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53 Wachusett Street Design

A Major Qualifying Project Report

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Degree of Bachelor of Science

By

John Bonina ____________________________

Matthew Rabasco ____________________________

James Rios ____________________________

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Approved:

Professor Leonard Albano ____________________________

Note: This is a student project and does not reflect the views of Professional Engineers

Abstract

This project proposed a replacement for 53 Wachusett Street, a building WPI owns and reclaimed following the 2018-2019 school year. The team determined a use for the building; designed a renovation and a replacement facility in accordance with *Massachusetts State Building Code, Ninth Edition*; and recommended one option to WPI. The scope of work included structural engineering using Load and Resistance Factored Design (LRFD) and fire protection design. This recommendation depended on structural designs, cost estimates, and building life spans.

Capstone Design Statement

This Major Qualifying Project focused on design options for either renovating or reconstructing 53 Wachusett Street, a fraternity house in Worcester, MA that WPI will be taking over at the end of the 2018-2019 school year. The design of these proposed renovations and new constructions required drawing on experience previously gained in the classroom, as well as acquiring practical experience in areas such as building code and zoning constraints. Real-world constraints that were addressed in this project included constructability, accessibility, health and safety, sustainability, and social aspects.

Constructability

Any engineering design, regardless of its quality, needs to be feasible and affordable to construct. To ensure that our designs could be constructed at a reasonable cost, we estimated the costs and construction times for these designs. We also needed to ensure that these designs were constructible in terms of materials used and layout. For example, many buildings in the Northeast rely on steel construction, but a wooden frame like the one currently used in 53 Wachusett Street is also sufficient for a building with a maximum of three stories. Acceptable building materials and layouts were confirmed by inspecting the existing building and by referencing the 9th edition of the *Massachusetts State Building Code*.

Accessibility

An important issue regarding renovating the building is the additional cost associated with ensuring compliance with ADA requirements. As an older building, 53 Wachusett Street is not currently ADA-compliant, but any renovations to the building require that some accessibility measures be implemented. If the cost of renovations exceeds 30% of the building’s value, the entire building must be made to comply with ADA requirements, which presents additional costs. Otherwise, only the areas being renovated need to comply with these requirements (521 CMR 3.00). If the existing building were replaced with a new one, the new building would have to conform to ADA requirements regardless of its cost. For dormitories and other transient lodging facilities, this requires making a minimum of 5% of dwelling units, as well as the routes to these units, fully accessible (521 CMR 8.00). These additional accessibility costs were included in the estimates for both the renovation and the new construction.

Health and Safety

Since 53 Wachusett Street was built in 1914 (Vision Government Solutions, n.d.), it likely contains many of the hazardous materials typically found in older buildings, including asbestos and lead. While most of the asbestos previously present in the building has been removed, some of the pipes in the basement are still lined with asbestos. Lead paint is a difficult hazard to identify, as it may be covered in layers of non-lead paint. Other lead hazards that may be prevalent in 53 Wachusett would be pipes and traps.

The removal of lead and asbestos from 53 Wachusett Street will contribute to the estimated cost of renovating the building. In this way, it may affect whether the entire building needs to be comply with accessibility requirements, or whether only the areas being impoved need to comply (521 CMR 3.00). Due to the invasive nature of performing lead tests on walls that have since been painted over (these tests require chipping outer layers of paint off the walls), the cost of this work was difficult to predict. Since removing lead and asbestos from the building does not change the building's use, the benefits of these construction activities cannot be quantified.

Not only do health and safety constraints affect the cost of construction, they determine the feasibility of proposed designs. Zoning regulations – a product of local health and safety concerns – restrict options for conceptual designs by specifying allowable building uses and dimensions. After the architectural design is completed, the building's systems must be designed in order to ensure that it can be safely used. In this MQP, the replacement building's structural system was designed in order to ensure that it could withstand loads prescribed by building codes. In addition, an automatic sprinkler system was designed in order to ensure that it could distribute water to every room in the building during a fire, without requiring a water pressure higher than the city could provide.

Sustainability

With climate change awareness and increased emphasis on environmental issues, sustainable design has become an important concern, especially on college campuses. A number of sustainability elements were incorporated as additions to the designs for both a renovation and a new construction. Some of these elements had quantifiable costs and benefits, separate from those for the remainder of the building. These elements, all of which were analyzed exclusively for the new construction, are listed below:

- Solar panels
- Rainwater storage tanks

Other elements of sustainable design do not have easily quantifiable monetary savings. These items were assumed to be part of the design and estimated accordingly, but were not designed using engineering methods. These sustainability elements, which were used in both the renovation and the new construction, are listed below:

- Cork-board flooring
- LED lights
- Energy Star Appliances
- Volatile Organic Chemical (VOC) free paints

Social

According to Amy Beth Laythe, an Associate Director of Residential Services, WPI students generally prefer apartment-style housing with kitchens in order to cook their own food and avoid purchasing a WPI meal plan (Amy Beth Laythe, personal communication). The potential of replacing the current layout of 53 Wachusett Street with apartments was not investigated due to the building's small size and the scale of renovations that this would have required. However, one design objective for the renovation was to preserve the kitchen, since the appliances that it contains are similar to those in other, current WPI residence houses.

WPI's residential houses do not have a consistent appearance. Rather, they contain architectural details and finishes typical of the original buildings. As a result, WPI is not likely to perform any significant aesthetic repairs to 53 Wachusett Street unless they enhance the building's safety or usage. For this reason, the renovations that were investigated focus on improving the building's function rather than its aesthetics.

Determining Client Needs

The designs proposed for 53 Wachusett Street needed to address WPI's current needs and reflect the constraints of the site. 53 Wachusett Street's location in a residential zone several blocks away from campus proper makes it less suitable for classroom or office facilities, which means that the building would likely be used for a residential space.

Various WPI stakeholders were consulted in order to determine WPI's facilities needs. WPI's residential needs were discussed with Amy Beth Laythe, an Associate Director of Residential Services, while the school's academic needs were discussed with Kristopher Sullivan, WPI's Associate Vice President for Academic Affairs. In order to gain a broader understanding of WPI's facilities needs and the considerations that influence the decisions that WPI makes regarding its facilities, Ronald O'Brien, WPI's Director of Design and Construction, and Nick Palumbo, WPI's Facilities Project Manager, were consulted.

Professional Licensure Statement

A professional engineer (PE) license is a major asset for an individual in any engineering field. This license gives engineers many additional job opportunities and liberties. However, it also comes with important responsibilities and high expectations. In order to receive a PE license, candidates must have met certain educational and vocational requirements and passed a series of exams. Once they have received their license, they are held legally responsible for the quality of their work. (National Society of Professional Engineers, n.d.)

Becoming a professional engineer not only requires educational and workplace qualifications, but also successful completion of a series of tests. Candidates must generally have a degree from an EAC- or ABET-accredited school, although different states have different requirements. Around the time that they earn their degree, young engineers typically take the Fundamentals of Engineering (FE) exam, the first of two licensing exams. Then, after four years of working under a professional engineer, they are eligible to take the Principles and Practices of Engineering (PE) exam ("Licensure", n.d.). This exam is more involved than the FE exam, containing 80 questions but lasting eight hours. The Civil Engineering PE exam is also different from the FE exam in that half of it is dedicated to a subdiscipline of civil engineering – either construction, geotechnical, structural, transportation, or water resources and environmental – chosen by the candidate based on their area of expertise.

Professional licensure affords engineers with a range of opportunities. Not only are there financial advantages of being a professional engineer ("Engineering Licensure", n.d.), but professional licensure is a prerequisite to be able to perform many types of engineering work. Only professional engineers can prepare, sign, and submit contract documents, or seal drawings for their clients. Unlike their unlicensed counterparts, only professional engineers can serve as consultants in private practice, and many government positions are only available to professional engineers. In addition, a growing number of states also require that engineering professors obtain Professional Engineer licenses as well, further increasing the importance of licensure as an engineer (NSPE, n.d.).

The licensure process is important to society because it restricts the practice of engineering to qualified individuals. This ensures that the work that engineers do is of a high quality and that the public can remain safe. This is especially important in engineering disciplines, as a single mistake made by an engineer can result in casualties on a large scale.

This MQP cannot be implemented without the approval of a professional engineer because only a licensed engineer may approve engineering plans and drawings (NSPE, n.d.). While this MQP can serve to recommend engineering options for 53 Wachusett Street, only a professional engineer can sign off on any of the proposed designs. This means that any construction on 53 Wachusett Street cannot begin without the approval of a professional engineer.

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1.0. Introduction

The objective of this MQP was to convert the property at 53 Wachusett Street, a fraternity house owned by WPI and rented to the Alpha Chi Rho fraternity, into a residence house or faculty office space. 53 Wachusett Street is located within a block of the east end of campus at Dean Street. WPI rented this building to Alpha Chi Rho beginning in the mid-2000s, but the contract ended at the conclusion of the 2018-2019 school year and WPI did not renew it. This MQP investigated the possibilities of renovating the building as well as demolishing it and erecting a new facility. The scope of the project involved consulting the Provost Office, Facilities Management, and WPI's Residential services to determine the most practical use of 53 Wachusett Street, which the students working on this project decided should be a residence house. From there, structural designs and cost estimates for both a renovation of the existing building and the construction of a new building were produced. The ultimate goal of this MQP was to produce a package for WPI of design alternatives for 53 Wachusett Street.

2.0. Background

2.1. 53 Wachusett Street

53 Wachusett Street is a three-story house located two blocks away from WPI's campus proper in an RG-5 residential zone (a general residential zone with a minimum lot size of 5,000 SF) (City of Worcester, MA, 2018). The building utilizes a wood-frame structure with clapboard exterior walls, plaster interior walls, and a gable/hip roof (Vision Government Solutions, n.d.). The building was constructed in 1914 and purchased by WPI over the summer of 2007 for a sale price of $342,000. Even before accounting for inflation, this sale price is significantly greater than the property's current assessed value of $251,100 ($176,800 for the building itself and $74,300 for the surrounding land) (Vision Government Solutions, n.d.).

53 Wachusett Street occupies a rectangular lot with side lengths of 96' and 63', giving the lot a total area of 6,048 SF (0.14 acres) (City of Worcester, MA, n.d.). The building's interior has a gross floor area of 6,073 SF. However, only 3,012 SF is considered to be living area, as the rest is occupied by the basement and multiple porches, and 80% of the top floor is not counted as living area. The gross and living areas of different sections of the building are given in Table 1 (Vision Government Solutions, n.d.).

Table 1. Floor area breakdown of 53 Wachusett Street

Code	Description	Gross Area (ft^2)	Living Area (ft^2)
BAS	First Floor	1,413	1,413
FUS	Upper Story, Finished	1,413	1,413
FAT	Attic, Finished	1,380	276
EPH	Enclosed Porch	48	0
OPH	Open Porch	326	0
UBM	Basement, Unfinished	1,413	0
WDK	Wood Deck	80	0
	Total	6,073	3,102

The house itself has three stories. The lower floor contains common areas, including a living room, a dining alcove, a kitchen, and a pantry (Figure 2). The top two floors, shown in Figure 3 and Figure 4, contain nine bedrooms - four on the second floor and five on the third floor. These bedrooms currently accommodate a total of 12 people, although they had fit 14 people during the 2017-2018 school year.

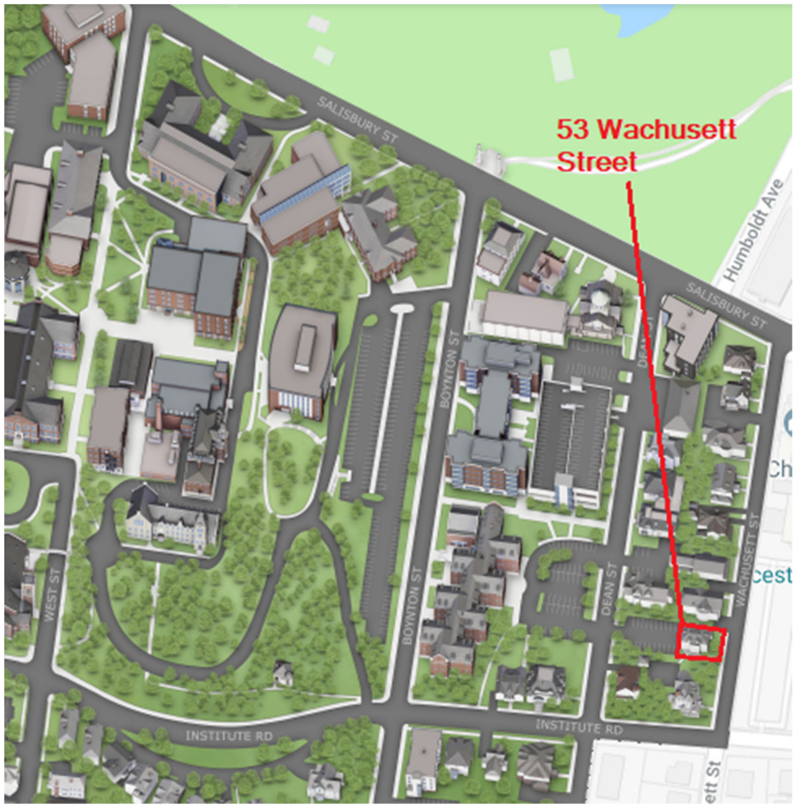


Figure 1: Aerial view of the east end of WPI's campus, with 53 Wachusett Street outlined in red.

Based on investigations of 53 Wachusett Street and meetings with stakeholders from WPI's staff, the structure is in stable condition but many of its systems need significant renovations. These renovations include upgrading the building's electrical equipment, increasing the number of bedrooms, reconfiguring the basement, and replacing the washing machines. An important consideration is the fact that a set of renovations that exceed 30% of the building's assessed value (521 CMR 3.00) will necessitate upgrading the building so that it fully complies with the ADA requirements. Since the building has an assessed replacement cost of $297,868 (Vision Government Solutions, n.d.), a set of renovations exceeding $89,360 will trigger full compliance with ADA accessibility standards.

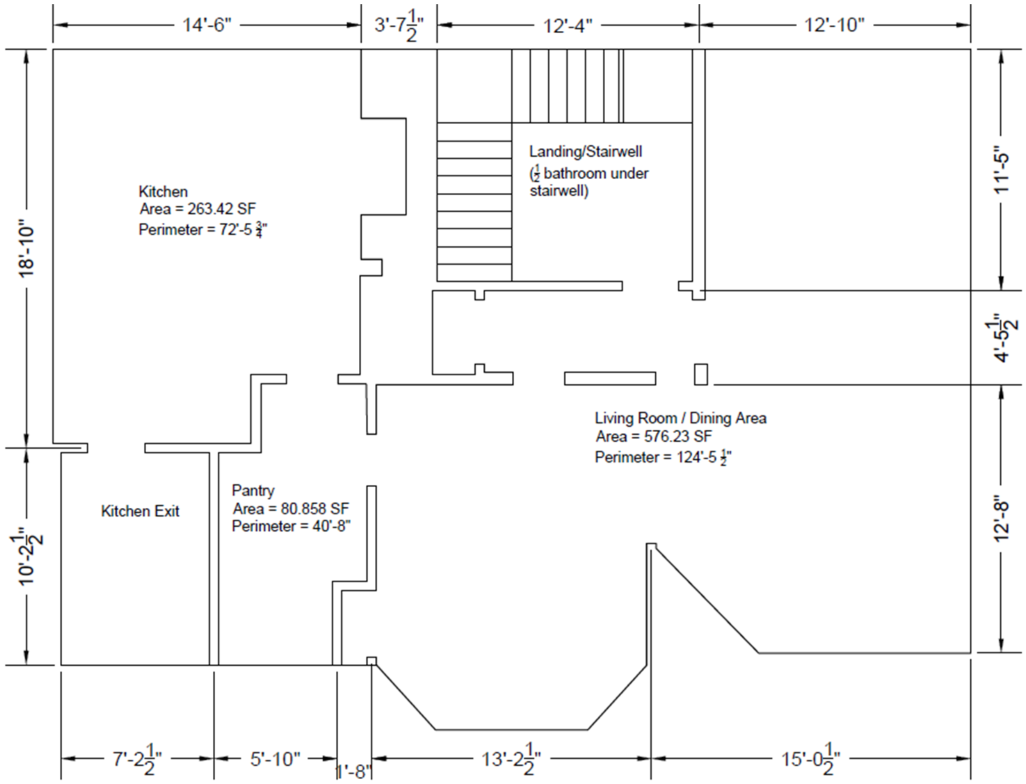


Figure 2: Existing first floor layout for 53 Wachusett Street

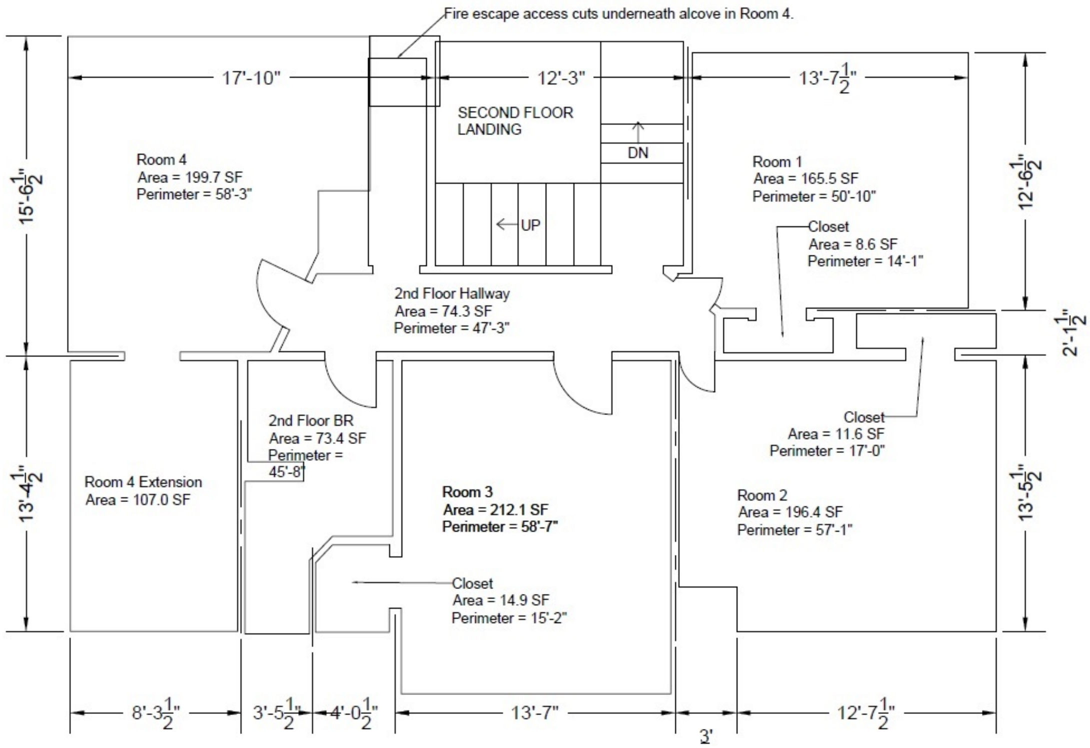


Figure 3: Existing second floor layout

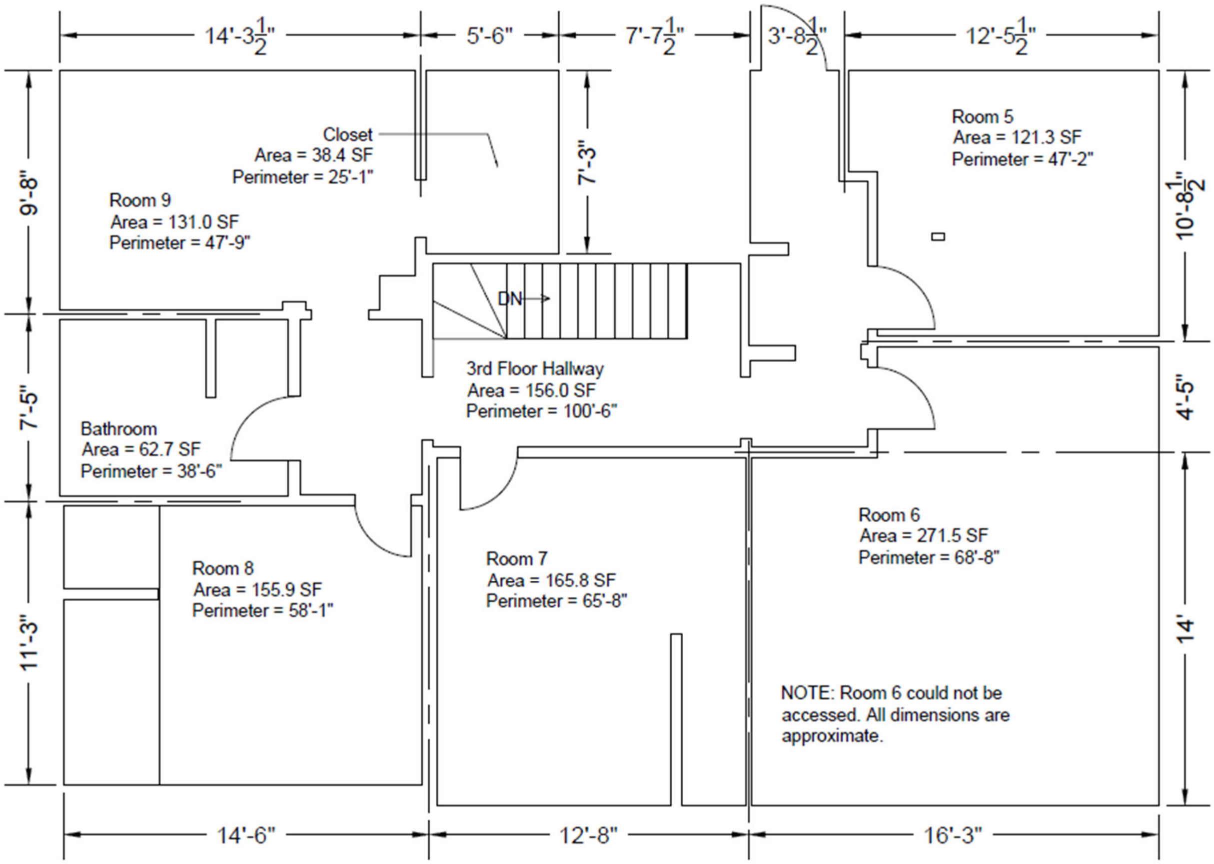


Figure 4: Existing third floor layout

2.2. Zoning

Although 53 Wachusett Street is roughly two blocks away from WPI, it is not located in the same institutional zone as the main campus. Rather, it is in an RG-5 residential zone, as shown in Figure 5, the same zone as the WPI-owned Elbridge house (”Worcester, MA Zoning Map”, 2016). Lots in this area must be at least 5,000 square feet for the “Other residential permitted” classification for which WPI would be most likely to use the building. Sites with this classification must also have the following characteristics (”Worcester, MA Zoning Ordinance”, 2018):

- Minimum Frontage = 50 LF
- Minimum Front Setback = 15 LF
- Minimum Side Setback = 10 LF
- Minimum Rear Setback = 15 LF
- The building must be no higher than three (3) stories or 45 feet.

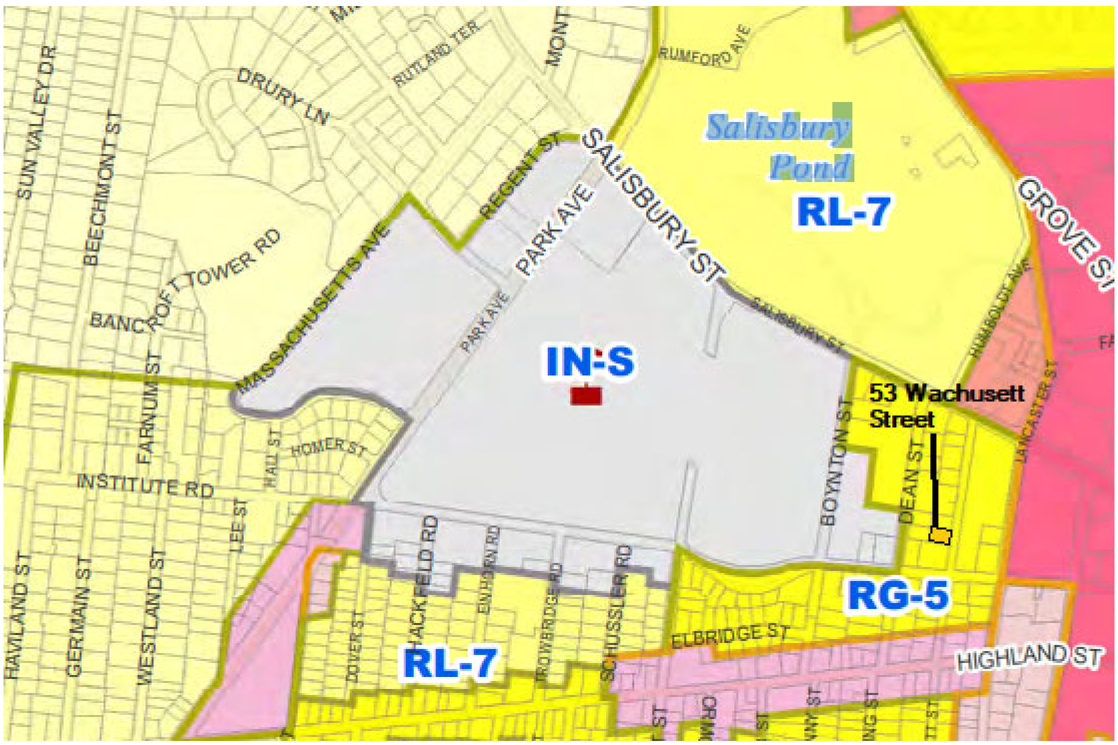


Figure 5: Zoning map of the area surrounding WPI, with 53 Wachusett Street highlighted in orange.

While buildings in the RG-5 zone can be used as dormitories, this use requires a permit. These permits are granted based on several factors, including whether existing utilities and public services are sufficient to provide for the building's use and the impacts on the local economy and the environment. Permit applications can be placed by filing an appeal to the Zoning Board of Appeals at no cost ("Zoning Board of Appeals", n.d.). However, the process can take up to half a year. Public hearings must take place within the first 65 days after filing an application, and a decision can be rendered up to 90 days after the hearing. Once this decision has been rendered, the permit does not take effect for another 20 days (City of Worcester, MA, 2018). While WPI would have to apply for a permit if they demolished and replaced the building, it is unclear whether a new special permit would need to be issued if the building were renovated.

2.3. ADA and Other Requirements

The American with Disabilities Act (ADA) ensures that buildings are made accessible and usable for individuals with disability needs (American National Standards Institute, 1982). When a building is renovated, accessibility modifications shall be made “to the maximum extent feasible,” as stated by Section 36.402 of the ADA code, giving people with disabilities a path of travel to any primary function areas, including water fountains and restrooms (Stein, 2011). Typically, only areas affected by renovations need to be made accessible (521 CMR 3.00). However, if the value of renovations exceeds 30% of the building’s value, then the building would have to be renovated to fully comply with ADA requirements (521 CMR 3.00). Maintenance activities such as reroofing, painting, asbestos removal, or changes to electrical spaces do not count towards the threshold for full compliance unless they affect the usability of the space. (Taylor, 2013).

Since the definition of persons with disabilities includes persons with wheelchairs, many buildings require either ramps or elevator service, as well as handlebars in bathrooms and accessible entryways. According to 521 CMR Section 8, all common areas and at least 5% of sleeping rooms must be made accessible for the building to comply with this regulation (521 CMR 8.00). However, not every room needs to be made accessible in order to achieve compliance, and 521 CMR 8.00 does not explicitly state where the accessible rooms must be located.

2.4. Structural Design Considerations

The structural design method that is used depends heavily on the engineer's preference and which method will produce a more economical result. Generally, Load and Resistance Factored Design (LRFD) is more widely used today because it is more economical and more precise (McCormac, 2018). Whereas Allowable Stress Design (ASD) uses unfactored loads but applies relatively large factors of safety to the capacity of structural members, LRFD uses narrower factors of safety for the strength of structural members but multiplies design loads by separate safety factors in order to account for uncertainties in predicting these loads. For these reasons, LRFD was used for this MQP.

The following load combinations must be considered in LRFD:

- 1.4(D+F)
- 1.2(D+F) + 1.6(L+H) + 0.5(L_r or S or R)
- 1.2(D+F) + 1.6(L_r or S or R) + 1.6H + (f_1L or 0.5W)
- 1.2(D+F) + 1.0W + f_1L + 1.6H + 0.5(L_r or S or R)
- 1.2(D+F) + 1.0E + f_1L + 1.6H + f_2S
- 0.9D + 1.0W + 1.6H
- 0.9(D+F) + 1.0E + 1.6H

Where D = dead load; E = earthquake load; F = fluid load; H = load due to lateral earth pressures; L represents either floor live load or any roof live load greater than 20 psf; L_r is roof live load not exceeding 20 psf; R = rain load; S = snow load; and W = wind load. The constant f_1

is equal to 1 for live loads in parking garages or in places of public assembly and in excess of 100 psf, and 0.5 for other live loads. The constant f_2 is equal to 0.7 for roof configurations that do not shed snow off of a structure, and 0.2 for all other roof configurations.

Each of the basic loads listed above is calculated for different building types using either tables, equations, or a combination of the two. Determining these loads requires consulting design values and formulas used in the local building code; in this case, the *Massachusetts State Building Code, 9th Edition* will be used in concurrence with the IBC 2018 and *ASCE 7-16* codes. Once the process to calculate each basic load has been determined, the calculations can be input into a spreadsheet and appropriate member sizes computed.

Earthquake loads were not considered in this MQP. As shown in the list above, earthquake loads and wind loads are not assumed to act concurrently with each other; as a result, the larger of these loads determines the design requirements for the lateral load resisting system. Since the building's wood-frame structure is lightweight compared to steel or reinforced concrete construction, it would remain largely unaffected by earthquake loads, which are proportional to its mass. In comparison, design wind loads are based on hurricane-force winds, with building codes requiring that buildings in Worcester withstand 124-mph winds (State of Massachusetts, 2015).

2.5. Fire Protection Design Considerations

Both the existing building and the proposed new building contain automatic sprinkler systems for fire mitigation. Specifically, both buildings use tree configurations, where smaller lines branch out from main piping lines to provide water for individual sprinklers (Shah, n.d.). Figure 6 contains an example of this configuration. In Figure 6, lines represent horizontal pipes, circles represent sprinklers, and the circle at the bottom of the figure represents the vertical pipe. As shown in Figure 6, water flows from the vertical pipe into main horizontal pipes at each level, which connect to smaller pipes that directly service the sprinklers.

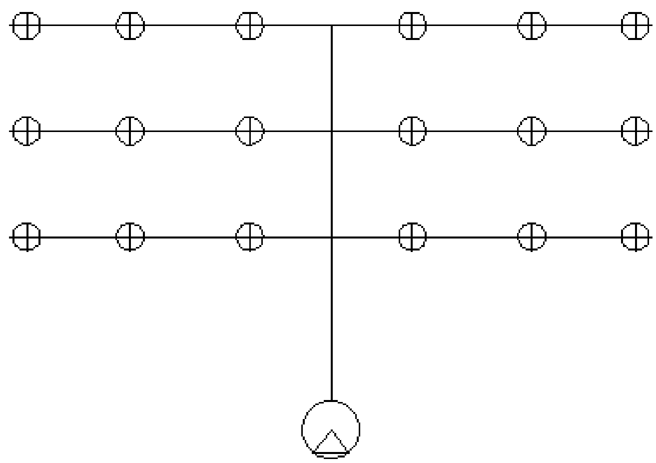


Figure 6. Automatic sprinkler system tree configuration

In this system, the three component types that need to be sized are sprinkler heads, horizontal pipes, and vertical pipes. The sizes of these components depend on the required flow rate and water pressure throughout the system.

The main design objective for a tree configuration sprinkler system is to allow water to flow to all rooms without the required input pressure exceeding the input pressure supplied to the building. In order to design such a system, the flow and pressure at the most remote sprinkler must first be obtained based on minimum requirements for pressure and flow rate. The flow rate exiting the sprinkler is taken as the larger of the two values produced by Equation 1 and Equation 2 (Canute, n.d., b):

$$Q = AD$$

Equation 1. Sprinkler flow based on design density

$$Q = k\sqrt{P_{min}}$$

Equation 2. Sprinkler flow based on minimum working pressure

The terms used in Equation 1 and Equation 2 are listed below:

- Q represents the flow rate of water exiting the sprinkler
- A represents the floor area over which the sprinkler discharges
- D represents the required discharge density
- k is a parameter that varies for different sprinkler types and relates the water pressure at a sprinkler head to the flow through that sprinkler
- P_{min} represents the minimum working pressure of the sprinkler used

After the required flow rate Q is calculated, Equation 2 can be rearranged to form Equation 3, which can be used to calculate the pressure at the sprinkler head.

$$P = \frac{Q^2}{k^2}$$

Equation 3. Sprinkler pressure

As water travels through pipes leading to the sprinkler heads, it loses pressure due to friction with the pipes. Equation 4 (Canute, n.d., b) relates the pressure loss per length in a horizontal pipe to the flow rate and the pipe's material and diameter.

$$\frac{\Delta P}{l} = 6.05\left(\frac{Q^{1.85}}{c^{1.85}d^{4.87}}\right)10^5$$

Equation 4. Pressure loss per length in horizontal pipes

The terms used in Equation 4 are listed below. As shown below, the terms in this equation are expressed in metric units:

- ΔP/l represents pressure loss per length (bars/meter)
- Q represents the flow rate of water exiting the sprinkler (L/min)
- c represents the piping material's friction loss coefficient
- d represents the pipe's diameter (mm)

Equation 4 can also be used to find the pressure loss due to friction, ΔP, in vertical pipes. ΔP can be combined with the Bernoulli equation to calculate the pressure, P_1, required at the bottom of a riser to support flow at the most remote sprinkler, as shown in Equation 5.

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2 + \Delta P$$

Equation 5. Modified Bernoulli equation with pressure loss term

Equation 5 can be simplified if the pipe has the same diameter at both points being analyzed. Since flow rate is inherently constant, velocity is also constant for pipes with constant diameters, and the velocity terms on both sides of the equation are equal.

Automatic sprinklers are not required in all rooms. *NFPA 13R, Installation of Sprinkler Systems in Residential Occupancies* allows sprinklers to be omitted from closets with areas less than 24 square feet (Klaus, 2011). Bathrooms do not need to have sprinklers installed if their area is less than 55 square feet (Klaus, 2011).

2.6. Construction Materials

Factors influencing the selection of materials used in construction include material properties such as strength and durability, as well as building location and size. Wood is commonly used for the structures of smaller residential buildings; for this reason, as well as due to its status as a renewable resource, it was chosen as the primary structural material for the superstructure of both designs. Mixed southern pine was selected due largely to the advantages listed by Southern Pine (n.d.): an abundant supply, a high load-bearing capacity, and the ability to be grown sustainably.

Several grades of mixed southern pine, the structural properties of which are shown in Table 2, were used for the new construction. Select Structural mixed southern pine, the strongest grade available, was used for joists subject to comparatively large loads. No. 1 mixed southern pine was used for nearly all framing members, including trusses, columns, frames, and the majority of joists. No. 3 mixed southern pine was used for railing members in the exterior fire escape, which were subjected to smaller loads than the whole structure. The difference between average elastic modulus (E) and minimum elastic modulus (E_{min}), both of which are shown in Table 2, should be noted. E was used in deflection calculations, which assessed the building's serviceability rather than its strength, while E_{min} was used for more critical strength calculations. It should also be noted that the parameters in Table 2 must be adjusted in accordance with a list of factors given in the National Design Specification for Wood Construction (2015).

Table 2. Selected properties of visually graded mixed southern pine (NDS, Nov. 2014)

Grade	Select Structural	No. 1	No. 3
Bending (psi)	2,050	1,450	650
Tension (psi)	1,200	875	400
Compression (psi)	1,800	1,650	850
Shear (psi)	175	175	175
E (psi)	1,600,000	1,500,000	1,200,000
E_min (psi)	580,000	550,000	440,000

The other factor in determining building materials is the lifespan of the material used. ETool Global (n.d.) gives the life expectancies of various building materials, some of which are shown in Table 3. As shown in Table 3, foundations are the most durable component of a typical building, while the life spans of other building components depend on their material composition.

Table 3. Life spans of selected building components

Element	Component Name	Life Expectancy (Years)
Substructure	Foundations	110
Frame	Steel frame	83
	Concrete frame	81
	Timber frame	69
	Laminated timber frame	65
Upper Floors	Profiled steel and reinforced concrete floor	71
	Precast concrete slab	78
	Timber joists	90
	Softwood decking to timber joists	71
	Chipboard decking to timber joists	51

2.7. Residential Services Needs

WPI's class of 2022 had such an unexpectedly high enrollment that WPI had to relocate the upperclassmen who had committed to living in Founders Hall to other areas on campus to provide enough room for the incoming freshmen. Founders Hall became a dorm for freshmen only, while upperclassmen were given the option to move to Salisbury Estates or to opt out of housing contracts. This solved the issue of housing undergraduates but forced graduate students out of WPI housing. It should be noted that this occurred the same year as the opening of a new residence hall, Messenger Hall, which holds 140 upperclassmen (Amy Beth Laythe, personal communication).

In general, the perceived shortage of on-campus housing at WPI is caused not by an actual shortage, but by a failure of the available facilities to meet students' demands. While WPI can accommodate all undergraduates who wish to live on campus, many of the accommodations offered are considered undesirable by upperclassmen, and rooms consequently remain vacant despite the number of students on the housing waitlist, once the main selection process is completed. Many upperclassmen exhibit a strong preference for apartments or dormitories with kitchens that do not require them to purchase a WPI meal plan. It is believed that if there was more housing that was attractive to students, more students would choose to stay on campus (Amy Beth Laythe, personal communication).

It is anticipated that the incoming classes in future years will lead to larger housing waitlists than WPI has previously experienced, similar to the summer of 2018, and that WPI will not be able to fully accommodate the increased demand for more attractive housing options. Part of the solution to this lies in Salisbury Estates and keeping Founders Hall entirely a freshmen residence area, but more housing is needed for upperclassmen. Therefore, in order to be a viable option for a WPI living space, any renovation or replacement to 53 Wachusett Street would need to house more than its current occupancy of 12 residents. This would make the space comparable to the Elbridge, Schussler, Trowbridge, and Hackfeld houses currently available on campus. However, WPI-owned houses are among WPI's least desirable housing options, so much so that

WPI is considering housing students there on a term-by-term basis to give students who are away for a term or a semester the option to pay less (Amy Beth Laythe, personal communication).

2.8. Academic Space Needs

As WPI grows and the size of its faculty and staff increases, the school is facing a general need for additional offices. The Interdisciplinary and Global Studies Division (IGSD) is in particular need of faculty offices since its aggressive expansion of off-campus project centers has resulted in an influx of faculty who need office space, even if only for part of the year (Kristopher Sullivan, personal communication). In addition, when existing facilities undergo renovations, many faculty members cannot find temporary office space due to a shortage of space on campus. WPI needs a surplus of offices to accommodate faculty members temporarily displaced by renovations to existing facilities.

2.9. College Campus Housing Trends

Establishing a community on a college campus is one of the most important challenges for residential architecture (Neuman, 2013). Key components of a residential building are a common room, laundry room, and large hallways. The common room is the most critical area of the building for enhancing community because it brings together not only all the students who live there but it also brings in students from elsewhere to study or entertain themselves together. Laundry rooms are similar in that they promote a stronger community through student interaction. The third key component of all residence halls is widening hallways to allow students to sit down and talk with their neighbors while leaving space for others to pass by (Neuman, 2013). In the case of a house-type residence hall, such as 53 Wachusett Street, shared facilities might include a lounge/study room, a kitchen, and a porch or terrace (Neuman, 2013).

The sizes of typical dormitory rooms depend on their occupancy. At Boston College, singles have an average size of 96 SF, doubles have an average size of 188 SF, and triples have an average size of 368 SF (DormStormer, 2017); these sizes were used to evaluate the capacity of the renovated building and as minimum guidelines when designing the new building. However, the preferences of many college students, or at least those of WPI students, have shifted toward options other than the traditional dormitory room. According to Amy Beth Laythe, an Associate Director of Residential Services at WPI, “Students [of WPI] want apartments with kitchens and they don’t want to have to purchase a WPI meal plan.” Mrs. Laythe also noted that upperclassmen desire more privacy which can be achieved with single or double bedrooms and private bathrooms; this was consistent with a trend observed by Neuman (2013).

2.10. Sustainability Design

Currently, WPI is making significant efforts for a more sustainable campus, with five buildings being Leadership in Energy and Environmental Design (LEED) certified since 2006. There has been a reduction in electricity consumption (5%), water consumption (9%), campus waste (3.6%), and greenhouse gas emissions (7.7%) from 2016 to 2017, alone (Worcester Polytechnic Institute, n.d.). WPI is also partnering with GreenerU, a sustainability solutions company for educational facilities (GreenerU, 2018), to assist in technical studies, along with installing and upgrading lighting systems, HVAC systems, retro-commissioning, variable frequency drives, ongoing performance monitoring, and occupant engagement and behavior change management (GreenerU, n.d.). By doing this, WPI hopes to achieve “20% reduction in greenhouse gas emissions by FY25 against an FY14 baseline,” (GreenerU, n.d.).

The most ambitious achievement for a residential facility at WPI would be one that meets LEED platinum standards, the highest LEED certification. While WPI does not currently have any such facilities, residential facilities at other schools can be used as examples of what can be done with a new construction at 53 Wachusett Street. Two engineering students at the University of Duke created a concept of a residential house that incentivized students living there to lead an energy-efficient lifestyle (Neuman, 2013). Called the “Smart Home,” it achieves LEED platinum standards by housing tanks to store and filter rainwater, solar panels, LED lights, and Life’s Good (LG) and General Electric (GE) Energy Star efficient kitchen and laundry appliances (Neuman, 2013). However, these innovations would only be possible for a new construction, as they would require significant upgrades to the existing building’s structure if they were added as part of a renovation.

Even for a renovation of 53 Wachusett Street, sustainability design can be accomplished with the use of reclaimed wooden or cork boards for flooring, low- or no- VOC paint, counters made from recycled materials, carefully positioned mirrors to increase natural lighting, the use of LED lights, draught-proofing window frames, green roofing, and low-flow bathroom appliances (Card, 2014). Other, more expensive considerations include solar panels and rainwater storage tanks.

2.10.1. Solar Panels

Photovoltaic solar panels, the most common type of solar panel for small-scale uses, generate DC currents when energy from the sun excites electrons on the panels. The most important parameter in evaluating a solar panel system is the system size, or the amount of power for which it is rated. System size is proportional to the amount of space used for solar panels, with roughly 67 square feet required per kilowatt (SolarReviews, n.d.), and it is the primary factor in estimating construction costs. The energy produced by the system annually can be roughly estimated using adjustment factors for area and system efficiency, such as those found in Zientara (n.d.).

2.10.2 Rainwater Filtration Storage System

When it rains on a building, the roof directs the rain to run off the roof. With a rainwater filtration storage system installed in a building, the rain will instead flow into gutters that direct the water into the basement where several 150-gallon storage tanks will filter and store the rain to be used for laundry and toilets. The idea for this system came from Duke University's Smart Home (Neuman, 2013). Implementing these tanks will reduce dependence on water from the city's distribution system. With the average American family using 300 gallons of water per day in their home, 44% of which is used for the toilet and laundry, rainwater tanks can save a significant amount of water (EPA, 2018). Given the loads that tanks filled with water would place on the building's foundation, this can only be implemented in the new construction.

2.11. Cost Estimating

A breakdown of costs and labor rates is one of the most important parts of a design proposal. Cost breakdown is used to evaluate the feasibility of construction projects, including whether the building needs to comply with all ADA specifications for a renovation process. Detailed cost estimates can only be performed after the design is complete. For these estimates, the current average values for material, labor, and equipment costs of building components are represented in the R.S. Means Construction Cost Estimating books, which are divided into topics such as electrical costs, building construction costs, and facility uses. This resource provides statistics on cost estimating and project management (The Gordian Group, 2018). If design details still need to be determined, R.S. Means also provides cost data for assemblies of discrete components, such as a flooring system designed to withstand a certain load intensity.

In order to facilitate the preparation of cost estimates for each design, separate spreadsheets were created for the renovation and new construction. These spreadsheets were organized by category of work and included the materials, labor, and equipment rates for each task. A section of the template that was used to categorize work, R.S. Means UNIFORMAT II (Charette & Marshall, 2012), is shown below in Table 4.

Table 4. Cost estimating template from R.S. Means

Level 1 Major Group Elements	Level 2 Group Elements	Level 3 Individual Elements
A Substructure	A10 Foundation	A1010 Standard Foundations
		A1020 Special Foundations
		A1030 Slab on Grade
	A20 Basement Construction	A2010 Basement Excavation
		A2020 Basement Walls
B Shell	B10 Super Structure	B1010 Floor Construction
		B1020 Roof Construction
	B20 Exterior Enclosure	B2010 Exterior Walls
		B2020 Exterior Windows
		Exterior Doors
	B30 Roofing	B3010 Roof Coverings
		B3020 Roof Openings
C Interiors	C10 Interior Construction	C1010 Partitions
		C1020 Interior Doors
		C1030 Fittings
	C20 Stairs	C2010 Stair Construction
		C2020 Stair Finishes
	C30 Interior Finishes	C3010 Wall Finishes
		C3020 Floor Finishes
		C3030 Ceiling Finishes

The costs of the renovation and new construction were compared to each other using two metrics. The first was the cost per square foot affected by each project. The second metric, given in Equation 6, compares construction costs to both building occupancy and the life span of each construction component in order to determine an effective annual cost per resident.

$$Value\ (\frac{\$}{Resident \times Year}) = \frac{1}{Capacity}\left(\frac{Cost_1}{Lifespan_1} + \frac{Cost_2}{Lifespan_2} + \cdots + \frac{Cost_n}{Lifespan_n}\right)$$

Equation 6. Building cost per resident-year

By adding the quotients of the cost of each building item and its lifespan, Equation 6 determines the effective annual cost of constructing and maintaining the project. Dividing this annual cost by the building’s capacity allows each project’s profitability to be evaluated by comparing its effective cost to the annual revenue generated per student.

Where the costs and benefits of individual building elements were quantifiable, the feasibility of these elements was evaluated using net present value (NPV) analysis. NPV analysis uses interest rates to determine the amount of money that would need to be invested at the present time in order to yield a certain amount of money in the future. Each cost or profit item is adjusted using Equation 7:

$$PV = \frac{P}{(1+i)^n}$$

Equation 7. Present value adjustment for a given transaction

In Equation 7, PV represents the present value of a transaction, P represents the unadjusted value of that transaction, *i* represents the average interest rate over time, and n represents the number of years between the present and the date of the transaction. Since interest rates are almost always greater than zero, transactions further in the future typically have lower present values than transactions in the near future. For this project, a 2% annual interest rate was used, in order to correspond with the 2% inflation rate projected by Amadeo (2019).

In order to find the net present value of an investment, Equation 7 must be applied to every cost and profit for the time period analyzed and the sum of each PV term must be calculated. When NPV analysis was used in this MQP, the net present value of investments was analyzed over the 20-year period specified by Mr. Palumbo, WPI's Facilities Project Manager.

3.0. Methodology

Table 5 lists the activities that this project involved. The first objective of this project was to determine WPI's space-related needs and the current capabilities of 53 Wachusett Street. Based on this investigation, it was determined that the building should be used for residential purposes. The next objective was to identify renovations that were necessary for allowing the building to serve this purpose. This involved structural designs, cost estimates, and a schedule for construction. A replacement building was designed as an alternative to renovating the building. The investigation of the new building began with a conceptual (architectural) design, followed by structural and fire protection designs and a cost estimate for the work.

The design for the new building contains a number of sustainability measures. The measures listed below have both significant costs and significant benefits, and were analyzed to determine their production levels and financial feasibility:

- Photovoltaic solar panels
- Rainwater storage tanks with filtration

Other sustainability measures had smaller costs and benefits that were more difficult to measure. As a result, they were assumed to be part of both the renovation and new construction, but were not analyzed for either. These measures are listed below:

- Energy Star appliances
- LED lights

Table 5. Project Scope

ACTIVITIES	NECESSARY REFERENCES
Determined WPI's Needs	● Met with individuals from Residential Services, Academic Affairs, and Facilities. ● Walked through and surveyed 53 Wachusett Street. ● Researched zoning constraints.
Determined building's capabilities and required work	● Investigated 53 Wachusett Street. ● Consulted with Facilities.
Conceptual Design - Renovation	● Researched building codes, apply researched sustainability measures.
Structural Design - Renovation	● Consulted American Wood Council-National Design Specification (AWC-NDS) for LRFD design and checked with RISA 2D. ● Drafted model in AutoCAD and Revit.
Cost Estimate - Renovation	● Used R.S. Means cost estimating books to estimate cost. ● Used R.S. Means and Microsoft Project to estimate project durations
Conceptual Design – New Bldg.	● Consulted Worcester Zoning Ordinance to determine zoning and design constraints. ● Determined building needs based on consulting with Facilities
Structural Design – New Bldg.	● Designed floor beam system using LRFD ● Designed columns and framing using LRFD and RISA 2D. ● Designed foundations using soil profiles from construction of East Hall. ● Created floor plans in AutoCAD and imported into Revit to create model.
Fire Protection Design - New Bldg.	● Determined sprinkler requirements using building codes. ● Used pressure loss calculations to size sprinklers and pipes.
Cost Estimate - New Bldg.	● Estimated costs using R.S. Means assembly cost data

3.1. Determining WPI's Needs

Influential staff members from the departments of Residential Services and Academic Affairs were consulted to gain different perspectives on potential uses for the building. 53 Wachusett Street was also surveyed to determine its capabilities as well as the scope of work required for the building to be able to serve as either residential or office space. In order to determine the optimal use for the building, zoning of 53 Wachusett Street was researched, as was the process for obtaining the special permits required to erect a dormitory or small office building within this zone. Finally, several administrators from the Facilities Department were consulted regarding unforeseen factors that might influence this decision. Residential options were investigated for 53 Wachusett Street based on the results of these meetings and this research.

3.2. 53 Wachusett's Capabilities and Trouble Spots

Based on multiple visits to 53 Wachusett Street and meetings with stakeholders from WPI's staff, the building was deemed structurally sound but in need of significant renovations to increase its capacity. For example, the basement needs to be finished, the building's kitchen and living room areas need to be increased in order to increase the building's capacity, and the building's electrical system needs to be reconfigured. Typical sizes of office spaces and dormitory rooms were compared to the sizes of rooms at 53 Wachusett Street in order to determine which of these issues could be addressed with a renovation. The sizes, arrangements, and conditions of rooms in similar WPI-owned residential buildings were also used to evaluate necessary renovations to the building.

3.3. Renovations - Design Phase

Since an increased capacity is one of WPI's most pressing needs for a residential facility, only renovations that increased the capacity of 53 Wachusett Street were investigated. In addition, since as-built drawings for 53 Wachusett Street could not be obtained, only renovations that conserved or increased the building's stability were investigated; for example, renovations that added or reinforced walls were viable but renovations that removed them were not. When the designs for the renovations were complete, a set of CAD drawings was created to highlight necessary renovations, and a Revit model was created to illustrate what the building might look like with these renovations.

3.4. Renovations - Estimating Phase

The cost of renovations was based on work items and building features, and unit costs determined from the R.S. Means building cost guides. Costs obtained were adjusted for inflation, using a 2% inflation rate after 2019, as well as for the costs of construction in Worcester compared to the rest of the country. The estimated cost includes making the means of access to any alterations ADA-compliant. Since the cost of renovation exceeded 30% of the building's value, the entire building needed to be made accessible (521 CMR 3.00). The costs of these accessibility improvements were determined by creating quantity takeoffs and using R.S. Means component costs. In order to account for indirect costs not associated with a specific work activity, the 25% overhead given in RS Means was added to the sum of direct construction costs (The Gordian Group, 2019).

3.5. New Constructions - Design Phase

The new building’s design consisted of two stories and a finished basement, supported by a wooden frame structure. Loads from the upper stories and the roof were transferred first to plywood sheathing and then to floor joists. These joists were supported by frames on the building’s exterior and by trusses on its interior. Loads on the building’s frames and trusses were then transferred to columns and eventually to the building’s foundation. Loads on the basement floor were transferred directly to a cast-in-place concrete slab.

The building's design consisted of the following components:

- Gravity load resisting system, including the roof, second and first floors, columns, and frames
- Lateral load resisting system
- The stairwell on the building's interior and fire escape on its exterior
- Foundations
- Sustainability elements, including storage tanks and solar panels

3.5.1. Gravity Load Resisting System

Figure 7 shows the design sequence for the roof. In this system, loads were transferred first to plywood sheathing, then to roof joists running from east to west along the building, then to prefabricated trusses, and finally to columns.

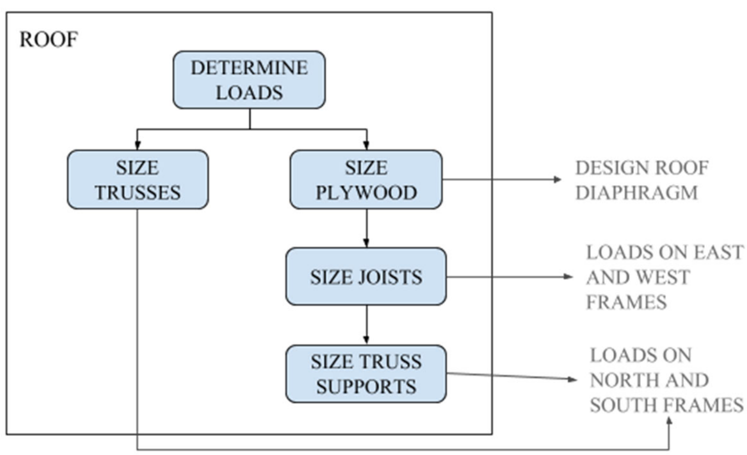


Figure 7. Sequence for roof design

Figure 8 shows a plan view of the roof's framing system. Spreadsheets created in Microsoft Excel were used to size all members except for the trusses. The trusses were sized using Alpine's "Roof Trusses" catalog (Alpine, n.d.), based on their required spans and a combined dead and live load of 50 PSF. Since Alpine likely used a stronger method of connecting their truss chords than a standard pin connection, the nominal strengths of each truss were not checked.

In order to avoid loading the truss chords in the middle of their spans, wooden girders were placed on top of the trusses. In order to reduce the loads on both the girders and trusses, pairs of girders and trusses were placed directly adjacent to each other at all locations except for the east and west exterior walls, as shown in Figure 8.

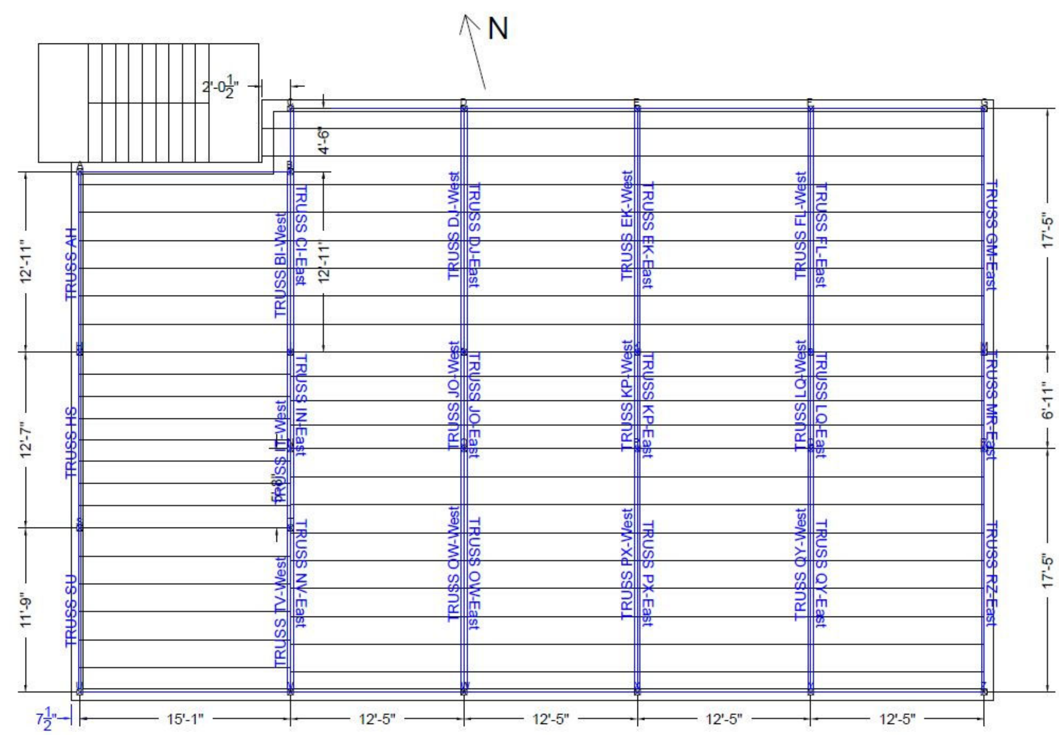


Figure 8. Roof framing system

Table 6 gives the design loads on the roof, not including the self-weight of each member. The 300-lb. moving load, which represents workers servicing the roof, was assumed to act in the location where it produced the maximum effects and was considered to act in conjunction with the 20-psf uniform live load.

Table 6. List of applied roof loads

Basic Load Case	Magnitude
Dead Load (D)	2.27 psf (solar panels) 3 psf (roof shingles) 1.5625 psf (insulation) 5 psf (MEP)
Roof Live Load (L_r)	20 psf 300 lb. moving load
Snow Load (S)	50 psf

Figure 9 shows the design sequence for the first and second floors. For these floors, loads were transferred first to plywood, next to joists, then to custom-designed trusses, and finally to columns.

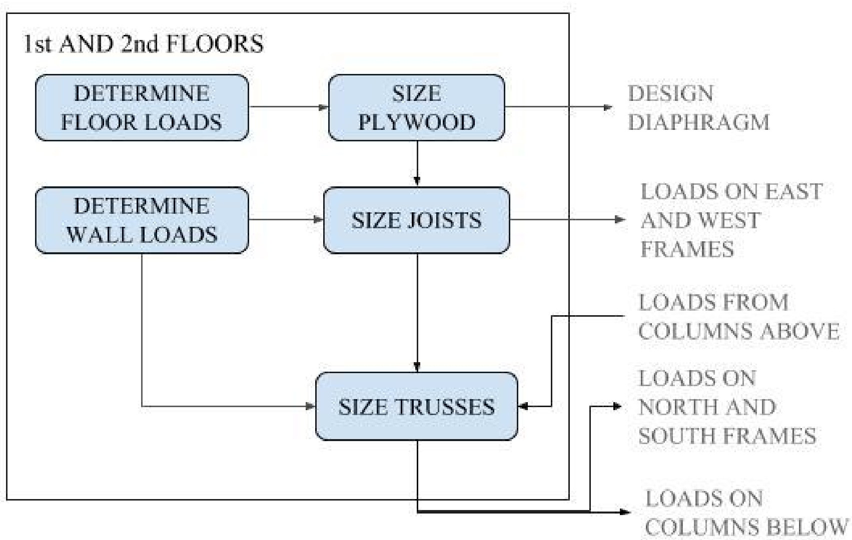


Figure 9. Design sequence for the first and second floors

The plywood and joists were mostly sized using spreadsheets developed in Microsoft Excel, although joists with multiple distributed and concentrated loads were sized using RISA-2D. The trusses were sized using the following process:

1. A model for each truss was created in RISA-3D and run, using 2x4s for all member sizes.

2. The resulting forces on each member were copied into Excel, where a formula was used to determine appropriate member sizes.
3. The appropriate member sizes and their associated self-weights were copied into RISA-3D and the model was run again.
4. The results of the RISA-3D model were copied into Excel. If all member sizes were sufficiently strong, the calculations were complete. Otherwise, the sizes of failing members were increased in RISA-3D, and the model was solved iteratively until all members were sufficiently strong.

Loads from the columns above each truss were assumed to act on that truss, and the reactions from these trusses were transferred to the columns below.

Figure 10 shows the design loads for the second floor, while Figure 11 shows the design loads for the first floor.

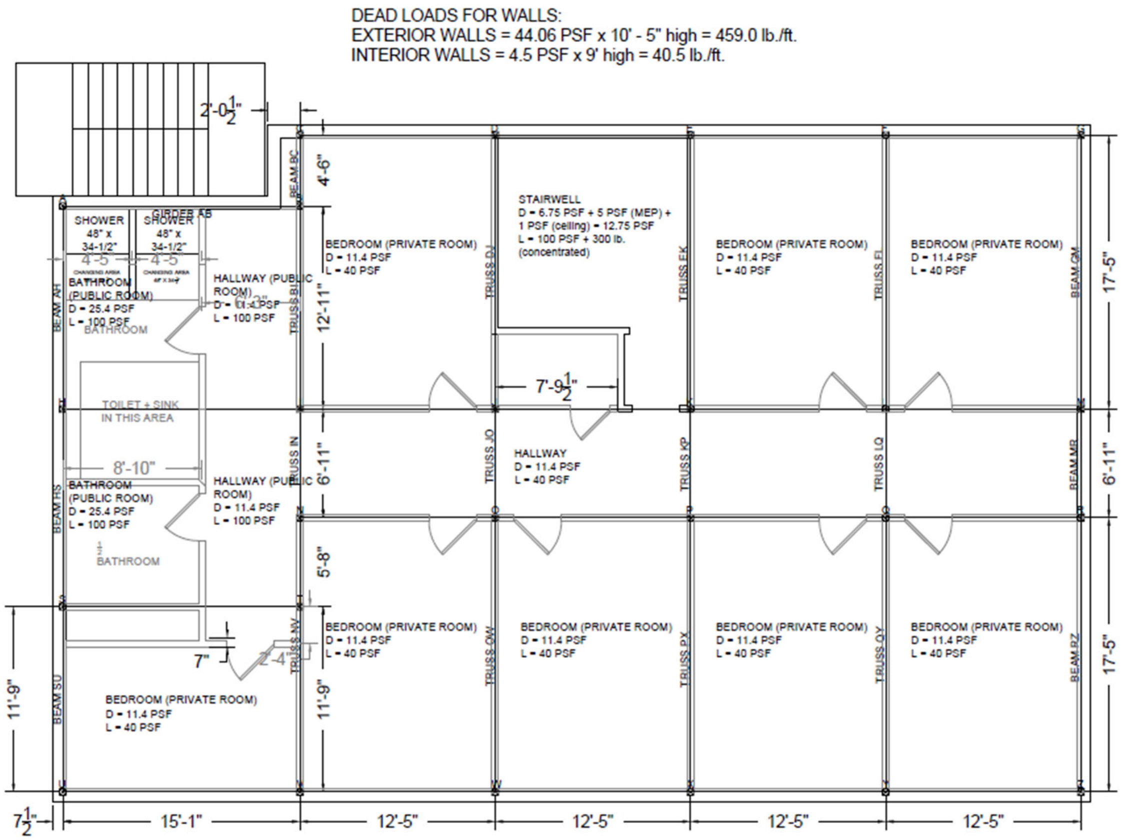


Figure 10. Second floor design loads

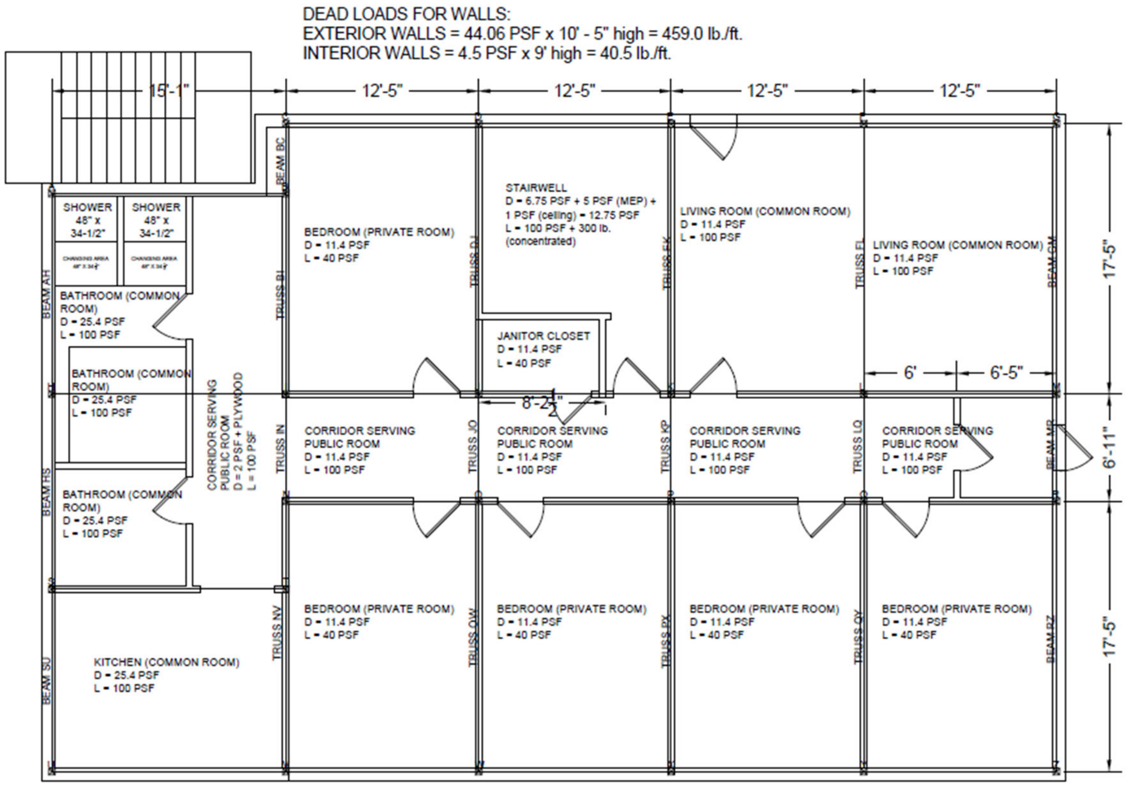


Figure 11. First floor design loads

The only design requirement for the basement flooring system was the concrete slab on grade. The necessary thickness of the slab was calculated using an appendix in *Assembly Costs with R.S. Means Data* and the largest LRFD load combination shown in Figure 12.

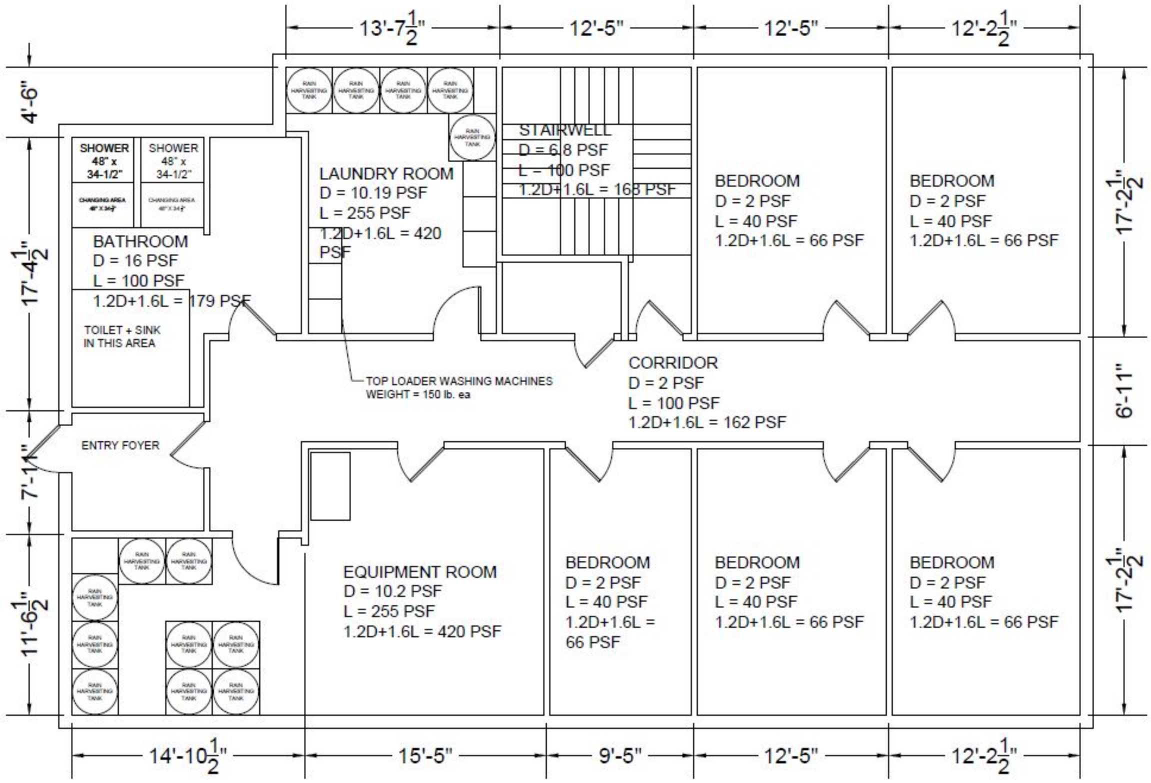


Figure 12. Basement design loads

Wooden frames were used to carry the loads on the exterior walls. Figure 13 contains an example of the system that was set up. As shown in Figure 13, the main columns were not considered to be part of the framing system and were analyzed separately.

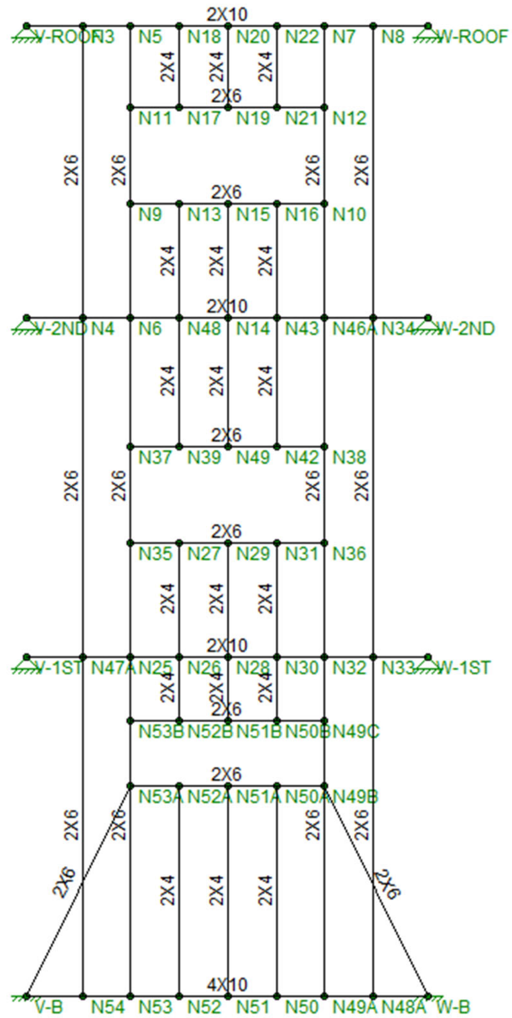


Figure 13. Sample wall frame model constructed in RISA-3D.

The frames were analyzed using the following process:

1. A separate frame was created for each side of the building in RISA-3D, using 3 x 10 sections for girders and 2 x 6 sections for all other members. The vertical and wind loads were input into this model, and the model was run.
2. The RISA model was solved, and the results were entered in a spreadsheet that used these results to determine appropriate member sizes.

3. The revised member sizes were input into RISA, and the model was retested until each member could withstand the applied load.

In order to size the columns, the loads on the columns from each level were added to the column loads at the upper stories. All of the columns consisted of multiple lumber sections placed adjacent to each other, and their total allowable strength was calculated as the sum of allowable strengths of each section.

3.5.2. Lateral Load Resisting System

Figure 14 shows the design sequence for the lateral load resisting system, which was not designed to withstand earthquake loads because the low weight of the building's wooden frame results in smaller earthquake loads than would result from using a heavier frame. The diaphragms were designed using Table 4.2C of the American Wood Council Special Design Provisions for Wind and Seismic Loading (AWC-SDPWS) and the shear walls were sized using design strengths in Table 4.3A of the AWC-SDPWS, adjusted for correction factors in Section 4.3 of the AWC-SDPWS. Loads from each diaphragm were transferred to the shear wall supporting it, and loads on the shear walls accumulated moving down the building.

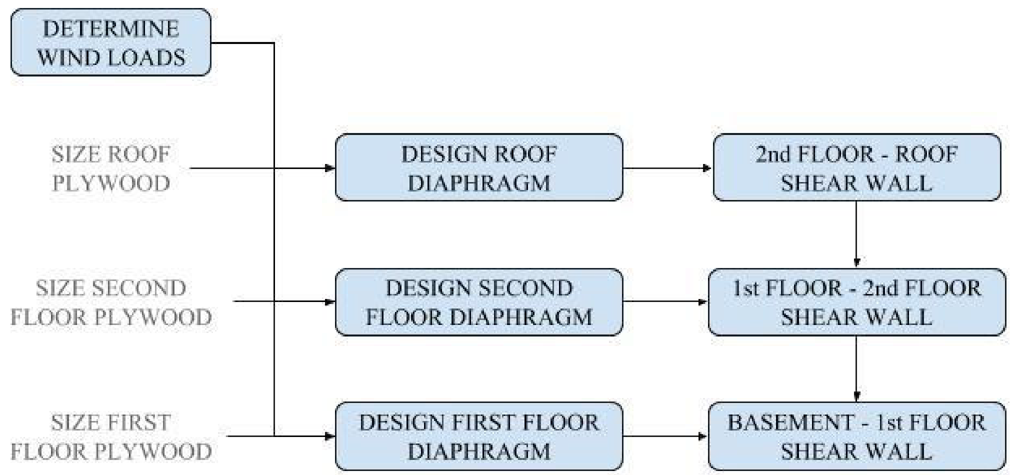


Figure 14. Design sequence for the wind resisting system.

3.5.3. Stairwell and Fire Escape

The new building features an L-shaped stairwell, similar to the existing building, wrapping around the walls of the stairwell area and with landings at each turn. This stairwell connects the basement, first, and second floors inside of the building, while the fire escape serves as the sole means of accessing the building's roof. The minimum dimensions for this were compared to state standards specifying a minimum width of 40 inches (1016 mm), a maximum length of 36 inches (914 mm), and a maximum distance of 8 inches (203 mm) below the door (International Building Code, 2017).

The fire escape was designed using the sequence shown in Figure 15.

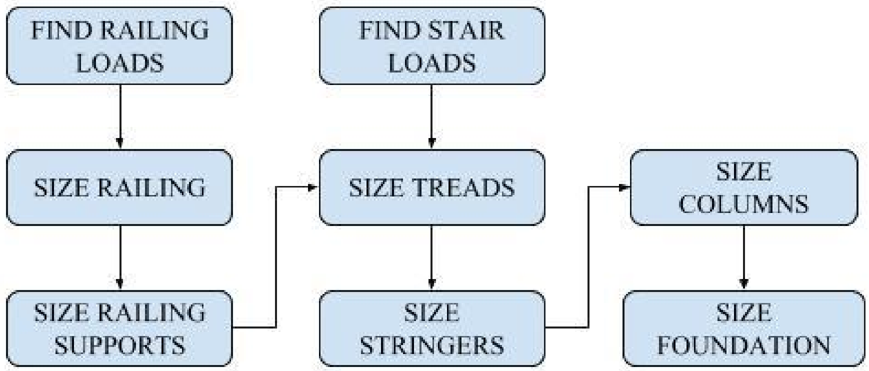


Figure 15. Fire escape design sequence

Table 7 lists the live loads on the fire escape, with loads listed as "Railing" acting on all structural elements, and with loads listed as "Stairs" acting on all structural elements except for the railing.

Table 7. Fire escape live loads

Location	Magnitude
Railing	50 lb./ft. AND 200 lb. moving load
Stairs	100 psf OR 300 lb. moving load

The dead loads on each element were calculated as the total weight of the members supported by the member being analyzed.

The building's stairwell was sized using the same methods that were used to size floor joists and columns. Loads were transferred through a 4 x 4 grid of columns to the basement, where foundations were placed in the stairwell's southwest and southeast corners, while the reactions at the northwest and northeast corners were transferred to the strip footing underneath the north wall (Section 3.5.4 contains more information on foundations).

The loads on the stairwell are given in Table 8 below:

Table 8. Interior stairwell loads

Basic Load Case	Magnitude
Dead Load (D)	6.75 psf 5.0 psf (MEP) 1.0 psf (finished ceiling)
Live Load (L)	100 psf OR 300 lb. moving load

3.5.4. Foundations

Figure 16 gives the locations of the building's foundations. Strip footings were used along the building's exterior, while spread footings were placed underneath columns and at the southwest and southeast corners of the stairwell.

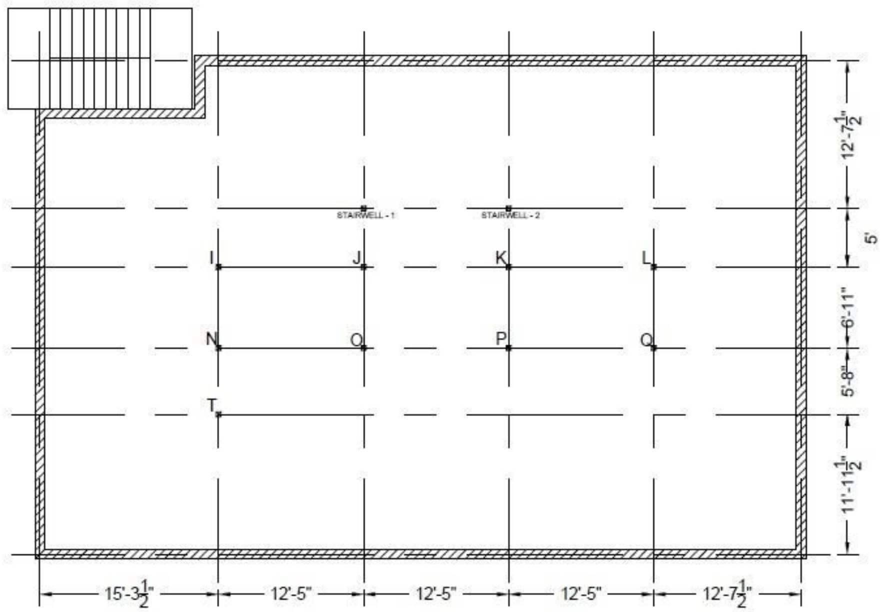


Figure 16. New construction foundation locations.

Required foundation sizes were determined by comparing ASD loads to allowable loads that acted upon the soil, as given in the *2015 Massachusetts Building Code*, while allowable shear and reinforcing requirements were determined using LRFD loads. The strip footings were designed based on the largest uniform load on any wall, using the equations found in StructurePoint (n.d.). The spread footings were designed using the largest load on any column in the building and equations contained in Coduto (2016).

3.5.5. Fire Protection

The objective of the fire protection system was to allow it to deliver water to all rooms without the water pressure entering the building exceeding 60 psi, which was used as a design water pressure because residential water pressure ranges from 40 psi to 80 psi (Reference, n.d.). Psi values above this range are often harmful to the appliances that require water, in which case a water pressure regulator would be needed. The spacing of the sprinklers from any walls, protrusions, or other sprinklers used were prescribed by NFPA 13, and once the proper layouts were set, this sprinkler layout was subjected to hydraulic analysis.

