
		3	-1.675	-21.537	-14.323
		4	-1.675	-46.537	70.77
		5	-1.675	-71.537	218.364
1	EF	1	-3.26	204.966	377.68
		2	-3.26	26.266	-144.129
		3	-3.26	-11.234	-172.313
		4	-3.26	-48.734	-59.872
		5	-3.26	-86.234	193.194
1	CF	1	64.501	12.603	112.967
		2	64.501	12.603	72.008
		3	64.501	12.603	31.049
		4	64.501	12.603	-9.91
		5	64.501	12.603	-50.868
1	CB	1	0	0	0
		2	0	0	0
		3	0	0	0
		4	0	0	0
		5	0	0	0
1	AB	1	13.65	-5.205	-38.058
		2	13.65	-5.205	-25.045
		3	13.65	-5.205	-12.032
		4	13.65	-5.205	.981
		5	13.65	-5.205	13.994
1	AE	1	-25.736	-4.689	-10.776
		2	-25.736	-4.689	8.448
		3	-25.736	-4.689	27.673
		4	-25.736	-4.689	46.898
		5	-25.736	-4.689	66.123
1	BE	1	299.761	-10.39	-93.194
		2	299.761	-10.39	-59.426
		3	299.761	-10.39	-25.658
		4	299.761	-10.39	8.109
		5	299.761	-10.39	41.877
1	BF	1	26.222	6.035	39.557
		2	26.222	6.035	9.611
		3	26.222	6.035	-20.335
		4	26.222	6.035	-50.281
		5	26.222	6.035	-80.227

Member Forces Calculated in Risa