Figure 17 shows the design sequence for the fire protection system:

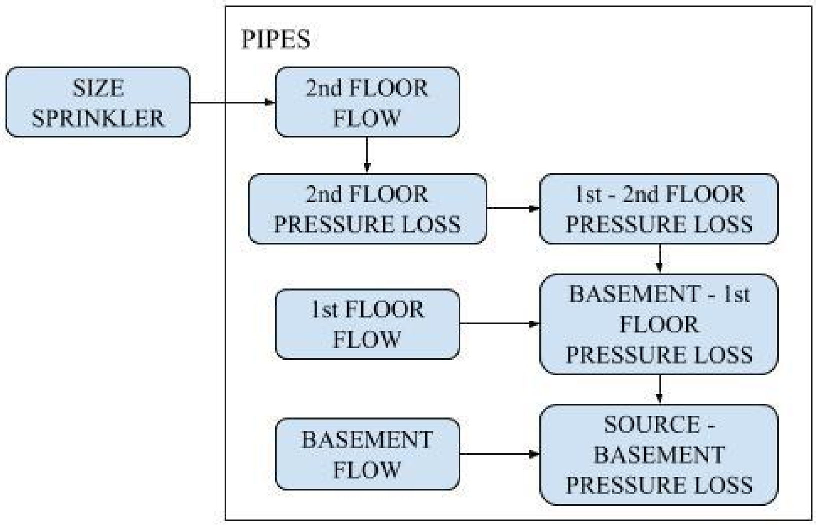


Figure 17. Fire protection system design sequence

In order to size the sprinkler heads, the sprinkler head furthest from the vertical pipe was used as reference. The pressure and flow through this sprinkler were sized using Equation 1 and Equation 2 from Section 2.5. Fire Protection Design Considerations, and the size chosen for this sprinkler head was used for all sprinkler heads.

Equation 4 from Section 2.5. Fire Protection Design Considerations was used to find the pressure loss within the pipes on the second floor. However, Q was taken as the total flow on the second floor, calculated by multiplying the sum of the discharge areas for each room by D = 0.10 gallons/minute/SF, the discharge density given by NFPA 13 for light hazard installations (Jessica, 2018). The total flows on the first floor and basement were calculated in the same manner, as were the pressure losses between each level. This calculation method simplified the calculation process but overestimated pressure losses in the pipes by assuming that all of the water distributed to each floor flowed through the longest pipe on that floor. The conservative nature of this method provided some safety in ensuring that the input pressure was less than 60 psi.

Equation 5 from Section 2.5. Fire Protection Design Considerations was used to calculate pressure at lower levels based on the pressure at the level immediately above.

3.5.6. Storage Tanks

In order to estimate the reduction in water use that storage tanks would enable, the daily water use was compared to the estimated water volume that the storage tanks can hold.

The daily water consumption by toilets and washing machines was estimated by obtaining the daily water usage in Worcester and multiplying that amount by the percentage of indoor residential water use allocated to these purposes. The sum of water uses for toilets and clothes washers was multiplied by one of the factors listed below in order to predict water use on a given day:

- 1.0 for weekdays and weekend days during which an academic term (A- through D-term only) was in session.
- 0.0 for the time period between Commencement and New Student Orientation, when the building is likely to be closed.
- 0.33 for any days during any other breaks, excluding the first and last days of any break. This assumes that the building's occupancy is at one-third of its capacity over the duration of a break.
- 0.67 for any day immediately preceding or following academic terms A through D.

The rainwater supply was calculated for each day from December 1, 2017, through November 30, 2018, as the product of the daily precipitation and the impermeable area of the property, which consists of the building's roof and exterior walkways. This calculation assumes that all of the rain that falls on these surfaces is drained to the storage tanks, but that none of the rain that falls on permeable surfaces, such as soil, reaches the drainage system that feeds the storage tanks.

If the water used on a given day exceeded the water provided by the storage tanks, any additional necessary water would be provided by the city's water distribution system. If less water was used than was provided, the excess water would be stored in the tanks for later use. However, if the volume of water stored in the tanks exceeded 2,100 gallons (the volume of the fourteen tanks that the basement was designed to hold), the tanks will not be able to hold any more water.

The design parameters that were extracted from this analysis were the water savings that the storage tanks would enable, and the volume of storage space necessary to house the maximum amount of rainwater that could accumulate at any given time, which was given by the maximum water accumulation over the course of a calendar year.

A 20-year net present value (NPV) analysis was conducted on this system by comparing the cost of installing the system with the water bill reduction that it would enable. The costs of installing the system were found by adding the total cost of the tanks to the daily rate for two laborers to place the tanks. The annual monetary savings were calculated by multiplying the water saved by the city's current water rate of $0.0367 per cubic foot (Guerin, n.d.).

3.5.7. Solar Panels

The feasibility of a photovoltaic solar panel system (PV system) on the roof was analyzed using a 20-year net present value analysis. The cost and power generation capacity of the PV system were obtained from SolarReviews (SolarReviews, n.d.), which provides location-specific data on solar panels. The system's power generation capacity was obtained from SolarReviews, based on the roof area of the building used for solar panels, and multiplied by the adjustment factors given by Zientara (n.d.) to obtain the annual energy output. The cost of constructing the solar system was estimated based on the system's power generation capacity, and the savings afforded by the system were estimated by multiplying the annual energy output by $0.1313/kWh, the electricity rate for Worcester, MA (Electricity Local, n.d.).

3.6. New Constructions - Estimating Phase

The cost of the new building was estimated using R.S. Means assembly cost data, which gives costs for systems of components rather than individual components and includes overhead costs. This streamlined the estimating process, but resulted in less precise estimates than those obtained for renovation costs. The estimate for the new construction also included the cost of demolishing the existing building, which was calculated by multiplying its approximate volume by a demolition cost per unit volume given in R.S. Means (“Building Construction”, 2019).

4.0. Investigation of Alternative Uses

It was decided that 53 Wachusett Street would become a residence house through assessment of the current building combined with speculation as to which purpose would be most practical to incorporate. This decision can be justified because the building is already fitted for that purpose. To make a renovation valuable for WPI, more beds needed to be added, ADA requirements needed to be implemented, and sustainability measures needed to be considered. The possibility of using the building as an office space or laboratory was dismissed, but these findings were included to help WPI understand the decision.

4.1. Labs

The main concern regarding laboratories was whether a given type of laboratory could be built at 53 Wachusett Street. This concern was amplified for chemical laboratories, where chemicals would be flushed down sinks and toxic fumes could escape into the surrounding area. Considering these factors, a wet lab was quickly dismissed. While a computer science or data science lab for graduate research remained a possibility, such a lab would require a significant amount of electrical reconfiguration and space remodeling and would affect only a small portion of the WPI community, since only 6.7% (WPI OIR, 2017) of WPI's graduate student population studies data science. Based on these factors, the idea of putting a lab in 53 Wachusett Street was withdrawn.

4.2. Office

Since 53 Wachusett Street does not comply with current ADA standards, it could not serve as an adequate office in its current state. In order to use the space for an office, the building would likely need to be demolished and a new building constructed. According to Kristopher

Sullivan, WPI’s Assistant Vice-President of Academic Affairs, the Interdisciplinary and Global Studies Division (IGSD) is in particular need of faculty offices since WPI’s aggressive expansion of off-campus project centers has resulted in an influx of faculty who need office space, even if only for part of the year (Kristopher Sullivan, personal communication). In addition, when WPI facilities undergo renovations, many faculty members cannot find temporary office space due to a shortage of space on campus. WPI needs a surplus of offices to accommodate faculty members temporarily displaced by renovations to existing facilities.

WPI could also use the office as an overflow office for the International and Global Studies Division (IGSD). Since the IGSD office is roughly 10,000 SF (Kristopher Sullivan, personal communication) and 53 Wachusett Street only has 3,102 SF of living area (Vision Government Solutions, n.d.), the IGSD would not be likely to use the building as their main office. However, the building could serve as the IGSD’s second office: it is estimated that the IGSD would need six offices in addition to its current location (Kristopher Sullivan, personal communication), with minimum spacing requirements of 120-150 SF, at 53 Wachusett (Office Space Calculator, 2018).

While an office space is more feasible than a laboratory, converting 53 Wachusett Street to an office space presents a number of difficulties. First, the building is in a residential zone, in which buildings can be used for office space but require a special permit in order to be used as such (City of Worcester, 2018). In addition, commercial buildings such as offices need accessibility features, such as elevators, that are not necessary for residential buildings (Kristopher Sullivan, personal communication) because residential buildings only require that at least 5% of sleeping rooms be made accessible for the building to comply with state regulations (521 CMR 8.00). Finally, office spaces have a higher maintenance cost because they are used year-round (Ronald O'Brien & Nick Palumbo, personal communication). Because of these issues associated with converting 53 Wachusett Street into an office space, only the possibility of using the building as a residential space was investigated.

4.3. Residence house

To discuss WPI's residential needs, meetings with Ronald O'Brien, WPI's Director of Design and Construction; Nick Palumbo, WPI's Facilities Project Manager; and Amy Beth Laythe, an Associate Director of Residential Services were set up. According to Mr. O'Brien and Mr. Palumbo, residential facilities are currently in greater demand at WPI than office buildings. Since residential facilities are typically only used during the academic year, they also have lower operating costs (Ronald O'Brien & Nick Palumbo, personal communication). In addition, the accessibility requirements for dormitories, where only 5% of bedrooms need to be made accessible (521 CMR 8.00), are less stringent than those for offices, which require accessibility features such as elevators. Finally, since the building is currently configured as a residential building, it would require a greater level of renovation in order to be used as office space.

Increasing the current capacity of 53 Wachusett Street to anticipate the increased class sizes at WPI was a major priority in the designs created. While the shortage of housing at WPI can be partially solved by housing undergraduates in Salisbury Estates and keeping Founders Hall entirely a freshmen residence area, Amy Beth Laythe noted that more housing is needed to accommodate a growing demand. Increasing 53 Wachusett Street's capacity would make the space comparable to the Elbridge, Trowbridge, Schussler, and Hackfeld houses; the former two hold 16 students each, and the latter two hold 8 students each. The capacities of these WPI-owned houses were used as a basis for certain design aspects.

5.0. Renovations

The following section includes recommendations for the renovation of 53 Wachusett Street. The program of renovations focused on increasing the building's capacity and making it accessible in accordance with the *Massachusetts State Building Code, Ninth Edition*. This was accomplished by moving utilities to the basement, adding accessible bedrooms on the first floor, and building ramps to access the basement and first floor. Table 9 shows the list of prescribed renovations, based on investigations of the building and meetings with representatives from WPI's Facilities Department.

Table 9. List of prescribed renovations

AREA	SCOPE OF WORK
Basement	● Install WPI Lock/Security System, including card access ● Replace washing & drying machines ● Finish usable areas ● Remove asbestos
First floor	● Add bedrooms on first floor ● Convert kitchen exit into extra bathroom
Second and Third Floor	● Seal wall edges in bathrooms
Exterior	● Add accessibility ramp on Wachusett Street ● Add accessibility ramp for basement ● Replace windows

5.1. Basement

The current basement of 53 Wachusett is largely unused, and much of the renovation analysis focused on making this space usable. The existing spaces will be repurposed as shown in Figure 18. While the possibility of placing a bedroom in Room C (shown in Figure 18) was assessed, the structural framework of the porch that is above this room makes it impossible to exit the building even if a window existed (Figure 19). The basement area would be made accessible, bathrooms included. An ADA accessible ramp leading to the basement floor should also be added at the southwest door, as shown in Figure 29.

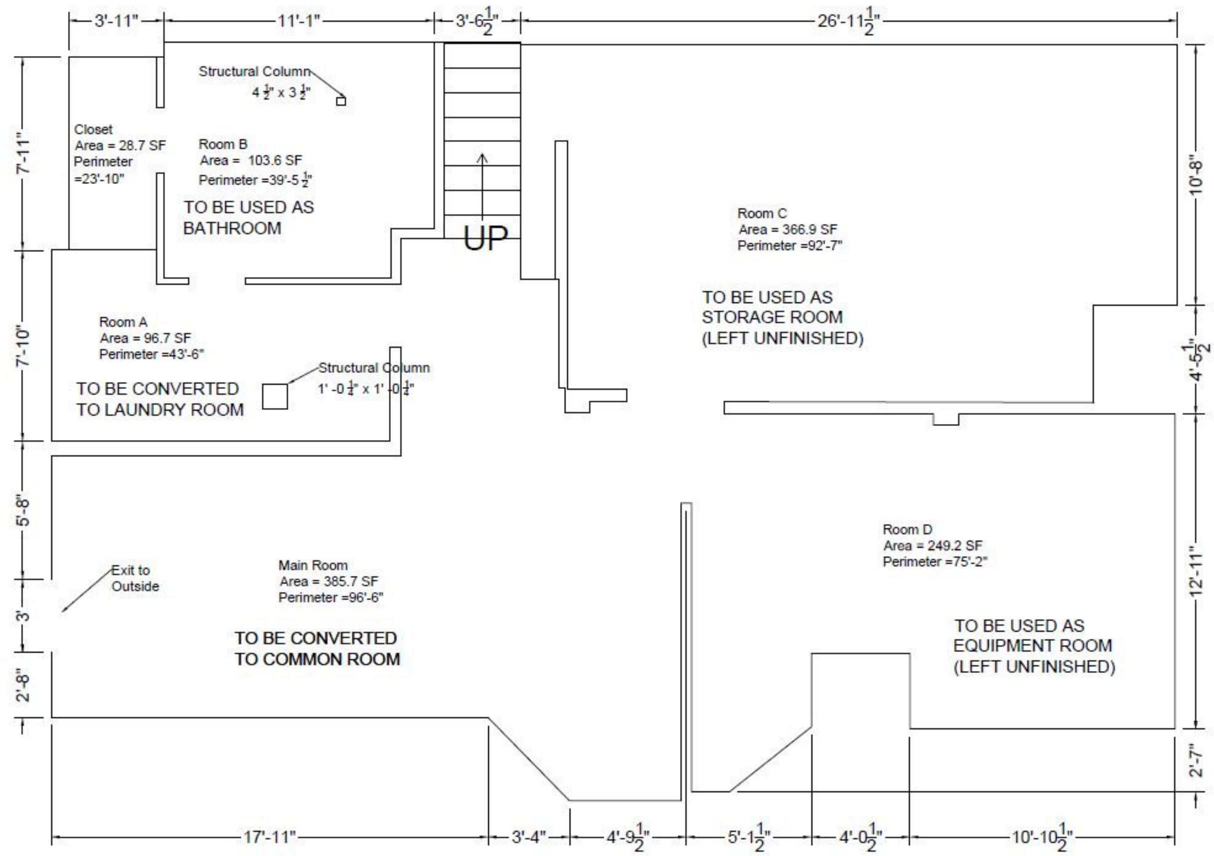


Figure 18. Proposed basement layout for renovation

Figure 19. Porch fencing preventing possible window access to Room C

Plumbing must run from the current system to where the additional bathroom will be on the first floor level. This will travel along the basement ceiling on the same path as the water systems going to the kitchen and branch when necessary.

Room D, which currently holds the building's boiler, will be sectioned off from the other basement areas for access only by WPI Facilities staff. This room is intended to hold most of the mechanical systems of the building, listed below, and therefore will be locked away from residents:

- Heating and cooling systems
- Fire alarm system
- Door locking mechanisms
- Card access machines

The electrical panel will be an exception, since it is currently located next to the fire escape and can be enclosed in a cabinet and locked from residents. The cost to move the electrical panel was considered unnecessary in the context of the renovation.

Since the basement is currently unfinished, extensive finishing work will be required for the floors, walls, and ceilings. Ceilings will be insulated and covered with 2x2 mineral fiber tiles and light fixtures. The floor will be reinforced with subfloor sleepers to prevent warping and moisture buildup and finished with poured concrete. Walls will also be insulated, covered with ½-inch thick gypsum wall panels, and painted. These will be done once the HVAC and electrical lines have been set up.

Table 10 shows the quantities of materials required for the basement work:

Table 10. Quantity takeoff for basement renovations

Activity Description	MasterFormat Code	Quantity	UOM
Pour concrete to level basement floor	03 31 13.70 4300	0.861	CY
2x4s underneath basement floor	06 11 10.18 2650	402.09	LF
Plywood, CDX, 5/8" thick, pneumatic nailed	06 16 23.10 0105	558.02	SF
Cork-board (1/8" thick) for basement floor	09 62 29.10 2200	558.02	SF
Fiberglass insulation basement walls - 1" thick	07 21 13.10 0040	1,406.51	SF
Gypsum finish (1/2" thick) basement walls	09 29 10.30 0700	1,406.51	SF
Paint basement walls	09 91 23.72 0800	1,406.51	SF
2' x 2' ceiling tile frame - basement	C3030 210 5900	558.02	SF
Cabinet for electrical box	13 32 23.10 5320	1	EA

5.2. First Floor

The renovation plan for the first floor is to add two bedrooms, remove one bathroom, and add one ADA-accessible bathroom. This renovation plan can be seen in Figure 20. In Figure 20, walls outlined in black refer to existing partitions, and solid black walls refer to new partitions.

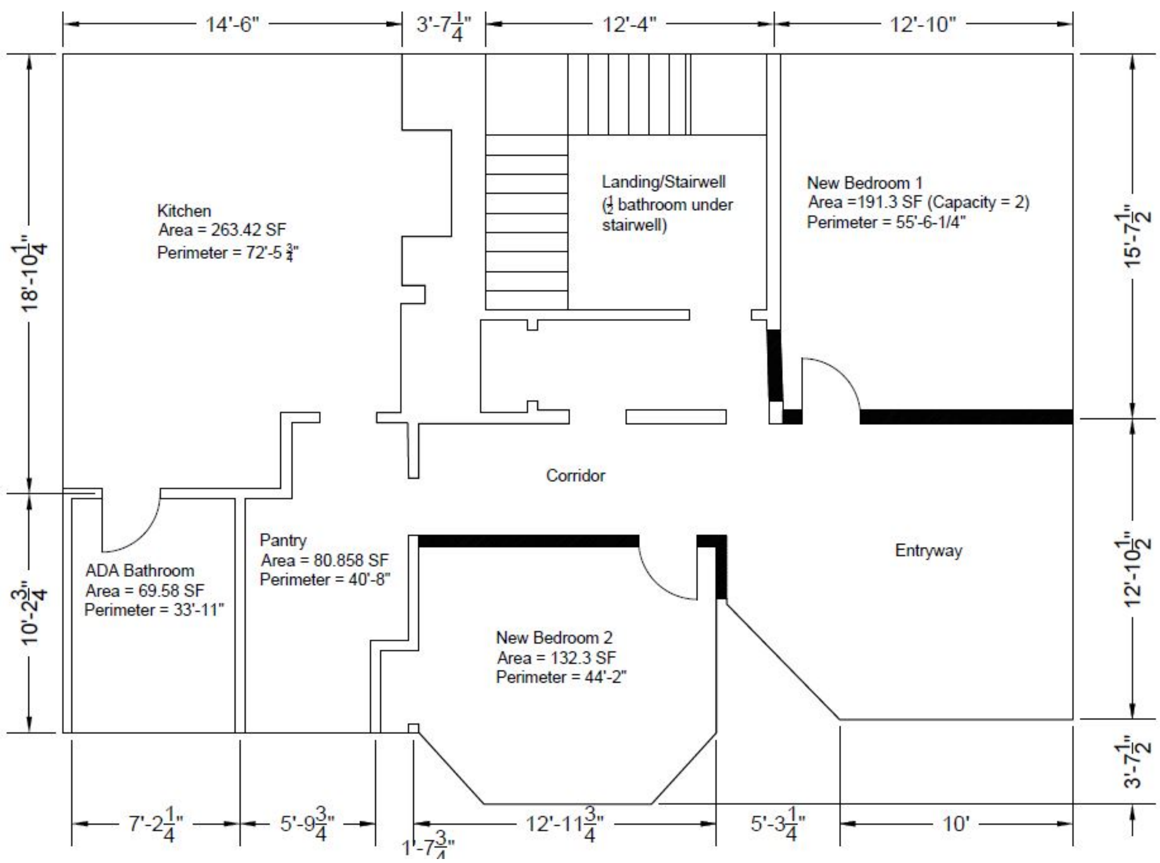


Figure 20. First floor renovation plan

The additional bedrooms will consist of a double and a single, as shown in Figure 20. This will require installing partition walls and doors. Erecting these partitions will not require installing any new sprinklers, since there are a sufficient number of sprinklers present in each of the rooms that the partitions would create. The quantities of materials required for the new partition walls are shown in

Table 11 at the end of this section.

The current building has a half bathroom under the staircase, shown in Figure 21. According to Mr. Palumbo, WPI's Facilities Project Manager, the area under a staircase is required to be an empty closet so that the stairs will not combust from the materials inside it, and this bathroom must be removed.

Figure 21. Existing first floor bathroom

The final major renovation to the first floor will be the addition of an ADA-accessible bathroom. The location of this bathroom will be in what is currently the kitchen exit, shown in Figure 23 (existing condition) and Figure 24 (proposed use) in the location shown in Figure 20. The proposed sequence of construction is shown in Figure 22. Note that plumbing connections will have to be added to the interior wall.

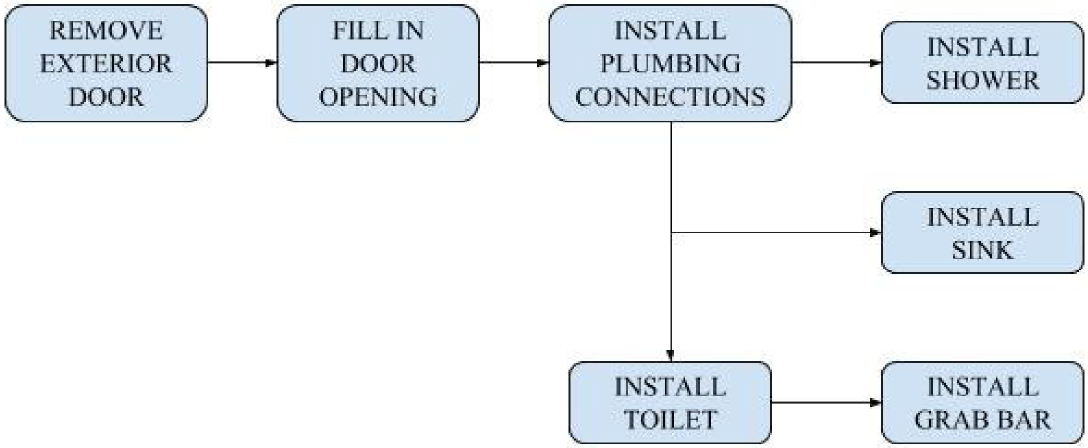


Figure 22. Proposed sequence of construction for the new first floor bathroom

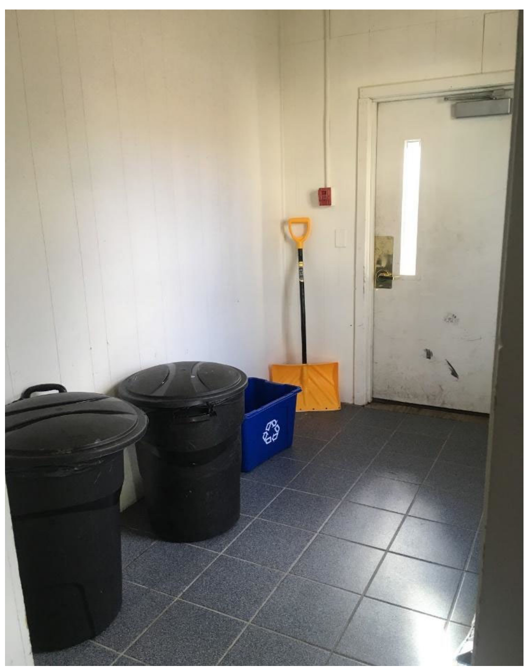


Figure 23. Existing kitchen exit, to be repurposed as a bathroom

Figure 24. Rendering of proposed first floor bathroom

Table 11 contains a list of required quantities for the first floor.

Table 11. Quantity takeoff for first floor renovations

Activity Description	UNIFORMAT / MasterFormat Code	Quantity	UOM
Tile finish for new first floor bathroom floor	09 60 58.10 9010	69.21	SF
Demolish 2' x 4' ceiling tiles	09 05 05.10 1120	576.23	SF
Remove 2’ x 4’ ceiling grid	09 05 05.10 1250	576.23	SF
2' x 2' ceiling tile frame - first floor	C3030 210 5900	576.23	SF
Remove toilet from first floor BR	22 05 05.10 1400	1.000	ea
Remove sink from first floor BR	22 05 05.10 1300	1.000	ea
Additional sink in first floor bathroom	22 41 16.30 3000	1	EA
Additional toilet in first floor bathroom - open front, elongated bowl	22 41 13.44 1280	1	EA
Shower: handicap, 48" x 34-1/2" x 72" corner seat	22 41 23.20 3210	1	EA
Addl. wiring for new bedroom, No 8 (1/8" diam.), stranded	26 05 19.90 0140	25.81	LF
Conduit for new bedroom, 1" diam.	26 05 33.13 5040	25.81	LF
Conduit elbows, 1" diam.	26 05 33.13 5700	6.00	EA
Additional power outlets for new bedrooms	26 05 33.17 0200	1	EA
Remove electrical exit sign	26 05 05.10 2100	1	ea
Desks for addl. bedrooms	12 56 43.10 1750	3	EA
Desk tops for addl. bedrooms, laminated plastic, 24" deep, max.	12 56 43.10 1200	3	EA
Wooden chairs for addl. bedrooms	12 52 23.13 2600	3	EA
Wardrobes for addl. bedrooms	12 56 43.10 7000	3	EA
Mirrors for addl. bedrooms	12 56 43.10 7000	3	EA
Chest, built-in, maximum	12 56 43.10 1020	3	EA
Bunkable bed, built-in, maximum	12 56 43.10 0320	3	EA
Demolish gypsum board along path of conduit	09 05 05.30 3400	4.301	SF
Remove visible conduits for kitchen exit sign	26 05 05.10 0100	6.000	LF

5.3. Second and Third Floors

According to 521 CMR 8.4, only 5% of the rooms in a building need to be made ADA-accessible. Consequently, there is no need to incorporate accessibility measures into the second and third floors. Based on guidelines for dormitory sizes at Boston College - at least 23’ x 16’ (388 SF) for a triple, 12’ x 16’ (192 SF) for a double, and 8’ x 12’ (96 SF) for a single (DormStormer, 2017) - the second and third floors do not need to be reconfigured because the bedrooms have sufficient space to retain their current capacities. All of the rooms on the second floor will be doubles, except for Room 4, which will be a triple, and Room 1, which will become a single. All of the rooms on the third floor will be singles, except Room 6 will be a double. Table 12 lists the sizes of each existing bedroom.

The major renovations on the second and third floors take place in the bathrooms. To manage existing cracks in the bottom of the walls, a tile flooring will run along the floors and continue up the walls. In addition, the cracks will be sealed with a butyl rubber filler. The areas where this filler will be applied in the second-floor bathroom are shown in Figure 25 and outlined in red.

Table 12. Floor areas and capacities of existing bedrooms

Bedrooms	Level	Net Floor Area (SF)	Capacity
1	Second Floor	165.50	1
2	Second Floor	196.40	2
3	Second Floor	212.10	2
4 (main room)	Second Floor	199.70	2
4 (extension)	Second Floor	107.00	1
5	Third Floor	121.30	1
6	Third Floor	271.50	2
7	Third Floor	165.80	1
8	Third Floor	155.90	1
9	Third Floor	131.00	1
Totals		1,726.20	14

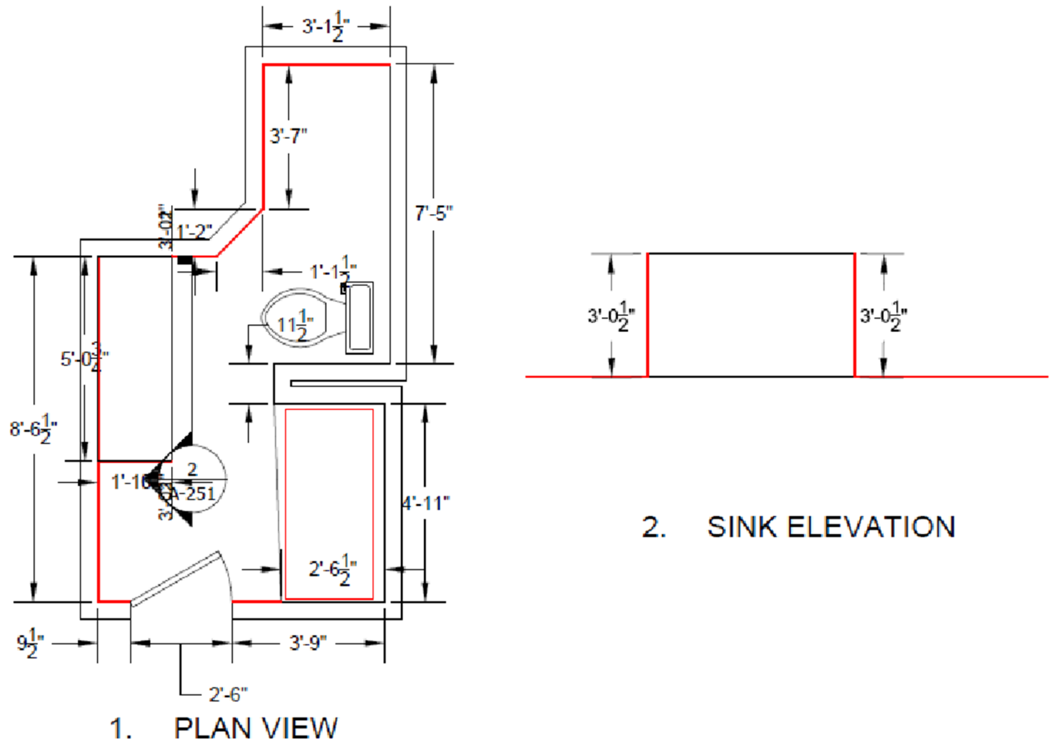
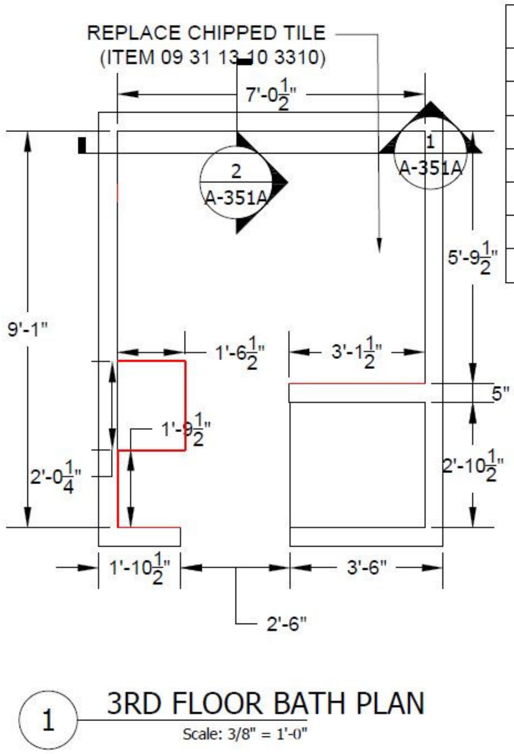


Figure 25. Second floor bathroom renovation plan

Butyl rubber fill and a layer of tile will also be applied in the third-floor bathroom. In addition, the third-floor bathroom requires several small repairs, including replacing a broken tile and patching a hole in the wall using plaster. Figure 26 is a plan showing the locations of these repairs, and Figure 27 presents an elevation and section.



RUBBER FILLER (ITEM 07 91 26.10 4360)			
Count	Name	d1	Column
1	Butyl Rubber Filler	1'-5 1/2"	1.46
2	Butyl Rubber Filler	1'-6 1/2"	3.08
1	Butyl Rubber Filler	1'-9 1/2"	1.79
1	Butyl Rubber Filler	2'-0 1/4"	2.02
1	Butyl Rubber Filler	3'-1 1/2"	3.13
			11.48

Figure 26. Plan view of 3rd floor bathroom renovations

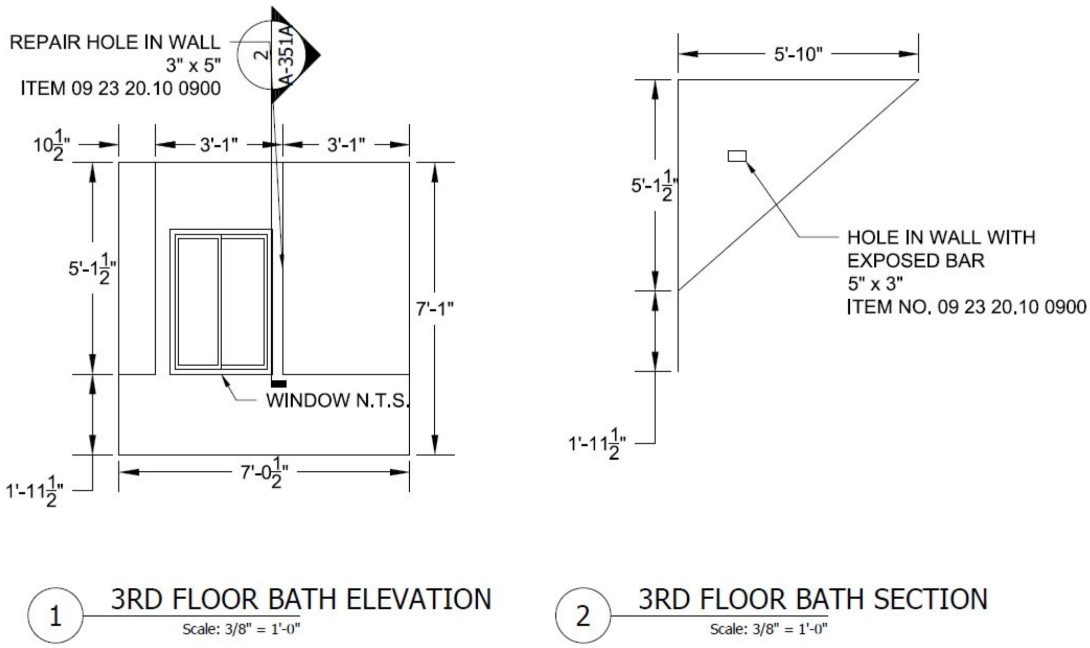


Figure 27. Elevation and section of 3rd floor bathroom renovations

Table 13 shows the list of quantities for renovations to the second and third floors.

Table 13. Quantity takeoffs for second and third floor renovations

Activity Description	MasterFormat Code	Quantity	UOM
Repair hole in wall with 2 coats gypsum plaster	09 23 20.10 0900	0.01	sq. yd.
(Addition for irregular surfaces)	09 23 20.10 1600	30	%
Tile finish for new basement bathroom walls	09 60 58.10 9010	355.50	SF
Tile finish for existing bathroom wall edges	09 60 58.10 9010	29.81	SF
Butyl rubber filler for third floor bathroom floor	07 91 26.10 4360	11.48	LF
Butyl rubber filler for second floor bathroom floor	07 91 26.10 4360	43.45	LF
Replace one (1) tile on third floor bathroom floor	09 31 13.10 3310	0.03	SF
Tile finish for new basement bathroom floor	09 60 58.10 9010	1,203.40	SF

5.4. Exterior Renovations

The location of amenities for the renovation design was intended to facilitate accessibility. However, the building still needed to be made accessible. According to Massachusetts Regulation 521 CMR, "If the work performed [on an existing building] amounts to [at least 30%] of the full and fair cash value (see 521 CMR 5.38) of the building the entire building is required to comply with 521 CMR," (521 CMR 3.00). This includes making at least 5% of all bedrooms, as well as all common areas, accessible (521 CMR 8.00). Since all of 53 Wachusett Street's common areas are in the basement and on the first floor, and two bedrooms and a bathroom will be added to the first floor, only the basement and first floor of the building need to be made accessible. This was achieved by designing accessibility ramps serving an emergency exit in the basement and a porch facing Wachusett Street, neither of which is currently used as an entrance.

The other objective for renovating the exterior of 53 Wachusett Street was to replace the existing windows and doors with newer ones that could retain a greater amount of heat. Based on a walk-through with Mr. Palumbo, the windows currently installed in the building are newer than the building itself but may need to be replaced with windows of a similar model. However, Mr. Palumbo did not believe that this was a critical work item.

5.4.1. Basement Accessibility Ramp

Figure 28 shows the current exterior layout of 53 Wachusett. As shown in this figure, the basement can currently be accessed through a stairwell located under an overhang on the side of the building. Since the bottom of the stairwell is nearly two feet above the grade of the basement, either the door frame needs to be removed and reinstalled two feet lower, or the ramp needs to continue into the basement. Since continuing the ramp into the main room of the basement would eliminate this room's potential as a common space, the decision was made to excavate down to the level of the basement floor and replace the door frame with one at grade with the basement floor.

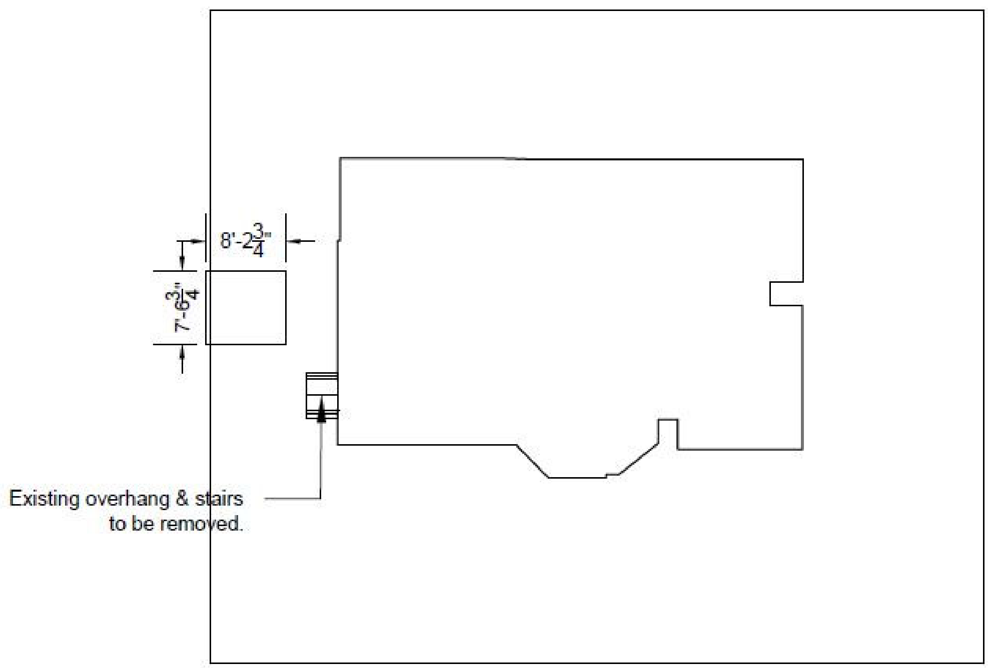


Figure 28. Current exterior layout of 53 Wachusett Street.

Figure 29 shows the layout for the proposed accessibility ramp, and Figure 30 shows a rendering of this ramp. The ramp would run nearly to the northern edge of the property, before switching back to continue its rise. The ramp would reach ground level just before encountering a concrete box that likely contains utility equipment.

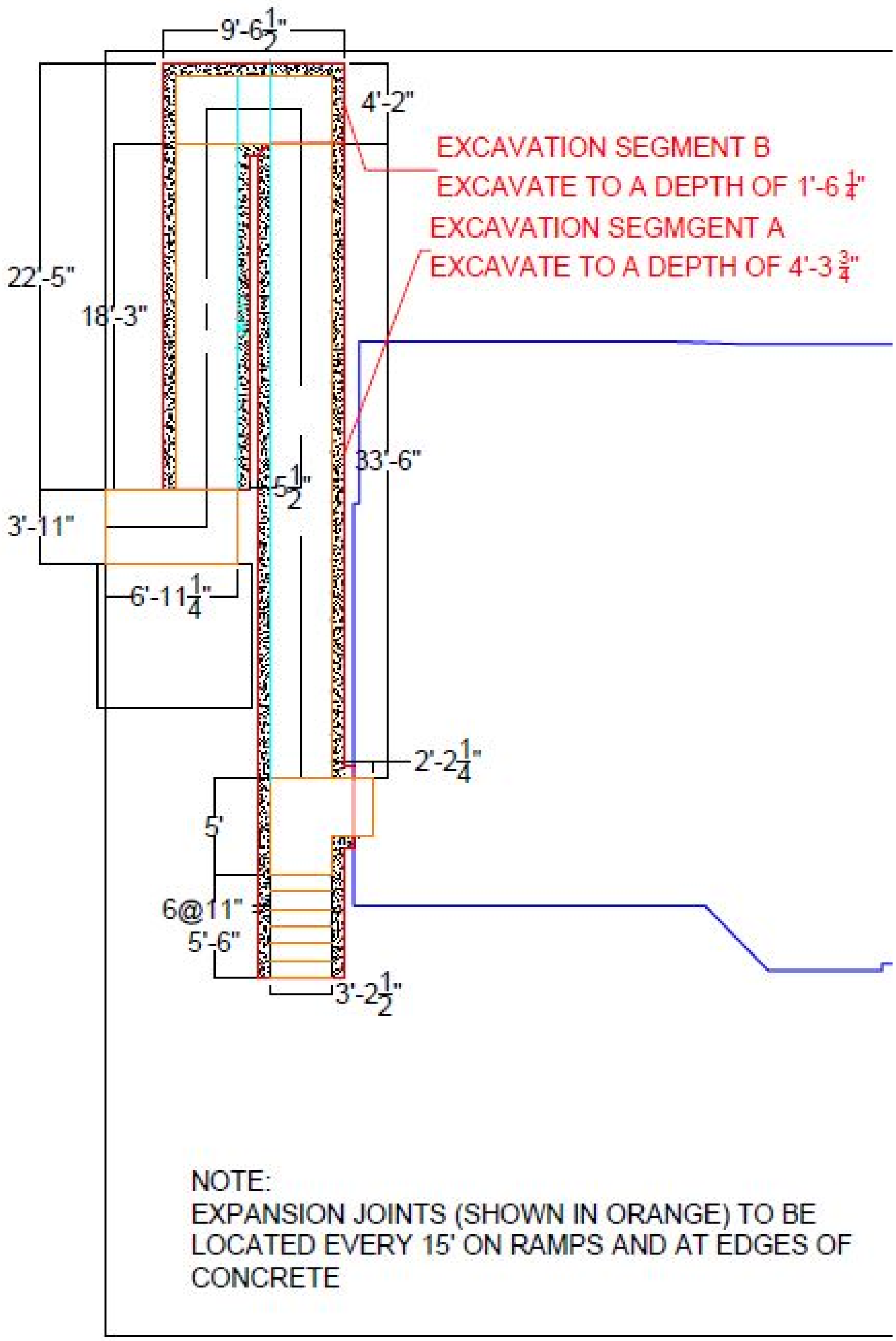


Figure 29. Proposed layout for accessibility ramp

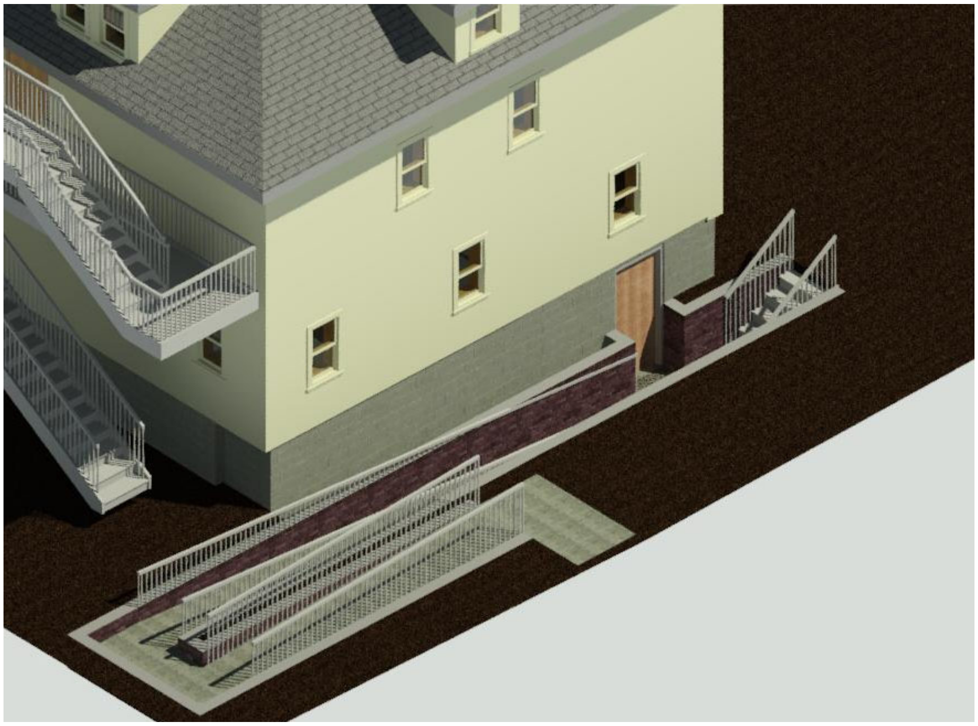


Figure 30. Rendering of the proposed basement accessibility ramp

Figure 31 shows the proposed sequence of construction for the installation of the ramp. This sequence involves excavating the site in two segments (shown in Figure 19), so that a concrete retaining wall can be placed around the edges of Segment A before Segment B is excavated. This wall is intended to prevent the narrow strip of soil between the two ramp segments from collapsing when Segment B is excavated.

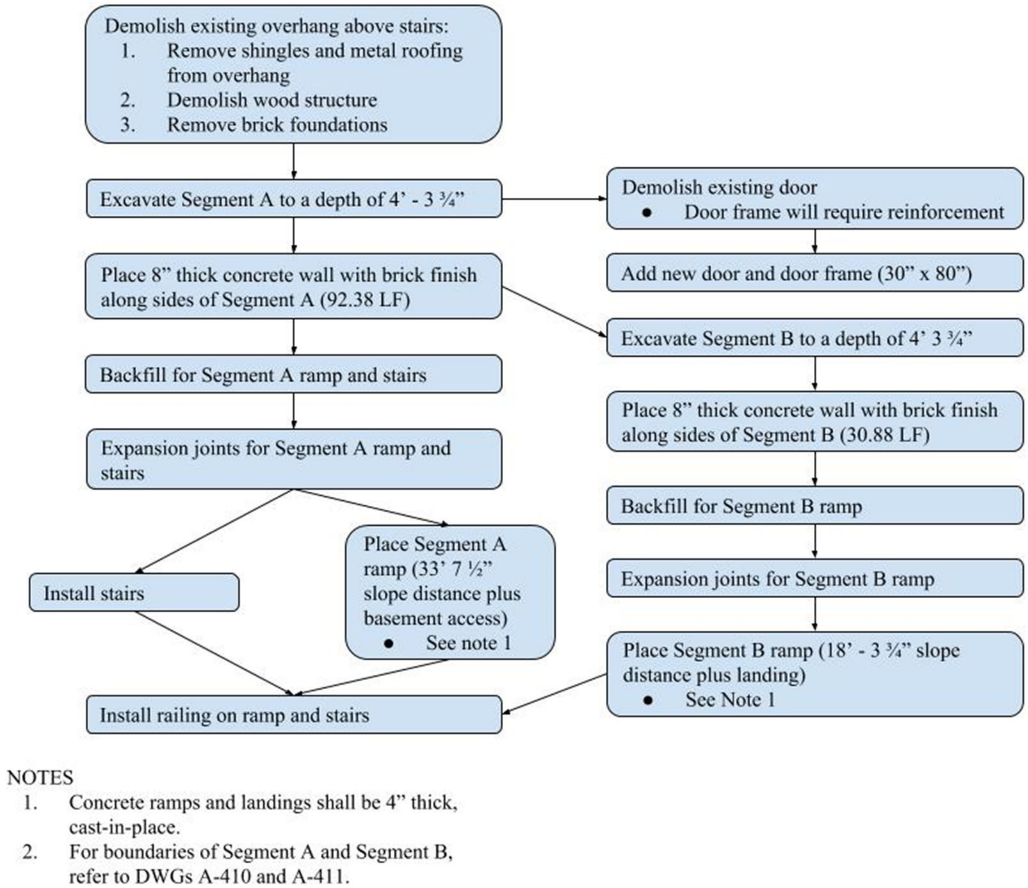


Figure 31. Proposed construction sequence for the basement exit ramp

This work will increase access to the basement, especially for the handicapped, which will allow the basement to serve a new role as host to a common room and laundry facilities. Table 14 contains a list of quantities for the basement accessibility ramp.

Table 14. Basement exit ramp quantity takeoffs

Activity Description	MasterFormat Code	Quantity	UOM
Remove metal from overhang	05 05 05.10 0500	16.434	SF
Remove asphalt roof from overhang	07 05 05.10 3170	16.434	SF
Selective Demolition, wood frame, not including re-framing	02 41 19.16 7410	1.000	EA
Disposal, wood frame, incl. loading and 5-mile haul to dump	02 41 19.18 0500	0.719	CY
Dumpster, weekly rental, 1 dump/week, 6 CY capacity	02 41 19.19 2000	3.600	Week
Remove brick overhang foundations	09 05 05.30 0100	1.150	CF
Excavate Segment 1 + Stairs (Excavation Zone A)	31 23 16.13 0050	32.232	CY
Excavate Landing + Segment 2 (Excavation Zone B)	31 23 16.13 0050	6.940	CY
Backfill Zone A by hand, no compaction, heavy soil	31 23 23.13 0100	6.741	CY
Backfill Zone B by hand, no compaction, heavy soil	31 23 23.13 0100	0.630	CY
Slab, 4" thick, non industrial, non reinforced - Basement Ramp	03 30 53.40 4650	2.633	CY
4' concrete wall, pumped, 8" thick for Excavation Zone A	A2020 110 1720	92.380	LF
4' concrete wall, pumped, 8" thick for Excavation Zone B	A2020 110 1720	30.880	LF
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	05 52 13.50 0020	90.000	LF
Rubberized asphalt expansion joint, 1/2" x 1" - Basement	03 15 16.30 0900	136.170	LF
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	05 52 13.50 0020	162.9	LF

5.4.2. First Floor Accessibility Ramp

The porch facing Wachusett Street, which is over 15’ long, offers nearly half of the length required for a ramp from the first floor to the ground. The porch is located 2’ - 9 ¾” off of ground level and would require a 33’ - 9” long ramp to reach the ground; the remainder of the ramp can be run along the east side of the house. In order to provide a more aesthetically desirable ramp at a lower cost, this ramp will be constructed with dimension lumber flanked with an aluminum railing. Figure 32 contains a layout for the proposed ramp, Figure 33 contains elevations for the ramp, Figure 34 depicts the wood schematic for the ramp, and Figure 35 contains a rendering of the proposed ramp.

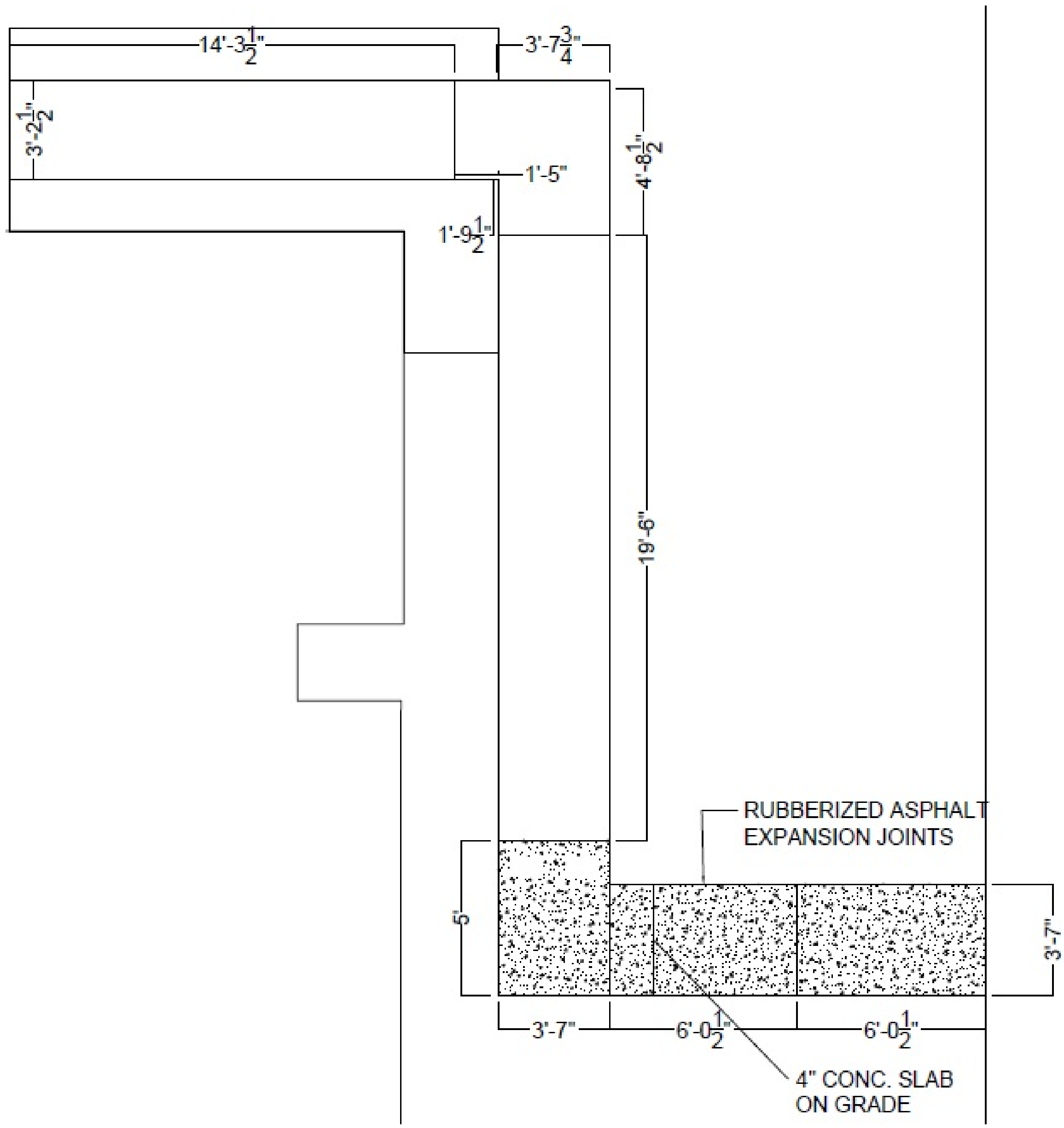


Figure 32. Proposed first floor accessibility ramp layout

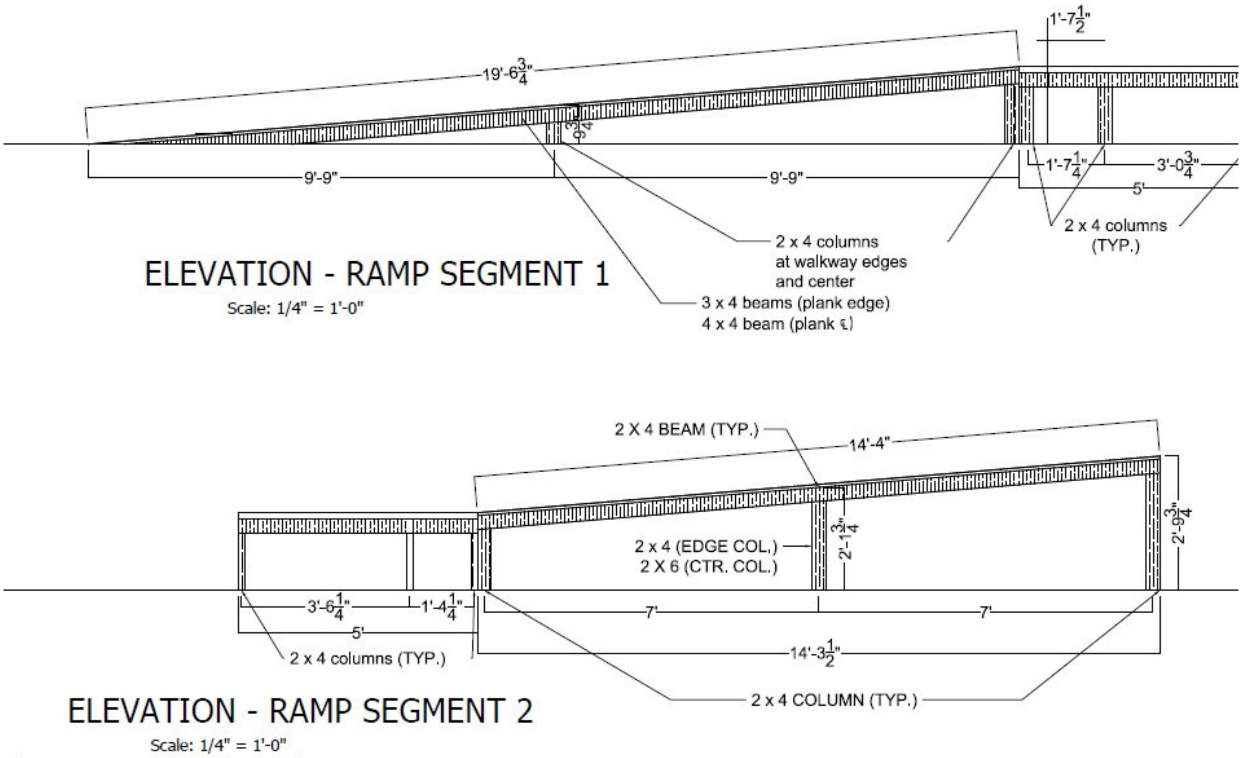


Figure 33. First floor accessibility ramp elevations

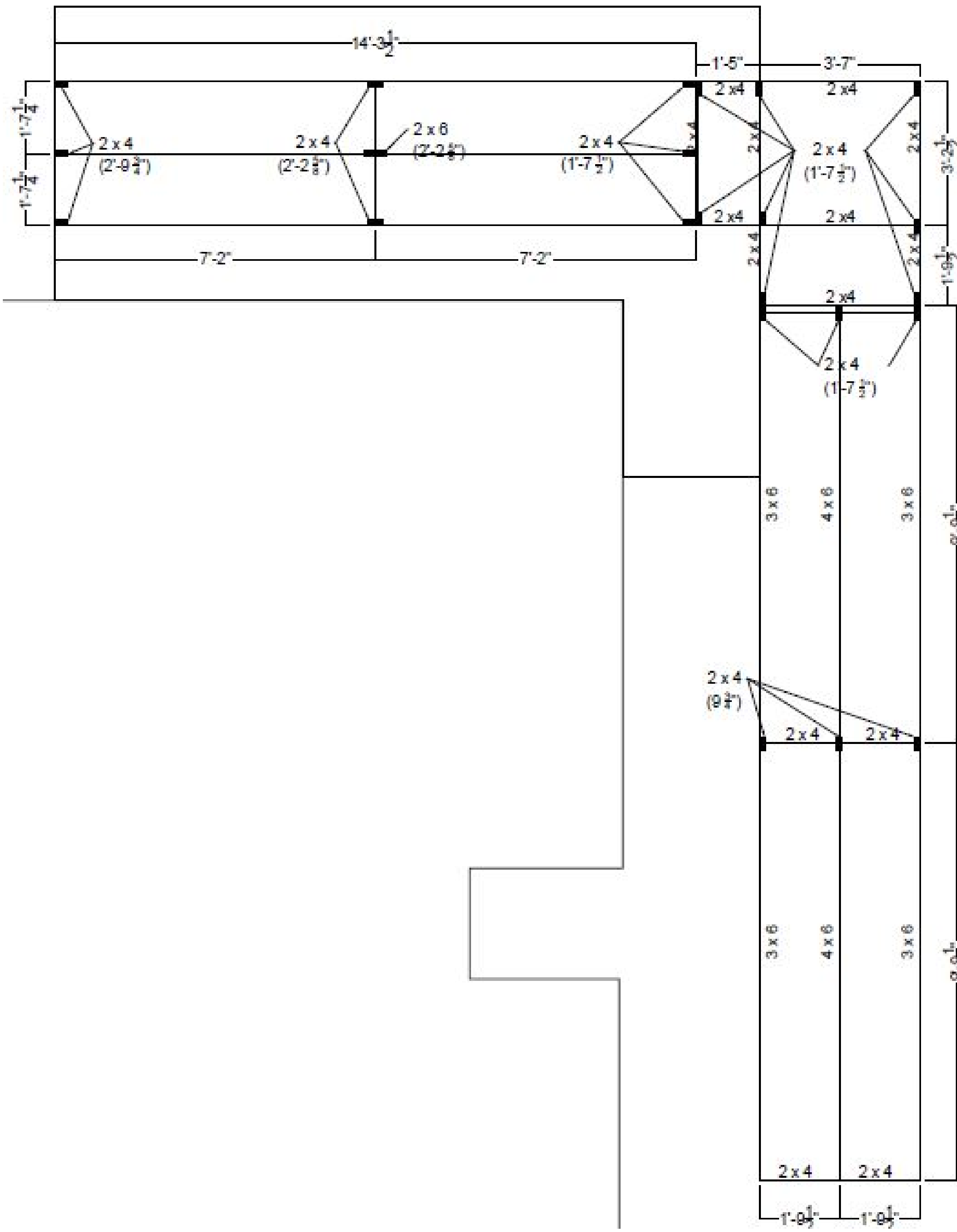


Figure 34. Wood schematic for the first floor accessibility ramp

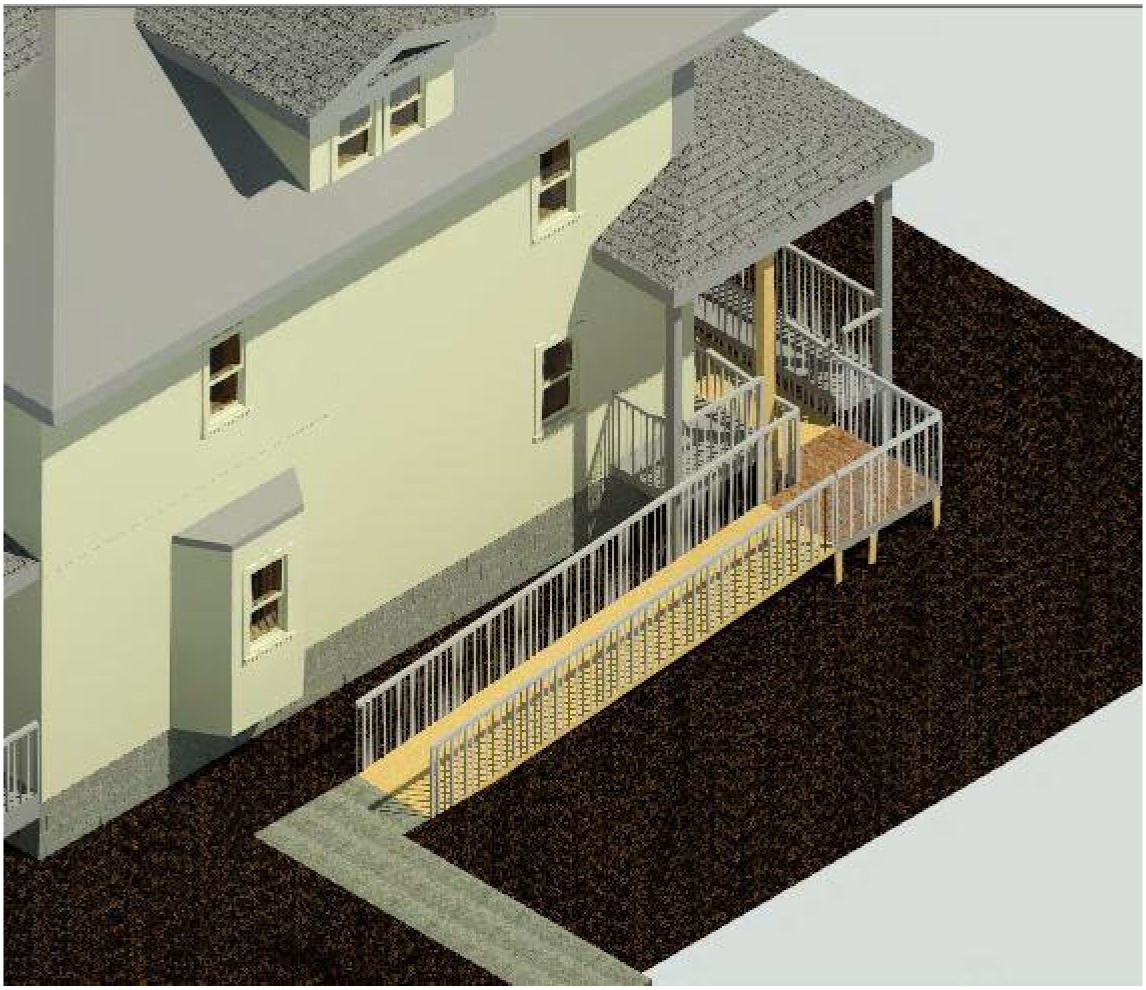


Figure 35. Rendering of the first floor accessibility ramp

This ramp will partially fulfill the accessibility requirements associated with spending over 30% of the building's value on renovations, as it allows access to two of the 11 bedrooms in the renovated building, passing the 5% requirement for accessibility given by 521 CMR 8.00. Due to the scale of renovations taking place on the first floor, this ramp may generate even more value than the basement accessibility ramp. Table 15 contains a list of quantities for the first floor accessibility ramp.

Table 15. Quantity takeoffs for first floor accessibility ramp

Individual Activities	MasterFormat Code	Units	UOM
Slab, 4" thick, non industrial, non reinforced - 1st Floor Walkway	03 30 53.40 4650	0.764	CY
Rubberized asphalt expansion joint, 1/2" x 1" - First Floor	03 15 16.30 0900	48.500	LF
Planks for all ramp segments - 1 x 6	06 11 10.38 0110	173.25	LF
Sawcut porch for first floor accessibility ramp	02 41 19.25 5020	34.625	LF
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	05 52 13.50 0020	80.9	LF
Segment 1 mid-beam - 4 x 6	06 11 10.38 0210	24.55	LF
Segment 1 end beams - 3 x 6	06 11 10.38 0210	49.1	LF
Segment 1 columns - 2 x 4	06 11 10.38 0100	9.75	LF
Segment 1 girders - 2 x 4	06 11 10.38 0100	7.17	LF
Segment 2 mid-beam - 4 x 6	06 11 10.38 0210	14.34	LF
Segment 2 end beams - 3 x 6	06 11 10.38 0210	28.69	LF
Segment 2 columns - 2 x 4	06 11 10.38 0100	17.75	LF
Segment 2 columns - 2 x 6	06 11 10.38 0110	2.22	LF
Segment 2 girders - 2 x 4	06 11 10.38 0100	9.625	LF
Midway landing planks - 2 x 4	06 11 10.38 0100	80.08	LF
Midway landing beams - 2 x 4	06 11 10.38 0100	23.21	LF
Midway landing columns - 2 x 4	06 11 10.38 0100	13	LF

5.4.3. Replacing Windows and Doors

Based on an inspection of the building, 53 Wachusett Street's windows were installed more recently than the building was constructed. However, their replacement is recommended in order to increase the building's energy efficiency. Since there is not a central air conditioning unit in 53 Wachusett Street, it is important to insulate the building properly. In order to achieve this purpose, the building's exterior and interior doors should also be replaced with models that retain heat more effectively.

Since the openings for the windows and doors already exist, replacing them with more energy-efficient models did not require any structural design and instead entailed estimating the costs for replacement windows. The costs of replacing each item were determined by finding the sizes of each opening or using assumptions for their sizes if they could not be measured.

A total of 33 windows were counted on 53 Wachusett Street. While these windows varied in sizes (many bathroom windows, for example, were smaller than windows in other rooms), a common size of 4’ x 5’ was used to simplify the estimating process.

53 Wachusett Street currently has four exterior doors that lead to the kitchen, living area, basement, and emergency exit on the first floor. In order to accommodate the new first floor bathroom, the entire door leading to the kitchen will be demolished and a wall constructed in the opening. Since the frame of this door is likely to be load bearing, it will not be removed. The remaining three doors will be replaced while leaving the frames intact. Table 16 contains a summary of quantities required for window and exterior door replacement.

Table 16. Quantity takeoffs for window and exterior door replacement

Individual Activities	**MasterFormat Code**	**Units**	**UOM**
Remove and reset window, up to a 4' x 5' window	08 05 05.20 5080	33	EA
Remove doors (not including kitchen door)	08 05 05.10 0200	3	EA
Install new wood doors	08 14 33.20 0200	3	EA

5.5. Renovation Schedule

Renovation work on 53 Wachusett Street was assumed to begin immediately following the Class of 2020 Commencement, since the project would be subject to approval by the Board of Trustees during its February or March meeting of that year. Upon beginning, this project is expected to take nearly 10 weeks and be completed in mid-to-late July of 2020. Table 17 contains a schedule of all construction activities by week:

Table 17. Construction schedule for renovation

Task Name	Start	Finish	5/15/2020	5/22/2020	5/29/2020	6/5/2020	6/12/2020	6/19/2020	6/26/2020	7/3/2020	7/10/2020	7/17/2020
Accessibility Ramp - Basement	5/11/2020	5/29/2020										
Accessibility Ramp - First Floor	5/13/2020	5/22/2020										
Basement Finish	7/2/2020	7/13/2020										
Basement Floor	6/25/2020	7/1/2020										
Bathroom Addition	5/15/2020	6/22/2020										
Bathroom Demolition	5/11/2020	5/12/2020										
Bathroom Repairs	6/15/2020	6/22/2020										
Ceiling Work	5/29/2020	6/1/2020										
Door Replacement - Exterior	5/11/2020	5/12/2020										
Replace Interior Doors	5/29/2020	6/2/2020										
Fire Protection	5/15/2020	6/12/2020										
Hazardous Material Removal	5/11/2020	6/2/2020										
Heating System	5/11/2020	5/12/2020										
Laundry Room	7/14/2020	7/20/2020										
Light Replacement	5/11/2020	5/28/2020										
New Bedrooms	5/12/2020	5/20/2020										
Plumbing	6/23/2020	6/24/2020										
Remove and Reset Windows	5/11/2020	6/2/2020										
Miscellaneous Items	5/11/2020	5/11/2020										

5.6. Alternative Options

Several design components were considered for the renovation of 53 Wachusett Street but not included in the final design. These include placing solar panels on the roof, moving the electrical box in the basement to the equipment room, and placing an extra bedroom in the basement. While each of these options offered a number of benefits, the conditions of the current building made them difficult to implement in a cost-effective manner.

5.6.1. Solar Panels

Solar panels were considered as an option for a renovation because they could provide the building with electricity, which would reduce the building's electricity bill and make it more sustainable. However, the layout of the current building's roof would have made the installation of solar panels exceedingly difficult. The south-facing side of the roof, typically the most ideal location for solar panels, is interrupted by a number of dormer windows which makes placing panels on the roof practically impossible. While some panels could be placed on the flat strip on top of the roof, a consultant advised us that no more than five or six panels could fit there, due to solar panels shading one another. In comparison, homes with solar panels on their roofs typically have roughly 30 panels installed. (Mona Reese, Personal Communication)

5.6.2. Electrical Box Relocation

The possibility of moving the electrical box in the basement to the equipment room was considered to create additional space for a common room in the basement. However, the electrical box is currently located in a corner of the basement where it does not impede the room's functionality. More importantly, moving the box, as well as all of the wiring, to a different corner of the building would be expensive and difficult to execute. In order to keep the electrical box secured, it will be kept in the same location but will have a locked cabinet installed around it.

5.6.3. Extra Bedroom in Basement

In order to increase the building's capacity, the possibility of placing a three-person bedroom in room C of the basement was evaluated. This option was found not to be possible because placing a bedroom here would have required adding a window, and the fencing for the porch obstructed any path of egress that a window might have offered. In addition, even if the window would have offered a means of egress, placing a window in a load-bearing foundation wall would have been prohibitively expensive.

6.0. New Construction

6.1. Overview

The new building was designed to allow for ease of construction and conformity with other WPI buildings. The building's roof will face south in order to allow for the maximum exposure for the solar panels. The exterior of the building will be made of brick, in order to match the brick exterior of other residence halls. The south wall, shown in Figure 36, will contain many windows in order to maximize the amount of natural light entering the building.

Figure 36. New construction rendering, created with Autoesk Revit

One objective of the new construction is to comfortably house as many residents as possible while meeting the criteria that WPI is looking for in a residence hall and future residents would be looking for in a living space. This was created based on a maximum lot size of 66' x

43'. The proposed design holds space for thirty-four residents with nine located in the basement, ten on the first floor, and fifteen on the second floor. In total, the building consists of sixteen doubles and two singles.

The first and basement floors are fully accessible. The building contains multiple bathrooms and showers on each floor, with the showers on the first and basement floors made accessible to residents. There will be common spaces of different sizes on the first floor and in the basement for residents to interact and study, as well as a kitchen on the first floor. Much of the space in the basement is allocated to an equipment room for WPI staff access only and a laundry room.

In order to maximize space and allow for ease of construction, the interior of the building has almost entirely symmetric floors. The west end of each floor contains bathrooms, and the west end of the first floor contains kitchen facilities, so that they can be aligned with the utilities in the west end of the basement. The east end of the building will feature a common room on the first floor only, as well as all bedrooms. Each floor will have a janitor's closet in order to make it easier for custodial staff to work, as the building does not feature an elevator.

All the building's functional equipment is housed in the basement (shown in Figure 37). This includes HVAC and MEP equipment, as well as lock mechanisms for the building and storage tanks to house collected rainwater. The basement floor also features five bedrooms, with a total capacity of nine, and a laundry room. This floor has two points of egress: one through the stairwell, and one through a separate exit ramp accessible on the west side of the basement.

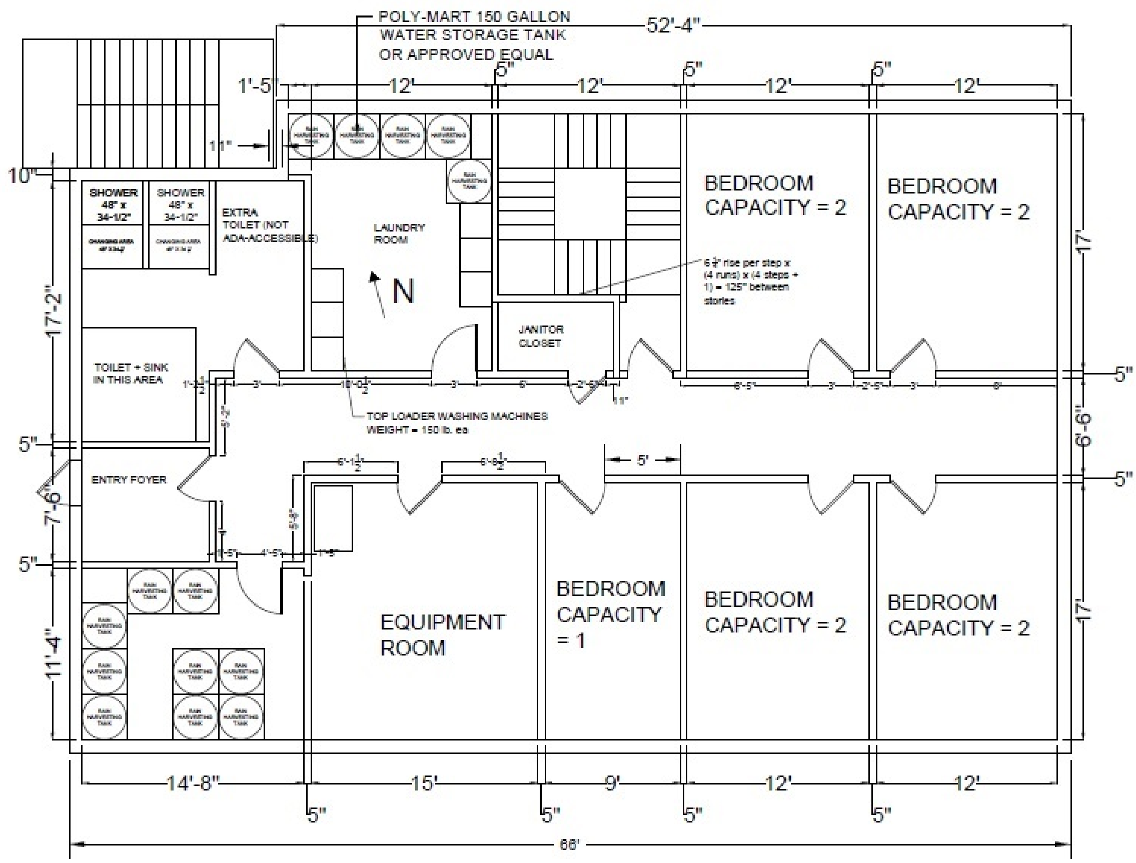


Figure 37. Proposed basement layout for the new construction

The first floor of the building (Figure 38) holds most of the building's communal facilities, including a kitchen and a large common area. This floor accommodates 10 residents in five double bedrooms. Points of egress include the main entrance on Wachusett Street, which features an entry foyer between two doors; an exit from the common room; and an exit underneath the fire escape.

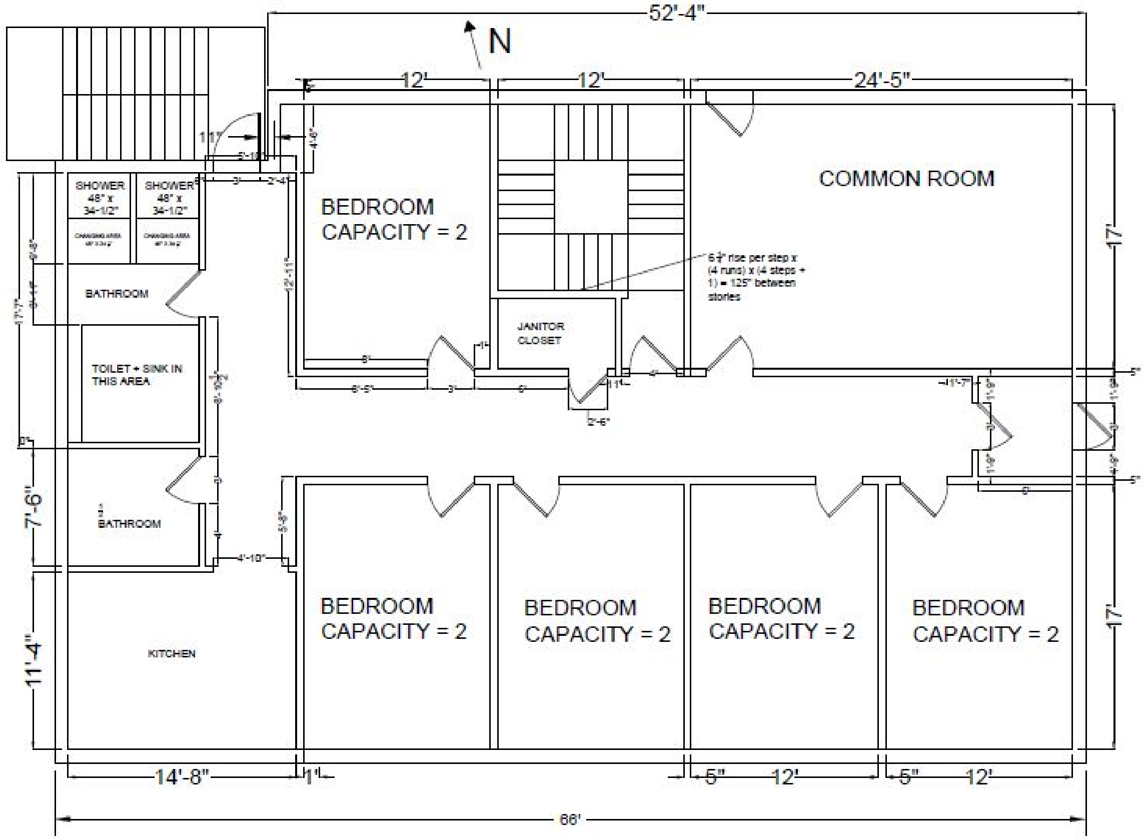


Figure 38. Proposed first floor layout for the new construction

The second floor of the building (Figure 39) holds many of the building's residents, accommodating 15 residents in seven doubles and a single. This floor has two points of egress: a fire escape in the northwest corner of the building, and the stairwell. Unlike the other floors in the building, the second floor is not designed to be accessible. Given that all amenities are located on the basement and first floors, which are accessible, and Massachusetts State Regulation 521 CMR 8.00 only requires 5% of the total rooms to be accessible, it was not necessary to make the second floor accessible.

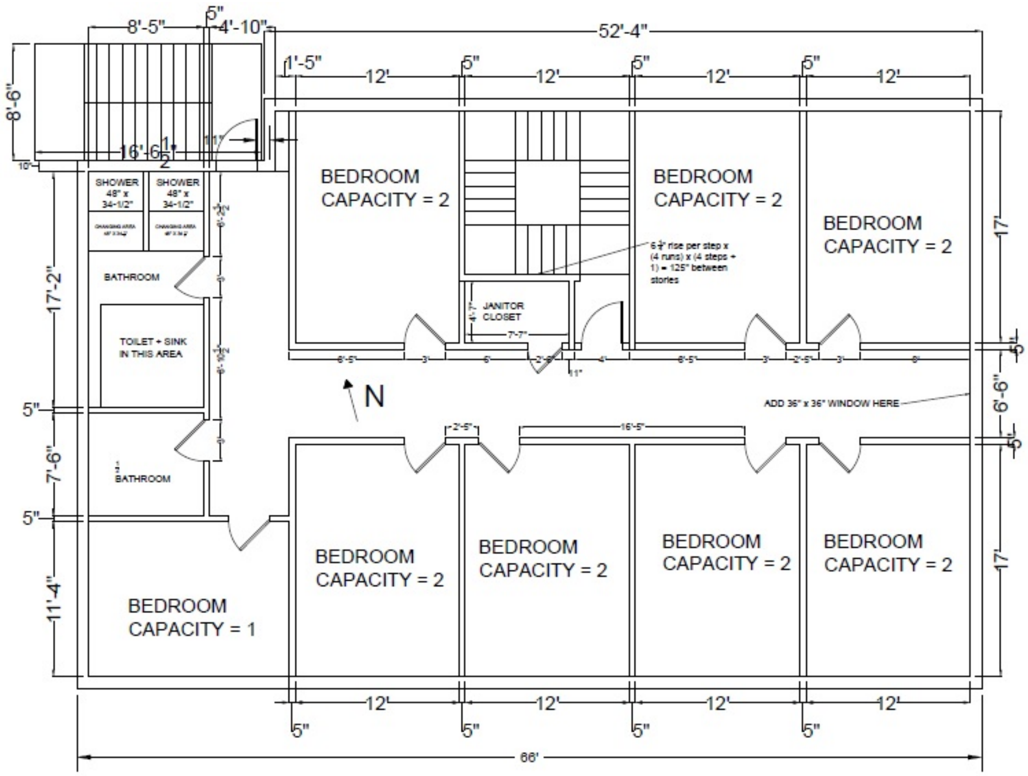


Figure 39. Proposed second floor layout for the new construction.

Figure 40 contains an elevation of the proposed building, shown from its southern side. As shown in Figure 40, the first floor is roughly 42” above ground level and the ceiling of the basement is roughly 2’ above ground.

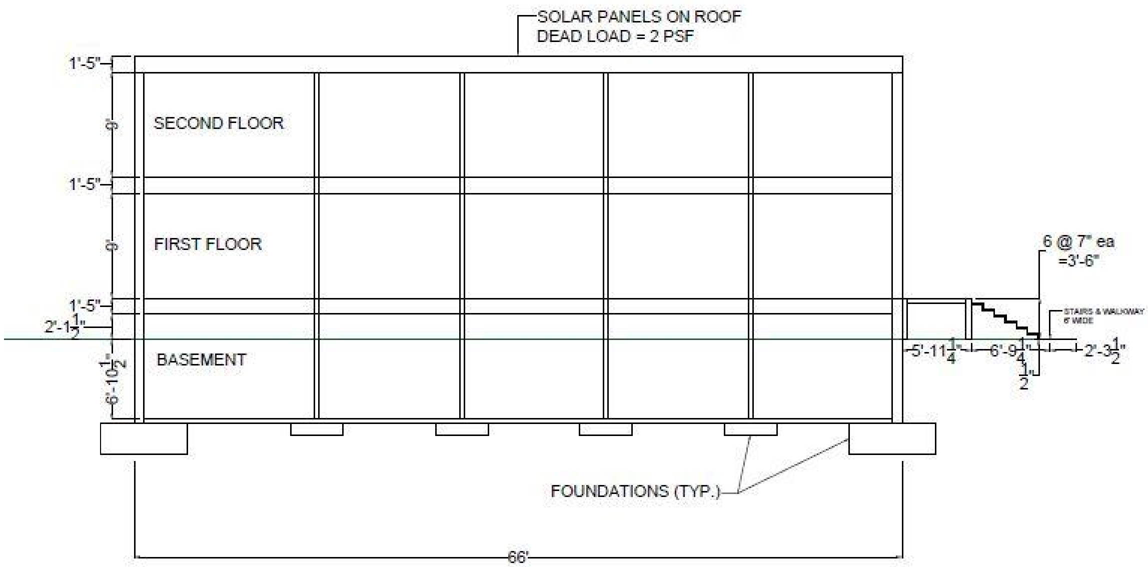


Figure 40. South elevation for the new construction

Figure 41 contains the layout for the exterior entrances to the building. The building features separate ADA-accessible ramps to the basement and first floor, as well as a stairwell leading out of the living room.

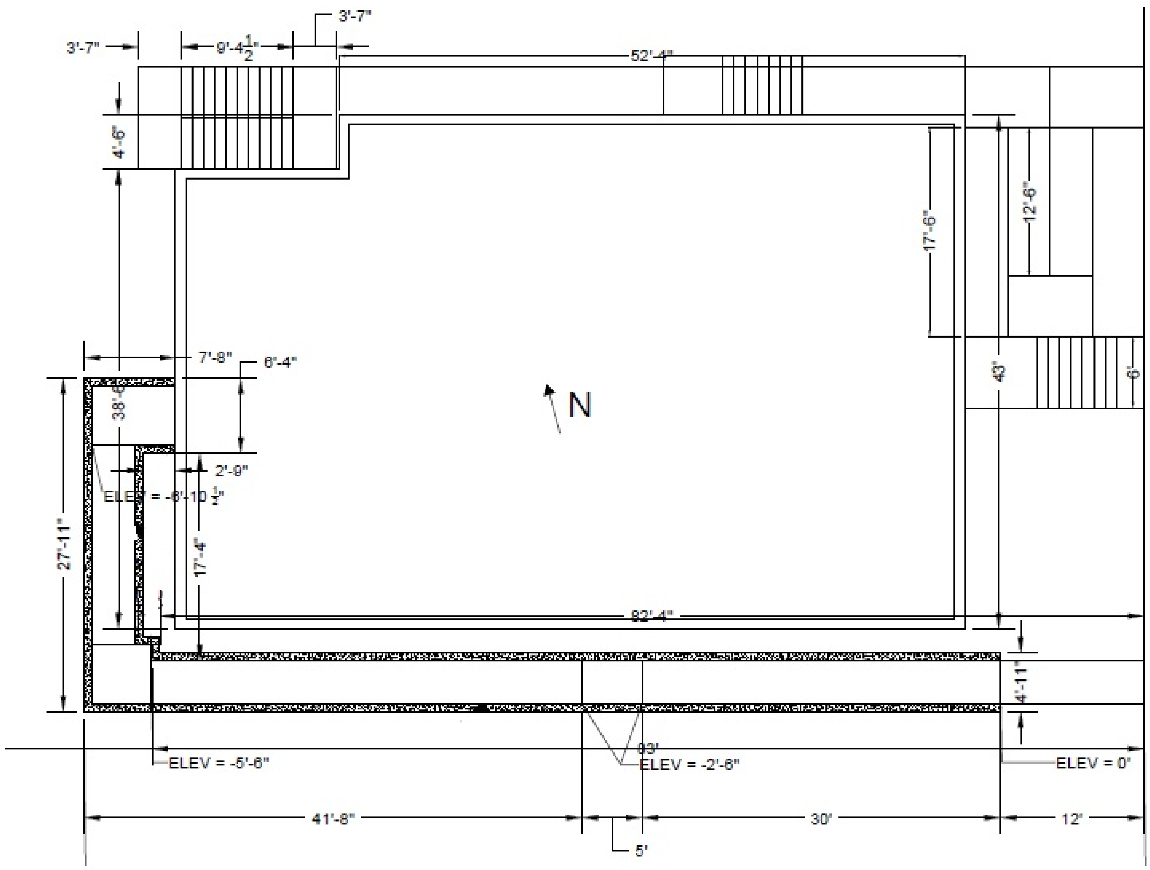


Figure 41. Exterior layout for the new building

Much of the new construction schematic was based loosely off the current setup of 53 Wachusett Street. The main entrance on the east side of the building opening towards Wachusett Street will have a two-lock system. All of the doors in the building will be equipped with WPI locking mechanisms. There was additional space located in front of the stairwells, so janitor closets were placed here to optimize the space.

6.2. Structural

The building's structure was a hybrid of light-frame lumber and heavy timber construction. In order to allow for flexible uses of the building, the interior walls were not designed to be load-bearing. The studs on the exterior walls, however, were designed to be load-bearing due to the large weight (~459 lb./ft. per story) of the brick exterior wall. In order to avoid seismic design requirements associated with larger timber sections, trusses were used to transfer load from dimension lumber purlins to columns in the middle of the building, and multiple lumber sections were placed adjacent to each other to create columns.

6.2.1. Gravity Load Resisting System

Figure 42 depicts the sheathing for the roof. As shown in Figure 42, the roof was designed using asphalt shingles, 7/8" plywood sheathing (the minimum thickness necessary to withstand the roof loads given by building codes), and high-density foam insulation. A 25% roof slope was used, in order to allow solar panels to be spaced closer together without shading one another while still allowing maintenance workers to safely service these solar panels.

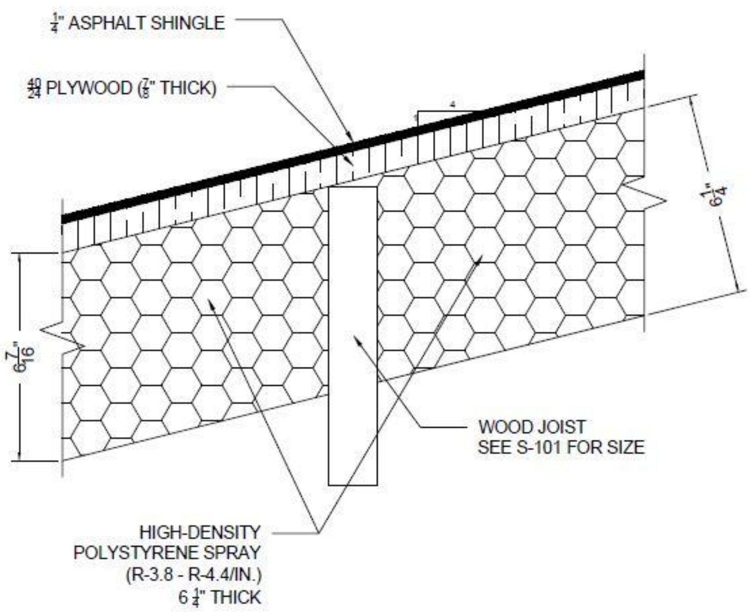


Figure 42. Roof sheathing details.

The joists that were used in each location are shown in Figure 43.

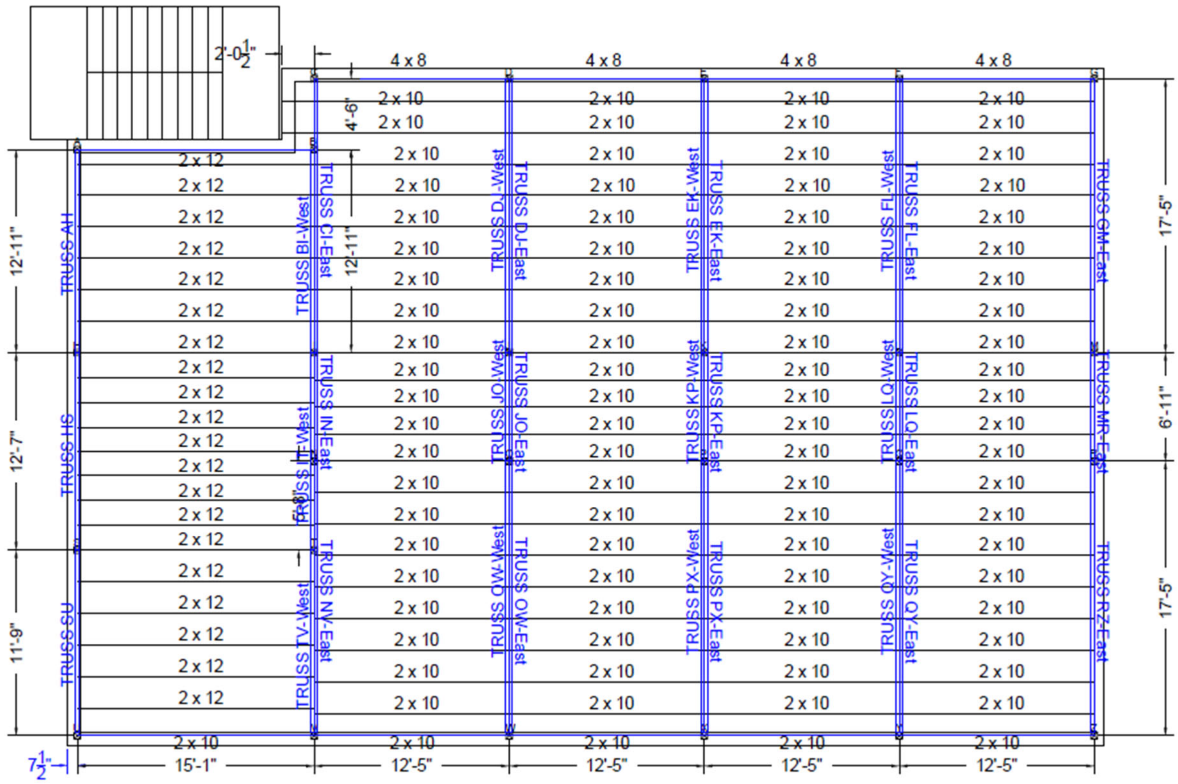


Figure 43. Roof member sizes by location.

Mono trusses were used for the roof span. Figure 44 shows the proportions used for these trusses.

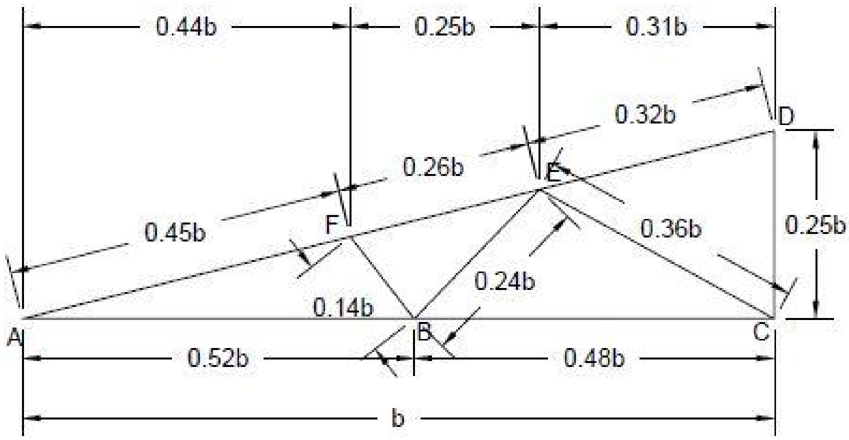


Figure 44. Roof truss dimensions relative to span, b

The required truss quantities by span are given in Table 18. According to Alpine (n.d.), mono trusses with a 25% slope, a total load of 55 psf, and a snow load of 40 psf have an allowable span of 30' if 2x4s are used for all chords. While the allowable snow load of 40 psf is less than the design snow load of 50 psf, the allowable span of 30' is also significantly longer than the maximum necessary span of 17'.

Table 18. Required number of roof trusses by span for the new construction

Span, b	# Trusses Needed
6'-11"	8
11'-9"	2
12'-7"	2
12'-11"	2
17'-5"	16

On the first and second floors, loads are transferred from 48o.c. (1-1/8" thick) plywood sheathing, to purlins oriented in an east-west direction, to shallow (<17" high) trusses running in a north-south direction, to columns. Figure 45 shows a section of the flooring system used for the first and second floors.

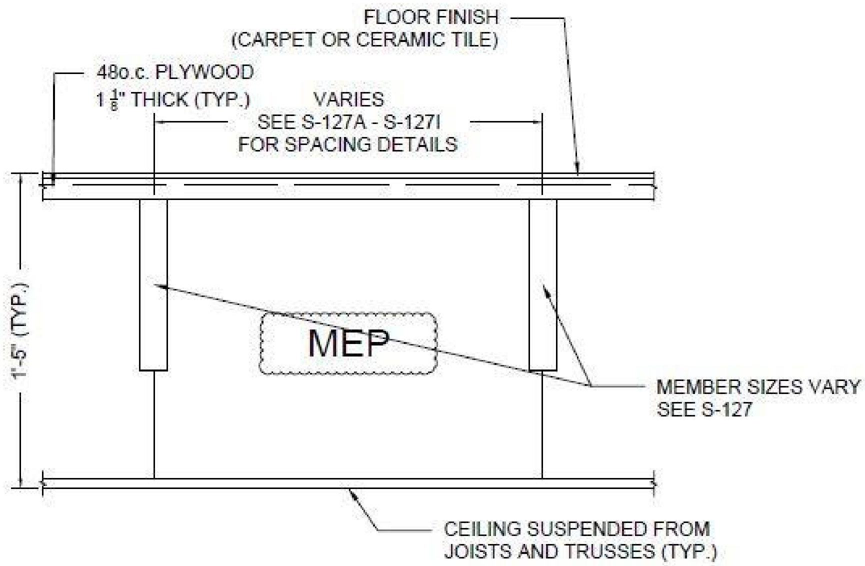


Figure 45. Typical floor framing section

Figure 46 shows the required sizes for the second floor joists. In Figure 46, “S.S.” refers to members using Select Structural Mixed Southern Pine. All other members use No. 1 Mixed Southern Pine.

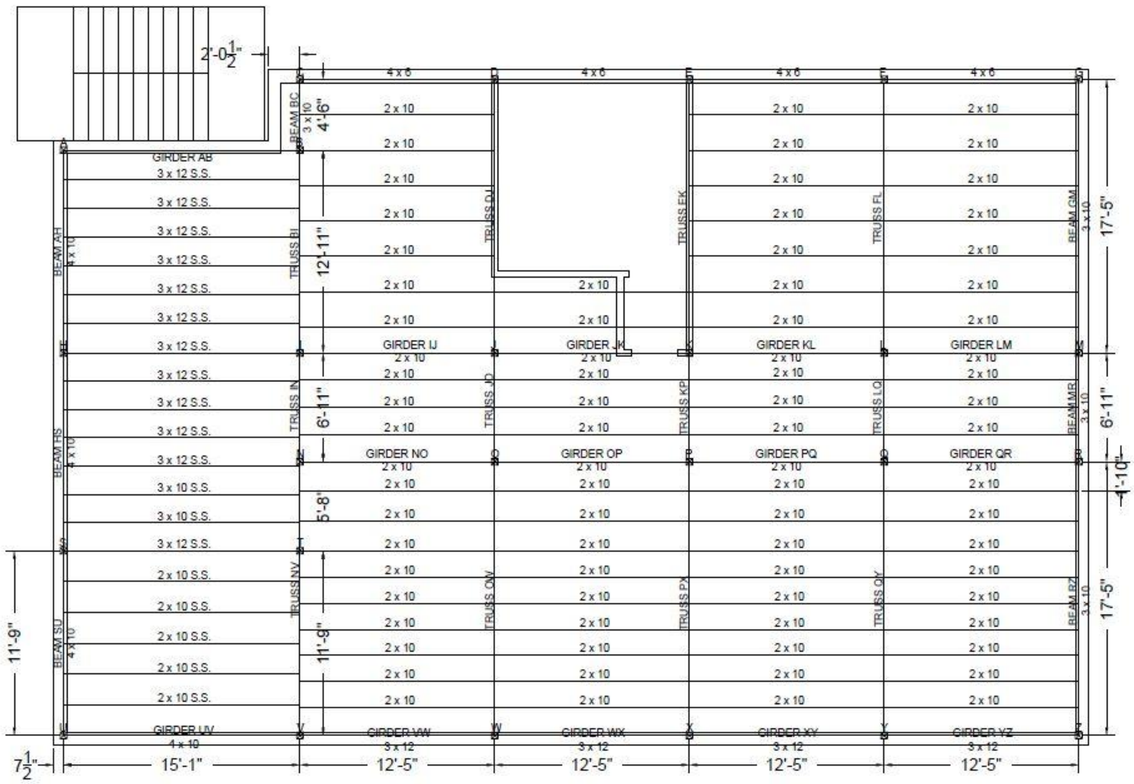


Figure 46. Second Floor Joist Sizes

Figure 47 shows the required sizes for the first floor joists.

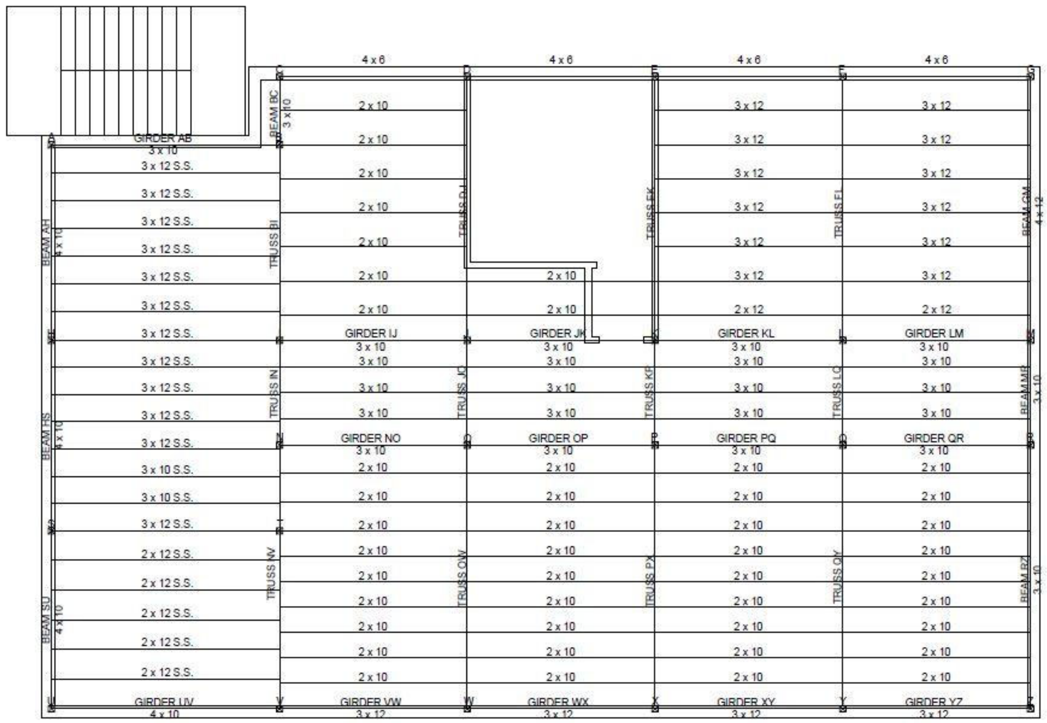


Figure 47. First Floor Joist Sizes

Four parallel-chord truss configurations were used for the first and second floors. Table 19 lists the truss type used for each span on the first and second floors.

Table 19. Truss types used for each span

Truss Designation	Spans Used
A	DJ, EK, FL
B	BI
C	IN, JK, KP, LQ
D	OW, PX, QY
E	NV

Figure 48 shows the locations of members in truss type A. Table 52 and Table 53 in Appendix F show the required sizes of the members in each truss.

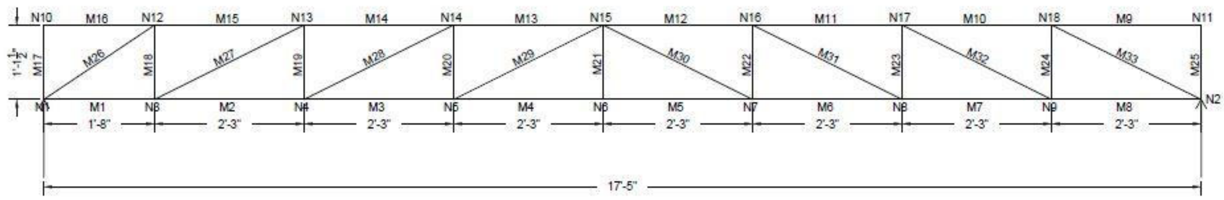


Figure 48. Truss type A members

Figure 49 shows the locations of members in truss type B. Table 54 in Appendix F shows the required sizes of the members in each truss.

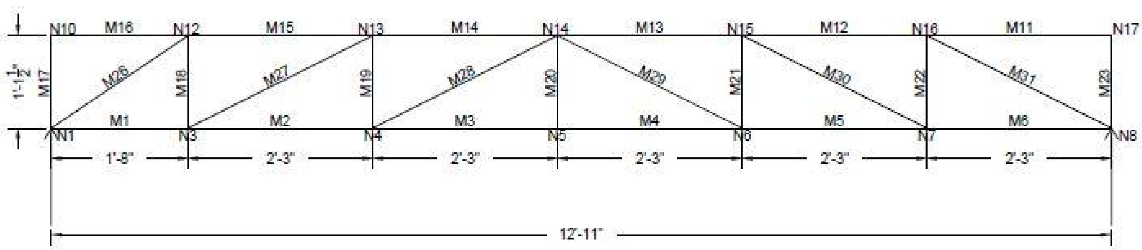


Figure 49. Truss type B members

Figure 50 shows the locations of members in truss type C. Table 55 and Table 56 in Appendix F show the required sizes of the members in each truss.

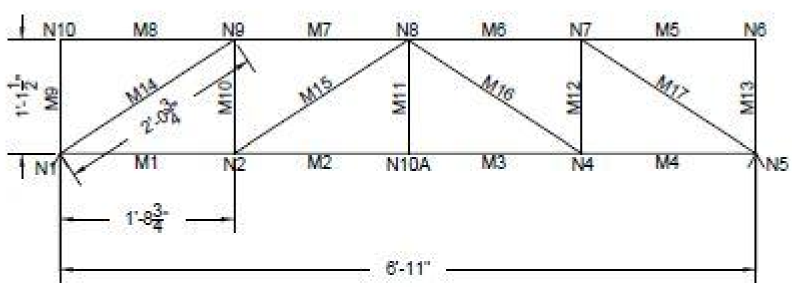


Figure 50. Truss type C members

Figure 51 shows the locations of members in truss type D. Table 57 and Table 58 in Appendix F show the required sizes of the members in each truss.

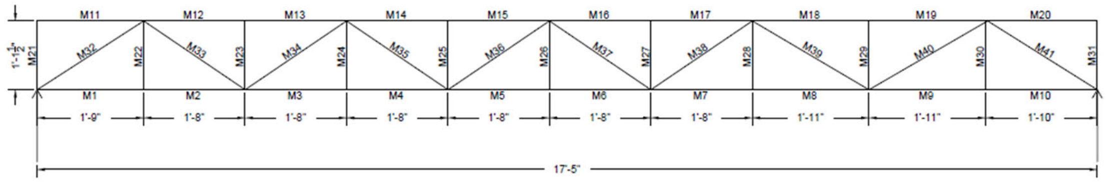


Figure 51. Truss type D members

Figure 52 shows the locations of members in truss type E. Table 59 in Appendix F shows the required sizes of the members in each truss.

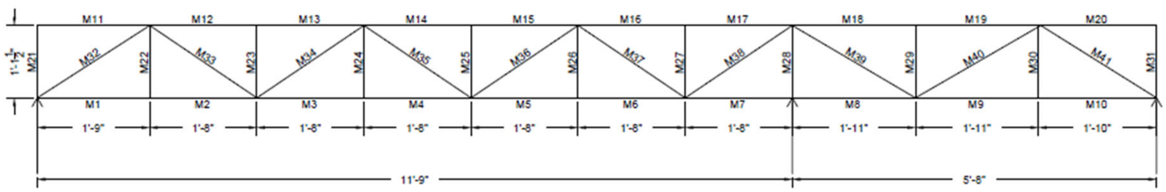


Figure 52. Truss type E members

The slab on grade in the basement needs to be 6” thick in order to support the LRFD factored load of 420 psf (10.19 psf dead load + 254.56 psf live load, with the weight of the rainwater included as a live load) of completely full rainwater storage tanks. While it was possible to use a 5” thick slab on grade underneath portions of the basement, using different slab thicknesses would have made the basement more difficult to construct.

The required sizes for the building’s framing can be found in Appendix F. As shown in this appendix, most of the studs are either 2x4 or 2x6 members. However, larger member sizes were sometimes required for longer studs.

The required sizes of the building’s columns are also contained in Appendix F. All of the columns consist of built-up column sections using multiple dimension lumber members. The allowable loading on each column was taken as the sum of the allowable loads on each member.

Table 20 shows the quantities used to estimate the cost of the gravity load resisting system.

Table 20. Assembly quantities for new building gravity load resisting system

Individual Activities	UniFormat Code	Units	UOM
6" slab-on-grade, non-industrial, reinforced	A1030 120 4480	2488.86	SF
Wood joists, 2 x 10, 24" o.c.	B1010 261 3400	2035	SF
Wood joists, 3 x 10, 24" o.c.	B1010 261 5400	0	SF
Wood joists, 3 x 12, 24" o.c.	B1010 261 5800	385	SF
Wood joists, 2 x 10, 24" o.c.	B1010 261 3400	1081.28	SF
Wood joists, 2 x 12, 24" o.c.	B1010 261 3800	177.23	SF
Wood joists, 3 x 10, 24" o.c.	B1010 261 5400	343.53	SF
Wood joists, 3 x 12, 24" o.c.	B1010 261 5800	343.53	SF
Columns	B1010 210 2400	8334	SF
3/12 slope, 2 x 10, 24" o.c.	B1020 102 3800	2319.59	SF
3/12 slope, 2 x 12, 24" o.c.	B1020 102 4200	542.36	SF
Asphalt strip shingles, 4" slope, inorganic class A 210-235 lb./sq.	B3010 140 1100	2861.95	SF

6.2.2. Lateral Load Resisting System

The building's wind-resisting system consisted of diaphragms at each level and shear walls supporting these diaphragms. Since the low weight of the building's wooden frame results in comparatively small earthquake forces, the effects of seismic loads on the new building were not considered.

Figure 53 shows the lengths of each wall that were considered to resist the building's wind load.

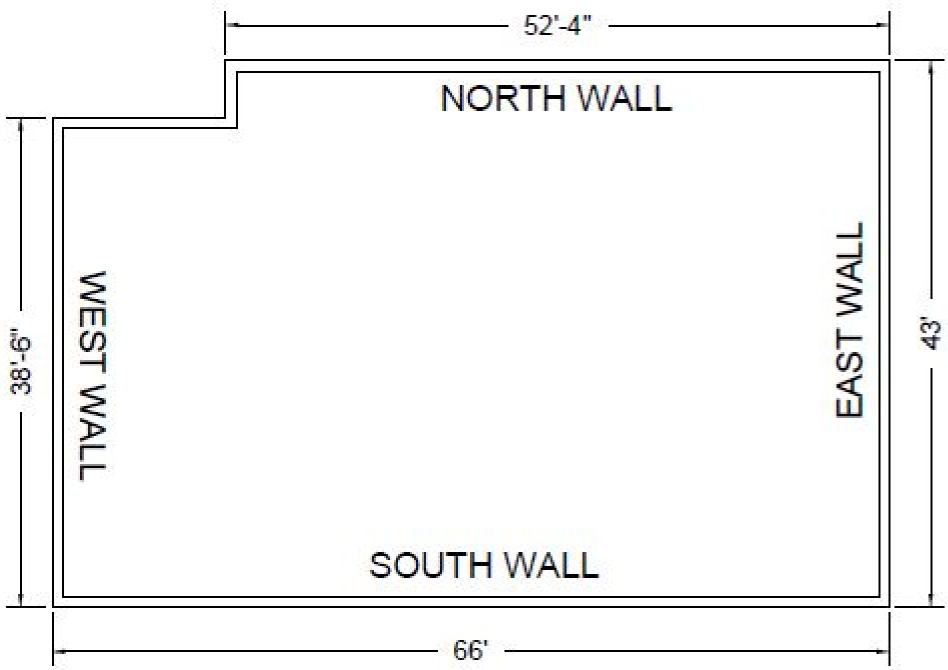


Figure 53. Design wall lengths for wind calculations

Table 21 shows the design loads on each side of the diaphragm. In this table, the loads under each wall refer to the loads supported by that wall as a result of wind in the perpendicular direction.

Table 21. Diaphragm design loads by level

		North		South		East		West	
Level	w (lb./ft)	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)
Roof	VARIES	6226	119.0	4423	67.0	12323	286.6	12323	320.1
2nd Floor	200.30	4307	82.3	4307	65.3	6610	153.7	6610	171.7
1st Floor	168.25	3617	69.1	3617	54.8	5552	129.1	5552	144.2

The diaphragm framing system for the roof is shown in Figure 54. Table 22 gives the allowable shear of this diaphragm in each direction. The allowable shear on each diaphragm was calculated using the American Wood Council *Special Design Provisions for Wind and Seismic Loading*.

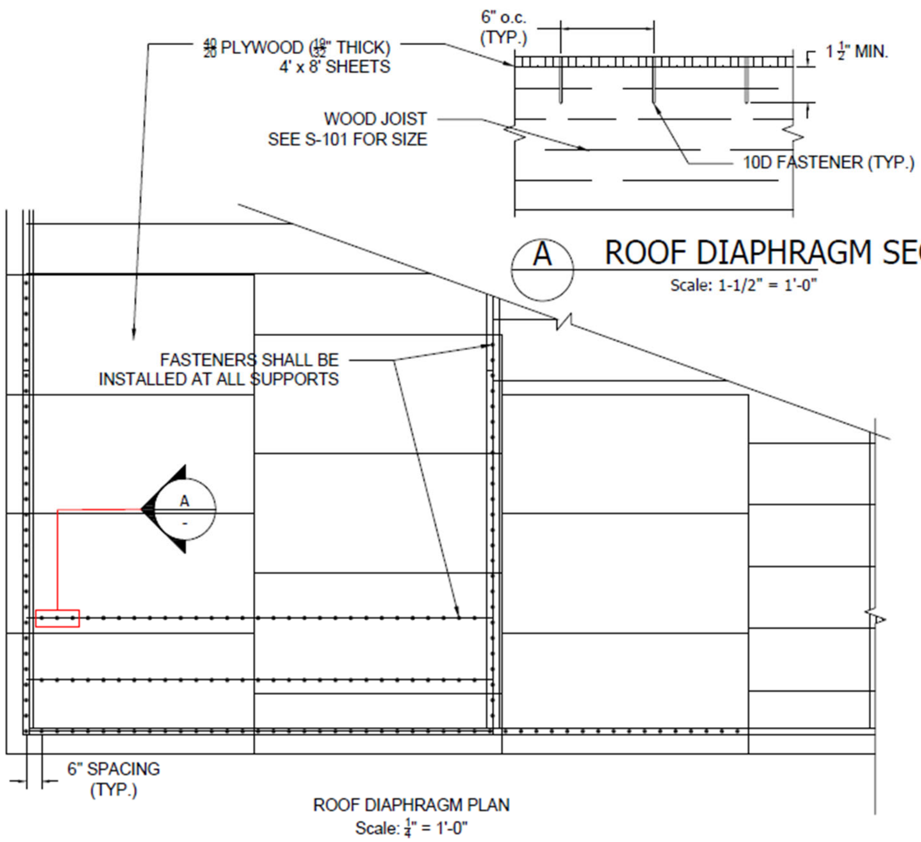


Figure 54. Roof diaphragm framing scheme

Table 22. Roof diaphragm allowable strengths

Wall	Allowable Load
East and West	300 lb./ft. (ASD) 480 lb./ft. (LRFD)
North and South	400 lb./ft. (ASD) 640 lb./ft. (LRFD)

Figure 55 shows the diaphragm framing scheme used for the first and second floors. Table 23 gives the allowable shear of this diaphragm in each direction.

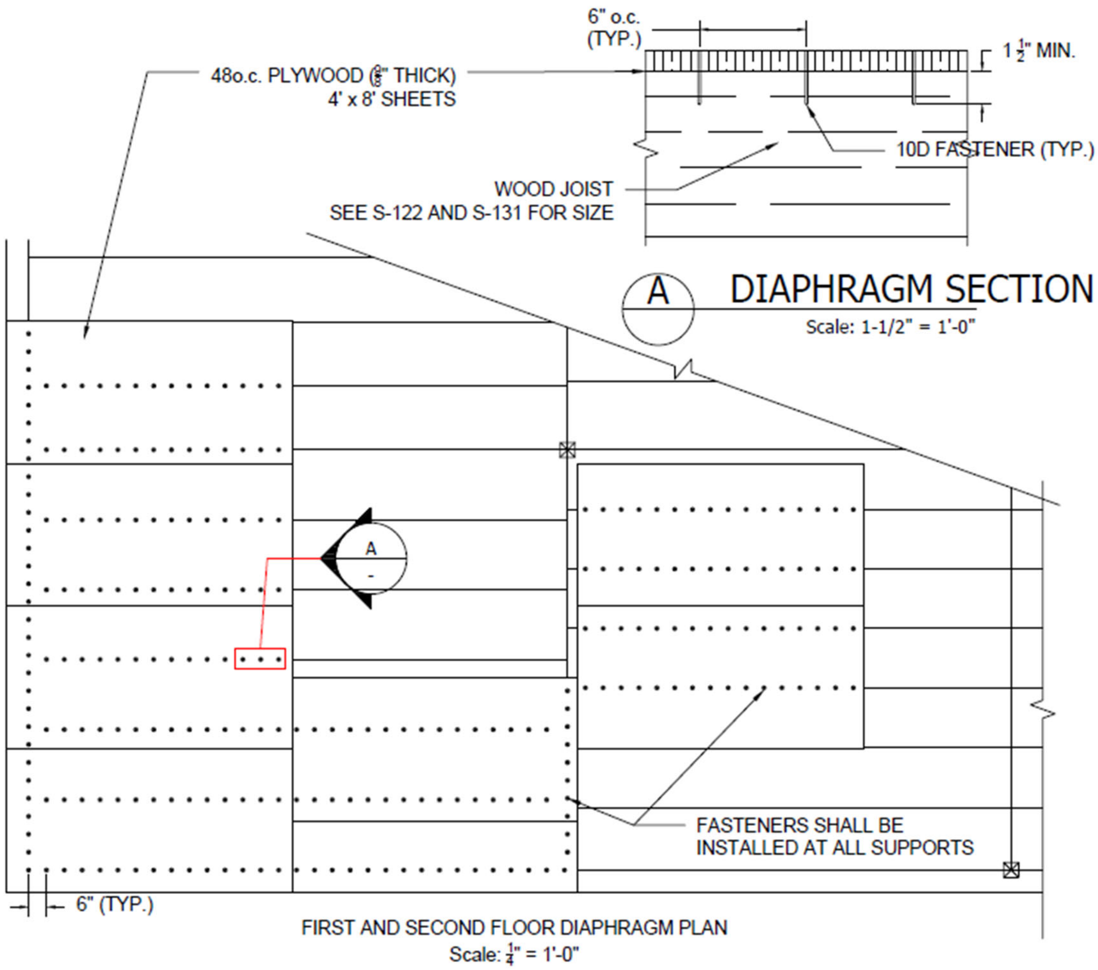


Figure 55. First and second floor diaphragm framing scheme

Table 23. 2nd floor diaphragm allowable strengths

Wall	Allowable Load
East and West	300 lb./ft. (ASD) 480 lb./ft. (LRFD)
North and South	400 lb./ft. (ASD) 640 lb./ft. (LRFD)

Table 24 shows the design forces on each shear wall at each level:

Table 24. Shear wall design forces by level

	North		East		South		West	
Level	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)	R (lb.)	v (lb./ft.)
2nd Floor - Roof	6226	118.97	12323	286.58	4423	67.02	12323	320.08
1st Floor - 2nd Floor	10532	201.26	18933	440.30	8730	132.27	18933	491.77
Basement - 1st Floor	14150	270.38	24485	569.43	12347	187.08	24485	635.98

The allowable LRFD forces on the north shear wall are shown in Table 25 for the interval from the basement to the first floor, and from the first floor to the second floor. The interval from the second floor to the roof was not analyzed for any of the shear walls because the shear walls in this interval were subjected to the smallest loads and because the openings were generally similar to those on the first floor. Figure 56 depicts the framing scheme for the north shear wall.

Table 25. North shear wall allowable forces

Parameter	**Basement – 1st Floor**	**1st Floor – 2nd Floor**
Structural Panel Thickness	3/8”	
Edge Fastener Spacing	4”	
Intermediate Fastener Spacing	12”	
Allowable Force (AWC SDPWS Table 4.3A)	840 lb./ft.	
LRFD Safety Factor	0.8	
C_{ub} (AWC SDPWS Table 4.3.3.2)	0.5	
C_o (AWC SDPWS Eqns. 4.3-5 and 4.3-6)	1.000	0.859
Factored LRFD Allowable Force	336.00 lb./ft.	288.48 lb./ft.

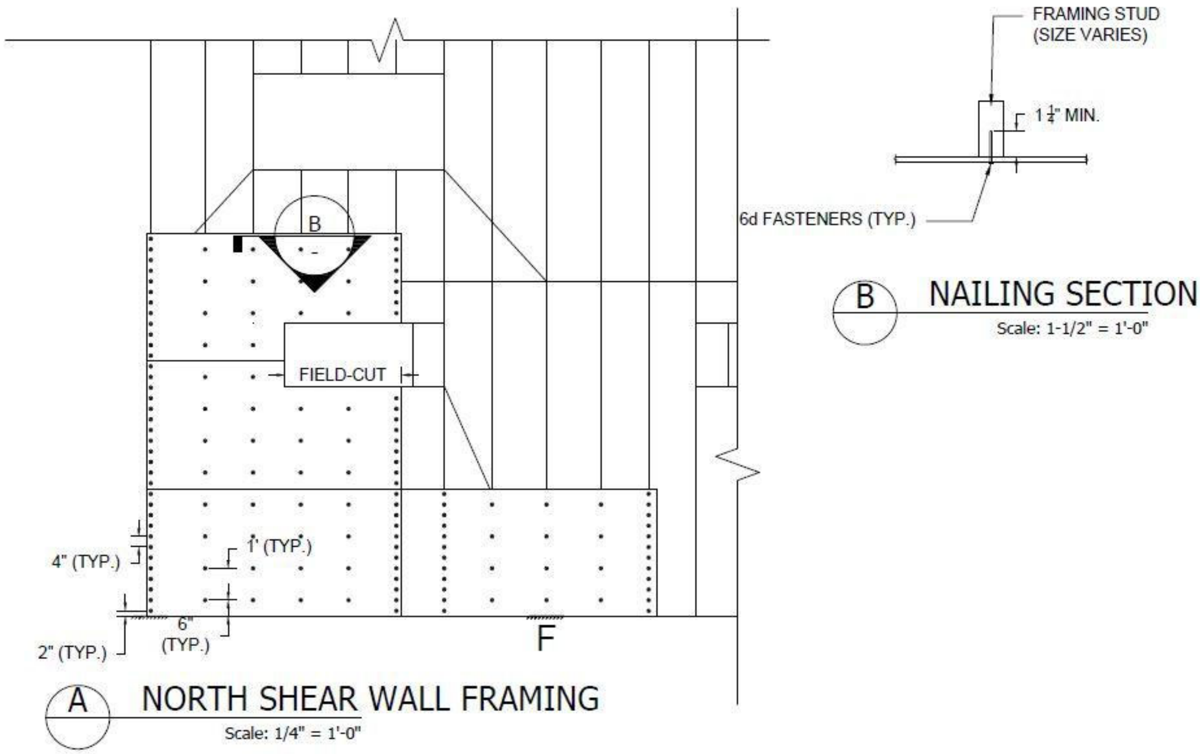


Figure 56. North shear wall framing scheme

Table 26 shows the allowable LRFD forces on the bottom two stories of the east shear wall. Figure 57 depicts the framing scheme for this wall.

Table 26. East shear wall allowable forces

Parameter	**Basement – 1st Floor**	**1st Floor – 2nd Floor**
Structural Panel Thickness	3/8”	
Edge Fastener Spacing	2”	
Intermediate Fastener Spacing	12”	
Allowable Force (AWC SDPWS Table 4.3A)	1430 lb./ft.	
LRFD Safety Factor	0.8	
C_{ub} (AWC SDPWS Table 4.3.3.2)	0.5	
C_o (AWC SDPWS Eqns. 4.3-5 and 4.3-6)	1.000	0.793
Factored LRFD Allowable Force	572.00 lb./ft.	453.43 lb./ft.

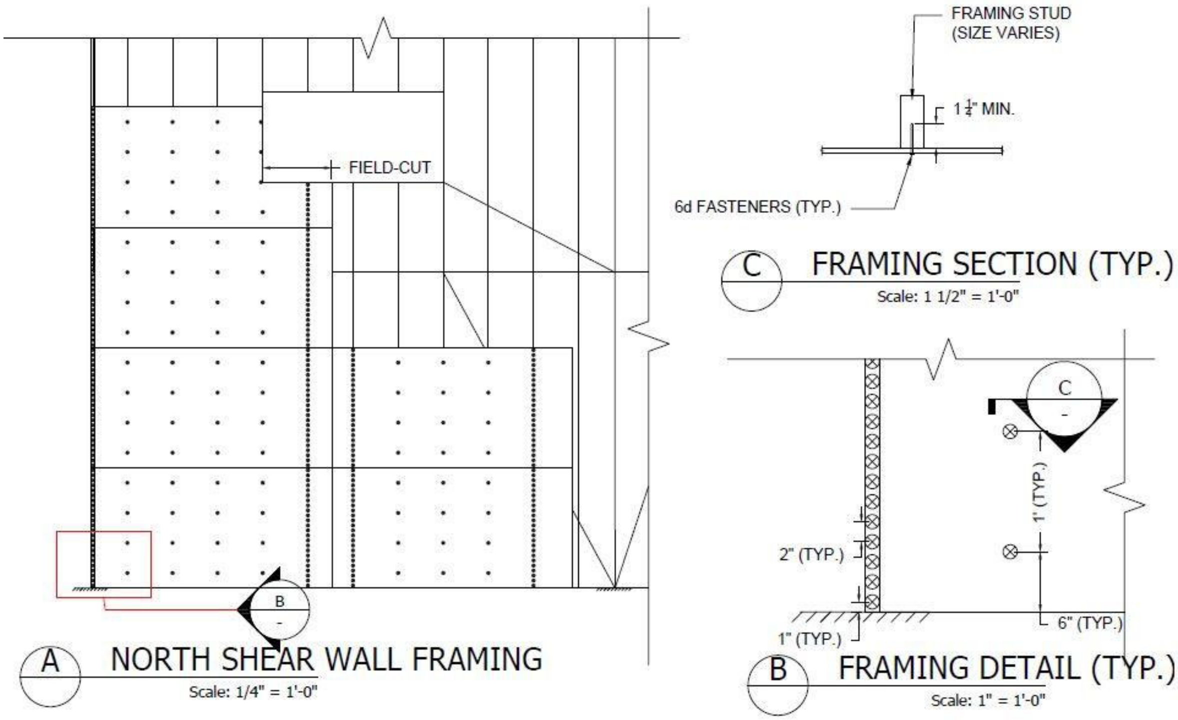


Figure 57. East shear wall framing scheme

Table 27 shows the allowable LRFD forces on the bottom two stories of the south shear wall. Figure 58 depicts the framing scheme for this wall.

Table 27. South shear wall allowable forces

Parameter	Basement – 1st Floor	1st Floor – 2nd Floor
Structural Panel Thickness	3/8”	
Edge Fastener Spacing	6”	
Intermediate Fastener Spacing	12”	
Allowable Force (AWC SDPWS Table 4.3A)	560 lb./ft.	
LRFD Safety Factor	0.8	
C_{ub} (AWC SDPWS Table 4.3.3.2)	0.5	
C_o (AWC SDPWS Eqns. 4.3-5 and 4.3-6)	1.000	1.000
Factored LRFD Allowable Force	224.00 lb./ft.	224.00 lb./ft.

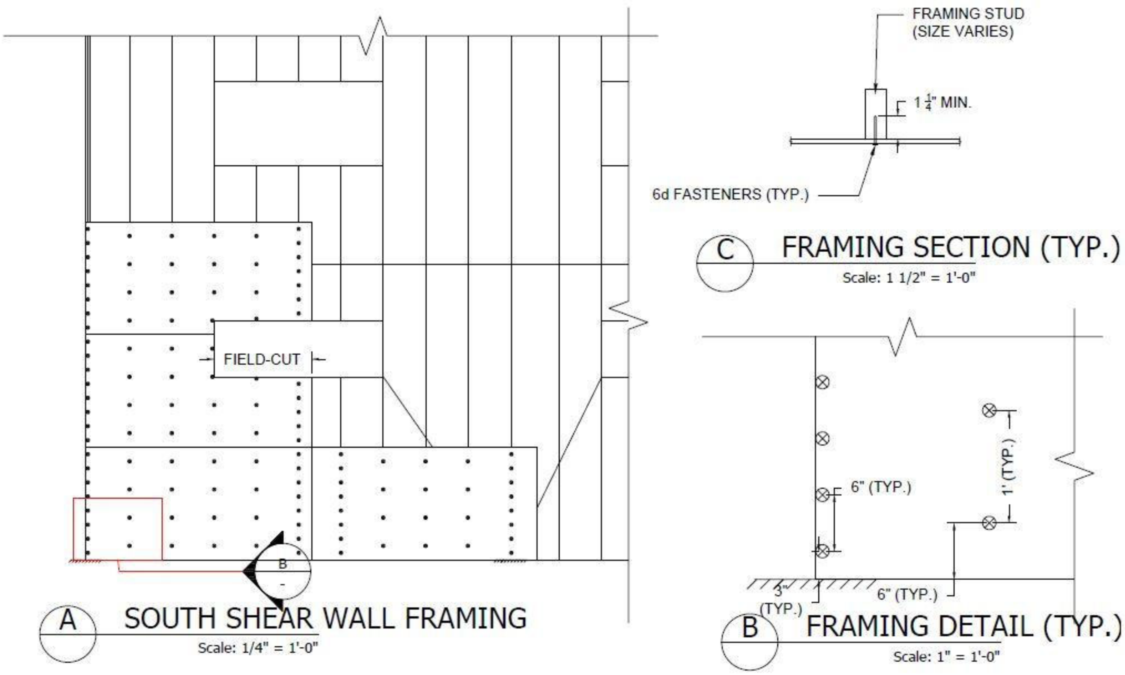


Figure 58. South shear wall framing scheme

Table 28 shows the allowable LRFD forces on the bottom two stories of the west shear wall. Figure 59 depicts the framing scheme for this wall.

Table 28. West shear wall allowable forces

Parameter	Basement – 1st Floor	1st Floor – 2nd Floor
Structural Panel Thickness	3/8”	
Edge Fastener Spacing	2”	
Intermediate Fastener Spacing	6”	
Allowable Force (AWC SDPWS Table 4.3A)	1430 lb./ft.	
LRFD Safety Factor	0.8	
C_{ub} (AWC SDPWS Table 4.3.3.2)	0.6	
C_o (AWC SDPWS Eqns. 4.3-5 and 4.3-6)	1.000	1.000
Factored LRFD Allowable Force	686.40	686.40

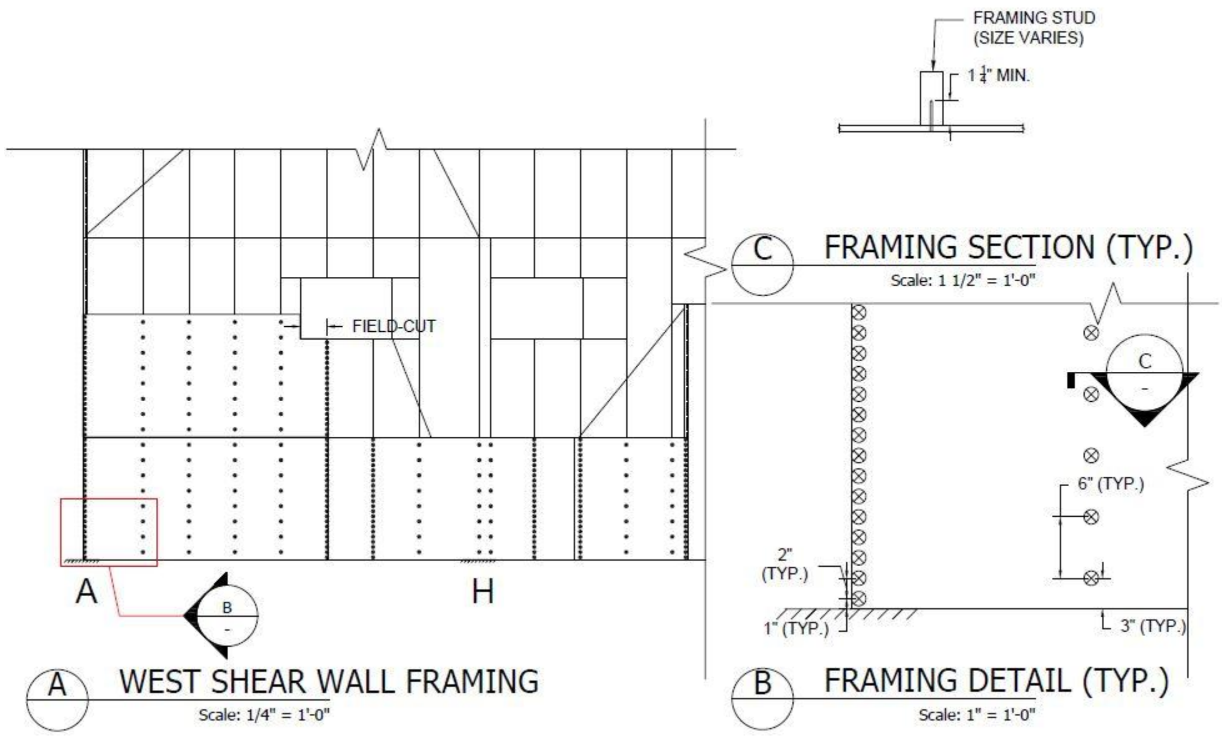


Figure 59. West shear wall framing scheme

All quantities for the lateral load resisting system were included in the assembly quantities for the flooring and framing systems. As a result, the lateral load resisting system was not considered as a separate line item in the estimated cost of the building's structure.

6.2.3. Stairwell and Fire Escape

Figure 60 shows the arrangement and sizes of the stairwell's supporting members.

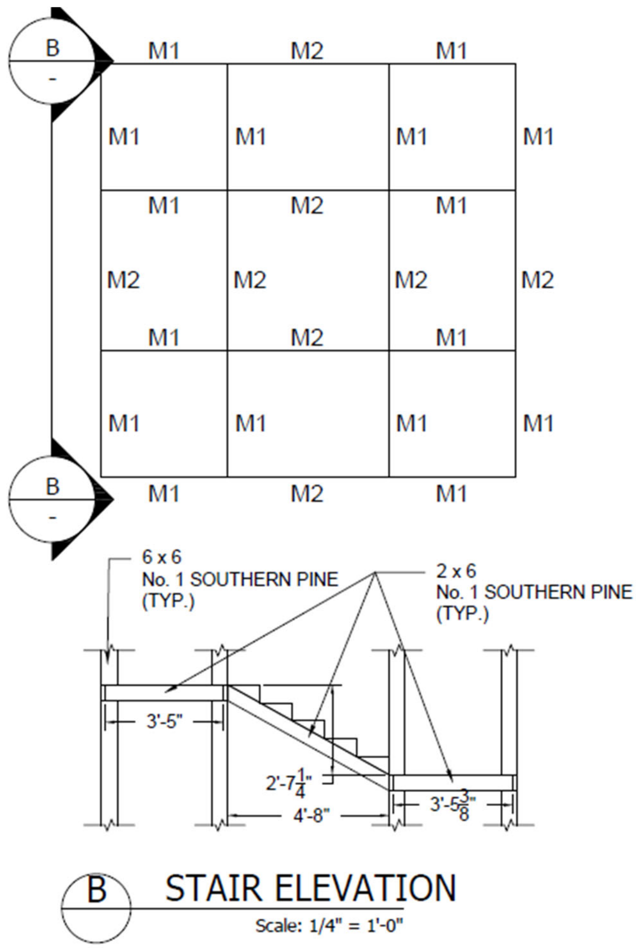


Figure 60. Stairwell member sizes

Table 29 shows the results of the moment calculations for the stairwell joists. Table 30 summarizes the calculations made for the column under the largest load. Table 31 lists the design loads on each foundation, calculated using RISA-3D. Table 32 shows the quantities used to estimate the cost of the stairwell:

Table 29. Moment calculations for stairwell joists

	M1	M2
Design Moment (lb.*ft.)	521.95	845.48
Allowable Moment (lb.*ft.)	1578.32	1578.32
Size	2 x 6	2 x 6

Table 30. Sizing calculations for critical columns

Member Size (Cross-Sectional Area)	6 x 6 (30.25 in.^2)
Design Load	D = 393 lb. L = 3056 lb. 1.2D + 1.6L = 5630 lb.
F_c (unadjusted)	1650 psi
F'_c (all adjustments made)	290.33 psi
Allowable Force	7086 lb.

Table 31. Stairwell basement reactions

	Dead Load (lb)	Live Load (lb)	1.2D + 1.6L (lb)
Northwest (transferred to north wall)	1314.1	8949.2	15896
Northeast (transferred to north wall)	1345.0	9343.4	16564
Southwest (separate spread footing)	1345.0	9343.4	16564
Southeast (separate spread footing)	1550.5	11963.9	21003

Table 32. Assembly quantities for new construction stairwell cost

Individual Activities	**UniFormat Code**	**Units**	**UOM**
Wood, prefab box type, oak treads, wood rails 3'-6" wide, 14 risers	C2010 110 1120	2	Flights

Figure 61 shows a plan view of the fire escape, and Figure 62 shows an elevation and detail view. The superstructure of the fire escape consists of the members listed in Table 33. As shown in Table 33, No. 3 Mixed Southern Pine was used for the surfaces of the fire escape, while No. 1 Mixed Southern Pine was used for members that carried larger loads.

Table 33. List of members for fire escape superstructure

Member Type	**Size**	**Material**
Handrail	1.5" x 1.75" (actual)	No. 3 Mixed Southern Pine
Baluster	1.5" x 1.75" (actual)	
Treads	2 x 12	
Stringers (Risers)	3 x 10	No. 1 Mixed Southern Pine
Stringers (Landings)	2 x 6	
Columns	6 x 6	

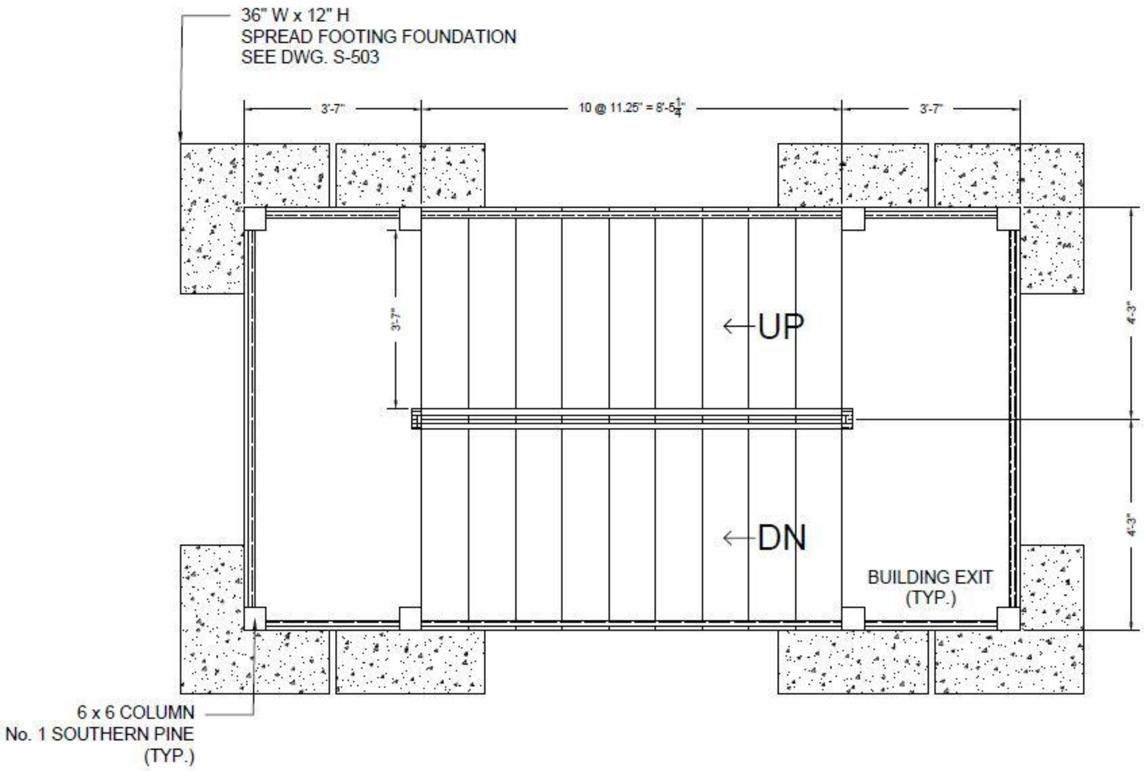


Figure 61. Fire escape plan

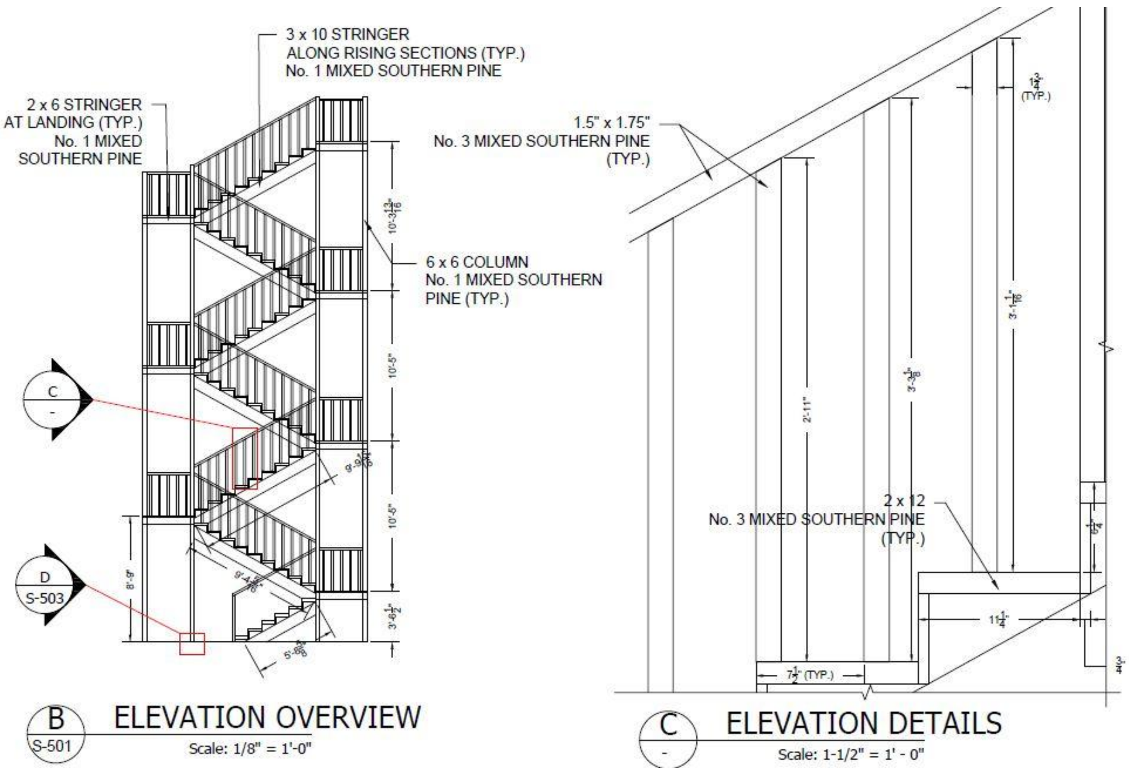


Figure 62. Fire escape elevation

Figure 63 shows an elevation of the fire escape foundations. These foundations, located at each corner of the stairs, have side lengths of 36” and a depth of 12”. The foundations are reinforced by No. 2 rebar (diameter = ¼"), each 29 ½" long and spaced 14 ¾" on center. As shown in Figure 63, the concrete was assumed to have a strength of 3000 psi and the reinforcing steel was assumed to be Grade 40 (F_y = 40,000 psi).

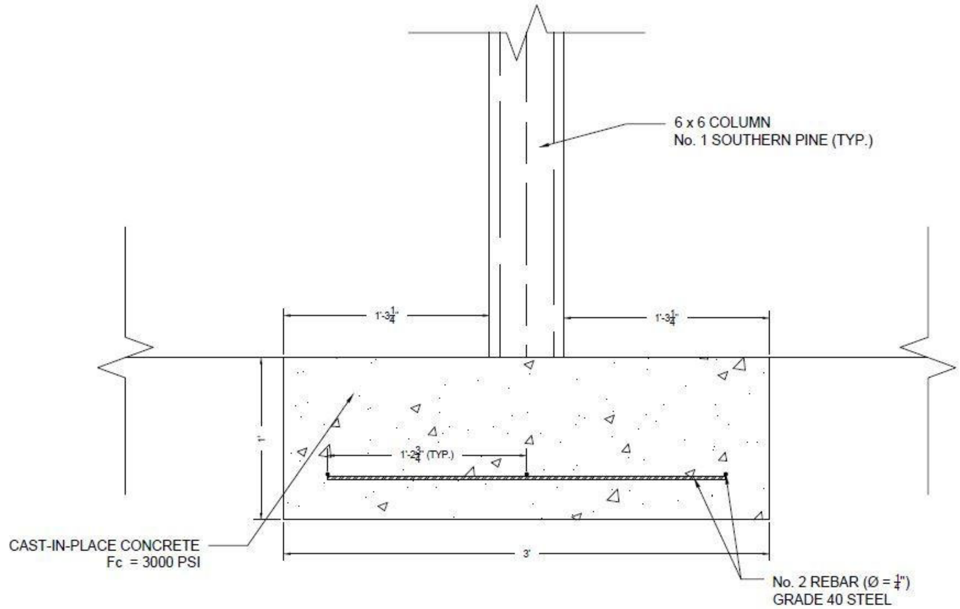


Figure 63. Fire escape footing elevation

Table 34 shows the quantities used to estimate the cost of the fire escape:

Table 34. Assembly quantities for new construction fire escape

Individual Activities	UniFormat Code	Units	UOM
Wood, prefab box type, oak treads, wood rails 3'-6" wide, 14 risers	C2010 110 1120	3	Flights

6.2.4. Foundations

Figure 64 contains the design for the strip footing foundations along the walls. The base of the foundation is 90" wide and 33" deep. This allows the foundation to support loads of up to nearly 9,930 lb./ft., including its own self-weight. While this loading raises the design load on the soil (1990 psf) close to the allowable load for the type of soil present (2000 psf), the allowable load is given by the Massachusetts Building Code and presents a conservative estimate. No. 3 rebar (diameter = 3/8") is used to reinforce this foundation, with each bar spaced 8 ¼" apart within the base and 3 ½" apart for the connection between the base and the concrete wall.

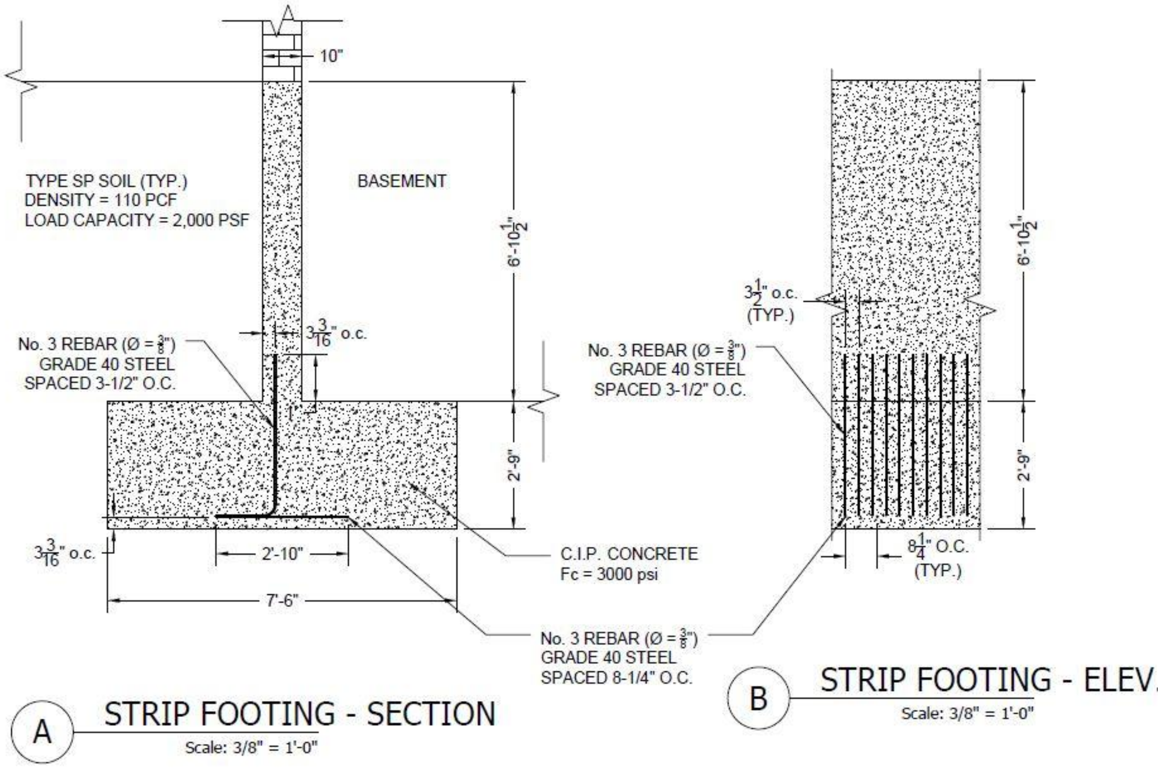


Figure 64. Strip footing section and elevation

Two foundation sizes were used for the spread footings. All foundations except for those underneath the stairwell have base lengths of 54” and depths of 12”. Reinforcement for these foundations consists of No. 3 rebar spaced roughly 4 3/16” on center and with bar lengths of 29 ½". Figure 65 shows an elevation view of this type of foundation:

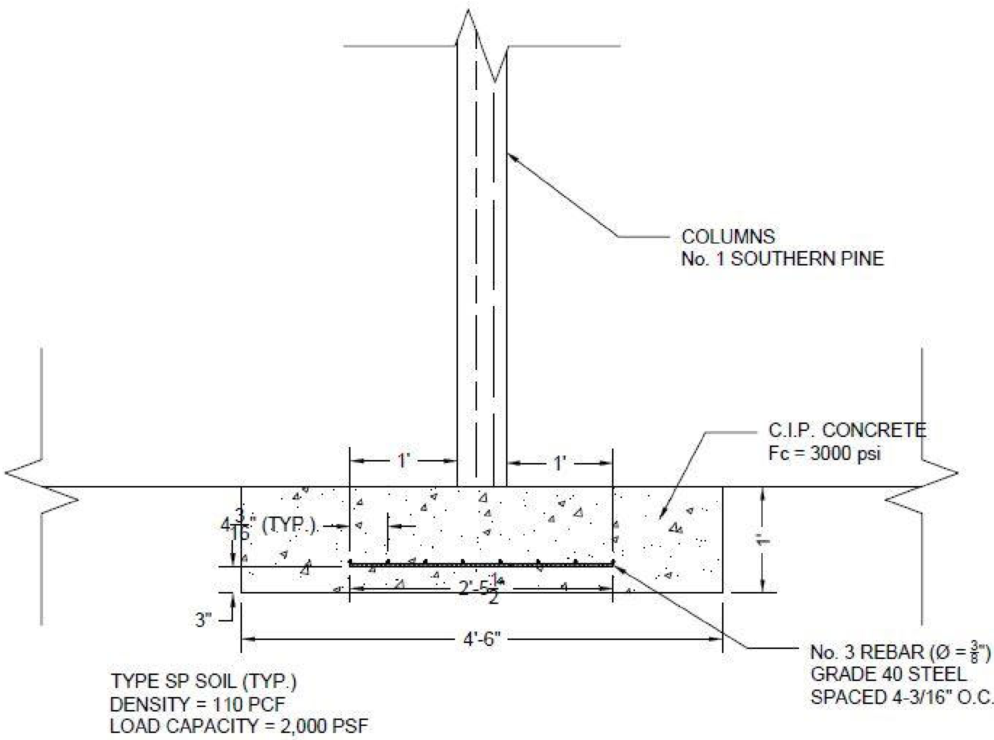


Figure 65. 54" spread footing elevation

The foundations underneath the southwest and southeast corners of the stairwell (Figure 16 shows the locations of these foundations) have base widths of 36" and thicknesses of 12". These foundations are reinforced by No. 3 rebar spaced 14 ¾" on center and with a length of 29.5". Figure 66 shows an elevation view for this type of foundation:

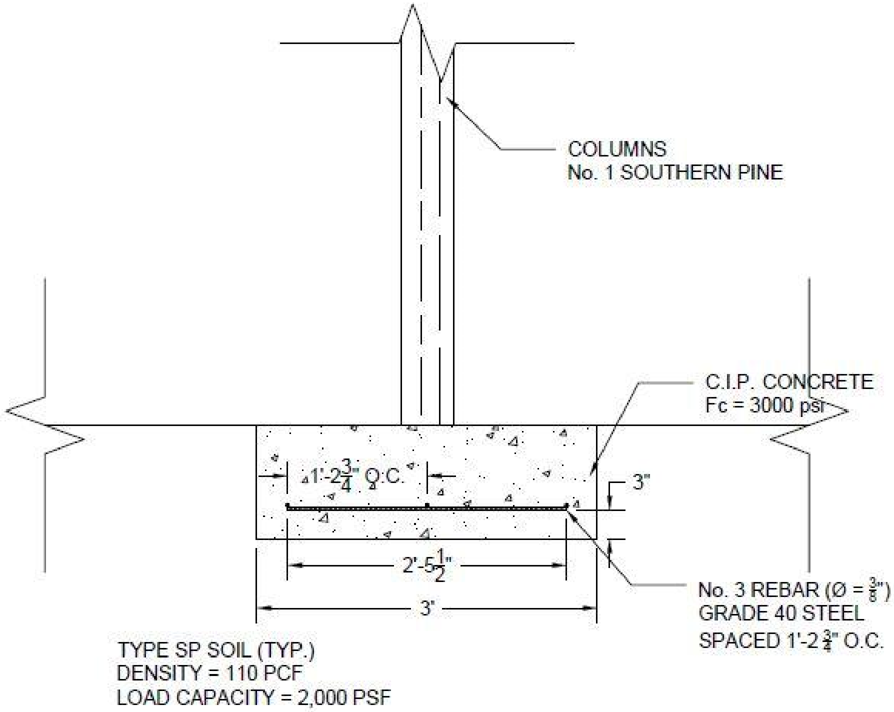


Figure 66. 36" spread footing elevation

Table 35 contains the cost items used to estimate the cost of the building's foundation system:

Table 35. Assembly quantities for new construction foundation cost

Individual Activities	**UniFormat Code**	**Units**	**UOM**
Load 25K, soil capacity 2 KSF, 3'-0" sq. x 12" deep	A1010 210 7100	4	ea
Load 50K, soil capacity 3 KSF, 4'-6" sq. x 12" deep	A1010 210 7150	7	ea
Load 20KLF, soil capacity 3 KSF, 96" wide x 24" deep, reinf.	A1010 110 6500	218	LF
8' wall, cast-in-place, direct chute, 8" thick	A2020 110 5020	218	LF

6.3. Fire Protection

Figure 67 depicts the sprinkler layout for the basement, Figure 68 depicts the sprinkler layout for the first floor, and Figure 69 depicts the sprinkler layout for the second floor. As shown in these figures, sprinklers were required in the bathroom as well as the janitor closets, as both the full bathrooms (Area = 145 SF) and the half bathrooms (Typical Area = 66 SF) were larger than 55 SF, and the janitor closets (Area = 36 SF) were larger than 24 SF.

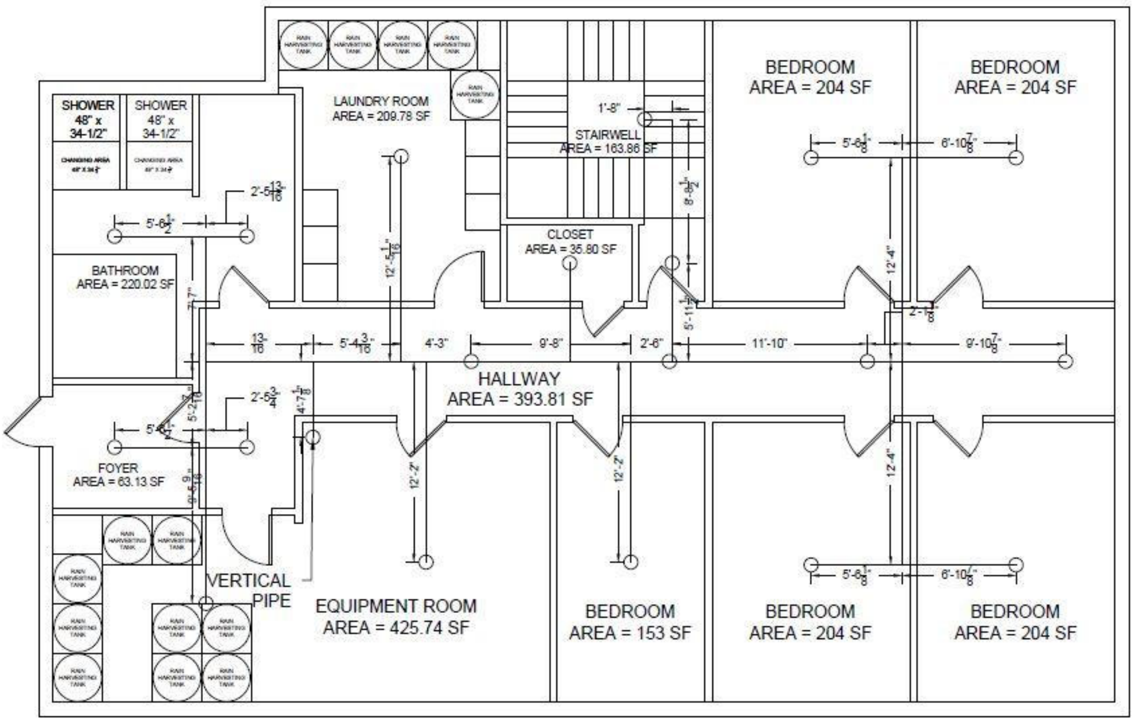


Figure 67. Sprinkler system layout - Basement

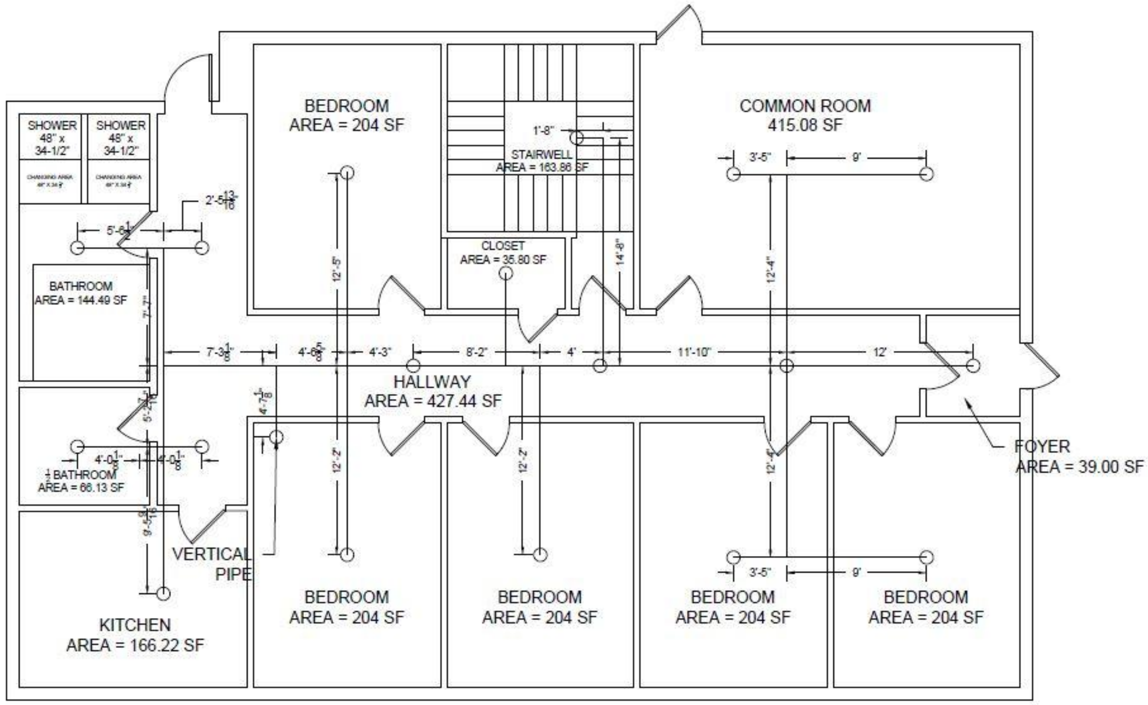


Figure 68. Sprinkler system layout – First floor

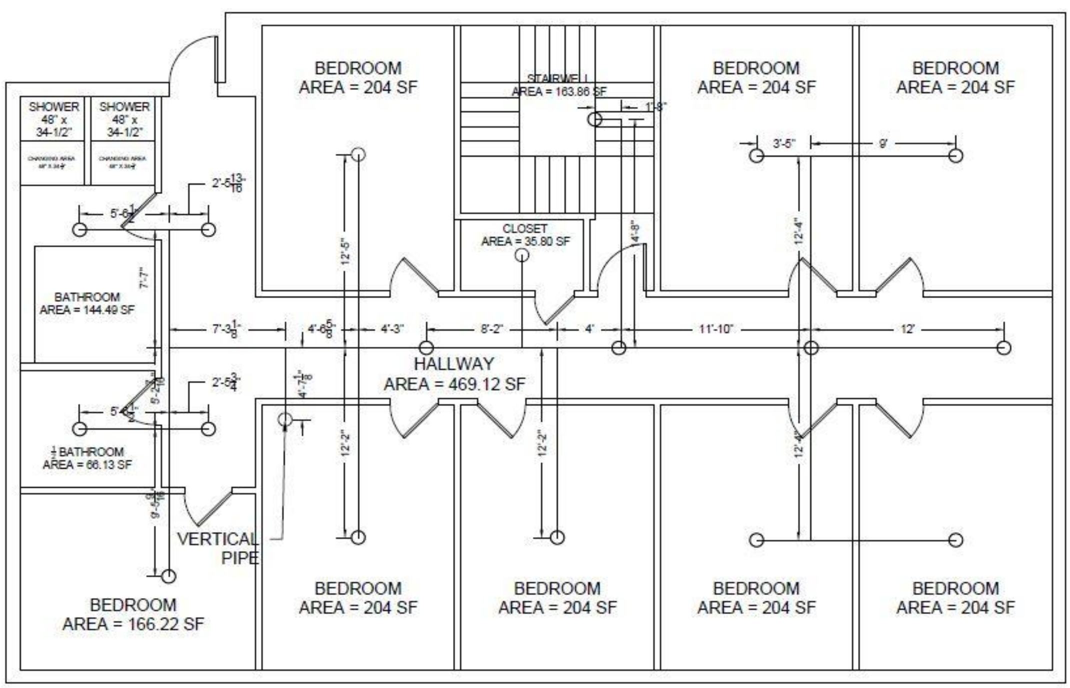


Figure 69. Sprinkler system layout – Second floor

Table 36 contains selected design properties for the sprinkler used. Table 37 contains the models and quantities required for the fire protection design.

Table 36. Product data for VK102 pendent sprinkler

	Imperial Units	Metric Units
Minimum Operating Pressure	7 psi	0.5 bar
Maximum Working Pressure	175 psi	12 bar
K-factor	5.6	80.6

Table 37. Fire protection system quantities

Component	Model	Quantity	UOM
Sprinkler	Viking VK102	55	EA
Horizontal Pipe	Copper (c = 140[1]), 2" diam.	586	LF
Vertical Pipe	Copper (c = 140), 3" diam.	22.96	LF

Figure 70 depicts the calculated pressures and fluid flows at each level. As shown in Figure 70, the required source pressure of 53.24 psi is less than the provided source pressure of 60 psi. Based on this condition, the fire protection system designed is acceptable.

[1] Engineers' Edge (n.d.)

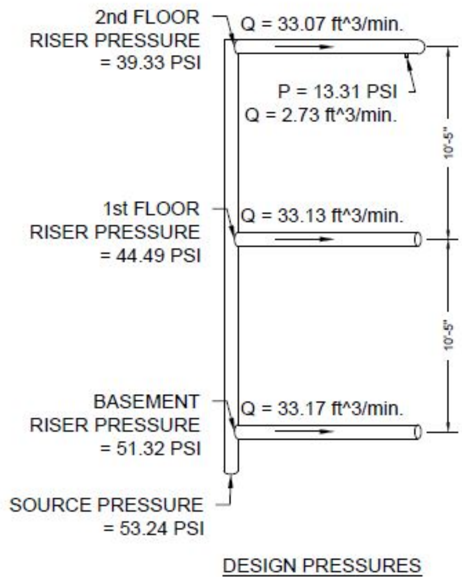


Figure 70. Fire protection system pressures and fluid flows

Table 38 lists the assembly quantities used to estimate the fire protection design.

Table 38. Assembly costs for new construction fire protection

Individual Activities	UniFormat Code	Units	UOM
On-off multicycle sprinkler system, ordinary hazard, one floor, 10,000 SF	D4010 390 1080	8343	SF
Wet standpipe risers, Class I, steel, black, sch. 40, 10' height, 4" diam., one floor	D4020 310 0560	1	Floors
(Additional floors)	D4020 310 0580	2	Floors
Rate of temperature rise detector	D4090 910 0060	32	EA
Multizone (4) control station with batteries	D4090 910 0470	1	EA
Battery standby power 10" x 10" x 17"	D4090 901 0640	1	EA

6.4. Sustainability Initiatives

6.4.1. Storage Tanks

The average water usage in Worcester, MA is 57 gallons/person/day (Boston.com, n.d.), or 1,938 gallons/day for a building with a capacity of 34. Assuming that indoor water use is allocated in the same proportions in Worcester as it is nationally, the breakdown of water use in the building is estimated in the table below. As shown in Table 39, roughly 795 gallons of the building's estimated daily water use of 1,938 gallons can be sourced from recovered rainwater. The breakdown of water usage, shown in Table 39, was determined based on the allocation of water use given by the Environmental Protection Agency (n.d.). The water usage allocated to each device is based on calculations performed on local and national averages, and could be reduced by using low-flow appliances.

Table 39. Estimated breakdown of water usage in the new building

	Total Water Use (gallons / day)	**% Water Use[2]**	**OK to use water from tanks?**
Toilet	465.12	24%	YES
Shower	387.6	20%	No
Faucet	368.22	19%	No
Clothes washer	329.46	17%	YES
Leaks	232.56	12%	No
Other	155.04	8%	No
Total	1938	100%	
Max. Amt. Supplied by Tanks	794.58	41%	

The calculations shown in Appendix F were used to evaluate the feasibility of rainwater storage tanks. These calculations assume that fourteen storage tanks are used, with a total capacity of 2100 gallons, as this was found to be the highest number of tanks that could fit in the basement due to spatial constraints. These calculations also assume that all rainwater that falls on impermeable surfaces within the property is drained into the tanks until the tanks are full. The design calculations shown in Table 40 were computed based on the Table 49 in Appendix F. In

[2] United States Environmental Protection Agency (n.d.)

total, the rainwater storage system evaluated can provide over 15% of the building's annual water use.

Table 40. Storage tank analysis results

Annual Water Use (Gallons)	Total Water Use	Water for Laundry + Toilets	Water from City	Water from Storage
Total	458,852	188,129	117,764	70,365
% Component		41.00%	25.67%	15.33%

If the rainwater storage system had an unlimited capacity, it could provide nearly one-quarter of the building's water. However, a total of 262 150-gallon tanks would be needed to store the maximum amount of water that will accumulate, making the addition of such a large number of tanks impractical for the relatively marginal benefits that this would offer.

Table 41 shows the construction cost and yearly savings generated by the storage tanks. Figure 71 contains a graph of the system's cumulative net present value over time. As shown in Figure 71, the storage tanks generate enough present value savings to recover their installation costs within 15 years and accumulate $1,219 in present value savings in 2039.

Table 41. Storage tank cost and revenue breakdown

Construction Cost	$229.95 / tank x 14 tanks $3219.30 for materials $59.34 / hour / laborer 2 laborers x 8 hours / laborer $949.44 for labor $4,168.74 total
Revenue	9,406 CF water recovered / year x $0.0367/CF[3] $345.22 / year

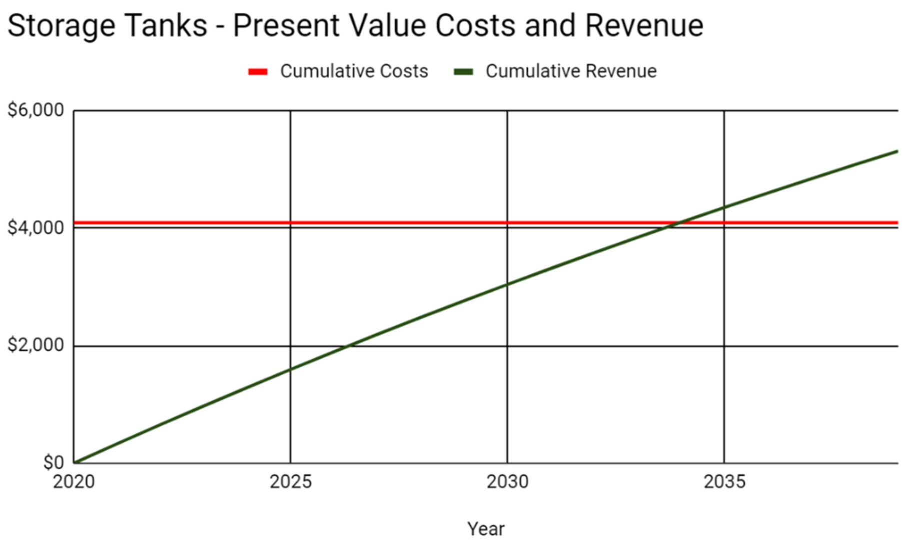


Figure 71. Storage tank net present value analysis

6.4.2. Solar Panels

Figure 72 shows the location of the solar panels on the roof. These solar panels were spaced as shown in order to prevent them from shading one another and to allow them to be serviced safely. As shown in Figure 72, the roof can accommodate a total of 35 5' x 10' panels,

[3] Guerin (n.d.)

for a total area of 1,750 SF. Each solar panel is tilted at a 43-degree angle from the horizontal in order to allow maximum exposure to sunlight.

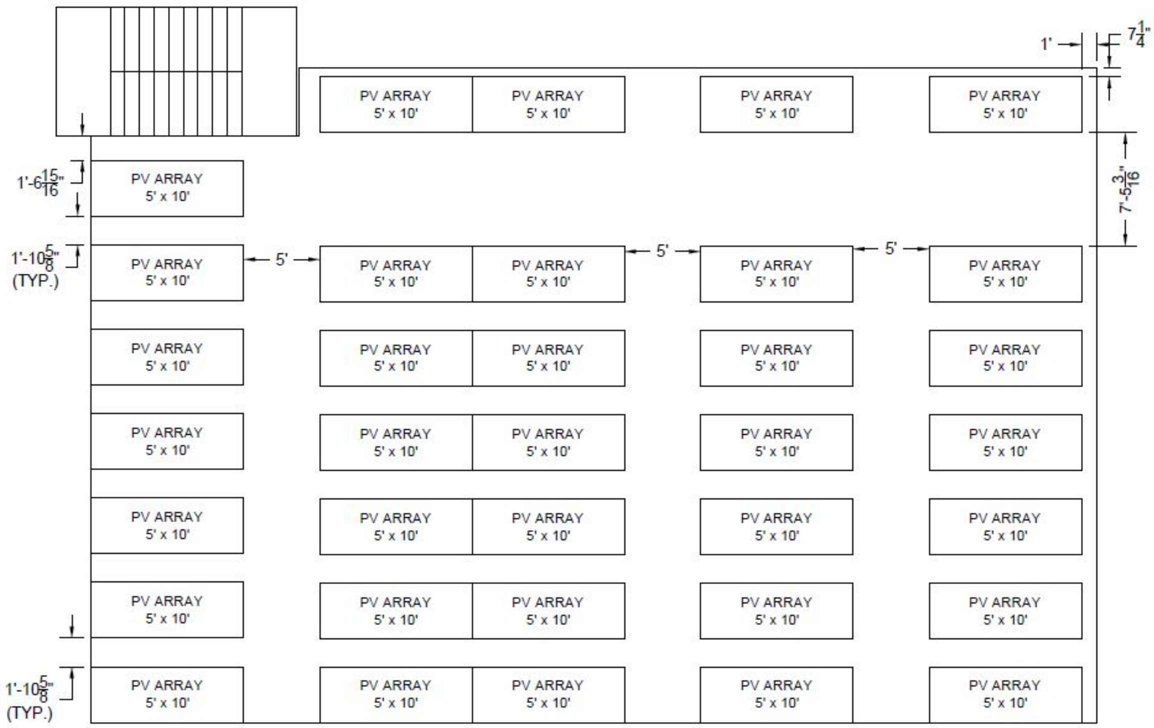


Figure 72. PV solar panel plan

A system of this size can accommodate a 26.1-kW solar panel system, which can generate 30,560 kWh/year in Worcester, MA (Zientara, n.d.). Table 42 contains a breakdown of this system's cost and revenue produced. As shown in Table 42, the maintenance cost for the solar panel system was assumed to be constant over time.

Table 42. Solar panel cost and revenue breakdown

Initial (Construction) Costs	26.1 kW x $3.47/kW[4] $90,634 construction cost Tax breaks: (26%) x $90,634 = $23,565 Net costs: $90,634 - $23,565 = $67,069
Annual (Maintenance) Costs	30,560 kWh/year x $0.03/kWh[5] $917/year
Annual Revenue	Electricity Savings: 30,560 kWh/year x $0.1313/kWh[6] $4,012/year Massachusetts SMART Reimbursement: 30,560 kWh/year x $0.02/kWh $611/year Total Savings: ($4,012/year) + ($611/year) = $4,623/year

Figure 73 provides a net present value analysis for the roof solar panel system, including both electricity savings and revenue generated by selling surplus energy to the power grid. The solar panel system begins to generate a positive net present value in 2039, when its cumulative net present value reaches $2,284. After 25 years, the life expectancy for each solar panel (Ecomark Solar, 2016), the solar panel system is expected to accumulate $19,656 in present value profits.

[4] SolarReviews (n.d.)
[5] US Dept. of Energy, as cited in Kalmus (n.d.)
[6] Electricity Local (n.d.)

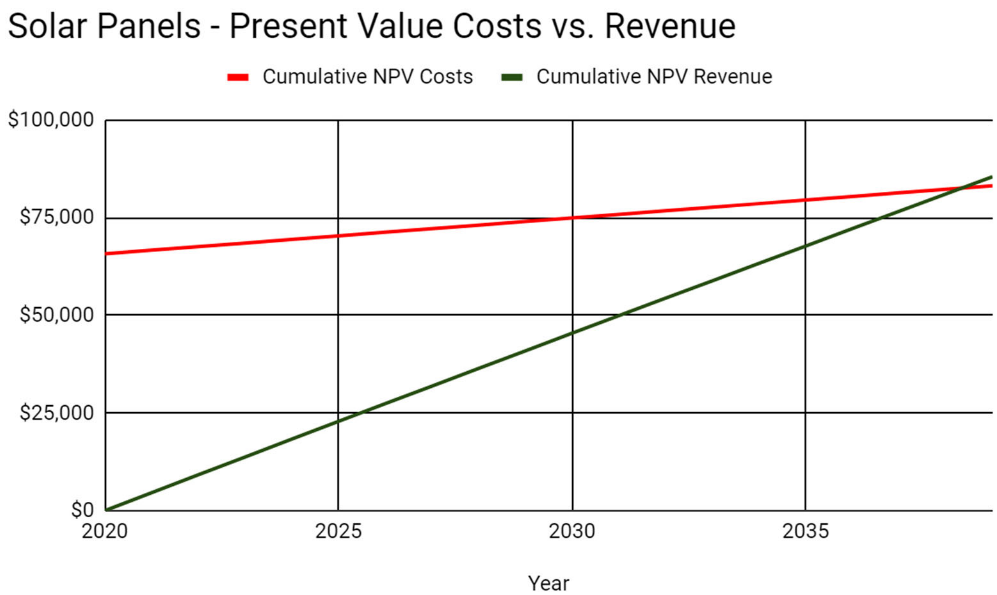


Figure 73. Solar panel net present value analysis

7.0. Cost Estimates

7.1. Renovation Costs

The total cost of the renovation is $261,198, or $150.71 per square foot affected by the renovation (Table 48 contains a list of areas included in this calculation).

Table 43 lists the components of the cost of renovation. Overhead costs make up the greatest portion of the project's cost, with total associated expenses of $52,239.51. The most expensive work activities are light replacement ($34,710), the accessibility ramp to the basement ($32,345), and the fire protection system ($23,516). The cost of the fire protection system was high because it was estimated as though it were a new system instead of as an improvement to an existing system.

The renovation's cost per year per resident was made significantly higher by the fact that the existing building is near the end of its life span. Since building foundations have a life expectancy of 110 years (eTool Global, n.d.), and 53 Wachusett Street was constructed in 1914 (Vision Government Solutions, n.d.), its foundations would need to be replaced in 2024. This would be an invasive construction procedure and might require replacing the building in its entirety. As a result, each component of the building was given a life expectancy of five years.

Table 43. Renovation cost breakdown

Work Item	Total
Indirect Costs	$53,235.50
Accessibility Ramp - Basement	$33,020.08
Accessibility Ramp - First Floor	$6,288.58
Basement Finish	$7,157.66
Basement Floor	$6,691.13
Bathroom Addition	$5,231.22
Bathroom Demo	$160.98
Bathroom Repairs	$8,641.04
Ceiling Work	$4,099.59
Door Replacement - Exterior	$1,371.89
Door Replacement - Interior	$2,188.98
Fire Protection	$23,969.95
Hazardous Material Removal	$3,066.67
Heating System	$7,202.90
HVAC	$0.00
Laundry Room	$4,418.10
Light Replacement	$35,331.27
New Bedrooms	$13,480.77
Plumbing	$3,261.93
Window Replacement	$8,627.51
WPI Takeover Item	$38,731.76
Total	**$266,178**
Cost / Year of Use	**$53,979**
# Residents	**17**
Cost / Resident / Year	**$3,175**

7.2. New Construction Costs

The new building is anticipated to have a total cost of $1,635,510, or $197.14/square foot for the 8,343-square foot building. This is slightly less than the $238.23/SF average cost of constructing a dormitory in the Boston area (Dalvit, 2016). The new building's cost includes the cost of demolishing and removing hazardous materials from the existing building, although those activities cost a total of $17,594, a small portion of the overall building cost. Table 44 contains a cost breakdown of this work by activity. The estimated costs shown in this table include 25% overhead and profit. Based on the building life expectancies given by eTool Global (n.d.), some of which are listed in Table 3, the new construction has an annual cost per resident of $1,844.

Table 44. New construction cost breakdown

	Cost	% of Total Cost
Accessibility	$54,980	3.3%
Basement	$75,532	4.6%
Bathrooms	$38,942	2.4%
Building Demolition	$14,472	0.9%
Columns	$2,604	0.2%
Demolition	$3,387	0.2%
Exterior Doors	$2,556	0.2%
Exterior Walls	$193,480	11.8%
Fire Protection	$98,769	6.0%
First Floor	$66,949	4.1%
Floor Finishes	$68,330	4.2%
Foundation	$97,740	5.9%
Hazardous Material Removal	$3,122	0.2%
HVAC	$280,289	17.0%
Kitchen	$2,082	0.1%
MEP	$309,758	18.8%
Roof	$18,907	1.1%
Second Floor	$72,375	4.4%
Stairs	$15,433	0.9%
Sustainability	$86,152	5.2%
Wall Finishes	$56,629	3.4%
Windows	$30,109	1.8%
WPI Takeover Item	$52,174	3.2%
Total	**$1,644,769**	
Total / Year	**$62,700**	
Capacity	**34**	
Total / Resident / Year	**$1,844**	

The annual cost per resident shown in Table 44 does not include the savings provided by solar panels and storage tanks. When the annual savings in electricity and water usage are included in the annual cost per resident, this value is reduced to $1,693 per resident per year, as shown in Table 45.

Table 45. Savings adjustments to new construction cost

	Total Cost
Unadjusted Construction Cost	$1,644,769
Cost / Year of Use	$62,700
# Residents	34
Annual Cost / Resident	**$1,844**
Annual Storage Tank Revenue	$345
Annual Solar Panel Revenue	$4,776
Adjusted Cost / Year of Use	$57,578
Adjusted Annual Cost / Resident	**$1,693**

8.0. Results and Conclusions

This project aimed to recommend a future use for 53 Wachusett Street as a WPI facility. During this project, it was determined that the building would more readily be used as a student residence than as a space for faculty offices or laboratories, due to its location and building codes pertaining to these uses. A renovation and a replacement building were then investigated. The set of renovations focused on increasing the building's capacity and did not include any structural improvements. Additions to the building were focused on meeting accessibility requirements while trying to minimize cost. The proposed new construction combines light-frame wood design on the exterior of the building with a truss framework in the building's interior, to allow the building to support solar panels, water storage tanks, and a brick façade.

Based on analyses of both options, replacing the building allows for the most optimal use of the site. First, the existing building is likely nearing the end of its life cycle. According to eTool Global (n.d.), building foundations have a life expectancy of 110 years. In comparison, the existing building was constructed in 1914 (Vision Government Solutions, n.d.) and has been in service for 105 years. Since replacing building foundations is incredibly difficult, the end of the foundations' life span may signify the end of the building's life span.

The limited life expectancy of the existing building is reflected in the difference between each design's calculated annual cost per resident, shown in Table 46. As shown in Table 46, the annual cost per resident associated with the renovation is 72% higher than that of the new construction. This means that the ratio of maintenance costs to revenue will be larger for the renovated building, and that it will be less lucrative for WPI than the new building. While the renovation has a lower cost per floor area than the new construction, this reflects the marginal scope of the renovations prescribed, compared to replacing the building, and does not necessarily justify renovating the building instead of replacing it.

Table 46. Renovation and new construction cost comparisons

	Renovation	**New Construction**
Cost	$261,198	$1,644,769
Capacity (Current capacity = 14)	17	34
Cost / Year	$53,979[7]	$62,700[8]
Cost / Resident / Year	$3,175	$1,844
Cost / Square Foot	$151	$197

In addition, renovating the building requires a large amount of uncertainty. Due to the limited scope of investigations, asbestos was only found in visible locations. Damage to interior walls due to leaking pipes could also not be determined, although several pipes were found to be leaking. Other risks might arise through proposed construction activities, including changing ceiling fixtures and moving an existing door frame downward to improve accessibility to the basement. While the replacement of ceiling fixtures was an aesthetic repair prescribed by Mr. Palumbo, WPI's Facilities Project Manager, the door frame would need to be moved to make the basement accessible without eliminating effectively all potential uses.

Although replacing the existing building at 53 Wachusett Street is the most advisable option, several measures could be taken to improve the new building's design. A major issue is that the new design contains a wooden frame and a brick façade. Wood is typically used for lighter loads, while brick is a somewhat heavy and expensive building material. This can be fixed in one of two ways. First, the brick exterior could be replaced with a wood façade, similar

[7] The annual cost of the renovation is based on the calculation that the existing building's foundations need to be replaced in 2024.
[8] The annual cost of the new construction was calculated based on the life spans of each building component, obtained from eTool Global (n.d.)

to the current building. Not only is wood a lighter material than brick, it is also a less expensive building material (The Gordian Group, "Assembly Costs", 2019), reducing the cost of the building by an estimated $92,000 (Table 70). Alternatively, the wood frame on the building's exterior could be replaced by a steel frame. Based on preliminary calculations, a steel frame would cost nearly $175,000 more than a wood frame (see Table 71 for a partial list of associated costs). However, due to steel's high durability, the annual cost per resident is only $66 more than for the wood frame (see Table 72). Replacing the wooden frame with a steel frame would allow for greater versatility in the building's use, including larger windows, and a more modern appearance to the building.

For this project to proceed, plans for demolishing the building and constructing a new one must be recommended to the WPI Board of Trustees. Before this can be done, the suggested revisions to the structural design should be investigated, and the new building's MEP needs to be designed. Completing the design and construction of 53 Wachusett Street will allow the site to be reincorporated as a long-lasting WPI facility.

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Appendix

Appendix A: Proposal

Project Number: MQP LDA-1902

53 Wachusett Street Design

A Major Qualifying Project Proposal

Submitted to the Faculty of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

By

John Bonina ______________________

Matt Rabasco ______________________

James Rios ______________________

Date: October 11, 2018

Approved:

Professor Leonard Albano ______________________

Abstract

The objective of this MQP is to design a potential use for 53 Wachusett Street, a building which WPI owns and will be taking over following the 2018-2019 school year. This MQP plans to reconfigure the building into student housing, by designing a renovation and a replacement facility to fit this purpose, and recommending a single option to WPI. This recommendation will depend on structural designs, cost estimates, and estimated project durations produced within this MQP.

Introduction

The objective of this MQP is to convert the property at 53 Wachusett Street, a fraternity house owned by WPI and rented to the Alpha Chi Rho fraternity, into a residence house. It is located within a block of the east end of campus at Dean Street. WPI has rented this building to Alpha Chi Rho since the mid-2000s, but this contract will end at the conclusion of the 2018-2019 school year and WPI does not plan to renew it. This MQP will investigate the possibilities of renovating the building, as well as demolishing it and erecting a new facility. The scope of the project will involve producing structural designs and cost estimates for both a renovation and a new construction for a residence house, while incorporating elements of sustainable design. The ultimate goal of this MQP is to produce a package for WPI of design alternatives for 53 Wachusett Street and a recommendation regarding which design WPI should implement.

Scope of Work

The first phase of this project required us to determine the type of facility that 53 Wachusett Street will house. We decided that this building should be used for residential purposes based on meetings with Ron O'Brien and Nick Palumbo, two executives from WPI's Department of Facilities, as well as visits and surveys of 53 Wachusett Street and research into zoning and permitting constraints.

Having decided to pursue a residential space for both a renovation and a new construction, we will begin with a conceptual design. This will include determining the layout of the building, the sizes, and purposes of the rooms. When each conceptual design is complete, we will produce structural designs, cost estimates, and project schedules for the renovation and new construction.

Government regulations will be an important consideration for the conceptual designs. One zoning constraint that presents some ambiguity is parking regulations. While a minimum number of parking spaces are required per resident in a university-owned building, it is not clear as to whether these parking spots must be adjacent to 53 Wachusett Street, or if parking spots in another location on campus can count towards the parking requirement. Another issue is compliance with Americans with Disabilities Act (ADA) requirements. If any portion of the building were to be renovated, up to 20% of the costs of the main renovation would have to be spent on improving accessibility to the area where the renovation was performed. If, however, the cost of renovations exceeds 30% of the building's value, the building would have to be made fully accessible (State of Massachusetts, 2017). The cost of accessibility measures is less of an issue when designing new constructions, since any new building would need to be made fully accessible.

We will include sustainability elements in our designs for both a renovation and a new construction. These include solar panels, LED lights, Energy Star efficient appliances, volatile organic chemical (VOC)-free paints, cork-board flooring, and surfaces made from recycled materials. Other sustainability elements, including rainwater retaining tubs in the basement, energy recycling HVAC systems, and geothermal heating, will only be considered for a new construction due to the difficulties of implementing them in an existing building.

Background

53 Wachusett Street

53 Wachusett Street is a three-story house located two blocks away from WPI's campus proper in an RG-5 residential zone (a general residential zone with a minimum lot size of 5,000 SF). The building was constructed in 1914 and purchased by WPI over the summer of 2007 for a sale price of $342,000. Even before accounting for inflation, this sale price is significantly greater than the property's current assessed value of $251,100 ($176,800 for the building itself and $74,300 for the surrounding land). (Vision Government Solutions, n.d.)

53 Wachusett Street occupies a rectangular lot with side lengths of 96' and 63', giving the lot a total area of 6,048 SF (0.14 acres) (City of Worcester, MA, n.d.). The interior of the building has a gross area of 6,073 SF. However, only 3,012 SF is considered to be living area, as the rest is occupied by the basement and multiple porches, and 80% of the top floor is not counted as living area. The gross and living areas of different sections of the building are given in Table 1 (Vision Government Solutions, n.d.):

Table 1: Floor Area Breakdown of 53 Wachusett Street

Code	Description	Gross Area (ft^2)	Living Area (ft^2)
BAS	First Floor	1,413	1,413
FUS	Upper Story, Finished	1,413	1,413
FAT	Attic, Finished	1,380	276
EPH	Enclosed Porch	48	0
OPH	Open Porch	326	0
UBM	Basement, Unfinished	1,413	0
WDK	Wood Deck	80	0
	Total	6,073	3,102

The house itself has three stories. The lower floor contains common areas, including a living room, a dining alcove, a kitchen, and a pantry. The top two floors contain nine bedrooms - four on the second floor and five on the third floor. These bedrooms currently accommodate a total of 12 people, although they had fit 14 people during the 2017-2018 school year.

53 Wachusett Street's building value was analyzed by comparing the positive and negative physical characteristics of the building to the building depreciation, adjusted cost per SF, and overall square footage (Taxpayer Information, 2012). The building utilizes a wood frame structure with clapboard exterior walls, plaster interior walls, and a gable/hip roof. (Vision Government Solutions, n.d.)

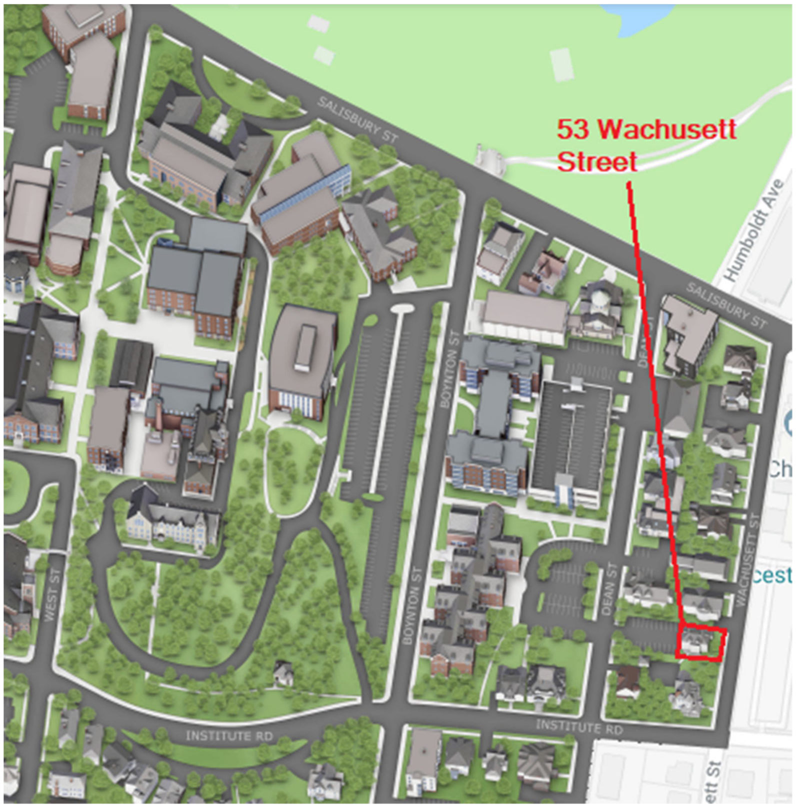


Figure 1: Aerial view of the east end of WPI's campus, with 53 Wachusett Street outlined in red.

Photo credit: https://maps.wpi.edu/?id=609#!sbc/?ct/0.

Based on our investigations of 53 Wachusett Street and meetings with stakeholders from WPI's staff, the structure is in stable condition but many of its systems need significant renovations. These renovations include upgrading the building's electrical equipment, increasing the number of bedrooms, and reconfiguring the basement and washing machines. An important consideration is the fact that a set of renovations that exceed 30% of the building's assessed value (State of Massachusetts, 2017) will necessitate upgrading the building so that it fully complies with the ADA requirements. Since the building has an assessed value of $251,100 (Vision Government Solutions, n.d.), a set of renovations exceeding $75,330 will trigger full compliance with ADA accessibility standards.

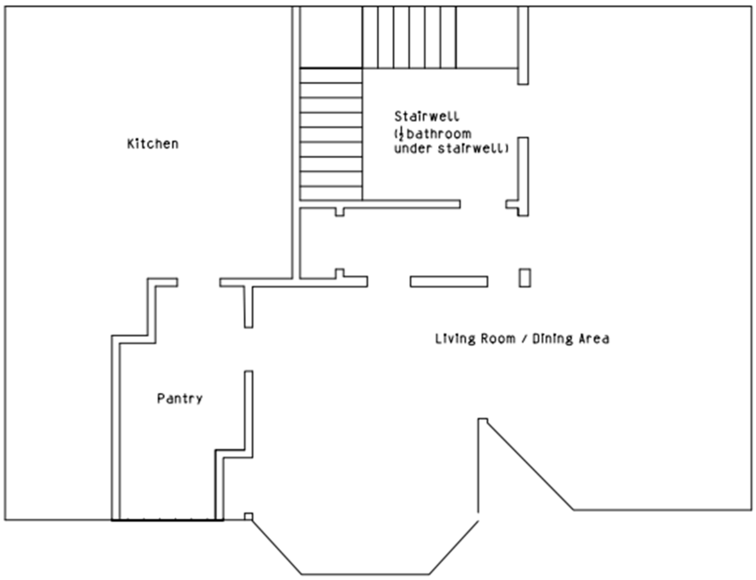


Figure 2: Existing first floor layout for 53 Wachusett Street. (not to scale)

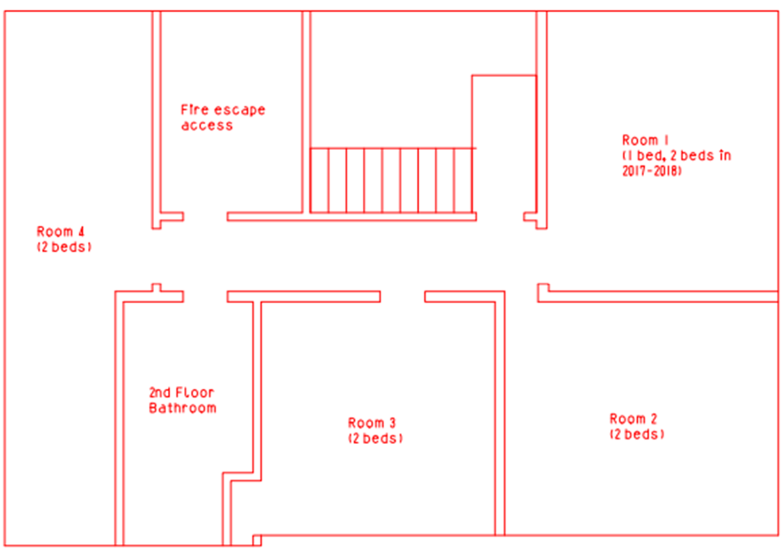


Figure 3: Existing second floor layout. (not to scale)

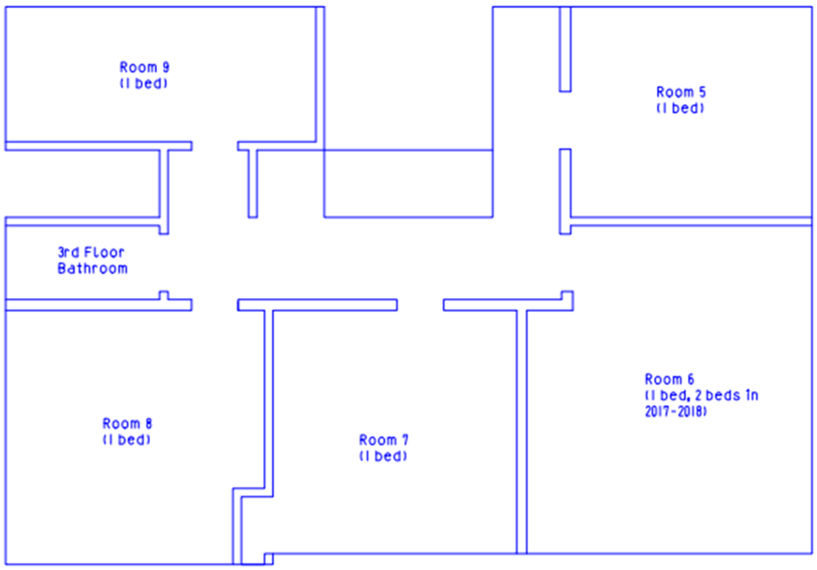


Figure 4: Existing third floor layout (not to scale)

Zoning

Although 53 Wachusett Street is roughly two blocks away from WPI, it is not located in the same institutional zone as the main campus. Rather, it is located in an RG-5 residential zone, the same zone as the WPI-owned Elbridge house (City of Worcester, MA, 2016), as shown in Figure 5. Lots in this area must be at least 5,000 square feet for the “Other residential permitted” classification for which WPI would be most likely to use the building. Sites with this classification must also have the following characteristics (City of Worcester, MA, 2018):

- Minimum Frontage = 50 LF
- Minimum Front Setback = 15 LF
- Minimum Side Setback = 10 LF
- Minimum Rear Setback = 15 LF
- The site must also be no higher than three (3) stories or 45 feet and cannot have a floor to area ratio greater than 1:1.

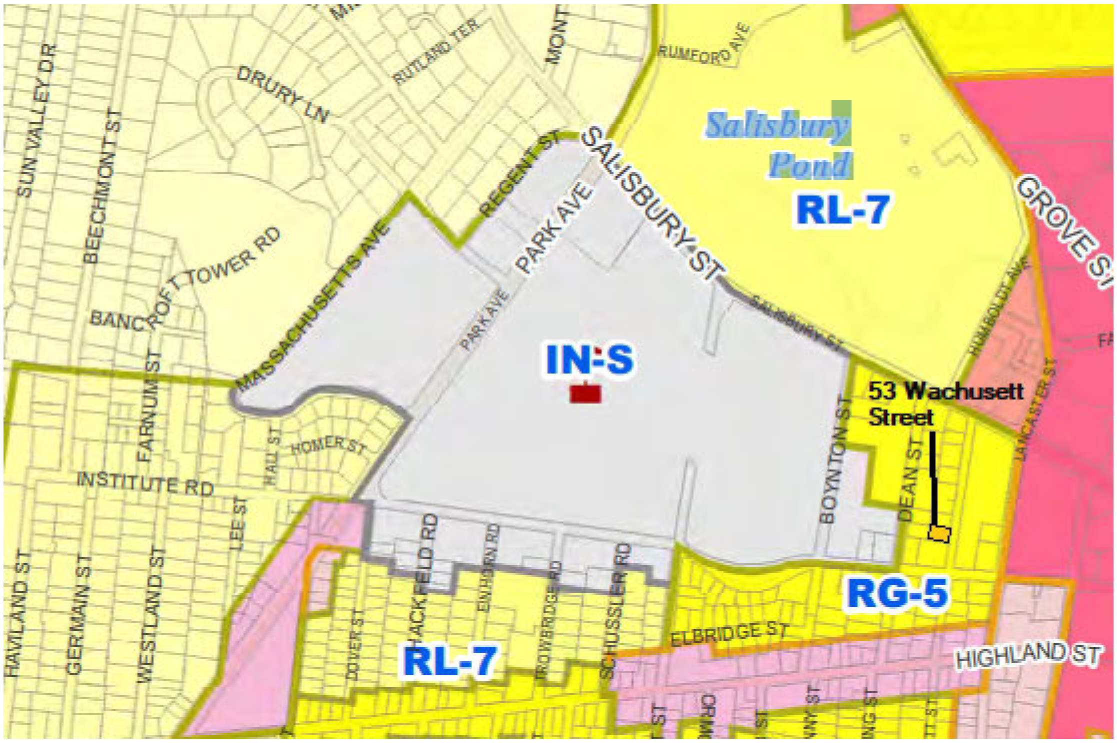


Figure 5: Zoning map of the area surrounding WPI, with 53 Wachusett Street highlighted in orange.

Source: http://www.worcesterma.gov/uploads/32/01/32015be9e3980157fbe0e0f9850ef567/zoning-map-5316.pdf.

While buildings in the RG-5 zone can be used as dormitories, this use requires a permit. These permits are granted based on a number of factors, including whether existing utilities and public services are sufficient to provide for this building's use and the impacts on the local economy and the environment. Permit applications can be placed by filing an appeal to the Zoning Board of Appeals at no cost ("Zoning Board of Appeals", n.d.). However, the process can take up to half a year. Public hearings must take place within the first 65 days after filing an application, and a decision can be rendered up to 90 days after the hearing. Once this decision has been rendered, the permit does not take effect for another 20 days. (City of Worcester, MA, 2018) While WPI would have to apply for a permit if they demolished and replaced the building, it is unclear whether a new special permit would need to be issued if the building were renovated.

ADA and Other Requirements

The American with Disabilities Act (ADA) ensures that buildings are made accessible and usable by individuals with disability needs (American National Standards Institute, 1982). Since this includes persons with wheelchairs, many buildings require either ramps or elevator service. When a building is renovated, accessibility modifications shall be made “to the maximum extent feasible,” as stated by Section 36.402 of the ADA code, giving people with disabilities a path of travel to any primary function areas, including water fountains and restrooms (Stein, 2011). The *International Building Code* (IBC) and *American National Standards Institute* (ANSI) state that the planned cost of renovations must not exceed 20% of the cost of the total renovation to the space lest compliance to ADA standards be met (2018 IBC, 2017). However, if the value of renovations exceeds 30% of the building’s value (State of Massachusetts, 2017), then the building would have to be renovated to fully comply with ADA requirements. Maintenance such as reroofing, painting, asbestos removal, or changes to electrical spaces do not count towards the threshold for full compliance unless they affect the usability of the space. However, changes in common areas and reorganizing the room layout of the space will require these changes (ANSI, 1982).

The current property listing value of 53 Wachusett Street at $251,100 (Vision Government Solutions, n.d.) would require the sum of renovations to it to be below $75,330 in order to avoid having to renovate the entire property to fully meet ADA requirements. If the building were demolished and a new building constructed in its place, all applicable ADA regulations would have to be met.

Structural Design Considerations

The members of any structure are sized using one of two design processes. The first, Allowable Stress Design (ASD), uses unfactored loads but applies relatively large factors of safety to the capacity of structural members. The second process, Load and Resistance Factored Design (LRFD), uses narrower factors of safety for the structural members but multiplies design loads by separate safety factors in order to account for uncertainties in predicting loads. The method that is used depends heavily on the engineer's preference and which method will produce a more economical result. Generally, LRFD is more widely used today because it is more economical (McCormac, 2018). Therefore, we will be using it for this MQP.

The following load combinations must be solved for in LRFD:

- 1.4(D+F)
- 1.2(D+F) + 1.6(L+H) + 0.5(L_r or S or R)
- 1.2(D+F) + 1.6(L_r or S or R) + 1.6H + (f_1L or 0.5W)
- 1.2(D+F) + 1.0W + f_1L + 1.6H + 0.5(L_r or S or R)
- 1.2(D+F) + 1.0E + f_1L + 1.6H + f_2S
- 0.9D + 1.0W + 1.6H
- 0.9(D+F) + 1.0E + 1.6H

Where D = dead load, E = earthquake load, F = fluid load, H = load due to lateral earth pressures, L represents either floor live load or any roof live load greater than 20 psf, L_r is roof live load not exceeding 20 psf, R = rain load, S = snow load, and W = wind load. The constant f_1 is equal to 1 for live loads in parking garages or in places of public assembly and in excess of 100 psf, and 0.5 for other live loads. The constant f_2 is equal to 0.7 for roof configurations that do not shed snow off of a structure, and 0.2 for all other roof configurations.

Each of these basic loads listed above are calculated for different building types using either tables, equations, or a combination of the two. Determining these loads requires consulting design values and formulas used in the local building code; in this case, the Massachusetts State Building Code 9th Edition will be used in concurrence with the IBC 2018 and ASCE 7-16 codes. Once the process to calculate each basic load has been determined, the calculations can be plugged into a spreadsheet and appropriate member sizes computed.

Residential Services Needs

WPI's class of 2022 had such an unexpectedly high enrollment that WPI had to relocate the upperclassmen who had committed to living in Founders Hall to other areas on campus to provide enough room for the incoming freshmen. Founders Hall became a dorm for freshmen only, while upperclassmen were given the option to move to Salisbury Estates or to opt out of housing contracts. This solved the issue of housing undergraduates but forced graduate students out of WPI housing. It should be noted that this occurred the same year as the opening of a new residence hall, Messenger Hall, which holds 140 upperclassmen (Amy Beth Laythe, personal communication).

In general, the perceived shortage of on-campus housing at WPI is caused not by an actual shortage, but by a failure of the available facilities to meet students' demands. While WPI can accommodate all undergraduates who wish to live on campus, many of the accommodations that the rooms offer are considered undesirable by upperclassmen, and rooms consequently remain vacant with students on the waitlist once the main selection process is completed. Many upperclassmen exhibit a strong preference for apartments or dormitories with kitchens that do not require them to purchase a WPI meal plan. It is believed that if there was more housing that was attractive to students, more students would choose to stay on campus (Amy Beth Laythe, personal communication).

It is anticipated that the incoming classes in future years will lead to larger housing waitlists than WPI has previously experienced, similar to the summer of 2018, and that WPI will not be able to fully accommodate the increased demand for more attractive housing options. Part of the solution to this lies in Salisbury Estates and keeping Founders Hall entirely a freshmen residence area, but more housing is needed for upperclassmen. Therefore, in order to be a viable option for a WPI living space, a renovation or replacement to 53 Wachusett Street would need to house more than its current capacity of 14 residents. This would make the space comparable to the Elbridge, Schussler, Trowbridge, and Hackfeld houses currently available on campus. However, WPI-owned houses are among WPI's least desirable housing options, so much so that WPI is considering housing students there on a term-by-term basis to give students who are away for a term or a semester the option to pay less (Amy Beth Laythe, personal communication).

According to Ronald O'Brien, WPI's Director of Design and Construction, residential facilities are currently in greater demand at WPI and typically have lower operating costs than office buildings, since they are only used during the academic year (Ronald O'Brien, personal communication). In addition, 53 Wachusett Street is currently configured as a residential building and would presumably require fewer renovations than it would if it were to be reconfigured to serve as an office space.

Academic Space Needs

As WPI grows and the size of its faculty and staff increases, the school is facing a general need for additional offices. The Interdisciplinary and Global Studies Division (IGSD) is in particular need of faculty offices since its aggressive expansion of off-campus project centers has resulted in an influx of faculty who need office space, even if only for part of the year (Kristopher Sullivan, personal communication). In addition, when existing facilities undergo renovations, many faculty members cannot find temporary office space due to a shortage of space on campus. WPI needs a surplus of offices to accommodate faculty members temporarily displaced by renovations to existing facilities.

WPI would likely be able to use 53 Wachusett Street for a combination of these two purposes. Since the current IGSD office is roughly 10,000 SF (Kristopher Sullivan, personal communication) and 53 Wachusett Street only has 3,102 SF of living area (Vision Government Solutions, n.d.), the IGSD would not be likely to use the building as their main office. It is estimated that the IGSD would need six offices in addition to its current state, with minimum spacing requirements of 120-150 SF, at 53 Wachusett (Office Space Calculator, 2018). With all nine of its bedrooms greater than 120 SF and seven of its bedrooms greater than 150 SF, 53 Wachusett Street has more than enough space to accommodate this need. Any additional space could be used as temporary offices for faculty and staff members displaced by renovations (Kristopher Sullivan, personal communication).

Converting 53 Wachusett Street to an office space presents a number of difficulties. First, 53 Wachusett Street is in a residential zone, in which buildings can be used for office space but require a special permit in order to be used as such. In addition, commercial buildings such as offices need certain safety and accessibility features, such as sprinklers and elevators, that are not necessary for residential buildings (Kristopher Sullivan, personal communication). Finally, office spaces have a higher cost of maintenance because they are used year-round (Ronald O'Brien, personal communication). Because of these issues associated with turning 53 Wachusett Street into an office space, we will only be investigating the possibility of using the building as a residential space.

College Campus Housing Trends

Establishing a community on a college campus is one of the most important challenges for residential architecture (Neuman, 2013). Key components of a residential building are a common room, laundry room, and large hallways. The common room is the most critical area of the building for enhancing community because it brings together not only all the students who live there but it also brings in students from elsewhere to study or entertain themselves together. Laundry rooms are similar in that they promote a stronger community through student interaction. The third key component of all residence halls is widening hallways to allow students to sit down and talk with their neighbors while leaving space for others to pass by (Neuman, 2013). In the case of a house-type residence hall, which is the case for 53 Wachusett Street, shared facilities might include a lounge/study room, a kitchen, and a porch or terrace (Neuman, 2013).

The sizes of typical dormitory rooms depend on their occupancy. At Boston College, singles have an average size of 96 SF, doubles have an average size of 188 SF, and triples have an average size of 368 SF (DormStormer, 2017). However, the preferences of many college students, or at least those of WPI students, have shifted toward options other than the traditional dormitory room. According to Amy Beth Laythe, an Associate Director of Residential Services at WPI, “Students [of WPI] want apartments with kitchens and they don’t want to have to purchase a WPI meal plan.” Mrs. Laythe also noted that upperclassmen desire more privacy which can be achieved with single and double bedrooms, even private bathrooms are desired; this was consistent with a trend observed by Neuman (2013).

Sustainability Design

Currently, WPI is making significant efforts for a more sustainable campus with five buildings being LEED certified since 2006. There has been a reduction in electricity consumption (5%), water consumption (9%), campus waste (3.6%), and greenhouse gas emissions (7.7%) from 2016 to 2017, alone (Worcester Polytechnic Institute, n.d.). WPI is also partnering with GreenerU, a sustainability solutions company for educational facilities (GreenerU, 2018), to assist in technical studies, along with installing and upgrading lighting systems, HVAC systems, retro-commissioning, variable frequency drives, ongoing performance monitoring, and occupant engagement and behavior change management (GreenerU, n.d.). By doing this, WPI hopes to achieve "20% reduction in greenhouse gas emissions by FY25 against an FY14 baseline," (GreenerU, n.d.).

The most ambitious achievement for a residential facility at WPI would be one that meets Leadership in Energy and Environmental Design (LEED) platinum standards, the highest LEED certification. While WPI does not currently have any such facilities, residential facilities at other schools can be used as examples of what can be done with a new construction at 53 Wachusett Street. Two engineering students at the University of Duke created a concept of a residential house that incentivized students living there to lead an energy-efficient lifestyle (Neuman, 2013). It achieves Leadership in Energy and Environmental Design (LEED) platinum standards by housing tanks to harvest and filter rainwater, solar panels, LED lights, and Life's Good (LG) and General Electric (GE) Energy Star efficient kitchen and laundry appliances (Neuman, 2013). If the reconstruction could match this type of housing, then it would be WPI's first LEED platinum building. However, this would only be possible for a new construction, as it would require significantly upgrading the building's existing structure if it were done as a renovation.

Even for a renovation of 53 Wachusett Street, sustainability design can still be accomplished with the use of reclaimed wooden or cork boards for flooring, low- or no- VOC paint, counters made from recycled materials, carefully positioned mirrors to increase natural lighting, the use of LED lights, draught-proofing window frames, green roofing, and low-flow bathroom appliances (Card, 2014). There are also other considerations dependent on the budget.

Cost Estimating

Providing a breakdown of costs and labor rates is one of the largest parts of a design proposal. This cost breakdown will provide a scope for this project and determine its feasibility, in addition to determining whether the building needs to comply with all ADA specifications for a renovation process. The method of delivery for the renovation of 53 Wachusett Street, such as design-bid-build, construction management, or design-build affects the overall cost. This information can be considered when commissioning a project and tailoring it to the wants of the owner and the requirements set forth for the project.

The first step in a cost estimation process is a comparison to similar projects, including past projects undertaken by WPI. This type of estimate is called an Order of Magnitude Estimate: "Made when project design has not yet gotten underway, you only use an order of magnitude estimate to determine the overall feasibility of a construction," (Construction Cost Estimating, 2018).

More detailed estimates can be performed after the design is complete. For these estimated, the current average values for material, labor, and equipment costs of building components are represented in the R.S. Means Construction Cost Estimating books, which are divided into topics such as electrical costs, building construction costs, and facility uses; this resource provides statistics on estimating and project management (MEANS, 2018).

Various construction templates, timelines, and charts are available online. The cost analysis spreadsheet will be organized by the different phases of the project and will include the task, types of labor and labor rates, as well as the price of the goods and overall cost for the task. An example of this is shown below in Figure 6, which is a spreadsheet provided by R.S. Means.

		LABOR		MATERIALS		FIXED COST	BUDGET	ACTUAL	UNDER/OVER
TASK	VENDOR SUBCONTRACTOR/CONTRACTOR	HRS	RATE	UNITS	$/UNIT				
SITE PREP									
Demolition (Remodel)							$ -		$ -
Jacking & Shoring (Remodel)							$ -		$ -
Dust control, Surface Protection							$ -		$ -
Job-Site Access							$ -		$ -
Job-Site Security							$ -		$ -
Dumpster & Removal							$ -		$ -
Clear Lot							$ -		$ -
Storage On Site							$ -		$ -
Portable Toilet							$ -		$ -
Temporary Power							$ -		$ -
Temporary Heat							$ -		$ -
Scaffolding Rental							$ -		$ -
Tool/Equipment Rental							$ -		$ -
Other							$ -		$ -

Figure 6. Cost estimating template from R.S. Means

Methodology

Table 2: 53 Wachusett Street MQP Team Schedule

ACTIVITIES	NECESSARY REFERENCES
Determine WPI's Needs (already completed)	● Met with individuals from Residential Services, Academic Affairs, and Facilities. ● Walked through and surveyed 53 Wachusett Street. ● Researched zoning constraints.
Determine building's capabilities and required work	● Investigate 53 Wachusett Street. ● Consult with Facilities
Conceptual Design - Renovation	● Research building codes, apply researched sustainability measures.
Structural Design - Renovation	● Consult American Wood Council-National Design Specification (AWC-NDS) for LRFD and check with RISA 2D. ● Draft model in AutoCAD and Revit.
Cost Estimate - Renovation	● Use R.S. Means cost estimating books to estimate cost. ● Use Microsoft Project to estimate renovation durations.
Conceptual Design – New Bldg.	● Consult Worcester Zoning Ordinance to determine zoning constraints.

	• Consult with Facilities individuals and Prof. LePage to determine design constraints. • Determine building materials based on consulting with Facilities
Structural Design – New Bldg.	• Design floor beam system using LRFD • Design columns and framing using LRFD and RISA 2D. • Design foundations using hand calculations (methods learned in CE 3044) and soil profiles from construction of East Hall. • Create floor plans in AutoCAD and import to Revit to create model.
Cost Estimate - New Bldg.	For the combined demolition and new construction: • Create a schedule in Microsoft Project in order to determine when a new construction project is likely to be completed. For the demolition of the existing building: • Estimate the costs of demolition using R.S. Means cost estimating books. Calculate disposal fees by researching disposal fees per unit volume at nearby waste disposal and recycling stations. • Calculate the labor costs by estimating productivity rates and obtaining labor rates for the trades used. • Estimate indirect costs by multiplying the direct costs by a factor to account for overhead and profit. This factor will be determined by consulting with Facilities representatives, and will likely be between 15% and 25%.

For the new building:

- Estimate the costs of construction using R.S. Means cost estimating books.

We have already worked on determining WPI’s space-related needs and the current capabilities of 53 Wachusett Street, and decided that the building should be used for residential purposes. Our next objective is to identify renovations that need to take place at 53 Wachusett Street in order to allow it to serve this purpose. In B-term, we will prepare structural designs, construction plans, and cost estimates for these renovations. We will then investigate the option of replacing the current building with new construction. This will begin with a conceptual design for the new building, followed by a design for a structure to support the conceptual design and a cost estimate for the work. When we have finished with this stage of work, we will modify the existing designs and cost estimates to include sustainability measures. Sustainability measures that we will investigate include:

- Rainwater harvesting tanks with filtration and solar heated water
- Solar panels
- Geothermal heating - using conduction properties of the ground to heat and cool the building
- Energy Star appliances
- LED lights

We will determine whether these sustainability measures are advisable based on their added costs and benefits. After this, the focus of the project will shift towards preparing a final report and presentation.

Project Tracking

To track the progress of our MQP, we have created a schedule (Appendix C) in Microsoft Project. This schedule includes a week at the end of each term to focus solely on preparing and submitting the most recent version of our report. The schedule also includes breaks for fall and winter break. While we plan to work on the MQP during term breaks, setting aside time off over these breaks accounts for reduced productivity during these time spans and allows a buffer to do additional research that may be necessary before the next term. We also plan to use Microsoft Project to create schedules for hypothetical construction projects.

Determining WPI's Needs

To gain different perspectives on potential uses for the building, we met with influential staff members from the departments of Residential Services and Academic Affairs. We also walked through 53 Wachusett Street to determine the building's capabilities as well as the scope of work required for the building to be able to serve as either residential or office space. In order to determine the optimal use for the building, we researched the zoning of 53 Wachusett Street, and the process for obtaining the special permits required to erect a dormitory or small office building within that zone. Finally, we met with several administrators from the Facilities Department to discuss unforeseen factors that might influence this decision. We decided to investigate residential options for 53 Wachusett Street based on the results of this meeting and our research.

53 Wachusett's Capabilities and Trouble Spots

Based on multiple visits to 53 Wachusett Street and meetings with stakeholders from WPI's staff, the building is structurally sound but needs significant renovations to increase its capacity. For example, the basement needs to be finished, the building's kitchen and living room need to be increased in order to increase the building's capacity, and the building's electrical system needs to be reconfigured. To determine which of these issues can be addressed with a renovation, we have found typical sizes of office spaces and dormitory rooms, measured the rooms at 53 Wachusett Street, and visited similar WPI-owned residential buildings with two representatives from WPI's Facilities Department, Ronald O'Brien and Nick Palumbo.

Renovations - Design Phase

Since an increased capacity is one of WPI's most pressing needs for a residential facility, we will only investigate renovations that would increase the capacity of 53 Wachusett Street. In addition, since we have been unable to find as-built drawings for 53 Wachusett Street, we will only investigate renovations that would increase or conserve the structure's stability; for example, renovations that add, or reinforce, walls would be possible but renovations that remove them would not. When the designs for the renovations are complete, we will create a set of CAD drawings highlighting the renovations that need to be made, and a Revit model to portray what the building might look like with these renovations.

Renovations - Estimating Phase

To estimate the costs of renovations, we will identify work items and building features, and use unit costs determined by the R.S. Means building cost guide. Among the costs that are likely to be faced are the costs of making the means of access to any alterations ADA-compliant. Typically, the costs associated with increasing accessibility are not required to exceed 20% of the costs of all other renovations. If the renovation cost exceeds 30% of the building's value

(State of Massachusetts, 2017), the existing building would need to fully comply with ADA requirements regardless of renovation costs.

New Constructions - Design Phase

Any designs for new constructions at 53 Wachusett Street need to account for zoning and building code constraints. After we have completed a conceptual design, we will consult Prof. Suzanne LePage, who specializes in zoning, to ensure that the design complies with some of the more ambiguous local zoning requirements. These requirements include a minimum requirement for parking spaces per bed, which could either refer exclusively to parking spaces adjacent to 53 Wachusett Street or to all parking spaces owned by WPI and may or may not account for street parking.

In order to complete a structural design for a new building, we will design a floor beam system using LRFD, before designing the building's framework and finishing with the design of the foundation. We will use RISA 2D to aid in the design of the framework. To aid in foundation design, we plan to obtain and analyze soil profiles created during WPI's construction of East Hall, since the soil profiles are likely to be similar in the two locations. When the design is complete, we will create AutoCAD and Revit models to illustrate it.

Since buildings in the RG-5 zone can have a maximum of three stories and a total floor area no greater than their lot area (City of Worcester, MA, 2018), we will design a wooden structure for the building. As a building material, wood is lightweight, easy to obtain, and a good insulator (Understand Building Construction, n.d.). However, since different species of wood have different properties, we will need to select a specific species to use for the building's structure.

New Constructions - Estimating Phase

As was the case with the cost estimates for renovations to 53 Wachusett Street, we will estimate the costs of new construction using the R.S. Means building cost index. In addition, we will need to account for the costs of demolishing the existing building. These costs can be calculated based on the fees required to dispose of the materials currently in the building, the costs of labor and equipment, and the indirect costs.

Capstone Design Statement

This Major Qualifying Project will focus on design options for either renovating or reconstructing 53 Wachusett Street, a fraternity house in Worcester, MA that WPI will be taking over at the end of the 2018-2019 school year. The design of these proposed renovations and new constructions will require us to draw on experience gained in the classroom in a number of areas, and to gain more practical experience in areas such as building code and zoning constraints. Areas that will be addressed in this project include constructability, accessibility, health and safety, sustainability, and social aspects.

Constructability

Any engineering design, regardless of its quality, needs to be feasible and affordable to construct. To ensure that our designs can be constructed at a reasonable cost, we plan to estimate the costs and construction times for these designs. We will also need to ensure that these designs are constructible in terms of materials used and layout. For example, many buildings in the Northeast rely on steel construction, but a wooden frame like the one currently used in 53 Wachusett Street is also likely to suffice for a building with a maximum of three stories. Acceptable building materials and layouts will be confirmed by inspecting the building and by referencing the 9th edition of the *Massachusetts Building Code*.

Accessibility

An important issue regarding renovating the building is the additional cost associated with ensuring compliance with ADA requirements. As an older building, 53 Wachusett Street is not currently ADA-compliant, but any renovations to the building would require that some accessibility measures be implemented. If the cost of renovations exceeds 30% of the building's value, (State of Massachusetts, 2017) the building must be made fully compliant with ADA requirements, which presents additional costs. Otherwise, only one-fifth of the renovation costs must be matched in order to increase accessibility. If the existing building were replaced with a new one, the new building would have to conform to ADA requirements regardless of its cost. If it is in WPI's interests to make the building accessible, it may be advisable to demolish and replace the building regardless of the difference between the costs of renovation and new construction.

Health and Safety

Since 53 Wachusett Street was built in 1914 (Vision Government Solutions, n.d.), it most likely contains many of the hazardous materials typically found in older buildings, including asbestos and lead. While most of the asbestos previously present in the building has been removed, some of the pipes in the basement are still lined with asbestos. Lead paint is a difficult hazard to identify, as it may be covered in layers of non-lead paint. Other lead hazards that may be prevalent in 53 Wachusett would be pipes and traps.

The removal of lead and asbestos from 53 Wachusett Street will contribute to the estimated cost of renovating the building. In this way, it may affect whether the entire building needs to be made fully accessible, or whether the cost of increasing accessibility can be capped at 20% of the costs of other renovations. Due to the invasive nature of performing lead tests on walls that have since been painted over (these tests require chipping outer layers of paint off the walls), the costs of this work will be difficult to predict. Since removing lead and asbestos from the building does not change the building's use, the benefits of these construction activities cannot be quantified.

Health and safety concerns also affect building design in the form of zoning regulations. We have already investigated zoning regulations to determine basic design constraints, and plan to meet with Prof. Suzanne LePage to resolve issues with more ambiguous zoning constraints after we have completed a conceptual design for a renovation.

Sustainability

In the current age of climate change and increased emphasis on environmental issues, sustainable design has become an important concern, especially on college campuses. We plan to incorporate sustainable elements as additions to our designs for both a renovation and a new construction. Design elements that would be feasible if the existing building were renovated include:

- Cork-board flooring
- Energy Star appliances
- LED lights
- Solar panels
- Surfaces made from recycled materials
- Volatile Organic Chemical (VOC)-free paints

Other design elements that we have investigated would lead to additional loads on the building, which the existing structure may not be able to support. As a result, these additions could only be implemented if the building were to be demolished and a new building constructed. These additions include:

- Geothermal heating
- Rainwater harvesting tanks with filtration and solar heated water

- Energy-recycling HVAC systems

Social

According to Amy Beth Laythe, WPI students generally prefer apartment-style housing with kitchens in order to cook their own food and avoid purchasing a WPI meal plan. While replacing the current layout of 53 Wachusett Street with apartments would require either significant renovations or a new construction, keeping the existing kitchen equipment in place may be advisable.

WPI's residential houses do not have a consistent appearance. Rather, they contain architectural details and finishes typical of the original buildings. As a result, WPI is not likely to perform any significant aesthetic repairs to 53 Wachusett Street unless they affect the building's safety or usage, and aesthetic repairs that affect neither of the building's safety or use will not be analyzed in the design for a renovation.

Determining Client Needs

The designs that we propose for 53 Wachusett Street need to address WPI's current needs and reflect the constraints of the site. 53 Wachusett Street's location in a residential zone several blocks away from campus proper makes it less suitable for classroom or office facilities, which means that the building would likely be used for a residential space.

In order to gain a better understanding of the facilities for which WPI has the greatest demand, we have met with various individuals with a stake in the process of determining these demands. We have already met with Amy Beth Laythe, an Associate Director of Residential Services and with Kristopher Sullivan, WPI's Associate Vice President for Academic Affairs, in order to gain an understanding of WPI's needs for residential and academic space, respectively.

We have also met with Ronald O'Brien, WPI's Director of Design and Construction, in order to gain a broader understanding of WPI's facilities needs and the considerations that influence the decisions that WPI makes regarding its facilities.

Deliverables

Since the beginning of this project, we have produced several deliverables regarding the existing state of 53 Wachusett Street:

- Photographs of the existing building at 53 Wachusett Street.
- A preliminary assessment of the condition of the building.
- A set of floor plans for every room, except for three bedrooms which we were not able to access.
- The recommendation that 53 Wachusett Street should be used for residential space instead of office space.

In addition to the deliverables listed above, our final deliverables will include the following:

- A recommendation to WPI regarding whether they should renovate or demolish 53 Wachusett Street.
- A list of zoning constraints that limit design options for the building.
- A design for both a renovation to the building and a new building that would allow it to serve its recommended purpose. Both designs will be created in Autodesk AutoCad/Revit/Navisworks. The Navisworks design will also allow us to estimate construction costs based on the sequence of constructions.
- Structural calculations for these designs, to be done by hand for simple calculations and confirmed in RISA 2D for more advanced load cases (i.e. lateral load-resisting systems).
- Cost estimates in Microsoft Excel for both renovation and demolition options.
- Project management/scheduling in Microsoft Project.

Conclusions

The final report will contain a recommendation regarding whether WPI should renovate or reconstruct 53 Wachusett Street in order to use it as a residential house. In order to support this recommendation, we will make a modified layout for a renovated building and design a separate layout for a new building. We will then determine the structural requirements for making each layout feasible and estimate the costs of both the renovation and the new construction. This will include a breakdown of costs and the results of whether the total cost of renovations would be below $75,330, since higher costs require full ADA compliance. We plan to analyze sustainability options for the building as well. Overall, we would like this MQP to simplify the process of selecting a course of action for 53 Wachusett Street. This will allow WPI to reach a decision faster so that any work that needs to be undertaken can occur and 53 Wachusett Street can continue to serve WPI's needs in the future.

Project Schedule

The figure below contains a summary of the projected schedule for this MQP. The full schedule, including the subtasks and the relationships between the subtasks, can be found in Appendix A. We will use this schedule as a guideline for assigning specific tasks, which will be done on a weekly basis.

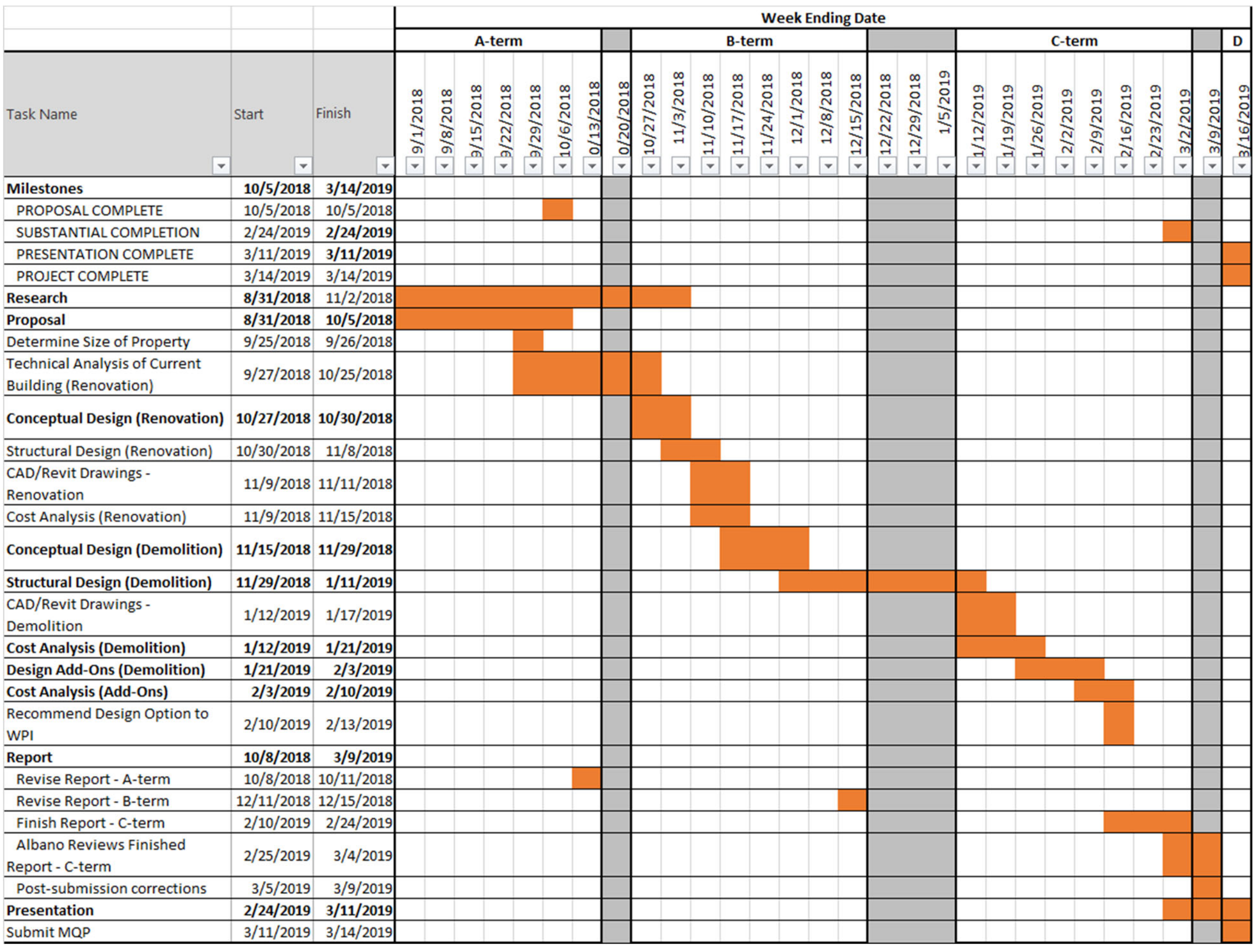


Figure 7. Summary project schedule

The durations listed in the term-by-term schedules do not include the final weeks of A- and B -terms, since these weeks are reserved for finalizing the report for submission at the end of the term. They also do not include fall and winter breaks, since we will not be able to meet during these periods and will likely use them to do research and make other preparations for the next term.

The figure below shows our schedule for A-term. Most of A-term was devoted to doing background research and writing our proposal. We also began to determine the scope of our project: we decided that the building should be used as a residential space and began to obtain the dimensions of the rooms in order to help determine quantities for renovations, many of which will be based on the square footage of the floors and walls of the rooms needing renovations.

					A-term							
Task Name	Duration	Start	Finish	% Complete	9/1/2018	9/8/2018	9/15/2018	9/22/2018	9/29/2018	10/6/2018	10/13/2018	10/20/2018
Milestones	**112.75 days**	**10/5/2018**	**3/14/2019**	**0%**								
PROPOSAL COMPLETE	0 days	10/5/2018	10/5/2018	0%						■		
Research	**50 days?**	**8/31/2018**	**11/2/2018**	**80%**	■	■	■	■	■	■	■	■
Proposal	**37.25 days?**	**8/31/2018**	**10/5/2018**	**81%**	■	■	■	■	■	■		
Determine Size of Property	2 days	9/25/2018	9/26/2018	75%					■			
Technical Analysis of Current Building (Renovation)	14 days	9/27/2018	10/25/2018	0%					■	■	■	■
Report	**158.25 days**	**10/8/2018**	**3/9/2019**	**0%**								
Revise Report - A-term	4 days	10/8/2018	10/11/2018	0%							■	

Figure 8: A-term project schedule.

In B-term, we will finish determining the constraints of the building as they pertain to renovation. We will then form a list of renovations that need to be performed on 53 Wachusett Street and create a conceptual design, a structural design, layout drawings, and a cost analysis for this set of renovations. When this analysis for a renovation is complete, we will design a layout for a new construction and begin the structural design for this layout. The structural design process will continue over winter break and into the start of C-term.

					B-term										
Task Name	Duration	Start	Finish	% Complete	10/27/2018	11/3/2018	11/10/2018	11/17/2018	11/24/2018	12/1/2018	12/8/2018	12/15/2018	12/22/2018	12/29/2018	1/5/2019
Research	**50 days?**	**8/31/2018**	11/2/2018	**80%**											
Technical Analysis of Current Building (Renovation)	14 days	9/27/2018	10/25/2018	0%											
Conceptual Design (Renovation)	**3 days**	**10/27/2018**	**10/30/2018**	**0%**											
Structural Design (Renovation)	10 days	10/30/2018	11/8/2018	0%											
CAD/Revit Drawings - Renovation	3 days	11/9/2018	11/11/2018	0%											
Cost Analysis (Renovation)	7 days	11/9/2018	11/15/2018	0%											
Conceptual Design (Demolition)	**9 days**	**11/15/2018**	**11/29/2018**	**0%**											
Structural Design (Demolition)	**14 days**	**11/29/2018**	**1/11/2019**	**0%**											
Report	**158.25 days**	**10/8/2018**	**3/9/2019**	**0%**											
Revise Report - B-term	5 days	12/11/2018	12/15/2018	0%											

Figure 9. B-term project schedule.

In C-term, we will complete our structural design and perform a cost-benefit analysis for it. We will then investigate the possibility of adding sustainability elements to our design (see the Methodology section for a list of more cutting-edge sustainability elements that we plan to investigate) by modifying our design and cost estimates to include these elements. When this is complete, we will recommend that WPI either renovate the existing building or demolish it and construct a new one according to our designs, and prepare a report and presentation. While the technical aspects of the project will most likely be complete before the end of C-term, the report and presentation may not be finished until one week after the start of D-term.

					C-term									D
Task Name	Duration	Start	Finish	% Complete	1/12/2019	1/19/2019	1/26/2019	2/2/2019	2/9/2019	2/16/2019	2/23/2019	3/2/2019	3/9/2019	3/16/2019
Milestones	**112.75 days**	**10/5/2018**	**3/14/2019**	**0%**										
SUBSTANTIAL COMPLETION	0 days	2/24/2019	**2/24/2019**	0%										
PRESENTATION COMPLETE	0 days	3/11/2019	**3/11/2019**	0%										
PROJECT COMPLETE	0 days	3/14/2019	3/14/2019	0%										
Structural Design (Demolition)	**14 days**	**11/29/2018**	**1/11/2019**	**0%**										
CAD/Revit Drawings - Demolition	6 days	1/12/2019	1/17/2019	0%										
Cost Analysis (Demolition)	**10 days**	**1/12/2019**	**1/21/2019**	**0%**										
Design Add-Ons (Demolition)	**13 days**	**1/21/2019**	**2/3/2019**	**0%**										
Cost Analysis (Add-Ons)	**8 days**	**2/3/2019**	**2/10/2019**	**0%**										
Recommend Design Option to WPI	3 days	2/10/2019	2/13/2019	0%										
Finish Report - C-term	14 days	2/10/2019	2/24/2019	0%										
Albano Reviews Finished Report - C-term	6 days	2/25/2019	3/4/2019	0%										
Post-submission corrections	5 days	3/5/2019	3/9/2019	0%										
Presentation	**15 days**	**2/24/2019**	**3/11/2019**	**0%**										
Submit MQP	3 days	3/11/2019	3/14/2019	0%										

Figure 10: C- and D-term Project Schedule

Appendix B: 53 Wachusett Street Photos

Figure 74. Eastside view of 53 Wachusett St.

Figure 75. Westside view of 53 Wachusett Street

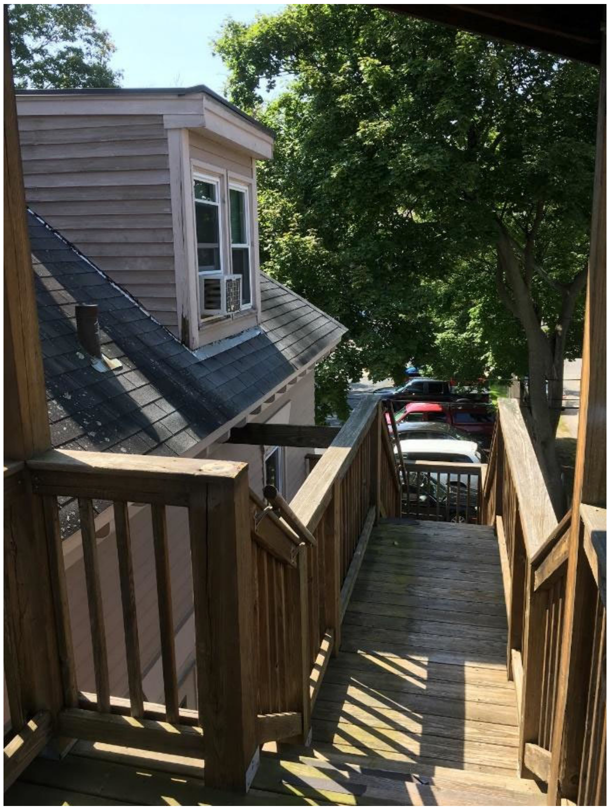


Figure 76. Fire escape from the top floor of 53 Wachusett Street (northside looking west)

Figure 77. Southwest view of 53 Wachusett Street

Figure 78. Common room of 53 Wachusett (view from the main entrance on the south end of the building)

Figure 79. Dining room of 53 Wachusett, view 1

Figure 80. Dining room of 53 Wachusett, view 2

Figure 81. 53 Wachusett pantry

Figure 82. 53 Wachusett kitchen

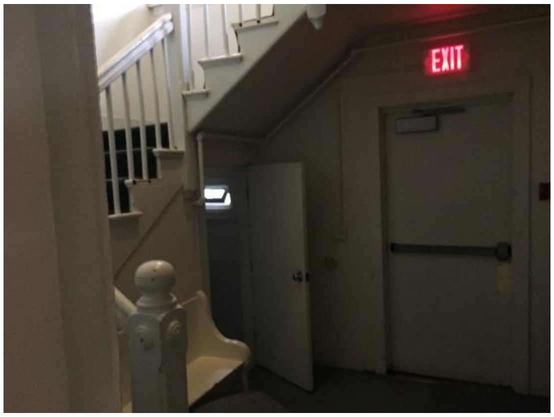


Figure 83. Staircase view from the first floor of 53 Wachusett, view 1

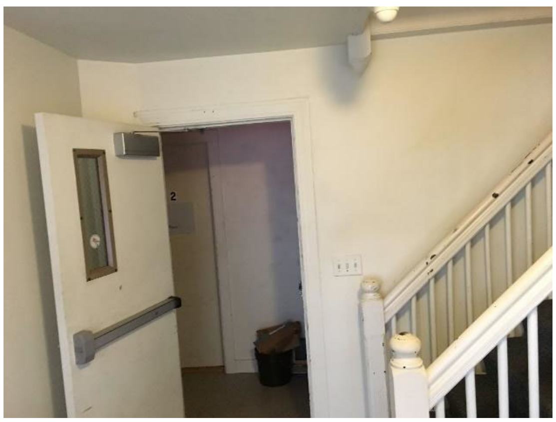


Figure 84. Staircase view from the first floor of 53 Wachusett, view 2

Figure 85. Half bathroom on the first floor of 53 Wachusett

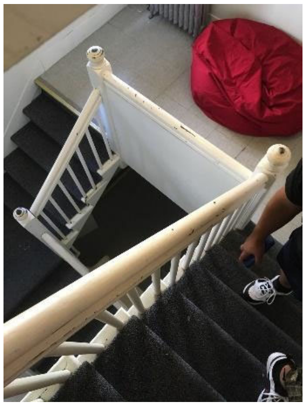


Figure 86. Staircase view from the second floor of 53 Wachusett

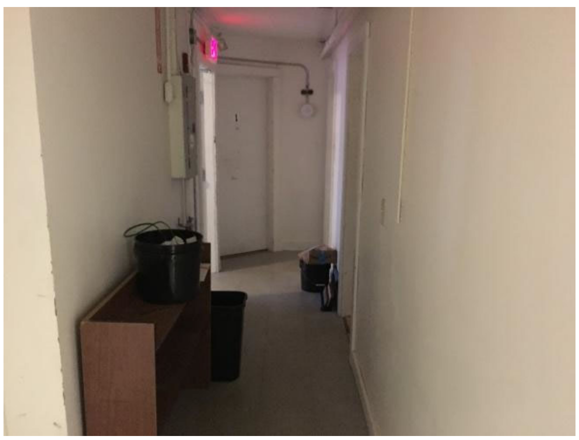


Figure 87. Hallway view of the second floor of 53 Wachusett

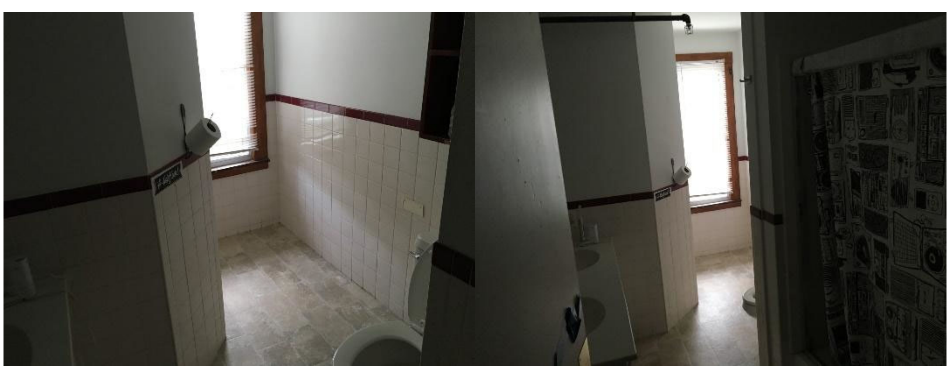


Figure 88. Bathroom on the second floor of 53 Wachusett

Figure 89. Bedroom 1 on the second floor of 53 Wachusett

Figure 90. Bedroom 2 on the second floor of 53 Wachusett, view 1

Figure 91. Bedroom 2 on the second floor of 53 Wachusett, view 2

Figure 92. Bedroom 3 on the second floor of 53 Wachusett, view 1

Figure 93. Bedroom 3 on the second floor of 53 Wachusett, view 2

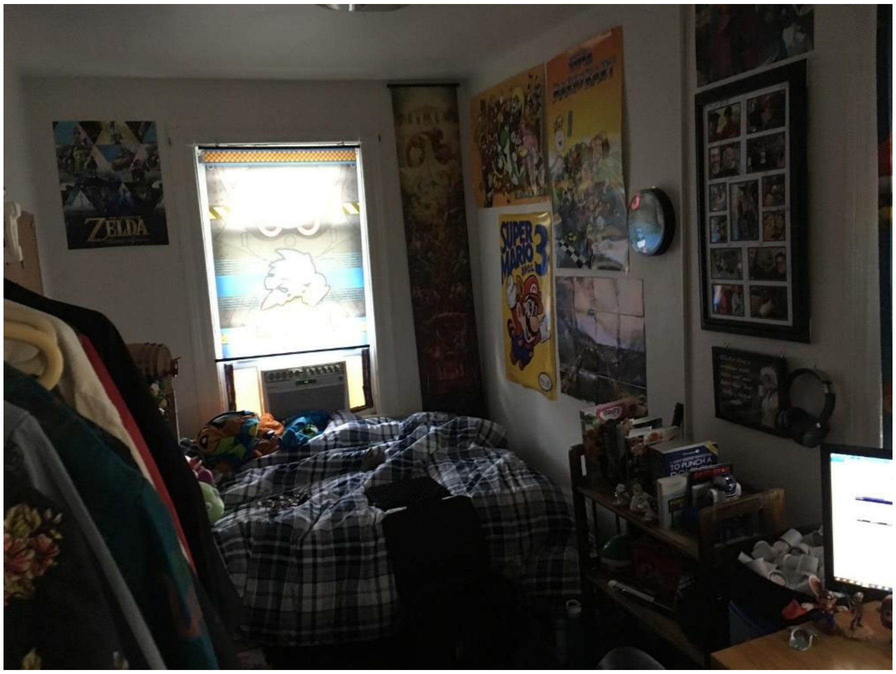


Figure 94. Bedroom 4 on the second floor of 53 Wachusett, view 1

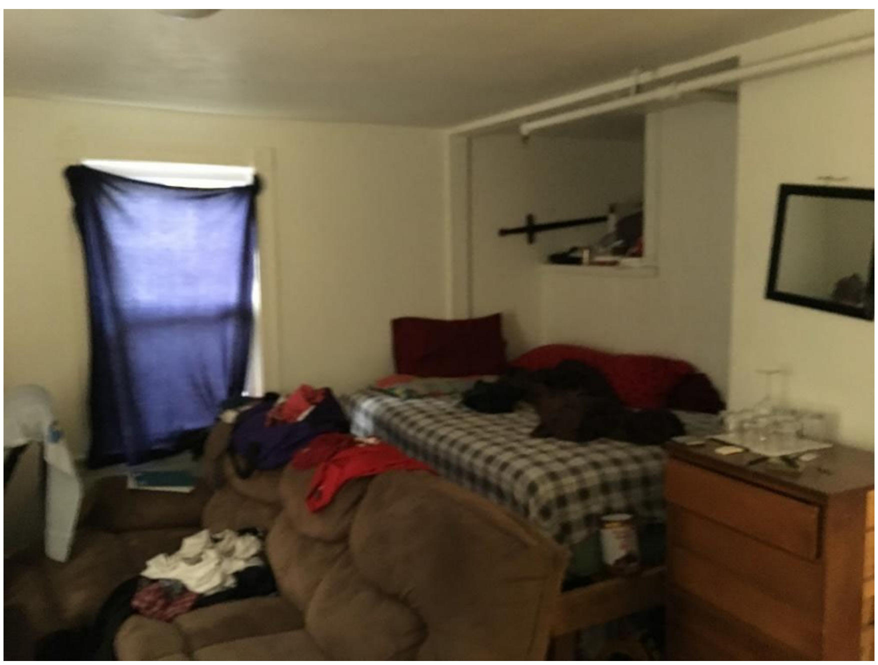


Figure 95. Bedroom 4 on the second floor of 53 Wachusett, view 2

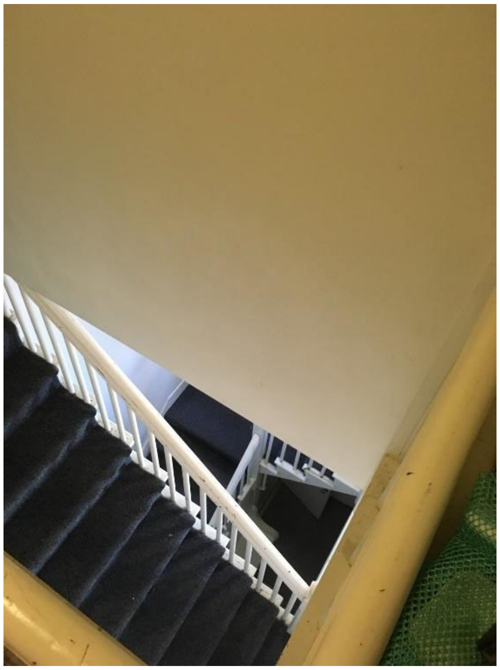


Figure 96. Staircase view from the third floor of 53 Wachusett

Figure 97. Hallway on the third floor of 53 Wachusett

Figure 98. Bathroom on the third floor of 53 Wachusett

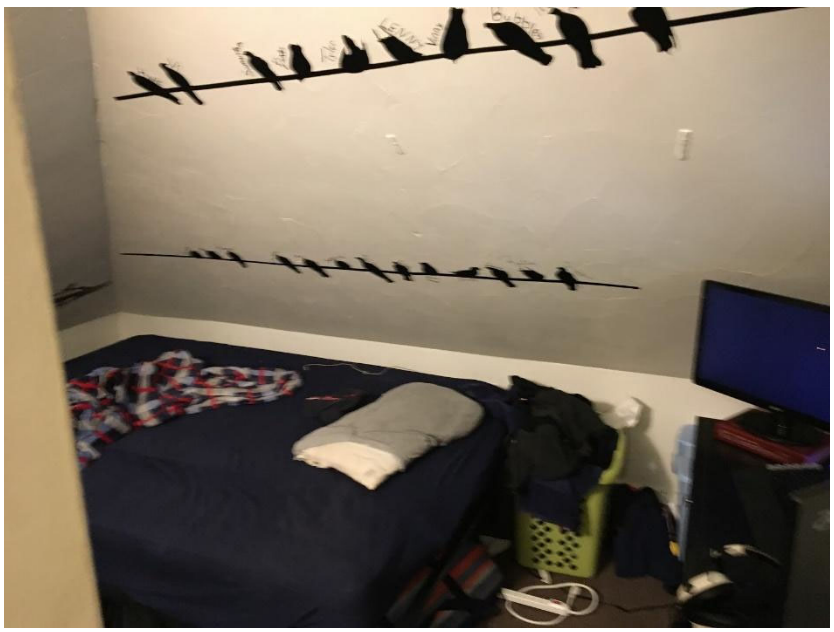


Figure 99. Bedroom 5 on the third floor of 53 Wachusett, view 1

Figure 100. Bedroom 5 on the third floor of 53 Wachusett, view 2

Figure 101. Bedroom 7 on the third floor of 53 Wachusett, view 1

Figure 102. Bedroom 7 on the third floor of 53 Wachusett, view 2

Figure 103. Bedroom 8 on the third floor of 53 Wachusett, view 1

Figure 104. Bedroom 8 on the third floor of 53 Wachusett, view 2

Figure 105. Bedroom 9 on the third floor of 53 Wachusett, view 1

Figure 106. Bedroom 9 on the third floor of 53 Wachusett, view 2

Figure 107. Bedroom 9 on the third floor of 53 Wachusett, view 3

Appendix C: List of WPI-Owned Properties

Table 47. List of WPI-owned properties by address

Streets/Roads	Addresses
Boynton Street	9
Einhorn Road	11, 12*, 15, 16*, 17
Elbridge Street	2, 8, 10, 16, 20, 30
Hackfeld Street	8, 10, 11, 18, 23, 24, 26, 27
Institute Road	47, 49
Schussler Road	13*, 15, 17, 19, 20, 22
Trowbridge Street	20, 25, 28*
Wachusett Street	53, 67
West Street	157

Appendix D: Existing Building Layout Drawings

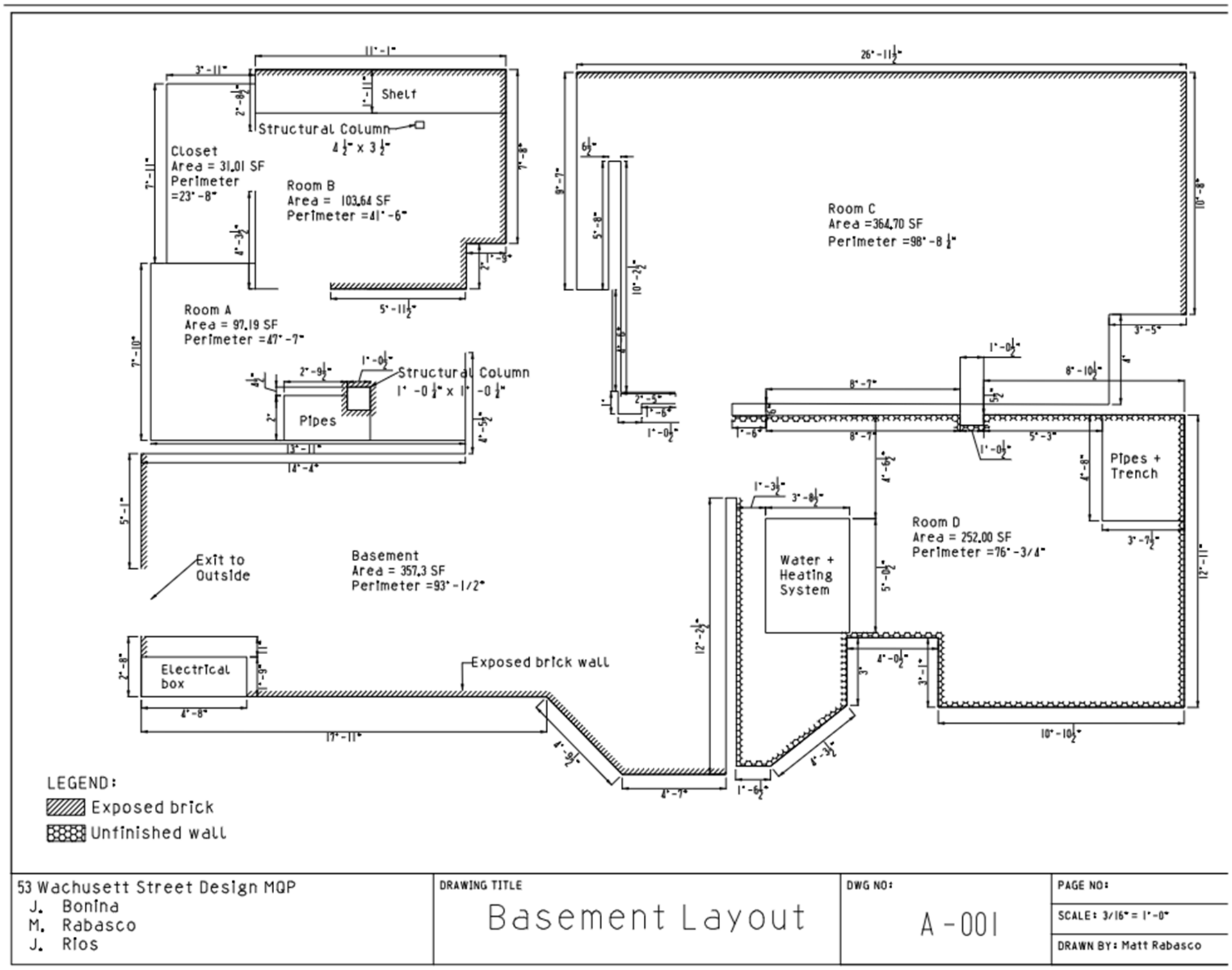


Figure 108. Layout drawing - basement

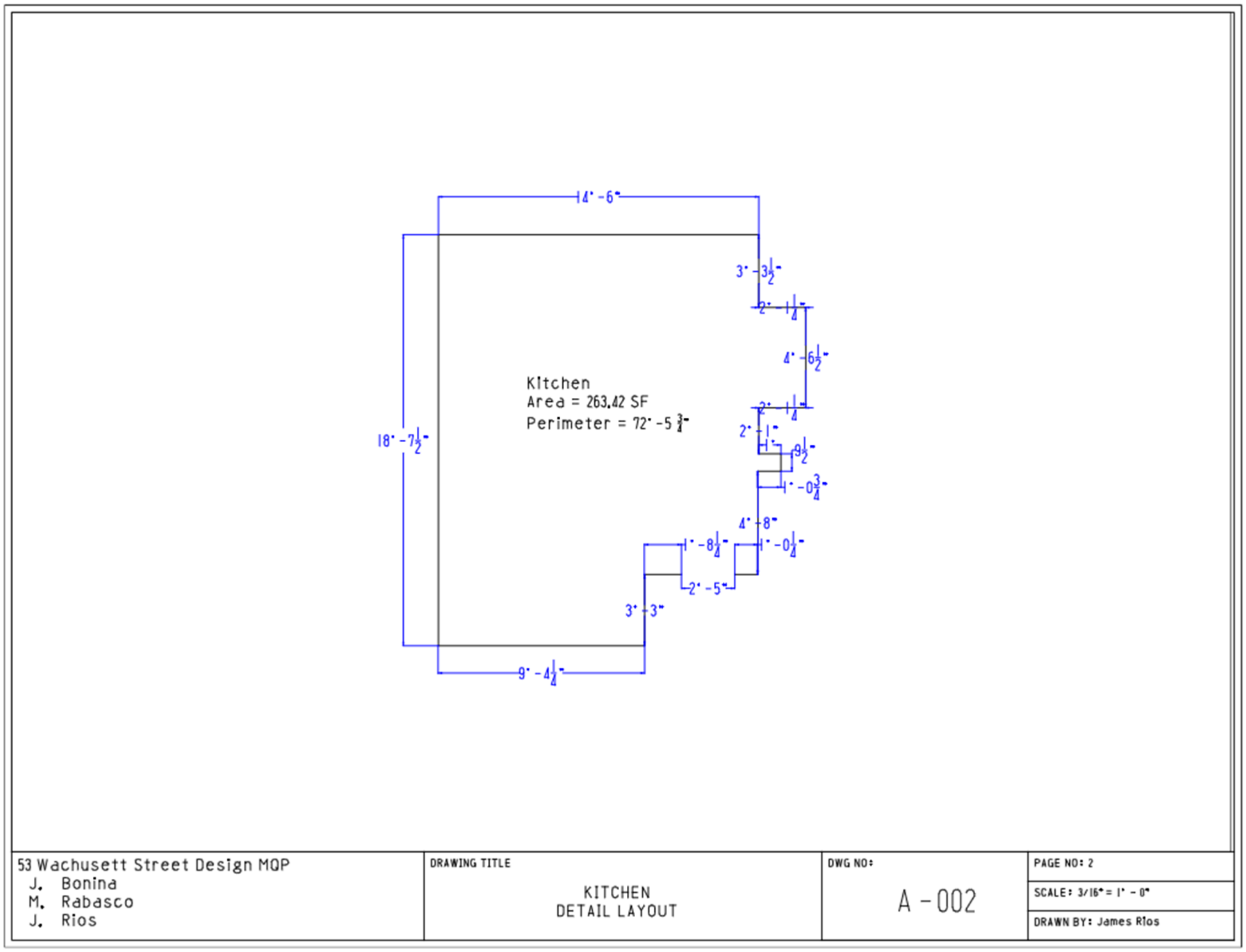


Figure 109. Layout drawing - Kitchen

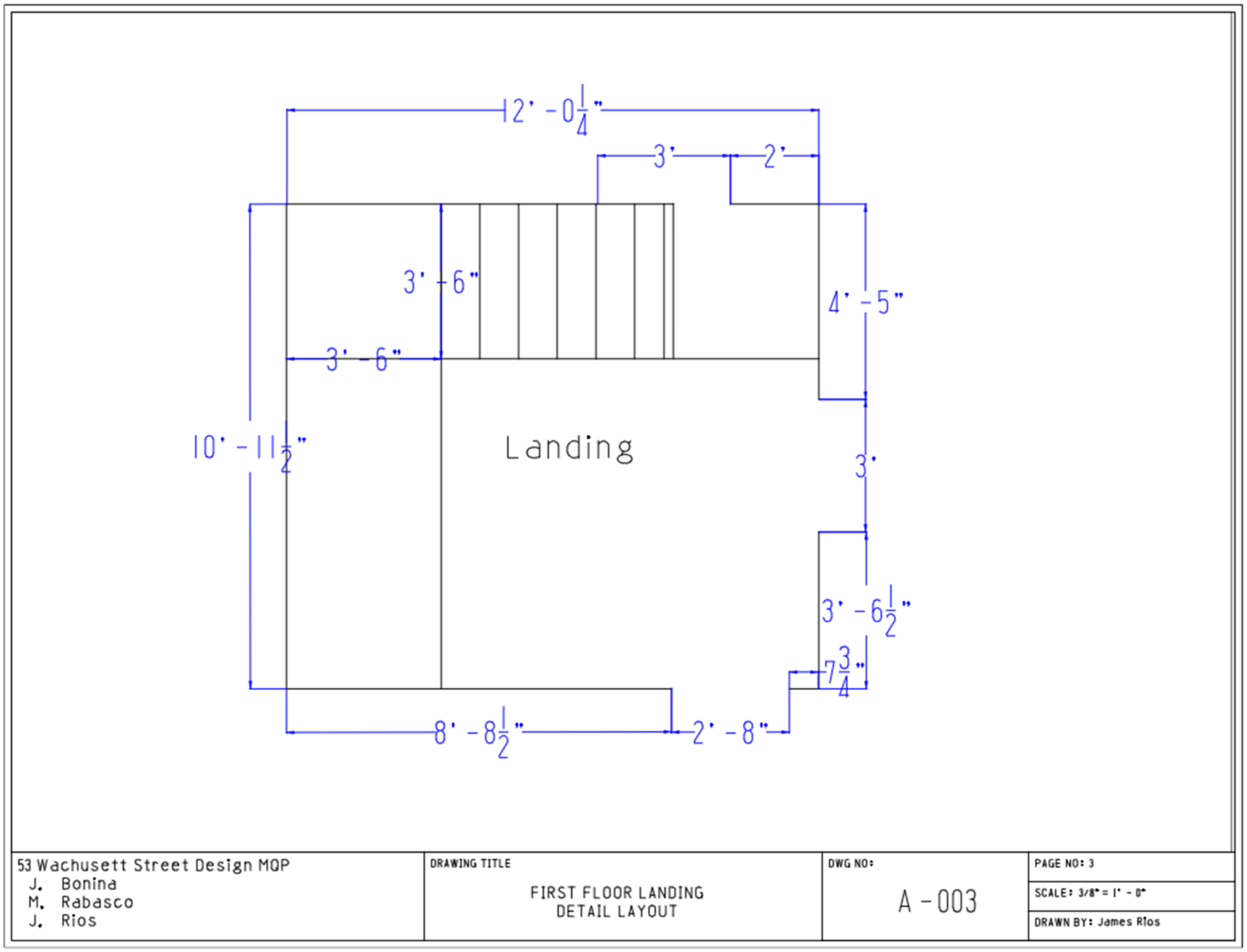


Figure 110. Layout drawing – first floor landing

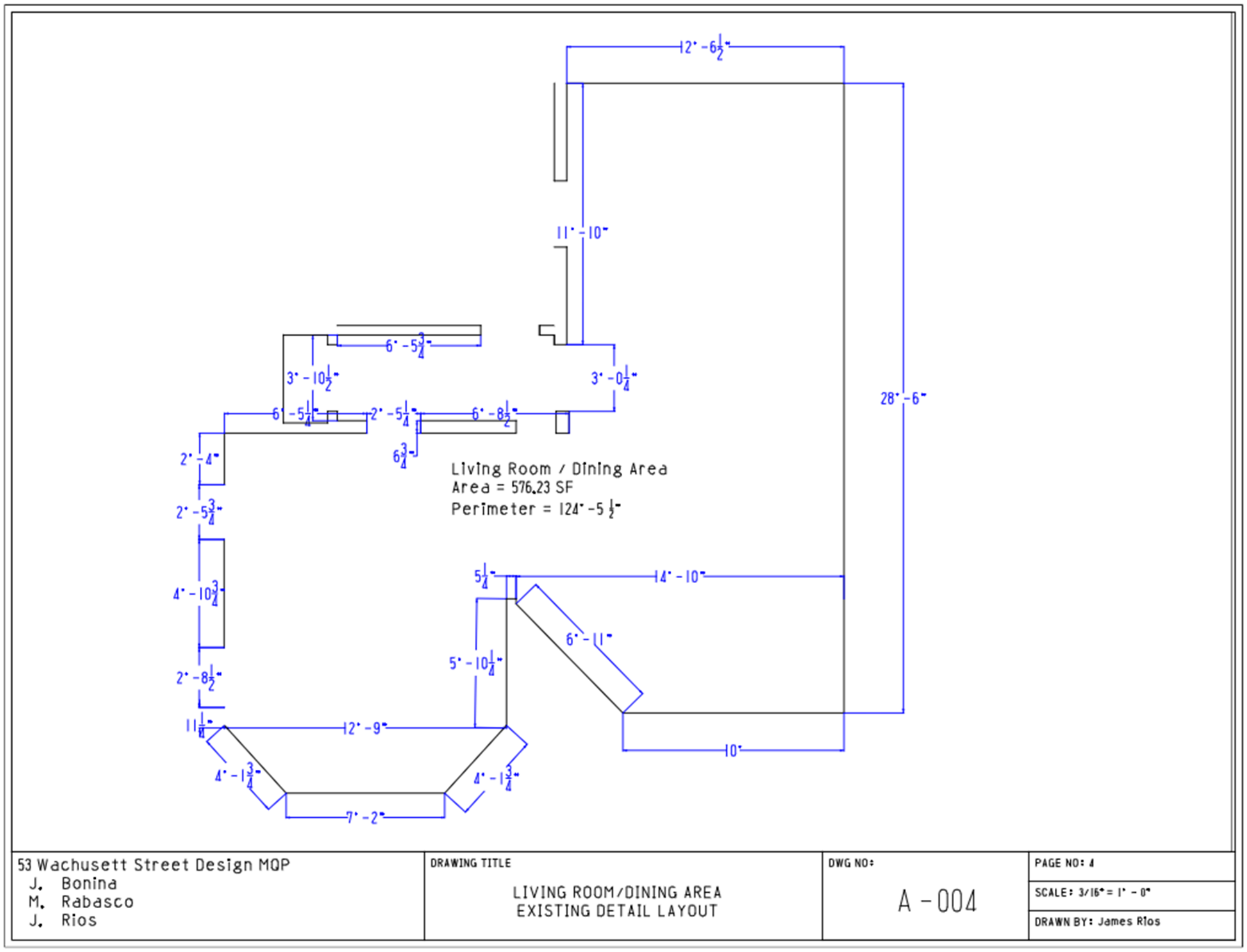


Figure 111. Layout drawing – living/dining area

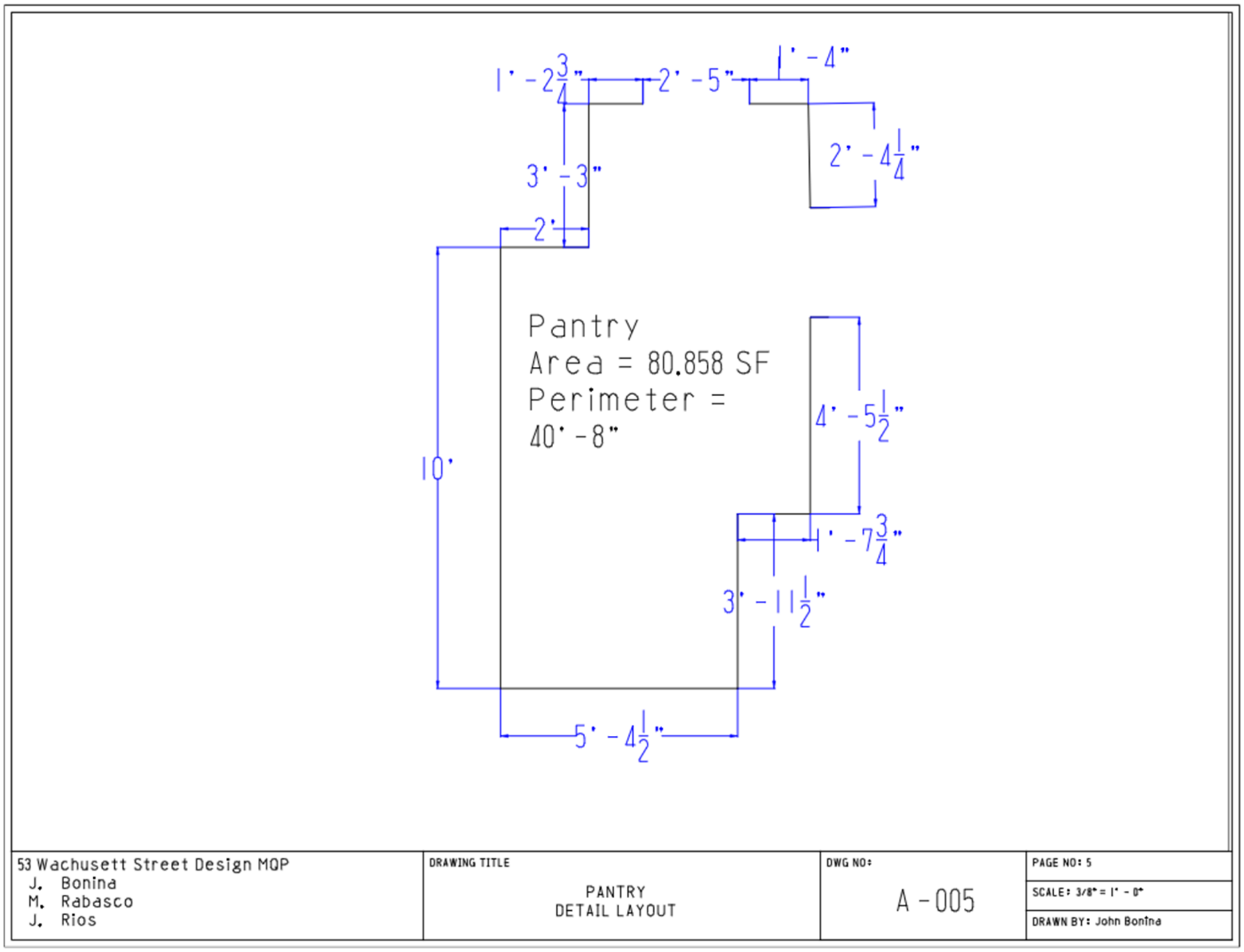


Figure 112. Layout drawing - pantry

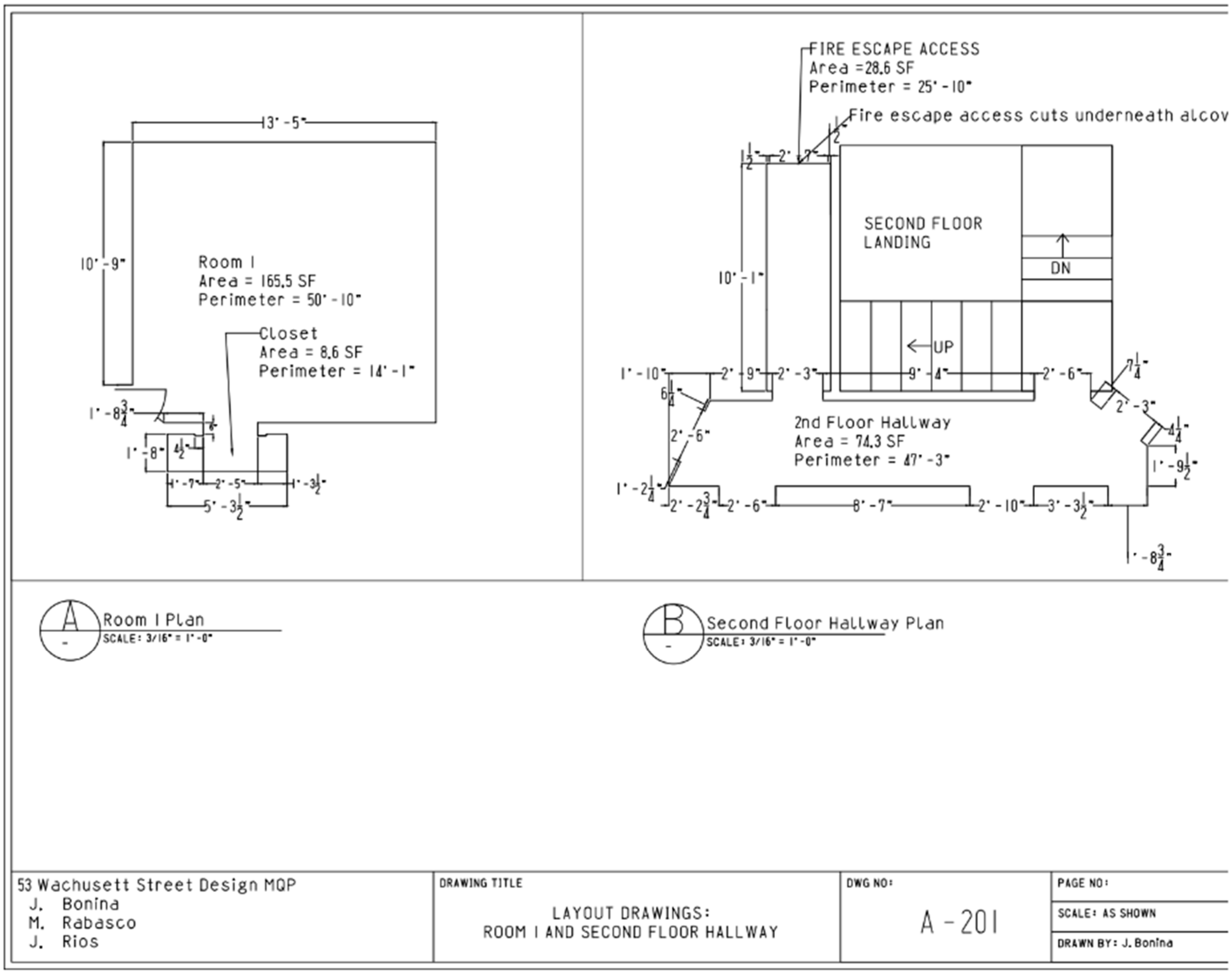


Figure 113. Layout drawings – room 1 and second floor hallway

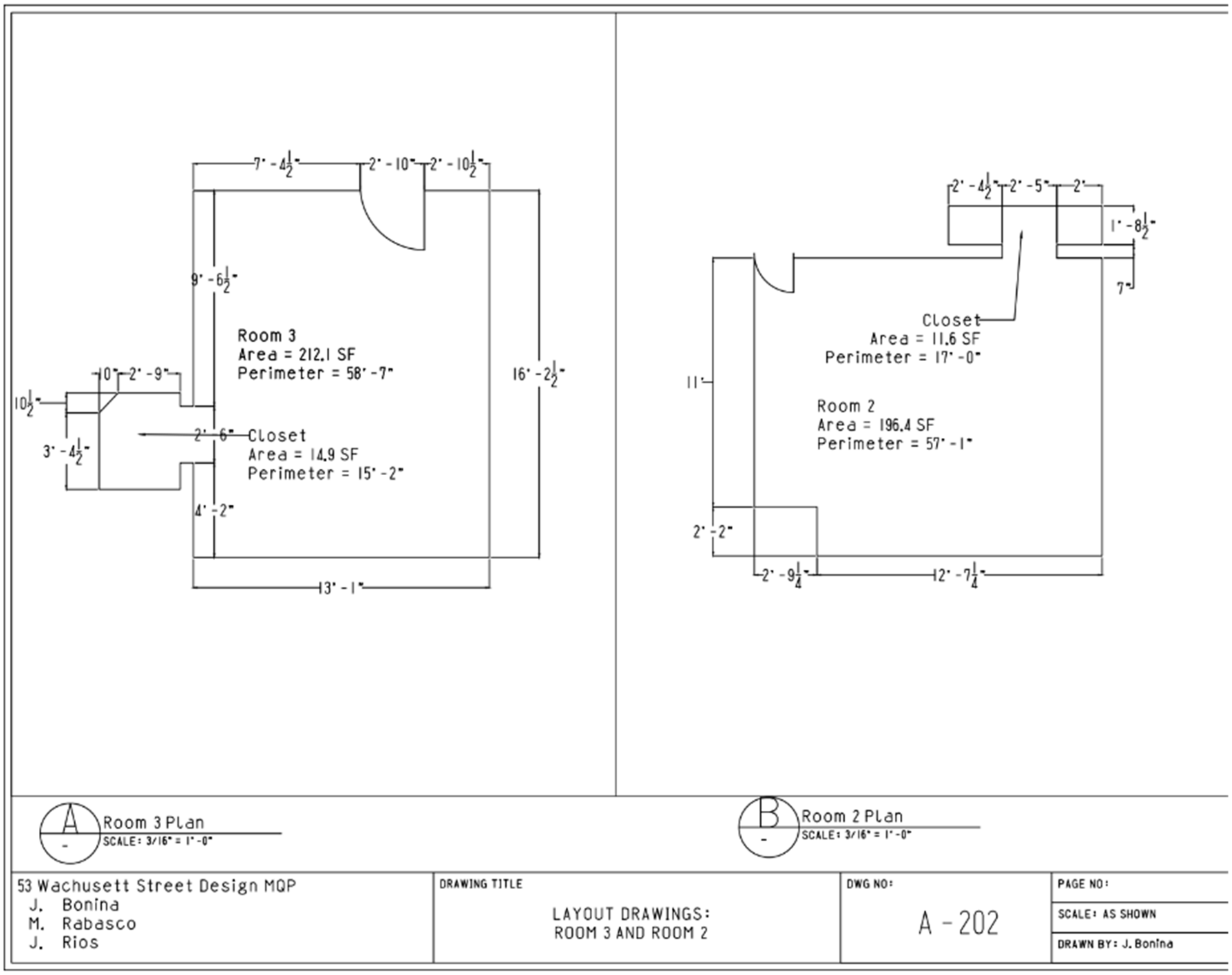


Figure 114. Layout drawings - Room 3 and room 2

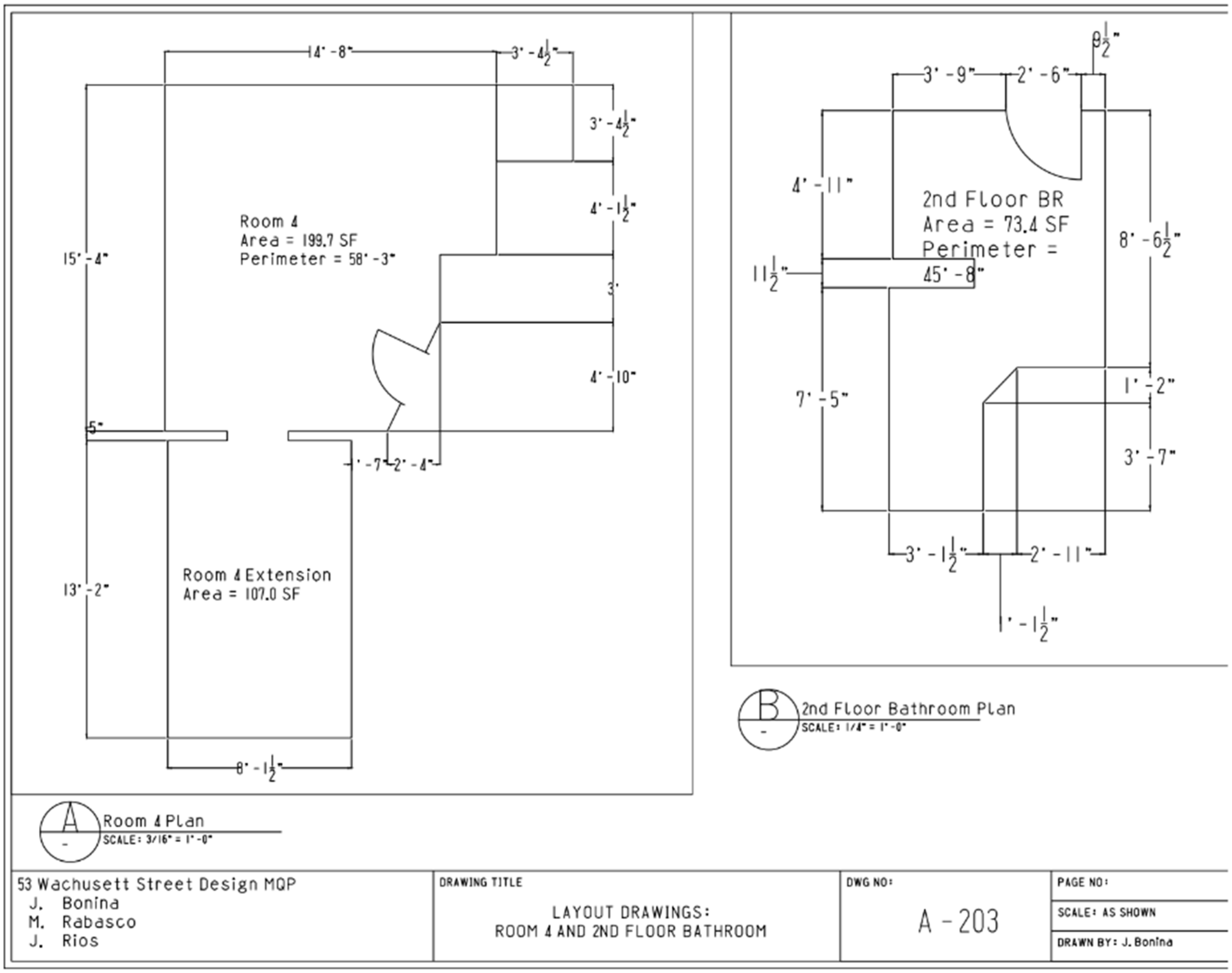


Figure 115. Layout drawings - Room 4 and Second floor bathroom

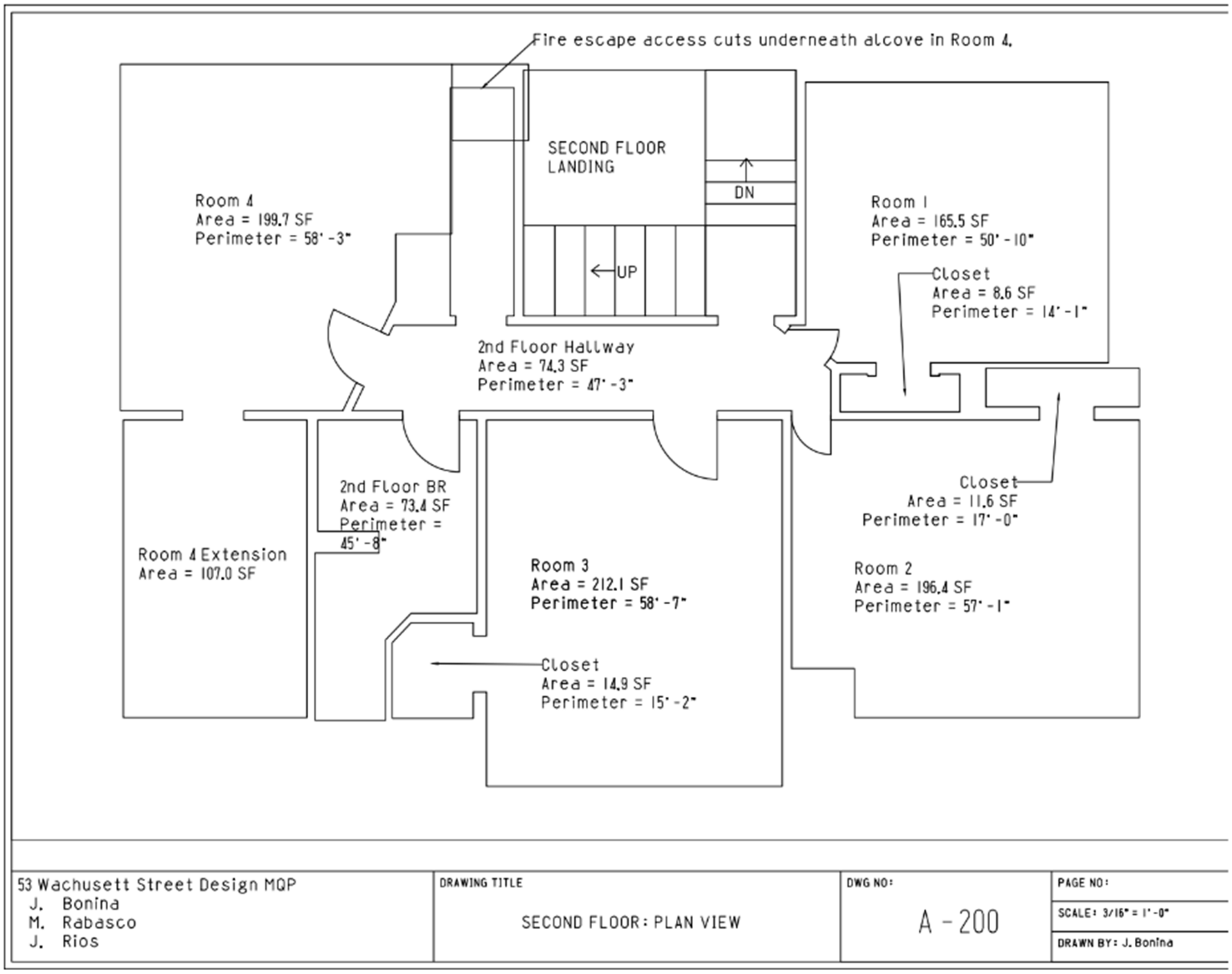


Figure 116. Layout drawing - Second floor

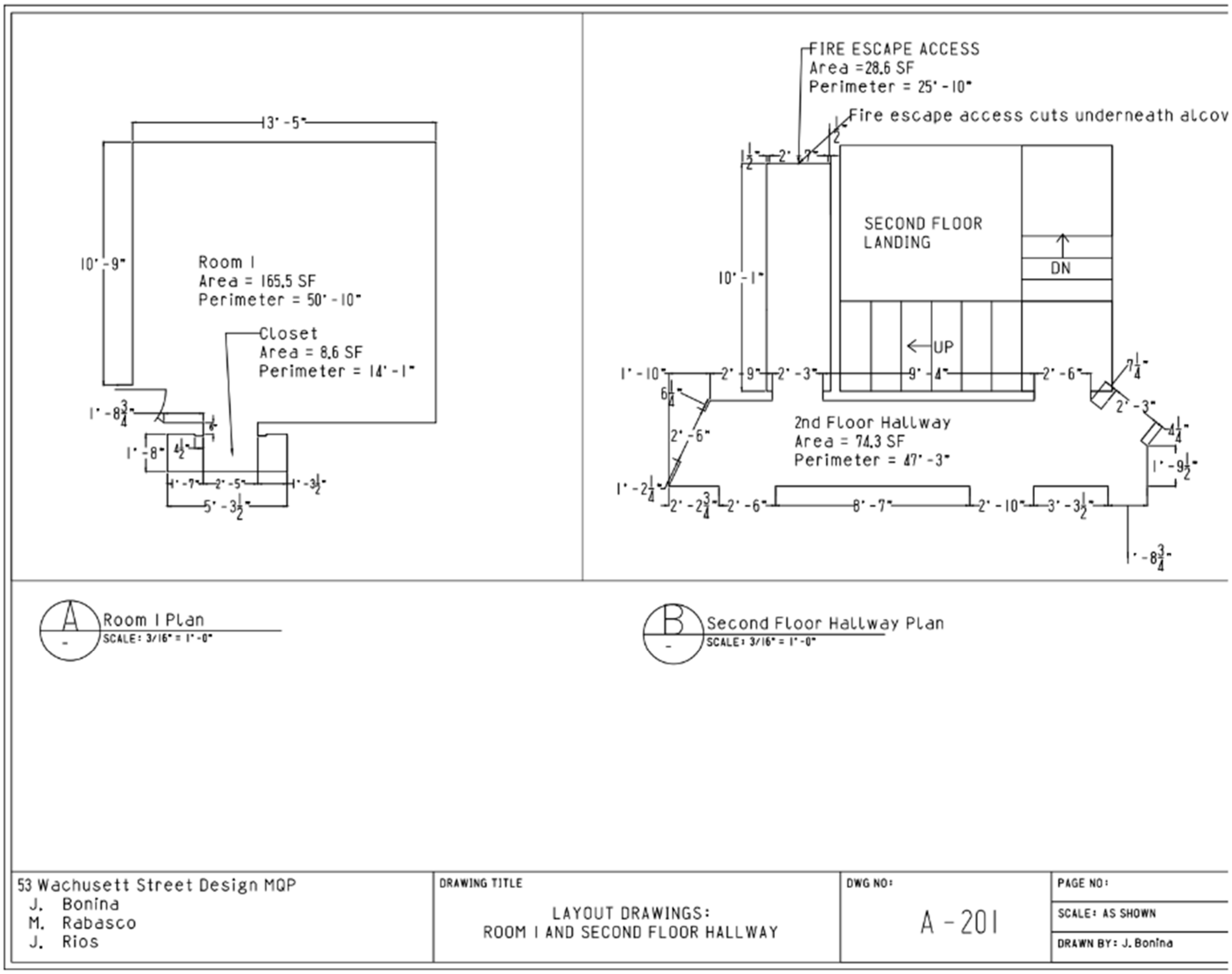


Figure 117. Layout drawing - Room 1

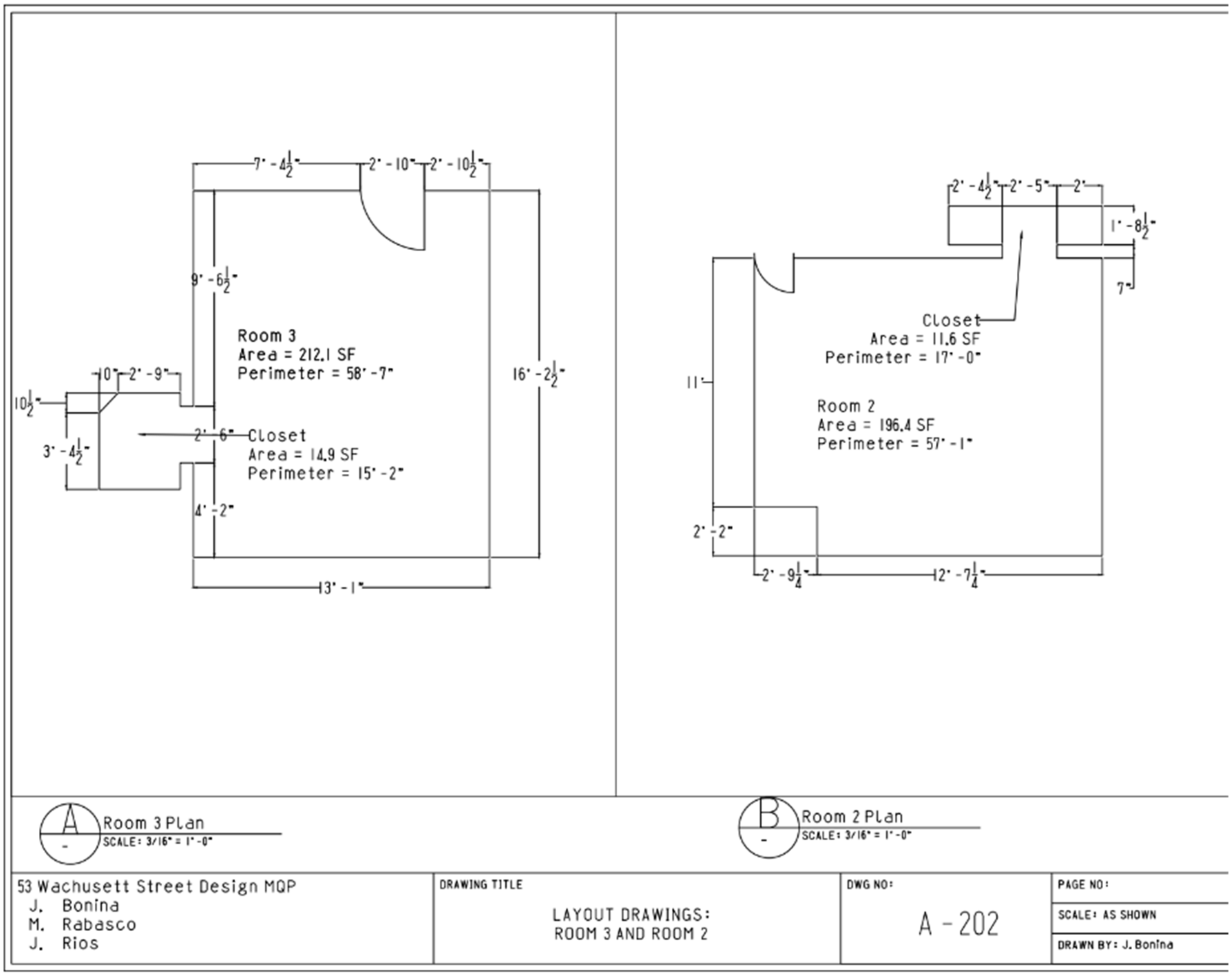


Figure 118. Layout drawing - Rooms 2 and 3

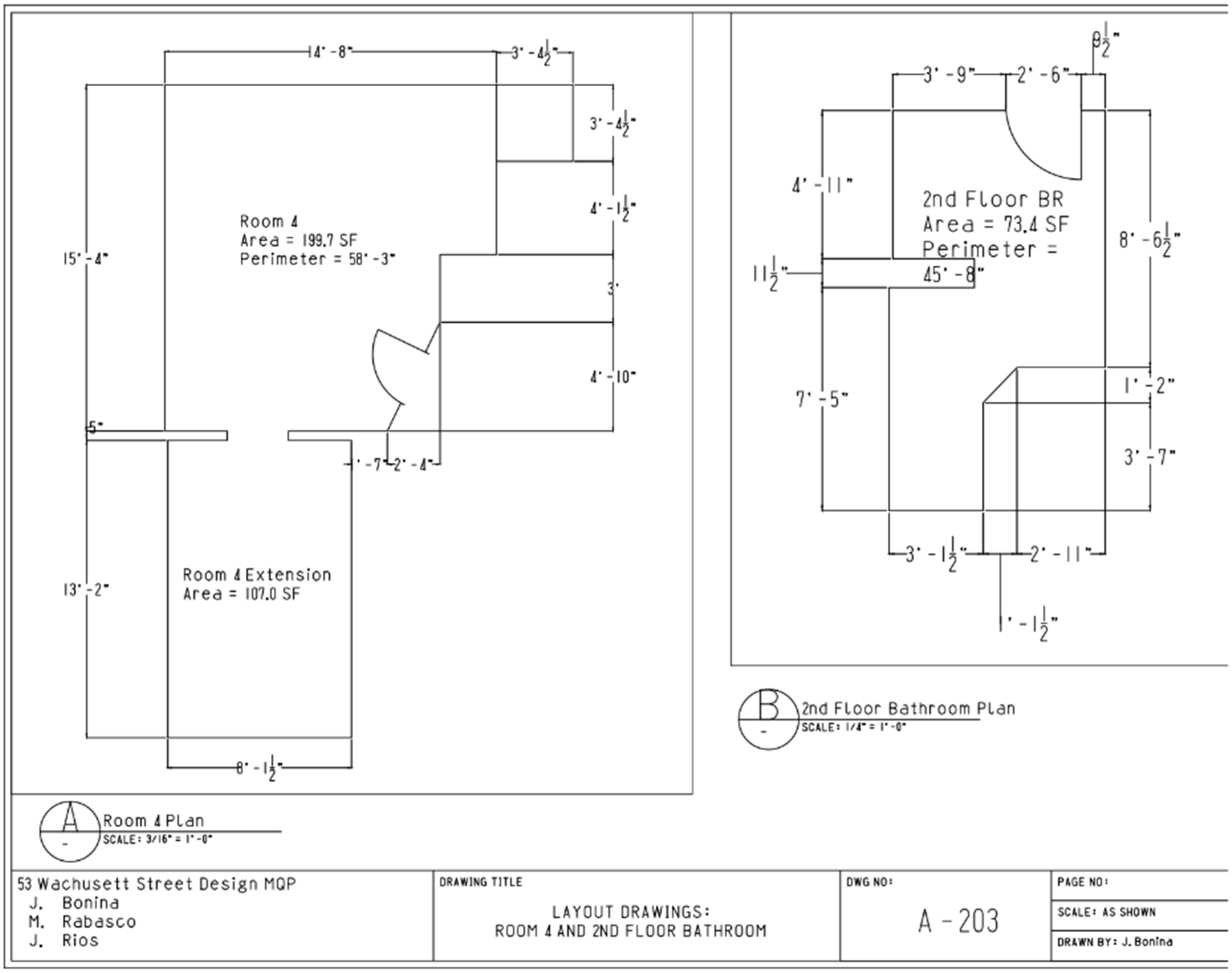


Figure 119. Layout drawing - Room 4 and Second floor bathroom

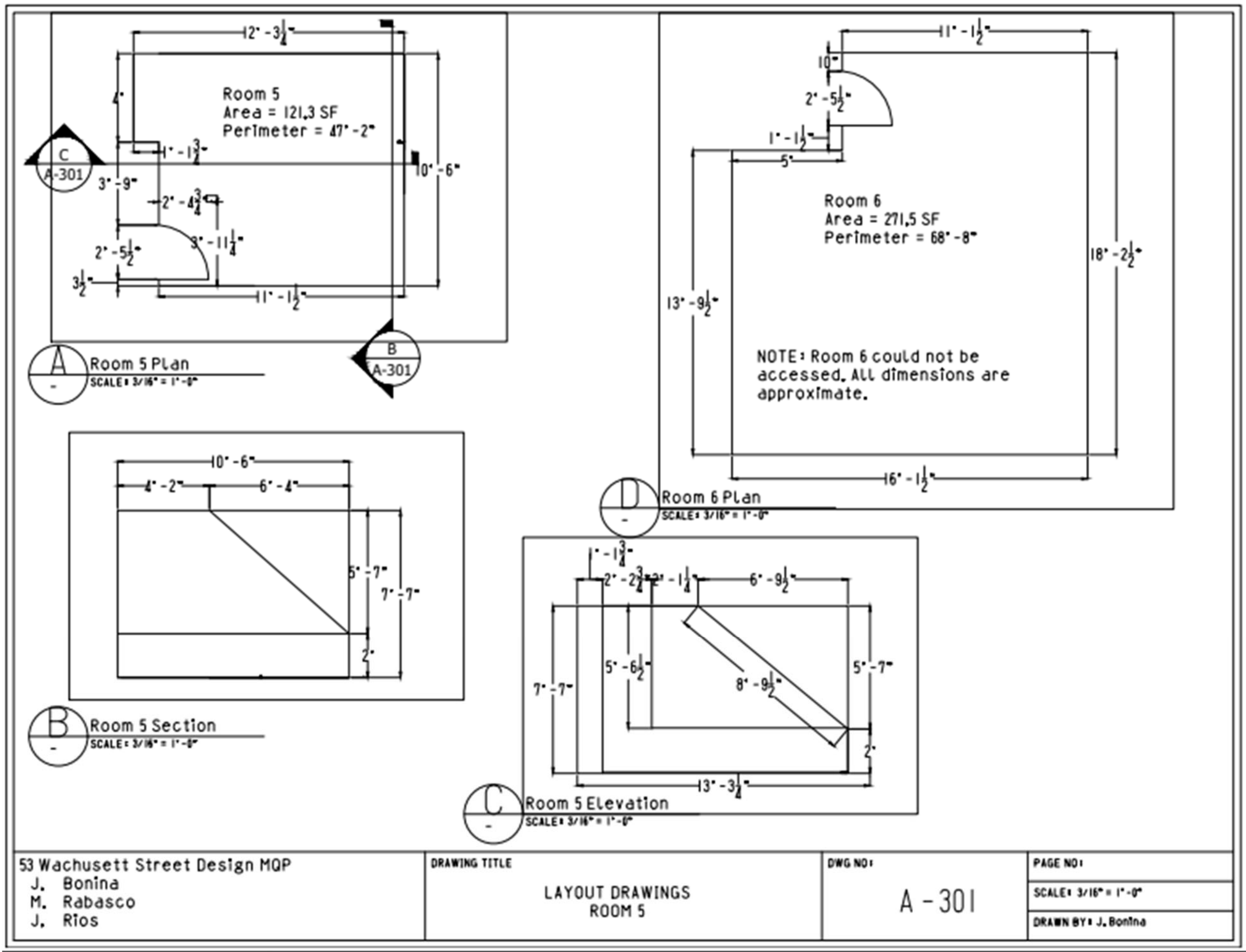


Figure 120. Layout drawing - Room 5 and 6

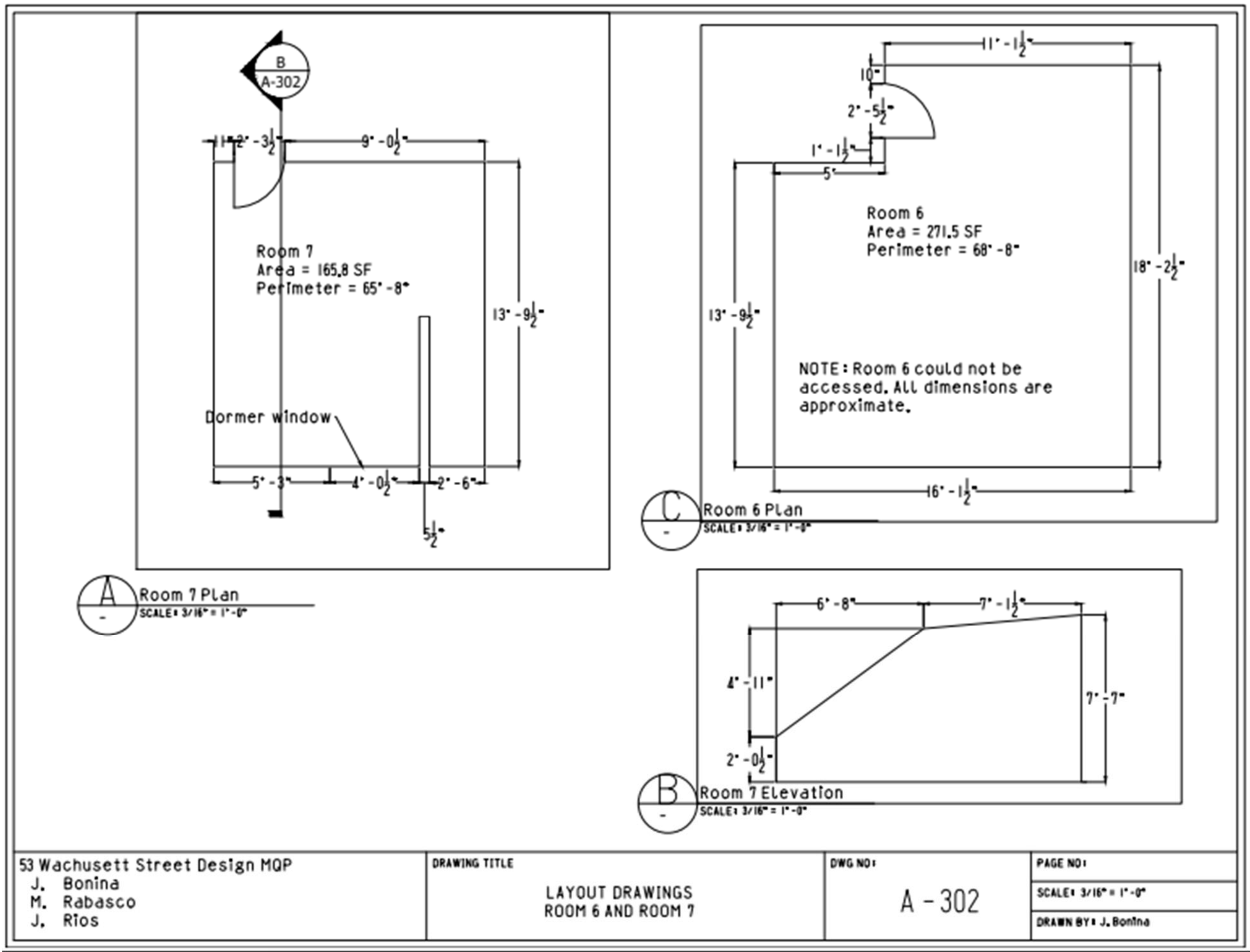


Figure 121. Layout drawings - Room 6 and Room 7

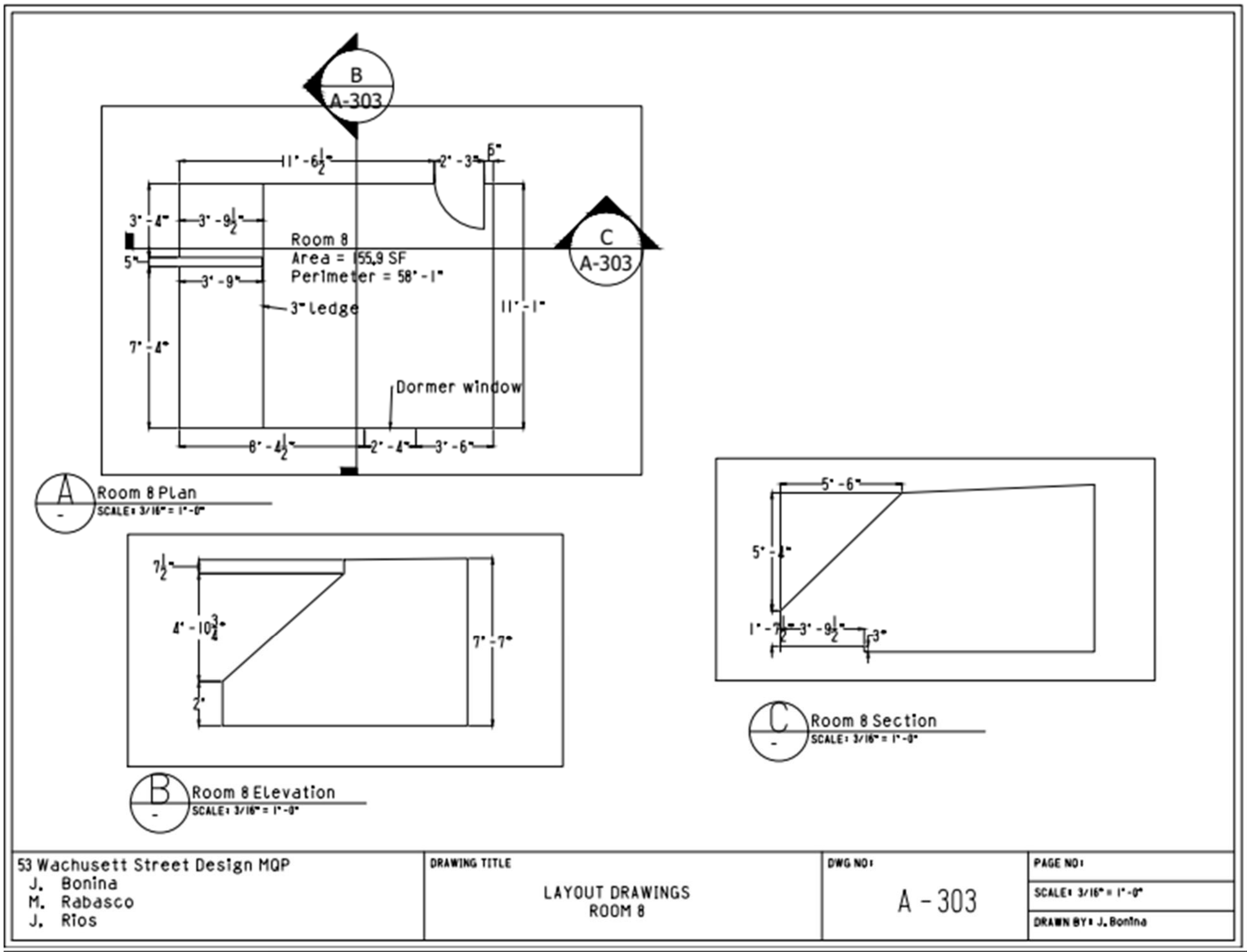


Figure 122. Layout drawing – room 8

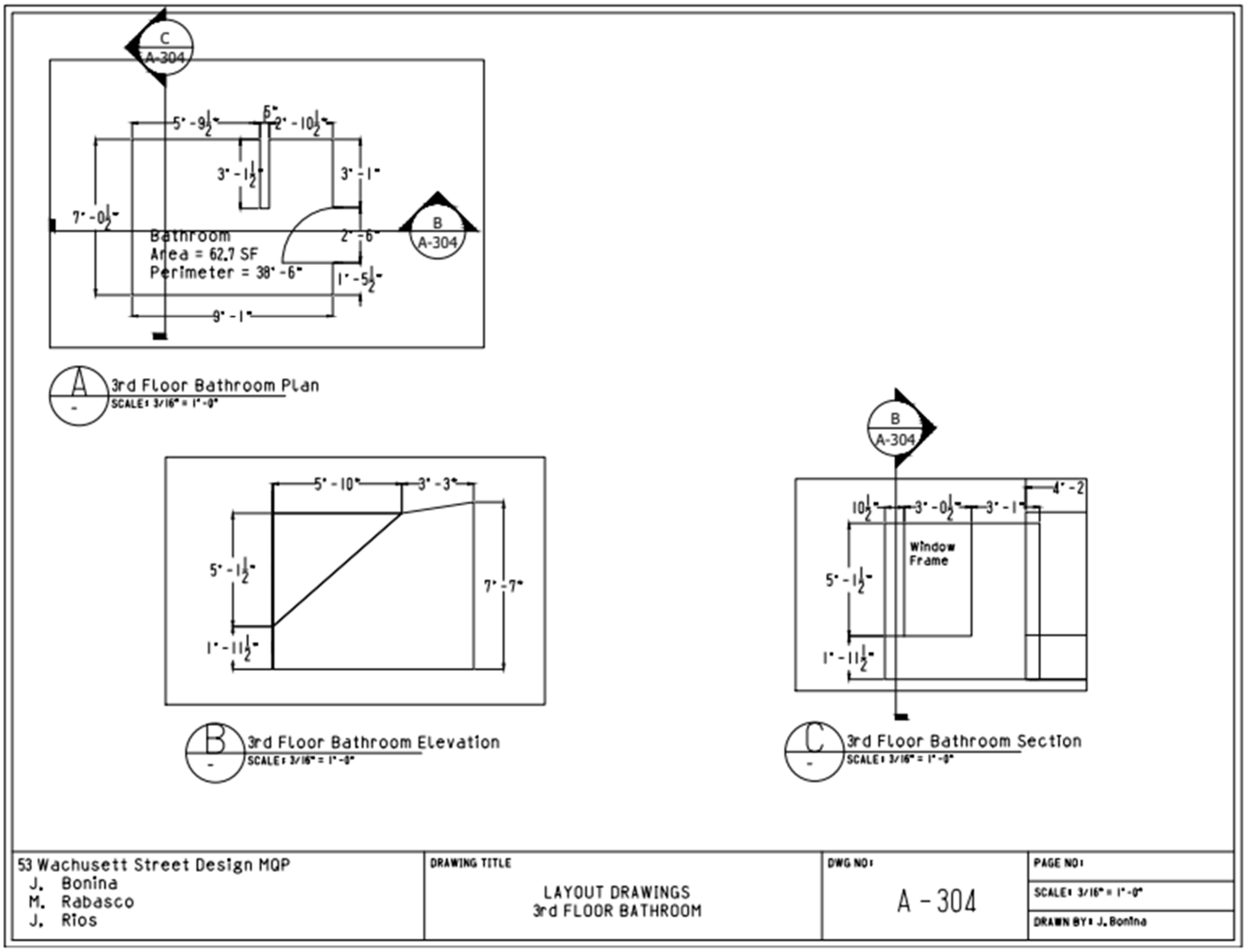


Figure 123. Layout drawing – third floor bathroom

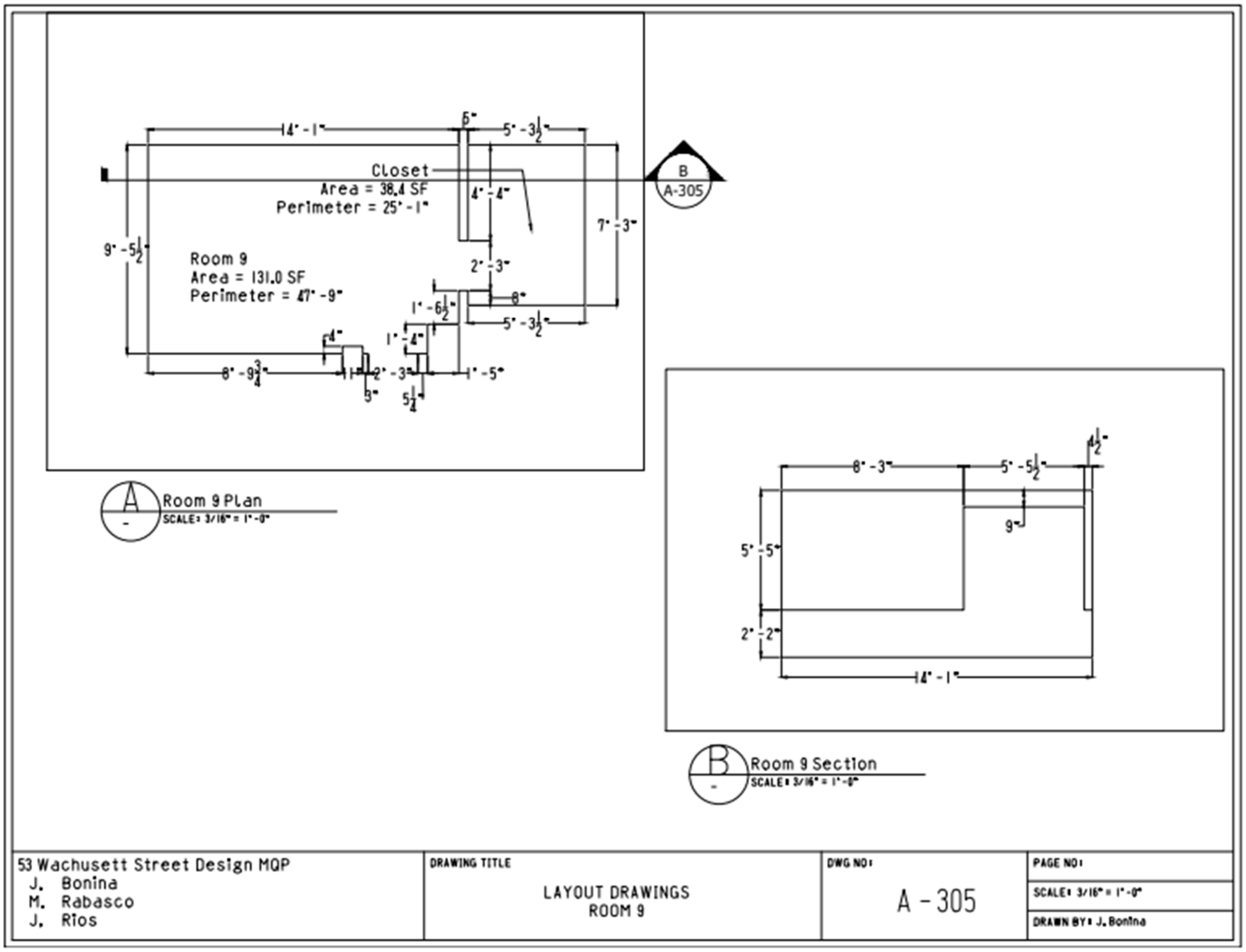


Figure 124. Layout drawing – room 9

Appendix E: Renovation Calculations

1

Bonina, Rabasco, and Rios
53 Wachusett Street Design MQP
11/06/18

Basement Flooring Calculations

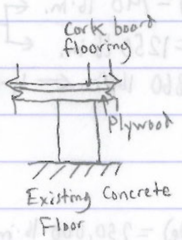
The necessary spacing of 2x4s should be determined for the three plywood thicknesses given in R.S. Means: $\frac{1}{2}$", $\frac{5}{8}$", and $\frac{3}{4}$".

In any case, the following loads need to be solved for, since this is a basement floor that will not be subject to weather or lateral loads.

- $1.4D$
- $1.2D + 1.6L$

D = Weight of plywood + Weight of cork board floor
L = Given by ASCE 7-10

Schematic:

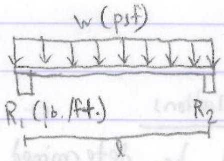


Basic Loads:
- Weight of plywood $(\frac{1}{2}") = 1.42$ PSF
- Weight of plywood $(\frac{5}{8}") = 1.77$ PSF
- Weight of plywood $(\frac{3}{4}") = 2.13$ PSF
- Weight of cork board $= \frac{36 \text{ lb.}}{25.866 \text{ SF}} = 1.39$ PSF
- Live Load = 100 psf for public rooms and corridors

Figure 125. Basement flooring calculations (page 1 of 6)

2

These calculations can be performed as shown below:



Conventionally, $\sigma = \frac{Mc}{I} = \frac{M\frac{h}{2}}{\frac{1}{12}bh^3} = \frac{6M}{bh^2}$

If the reactions are in pounds per foot,

$\sigma = \frac{6\left(\frac{M}{b}\right)}{h^2}$

Design factors for plywood:

$F_b' S = F_b S\, C_M C_t C_s (K_F = 2.54)(\phi = 0.85)(\lambda = \text{varies})$

$C_s = 1.0$ for 24"-wide panels

$C_M = C_t = 1.0$ for normal indoor conditions

$\lambda = 0.6$ for 1.4D

0.8 for 1.2D+1.6L (when L is from occupancy)

$S = \frac{bd^2}{6}$

For 2x4s, $S = \frac{(1.5")(3.5")^2}{6} = 3.0625$ in.^{3}

For plywood ($\frac{1}{2}$" thick × 24" wide), $S = \frac{(24")(0.5")^2}{6} = 1$ in.^{3}

For plywood ($\frac{5}{8}$" thick × 24" wide), $S = \frac{(24")(5/8")^2}{6} = 1.5625$ in.^{3}

For plywood ($\frac{3}{4}$" thick × 24" wide), $S = \frac{(24")(3/4")^2}{6} = 2.25$ in.^{3}

Plywood bending strengths:

$\frac{1}{2}$" thick (32/16): $F_b S = (370$ lb·in/ft.$)(2'$ wide$) = 740$ lb·in. ← 3-ply

$\frac{5}{8}$" thick (40/20): $F_b S = (625$ lb·in./ft.$)(2'$ wide$) = 1250$ lb·in. ← 3-ply

$\frac{3}{4}$" thick (48/24): $F_b S = (930$ lb·in./ft.$)(2'$ wide$) = 1860$ lb·in ← 4-ply

Plywood stiffnesses:

$\frac{1}{2}$" thick (32/16): $EI = (125{,}000$ lb·in^2/ft.$)(2'$ wide$) = 250{,}000$ lb·in^2 ← 3-ply

$\frac{5}{8}$" thick (40/20): $EI = (250{,}000$ lb·in^2/ft.$)(2'$ wide$) = 500{,}000$ lb·in^2 ← 3-ply

$\frac{3}{4}$" thick (48/24): $EI = (440{,}000$ lb·in^2/ft.$)(2'$ wide$) = 880{,}000$ lb·in.^{2} ← 4-ply

Figure 126. Basement flooring calculations (page 2 of 6)

(Basement Floor Calculations) 3

For the $\frac{1}{2}''$ thick plywood board:

D = Weight of plywood + Weight of cork board

$= (1.42\ \text{PSF}) + (1.39\ \text{PSF})$

$D = 2.81\ \text{PSF} \times (2'\ \text{width}) = 5.62\ \text{lb./ft.}$

$L = 100\ \text{PSF} \times (2'\ \text{width}) = 200\ \text{lb./ft.}$

- $1.4D = 1.4(5.62\ \text{lb./ft.}) = 7.87\ \text{lb./ft.}$

  The unsupported length of plywood at which $f_b S = F_b' S$ is given by $\frac{wL^2}{8} = F_b S C_m C_t C_s K_F \phi \lambda$

  $$\frac{\left(\frac{1'}{12''}\right)(7.87\ \text{lb./ft.})L^2}{8} = (740\ \text{lb}\cdot\text{in.})(1.0)(1.0)(1.0)(2.84)(0.85)(0.6)$$

  $0.0820\ \text{lb/in.}\cdot L^2 = 1071.8\ \text{lb}\cdot\text{in.} \rightarrow L = 114.4''$

- $1.2D + 1.6L = 1.2(5.62\ \text{lb./ft.}) + 1.6(200\ \text{lb./ft.}) = 326.744\ \text{lb./ft.}$

  $$\frac{\left(\frac{1'}{12''}\right)(326.744\ \text{lb./ft.})L^2}{8} = (740\ \text{lb}\cdot\text{in.})(1.0)(1.0)(1.0)(2.84)(0.85)(0.8)$$

  $3.404\ \text{lb./in.}\cdot L^2 = 1429.1\ \text{lb}\cdot\text{in.} \rightarrow L = 20.5''$

- Solve for deflection caused by D+L:

  $D + L = (5.62\ \text{lb./ft.}) + (200\ \text{lb./ft.}) = 205.62\ \text{lb./ft.}$

  $\Delta_T = K_{cr}\Delta_{LT} + \Delta_{ST}$

  $K_{cr} = 2.0$, for structural panels

  $$\Delta_T = (2.0)\frac{5w_D l^4}{384EI} + \frac{5w_L L^4}{384EI} = (2.0)\frac{5(5.62\ \text{lb./ft.})L^4\left(\frac{1'}{12''}\right)}{384(250{,}000\ \text{lb}\cdot\text{in.}^2)} + \frac{5(200\ \text{lb./ft.})L^4\left(\frac{1'}{12''}\right)}{384(250{,}000\ \text{lb}\cdot\text{in}^2)}$$

  $\Delta_T = 9.17\times10^{-7}\ \text{in}^{-3}\cdot L^4$

  Let $\Delta_c = \frac{L}{180}$

  $$\frac{L}{180} = 9.17\times10^{-7}\ \text{in}^{-3}\cdot L^4 \rightarrow L^3 = \frac{1}{(180)(9.17\times10^{-7}\ \text{in}^{-3})} = 6058\ \text{in.}^3$$

  $L = 18.23'' \rightarrow$ Round to $L = 18.25''$

  $L = 18.25''$ is the governing value for this, since it's the most stringent value.

Figure 127. Basement flooring calculations (page 3 of 6)

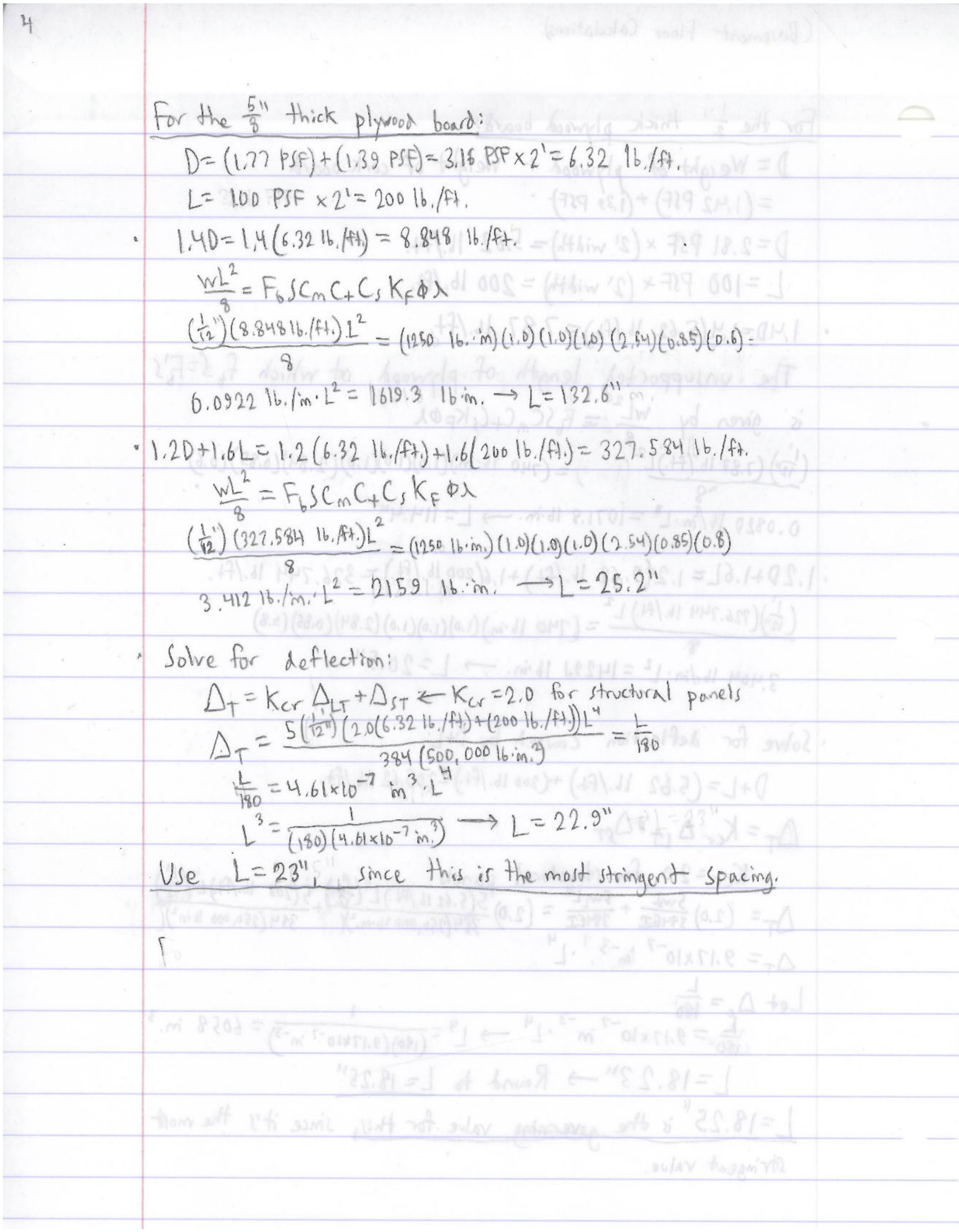


Figure 128. Basement flooring calculations (page 4 of 6)

5

· For the $\frac{3}{4}$" thick plywood board:

$D = (2.13\ PSF) + (1.39\ PSF) = 3.52\ PSF \times 2' = 7.04\ lb./ft.$

$L = 100\ PSF \times 2' = 200\ lb./ft.$

· $1.4D = 1.4(7.04\ lb./ft.) = 9.856\ lb./ft.$

$\frac{wL^2}{8} = F_b S C_m C_t C_s K_F \phi \lambda$

$\frac{(\frac{1'}{12"})(9.856\ lb./ft.)L^2}{8} = (1860\ lb.\cdot in.)(1.0)(1.0)(1.0)(2.54)(0.85)(0.6)$

$0.103\ lb./in.\cdot L^2 = 2409.4\ lb\cdot in. \longrightarrow L = 153"$

· $1.2D + 1.6L = 1.2(7.04\ lb./ft.) + 1.6(200\ lb./ft.) = 328.448\ lb./ft.$

$\frac{wL^2}{8} = F_b S C_m C_t C_s K_F \phi \lambda$

$\frac{(\frac{1'}{12"})(328.448\ lb./ft.)L^2}{8} = (1860\ lb\cdot in.)(1.0)(1.0)(1.0)(2.54)(0.85)(0.8)$

$3.421\ lb./in.\cdot L^2 = 3212.592\ lb\cdot in. \rightarrow L = 30.65"$

· Solve for deflection:

$\Delta_T = K_{cr}\Delta_{LT} + \Delta_{ST} \leftarrow K_{cr} = 2.0$ for structural panels

$\Delta_T = \frac{5(\frac{1}{12"})[2.0(7.04\ lb./ft.) + (200\ lb./ft.)]L^4}{384(880{,}000\ lb\cdot in.^2)} = \frac{L}{180}$

$\frac{L}{180} = 2.64 \times 10^{-7}\ in^{-3}\cdot L^4$

$L^3 = \frac{1}{(180)(2.64\times10^{-7}\ in^{-3})} \longrightarrow L = 27.6" \rightarrow$ Round up to $L = 27.75"$

$\underline{L = 27.75"}$, the most stringent requirement.

· Rough cost estimates (to determine which thickness plywood to use):

· For 1 SF of floor, you have 1 SF plywood & $\frac{1\ SF}{Spacing}$ 2x4s

· Costs: 2x4s = \$1.54/LF, Plywood ($\frac{1}{2}$") = \$1.06/SF

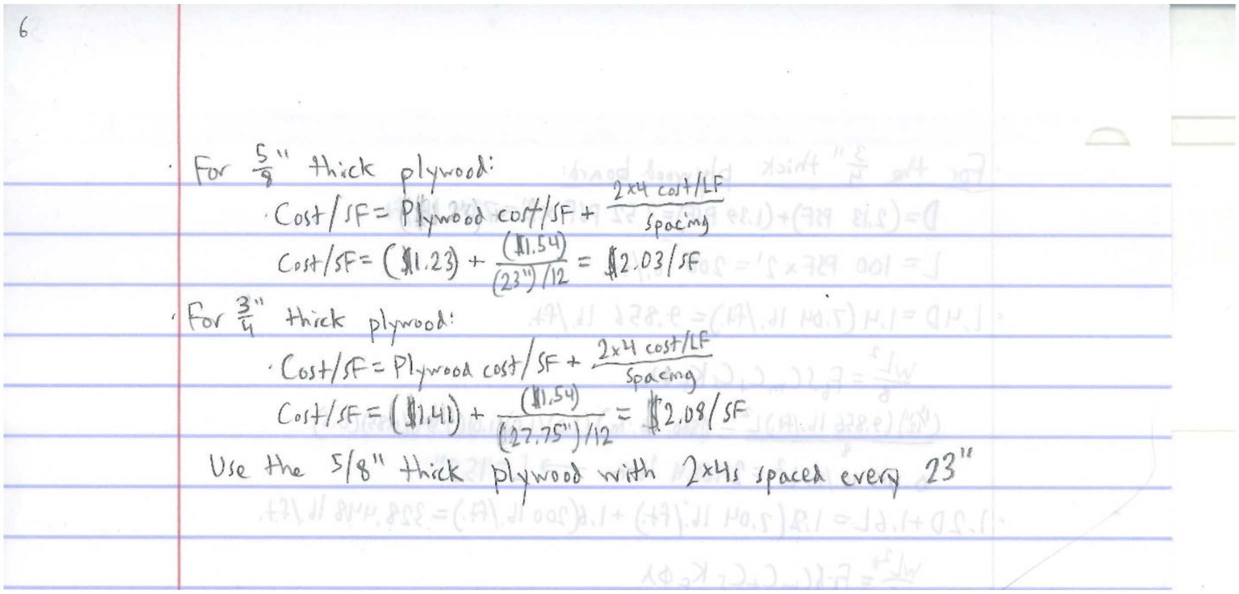
Plywood ($\frac{5}{8}$) = \$1.23/SF, Plywood ($\frac{3}{4}$") = \$1.41/SF

· For $\frac{1}{2}$" thick plywood,

$Cost/SF = Plywood\ cost/SF + \frac{2\times4\ cost/LF}{Spacing} = (\$1.06/SF) + \frac{(\$1.54/LF)}{(18.25")(1'/12")}$

$Cost/SF = \$2.07$

Figure 129. Basement flooring calculations (page 5 of 6)



6

For $\frac{5}{8}$" thick plywood:

$$\text{Cost/SF} = \text{Plywood cost/SF} + \frac{\text{2x4 cost/LF}}{\text{Spacing}}$$

$$\text{Cost/SF} = (\$1.23) + \frac{(\$1.54)}{(23")/12} = \$2.03/\text{SF}$$

For $\frac{3}{4}$" thick plywood:

$$\text{Cost/SF} = \text{Plywood cost/SF} + \frac{\text{2x4 cost/LF}}{\text{Spacing}}$$

$$\text{Cost/SF} = (\$1.41) + \frac{(\$1.54)}{(27.75")/12} = \$2.08/\text{SF}$$

Use the 5/8" thick plywood with 2x4s spaced every 23"

Figure 130. Basement flooring calculations (page 6 of 6)

Table 48. Breakdown for square footage affected by renovation

Description	Area (SF)
Basement	**Total = 614.7 SF**
Main Room	385.7
Room A	96.7
Room B	103.6
Closet	28.7
First Floor	**Total = 1015.77 SF**
Living Room	576.23
Kitchen	236.42
Kitchen Exit	69.58
Stairwell	133.54
Upper Floors	**Total = 135.74 SF**
2nd Floor BR	73.27
3rd Floor BR	62.47
Total (SF)	**1766.21 SF**

Appendix F: New Construction Calculations and Results

Storage Tank Calculations

Table 49. Storage tank calculations by day

Day	Term	Precip. (inch)	Snow (inch)	Snow depth (inch)	Water to tanks (CF)	Water Used (CF)	Water from Storage	Water Used From Outside (CF)	Water to Storage	Water Stored (CF)
1 Jan 2018		0	0	-	0.00	36.45	0	36.45	0	0.00
2 Jan 2018		0	0	-	0.00	36.45	0.00	36.45	0	0.00
3 Jan 2018		0	0	-	0.00	36.45	0.00	36.45	0	0.00
4 Jan 2018		1.03	16.81	-	327.57	36.45	36.45	0.00	291.12	254.67
5 Jan 2018		0	0	-	0.00	36.45	36.45	0.00	0	218.22
6 Jan 2018		0	0	-	0.00	36.45	36.45	0.00	0	181.77
7 Jan 2018		0	0	-	0.00	36.45	36.45	0.00	0	145.33
8 Jan 2018		0.02	0.39	-	6.36	36.45	36.45	0.00	0	108.88
9 Jan 2018		0	0	-	0.00	72.90	72.90	0.00	0	35.98
10 Jan 2018	C	0	0	-	0.00	109.34	35.98	73.36	0	0.00
11 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
12 Jan 2018	C	0.71	0	-	225.80	109.34	109.34	0.00	116.45	7.11
13 Jan 2018	C	0.31	0	-	98.59	109.34	7.11	3.65	0	0.00
14 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
15 Jan 2018	C	T	T	-	0.00	109.34	0.00	109.34	0	0.00
16 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
17 Jan 2018	C	0.3	3.9	-	95.41	109.34	0.00	13.94	0	0.00
18 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
19 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
20 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
21 Jan 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00

22 Jan 2018	C	0.17	0	0	54.06	109.34	0.00	55.28	0	0.00
23 Jan 2018	C	0.88	-	-	279.86	109.34	109.34	0.00	170.52	61.17
24 Jan 2018	C	0	-	-	0.00	109.34	61.17	48.17	0	0.00
25 Jan 2018	C	0	-	-	0.00	109.34	0.00	109.34	0	0.00
26 Jan 2018	C	0	-	-	0.00	109.34	0.00	109.34	0	0.00
27 Jan 2018	C	0	-	-	0.00	109.34	0.00	109.34	0	0.00
28 Jan 2018	C	0.15	-	-	47.70	109.34	0.00	61.64	0	0.00
29 Jan 2018	C	T	-	-	0.00	109.34	0.00	109.34	0	0.00
30 Jan 2018	C	0.05	-	-	15.90	109.34	0.00	93.44	0	0.00
31 Jan 2018	C	0	-	-	0.00	109.34	0.00	109.34	0	0.00
1 Feb 2018	C	0.14	-	-	44.52	109.34	0.00	64.82	0	0.00
2 Feb 2018	C	0.18	-	-	57.24	109.34	0.00	52.10	0	0.00
3 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
4 Feb 2018	C	0.49	0	-	155.83	109.34	109.34	0.00	46.49	-62.86
5 Feb 2018	C	0.13	0	-	41.34	109.34	-62.86	130.86	0	0.00
6 Feb 2018	C	0.02	0.51	-	6.36	109.34	0.00	102.98	0	0.00
7 Feb 2018	C	0.76	2.52	-	241.70	109.34	109.34	0.00	132.35	23.01
8 Feb 2018	C	0	0	-	0.00	109.34	23.01	86.33	0	0.00
9 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
10 Feb 2018	C	0.44	0	0	139.93	109.34	109.34	0.00	30.59	-78.76
11 Feb 2018	C	0.85	0	-	270.32	109.34	109.34	0.00	160.98	-27.12
12 Feb 2018	C	0.01	0	-	3.18	109.34	-27.12	133.29	0	0.00
13 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
14 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
15 Feb 2018	C	T	0	-	0.00	109.34	0.00	109.34	0	0.00
16 Feb 2018	C	0.01	0	-	3.18	109.34	0.00	106.16	0	0.00
17 Feb 2018	C	0.29	2.99	-	92.23	109.34	0.00	17.12	0	0.00
18 Feb 2018	C	0.25	2.99	-	79.51	109.34	0.00	29.84	0	0.00
19 Feb 2018	C	0.28	0	-	89.05	109.34	0.00	20.30	0	0.00
20 Feb 2018	C	0.03	0	-	9.54	109.34	0.00	99.80	0	0.00
21 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
22 Feb 2018	C	0.12	0.79	-	38.16	109.34	0.00	71.18	0	0.00

23 Feb 2018	C	0.27	0	-	85.87	109.34	0.00	23.48	0	0.00
24 Feb 2018	C	T	0	-	0.00	109.34	0.00	109.34	0	0.00
25 Feb 2018	C	0.6	0.31	-	190.82	109.34	109.34	0.00	81.47	-27.87
26 Feb 2018	C	0	0	-	0.00	109.34	-27.87	137.22	0	0.00
27 Feb 2018	C	0	0	-	0.00	109.34	0.00	109.34	0	0.00
28 Feb 2018	C	T	0	-	0.00	109.34	0.00	109.34	0	0.00
1 Mar 2018	C	0.02	0	-	6.36	109.34	0.00	102.98	0	0.00
2 Mar 2018	C	1.62	1.18	-	515.20	109.34	109.34	0.00	405.86	280.73
3 Mar 2018		0	0	-	0.00	72.90	72.90	0.00	0	207.83
4 Mar 2018		T	T	-	0.00	36.45	36.45	0.00	0	171.38
5 Mar 2018		0.07	0.59	-	22.26	36.45	36.45	0.00	0	134.94
6 Mar 2018		0	0	-	0.00	36.45	36.45	0.00	0	98.49
7 Mar 2018		0.95	11.18	-	302.12	36.45	36.45	0.00	265.68	280.73
8 Mar 2018		0.4	5.2	-	127.21	36.45	36.45	0.00	90.76	280.73
9 Mar 2018		0.02	T	-	6.36	36.45	36.45	0.00	0	244.28
10 Mar 2018		T	T	-	0.00	36.45	36.45	0.00	0	207.83
11 Mar 2018		0	0	-	0.00	72.90	72.90	0.00	0	134.94
12 Mar 2018	D	T	T	-	0.00	109.34	109.34	0.00	0	25.59
13 Mar 2018	D	1.59	21.81	-	505.66	109.34	109.34	0.00	396.32	280.73
14 Mar 2018	D	0.01	T	0	3.18	109.34	109.34	0.00	0	171.38
15 Mar 2018	D	T	T	-	0.00	109.34	109.34	0.00	0	62.04
16 Mar 2018	D	T	T	-	0.00	109.34	62.04	47.30	0	0.00
17 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
18 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
19 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
20 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
21 Mar 2018	D	T	T	-	0.00	109.34	0.00	109.34	0	0.00
22 Mar 2018	D	0.09	1.81	-	28.62	109.34	0.00	80.72	0	0.00
23 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
24 Mar 2018	D	T	T	-	0.00	109.34	0.00	109.34	0	0.00
25 Mar 2018	D	0.04	0.51	-	12.72	109.34	0.00	96.62	0	0.00
26 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00

27 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
28 Mar 2018	D	T	0	-	0.00	109.34	0.00	109.34	0	0.00
29 Mar 2018	D	0.03	0	-	9.54	109.34	0.00	99.80	0	0.00
30 Mar 2018	D	0.06	0	-	19.08	109.34	0.00	90.26	0	0.00
31 Mar 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
1 Apr 2018	D	T	0	-	0.00	109.34	0.00	109.34	0	0.00
2 Apr 2018	D	0.22	2.6	-	69.97	109.34	0.00	39.38	0	0.00
3 Apr 2018	D	0.49	T	-	155.83	109.34	109.34	0.00	46.49	-62.86
4 Apr 2018	D	0.36	0	-	114.49	109.34	-62.86	57.71	5.14	5.14
5 Apr 2018	D	0	0	-	0.00	109.34	5.14	104.20	0	0.00
6 Apr 2018	D	0.24	2.8	-	76.33	109.34	0.00	33.02	0	0.00
7 Apr 2018	D	0.06	T	-	19.08	109.34	0.00	90.26	0	0.00
8 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
9 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
10 Apr 2018	D	0.02	T	0	6.36	109.34	0.00	102.98	0	0.00
11 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
12 Apr 2018	D	0.07	0	-	22.26	109.34	0.00	87.08	0	0.00
13 Apr 2018	D	T	0	-	0.00	109.34	0.00	109.34	0	0.00
14 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
15 Apr 2018	D	0.28	0.39	-	89.05	109.34	0.00	20.30	0	0.00
16 Apr 2018	D	2.02	0.79	-	642.41	109.34	109.34	0.00	533.07	280.73
17 Apr 2018	D	T	T	-	0.00	109.34	109.34	0.00	0	171.38
18 Apr 2018	D	0	0	-	0.00	109.34	109.34	0.00	0	62.04
19 Apr 2018	D	0.23	0.59	-	73.15	109.34	109.34	0.00	0	-47.30
20 Apr 2018	D	0	0	-	0.00	109.34	-47.30	156.65	0	0.00
21 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
22 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
23 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
24 Apr 2018	D	0	0	-	0.00	109.34	0.00	109.34	0	0.00
25 Apr 2018	D	0.97	0	-	308.48	109.34	109.34	0.00	199.14	89.80
26 Apr 2018	D	0.03	0	-	9.54	109.34	89.80	10.01	0	0.00
27 Apr 2018	D	0.32	0	-	101.77	109.34	0.00	7.58	0	0.00

28 Apr 2018	D	0.01	0	-	3.18	109.34	0.00	106.16	0	0.00
29 Apr 2018	D	0.12	0	-	38.16	109.34	0.00	71.18	0	0.00
30 Apr 2018	D	0.18	0	-	57.24	109.34	0.00	52.10	0	0.00
1 May 2018	D	T	0	-	0.00	109.34	0.00	109.34	0	0.00
2 May 2018		0	0	-	0.00	72.90	0.00	72.90	0	0.00
3 May 2018		0.07	0	-	22.26	36.45	0.00	14.19	0	0.00
4 May 2018		0.01	0	-	3.18	36.45	0.00	33.27	0	0.00
5 May 2018		0	0	-	0.00	36.45	0.00	36.45	0	0.00
6 May 2018		0.31	0	-	98.59	36.45	36.45	0.00	62.14	25.69
7 May 2018		0	0	-	0.00	36.45	25.69	10.76	0	0.00
8 May 2018		0	0	-	0.00	36.45	0.00	36.45	0	0.00
9 May 2018		0	0	0	0.00	36.45	0.00	36.45	0	0.00
10 May 2018		T	-	-	0.00	36.45	0.00	36.45	0	0.00
11 May 2018		0	0	-	0.00	72.90	0.00	72.90	0	0.00
12 May 2018	Summer	0.23	0	-	73.15	0.00	0.00	0.00	73.15	73.15
13 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	73.15
14 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	73.15
15 May 2018	Summer	1.09	0	-	346.65	0.00	0.00	0.00	346.65	280.73
16 May 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
17 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
18 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
19 May 2018	Summer	0.26	0	-	82.69	0.00	0.00	0.00	82.69	280.73
20 May 2018	Summer	0.09	0	-	28.62	0.00	0.00	0.00	28.62	280.73
21 May 2018	Summer	0	0	0	0.00	0.00	0.00	0.00	0	280.73
22 May 2018	Summer	0.03	0	-	9.54	0.00	0.00	0.00	9.54	280.73
23 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73

24 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
25 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
26 May 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
27 May 2018	Summer	0.2	0	-	63.61	0.00	0.00	0.00	63.61	280.73
28 May 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
29 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
30 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
31 May 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
1 Jun 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
2 Jun 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
3 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
4 Jun 2018	Summer	0.43	0	-	136.75	0.00	0.00	0.00	136.75	280.73
5 Jun 2018	Summer	0.14	0	-	44.52	0.00	0.00	0.00	44.52	280.73
6 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
7 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
8 Jun 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
9 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
10 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
11 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
12 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
13 Jun 2018	Summer	0.02	0	-	6.36	0.00	0.00	0.00	6.36	280.73
14 Jun 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
15 Jun 2018	Summer	0.02	0	-	6.36	0.00	0.00	0.00	6.36	280.73
16 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
17 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
18 Jun 2018	Summer	0.93	0	-	295.76	0.00	0.00	0.00	295.76	280.73
19 Jun 2018	Summer	0.11	0	-	34.98	0.00	0.00	0.00	34.98	280.73
20 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73

21 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
22 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
23 Jun 2018	Summer	0.03	0	-	9.54	0.00	0.00	0.00	9.54	280.73
24 Jun 2018	Summer	0.49	0	-	155.83	0.00	0.00	0.00	155.83	280.73
25 Jun 2018	Summer	0.11	0	-	34.98	0.00	0.00	0.00	34.98	280.73
26 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
27 Jun 2018	Summer	0.3	0	-	95.41	0.00	0.00	0.00	95.41	280.73
28 Jun 2018	Summer	1.44	0	-	457.96	0.00	0.00	0.00	457.96	280.73
29 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
30 Jun 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
1 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
2 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
3 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
4 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
5 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
6 Jul 2018	Summer	0.28	0	-	89.05	0.00	0.00	0.00	89.05	280.73
7 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
8 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
9 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
10 Jul 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
11 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
12 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
13 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
14 Jul 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
15 Jul 2018	Summer	0.01	0	-	3.18	0.00	0.00	0.00	3.18	280.73
16 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
17 Jul 2018	Summer	2.67	0	-	849.13	0.00	0.00	0.00	849.13	280.73
18 Jul 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
19 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
20 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
21 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
22 Jul 2018	Summer	0.68	0	-	216.26	0.00	0.00	0.00	216.26	280.73

23 Jul 2018	Summer	0.26	0	-	82.69	0.00	0.00	0.00	82.69	280.73
24 Jul 2018	Summer	0.09	0	-	28.62	0.00	0.00	0.00	28.62	280.73
25 Jul 2018	Summer	0.61	0	-	194.00	0.00	0.00	0.00	194.00	280.73
26 Jul 2018	Summer	0.54	0	-	171.73	0.00	0.00	0.00	171.73	280.73
27 Jul 2018	Summer	0.02	0	-	6.36	0.00	0.00	0.00	6.36	280.73
28 Jul 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
29 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
30 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
31 Jul 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
1 Aug 2018	Summer	0.13	0	-	41.34	0.00	0.00	0.00	41.34	280.73
2 Aug 2018	Summer	0.33	0	-	104.95	0.00	0.00	0.00	104.95	280.73
3 Aug 2018	Summer	0.02	0	-	6.36	0.00	0.00	0.00	6.36	280.73
4 Aug 2018	Summer	0.42	0	-	133.57	0.00	0.00	0.00	133.57	280.73
5 Aug 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
6 Aug 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
7 Aug 2018	Summer	0.05	0	-	15.90	0.00	0.00	0.00	15.90	280.73
8 Aug 2018	Summer	0.11	0	-	34.98	0.00	0.00	0.00	34.98	280.73
9 Aug 2018	Summer	0.09	0	-	28.62	0.00	0.00	0.00	28.62	280.73
10 Aug 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
11 Aug 2018	Summer	1.22	0	-	387.99	0.00	0.00	0.00	387.99	280.73
12 Aug 2018	Summer	0.01	0	-	3.18	0.00	0.00	0.00	3.18	280.73
13 Aug 2018	Summer	1.29	0	-	410.25	0.00	0.00	0.00	410.25	280.73
14 Aug 2018	Summer	0.44	0	-	139.93	0.00	0.00	0.00	139.93	280.73
15 Aug 2018	Summer	T	0	-	0.00	0.00	0.00	0.00	0	280.73
16 Aug 2018	Summer	0	0	-	0.00	0.00	0.00	0.00	0	280.73
17 Aug 2018	Summer	0.86	0	-	273.50	0.00	0.00	0.00	273.50	280.73
18 Aug 2018	Summer	0.29	0	-	92.23	0.00	0.00	0.00	92.23	280.73

19 Aug 2018		0.01	0	-	3.18	72.90	72.90	0.00	0	207.83
20 Aug 2018		0.01	0	-	3.18	36.45	36.45	0.00	0	171.38
21 Aug 2018		T	0	-	0.00	36.45	36.45	0.00	0	134.94
22 Aug 2018		0.62	0	-	197.18	72.90	72.90	0.00	124.28	186.32
23 Aug 2018	A	T	0	-	0.00	109.34	109.34	0.00	0	76.98
24 Aug 2018	A	0	0	-	0.00	109.34	76.98	32.37	0	0.00
25 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
26 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
27 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
28 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
29 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
30 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
31 Aug 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
1 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
2 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
3 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
4 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
5 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
6 Sep 2018	A	0.03	0	-	9.54	109.34	0.00	99.80	0	0.00
7 Sep 2018	A	T	0	-	0.00	109.34	0.00	109.34	0	0.00
8 Sep 2018	A	T	0	-	0.00	109.34	0.00	109.34	0	0.00
9 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
10 Sep 2018	A	1.28	0	-	407.07	109.34	109.34	0.00	297.73	188.38
11 Sep 2018	A	0.35	0	-	111.31	109.34	109.34	0.00	1.96	81.00
12 Sep 2018	A	0.66	0	-	209.90	109.34	109.34	0.00	100.55	72.21

13 Sep 2018	A	0.1	0	-	31.80	109.34	72.21	5.33	0	0.00
14 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
15 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
16 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
17 Sep 2018	A	0.02	0	-	6.36	109.34	0.00	102.98	0	0.00
18 Sep 2018	A	1.82	0	-	578.81	109.34	109.34	0.00	469.46	280.73
19 Sep 2018	A	T	0	-	0.00	109.34	109.34	0.00	0	171.38
20 Sep 2018	A	0	0	-	0.00	109.34	109.34	0.00	0	62.04
21 Sep 2018	A	0	0	-	0.00	109.34	62.04	47.30	0	0.00
22 Sep 2018	A	0.1	0	-	31.80	109.34	0.00	77.54	0	0.00
23 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
24 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
25 Sep 2018	A	2.16	-	-	686.93	109.34	109.34	0.00	577.59	280.73
26 Sep 2018	A	0.4	0	-	127.21	109.34	109.34	0.00	17.87	189.25
27 Sep 2018	A	T	0	-	0.00	109.34	109.34	0.00	0	79.91
28 Sep 2018	A	T	-	-	0.00	109.34	79.91	29.44	0	0.00
29 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
30 Sep 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
1 Oct 2018	A	0.07	0	-	22.26	109.34	0.00	87.08	0	0.00
2 Oct 2018	A	1.03	0	-	327.57	109.34	109.34	0.00	218.22	108.88
3 Oct 2018	A	0.05	0	-	15.90	109.34	109.34	0.00	0	-0.47
4 Oct 2018	A	0	0	-	0.00	109.34	-0.47	109.81	0	0.00
5 Oct 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
6 Oct 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00

7 Oct 2018	A	0.01	0	-	3.18	109.34	0.00	106.16	0	0.00
8 Oct 2018	A	0.01	0	-	3.18	109.34	0.00	106.16	0	0.00
9 Oct 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
10 Oct 2018	A	0	0	-	0.00	109.34	0.00	109.34	0	0.00
11 Oct 2018	A	1.43	0	-	454.78	109.34	109.34	0.00	345.43	236.09
12 Oct 2018		0	0	-	0.00	72.90	72.90	0.00	0	163.19
13 Oct 2018		0.15	0	-	47.70	36.45	36.45	0.00	11.26	138.00
14 Oct 2018		0	0	-	0.00	36.45	36.45	0.00	0	101.55
15 Oct 2018		0.21	0	-	66.79	36.45	36.45	0.00	30.34	95.44
16 Oct 2018		0.02	0	-	6.36	36.45	36.45	0.00	0	58.99
17 Oct 2018		0.05	0	-	15.90	36.45	36.45	0.00	0	22.54
18 Oct 2018		0	0	-	0.00	36.45	22.54	13.90	0	0.00
19 Oct 2018		0	0	-	0.00	36.45	0.00	36.45	0	0.00
20 Oct 2018		0.01	0	-	3.18	36.45	0.00	33.27	0	0.00
21 Oct 2018		0.02	0	-	6.36	36.45	0.00	30.09	0	0.00
22 Oct 2018		0	0	-	0.00	72.90	0.00	72.90	0	0.00
23 Oct 2018	B	0.06	0	-	19.08	109.34	0.00	90.26	0	0.00
24 Oct 2018	B	T	0	-	0.00	109.34	0.00	109.34	0	0.00
25 Oct 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
26 Oct 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
27 Oct 2018	B	1.04	0	-	330.75	109.34	109.34	0.00	221.40	112.06
28 Oct 2018	B	0.03	0	-	9.54	109.34	109.34	0.00	0	2.71
29 Oct 2018	B	0.26	0	0	82.69	109.34	2.71	23.94	0	0.00
30 Oct 2018	B	T	0	0	0.00	109.34	0.00	109.34	0	0.00
31 Oct 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
1 Nov 2018	B	0.05	0	0	15.90	109.34	0.00	93.44	0	0.00
2 Nov 2018	B	1.17	0	0	372.09	109.34	109.34	0.00	262.75	153.40
3 Nov 2018	B	1.64	0	-	521.56	109.34	109.34	0.00	412.22	280.73
4 Nov 2018	B	0	0	-	0.00	109.34	109.34	0.00	0	171.38
5 Nov 2018	B	0.31	0	-	98.59	109.34	109.34	0.00	0	62.04
6 Nov 2018	B	0.65	0	-	206.72	109.34	109.34	0.00	97.37	50.07
7 Nov 2018	B	0	0	-	0.00	109.34	50.07	59.28	0	0.00

8 Nov 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
9 Nov 2018	B	0.98	0	-	311.66	109.34	109.34	0.00	202.32	92.98
10 Nov 2018	B	0.14	0	-	44.52	109.34	109.34	0.00	0	-16.37
11 Nov 2018	B	0	0	-	0.00	109.34	-16.37	125.71	0	0.00
12 Nov 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
13 Nov 2018	B	1.4	0	-	445.24	109.34	109.34	0.00	335.89	226.55
14 Nov 2018	B	T	T	-	0.00	109.34	109.34	0.00	0	117.20
15 Nov 2018	B	0.71	7.8	-	225.80	109.34	109.34	0.00	116.45	124.31
16 Nov 2018	B	0.52	0.59	-	165.37	109.34	109.34	0.00	56.03	71.00
17 Nov 2018	B	0	0	-	0.00	109.34	71.00	38.35	0	0.00
18 Nov 2018	B	0.01	-	-	3.18	109.34	0.00	106.16	0	0.00
19 Nov 2018	B	0.61	T	-	194.00	109.34	109.34	0.00	84.65	-24.69
20 Nov 2018	B	0.39	0.79	-	124.03	109.34	-24.69	10.01	14.69	14.69
21 Nov 2018	B	T	T	-	0.00	109.34	14.69	94.66	0	0.00
22 Nov 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
23 Nov 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
24 Nov 2018	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
25 Nov 2018	B	0.28	0	-	89.05	109.34	0.00	20.30	0	0.00
26 Nov 2018	B	0.92	0	-	292.58	109.34	109.34	0.00	183.24	73.89
27 Nov 2018	B	0.22	T	-	69.97	109.34	109.34	0.00	0	-35.45
28 Nov 2018	B	T	T	-	0.00	109.34	-35.45	144.79	0	0.00
29 Nov 2018	B	T	-	-	0.00	109.34	0.00	109.34	0	0.00
30 Nov 2018	B	T	-	-	0.00	109.34	0.00	109.34	0	0.00

1 Dec 2017	B	0.08	0	-	25.44	109.34	0.00	83.90	0	0.00
2 Dec 2017	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
3 Dec 2017	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
4 Dec 2017	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
5 Dec 2017	B	0.77	0	-	244.88	109.34	109.34	0.00	135.54	26.19
6 Dec 2017	B	0.16	0	-	50.88	109.34	26.19	32.27	0	0.00
7 Dec 2017	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
8 Dec 2017	B	0	-	-	0.00	109.34	0.00	109.34	0	0.00
9 Dec 2017	B	0.57	6.81	-	181.27	109.34	109.34	0.00	71.93	-37.41
10 Dec 2017	B	T	0.31	-	0.00	109.34	-37.41	146.76	0	0.00
11 Dec 2017	B	0	0	-	0.00	109.34	0.00	109.34	0	0.00
12 Dec 2017	B	0.22	0.39	-	69.97	109.34	0.00	39.38	0	0.00
13 Dec 2017	B	T	0	-	0.00	109.34	0.00	109.34	0	0.00
14 Dec 2017	B	0.01	0	-	3.18	109.34	0.00	106.16	0	0.00
15 Dec 2017	B	0.02	0.2	-	6.36	109.34	0.00	102.98	0	0.00
16 Dec 2017		T	0	-	0.00	72.90	0.00	72.90	0	0.00
17 Dec 2017		0	0	-	0.00	36.45	0.00	36.45	0	0.00
18 Dec 2017		T	0	-	0.00	36.45	0.00	36.45	0	0.00
19 Dec 2017		T	0	-	0.00	36.45	0.00	36.45	0	0.00
20 Dec 2017		0	0	-	0.00	36.45	0.00	36.45	0	0.00
21 Dec 2017		0	0	-	0.00	36.45	0.00	36.45	0	0.00
22 Dec 2017		0.09	0.79	-	28.62	36.45	0.00	7.83	0	0.00
23 Dec 2017		0.56	0	-	178.09	36.45	36.45	0.00	141.65	105.20
24 Dec 2017		0	0	-	0.00	36.45	36.45	0.00	0	68.75
25 Dec 2017		0.33	4.29	-	104.95	36.45	36.45	0.00	68.50	100.80
26 Dec 2017		T	0	-	0.00	36.45	36.45	0.00	0	64.35
27 Dec 2017		0	0	-	0.00	36.45	36.45	0.00	0	27.91
28 Dec 2017		0	0	-	0.00	36.45	27.91	8.54	0	0.00
29 Dec 2017		0	0	-	0.00	36.45	0.00	36.45	0	0.00
30 Dec 2017		0.06	0.59	-	19.08	36.45	0.00	17.37	0	0.00
31 Dec 2017		0	0	-	0.00	36.45	0.00	36.45	0	0.00

Table 50. Storage tank NPV analysis by year

	Costs			Savings						
Year	Construction	Total Costs	Cumulative Costs	CF Water Recovered	Water Savings	Total Revenue	Cumulative Revenue	Inflation Adjustment	Yearly Net Present Value	Cumulative Net Present Value
2020	$4,168.74	$4,168.74	$4,087		0	$0.00	$0	0.980	-$4,087.00	-$4,087.00
2021		0	$4,087	9,406	$345.22	$345.22	$332	0.961	$331.81	-$3,755.19
2022		0	$4,087	9,406	$345.22	$345.22	$657	0.942	$325.30	-$3,429.89
2023		0	$4,087	9,406	$345.22	$345.22	$976	0.924	$318.93	-$3,110.96
2024		0	$4,087	9,406	$345.22	$345.22	$1,289	0.906	$312.67	-$2,798.29
2025		0	$4,087	9,406	$345.22	$345.22	$1,595	0.888	$306.54	-$2,491.75
2026		0	$4,087	9,406	$345.22	$345.22	$1,896	0.871	$300.53	-$2,191.22
2027		0	$4,087	9,406	$345.22	$345.22	$2,190	0.853	$294.64	-$1,896.58
2028		0	$4,087	9,406	$345.22	$345.22	$2,479	0.837	$288.86	-$1,607.72
2029		0	$4,087	9,406	$345.22	$345.22	$2,762	0.820	$283.20	-$1,324.52
2030		0	$4,087	9,406	$345.22	$345.22	$3,040	0.804	$277.64	-$1,046.88
2031		0	$4,087	9,406	$345.22	$345.22	$3,312	0.788	$272.20	-$774.68
2032		0	$4,087	9,406	$345.22	$345.22	$3,579	0.773	$266.86	-$507.81
2033		0	$4,087	9,406	$345.22	$345.22	$3,841	0.758	$261.63	-$246.18
2034		0	$4,087	9,406	$345.22	$345.22	$4,097	0.743	$256.50	$10.32
2035		0	$4,087	9,406	$345.22	$345.22	$4,349	0.728	$251.47	$261.79
2036		0	$4,087	9,406	$345.22	$345.22	$4,595	0.714	$246.54	$508.33
2037		0	$4,087	9,406	$345.22	$345.22	$4,837	0.700	$241.71	$750.03
2038		0	$4,087	9,406	$345.22	$345.22	$5,074	0.686	$236.97	$987.00
2039		0	$4,087	9,406	$345.22	$345.22	$5,306	0.673	$232.32	$1,219.32

Solar Panel Calculations

Table 51. Solar Panel NPV Analysis

		Costs				Revenue								
Year	kWh produced	Construction	Maintenance	Total Costs	Cumulative NPV Costs	Federal Tax Credit	Energy Revenue	SMART Reimbursement	Total Revenue	Cumulative NPV Revenue	Inflation Adjustment	Yearly Net Present Value	Cumulative Net Present Value	
2020		$90,634.33	$0.00	$90,634.33	$88,857	$23,564.93	0	0	$23,564.93	$23,103	0.980	-$65,754.32	-$65,754.32	
2021	30,559.70		$953.83	$953.83	$89,774		$4,165.06	$611.19	$4,776.25	$27,694	0.961	$3,673.99	-$62,080.33	
2022	30,559.70		$972.91	$972.91	$90,691		$4,248.36	$611.19	$4,859.55	$32,273	0.942	$3,662.47	-$58,417.85	
2023	30,559.70		$992.36	$992.36	$91,608		$4,333.32	$611.19	$4,944.52	$36,841	0.924	$3,651.18	-$54,766.68	
2024	30,559.70		$1,012.21	$1,012.21	$92,524		$4,419.99	$611.19	$5,031.18	$41,398	0.906	$3,640.11	-$51,126.57	
2025	30,559.70		$1,032.46	$1,032.46	$93,441		$4,508.39	$611.19	$5,119.58	$45,944	0.888	$3,629.25	-$47,497.32	
2026	30,559.70		$1,053.10	$1,053.10	$94,358		$4,598.56	$611.19	$5,209.75	$50,479	0.871	$3,618.61	-$43,878.71	
2027	30,559.70		$1,074.17	$1,074.17	$95,275		$4,690.53	$611.19	$5,301.72	$55,004	0.853	$3,608.18	-$40,270.53	
2028	30,559.70		$1,095.65	$1,095.65	$96,192		$4,784.34	$611.19	$5,395.53	$59,519	0.837	$3,597.95	-$36,672.58	
2029	30,559.70		$1,117.56	$1,117.56	$97,108		$4,880.03	$611.19	$5,491.22	$64,024	0.820	$3,587.92	-$33,084.66	
2030	30,559.70		$1,139.91	$1,139.91	$98,025		$4,977.63	$611.19	$5,588.82	$68,519	0.804	$3,578.09	-$29,506.56	
2031	30,559.70		$1,162.71	$1,162.71	$98,942		$5,077.18	$611.19	$5,688.37	$73,004	0.788	$3,568.45	-$25,938.11	
2032	30,559.70		$1,185.97	$1,185.97	$99,859		$5,178.72	$611.19	$5,789.92	$77,480	0.773	$3,559.00	-$22,379.11	
2033	30,559.70		$1,209.69	$1,209.69	$100,775		$5,282.30	$611.19	$5,893.49	$81,946	0.758	$3,549.74	-$18,829.37	
2034	30,559.70		$1,233.88	$1,233.88	$101,692		$5,387.94	$611.19	$5,999.14	$86,404	0.743	$3,540.66	-$15,288.72	
2035	30,559.70		$1,258.56	$1,258.56	$102,609		$5,495.70	$611.19	$6,106.90	$90,852	0.728	$3,531.75	-$11,756.96	
2036	30,559.70		$1,283.73	$1,283.73	$103,526		$5,605.62	$611.19	$6,216.81	$95,292	0.714	$3,523.02	-$8,233.94	
2037	30,559.70		$1,309.40	$1,309.40	$104,443		$5,717.73	$611.19	$6,328.92	$99,723	0.700	$3,514.46	-$4,719.48	
2038	30,559.70		$1,335.59	$1,335.59	$105,359		$5,832.08	$611.19	$6,443.28	$104,146	0.686	$3,506.07	-$1,213.41	
2039	30,559.70		$1,362.30	$1,362.30	$106,276		$5,948.72	$611.19	$6,559.92	$108,561	0.673	$3,497.85	$2,284.44	20-year NPV period ends here
2040	30,559.70		$1,389.55	$1,389.55	$107,193		$6,067.70	$611.19	$6,678.89	$112,967	0.660	$3,489.78	$5,774.22	
2041	30,559.70		$1,417.34	$1,417.34	$108,110		$6,189.05	$611.19	$6,800.25	$117,366	0.647	$3,481.87	$9,256.09	
2042	30,559.70		$1,445.69	$1,445.69	$109,027		$6,312.83	$611.19	$6,924.03	$121,757	0.634	$3,474.12	$12,730.22	
2043	30,559.70		$1,474.60	$1,474.60	$109,943		$6,439.09	$611.19	$7,050.28	$126,140	0.622	$3,466.52	$16,196.74	
2044	30,559.70		$1,504.09	$1,504.09	$110,860		$6,567.87	$611.19	$7,179.07	$130,516	0.610	$3,459.07	$19,655.81	End of solar panel life cycle

Plywood Calculations and Results

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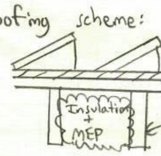
Bonina, Rabasco, Rios
53 Wachusett Street Design
Prof. Albano

Plywood Sizing Calculations – Roof

The sheathing on the roof is made of plywood. Since the solar panels on the roof add some load, the typical type of plywood used must be checked.

Roofing scheme:



← PV solar panels
← Asphalt shingles
← Plywood sheathing (thickness TBD)
← Purlins

The plywood carries the following loads:

- Dead Loads
  - PV solar panels = 2.27 psf
  - Asphalt shingles = 3.00 psf
  - It's self-weight
- Live Loads
  - 20 psf
  - 300 lb. concentrated
- Snow Loads
  - 50 psf

For a combination of moving point loads and distributed loads, the maximum moment and shear are given by:

- $M_{max} = \frac{wL^2}{8} + \frac{PL}{4}$ (P in center of beam)
- $V_{max} = \frac{wL}{2} + P$ (P at edge of beam)

The plywood over Purlin Type B will be sized as an example.

Typical roofs use 5/8"-thick plywood. Therefore, the 40/20 section will be analyzed (4-ply, 40/20 span rating). Characteristics include:

- $F_b S = 690$ lb·in./ft. of width
- $F_v t_v = 80$ lb./in. of width
- $EI = 250{,}000$ lb·in²/ft. of width

Since the purlins are spaced 23.25" apart, L = 23.25"

Figure 131. Sample plywood sizing calculations (page 1 of 3)

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The following load combinations need to be solved:

- $1.4D$ $(\lambda=0.6)$
- $1.2D+1.6L+0.5(L_r \text{ or } S \text{ or } R)$, where L_r refers to roof live load. This means that the following load combinations must be solved:
  - $1.2D+0.5L_r$ $(\lambda=0.8$ for occupancy$)$
  - $1.2D+0.5S$ $(\lambda=0.8)$
- $1.2D+1.6(L_r \text{ or } S \text{ or } R)+(L \text{ or } 0.5W)$ $(\lambda=0.8)$
  - $1.2D+1.6L_r$ $(\lambda=0.8)$
  - $1.2D+1.6S$ $(\lambda=0.8)$
- $1.2D+1.0E+L+0.2S$

For 1.4D:

$w=1.4w_D$

$w_D = 2.27$ psf for solar panels $\times 23.25'' \times 1'/12''$
$+ 3.00$ psf for shingles $\times 23.25'' \times 1'/12''$
$+ 1.80$ psf for plywood $\times 23.25'' \times 1'/12''$

$w_D = 13.70$ lb./ft.

$w = 1.4(13.70 \text{ lb./ft.}) = 19.18$ lb./ft.

$$M_{max} = \frac{wL^2}{8} = \frac{(19.18 \text{ lb./ft.})[(23.25'')/(12''/1')]^2}{8} = 9.00 \text{ lb}\cdot\text{ft.}$$

$V_{max} = (19.18 \text{ lb./ft.})(23.25'')(1'/12'')/2 = 18.58$ lb.

For $1.2D+0.5L_r$:

$w = 1.2w_D + 0.5L_r = 1.2(13.70 \text{ lb./ft.}) + 0.5(20 \text{ psf})(23.25'')(1'/12'')$

$w = 35.81$ lb./ft.

$P = 0.5(300 \text{ lb.}) = 150$ lb.

$$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(35.81 \text{ lb./ft.})[(23.25'')/(12''/1')]^2}{8} + \frac{(150 \text{ lb.})[(23.25'')/(12''/1')]}{4}$$

$M_{max} = 89.46$ lb·ft.

$$V_{max} = \frac{wL}{2} + P = \frac{(35.81 \text{ lb./ft.})(23.25'')(1'/12'')}{2} + (150 \text{ lb.})$$

$V_{max} = 184.69$ lb.

For $1.2D+0.5S$:

$w = 1.2w_D + 0.5w_S = 1.2(13.70 \text{ lb./ft.}) + 0.5(50 \text{ psf})(23.25'')(1'/12'')$

$w = 64.88$ lb./ft.

$$M_{max} = \frac{wL^2}{8} = \frac{(64.88 \text{ lb./ft.})[(23.25'')(1'/12'')]^2}{8} = 30.44 \text{ lb}\cdot\text{ft.}$$

$$V_{max} = \frac{wL}{2} = \frac{(64.88 \text{ lb./ft.})(23.25'')(1'/12'')}{2} = 62.85 \text{ lb.}$$

For $1.2D+1.6L_r$:

$w = 1.2w_D + 1.6w_L = 1.2(13.70 \text{ lb./ft.}) + 1.6(20 \text{ psf})(23.25'')(1'/12'')$

$w = 78.44$ lb./ft.

$P = 1.6(300 \text{ lb.}) = 480$ lb.

$$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(78.44 \text{ lb./ft.})[(23.25'')(1'/12'')]^2}{8} + \frac{(480 \text{ lb.})(23.25'')(1'/12'')}{4}$$

$M_{max} = 269.31$ lb·ft.

$$V_{max} = \frac{wL}{2} + P = \frac{(78.44 \text{ lb./ft.})(23.25'')(1'/12'')}{2} + (480 \text{ lb.})$$

$V_{max} = 555.99$ lb.

Figure 132. Sample plywood sizing calculations (page 2 of 3)

For 1.2D+1.6S:

$w = 1.2w_D + 1.6w_s = 1.2(13.70 \text{ lb./ft.}) + 1.6(50 \text{ psf})(23.25")(1'/12")$

$w = 269.31 \text{ lb./ft.}$

$M_{max} = \frac{wL^2}{8} = \frac{(269.31 \text{ lb/ft.})[(23.25")(1'/12")]^2}{8} = 80.45 \text{ lb}\cdot\text{ft.}$

$V_{max} = \frac{wL}{2} = \frac{(269.31 \text{ lb./ft.})(23.25")(1'/12")}{2} = 166.08 \text{ lb.}$

For 1.2D+1.0E+L+0.2S:

$w = 1.2w_D + 1.0w_L + 0.2w_s$

$= 1.2(13.70 \text{ lb./ft.}) + 1.0(20 \text{ psf})(23.25")(1'/12") + 0.2(50 \text{ psf})(23.25")(1'/12")$

$w = 74.56 \text{ lb.}$

$P = 300 \text{ lb.}$

$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(74.56 \text{ lb./ft.})[(23.25")(1'/12")]^2}{8} + \frac{(300 \text{ lb.})(23.25")(1'/12")}{4}$

$M_{max} = 180.30 \text{ lb}\cdot\text{ft.}$

$V_{max} = \frac{wL}{2} + P = \frac{(74.56 \text{ lb/ft.})(23.25")(1'/12")}{2} + (300 \text{ lb.})$

$V_{max} = 372.23 \text{ lb.}$

The load case that produces the greatest load is 1.2D+1.6Lr. This load case produces:

- $M_{max} = 269.31 \text{ lb}\cdot\text{ft.} = 3231.67 \text{ lb}\cdot\text{in.}$
- $V_{max} = 555.99 \text{ lb.}$
- $\lambda = 0.8$

The ability of the 40/20 section to withstand this load needs to be checked.

The allowable bending moment for this section is given by $F_bS = 690 \text{ lb}\cdot\text{in./ft.}$

$F_bS = (690 \text{ lb}\cdot\text{in./ft.})(23.25")(1'/12") = 1336.88 \text{ lb}\cdot\text{in.}$

$F_b'S = F_bS \times C_m C_t C_s (K_F = 2.54)(\phi = 0.85)(\lambda = 0.8)$

Assuming that the plywood is fully covered by shingles, $C_m = C_t = 1$

$F_b'S = (1336.88 \text{ lb}\cdot\text{in.})(1.0)(1.0)(0.977)(2.54)(0.85)(0.8)$

$C_s = \frac{8 + (23.25")}{24} = 0.977$, since $8" < L < 24"$

$F_b'S = 2254.93 \text{ lb}\cdot\text{in.} < 3231.67 \text{ lb}\cdot\text{in.}$

The 40/20 plywood is not capable of withstanding the applied loads.

For sample shear and bending calculations, refer to "Plywood Sizing Calculations — Typical."

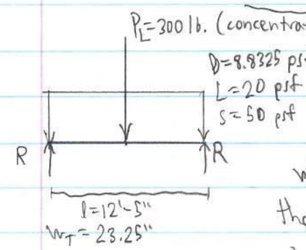
Figure 133. Sample plywood sizing calculations (page 3 of 3)

Joist Calculations and Results

)

Bonina, Rabasco, Rios
53 Wachusett Street Design MQP
1/11/19

Roof Purlins, Type B



Due to the moving load, for which the design moment equals the moment when the force is applied to the center of the beam and the design shear equals the shear when the force is applied to the end of the beam,

$$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} \quad \text{and} \quad V_{max} = \frac{wL}{2} + P$$

↳ M_{max} & V_{max} should be divided by λ for each case to figure out which case to use.

The following load combinations need to be evaluated:

- 1.4D (λ=0.6)
- 1.2D+1.6L+0.5(L_r or S or R), where L_r refers to roof live load

  This means that the following load combinations must be solved:
  - 1.2D+0.5L_r (λ=0.8 for occupancy)
  - 1.2D+0.5S (λ=0.8)
- 1.2D+1.6(L_r or S or R) + (L or 0.5W) (λ=0.8)
  - 1.2D+1.6L_r (λ=0.8)
  - 1.2D+1.6S (λ=0.8)
- 1.2D+1.0E+L+0.2S (λ=1.0)

  ↳ L_r will be used as a substitute for L

The other load combinations are not likely to lead to large loads.

Figure 134. Sample joist calculations (page 1 of 6)

2

w_D, w_L, and w_s need to be solved based on the tributary areas:

$w_D = (8.8325\ psf)(23.25'')(1'/12'') = 17.11\ lb./ft.$

$w_L = (20\ psf)(23.25'')(1'/12'') = 38.75\ lb./ft.$

$w_s = (50\ psf)(23.25'')(1'/12'') = 96.88\ lb./ft.$

Load combinations:

1. 1.4D:

$M_{max} = \frac{[1.4w_D]L^2}{8} + \frac{[1.4P_D]L}{4} = \frac{(1.4)(17.11\ lb./ft.)(12\frac{5}{12}')^2}{8} + \frac{(0)}{4}$

$M_{max} = 461.71\ lb.\cdot ft.$

$V_{max} = \frac{[1.4w_D]L}{2} = \frac{(1.4)(17.11\ lb./ft.)(12\frac{5}{12}')}{2} = 148.74\ lb.$

$M'_{max} = \frac{M_{max}}{(\lambda=0.6)} = \frac{(461.71\ lb.\cdot ft.)}{(0.6)} = 769.52\ lb.\cdot ft.$

$V'_{max} = \frac{V_{max}}{(\lambda=0.6)} = \frac{(148.74\ lb.)}{(0.6)} = 247.90\ lb.$

2. 1.2D+0.5Lr

$w = 1.2w_D + 0.5w_L = (1.2)(17.11\ lb./ft.) + 0.5(38.75\ lb./ft.) = 39.91\ lb./ft.$

$P = 0.5(300\ lb.) = 150\ lb.$

$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(39.91\ lb./ft.)(12.42')^2}{8} + \frac{(150\ lb.)(12.42')}{4} = 1234.77\ lb.\cdot ft.$

$M'_{max} = \frac{M_{max}}{(\lambda=0.8)} = \frac{(1234.77\ lb.\cdot ft.)}{(0.8)} = 1543.46\ lb.\cdot ft.$

$V_{max} = \frac{wL}{2} + P = \frac{(39.91\ lb./ft.)(12.42')}{2} + (150\ lb.) = 397.78\ lb.$

$V'_{max} = \frac{V_{max}}{(\lambda=0.8)} = \frac{(397.78\ lb.)}{(0.8)} = 497.22\ lb.$

3. 1.2D+0.5S

$w = 1.2w_D + 0.5w_s = 1.2(17.11\ lb./ft.) + 0.5(96.88\ lb./ft.) = 68.97\ lb./ft.$

$P = 0$

$M_{max} = \frac{wL^2}{8} = \frac{(68.97\ lb./ft.)(12.42')^2}{8} = 1329.23\ lb.\cdot ft.$

$M'_{max} = \frac{M_{max}}{(\lambda=0.8)} = \frac{(1329.23\ lb.\cdot ft.)}{(0.8)} = 1661.54\ lb.\cdot ft.$

$V_{max} = \frac{wL}{2} = \frac{(68.97\ lb./ft.)(12.42')}{2} = 428.21\ lb.$

$V'_{max} = \frac{V_{max}}{(\lambda=0.8)} = \frac{(428.21\ lb.)}{(0.8)} = 535.26\ lb.$

Figure 135. Sample joist calculations (page 2 of 6)

4. $1.2D + 1.6L_r$

$w = 1.2w_D + 1.6w_L = 1.2(17.11\ lb./ft.) + 1.6(38.75\ lb./ft.) = 82.54\ lb./ft.$

$P = 1.6P_L = 1.6(300\ lb.) = 480\ lb.$

$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(82.54\ lb./ft.)(12.42')^2}{8} + \frac{(480\ lb.)(12.42')}{4} = 3080.60\ lb \cdot ft.$

$M'_{max} = \frac{M_{max}}{(\lambda = 0.8)} = \frac{(3080.60\ lb \cdot ft.)}{(0.8)} = 3850.75\ lb \cdot ft.$

$V_{max} = \frac{wL}{2} + P = \frac{(82.54\ lb./ft.)(12.42')}{2} + (480\ lb.) = 992.41\ lb.$

$V'_{max} = \frac{V_{max}}{(\lambda = 0.8)} = \frac{(992.41\ lb)}{(0.8)} = 1240.51\ lb.$

5. $1.2D + 1.6S$

$w = 1.2w_D + 1.6w_S = 1.2(17.11\ lb./ft.) + 1.6(96.88\ lb./ft.) = 175.54\ lb./ft.$

$P = 0$

$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(175.54\ lb./ft.)(12.42')^2}{8} + (0) = 3382.87\ lb.$

$M'_{max} = \frac{M_{max}}{(\lambda = 0.8)} = \frac{(3382.87\ lb.)}{(0.8)} = 4228.59\ lb.$

$V_{max} = \frac{wL}{2} + P = \frac{(175.54\ lb./ft.)(12.42')}{2} + (0) = 1089.78\ lb.$

$V'_{max} = \frac{V_{max}}{(\lambda = 0.8)} = \frac{(1089.78\ lb.)}{(0.8)} = 1362.23\ lb.$

6. $1.2D + 1.0E + L + 0.2S$

$w = 1.2w_D + 1.0w_L + 0.2w_S = 1.2(17.11\ lb./ft.) + 1.0(38.75\ lb./ft.) + 0.2(96.88\ plf)$

$w = 78.66\ lb./ft.$

$P = 1.0(300\ lb.) = 300\ lb.$

$M_{max} = \frac{wL^2}{8} + \frac{PL}{4} = \frac{(78.66\ lb./ft.)(12.42')^2}{8} + \frac{(300\ lb.)(12.42')}{4} = 2447.17\ lb \cdot ft.$

Since $\lambda = 1.0$, $M'_{max} = M_{max} = 2447.17\ lb \cdot ft.$

$V_{max} = \frac{wL}{2} + P = \frac{(78.66\ lb./ft.)(12.42')}{2} + (300\ lb.) = 788.35\ lb.$

Since $\lambda = 1.0$, $V'_{max} = V_{max} = 788.35\ lb.$

The load combination 1.2D+1.6S should be used to design Roof Purlin, Type B. This gives:

- $M_{max} = 3382.87\ lb. \cdot ft.$
- $V_{max} = 1089.78\ lb.$
- $\lambda = 0.8$

Figure 136. Sample joist calculations (page 3 of 6)

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Design Adjustments:

$F_b' = F_b C_m C_t C_L C_F C_{fu} C_i C_r \cdot 2.54 \cdot 0.85 \cdot \lambda$

$F_v' = F_v C_m C_t C_i \cdot (2.88)(0.75)\lambda$

$E' = E C_m C_t C_i$

$E_{min}' = E_{min} C_m C_t C_i C_T \cdot 1.76 \cdot 0.85$

In order to select a size to use,

$F_b S = M \rightarrow S = \frac{M}{F_b}$

- $M = 3382.87$ lb.·ft.
- $F_b = 1450$ psi for No. 1 southern pine

$S = \frac{(3382.87 \text{ lb.·ft.})(12''/1')}{(1450 \text{ psi})} = 28.00 \text{ in.}^3$

A 4×8 section could be used ($S = 30.66$ in.^{3})

The capacity of this section should be checked.

$F_b' = F_b C_M C_t C_L C_F C_{fu} C_i C_r (2.54)(0.85)(\lambda = 0.8)$

- $F_b = 1450$ psi
- $C_M = 1.0$ for no moisture exposure
- $C_t = 1.0$ for no extreme heat exposure
- C_L must be solved for last
- $C_F = 1.2$ for a 4×8
- $C_{fu} = 1$
- $C_i = 0.8$ for incisions present
- $C_r = 1.15$ for repetitive members
- $K_F = 2.54$ for bending
- $\phi = 0.85$ for bending
- $\lambda = 0.8$ for this load combination

$F_b^* = 2764.90$ psi

Calculations for C_L:

Since $l_u/d > 7$, $l_e = 1.63 l_u + 3d = 1.63(149'') + 3(7.25'') = 264.62''$

Figure 137. Sample joist calculations (page 4 of 6)

5

$R_B = \sqrt{\frac{l_e d}{b^2}} = \sqrt{\frac{(264.62\ in.)(7.25\ in.)}{(3.5'')^2}} = 12.51 < 50$

$F_{bE} = \frac{1.20\,E_{min}'}{R_B^2} = \frac{1.20(781{,}660\ psi)}{(12.51)^2} = 5989.28\ psi$

$C_L = \frac{1+F_{bE}/F_b^*}{1.9} - \sqrt{\left[\frac{1+F_{bE}/F_b^*}{1.9}\right]^2 - \frac{F_{bE}/F_b^*}{0.95}}$

$C_L = \frac{1+(5989.28\ psi)/(2764.90\ psi)}{1.9} - \sqrt{\left[\frac{1+(5989.28\ psi)/(2764.90\ psi)}{1.9}\right]^2 - \frac{(5989.28\ psi)/(2764.90\ psi)}{0.95}}$

$C_L = 0.962$

$F_b' = F_b^* C_L = (2764.90\ psi)(0.962) = 2658.78\ psi$

$M' = F_b' S = (2658.78\ psi)(30.66\ in.^3)\left(\frac{1'}{12''}\right) = 6793.45\ lb\cdot ft. > 3382.87\ lb\cdot ft.$

Therefore, the 4x8 could be used. However, its deflection needs to be checked.

Deflection requirements:

- Use $l/360$ for L, assuming that roof supports plaster ceiling
- Use $l/360$ for S, operating on the same assumption
- Use $l/240$ for D+L

$\Delta = \frac{5wL^4}{384EI}$ for distributed loads and $\Delta = \frac{PL^3}{48EI}$ for concentrated loads

For live load only,

$\Delta = \frac{5wL^4}{384E'I} + \frac{PL^3}{48E'I} = \frac{5(38.75\ lb./ft.)\left(\frac{1'}{12''}\right)(149'')^4}{384(1{,}425{,}000\ psi)(111.15\ in.^4)} + \frac{(300\ lb.)(149'')^3}{48(1{,}425{,}000\ psi)(111.15\ in.^4)}$

↳ E' was found by multiplying E = 1,500,000 psi by $C_i = 0.95$

$\Delta = (0.131'') + (0.131'') = 0.261''$

$\Delta_{all} = \frac{l}{360} = \frac{(149'')}{360} = 0.414''$

Since $\Delta < \Delta_{all}$, this design is acceptable

Figure 138. Sample joist calculations (page 5 of 6)

6

For the snow load deflection:

$$\Delta = \frac{5wL^4}{384EI} = \frac{5(36.98\ lb./ft.)(1'/12")(149")^4}{384(1{,}425{,}000\ psi)(111.15\ in.^4)} = 0.327"$$

$$\Delta_{all} = \frac{L}{360} = \frac{(149")}{360} = 0.414"$$

Since $\Delta < \Delta_{all}$, this is acceptable.

For the dead + live load deflection:

$$w = w_D + w_L = (17.11\ lb./ft.) + (38.75\ lb./ft.) = 55.86\ lb./ft.$$

$$\Delta = \frac{5wL^4}{384EI} + \frac{PL^3}{48EI} = \frac{5(55.86\ lb./ft.)(1'/12")(149")^4}{384(1{,}425{,}000\ psi)(111.15\ in.^4)} + \frac{(300\ lb.)(149")^3}{48(1{,}425{,}000\ psi)(111.15\ in.^4)}$$

$$\Delta = 0.189" + 0.131" = 0.319"$$

$$\Delta_{all} = \frac{L}{240} = \frac{(149")}{240} = 0.621"$$

Since $\Delta < \Delta_{all}$, this is acceptable

The 4x8 satisfies both the bending and deflection criteria. Its ability to withstand shear still needs to be checked:

$$F_v' = F_v C_m C_t C_i K_F \phi \lambda$$

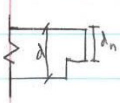
$$F_v' = (175\ psi)(1)(1)(C_i = 0.8 \text{ for incised members})(2.88)(0.75)(0.8)$$

$$F_v' = 241.92\ psi$$

$$f_v = \frac{3V_{max}}{2bd} = \frac{3(1089.78\ lb.)}{2(3.5")(7.25")} = 64.42\ psi < 241.92\ psi$$

This beam is acceptable

The extent to which the beam can be notched should also be checked:



$$V_r' = \frac{2}{3} F_v' b d_n \left[\frac{d_n}{d}\right]^2$$

$$V_r' = \frac{2}{3} F_v' b \frac{d_n^3}{d^2}$$

$$V_r' d^2 = \frac{2}{3} F_v' b\, d_n^3$$

$$d_n^3 = \frac{1.5 V_r' d^2}{F_v' b} \longrightarrow d_n = \sqrt[3]{\frac{1.5 V_r' d^2}{F_v' b}}$$

$$d_n = \sqrt[3]{\frac{1.5(1135.75\ lb.)(7.25")^2}{(241.92\ psi)(3.5")}} = 4.75"$$

If the shear force is 25% more than anticipated,

$$d_n = \sqrt[3]{\frac{1.5(1.25 \cdot 1135.75\ lb)(7.25")^2}{(241.92\ psi)(3.5")}} = 5\ 1/8"$$

Figure 139. Sample joist calculations (page 6 of 6)

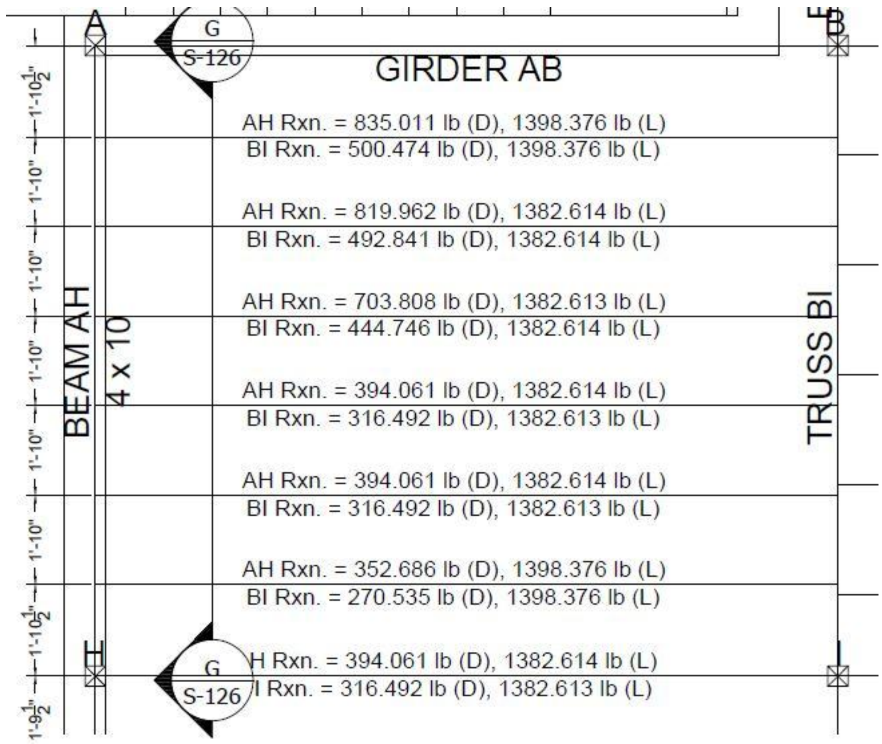


Figure 140. 2nd floor joist reactions (section 1 of 9)

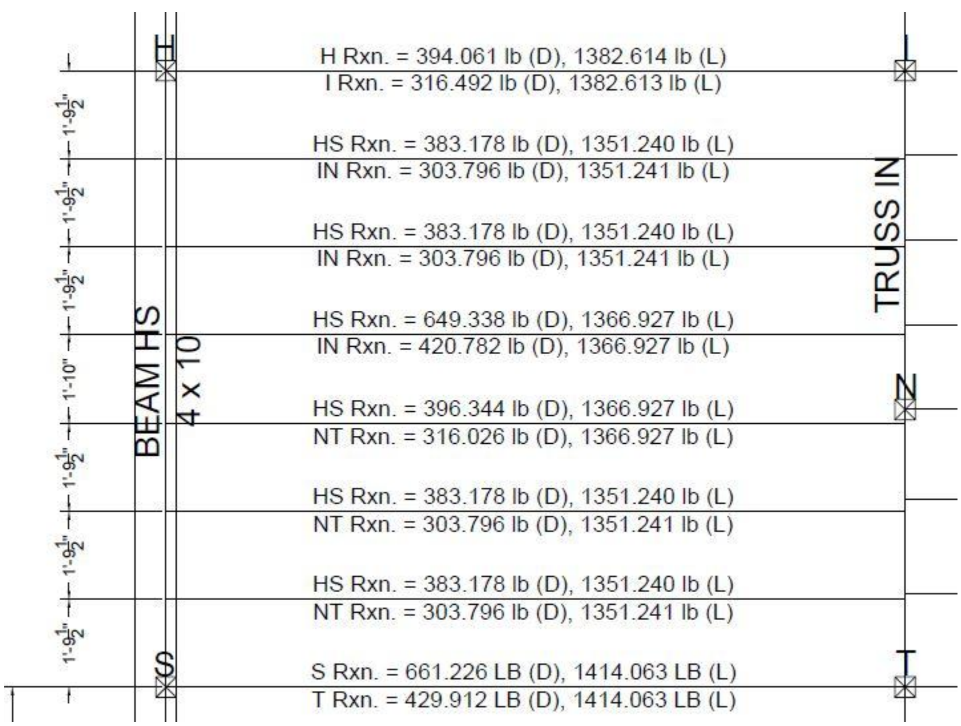


Figure 141. 2nd floor joist reactions (section 2 of 9)

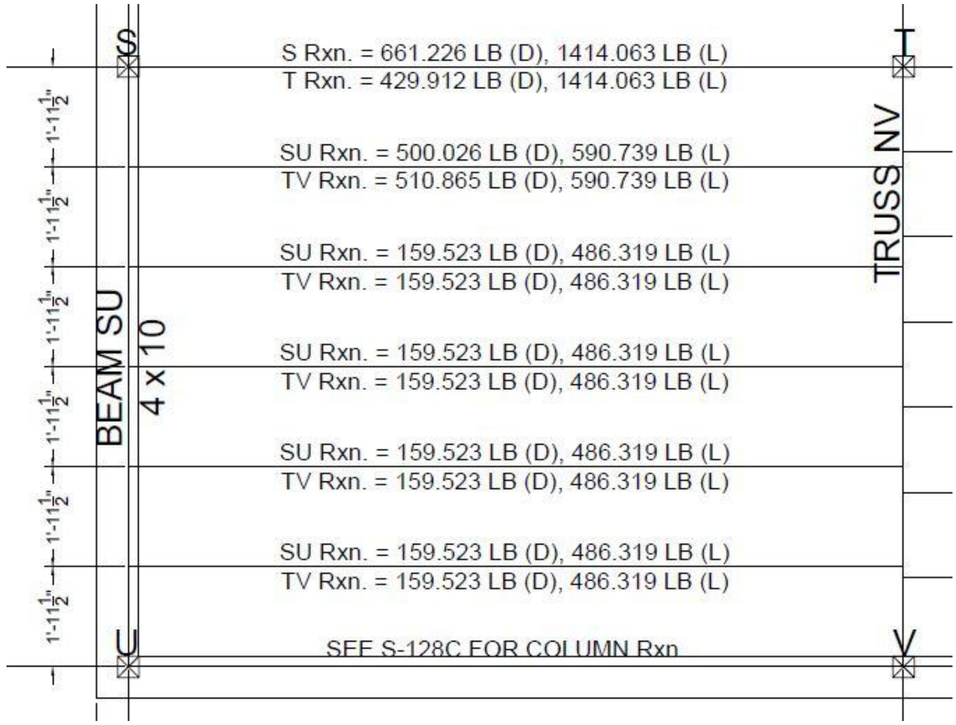


Figure 142. 2nd floor joist reactions (section 3 of 9)

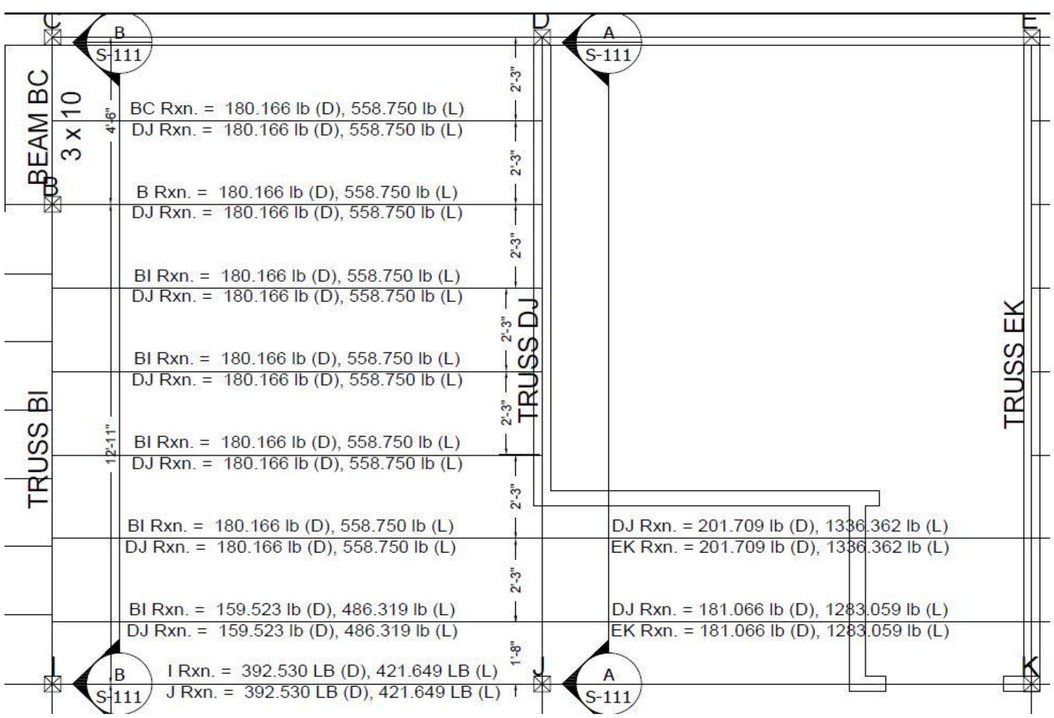


Figure 143. 2^{nd} floor joist reactions (section 4 of 9)

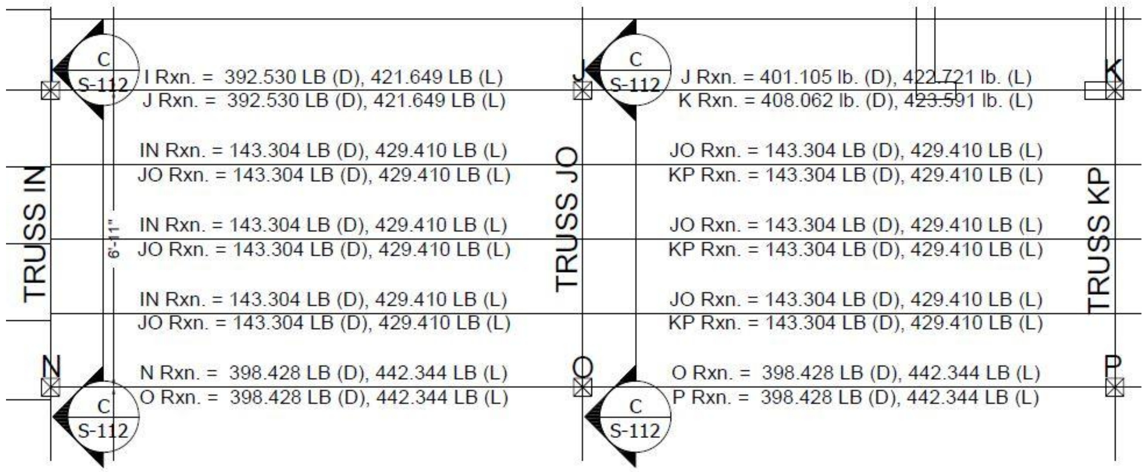


Figure 144. 2nd floor joist reactions (section 5 of 9)

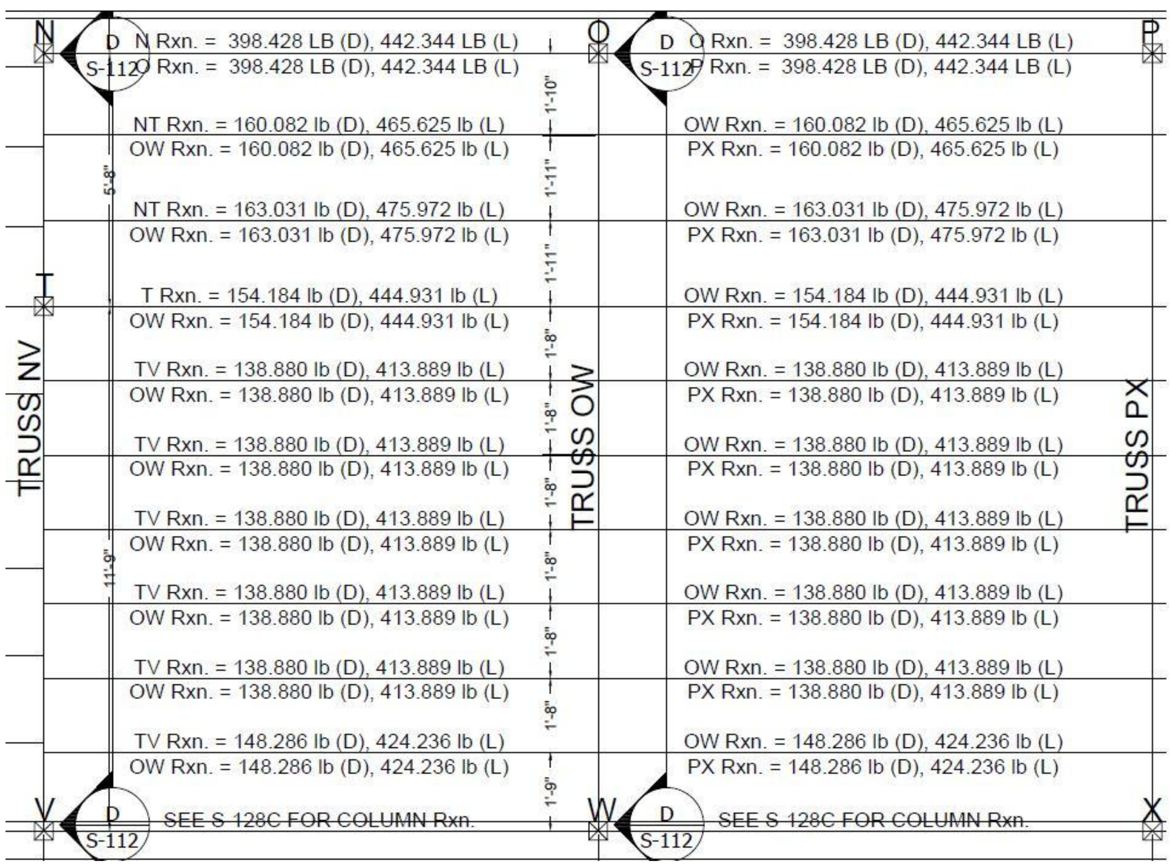


Figure 145. 2nd floor joist reactions (section 6 of 9)

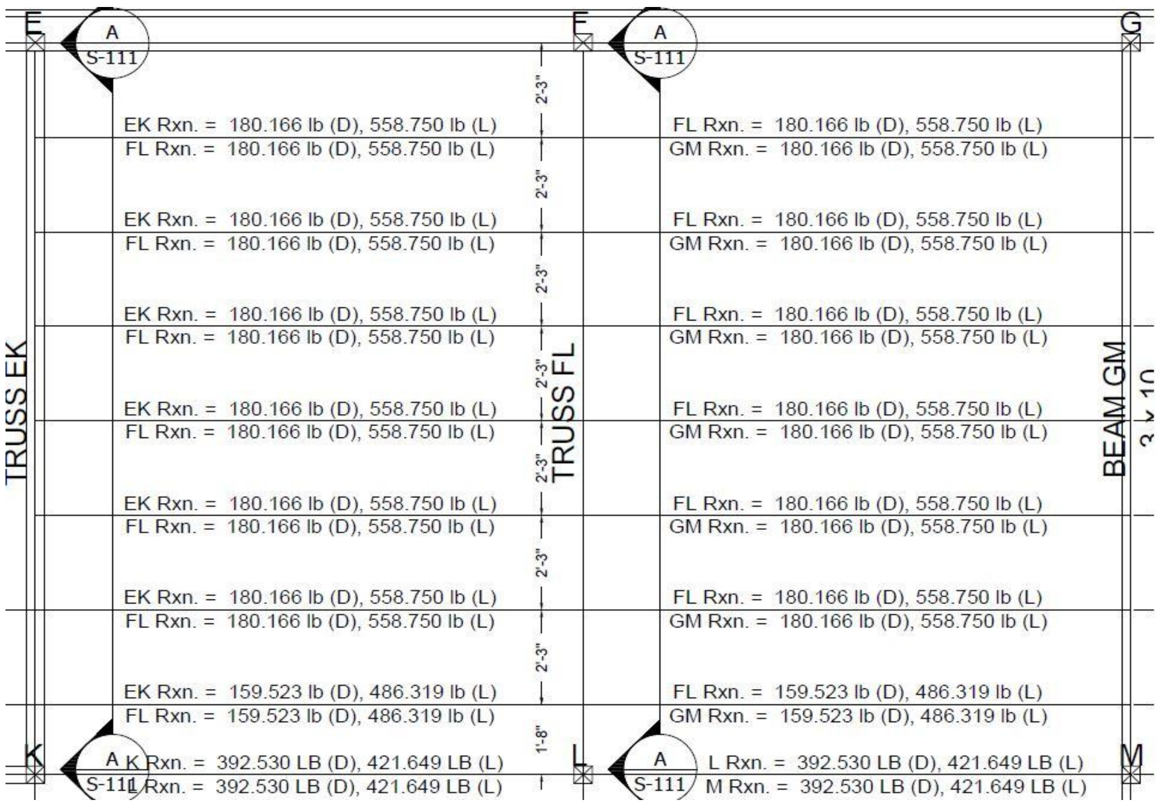


Figure 146. 2nd floor joist reactions (section 7 of 9)

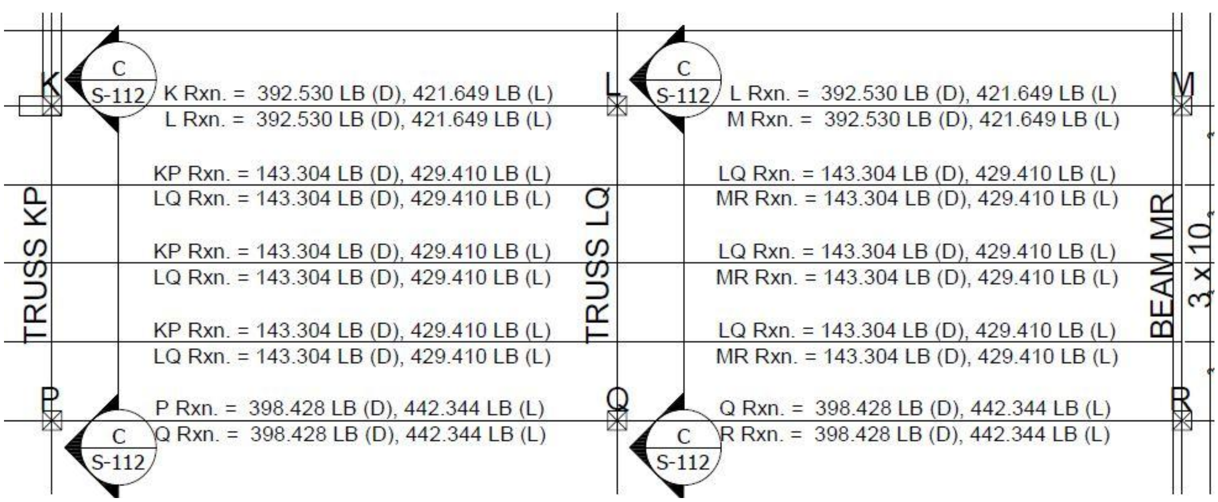


Figure 147. 2nd floor joist reactions (section 8 of 9)

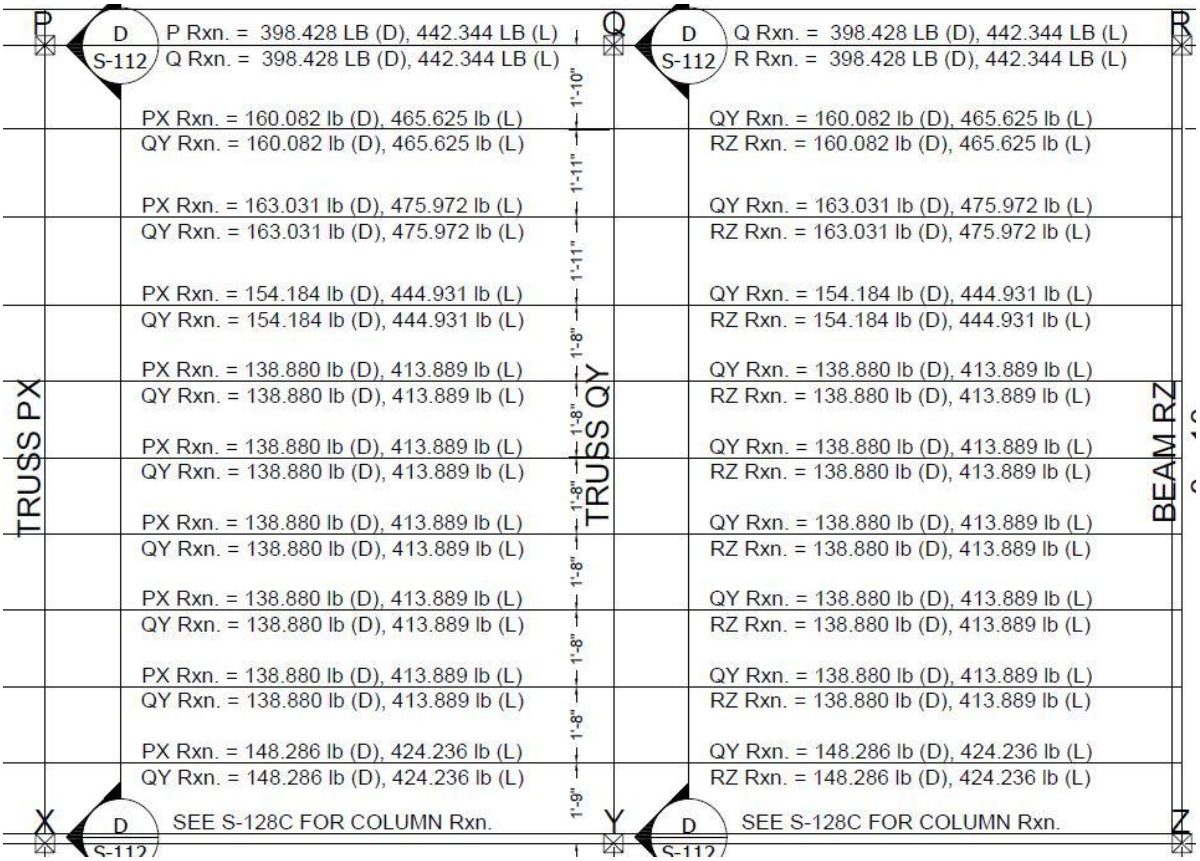


Figure 148. 2nd floor joist reactions (section 9 of 9)

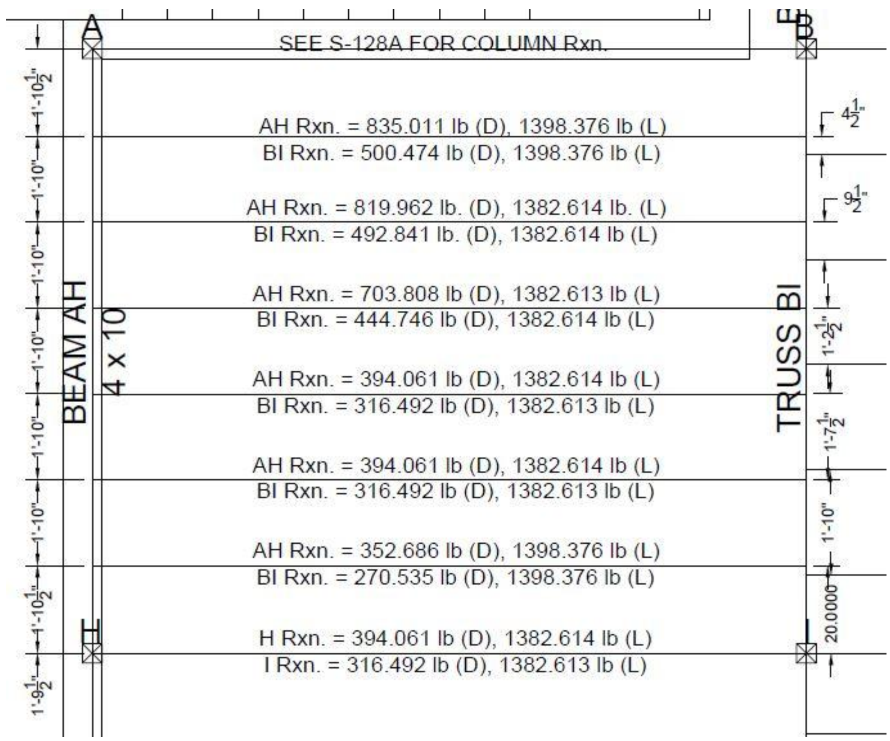


Figure 149. 1st floor joist reactions (section 1 of 9)

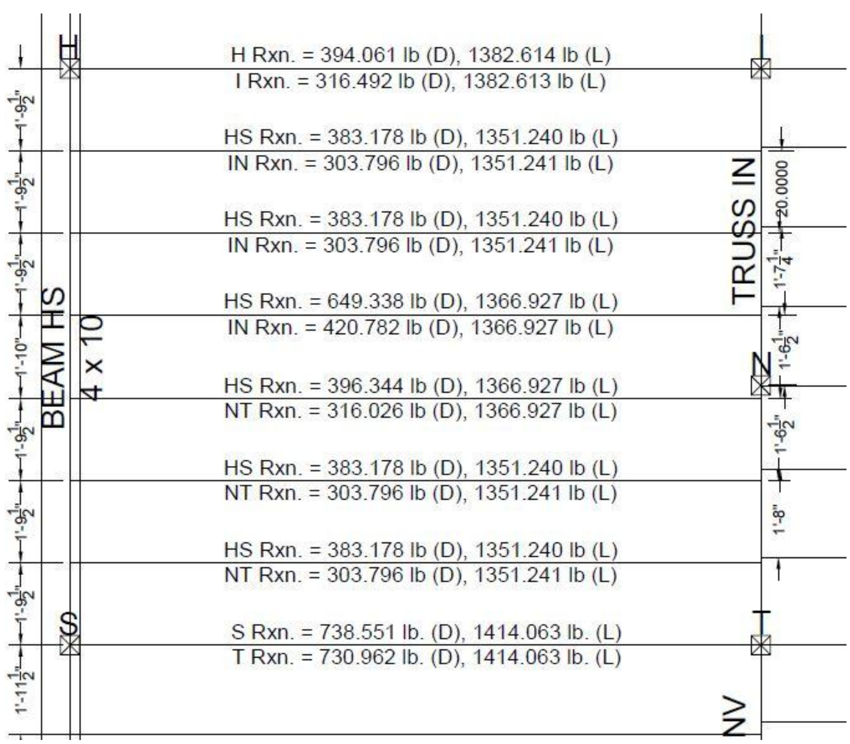


Figure 150. 1st floor joist reactions (section 2 of 9)

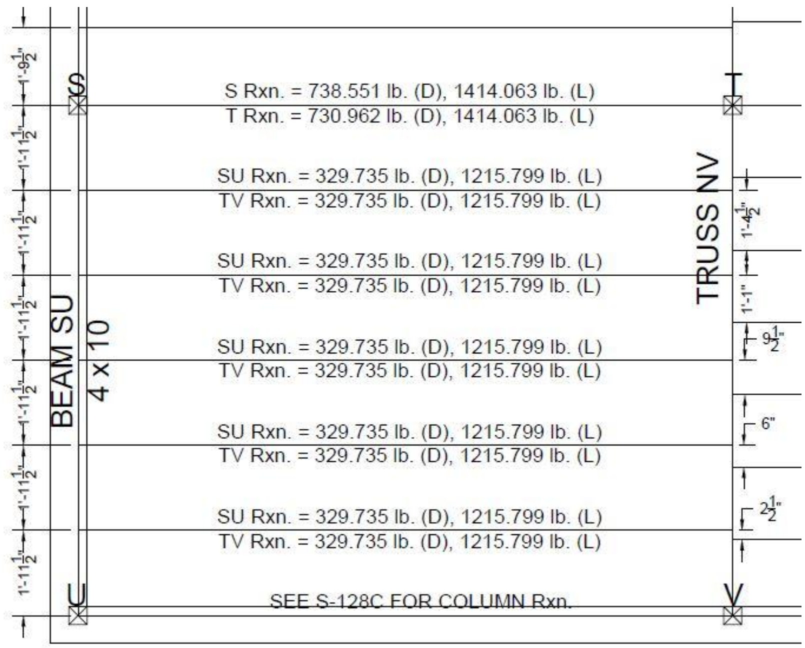


Figure 151. 1st floor joist reactions (section 3 of 9)

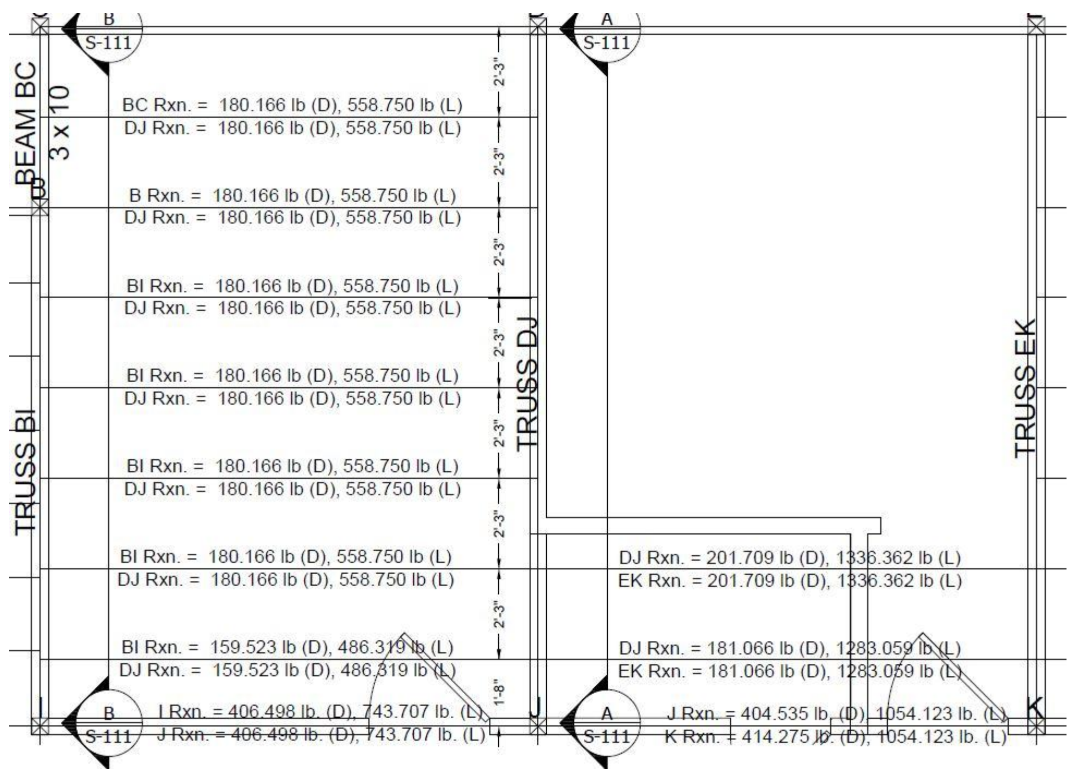


Figure 152. 1st floor joist reactions (section 4 of 9)

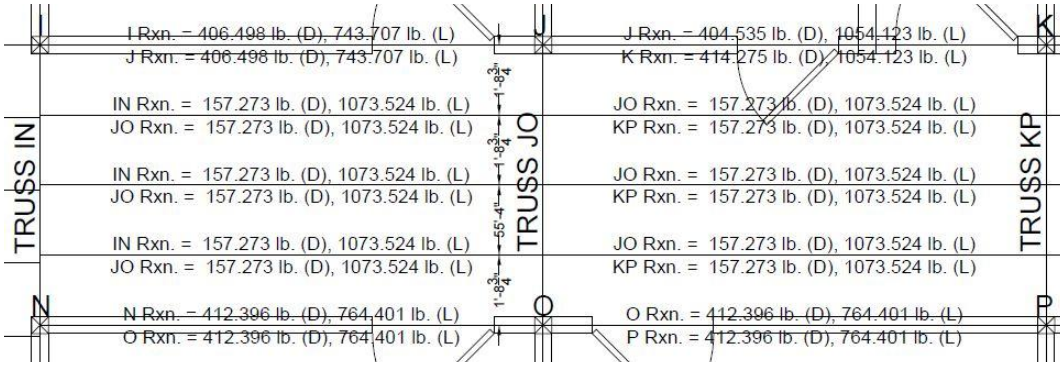


Figure 153. 1st floor joist reactions (section 5 of 9)

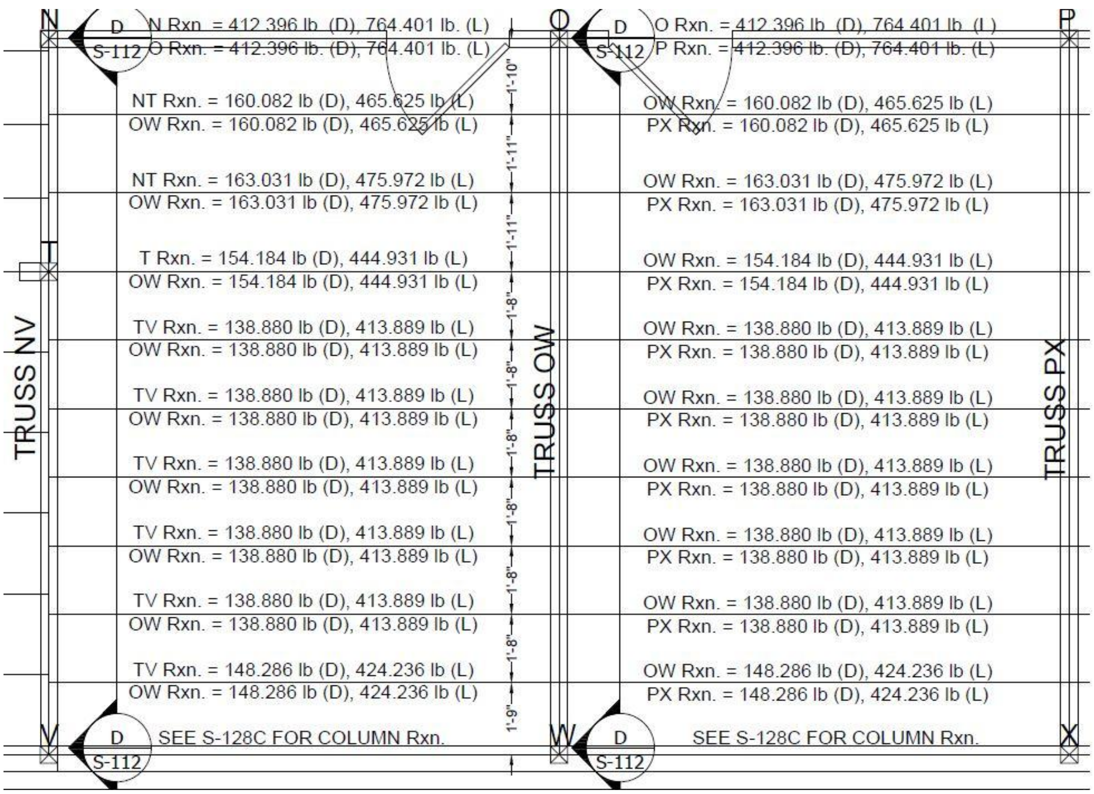


Figure 154. 1st floor joist reactions (section 6 of 9)

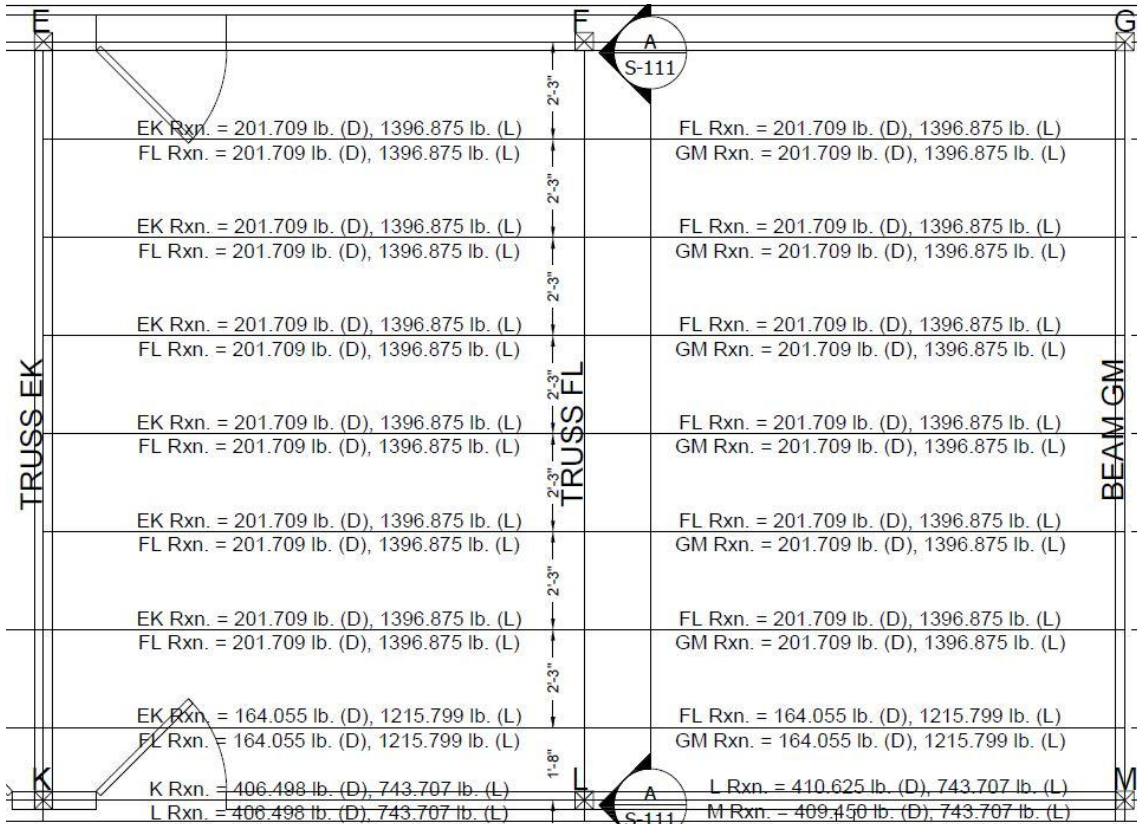


Figure 155. 1st floor joist reactions (section 7 of 9)

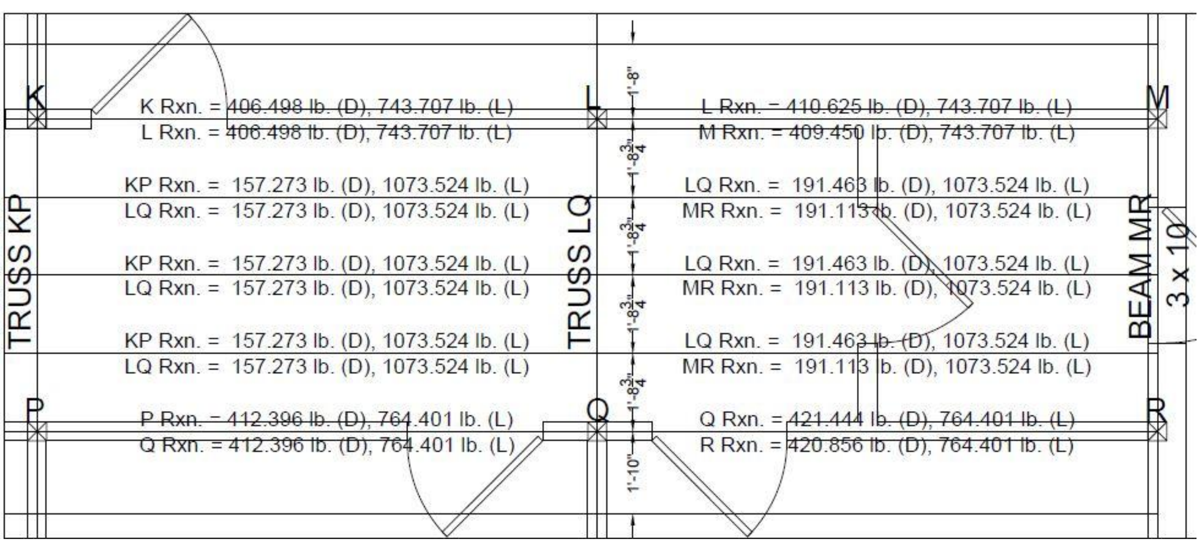


Figure 156. 1st floor joist reactions (section 8 of 9)

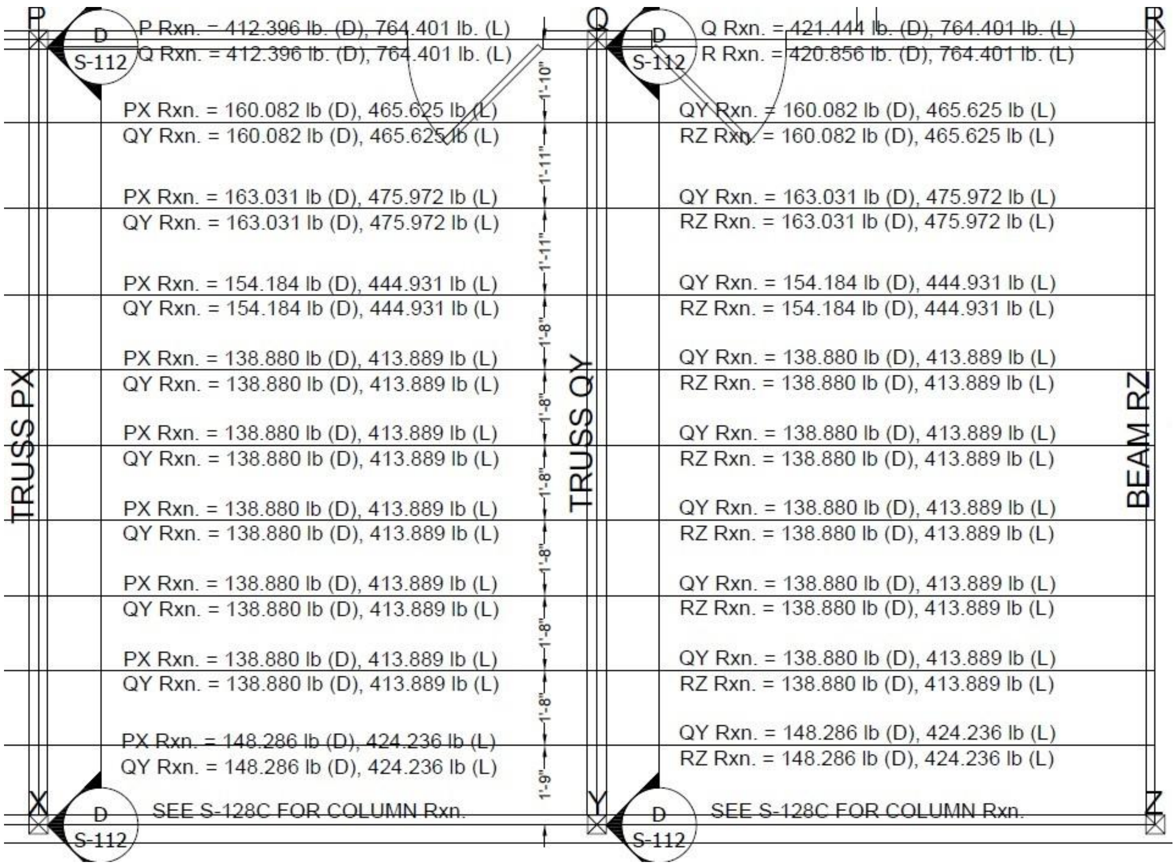


Figure 157. 1st floor joist reactions (section 9 of 9)

Truss Calculation Results

Table 52. Member sizes for truss type A (second floor)

		Truss FL		Truss EK		Truss DJ	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	20	3X6	0.544	3X6	0.285	3X6	0.285
M2	27	2X4	0.617	2X4	0.263	2X4	0.263
M3	27	2X6	0.345	2X6	0.360	2X6	0.360

M4	27	2X6	0.675	2X6	0.395	2X6	0.395
M5	27	2X6	0.691	2X6	0.402	2X6	0.402
M6	27	2X6	0.517	2X6	0.158	2X6	0.158
M7	27	2X4	0.210	2X4	0.560	2X4	0.560
M8	27	3X6	0.452	3X6	0.393	3X6	0.393
M9	27	2X4	0.000	2X4	0.000	2X4	0.000
M10	27	3X6	0.578	3X6	0.361	3X6	0.361
M11	27	4X6	0.649	4X6	0.417	4X6	0.417
M12	27	4X6	0.804	4X6	0.536	4X6	0.536
M13	27	4X6	0.763	4X6	0.584	4X6	0.584
M14	27	4X6	0.591	4X6	0.532	4X6	0.532
M15	27	3X6	0.445	3X6	0.447	3X6	0.447
M16	20	2X4	0.000	2X4	0.000	2X4	0.000
M17	13.5	3X6	0.073	3X6	0.308	3X6	0.245
M18	13.5	2X6	0.617	2X6	0.493	2X6	0.493
M19	13.5	2X4	0.697	2X4	0.232	2X4	0.232
M20	13.5	2X4	0.209	2X4	0.030	2X4	0.030
M21	13.5	2X4	0.002	2X4	0.002	2X4	0.002
M22	13.5	2X4	0.160	2X4	0.224	2X4	0.224
M23	13.5	2X4	0.587	2X4	0.450	2X4	0.450
M24	13.5	2X6	0.557	2X6	0.371	2X6	0.371
M25	13.5	3X6	0.604	3X6	0.492	3X6	0.494
M26	24.13	3X6	0.518	3X6	0.521	3X6	0.521
M27	30.187	3X6	0.529	3X6	0.422	3X6	0.422
M28	30.187	3X6	0.306	3X6	0.092	3X6	0.092

M29	30.187	3X6	0.137	3X6	0.022	3X6	0.022
M30	30.187	3X6	0.075	3X6	0.105	3X6	0.105
M31	30.187	3X6	0.276	3X6	0.211	3X6	0.211
M32	30.187	3X6	0.477	3X6	0.318	3X6	0.318
M33	30.187	3X6	0.678	3X6	0.424	3X6	0.424

Table 53. Member sizes for truss type A (first floor)

		Truss FL		Truss EK		Truss DJ	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	20	4X6	0.786	3X6	0.604	3X6	0.307
M2	27	2X6	0.686	2X4	0.138	2X4	0.121
M3	27	2X6	0.817	2X6	0.603	2X4	0.558
M4	27	3X6	0.878	2X6	0.779	2X4	0.575
M5	27	3X6	0.899	2X6	0.799	2X4	0.588
M6	27	3X6	0.679	2X6	0.457	2X4	0.150
M7	27	2X4	0.382	2X4	0.685	2X4	0.678
M8	27	4X6	0.623	3X6	0.656	3X6	0.416
M9	27	2X4	0.000	2X4	0.000	2X4	0.000
M10	27	4X6	0.807	3X6	0.698	3X6	0.359
M11	27	6X6	0.842	4X6	0.795	3X6	0.627
M12	27	6X8	0.719	6X6	0.615	3X6	0.805
M13	27	6X8	0.687	6X6	0.636	3X6	0.887
M14	27	6X6	0.765	4X6	0.874	3X6	0.799
M15	27	4X6	0.620	3X6	0.704	3X6	0.444
M16	20	2X4	0.000	2X4	0.000	2X4	0.000

M17	13.5	2X6	0.827	2X6	0.805	4X6	0.298
M18	13.5	3X6	0.784	2X6	0.850	2X4	0.886
M19	13.5	2X6	0.810	2X4	0.641	2X4	0.230
M20	13.5	2X4	0.488	2X4	0.132	2X4	0.035
M21	13.5	2X4	0.003	2X4	0.003	2X4	0.001
M22	13.5	2X4	0.336	2X4	0.314	2X4	0.220
M23	13.5	2X6	0.681	2X4	0.790	2X4	0.444
M24	13.5	3X6	0.707	2X6	0.695	2X4	0.670
M25	13.5	4X6	0.722	4X6	0.695	4X6	0.682
M26	24.13	4X6	0.738	3X6	0.820	3X6	0.517
M27	30.187	4X6	0.717	3X6	0.728	3X6	0.417
M28	30.187	3X6	0.671	3X6	0.294	2X6	0.290
M29	30.187	2X6	0.767	2X4	0.379	2X4	0.077
M30	30.187	2X4	0.807	2X4	0.753	2X4	0.529
M31	30.187	3X6	0.584	3X6	0.371	2X6	0.588
M32	30.187	4X6	0.646	3X6	0.595	3X6	0.315
M33	30.187	6X6	0.556	3X6	0.819	3X6	0.421

Table 54. Member sizes for truss type B

		Truss BI (1st Floor)		Truss BI (2nd Floor)	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	20	3X6	0.503	3X6	0.503
M2	27	2X6	0.027	2X6	0.027
M3	27	2X6	0.514	2X6	0.514
M4	27	2X6	0.514	2X6	0.514
M5	27	2X6	0.234	2X6	0.234
M6	27	3X6	0.358	3X6	0.358
M11	27	2X6	0.000	2X6	0.000

M12	27	3X6	0.778	3X6	0.778
M13	27	4X6	0.807	4X6	0.807
M14	27	4X6	0.746	4X6	0.746
M15	27	3X6	0.594	3X6	0.594
M16	20	2X6	0.000	2X6	0.000
M17	13.5	3X6	0.486	2X6	0.399
M18	13.5	2X6	0.734	2X6	0.734
M19	13.5	2X4	0.483	2X4	0.483
M20	13.5	2X4	0.002	2X4	0.002
M21	13.5	2X4	0.282	2X4	0.282
M22	13.5	2X6	0.608	2X6	0.608
M23	13.5	3X6	0.743	2X6	0.506
M26	24.13	4X6	0.466	4X6	0.466
M27	30.187	3X6	0.630	3X6	0.630
M28	30.187	2X6	0.639	2X6	0.639
M29	30.187	2X6	0.342	2X6	0.342
M30	30.187	3X6	0.521	3X6	0.521
M31	30.187	4X6	0.585	4X6	0.585

Table 55. Member sizes for truss type C (second floor only)

		Truss IN		Truss JO		Truss KP		Truss LQ	
Label	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	20.75	3X6	0.41	2X4	0.65	2X4	0.65	2X4	0.33
M2	20.75	3X6	0.55	2X6	0.49	2X6	0.49	2X6	0.25
M3	20.75	3X6	0.55	2X6	0.49	2X6	0.49	2X6	0.25
M4	20.75	3X6	0.40	2X4	0.65	2X4	0.65	2X4	0.33
M5	20.75	3X6	0.02	2X4	0.03	2X4	0.03	2X4	0.01
M6	20.75	3X6	0.24	2X4	0.48	2X4	0.48	2X4	0.24
M7	20.75	3X6	0.24	2X4	0.48	2X4	0.48	2X4	0.24
M8	20.75	3X6	0.02	2X4	0.03	2X4	0.03	2X4	0.01
M9	13.5	2X4	0.50	2X4	0.83	2X4	0.82	2X4	0.77
M10	13.5	2X4	0.15	2X4	0.12	2X4	0.12	2X4	0.06
M11	13.5	2X4	0.02	2X4	0.02	2X4	0.02	2X4	0.01

M12	13.5	2X4	0.16	2X4	0.12	2X4	0.12	2X4	0.06
M13	13.5	2X4	0.74	2X4	0.83	2X4	0.83	2X4	0.78
M14	24.755	2X6	0.62	2X4	0.61	2X4	0.61	2X4	0.31
M15	24.755	2X6	0.21	2X4	0.20	2X4	0.20	2X4	0.10
M16	24.755	2X6	0.21	2X4	0.20	2X4	0.20	2X4	0.10
M17	24.755	2X6	0.61	2X4	0.61	2X4	0.61	2X4	0.31

Table 56. Member sizes for truss type C (first floor only)

		Truss IN		Truss JO		Truss KP		Truss LQ	
Label	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	20.75	2X4	0.16	2X4	0.12	2X6	0.77	2X6	0.77
M2	20.75	3X6	0.49	3X6	0.52	3X6	0.65	3X6	0.64
M3	20.75	3X6	0.47	3X6	0.52	3X6	0.65	3X6	0.64
M4	20.75	2X4	0.13	2X4	0.12	2X6	0.77	2X6	0.77
M5	20.75	4X6	0.35	3X6	0.67	2X4	0.07	2X4	0.09
M6	20.75	2X4	0.33	2X4	0.22	2X4	0.85	2X6	0.57
M7	20.75	2X4	0.11	2X4	0.09	2X4	0.85	2X6	0.57
M8	20.75	2X4	0.29	2X4	0.22	2X4	0.07	2X4	0.09
M9	13.5	4X6	0.67	3X6	0.68	2X6	0.76	2X6	0.53
M10	13.5	3X6	0.82	4X6	0.64	2X4	0.20	2X4	0.19
M11	13.5	4X6	0.74	4X6	0.82	2X4	0.04	2X4	0.04
M12	13.5	4X6	0.74	4X6	0.82	2X4	0.20	2X4	0.19
M13	13.5	3X6	0.79	4X6	0.64	2X6	0.88	2X6	0.49
M14	24.755	3X6	0.54	3X6	0.57	2X6	0.70	2X6	0.71

M15	24.755	2X4	0.57	2X4	0.58	2X4	0.49	2X4	0.44
M16	24.755	3X6	0.52	3X6	0.57	2X4	0.49	2X4	0.44
M17	24.755	2X4	0.62	2X4	0.58	2X6	0.70	2X6	0.71

Table 57. Member sizes for truss type D (second floor only)

		Truss OW		Truss PX		Truss QY	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	21	2X6	0.721	2X6	0.721	2X6	0.721
M2	20	2X6	0.688	2X6	0.688	2X6	0.688
M3	20	2X6	0.579	2X6	0.579	2X6	0.579
M4	20	2X6	0.579	2X6	0.579	2X6	0.579
M5	20	3X6	0.714	3X6	0.714	3X6	0.714
M6	20	3X6	0.714	3X6	0.714	3X6	0.714
M7	20	2X6	0.763	2X6	0.763	2X6	0.763
M8	23	2X6	0.763	2X6	0.763	2X6	0.763
M9	23	2X6	0.721	2X6	0.721	2X6	0.721
M10	22	2X6	0.703	2X6	0.703	2X6	0.703
M11	21	2X6	0.000	2X6	0.000	2X6	0.000
M12	20	3X6	0.758	3X6	0.758	3X6	0.758
M13	20	3X6	0.758	3X6	0.758	3X6	0.758
M14	20	4X6	0.787	4X6	0.787	4X6	0.787
M15	20	4X6	0.787	4X6	0.787	4X6	0.787
M16	20	4X6	0.809	4X6	0.809	4X6	0.809
M17	20	4X6	0.809	4X6	0.809	4X6	0.809

M18	23	3X6	0.817	3X6	0.817	3X6	0.817
M19	23	3X6	0.817	3X6	0.817	3X6	0.817
M20	22	2X6	0.000	2X6	0.000	2X6	0.000
M21	13.5	2X6	0.731	2X6	0.725	2X6	0.731
M22	13.5	2X4	0.001	2X4	0.001	2X4	0.001
M23	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M24	13.5	2X4	0.001	2X4	0.001	2X4	0.001
M25	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M26	13.5	2X4	0.002	2X4	0.002	2X4	0.002
M27	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M28	13.5	2X4	0.058	2X4	0.058	2X4	0.058
M29	13.5	2X4	0.168	2X4	0.168	2X4	0.168
M30	13.5	2X4	0.002	2X4	0.002	2X4	0.002
M31	13.5	2X6	0.450	2X6	0.450	2X6	0.451
M32	24.965	3X6	0.555	3X6	0.555	3X6	0.555
M33	24.13	3X6	0.663	3X6	0.663	3X6	0.663
M34	24.13	2X6	0.672	2X6	0.672	2X6	0.672
M35	24.13	2X6	0.524	2X6	0.524	2X6	0.524
M36	24.13	2X6	0.170	2X6	0.170	2X6	0.170
M37	24.13	2X6	0.081	2X6	0.081	2X6	0.081
M38	24.13	2X6	0.414	2X6	0.414	2X6	0.414
M39	26.669	2X6	0.808	2X6	0.808	2X6	0.808
M40	26.669	3X6	0.661	3X6	0.661	3X6	0.661
M41	25.812	3X6	0.580	3X6	0.580	3X6	0.580

Table 58. Member sizes for truss type D (first floor only)

		Truss OW		Truss PX		Truss QY	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	21	2X6	0.721	2X6	0.721	2X6	0.721
M2	20	2X6	0.688	2X6	0.688	2X6	0.688
M3	20	2X6	0.579	2X6	0.579	2X6	0.579
M4	20	2X6	0.579	2X6	0.579	2X6	0.579
M5	20	3X6	0.713	3X6	0.713	3X6	0.714
M6	20	3X6	0.713	3X6	0.713	3X6	0.714
M7	20	2X6	0.763	2X6	0.763	2X6	0.763
M8	23	2X6	0.763	2X6	0.763	2X6	0.763
M9	23	2X6	0.720	2X6	0.720	2X6	0.721
M10	22	2X6	0.702	2X6	0.702	2X6	0.703
M11	21	2X4	0.000	2X4	0.000	2X4	0.000
M12	20	3X6	0.758	3X6	0.758	3X6	0.758
M13	20	3X6	0.758	3X6	0.758	3X6	0.758
M14	20	4X6	0.787	4X6	0.787	4X6	0.787
M15	20	4X6	0.787	4X6	0.787	4X6	0.787
M16	20	4X6	0.809	4X6	0.808	4X6	0.809
M17	20	4X6	0.809	4X6	0.808	4X6	0.809
M18	23	3X6	0.816	3X6	0.816	3X6	0.817
M19	23	3X6	0.816	3X6	0.816	3X6	0.817
M20	22	2X4	0.000	2X4	0.000	2X4	0.000
M21	13.5	3X6	0.679	3X6	0.676	3X6	0.413

M22	13.5	2X4	0.001	2X4	0.001	2X4	0.001
M23	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M24	13.5	2X4	0.001	2X4	0.001	2X4	0.001
M25	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M26	13.5	2X4	0.002	2X4	0.002	2X4	0.002
M27	13.5	2X4	0.183	2X4	0.183	2X4	0.183
M28	13.5	2X4	0.058	2X4	0.058	2X4	0.058
M29	13.5	2X4	0.168	2X4	0.168	2X4	0.168
M30	13.5	2X4	0.002	2X4	0.002	2X4	0.002
M31	13.5	3X6	0.412	2X6	0.823	2X6	0.451
M32	24.965	3X6	0.555	3X6	0.555	3X6	0.555
M33	24.13	3X6	0.662	3X6	0.662	3X6	0.663
M34	24.13	2X6	0.672	2X6	0.672	2X6	0.672
M35	24.13	2X6	0.524	2X6	0.524	2X6	0.524
M36	24.13	2X4	0.310	2X4	0.309	2X6	0.170
M37	24.13	2X4	0.147	2X4	0.148	2X6	0.081
M38	24.13	2X6	0.413	2X4	0.752	2X6	0.414
M39	26.669	2X6	0.808	2X6	0.807	2X6	0.808
M40	26.669	3X6	0.661	3X6	0.661	3X6	0.661
M41	25.812	3X6	0.580	3X6	0.580	3X6	0.580

Table 59. Truss Type E member sizes (both floors)

		Truss NV (2nd floor)		Truss NV (first floor)	
Member	Length (in)	Shape	Code Check (1" nail)	Shape	Code Check (1" nail)
M1	21	2X6	0.061	2X4	0.049
M2	20	2X6	0.055	2X4	0.034
M3	20	2X6	0.580	3X6	0.535

M4	20	2X6	0.580	3X6	0.535
M5	20	3X6	0.134	2X4	0.244
M6	20	3X6	0.134	2X4	0.244
M7	20	2X6	0.853	3X6	0.784
M8	23	2X6	0.445	2X6	0.786
M9	23	2X6	0.302	2X4	0.627
M10	22	2X6	0.294	2X4	0.591
M11	21	2X6	0.000	2X4	0.000
M12	20	3X6	0.414	3X6	0.626
M13	20	3X6	0.414	3X6	0.626
M14	20	4X6	0.321	3X6	0.654
M15	20	4X6	0.321	3X6	0.654
M16	20	4X6	0.115	2X6	0.222
M17	20	4X6	0.115	2X6	0.222
M18	23	3X6	0.107	2X4	0.206
M19	23	3X6	0.107	2X4	0.206
M20	22	2X6	0.000	2X4	0.000
M21	13.5	2X6	0.664	3X6	0.563
M22	13.5	2X4	0.001	2X4	0.001
M23	13.5	2X4	0.180	2X4	0.298
M24	13.5	2X4	0.001	2X4	0.002
M25	13.5	2X4	0.180	2X4	0.298
M26	13.5	2X4	0.002	2X4	0.001
M27	13.5	2X4	0.231	2X4	0.298
M28	13.5	3X6	0.716	4X8	0.659
M29	13.5	2X4	0.392	2X4	0.379
M30	13.5	2X4	0.002	2X4	0.001
M31	13.5	2X6	0.340	2X6	0.619
M32	24.965	3X6	0.321	3X6	0.494
M33	24.13	3X6	0.331	2X6	0.808
M34	24.13	2X6	0.197	2X4	0.445
M35	24.13	2X6	0.049	2X4	0.298
M36	24.13	2X6	0.369	2X6	0.711
M37	24.13	2X6	0.558	3X6	0.430
M38	24.13	3X6	0.653	4X6	0.740
M39	26.669	2X6	0.834	3X6	0.690
M40	26.669	3X6	0.066	2X4	0.730
M41	25.812	3X6	0.197	2X4	0.462

Framing Calculation Results

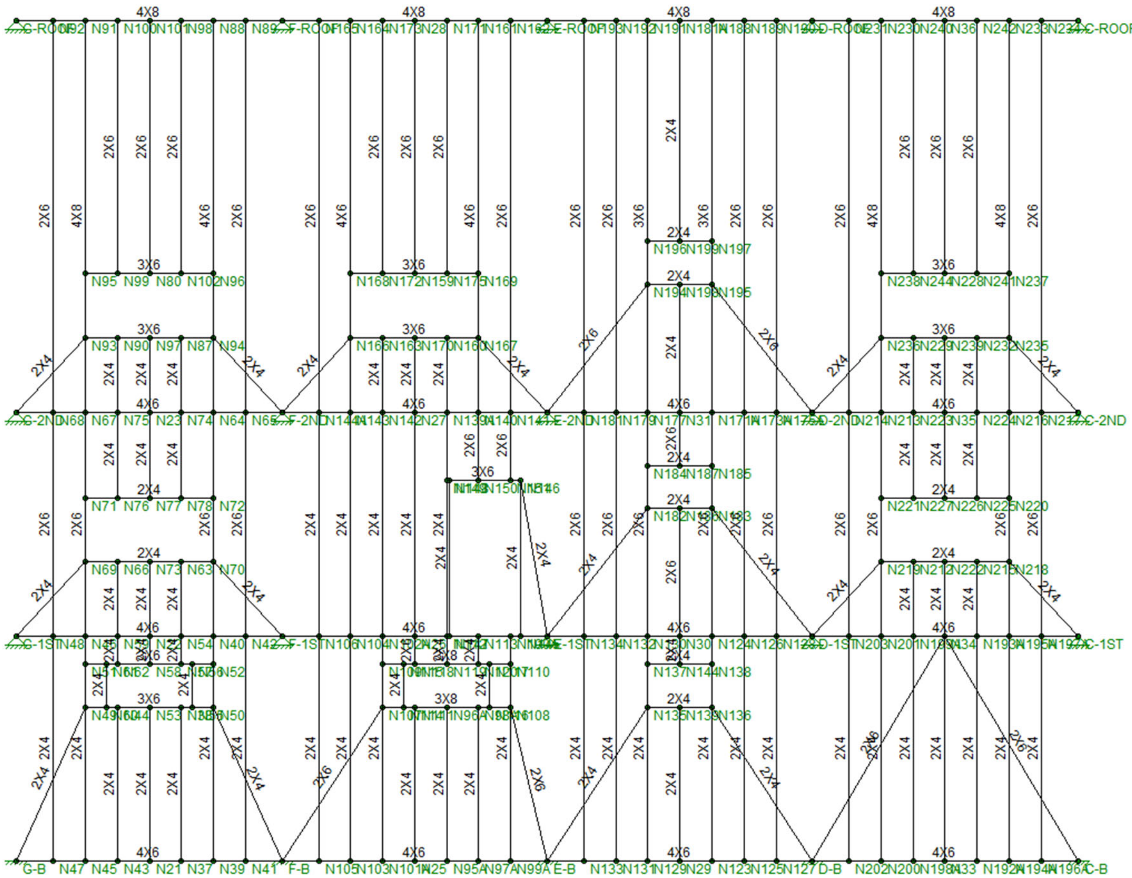


Figure 158. North wall framing scheme

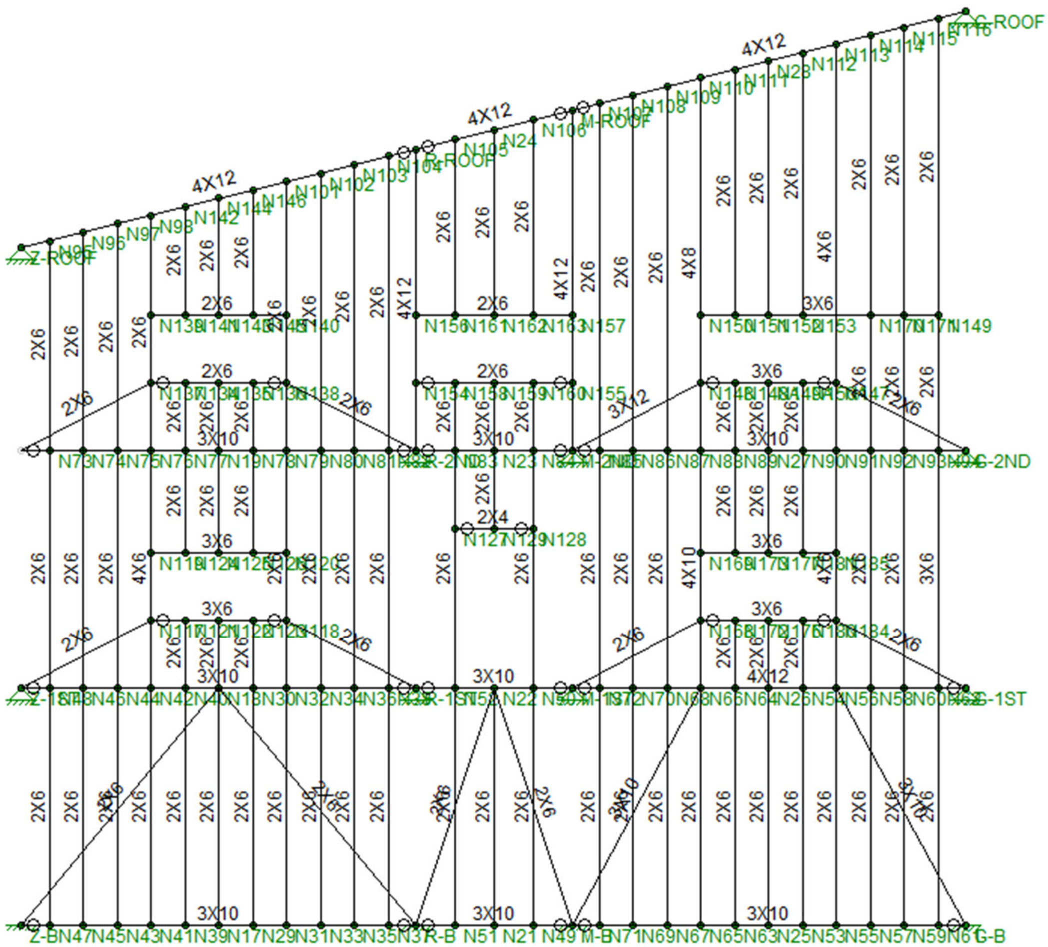


Figure 159. East wall framing scheme

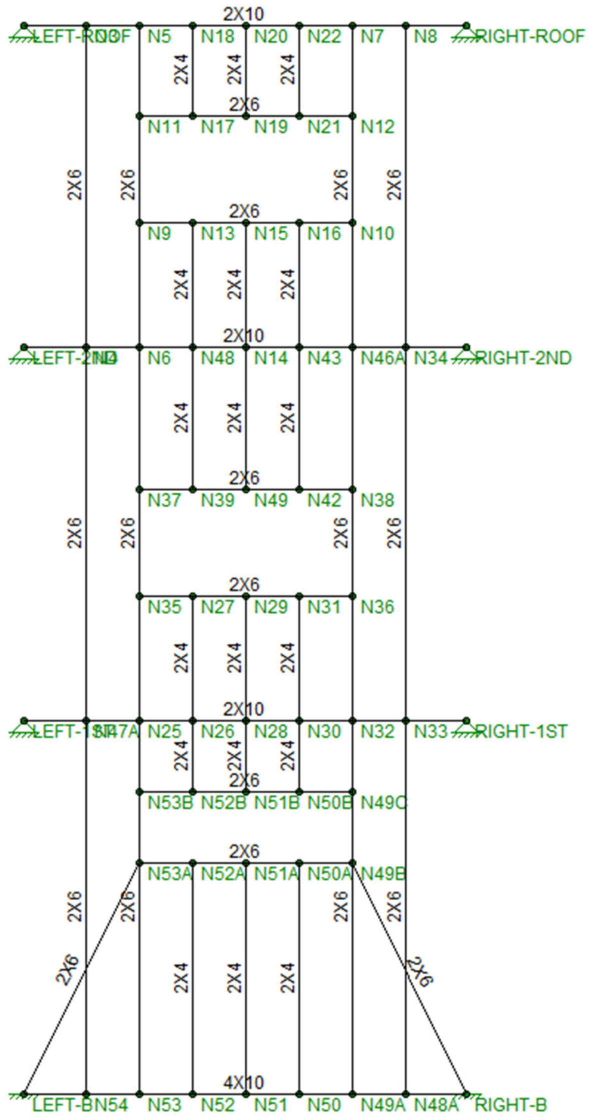


Figure 160. Framing schemes from Column X to Column Y, and Column Y to Column Z

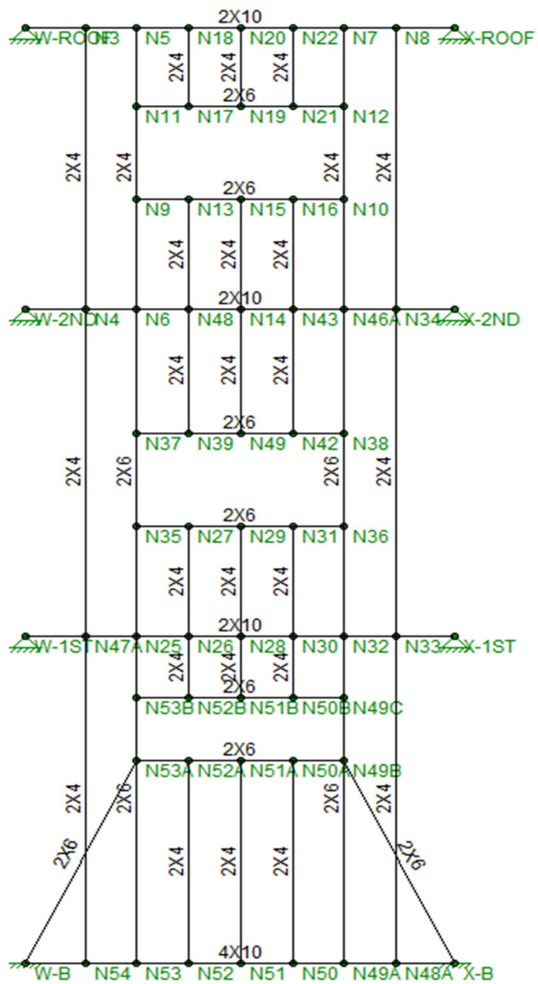


Figure 161. Framing scheme from Column W to Column X

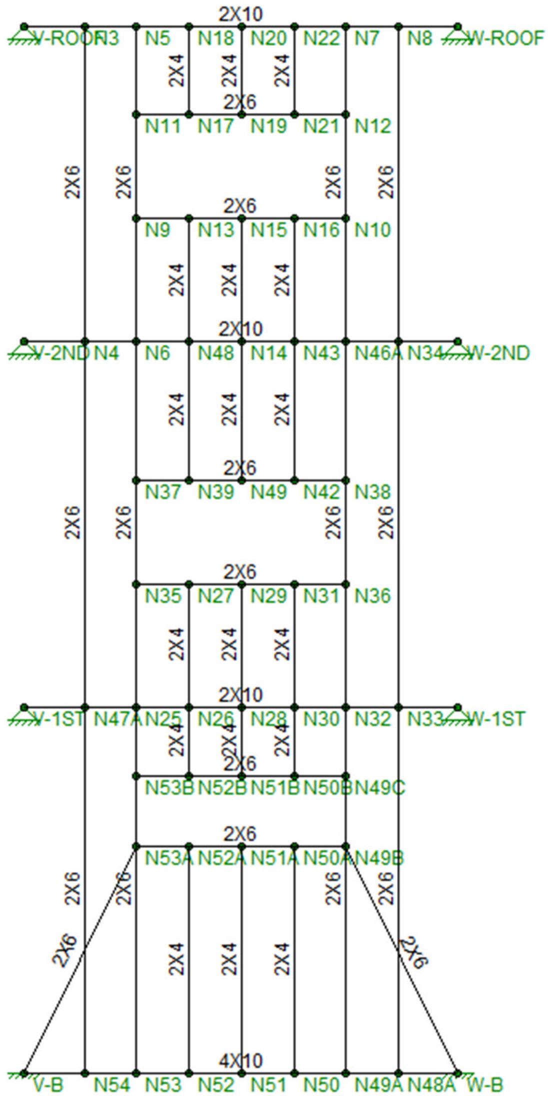


Figure 162. Framing scheme from Column V to Column W

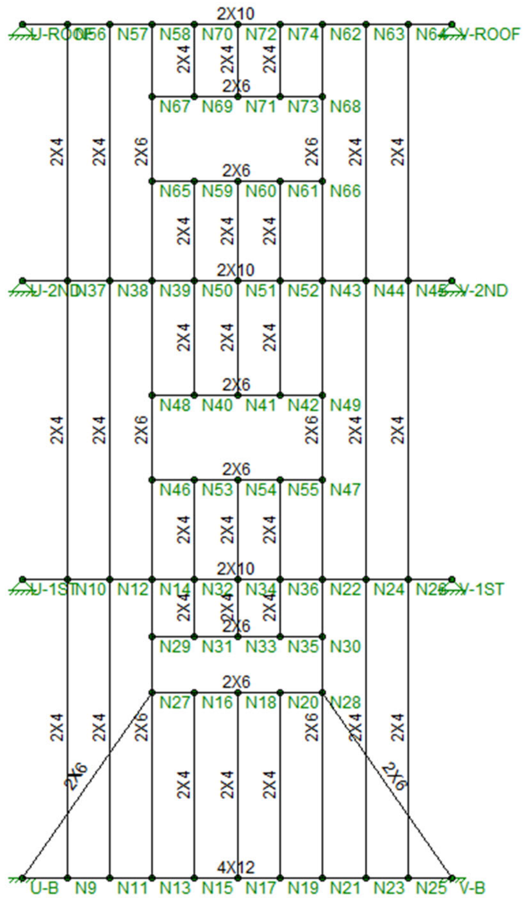


Figure 163. Framing scheme from Column U to Column V

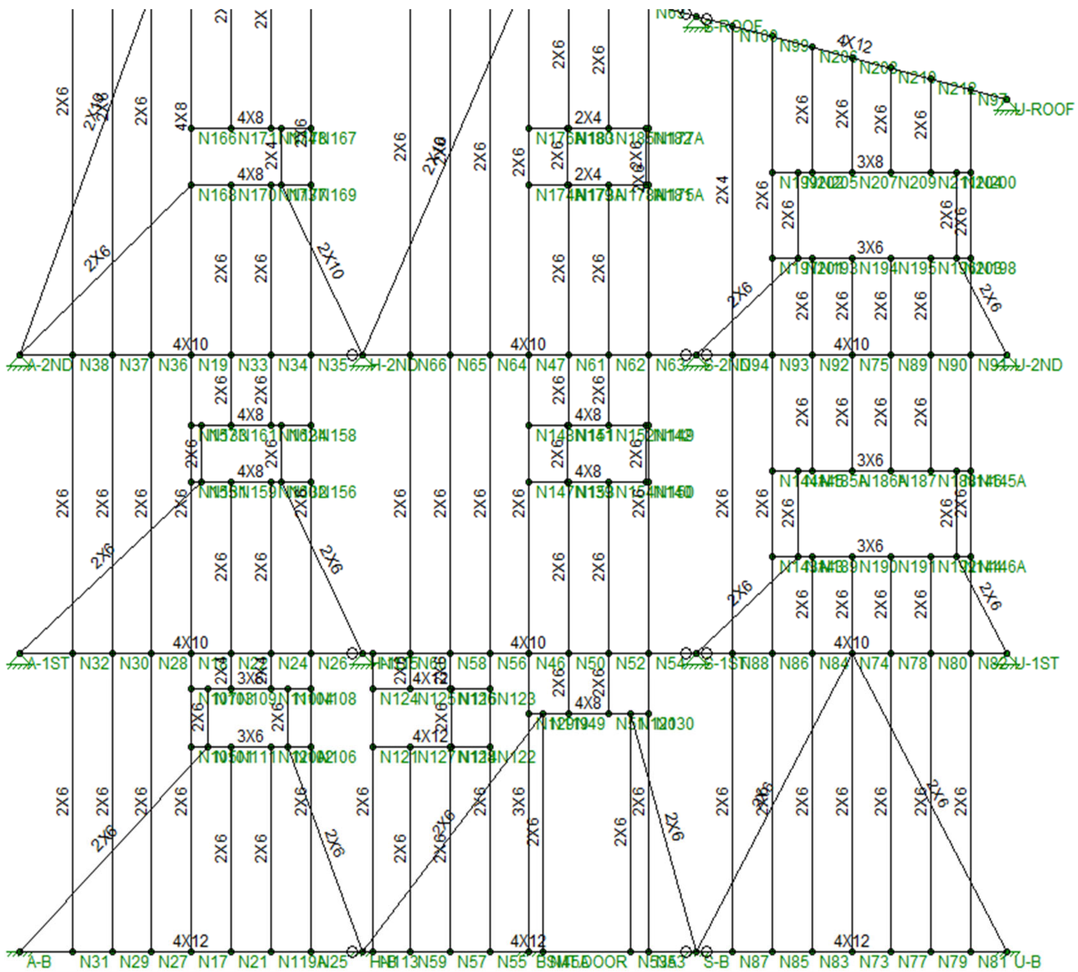


Figure 164. West wall framing scheme – lower stories only

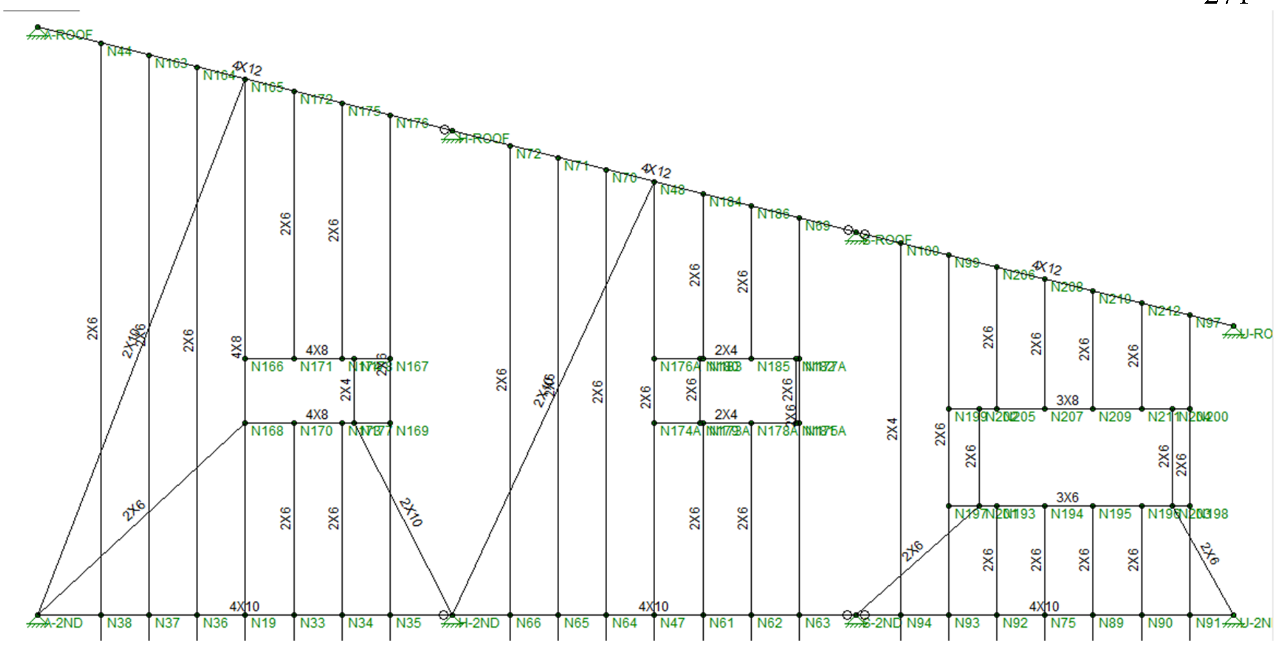


Figure 165. West wall framing scheme – second floor to roof

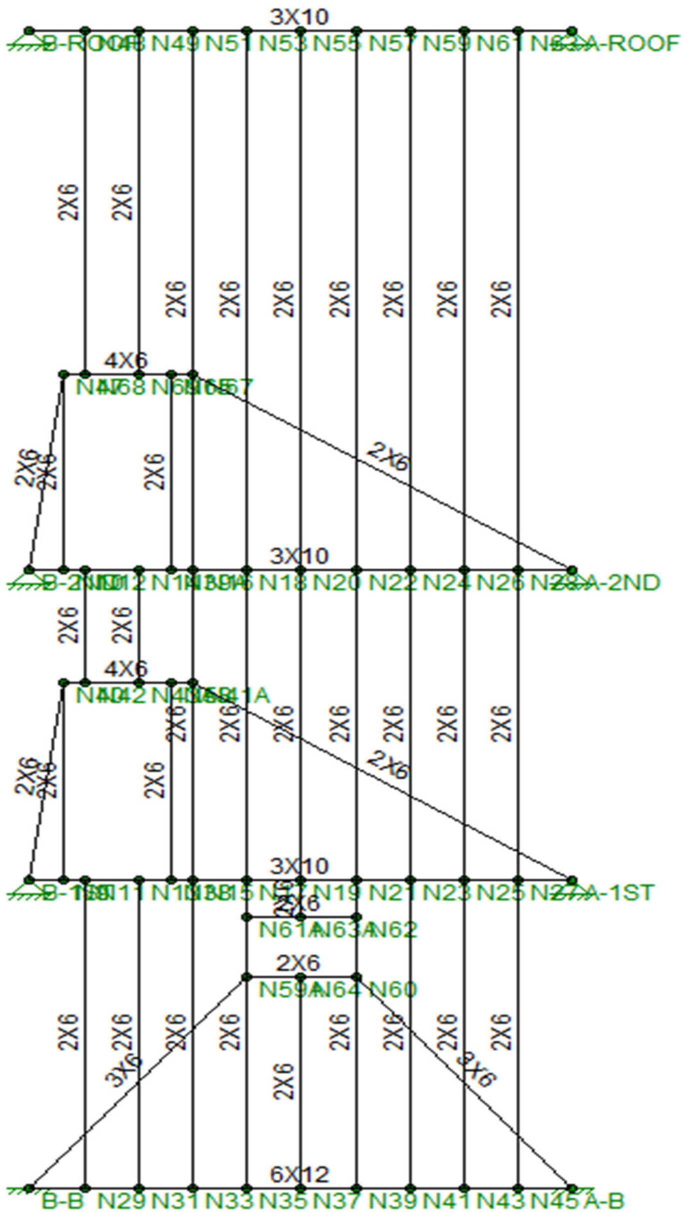


Figure 166. Framing scheme from Column A to Column B

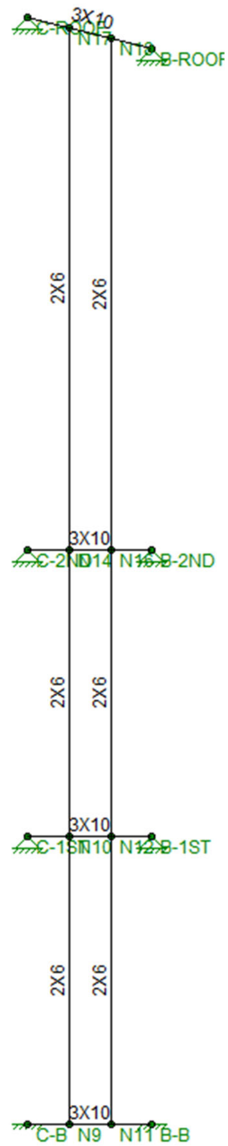


Figure 167. Framing scheme from Column B to Column C

Column Calculations and Results

Table 60. Second floor - roof column sizes and loading

Column	Length (ft.)	Member Size	Members Used	Design Compression (lb.)	Max. Compression (lb.)	
					Each member	Total
A	16.021	3 x 6	3	13990.45	5873.14	17619.41

B	16.021	2 x 6	3	8075.14	3523.88	10571.65
C	16.021	2 x 6	3	8850.56	3523.88	10571.65
D	16.021	3 x 6	3	15160.46	5873.14	17619.41
E	16.021	3 x 6	3	15169.70	5873.14	17619.41
F	16.021	3 x 6	3	15306.04	5873.14	17619.41
G	16.021	3 x 6	3	13771.43	5873.14	17619.41
H	12.615	2 x 6	3	12969.12	5494.85	16484.54
I	14.063	2 x 6	3	12413.13	4502.22	13506.65
J	14.063	2 x 6	4	15192.73	4502.22	18008.87
K	14.063	2 x 6	4	15158.98	4502.22	18008.87
L	14.063	2 x 6	4	15158.98	4502.22	18008.87
M	14.063	2 x 6	3	11717.88	4501.92	13505.76
N	9.417	2 x 6	2	8461.83	4502.22	9004.43
O	9.417	2 x 6	2	14940.18	9027.24	18054.49
P	9.417	2 x 6	2	14940.18	9027.24	18054.49
Q	9.417	2 x 6	2	14962.78	9027.24	18054.49
R	9.417	2 x 6	2	11938.00	7673.83	15347.66
S	9.417	2 x 6	2	12866.65	9026.75	18053.50
T	9.417	2 x 6	3	19133.97	7673.42	23020.26
U	9.417	3 x 6	1	9963.02	15045.41	15045.41
V	9.417	2 x 6	2	11503.74	7673.42	15346.84
W	9.417	2 x 6	2	12611.98	7673.42	15346.84
X	9.417	2 x 6	2	12573.05	7673.83	15347.66
Y	9.417	2 x 6	2	12673.29	7673.83	15347.66
Z	9.417	2 x 6	3	14258.77	7673.83	23021.49

Table 61. First floor – second floor column sizes and loading

Column	Length (ft.)	Member Size	Members Used	Design Compression (lb.)	Max. Compression (lb.)	
					Each member	Total
A	10.417	3 x 6	3	30278.60	12789.71	38369.14
B	10.417	2 x 6	3	21865.56	7673.83	23021.49
C	10.417	2 x 6	3	16151.11	7673.83	23021.49
D	10.417	3 x 6	3	29746.33	12789.71	38369.14
E	10.417	3 x 6	3	30297.09	12789.71	38369.14
F	10.417	3 x 6	3	33982.47	12789.71	38369.14
G	10.417	3 x 6	3	24469.83	12789.71	38369.14
H	10.417	3 x 6	3	32196.30	12789.03	38367.10
I	10.417	3 x 6	3	34043.42	12789.03	38367.10
J	10.417	3 x 6	2	23151.06	12789.71	25579.43
K	10.417	2 x 6	4	25123.83	7673.83	30695.32
L	10.417	2 x 6	3	21442.83	7673.83	23021.49
M	10.417	2 x 6	3	19531.57	7673.83	23021.49

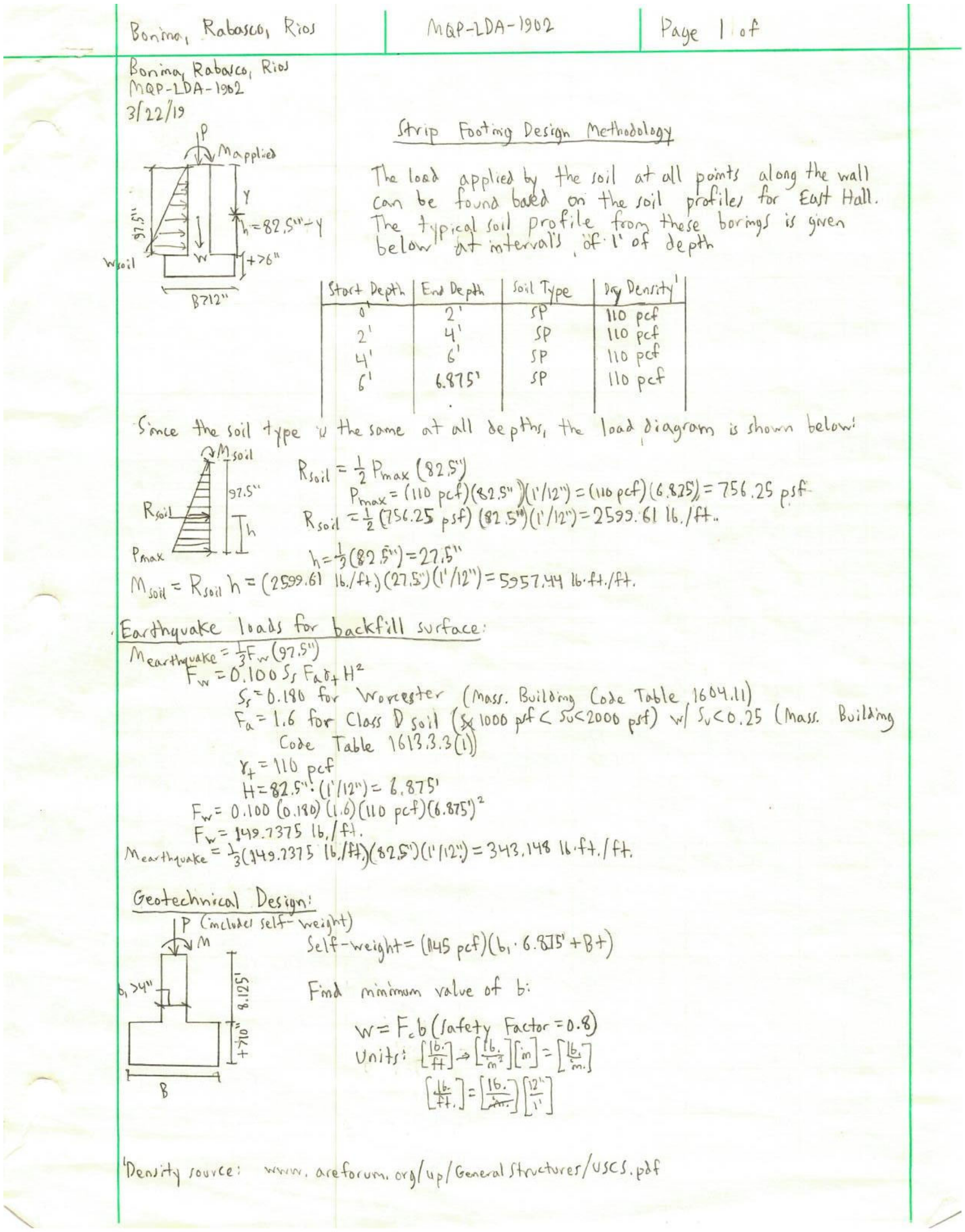
N	10.417	2 x 6	3	16193.69	7673.83	23021.49
O	10.417	2 x 6	4	23548.58	7673.83	30695.32
P	10.417	2 x 6	4	23482.97	7673.83	30695.32
Q	10.417	2 x 6	3	22135.41	7673.83	23021.49
R	10.417	2 x 6	3	21199.42	7673.83	23021.49
S	10.417	2 x 6	3	22362.11	7673.83	23021.49
T	10.417	2 x 6	3	22327.02	7673.83	23021.49
U	10.417	2 x 6	3	16908.74	7673.83	23021.49
V	10.417	2 x 6	3	17298.69	7673.83	23021.49
W	10.417	2 x 6	3	20869.37	7673.83	23021.49
X	10.417	2 x 6	3	20760.03	7673.83	23021.49
Y	10.417	2 x 6	3	20900.63	7673.83	23021.49
Z	10.417	2 x 6	3	20445.62	7673.83	23021.49

Table 62. Basement – first floor column sizes and loading

Column	Length (ft.)	Member Size	Members Used	Design Compression (lb.)	Max. Compression (lb.)	
					Each member	Total
A	10.417	3 x 6	3	36411.83	12789.71	38369.14
B	10.417	3 x 6	4	39326.97	12789.71	51158.84
C	10.417	2 x 6	3	21473.72	7673.83	23021.49
D	10.417	3 x 6	4	41512.23	12789.71	51158.84
E	10.417	3 x 6	4	42557.29	12789.71	51158.84
F	10.417	3 x 6	5	51050.55	12789.71	63948.55
G	10.417	3 x 6	3	33536.51	12789.71	38369.14
H	10.417	3 x 6	4	46573.53	12789.03	51156.13
I	10.417	3 x 6	4	49284.32	12789.03	51156.12
J	10.417	3 x 6	3	37315.59	12789.71	38369.13
K	10.417	3 x 6	4	42447.18	12789.71	51158.84
L	10.417	3 x 6	4	47463.32	12789.71	51158.84
M	10.417	3 x 6	3	28052.73	12789.71	38369.14
N	10.417	3 x 6	3	27963.87	12789.71	38369.13
O	10.417	3 x 6	3	30481.11	12789.71	38369.13
P	10.417	3 x 6	3	29391.44	12789.71	38369.13
Q	10.417	3 x 6	3	34906.84	12789.71	38369.13
R	10.417	3 x 6	3	30812.54	12789.71	38369.14
S	10.417	3 x 6	3	31314.52	12789.71	38369.14
T	10.417	3 x 6	4	40355.96	12789.71	51158.86
U	10.417	3 x 6	2	23310.10	12789.71	25579.43
V	10.417	3 x 6	3	24786.72	12789.71	38369.13

W	10.417	3 x 6	3	20919.03	12789.71	38369.13
X	10.417	3 x 6	3	26883.89	12789.71	38369.13
Y	10.417	3 x 6	3	29133.48	12789.71	38369.13
Z	10.417	3 x 6	3	27963.73	12789.71	38369.14

Foundation Calculations



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Strip Footing Design Methodology

The load applied by the soil at all points along the wall can be found based on the soil profiles for East Hall. The typical soil profile from these borings is given below at intervals of 1' of depth

Start Depth	End Depth	Soil Type	Dry Density[1]
0'	2'	SP	110 pcf
2'	4'	SP	110 pcf
4'	6'	SP	110 pcf
6'	6.875'	SP	110 pcf

Since the soil type is the same at all depths, the load diagram is shown below:

$R_{soil} = \frac{1}{2} P_{max} (82.5")$

$P_{max} = (110\ pcf)(82.5")(1'/12") = (110\ pcf)(6.875') = 756.25\ psf$

$R_{soil} = \frac{1}{2}(756.25\ psf)(82.5")(1'/12") = 2599.61\ lb./ft.$

$h = \frac{1}{3}(82.5") = 27.5"$

$M_{soil} = R_{soil} h = (2599.61\ lb./ft.)(27.5")(1'/12") = 5957.44\ lb{\cdot}ft./ft.$

Earthquake loads for backfill surface:

$M_{earthquake} = \frac{1}{3} F_w (97.5")$

$F_w = 0.100 S_s F_a \gamma_t H^2$

$S_s = 0.180$ for Worcester (Mass. Building Code Table 1604.11)

$F_a = 1.6$ for Class D soil (≤ 1000 psf < Su < 2000 psf) w/ $S_s < 0.25$ (Mass. Building Code Table 1613.3.3(1))

$\gamma_t = 110\ pcf$

$H = 82.5"(1'/12") = 6.875'$

$F_w = 0.100(0.180)(1.6)(110\ pcf)(6.875')^2$

$F_w = 149.7375\ lb./ft.$

$M_{earthquake} = \frac{1}{3}(149.7375\ lb./ft.)(82.5")(1'/12") = 343.148\ lb{\cdot}ft./ft.$

Geotechnical Design:

Self-weight = (145 pcf)($b_1 \cdot$ 6.875' + Bt)

Find minimum value of b:

$w = F_c b$ (Safety Factor = 0.8)

Units: $\left[\frac{lb.}{ft.}\right] \rightarrow \left[\frac{lb.}{in.^2}\right][in.] = \left[\frac{lb.}{in.}\right]$

$\left[\frac{lb.}{ft.}\right] = \left[\frac{lb.}{in.}\right]\left[\frac{12"}{1'}\right]$

[1] Density source: www.areforum.org/up/GeneralStructures/USCS.pdf

Figure 168. Strip footing sample calculations (page 1 of 4)

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Another constraint on the minimum value of B is the slenderness ratio

$Kl_u/r < 22$,[2]

$K = 2.0$, based on a fixed bottom support and a free top support[3]

$l_u = 97.5''$

$r = b_1$

$\frac{Kl_u}{b_1} < 22 \rightarrow 22b_1 > Kl_u$

$b_1 > \frac{Kl_u}{22} = \frac{(97.5'')(2)}{22}$

$b_1 > 8.86'' \rightarrow$ Set $t > 9''$

This allows the column to be exempt from buckling analysis.

Geotechnical design for footing:

- Design load $= \frac{W}{B}\left(1 + 6\frac{e}{B}\right)$, where $e = \frac{M\ [lb \cdot ft./ft.]}{W\ [lb./ft.]}$
- Allowable load (psf) = 2000 psf for SP soil

Structural Design:

- Shear (See Rev. 2 for design and allowable shear)
  - Presumably, only one-way shear needs to be solved ~~for~~ in strip footings
  - ~~$\tau_v = \frac{V_u}{bd}$[4]~~
  - ~~b = width of critical section = b_1~~
  - ~~$d = t - 3'' - d_{steel}$~~
- Moment

  $M_{uc} = \frac{P_u l^2}{2B} + \frac{2M_u l}{B}$, typically

  $l = (B - b_1)/2$

  Since the footing is a strip footing instead of a spread footing,

  $M_{uc} = \frac{wl^2}{2} + 2M_u l$, where M_u is in units of [lb·ft./ft.]

  $\hookrightarrow l = (B - b_1)/2$

MOMENT AND STEEL CALC'S SUPERSEDED. SEE REVISION 3

- Reinforcing steel
  - Typically, $A_s = \left(\frac{f'_c b_w}{1.176 f_y}\right)\left(d - \sqrt{d^2 - \frac{2.353 M_{uc}}{(FS) f'_c b_w}}\right)$

    where $d = t - 3'' - d_{steel}$

    $b_w = B$

    $FS = 0.45$

    $f'_c = 3000$ psi

    $f_y = 40{,}000$ psi
  - For the strip footing,

    $\frac{A_s}{L} = \left(\frac{f'_c b_w}{1.176 f_y}\right)\left(d - \sqrt{d^2 - \frac{2.353 M_{uc}}{(FS) f'_c b_w}}\right)/L$,

    where L is the length of the foundation
  - Spacing:

    $Spacing = \frac{A_s}{L} \times \frac{1}{\text{rod area}}$

[2] dot.ca.gov/des/techpubs/manuals/bridge-design-practice/page/bdp-13.pdf

[3] wikiengineer.com/Structural/EffectiveLengthFactor

[4] https://theconstructor.org/structural-engg/design-reinforced-concrete-footings/7325/

Figure 169. Strip footing sample calculations (page 2 of 4)

- Required development length

$$l_d = \frac{3}{40}\left(\frac{f_y}{\sqrt{f_c'}}\right)\frac{d_b}{2.5}$$, where f_y and f_c' are in psi

Revision 1:

- For the purposes of determining reinforcement requirements, d_1 and d_2 should be given as follows:

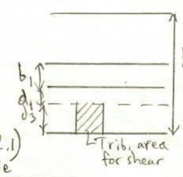
$$d_1 = t - 3'' - \frac{d_b}{2}$$
$$d_2 = b_1 - 3'' - \frac{d_b}{2}$$

Revision 2: Design Shear

According to https://structurepoint.org/pdfs/Concrete-Shear-Wall-Strip-Footing-Foundation-Analysis-Design-ACI318-14.htm,

- Only one-way shear needs to be found in wall footings
- One-way shear is greatest at distance d_1 from the wall, where
$$d_1 = t - 3'' - \frac{d_b}{2}$$

$$\frac{V_{uc}}{ft.} = \text{Load on foundation} \times d_3 \quad [\text{units} = lb./ft.]$$
$$d_3 = \frac{B}{2} - \frac{b_1}{2} - \left(d_1 = t - 3'' - \frac{d_b}{2}\right)$$



Allowable shear is given by

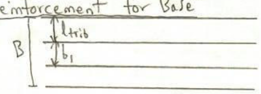
$$\frac{V_{nc}}{ft.} = \phi \times 2 \times \lambda \times \sqrt{f_c} \times b_w \times d_1$$ (5)

↳ $\phi = 0.75$, according to ACI 318-14 (Table 21.2.1)

Revision 3: Design Moment & Reinforcement for Base

$$M_u = q_u \cdot \frac{l_{trib}^2}{2}$$ (5)

- $l_{trib} = \frac{B - b_1}{2}$ (5)



$$A_s = \frac{M_u}{\phi f_y j d_1}$$ (Initial check)

- Use $\phi = 0.9$ (5)
- $f_y = 40{,}000$ psi for reinforcing steel
- $j = 0.95$

Recalculate a to arrive at the actual A_s

$$a = \frac{A_s f_y}{0.85 f_c' b} = \frac{[in.][psi]}{[psi][in.]} = \text{unitless}$$

- b = footing thickness t

$$c = \frac{a}{\beta_1}$$

↳ $\beta_1 = 0.85$

$$\varepsilon_1 = \left(\frac{0.003}{c}\right) d_1 - 0.003$$

↳ In order for the section to be tension-controlled, $\varepsilon_1 > 0.005$

Revised value of A_s:

$$A_s = \frac{M_u}{\phi f_y (d - a/2)}$$

[5] https://structurepoint.org/pdfs/Concrete-Shear-Wall-Strip-Footing-Foundation-Analysis-Design-ACI318-14.htm

Figure 170. Strip footing sample calculations (page 3 of 4)

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Revision 3 (cont.)

$$A_{s,min} = \max\left\{\begin{matrix}\frac{0.0018 \times 60{,}000}{f_y} \\ 0.0014\end{matrix}\right\} \times b_1 t$$

Maximum spacing:

$$S_{max} = \min\left\{\begin{matrix}3t \\ 18''\end{matrix}\right\}$$

Required development length $= l_d = \left(\frac{3}{40}\right)\left(\frac{f_y}{\sqrt{f_c'}}\right) \times \frac{d_b}{2.5}$ (from CE 3044 textbook)

Provided development length $= l_{trib} - 3''$

↳ $l_{trib} = \frac{B - b_1}{2}$

Revision 4: Design Moment and Reinforcement for Steel Bars

↳ Many of these equations are just educated guesses

$M_u = M_{applied}$

↳ Where $M_{applied}$ is the maximum given by the LRFD load cases

$A_s = \frac{M_u}{\phi f_y j d_2}$ (Initial Check)

- Use $\phi = 0.9$ and $j = 0.95$
- $f_y = 40{,}000$ psi for reinforcing steel
- $d_2 = b_1 - 3'' - \frac{d_b}{2}$

↳ where b_1 is the width of the concrete wall

Recalculate a to arrive at the actual A_s:

$a_2 = \frac{A_s f_y}{0.85 f_c' b_1}$

$c_2 = \frac{a_2}{\beta_1}$, where $\beta_1 = 0.85$

$\varepsilon_2 = \left(\frac{0.003}{c_2}\right) d_2 - 0.003$

↳ In order for the section to be analyzed as tension-controlled, $\varepsilon_2 > 0.005$

Revised value of A_s:

$A_s = \frac{M_u}{\phi f_y (d_2 - a_2/2)}$

Minimum value of A_s:

$$A_{s,min} = \max\left\{\begin{matrix}\frac{0.0018 \times 60{,}000 \text{ psi}}{f_y} \\ 0.0014\end{matrix}\right\} \times b_1 t$$

Maximum spacing:

$$S_{max} = \min\left\{\begin{matrix}3t \\ 18''\end{matrix}\right\}$$

Required development length $l_d = \left(\frac{3}{40}\right)\left(\frac{f_y}{\sqrt{f_c}}\right)\frac{d_b}{2.5}$ (from CE 3044 textbook)

Provided development length $= l_{trib} - 3''$

↳ Use $l_{trib} = 82.5''$

Figure 171. Strip footing sample calculations (page 4 of 4)

NOTES:
Formula cells are shown in red
Comments are shown in blue

Soil Characteristics

Basement Depth	82.5	in	
Foundation Height	33	in	
Foundation Depth	115.5	in	
USCS Classification	SP		
Allowable Pressure (psf)	2000		

Foundation Characteristics

Base B	90	in	
Footing Depth, T	33	in	
b1	10	in	
Concrete Density	145	pcf	https://www.everything-about-concrete.com/density-of-concrete.html
Concrete Strength	3000	psi	Placeholder value
Column Type	Concrete		
Reinforcing Steel Type	Grade 40		
Steel Type F_y =	40000	psi	
Steel Bar Size	2	https://www.upstatesteel.com/products/ReBar.pdf	

Input Loads

Self-Weight	3821.35	lb/ft

Load Combinations

	w (lb./ft)	M_z (lb.*ft/ft)	q_max (psf)
LRFD Governing Load	9928.75	8322.92	2596.97
ASD Governing Load			1990.23

Foundation Design

Wall Thickness Check

Safety Factor	0.8	Maximum ratio of design load to allowable load - cannot be greater than 1
Concrete Strength	3000	psi
b1 (wall thickness)	10	in
w_max = F_c*b1	360000	lb./ft
w / w_max	0.0276	LRFD loads used for concrete design
OK?	TRUE	

$$\frac{kl_u}{b_1} < 22$$

Figure 172. Strip footing spreadsheet calculations (page 1 of 5)

k	2		wikiengineer.com/Structural/EffectiveLengthFactor
l_u	82.5	in	
b1 (wall thickness)	10	in	
k*l_u/b1	16.5		
OK?	TRUE		

Footing Width Check

Load on foundation (q)	1990.23	psf	Use ASD for geotechnical constraints
Allowable Load	2000	psf	
Code Check	1.00		
OK?	TRUE		

Structural Design

Shear Force

Design One-Way Shear

$$V_{uc} = qd_3$$

$$d_3 = \frac{B}{2} - \frac{b_1}{2} - d_1$$

q	2596.97	psf	Use LRFD for structural constraints
B	90	in	
d1	29.875	in	
d3	10.125	in	
V_uc / ft	2191.19	lb/ft	

Allowable Shear

$$V_{nc} = \varphi 2 \lambda d_1 \sqrt{f'_c}$$

Safety Factor ϕ =	0.75	
λ =	1	
d1 =	29.875	in
f'c =	3000	psi
V_nc /ft =	2454	lb/ft

Code Check

V_uc / ft =	2191.19	lb
V_nc /ft =	2454	lb
Code Check =	0.89	
OK?	TRUE	

Bending Moment / Reinforcement for Base

Design Moment

q =	2596.97	psf	Use LRFD for structural constraints
B =	90	in	
b_1 =	10	in	

Figure 173. Strip footing spreadsheet calculations (page 2 of 5)

$l_{trib} = \frac{B - b_1}{2}$	40	in

$$M_u = q_u (l_{trib})^2 / 2$$

M_u	14427.59	lb*ft/ft

Initial Steel Area Calculation

$$A_s = \frac{M_u}{\varphi f_y j d_1}$$

M_u =	14427.59	lb*ft/ft
Safety Factor ϕ =	0.9	
Steel Strength f_y =	40000	psi
j =	0.95	
d_1 =	29.875	in
A_s =	0.01	in^2/in

Recalculate Required Steel Area

$$a = \frac{A_s f_y}{0.85 f'_c t}$$

A_s =	0.01	in^2/in
Steel Strength f_y =	40000	psi
f_c =	3000	psi
t =	33.00	in
a =	0.01	

$$c = a / \beta_1$$

a =	0.01	
β_1 =	0.85	
c =	0.01	

$$\varepsilon_1 = \frac{0.003}{c} d_1 - 0.003$$

d_1 =	29.875	in
ε_1 =	11.34664971	in
ε_1 > 0.005?	TRUE	

$$A_s = \frac{M_u}{\varphi f_y (d - \frac{a}{2})}$$

M_u =	14427.59	lb*ft/ft
Safety Factor ϕ =	0.9	
Steel Strength f_y =	40000	psi
d_1 =	29.875	in
a =	0.01	in
A_s =	0.013416281	in^2/in

Figure 174. Strip footing spreadsheet calculations (page 3 of 5)

Minimum A_s =	0.0027	Either 0.0018 x 60,000 / F_y or 0.0014 shall be multiplied by b_1 and t.
A_s to use =	0.013416281	in
Area / Steel Rod =	0.0491	in^2
Desired Spacing =	3.6588	in
Maximum Spacing =	18.00	in
Spacing to Use =	3.66	in

Required Development Length

$$l_d = \frac{3}{40}\left(\frac{f_y}{\sqrt{f'_c}}\right)\frac{d_b}{2.5}$$

f_y =	40000	psi
f'_c =	3000	psi
d_b =	0.25	in
Required l_d =	12	in
l_d provided =	37	in

Bending Moment / Reinforcement for Wall

Initial Steel Area Calculation

$$A_s = \frac{M_u}{\varphi f_y j d_2}$$

M_u =	8322.92	lb*ft/ft
Safety Factor ϕ =	0.9	
Steel Strength f_y =	40000	psi
j =	0.95	
d2 =	6.88	in
A_s =	0.04	in^2/in

Recalculate Required Steel Area

$$a = \frac{A_s f_y}{0.85 f'_c d_2}$$

A_s =	0.04	in^2/in
Steel Strength f_y =	40000	psi
f_c =	3000	psi
d2 =	6.88	in
a =	0.08	

$$c = a/\beta_1$$

a =	0.08	
β_1 =	0.85	
c =	0.10	

Figure 175. Strip footing spreadsheet calculations (page 4 of 5)

$$\varepsilon_1 = \frac{0.003}{c} d_2 - 0.003$$

d2 =	6.88	in
ε_1 =	0.214064421	in
ε_1 > 0.005?	TRUE	

$$A_s = \frac{M_u}{\varphi f_y (d - \frac{a}{2})}$$

M_u =	8322.92	lb*ft/ft
Safety Factor ϕ =	0.9	
Steel Strength f_y =	40000	psi
d2 =	6.88	in
a =	0.01	in
A_s =	0.0336444	in^2/in
Minimum A_s =	0.0027	Either 0.0018 x 60,000 / F_y or 0.0014 shall be multiplied by b_1 and t.
A_s to use =	0.0336444	in
Area / Steel Rod =	0.0491	in^2
Desired Spacing =	1.4590	in
Maximum Spacing =	18.00	in
Spacing to Use =	1.4590	

Required Development Length

$$l_d = \frac{3}{40}\left(\frac{f_y}{\sqrt{f'_c}}\right)\frac{d_b}{2.5}$$

f_y =	40000	psi
f'_c =	3000	psi
d_b =	0.25	in
Required l_d =	12	in
l_d provided =	79.5	in
Sufficient l_d?	TRUE	

Figure 176. Strip footing spreadsheet calculations (page 5 of 5)

Fire Protection Calculations

Table 63. Required pressure for various pipe configurations using VK102 sprinklers

		Horizontal Pipe Diameter (in)				
		2	**3**	**4**	**6**	**8**
Riser Diameter (in)	**2**	109.60	76.89	72.91	71.79	71.66
	3	73.77	41.05	37.08	35.96	35.82
	4	69.42	36.70	32.73	31.61	31.47
	6	68.19	35.48	31.50	30.38	30.25
	8	68.04	35.33	31.35	30.23	30.10

Sprinkler to Use	VK102		
Operation Area	204	ft^2	
Operation Area	18.95	m^2	
Design Density	0.10	gpm/ft^2	
Design Density	4.07	(L/min)/m^2	From the report
Flow Q = DA	77.22	L/min	
Required Pressure	7	psi	Refer to "Minimum Operating Pressure"
Required Pressure	0.48	bar	Refer to "Minimum Operating Pressure"
Discharge Coefficient k	80.6		
$Q = k\sqrt{P}$			
Minimum Flow Q	55.99	L/min	
Flow to use, Q	77.22	L/min	
Q (English units)	2.73	ft^3/min	
Design P	0.92	bar	
Design P	13.31	psi	

Figure 177. Sprinkler design calculations

Pipe Diam	2	in		
Material	Copper			
Pipe Diam	50.80	mm		
Q	936.37	L/min		
Q (English units)	33.07	ft^3/min		
c	140		https://www.engineersedge.com/fluid_flow/pipe-roughness.htm	
$\frac{P}{l} = 6.05\left(\frac{Q^{1.85}}{C^{1.85}d^{4.87}}\right)10^5$		Pressure loss	https://www.canutesoft.com/how-to-calculate-a-fire-sprinkler-system.html	
P/l	1.00E-01	bars / meter		
Length	58.71	ft		
Length	17.8943	m		
Pressure loss	1.79E+00	bar		
Pressure at valve	0.92	bar	13.31	psi
Pressure at riser	2.71	bar	39.33	psi
Flow Calculations				
Areas (SF)	204			
	163.86			
	204			
	204			
	204			
	204			
	204			
	204			
	166.22			
	66.13			
	144.49			
	469.12			
	35.8			
Total	2473.62	ft^2		
Total Area	229.81	m^2		
Design Density	4.07	(L/min)/m^2		
Flow Q = DA	936.37	L/min		

Figure 178. 2nd floor pipe pressure loss calculations

Riser Diam	3	in				
Material	Copper					
Pipe Diam	0.08	m				
Pipe Area	0.0046	m^2				

<u>Physical Constants</u>

g	9.81	m/s^2
ρ	1000	kg/m^3

<u>Input Parameters</u>

Q	936.37	L	/	min
Q	1.56E-02	m^3	/	s
v	3.4221	m	/	s
Pressure at top	2.71	bar		
Pressure at top	271165	Pa		

Start Elevation	12.54	ft	3.8227	m
End Elevation	22.96	ft	7.00	m

<u>Head Loss</u>

$$\frac{P}{l} = 6.05\left(\frac{Q^{1.85}}{C^{1.85}d^{4.87}}\right)10^{5}$$

Q	936.37	L	/	min
c	140			
d	0.08	m		
P/l	1.39E-02	bar	/	m
l	3.18	m		
ΔP	4417.91	Pa		

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2 + \Delta P$$

<u>Equation Solution</u>

Input pressure	306730	Pa
Input pressure	44.49	psi

Figure 179. 1st floor – 2nd floor standpipe pressure loss calculations

Riser Diam	3	in				
Material	Copper					
Pipe Diam	0.08	m				
Pipe Area	0.0046	m^2				

<u>Physical Constants</u>

g	9.81	m/s^2
ρ	1000	kg/m^3

<u>Input Parameters</u>

Q	2813.61	L	/	min
Q	4.69E-02	m^3	/	s
v	10.2828	m	/	s
Pressure at top	353830	Pa		

Start Elevation	0.00	ft	0	m
End Elevation	2.13	ft	0.65	m

<u>Head Loss</u>

$$\frac{\Delta P}{l} = 6.05\left(\frac{Q^{1.85}}{C^{1.85}d^{4.87}}\right)10^5$$

Q	2813.61	L	/	min
c	140			
d	0.08	m		
P/l	1.07E-01	bar	/	m
l	0.65	m		
ΔP	6899.39	Pa		

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2 + \Delta P$$

<u>Equation Solution</u>

P1	367083	Pa
P1	53.24	psi

<u>Additional Basement Flow</u>

Total	2481.14	ft^2
Total Area	230.51	m^2
Design Density	4.07	(L/min)/m^2
Flow Q = DA	939.21	L/min
Flow (English Units)	33.17	ft^3/min

Figure 180. Basement - 1st floor standpipe pressure loss calculations

Riser Diam	3	in
Material	Steel	
Pipe Diam	0.08	m
Pipe Area	0.0046	m^2

Physical Constants

g	9.81	m/s^2
ρ	1000	kg/m^3

Input Parameters

Q	3452.64	L	/	min
Q	5.75E-02	m^3	/	s
v	12.6183	m	/	s
Pressure at top	266627	Pa		
Start Elevation	0.00	ft	0	m
End Elevation	2.13	ft	0.65	m

Head Loss

$$\frac{\Delta P}{l} = 6.05\left(\frac{Q^{1.85}}{C^{1.85}d^{4.87}}\right)10^5$$

Q	3452.64	L	/	min
c	140			
d	0.08	m		
P/l	1.56E-01	bar	/	m
l	0.65	m		
ΔP	10075.15	Pa		

$$P_1 + \frac{1}{2}\rho {v_1}^2 + \rho g h_1 = P_2 + \frac{1}{2}\rho {v_2}^2 + \rho g h_2 + \Delta P$$

Equation Solution

P1	283056	Pa
P1	41.05	psi

Additional First Floor Flow

Total	2481.14	ft^2
Total Area	230.51	m^2
Design Density	5.00	(L/min)/m^2
Flow Q = DA	1152.53	L/min

Figure 181. Source – Basement standpipe pressure loss calculations

Appendix G: Cost Estimates

Table 64. Renovation cost estimates

Individual Activities	Year	Inflation Factor	MasterFormat Code	Units	UOM	Unit Costs Material	Unit Costs Installation	Total Costs Material	Total Costs Installation
A Substructure								**$0.00**	**$0.00**
A10 Foundation								**$0.00**	**$0.00**
A1010 Standard Foundations								$0.00	$0.00
A1020 Special Foundations								$0.00	$0.00
A1030 Slab on Grade								$0.00	$0.00
A20 Basement Construction								**$0.00**	**$0.00**
A2010 Basement Excavation								$0.00	$0.00
A2020 Basement Walls								$0.00	$0.00
B Shell								**$6,213.08**	**$8,849.78**
B10 Super Structure								**$4,977.41**	**$1,416.46**
B1010 Floor Construction								$4,977.41	$1,416.46
Pour concrete to level basement floor	2015	1.105	03 31 13.70 4300	0.861	CY	17.10	57	$16.27	$54.25
2x4s underneath basement floor	2015	1.105	06 11 10.18 2650	402.09	LF	0.635	0.905	$282.18	$402.16
Plywood, CDX, 5/8" thick, pneumatic nailed	2015	1.105	06 16 23.10 0105	558.02	SF	0.78	0.45	$481.03	$277.52
Cork-board (1/8" thick) for basement floor	2016	1.082	09 62 29.10 2200	558.02	SF	6.95	1.13	$4,197.93	$682.54
B1020 Roof Construction								$0.00	$0.00
B20 Exterior Enclosure								**$1,235.67**	**$7,433.31**
B2010 Exterior Walls								$241.02	$171.82
site-cast concrete panel for new wall	2015	1.105	03 47 13.50 0100	23.99	SF	6.9	5.34	$182.96	$141.59

White pine, rough sawn, 1" x 8", stained	2015	1.105	07 46 23.10 5500	23.99	SF	2.19	1.14	$58.07	$30.23
B2020 Exterior Windows								$0.00	$6,929.72
Remove and reset window, up to a 4' x 5' window	2016	1.082	08 05 05.20 5080	33	EA	0	194	$0.00	$6,929.72
Premium, double insulated glass, 3-6" x 6'-0"	2016	1.082	08 53 13.30 0380	0	EA	390	48.5	$0.00	$0.00
Exterior Doors								$994.65	$331.77
Remove doors (not including kitchen door)	2015	1.105	08 05 05.10 0200	3	EA	0	18.8	$0.00	$62.33
Demolish first floor kitchen door	2015	1.105	08 05 05.10 0200	1	EA	0	18.8	$0.00	$20.78
New wood doors	2015	1.105	08 14 33.20 0200	3	EA	300	75	$994.65	$248.66
B30 Roofing								**$0.00**	**$0.00**
B3010 Roof Coverings								$0.00	$0.00
B3020 Roof Openings								$0.00	$0.00
C Interiors								**$18,633.54**	**$12,517.04**
C10 Interior Construction								**$5,520.27**	**$4,139.02**
C1010 Partitions								$1,418.94	$2,715.09
2x4s for new interior walls	2016	1.082	06 11 10.26 0180	277.19	LF	4.4	8.1	$1,320.17	$2,640.34
2" sound batts for new living room walls	2016	1.082	09 84 36.10 0970	246.61	SF	0.37	0.28	$98.77	$74.74
C1020 Interior Doors								$4,101.33	$1,423.94
Replace doors - 27" x 80"	2016	1.082	08 14 33.20 7340	13	EA	47.5	43	$668.40	$605.08
Replace exit door - 31" x 80"	2016	1.082	08 14 13.15 0540	1	EA	665	45.5	$719.82	$49.25
New doors in living room - 30" x 80"	2016	1.082	08 14 33.20 7340	2	EA	47.5	43	$102.83	$93.09
Door for new first floor bathroom - 30" x 80"	2016	1.082	08 14 33.20 7340	1	EA	47.5	43	$51.42	$46.54
Replace external locks	2016	1.082	08 71 20.42 0100	3	EA	197	48.5	$639.72	$157.49
Replace internal locks	2016	1.082	08 71 20.42 0100	9	EA	197	48.5	$1,919.15	$472.48
C1030 Fittings								$0.00	$0.00

C20 Stairs								**$0.00**	**$0.00**
C2010 Stair Construction								$0.00	$0.00
C2020 Stair Finishes								$0.00	$0.00
C30 Interior Finishes								**$13,113.27**	**$8,378.01**
C3010 Wall Finishes								$4,332.16	$4,049.69
Repaint walls on first floor	2016	1.082	09 91 23.72 0800	513.40	SF	0.14	0.47	$77.80	$261.19
Grab bar, 1-1/2" diameter, 42" long	2016	1.082	10 28 13.13 1310	2	EA	105	20.5	$227.31	$44.38
Fiberglass insulation basement walls - 1" thick	2016	1.082	07 21 13.10 0040	1,406.51	SF	0.29	0.39	$441.51	$593.76
Fiberglass insulation bathroom walls - 1" thick	2016	1.082	07 21 13.10 0040	207.10	SF	0.34	0.41	$76.22	$91.91
Gypsum finish (1/2" thick) basement walls	2016	1.082	09 29 10.30 0700	1,406.51	SF	0.43	0.39	$654.65	$593.76
Paint basement walls	2016	1.082	09 91 23.72 0800	1,406.51	SF	0.14	0.47	$213.14	$715.55
1/2" thick gypsum board for new walls	2016	1.082	09 29 10.30 0700	493.23	SF	0.43	0.39	$229.57	$208.22
Cover cut-out areas with new gypsum board	2016	1.082	09 29 10.30 0700	4.301	SF	0.43	0.39	$2.00	$1.82
Paint new living room walls	2016	1.082	09 91 23.72 0800	493.23	SF	0.14	0.47	$74.74	$250.93
4-1/4" x 4-1/4" tile for bathroom wall	2015	1.105	09 30 13.10 5400	267	SF	2.26	3.22	$666.88	$950.15
Repair hole in wall with 2 coats gypsum plaster	2018	1.040	09 23 20.10 0900	0.01	SY	3.76	17.92	$0.05	$0.22
(Addition for irregular surfaces)	2018	1.040	09 23 20.10 1600		%		30%	$0.00	$0.00
Tile finish for new basement bathroom walls	2016	1.082	09 60 58.10 9010	355.50	SF	4	0.81	$1,539.22	$311.69
Tile finish for existing bathroom wall edges	2016	1.082	09 60 58.10 9010	29.81	SF	4	0.81	$129.07	$26.14
C3020 Floor Finishes								$5,518.56	$1,186.64
Butyl rubber filler for third floor bathroom floor	2016	1.082	07 91 26.10 4360	11.48	LF	0.14	1.19	$1.74	$14.79
Butyl rubber filler for second floor bathroom floor	2016	1.082	07 91 26.10 4360	43.45	LF	0.14	1.19	$6.58	$55.97

Replace one (1) tile on third floor bathroom floor	2018	1.040	09 31 13.10 3310	0.03	SF	6.25	3.54	$0.18	$0.10
Tile finish for new basement bathroom floor	2016	1.082	09 60 58.10 9010	1,203.40	SF	4	0.81	$5,210.39	$1,055.10
Tile finish for new first floor bathroom floor	2016	1.082	09 60 58.10 9010	69.21	SF	4	0.81	$299.66	$60.68
C3030 Ceiling Finishes								$3,262.56	$3,141.68
Demolish 2' x 4' ceiling tiles	2019	1.020	09 05 05.10 1120	576.23	SF	0	1.31	$0.00	$769.96
2' x 2' ceiling tile frame - first floor	2019	1.020	C3030 210 5900	576.23	SF	2.82	2.05	$1,657.47	$1,204.90
2' x 2' ceiling tile frame - basement	2019	1.020	C3030 210 5900	558.02	SF	2.82	2.05	$1,605.09	$1,166.82
D Services								**$23,320.94**	**$10,548.41**
D10 Conveying								**$0.00**	**$0.00**
D1010 Elevators & Lifts								$0.00	$0.00
D1020 Escalators & Moving Walks								$0.00	$0.00
D1090 Other Conveying Systems								$0.00	$0.00
D20 Plumbing								**$6,790.81**	**$3,179.29**
D2010 Plumbing Fixtures								$1,461.82	$500.31
Remove toilet from first floor BR	2015	1.105	22 05 05.10 1400	1.000	ea	0	58.5	$0.00	$64.65
Remove sink from first floor BR	2015	1.105	22 05 05.10 1300	1.000	ea	0	58.5	$0.00	$64.65
Additional sink in first floor bathroom	2016	1.082	22 41 16.30 3000	1	EA	605	152	$654.87	$164.53
Additional toilet in first floor bathroom - open front, elongated bowl	2016	1.082	22 41 13.44 1280	1	EA	50.5	19.75	$54.66	$21.38
Shower: handicap, 48" x 34-1/2" x 72" corner seat	2016	1.082	22 41 23.20 3210	1	EA	695	171	$752.29	$185.10
D2020 Domestic Water Distribution								$3,496.25	$768.53
Washer, Residential, 4 cycle, average	2016	1.082	11 30 13.24 5000	2	EA	890	158	$1,926.73	$342.05

Dryer, Gas fired residential, 16 lb. capacity, average	2016	1.082	11 30 13.25 0500	2	EA	685	158	$1,482.93	$342.05
Dryer, Vent kit for dryer	2016	1.082	11 30 13.25 7450	2	EA	40	39	$86.59	$84.43
D2030 Sanitary Waste								$0.00	$0.00
D2040 Rain Water Drainage								$0.00	$0.00
D2090 Other Plumbing Systems								$1,832.74	$1,910.46
Std-spray wet pipe sprinkler heads, 1/2" NPT, 1/2" orifice	2019	1.020	21 13 13.50 3740	43	EA	10.6	31	$464.92	$1,359.66
Fire Alarm signal bell 10" red 20-24V P for each door	2019	1.020	28 46 21.50 4610	9	EA	149	60	$1,367.82	$550.80
D30 HVAC								**$0.00**	**$0.00**
D3010 Energy Supply								$0.00	$0.00
D3020 Heat Generating Systems								$0.00	$0.00
Heating and Ventilating Split System Mixed air control 10 to 20 tons	2011	1.158	23 09 43.10 0240	1	EA	$3,925.00	1875	$4,545.15	$2,171.25
D3030 Cooling Generating Systems								$0.00	$0.00
D3040 Distribution Systems								$0.00	$0.00
D3050 Terminal & Package Units								$0.00	$0.00
D3060 Controls & Instrumentation								$0.00	$0.00
D3070 Systems Testing & Balancing								$0.00	$0.00
D3090 Other HVAC Systems & Equipment								$0.00	$0.00
D40 Fire Protection								**$14,374.27**	**$7,075.04**
D4010 Sprinklers								$2,103.55	$3,023.86
Sprinkler heads 1/2" NPT, 3/8" artifice	2016	1.082	21 13 13.50 3720	66	EA	12.15	26.5	$801.90	$1,749.00
Upgrade sprinkler system	2016	1.082	32 84 23.10 0800	6073	S.F.	0.32	0.46	$2,103.55	$3,023.86
D4020 Standpipes								$443.53	$2,267.33

PEX Tubing Fittings Coupling 1/2" x 1/2"	2016	1.082	23 83 16.10 7120	2	EA	6.7	18	$14.50	$38.95
PEX Tubing Fittings Adapter 1/2" x 1/2"	2016	1.082	23 83 16.10 7132	2	EA	4.36	18	$9.44	$38.95
PEX Tubing Fittings Elbow 1/2" x 1/2"	2016	1.082	23 83 16.10 7142	3	EA	6.65	18	$21.59	$58.43
PEX Pipe, Plastic 1/2" diameter x 100'	2016	1.082	22 11 13.74 7360	85	LF	0.61	21.5	$56.10	$1,977.36
CPVC Pipe 4" diameter	2016	1.082	22 11 13.74 5540	8	LF	39.5	17.75	$341.91	$153.64
D4030 Fire Protection Specialties								$11,827.18	$1,783.85
Fire Alarm Signal Bell	2016	1.082	28 31 23.50 4600	9	EA	96.5	55	$940.09	$535.80
Fire Alarm Control Panel (4 Zone)	2016	1.082	28 31 23.50 3600	1	EA	405	440	$438.38	$476.27
Fire Alarm Device	2016	1.082	28 31 23.50 4020	1	EA	238	55	$257.62	$59.53
Fire Actuating Device	2016	1.082	28 31 23.50 4050	9	EA	335	55	$3,263.53	$535.80
Fire Alarm Master Box	2016	1.082	28 31 23.50 6800	1	EA	6400	163	$6,927.56	$176.44
D4090 Other Fire Protection Systems								$0.00	$0.00
D50 Electrical								**$2,155.86**	**$294.08**
D5010 Electrical Service & Distribution								$120.82	$208.89
Addl. wiring for new bedroom, No 8 (1/8" diam.), stranded	2016	1.082	26 05 19.90 0140	25.81	LF	0.325	0.55	$9.08	$15.36
Conduit for new bedroom, 1" diam.	2011	1.158	26 05 33.13 5040	25.81	LF	1.7	3.5	$50.80	$104.60
Conduit elbows, 1" diam.	2011	1.158	26 05 33.13 5700	6.00	EA	8.05	10.05	$55.93	$69.83
Additional power outlets for new bedrooms	2016	1.082	26 05 33.17 0200	1	EA	4.63	17.65	$5.01	$19.10
D5020 Lighting and Branch Wiring								$26,089.42	$7,632.73
Remove existing fluorescent lights	2016	1.082	26 05 05.50 4200	51	EA	0	54.5	$0.00	$3,008.62
Remove existing 2'x4' light tiles	2015	1.105	26 05 05.10 2260	11	EA	$0.00	$26.50	$0.00	$322.15

Remove existing strip lights	2016	1.082	26 05 05.50 5000	2	EA	$0.00	$18.35	$0.00	$39.73
Additional light panels	2015	1.105	26 51 13.55 1200	12	EA	$251.00	$77.00	$3,328.75	$1,021.17
LED Lamp - 10 W, PAR20, equal to 60 Watt	2015	1.105	26 51 13.55 0100	55	EA	$47.50	$3.37	$2,887.24	$204.84
Install LED lights - Downlight, recess mounted, 10" diam, 36 W	2016	1.082	26 51 13.55 0120	51	EA	360	55	$19,873.44	$3,036.22
Install LED lights - cylinder, 10 W	2016	1.082	26 51 13.55 0160	0	EA	102	55	$0.00	$0.00
Install LED lights - cylinder, 20 W	2016	1.082	26 51 13.55 0180	0	EA	166	55	$0.00	$0.00
D5030 Communications & Security								$34,935.06	$46.73
Card key system for 1 door	2016	1.082	08 74 13.50 0020	14	EA	$1,275		$19,321.40	$0.00
Additional Ethernet port for first floor bedroom	2016	1.082	26 05 33.17 0200	1	EA	4.63	17.65	$5.01	$19.10
Processor for card key access system	2016	1.082	08 74 13.50 0100	14	EA	$900		$13,638.63	$0.00
Proximity Card Reader	2016	1.082	08 74 13.50 0100	14	EA	130		$1,970.02	$0.00
Remove electrical exit sign	2015	1.105	26 05 05.10 2100	1	ea	0	25	$0.00	$27.63
D5090 Other Electrical Systems								$0.00	$0.00
E Equipment & Furnishings								**$7,372.44**	**$299.51**
E10 Equipment								**$0.00**	**$0.00**
E1010 Commercial Equipment								$0.00	$0.00
E1020 Institutional Equipment								$0.00	$0.00
E1030 Vehicular Equipment								$0.00	$0.00
E1040 Other Equipment								$0.00	$0.00
E20 Furnishings								**$7,372.44**	**$299.51**
E2010 Fixed Furnishings								$400.50	$43.30
Cabinet for E-box	2016	1.082	13 32 23.10 5320	1	EA	370	40	$400.50	$43.30
E2020 Movable Furnishings								$6,971.94	$256.21
Desks for addl. bedrooms	2016	1.082	12 56 43.10 1750	3	EA	530		$1,721.07	$0.00

Desk tops for addl. bedrooms, laminated plastic, 24" deep, max.	2016	1.082	12 56 43.10 1200	3	EA	134	19.4	$435.14	$63.00
Wooden chairs for addl. bedrooms	2016	1.082	12 52 23.13 2600	3	EA	110		$357.20	$0.00
Wardrobes for addl. bedrooms	2016	1.082	12 56 43.10 7000	3	EA	545		$1,769.77	$0.00
Mirrors for addl. bedrooms	2016	1.082	12 56 43.10 7000	3	EA	120		$389.68	$0.00
Chest, built-in, maximum	2016	1.082	12 56 43.10 1020	3	EA	123	59.5	$399.42	$193.21
Bunkable bed, built-in, maximum	2016	1.082	12 56 43.10 0320	3	EA	585		$1,899.67	$0.00
F Special Construction & Demolition								**$10,033.91**	**$12,399.58**
F10 Special Construction								**$0.00**	**$0.00**
F1010 Special Structures								$0.00	$0.00
F1020 Integrated Construction								$0.00	$0.00
F1030 Special Construction Systems								$0.00	$0.00
F1040 Special Facilities								$0.00	$0.00
F1050 Special Controls and Instrumentation								$0.00	$0.00
F20 Selective Building Demolition								**$10,033.91**	**$12,399.58**
F2010 Building Elements Demolition								$1,651.11	$423.90
Demolish gypsum board along path of conduit	2011	1.158	09 05 05.30 3400	4.301	SF	0	0.67	$0.00	$3.34
Remove metal from overhang	2015	1.105	05 05 05.10 0500	16.434	SF	0	0.3	$0.00	$5.45
Remove asphalt roof from overhang	2015	1.105	07 05 05.10 3170	16.434	SF	0	0.43	$0.00	$7.81
Selective Demolition, wood frame, not including re-framing	2015	1.105	02 41 19.16 7410	1.000	EA	0	43	$0.00	$47.52
Disposal, wood frame, incl. loading and 5-mile haul to dump	2015	1.105	02 41 19.18 0500	0.719	CY	0	18.35	$0.00	$14.57
Dumpster, weekly rental, 1 dump/week, 6 CY capacity	2015	1.105	02 41 19.19 2000	3.600	Week	415		$1,651.11	$0.00

Remove brick overhang foundations	2016	1.082	09 05 05.30 0100	1.150	CF	0	7.99	$0.00	$9.95
Remove 2' x 4' ceiling grid	2019	1.020	09 05 05.10 1250	576.230	SF	0	0.55	$0.00	$323.27
Remove visible conduits for kitchen exit sign	2015	1.105	26 05 05.10 0100	6.000	LF	0	1.81	$0.00	$12.00
F2020 Hazardous Components Abatement								$8,382.80	$11,975.68
OSHA Testing - Certified technician - Maximum	2016	1.082	02 82 13.45 0110	1	Day	0	300	$0.00	$324.73
OSHA Testing - Industrial hygenist - Maximum	2016	1.082	02 82 13.45 0130	1	Day	0	400	$0.00	$432.97
Asbestos sampling and PCM analysis, NIOSH 7400, max.	2016	1.082	02 82 13.45 0210	3	Ea	22	107	$71.44	$347.46
Cleaned area samples - PCM air sample analysis, NIOSH 7400, maximum	2016	1.082	02 82 13.45 1000	3	Ea	2.2	107	$7.14	$347.46
Spray exposed substrate with surfactant (bridging)	2016	1.082	02 82 13.46 0300	12	LF	0.6	1.71	$7.79	$22.21
Spray encapsulate polyethylene sheeting	2016	1.082	02 82 13.46 1000	16.78	SF	0.4	0.43	$7.27	$7.81
Roll down polyethylene sheeting	2016	1.082	02 82 13.46 1100	16.78	SF	0	0.43	$0.00	$7.81
Bag polyethylene sheeting	2016	1.082	02 82 13.46 1500	3	EA	1	8.55	$3.25	$27.76
Fine clean exposed substrate, with nylon brush	2016	1.082	02 82 13.46 2000	16.78	SF	0	1.43	$0.00	$25.97
Wet wipe substrate	2016	1.082	02 82 13.46 2500	16.78	SF	0	0.71	$0.00	$12.90
Vacuum surfaces, fine brush	2016	1.082	02 82 13.46 2600	16.78	SF	0	0.53	$0.00	$9.63
Remove portable decontamination facility	2016	1.082	02 82 13.46 4100	3	EA	13.35	107	$43.35	$347.46
HEPA vacuum, shampoo carpeting	2016	1.082	02 82 13.46 5000	0	SF	0.1	0.71	$0.00	$0.00
Final cleaning of protected surfaces	2016	1.082	02 82 13.46 9000	1532.62	SF	0	0.16	$0.00	$265.43
Collect and bag bulk material, 3 CF. bags, by hand	2016	1.082	02 82 13.47 0100	1	EA	0.84	8.55	$0.91	$9.25
Double bag and decontaminate	2016	1.082	02 82 13.47 1000	1	EA	0.84	3.56	$0.91	$3.85

Containerize bagged material in drums, per 3 CF. drum	2016	1.082	02 82 13.47 2000	1	EA	18.55	4.28	$20.08	$4.63
Cart bags 50' to dumpster	2016	1.082	02 82 13.47 5000	1	EA	0	2.14	$0.00	$2.32
Disposal charges, not including haul, maximum	2016	1.082	02 82 13.47 5020	0.029	CY	0	355	$0.00	$11.14
Type B (supplied air) respirator equipment	2016	1.082	02 82 13.47 9000	1	LS			$0.00	$0.00
Asbestos encapsulation with sealants - pipes to 12" diameter	2016	1.082	02 82 13.48 0310	12	LF	1.2	8.55	$15.59	$111.06
G Building Sitework								**$8,205.07**	**$9,653.82**
G10 Site Preparation								**$0.00**	**$0.00**
G1010 Site Clearing								$0.00	$0.00
G1020 Demolition and Relocations								$0.00	$0.00
G1030 Site Earthwork								$0.00	$0.00
G1040 Hazardous Waste Remediation								$0.00	$0.00
G20 Site Improvements								**$8,205.07**	**$9,653.82**
G2010 Roadways								$0.00	$0.00
G2020 Parkings Lots								$0.00	$0.00
G2030 pedestrian Paving								$8,205.07	$9,653.82
Excavate Segment 1 + Stairs (Excavation Zone A)	2016	1.082	31 23 16.13 0050	32.232	CY		7.19	$0.00	$250.85
Excavate Landing + Segment 2 (Excavation Zone B)	2016	1.082	31 23 16.13 0050	6.940	CY		7.19	$0.00	$54.01
Backfill Zone A by hand, no compaction, heavy soil	2016	1.082	31 23 23.13 0100	6.741	CY		27.5	$0.00	$200.65
Backfill Zone B by hand, no compaction, heavy soil	2016	1.082	31 23 23.13 0100	0.630	CY		27.5	$0.00	$18.74
Slab, 4" thick, non industrial, non reinforced - Basement Ramp	2016	1.082	03 30 53.40 4650	2.633	CY	129	69.02	$367.70	$196.73
Slab, 4" thick, non industrial, non reinforced - 1st Floor Walkway	2016	1.082	03 30 53.40 4650	0.764	CY	129	69.02	$106.64	$57.06

4' concrete wall, pumped, 8" thick for Excavation Zone A	2016	1.082	A2020 110 1720	92.380	LF	20.5	57	$2,049.90	$5,699.71
4' concrete wall, pumped, 8" thick for Excavation Zone B	2016	1.082	A2020 110 1720	30.880	LF	20.5	57	$685.22	$1,905.25
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	2016	1.082	05 52 13.50 0020	90.000	LF	50.5	11.67	$4,919.65	$1,136.88
Rubberized asphalt expansion joint, 1/2" x 1" - First Floor	2016	1.082	03 15 16.30 0900	48.500	LF	0.38	0.67	$19.95	$35.17
Rubberized asphalt expansion joint, 1/2" x 1" - Basement	2016	1.082	03 15 16.30 0900	136.170	LF	0.38	0.67	$56.01	$98.75
G2040 Site Development								$13,655.66	$3,137.95
Planks for all ramp segments - 1 x 6	2015	1.105	06 11 10.38 0110	173.25	LF	$0.39		$73.72	$0.00
Sawcut porch for first floor accessibility ramp	2019	1.020	02 41 19.25 5020	34.625	LF	$0.00	1.65	$0.00	$58.27
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	2016	1.082	05 52 13.50 0020	80.9	LF	$50.50	11.67	$4,422.22	$1,021.93
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	2016	1.082	05 52 13.50 0020	162.9	LF	$50.50	11.67	$8,904.57	$2,057.75
Segment 1 mid-beam - 4 x 6	2015	1.105	06 11 10.38 0210	24.55	LF	$0.93		$25.10	$0.00
Segment 1 end beams - 3 x 6	2015	1.105	06 11 10.38 0210	49.1	LF	$0.93		$50.19	$0.00
Segment 1 columns - 2 x 4	2015	1.105	06 11 10.38 0100	9.75	LF	$0.76		$8.14	$0.00
Segment 1 girders - 2 x 4	2015	1.105	06 11 10.38 0100	7.17	LF	$0.76		$5.98	$0.00
Segment 2 mid-beam - 4 x 6	2015	1.105	06 11 10.38 0210	14.34	LF	$0.93		$14.66	$0.00
Segment 2 end beams - 3 x 6	2015	1.105	06 11 10.38 0210	28.69	LF	$0.93		$29.33	$0.00
Segment 2 columns - 2 x 4	2015	1.105	06 11 10.38 0100	17.75	LF	$0.76		$14.81	$0.00
Segment 2 columns - 2 x 6	2015	1.105	06 11 10.38 0110	2.22	LF	$0.77		$1.89	$0.00
Segment 2 girders - 2 x 4	2015	1.105	06 11 10.38 0100	9.625	LF	$0.76		$8.03	$0.00
Midway landing planks - 2 x 4	2015	1.105	06 11 10.38 0100	80.08	LF	$0.76		$66.82	$0.00
Midway landing beams - 2 x 4	2015	1.105	06 11 10.38 0100	23.21	LF	$0.76		$19.37	$0.00
Midway landing columns - 2 x 4	2015	1.105	06 11 10.38 0100	13	LF	$0.76		$10.85	$0.00
G2050 Landscaping								$0.00	$0.00

G30 Site Mechanical Utilities			$0.00	$0.00
G3010 Water Supply			$0.00	$0.00
G3020 Sanitary Sewer			$0.00	$0.00
G3030 Storm Sewer			$0.00	$0.00
G3040 Heating Distribution			$0.00	$0.00
G3050 Cooling Distribution			$0.00	$0.00
G3060 Fuel Distribution			$0.00	$0.00
G3070 Other Site Mechanical Utilities			$0.00	$0.00
G40 Site Electrical Utilities			$0.00	$0.00
G4010 Electrical Distributions			$0.00	$0.00
G4020 Site Lighting			$0.00	$0.00
G4030 Site Communications and Security			$0.00	$0.00
G4050 Other Site Electrical Utilities			$0.00	$0.00
G50 Other Site Construciton			$0.00	$0.00
G5010 Service and Pedestrian Tunnels			$0.00	$0.00
G5020 Other Site Systems and Equipment			$0.00	$0.00

Table 65. Renovation cost adjustments

	Materials	Labor	Equipment	Total
Unadjusted Costs	$137,877.11	$53,397.53	$1,795.36	
Worcester, MA Adjustment Factor	99	124.5	124.5	
Adjusted Costs	**$136,498.34**	**$66,479.92**	**$2,235.22**	**$205,213.48**

Table 66. Renovation life span cost data

Individual Activities	Units	UOM	Unit Cost Material	Unit Cost Installation	Total Cost Material	Total Cost Installation	Life Span (Years)	Cost / Year
A Substructure					**$0.00**	**$0.00**		
A10 Foundation					**$0.00**	**$0.00**		
A1010 Standard Foundations					$0.00	$0.00		
A1020 Special Foundations					$0.00	$0.00		
A1030 Slab on Grade					$0.00	$0.00		
A20 Basement Construction					**$0.00**	**$0.00**		
A2010 Basement Excavation					$0.00	$0.00		
A2020 Basement Walls					$0.00	$0.00		
B Shell					**$6,213.08**	**$8,849.78**		
B10 Super Structure					**$4,977.41**	**$1,416.46**		
B1010 Floor Construction					$4,977.41	$1,416.46		
Pour concrete to level basement floor	0.861	CY	$17.10	$57.00	$16.27	$54.25	5	$16.73
2x4s underneath basement floor	402.09	LF	$0.64	$0.91	$282.18	$402.16	5	$156.01
Plywood, CDX, 5/8" thick, pneumatic nailed	558.02	SF	$0.78	$0.45	$481.03	$277.52	5	$164.35
Cork-board (1/8" thick) for basement floor	558.02	SF	$6.95	$1.13	$4,197.93	$682.54	5	$1,001.14
B1020 Roof Construction					$0.00	$0.00		
B20 Exterior Enclosure					**$1,235.67**	**$7,433.31**		
B2010 Exterior Walls					$241.02	$171.82		
site-cast concrete panel for new wall	23.99	SF	$6.90	$5.34	$182.96	$141.59	5	$71.48
White pine, rough sawn, 1" x 8", stained	23.99	SF	$2.19	$1.14	$58.07	$30.23	5	$19.02
B2020 Exterior Windows					$0.00	$6,929.72		
Remove and reset window, up to a 4' x 5' window	33	EA	$0.00	$194.00	$0.00	$6,929.72	5	$1,725.50

Premium, double insulated glass, 3-6" x 6'-0"	0	EA	$390.00	$48.50	$0.00	$0.00	5	$0.00
Exterior Doors					$994.65	$331.77		
Remove doors (not including kitchen door)	3	EA	$0.00	$18.80	$0.00	$62.33	5	$15.52
Demolish first floor kitchen door	1	EA	$0.00	$18.80	$0.00	$20.78	5	$5.17
New wood doors	3	EA	$300.00	$75.00	$994.65	$248.66	5	$258.86
B30 Roofing					**$0.00**	**$0.00**		
B3010 Roof Coverings					$0.00	$0.00		
B3020 Roof Openings					$0.00	$0.00		
C Interiors					**$18,633.54**	**$12,517.04**		
C10 Interior Construction					**$5,520.27**	**$4,139.02**		
C1010 Partitions					$1,418.94	$2,715.09		
2x4s for new interior walls	277.19	LF	$4.40	$8.10	$1,320.17	$2,640.34	5	$918.84
2" sound batts for new living room walls	246.61	SF	$0.37	$0.28	$98.77	$74.74	5	$38.17
C1020 Interior Doors					$4,101.33	$1,423.94		
Replace doors - 27" x 80"	13	EA	$47.50	$43.00	$668.40	$605.08	5	$283.01
Replace exit door - 31" x 80"	1	EA	$665.00	$45.50	$719.82	$49.25	5	$154.79
New doors in living room - 30" x 80"	2	EA	$47.50	$43.00	$102.83	$93.09	5	$43.54
Door for new first floor bathroom - 30" x 80"	1	EA	$47.50	$43.00	$51.42	$46.54	5	$21.77
Replace external locks	3	EA	$197.00	$48.50	$639.72	$157.49	5	$165.88
Replace internal locks	9	EA	$197.00	$48.50	$1,919.15	$472.48	5	$497.64
C1030 Fittings					$0.00	$0.00		
C20 Stairs					**$0.00**	**$0.00**		
C2010 Stair Construction					$0.00	$0.00		
C2020 Stair Finishes					$0.00	$0.00		
C30 Interior Finishes					**$13,113.27**	**$8,378.01**		
C3010 Wall Finishes					$4,332.16	$4,049.69		

Repaint walls on first floor	513.40	SF	$0.14	$0.47	$77.80	$261.19	5	$80.44
Grab bar, 1-1/2" diameter, 42" long	2	EA	$105.00	$20.50	$227.31	$44.38	5	$56.06
Fiberglass insulation basement walls - 1" thick	1,406.51	SF	$0.29	$0.39	$441.51	$593.76	5	$235.26
Fiberglass insulation bathroom walls - 1" thick	207.10	SF	$0.34	$0.41	$76.22	$91.91	5	$37.98
Gypsum finish (1/2" thick) basement walls	1,406.51	SF	$0.43	$0.39	$654.65	$593.76	5	$277.47
Paint basement walls	1,406.51	SF	$0.14	$0.47	$213.14	$715.55	5	$220.37
1/2" thick gypsum board for new walls	493.23	SF	$0.43	$0.39	$229.57	$208.22	5	$97.30
Cover cut-out areas with new gypsum board	4.301	SF	$0.43	$0.39	$2.00	$1.82	5	$0.85
Paint new living room walls	493.23	SF	$0.14	$0.47	$74.74	$250.93	5	$77.28
4-1/4" x 4-1/4" tile for bathroom wall	267	SF	$2.26	$3.22	$666.88	$950.15	5	$368.63
Repair hole in wall with 2 coats gypsum plaster	0.01	SY	$3.76	$17.92	$0.05	$0.22	5	$0.06
(Addition for irregular surfaces)		%		$0.30	$0.00	$0.00	5	$0.00
Tile finish for new basement bathroom walls	355.50	SF	$4.00	$0.81	$1,539.22	$311.69	5	$382.38
Tile finish for existing bathroom wall edges	29.81	SF	$4.00	$0.81	$129.07	$26.14	5	$32.06
C3020 Floor Finishes					$5,518.56	$1,186.64		
Butyl rubber filler for third floor bathroom floor	11.48	LF	$0.14	$1.19	$1.74	$14.79	5	$4.03
Butyl rubber filler for second floor bathroom floor	43.45	LF	$0.14	$1.19	$6.58	$55.97	5	$15.24
Replace one (1) tile on third floor bathroom floor	0.03	SF	$6.25	$3.54	$0.18	$0.10	5	$0.06
Tile finish for new basement bathroom floor	1,203.40	SF	$4.00	$0.81	$5,210.39	$1,055.10	5	$1,294.38
Tile finish for new first floor bathroom floor	69.21	SF	$4.00	$0.81	$299.66	$60.68	5	$74.44
C3030 Ceiling Finishes					$3,262.56	$3,141.68		
Demolish 2' x 4' ceiling tiles	576.23	SF	$0.00	$1.31	$0.00	$769.96	5	$191.72
2' x 2' ceiling tile frame - first floor	576.23	SF	$2.82	$2.05	$1,657.47	$1,204.90	5	$628.20

2' x 2' ceiling tile frame - basement	558.02	SF	$2.82	$2.05	$1,605.09	$1,166.82	5	$608.35
D Services					**$23,320.94**	**$10,548.41**		
D10 Conveying					**$0.00**	**$0.00**		
D1010 Elevators & Lifts					$0.00	$0.00		
D1020 Escalators & Moving Walks					$0.00	$0.00		
D1090 Other Conveying Systems					$0.00	$0.00		
D20 Plumbing					**$6,790.81**	**$3,179.29**		
D2010 Plumbing Fixtures					$1,461.82	$500.31		
Remove toilet from first floor BR	1.000	ea	$0.00	$58.50	$0.00	$64.65	5	$16.10
Remove sink from first floor BR	1.000	ea	$0.00	$58.50	$0.00	$64.65	5	$16.10
Additional sink in first floor bathroom	1	EA	$605.00	$152.00	$654.87	$164.53	5	$170.63
Additional toilet in first floor bathroom - open front, elongated bowl	1	EA	$50.50	$19.75	$54.66	$21.38	5	$16.15
Shower: handicap, 48" x 34-1/2" x 72" corner seat	1	EA	$695.00	$171.00	$752.29	$185.10	5	$195.04
D2020 Domestic Water Distribution					$3,496.25	$768.53		
Washer, Residential, 4 cycle, average	2	EA	$890.00	$158.00	$1,926.73	$342.05	5	$466.66
Dryer, Gas fired residential, 16 lb. capacity, average	2	EA	$685.00	$158.00	$1,482.93	$342.05	5	$378.79
Dryer, Vent kit for dryer	2	EA	$40.00	$39.00	$86.59	$84.43	5	$38.17
D2030 Sanitary Waste					$0.00	$0.00		
D2040 Rain Water Drainage					$0.00	$0.00		
D2090 Other Plumbing Systems					$1,832.74	$1,910.46		
Std-spray wet pipe sprinkler heads, 1/2" NPT, 1/2" orifice	43	EA	$10.60	$31.00	$464.92	$1,359.66	5	$430.61
Fire Alarm signal bell 10" red 20-24V P for each door	9	EA	$149.00	$60.00	$1,367.82	$550.80	5	$407.98
D30 HVAC					**$0.00**	**$0.00**		
D3010 Energy Supply					$0.00	$0.00		
D3020 Heat Generating Systems					$0.00	$0.00		

Heating and Ventilating Split System Mixed air control 10 to 20 tons	1	EA	$3,925.00	$1,875.00	$4,545.15	$2,171.25	5	$1,440.58
D3030 Cooling Generating Systems					$0.00	$0.00		
D3040 Distribution Systems					$0.00	$0.00		
D3050 Terminal & Package Units					$0.00	$0.00		
D3060 Controls & Instrumentation					$0.00	$0.00		
D3070 Systems Testing & Balancing					$0.00	$0.00		
D3090 Other HVAC Systems & Equipment					$0.00	$0.00		
D40 Fire Protection					**$14,374.27**	**$7,075.04**		
D4010 Sprinklers					$2,103.55	$3,023.86		
Sprinkler heads 1/2" NPT, 3/8" artifice	66	EA	$12.15	$26.50	$801.90	$1,749.00	5	$594.28
Upgrade sprinkler system	6073	S.F.	$0.32	$0.46	$2,103.55	$3,023.86	5	$1,169.44
D4020 Standpipes					$443.53	$2,267.33		
PEX Tubing Fittings Coupling 1/2" x 1/2"	2	EA	$6.70	$18.00	$14.50	$38.95	5	$12.57
PEX Tubing Fittings Adapter 1/2" x 1/2"	2	EA	$4.36	$18.00	$9.44	$38.95	5	$11.57
PEX Tubing Fittings Elbow 1/2" x 1/2"	3	EA	$6.65	$18.00	$21.59	$58.43	5	$18.82
PEX Pipe, Plastic 1/2" diameter x 100'	85	LF	$0.61	$21.50	$56.10	$1,977.36	5	$503.47
CPVC Pipe 4" diameter	8	LF	$39.50	$17.75	$341.91	$153.64	5	$105.96
D4030 Fire Protection Specialties					$11,827.18	$1,783.85		
Fire Alarm Signal Bell	9	EA	$96.50	$55.00	$940.09	$535.80	5	$319.55
Fire Alarm Control Panel (4 Zone)	1	EA	$405.00	$440.00	$438.38	$476.27	5	$205.39
Fire Alarm Device	1	EA	$238.00	$55.00	$257.62	$59.53	5	$65.83
Fire Actuating Device	9	EA	$335.00	$55.00	$3,263.53	$535.80	5	$779.59
Fire Alarm Master Box	1	EA	$6,400.00	$163.00	$6,927.56	$176.44	5	$1,415.59
D4090 Other Fire Protection Systems					$0.00	$0.00		
D50 Electrical					**$2,155.86**	**$294.08**		
D5010 Electrical Service & Distribution					$120.82	$208.89		

Addl. wiring for new bedroom, No 8 (1/8" diam.), stranded	25.81	LF	$0.33	$0.55	$9.08	$15.36	5	$5.62
Conduit for new bedroom, 1" diam.	25.81	LF	$1.70	$3.50	$50.80	$104.60	5	$36.10
Conduit elbows, 1" diam.	6.00	EA	$8.05	$10.05	$55.93	$69.83	5	$28.46
Additional power outlets for new bedrooms	1	EA	$4.63	$17.65	$5.01	$19.10	5	$5.75
D5020 Lighting and Branch Wiring					$26,089.42	$7,632.73		
Remove existing fluorescent lights	51	EA	$0.00	$54.50	$0.00	$3,008.62	5	$749.15
Remove existing 2'x4' light tiles	11	EA	$0.00	$26.50	$0.00	$322.15	5	$80.22
Remove existing strip lights	2	EA	$0.00	$18.35	$0.00	$39.73	5	$9.89
Additional light panels	12	EA	$251.00	$77.00	$3,328.75	$1,021.17	5	$913.36
LED Lamp - 10 W, PAR20, equal to 60 Watt	55	EA	$47.50	$3.37	$2,887.24	$204.84	5	$622.68
Install LED lights - Downlight, recess mounted, 10" diam, 36 W	51	EA	$360.00	$55.00	$19,873.44	$3,036.22	5	$4,690.96
Install LED lights - cylinder, 10 W	0	EA	$102.00	$55.00	$0.00	$0.00	5	$0.00
Install LED lights - cylinder, 20 W	0	EA	$166.00	$55.00	$0.00	$0.00	5	$0.00
D5030 Communications & Security					$34,935.06	$46.73		
Card key system for 1 door	14	EA	$1,275.00		$19,321.40	$0.00	5	$3,825.64
Additional Ethernet port for first floor bedroom	1	EA	$4.63	$17.65	$5.01	$19.10	5	$5.75
Processor for card key access system	14	EA	$900.00		$13,638.63	$0.00	5	$2,700.45
Proximity Card Reader	14	EA	$130.00		$1,970.02	$0.00	5	$390.06
Remove electrical exit sign	1	ea	$0.00	$25.00	$0.00	$27.63	5	$6.88
D5090 Other Electrical Systems					$0.00	$0.00		
E Equipment & Furnishings					**$7,372.44**	**$299.51**		
E10 Equipment					**$0.00**	**$0.00**		
E1010 Commercial Equipment					$0.00	$0.00		
E1020 Institutional Equipment					$0.00	$0.00		
E1030 Vehicular Equipment					$0.00	$0.00		

E1040 Other Equipment					$0.00	$0.00		
E20 Furnishings					**$7,372.44**	**$299.51**		
E2010 Fixed Furnishings					$400.50	$43.30		
Cabinet for E-box	1	EA	$370.00	$40.00	$400.50	$43.30	5	$90.08
E2020 Movable Furnishings					$6,971.94	$256.21		
Desks for addl. bedrooms	3	EA	$530.00		$1,721.07	$0.00	5	$340.77
Desk tops for addl. bedrooms, laminated plastic, 24" deep, max.	3	EA	$134.00	$19.40	$435.14	$63.00	5	$101.84
Wooden chairs for addl. bedrooms	3	EA	$110.00		$357.20	$0.00	5	$70.73
Wardrobes for addl. bedrooms	3	EA	$545.00		$1,769.77	$0.00	5	$350.42
Mirrors for addl. bedrooms	3	EA	$120.00		$389.68	$0.00	5	$77.16
Chest, built-in, maximum	3	EA	$123.00	$59.50	$399.42	$193.21	5	$127.19
Bunkable bed, built-in, maximum	3	EA	$585.00		$1,899.67	$0.00	5	$376.13
F Special Construction & Demolition					**$10,033.91**	**$12,399.58**		
F10 Special Construction					**$0.00**	**$0.00**		
F1010 Special Structures					$0.00	$0.00		
F1020 Integrated Construction					$0.00	$0.00		
F1030 Special Construction Systems					$0.00	$0.00		
F1040 Special Facilities					$0.00	$0.00		
F1050 Special Controls and Instrumentation					$0.00	$0.00		
F20 Selective Building Demolition					**$10,033.91**	**$12,399.58**		
F2010 Building Elements Demolition					$1,651.11	$423.90		
Demolish gypsum board along path of conduit	4.301	SF	$0.00	$0.67	$0.00	$3.34	5	$0.83
Remove metal from overhang	16.434	SF	$0.00	$0.30	$0.00	$5.45	5	$1.36
Remove asphalt roof from overhang	16.434	SF	$0.00	$0.43	$0.00	$7.81	5	$1.94
Selective Demolition, wood frame, not including re-framing	1.000	EA	$0.00	$43.00	$0.00	$47.52	5	$11.83

Disposal, wood frame, incl. loading and 5-mile haul to dump	0.719	CY	$0.00	$18.35	$0.00	$14.57	5	$3.63
Dumpster, weekly rental, 1 dump/week, 6 CY capacity	3.600	Week	$415.00		$1,651.11	$0.00	5	$326.92
Remove brick overhang foundations	1.150	CF	$0.00	$7.99	$0.00	$9.95	5	$2.48
Remove 2' x 4' ceiling grid	576.230	SF	$0.00	$0.55	$0.00	$323.27	5	$80.49
Remove visible conduits for kitchen exit sign	6.000	LF	$0.00	$1.81	$0.00	$12.00	5	$2.99
F2020 Hazardous Components Abatement					$8,382.80	$11,975.68		
OSHA Testing - Certified technician - Maximum	1	Day	$0.00	$300.00	$0.00	$324.73	5	$80.86
OSHA Testing - Industrial hygenist - Maximum	1	Day	$0.00	$400.00	$0.00	$432.97	5	$107.81
Asbestos sampling and PCM analysis, NIOSH 7400, max.	3	Ea	$22.00	$107.00	$71.44	$347.46	5	$100.66
Cleaned area samples - PCM air sample analysis, NIOSH 7400, maximum	3	Ea	$2.20	$107.00	$7.14	$347.46	5	$87.93
Spray exposed substrate with surfractant (bridging)	12	LF	$0.60	$1.71	$7.79	$22.21	5	$7.07
Spray encapsulate polyethylene sheeting	16.78	SF	$0.40	$0.43	$7.27	$7.81	5	$3.38
Roll down polyethylene sheeting	16.78	SF	$0.00	$0.43	$0.00	$7.81	5	$1.94
Bag polyethylene sheeting	3	EA	$1.00	$8.55	$3.25	$27.76	5	$7.56
Fine clean exposed substrate, with nylon brush	16.78	SF	$0.00	$1.43	$0.00	$25.97	5	$6.47
Wet wipe substrate	16.78	SF	$0.00	$0.71	$0.00	$12.90	5	$3.21
Vacuum surfaces, fine brush	16.78	SF	$0.00	$0.53	$0.00	$9.63	5	$2.40
Remove portable decontamination facility	3	EA	$13.35	$107.00	$43.35	$347.46	5	$95.10
HEPA vacuum, shampoo carpeting	0	SF	$0.10	$0.71	$0.00	$0.00	5	$0.00
Final cleaning of protected surfaces	1532.62	SF	$0.00	$0.16	$0.00	$265.43	5	$66.09
Collect and bag bulk material, 3 CF. bags, by hand	1	EA	$0.84	$8.55	$0.91	$9.25	5	$2.48
Double bag and decontaminate	1	EA	$0.84	$3.56	$0.91	$3.85	5	$1.14

Containerize bagged material in drums, per 3 CF. drum	1	EA	$18.55	$4.28	$20.08	$4.63	5	$5.13
Cart bags 50' to dumpster	1	EA	$0.00	$2.14	$0.00	$2.32	5	$0.58
Disposal charges, not including haul, maximum	0.029	CY	$0.00	$355.00	$0.00	$11.14	5	$2.77
Type B (supplied air) respirator equipment	1	LS			$0.00	$0.00	5	$0.00
Asbestos encapsulation with sealants - pipes to 12" diameter	12	LF	$1.20	$8.55	$15.59	$111.06	5	$30.74
G Building Sitework					**$8,205.07**	**$9,653.82**		
G10 Site Preparation					**$0.00**	**$0.00**		
G1010 Site Clearing					$0.00	$0.00		
G1020 Demolition and Relocations					$0.00	$0.00		
G1030 Site Earthwork					$0.00	$0.00		
G1040 Hazardous Waste Remediation					$0.00	$0.00		
G20 Site Improvements					**$8,205.07**	**$9,653.82**		
G2010 Roadways					$0.00	$0.00		
G2020 Parkings Lots					$0.00	$0.00		
G2030 pedestrian Paving					$8,205.07	$9,653.82		
Excavate Segment 1 + Stairs (Excavation Zone A)	32.232	CY		$7.19	$0.00	$250.85	5	$62.46
Excavate Landing + Segment 2 (Excavation Zone B)	6.940	CY		$7.19	$0.00	$54.01	5	$13.45
Backfill Zone A by hand, no compaction, heavy soil	6.741	CY		$27.50	$0.00	$200.65	5	$49.96
Backfill Zone B by hand, no compaction, heavy soil	0.630	CY		$27.50	$0.00	$18.74	5	$4.67
Slab, 4" thick, non industrial, non reinforced - Basement Ramp	2.633	CY	$129.00	$69.02	$367.70	$196.73	5	$121.79
Slab, 4" thick, non industrial, non reinforced - 1st Floor Walkway	0.764	CY	$129.00	$69.02	$106.64	$57.06	5	$35.32
4' concrete wall, pumped, 8" thick for Excavation Zone A	92.380	LF	$20.50	$57.00	$2,049.90	$5,699.71	5	$1,825.11

4' concrete wall, pumped, 8" thick for Excavation Zone B	30.880	LF	$20.50	$57.00	$685.22	$1,905.25	5	$610.08
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	90.000	LF	$50.50	$11.67	$4,919.65	$1,136.88	5	$1,257.17
Rubberized asphalt expansion joint, 1/2" x 1" - First Floor	48.500	LF	$0.38	$0.67	$19.95	$35.17	5	$12.71
Rubberized asphalt expansion joint, 1/2" x 1" - Basement	136.170	LF	$0.38	$0.67	$56.01	$98.75	5	$35.68
G2040 Site Development					$13,655.66	$3,137.95		
Planks for all ramp segments - 1 x 6	173.25	LF	$0.39		$73.72	$0.00	5	$14.60
Sawcut porch for first floor accessibility ramp	34.625	LF	$0.00	$1.65	$0.00	$58.27	5	$14.51
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	80.9	LF	$50.50	$11.67	$4,422.22	$1,021.93	5	$1,130.06
Railing - Aluminum, 2 rail, satin finish, 1-1/4" diameter	162.9	LF	$50.50	$11.67	$8,904.57	$2,057.75	5	$2,275.48
Segment 1 mid-beam - 4 x 6	24.55	LF	$0.93		$25.10	$0.00	5	$4.97
Segment 1 end beams - 3 x 6	49.1	LF	$0.93		$50.19	$0.00	5	$9.94
Segment 1 columns - 2 x 4	9.75	LF	$0.76		$8.14	$0.00	5	$1.61
Segment 1 girders - 2 x 4	7.17	LF	$0.76		$5.98	$0.00	5	$1.18
Segment 2 mid-beam - 4 x 6	14.34	LF	$0.93		$14.66	$0.00	5	$2.90
Segment 2 end beams - 3 x 6	28.69	LF	$0.93		$29.33	$0.00	5	$5.81
Segment 2 columns - 2 x 4	17.75	LF	$0.76		$14.81	$0.00	5	$2.93
Segment 2 columns - 2 x 6	2.22	LF	$0.77		$1.89	$0.00	5	$0.37
Segment 2 girders - 2 x 4	9.625	LF	$0.76		$8.03	$0.00	5	$1.59
Midway landing planks - 2 x 4	80.08	LF	$0.76		$66.82	$0.00	5	$13.23
Midway landing beams - 2 x 4	23.21	LF	$0.76		$19.37	$0.00	5	$3.83
Midway landing columns - 2 x 4	13	LF	$0.76		$10.85	$0.00	5	$2.15
G2050 Landscaping					$0.00	$0.00		
G30 Site Mechanical Utilities					**$0.00**	**$0.00**		
G3010 Water Supply					$0.00	$0.00		

G3020 Sanitary Sewer					$0.00	$0.00		
G3030 Storm Sewer					$0.00	$0.00		
G3040 Heating Distribution					$0.00	$0.00		
G3050 Cooling Distribution					$0.00	$0.00		
G3060 Fuel Distribution					$0.00	$0.00		
G3070 Other Site Mechanical Utilities					$0.00	$0.00		
G40 Site Electrical Utilities					**$0.00**	**$0.00**		
G4010 Electrical Distributions					$0.00	$0.00		
G4020 Site Lighting					$0.00	$0.00		
G4030 Site Communications and Security					$0.00	$0.00		
G4050 Other Site Electrical Utilities					$0.00	$0.00		
G50 Other Site Construciton					**$0.00**	**$0.00**		
G5010 Service and Pedestrian Tunnels					$0.00	$0.00		
G5020 Other Site Systems and Equipment					$0.00	$0.00		

Table 67. Adjustments to annual cost per resident for renovation

	Total/Year	Total/Year/Resident
No Overhead	$43,184	$2,540
With Overhead	$53,979	$3,175

Table 68. New construction costs

Activities	Year	Location adjusted?	Inflation Factor	UniFormat Code	Units	UOM	Unit Costs (unadjusted) Material	Unit Costs (unadjusted) Installation	Total Costs (Location + Inflation-adjusted) Material	Total Costs (Location + Inflation-adjusted) Installation
A Substructure									**$42,184.36**	**$79,039.94**
A10 Foundation									**$32,682.92**	**$34,286.14**
A1010 Standard Foundations									$23,660.35	$23,211.34
Load 25K, soil capacity 2 KSF, 3'-0" sq. x 12" deep	2019	Yes	1.020	A1010 210 7100	4	ea	$62.49	$163.88	$254.96	$835.79
Load 50K, soil capacity 3 KSF, 4'-6" sq. x 12" deep	2019	Yes	1.020	A1010 210 7150	7	ea	$133.26	$280.35	$951.48	$2,502.12
Load 20KLF, soil capacity 3 KSF, 96" wide x 24" deep, reinf.	2019	No	1.020	A1010 110 6500	218	LF	$102.00	$71.50	$22,453.91	$19,873.43
A1020 Special Foundations										
A1030 Slab on Grade									$9,022.57	$11,074.80
6" slab-on-grade, non-industrial, reinforced	2019	No	1.020	A1030 120 4480	2488.86	SF	$3.59	$3.49	$9,022.57	$11,074.80
A20 Basement Construction									**$9,501.44**	**$44,753.80**
A2010 Basement Excavation									$0.00	$3,386.50
Excavate and Fill, 1000 SF, 4' sand, gravel, or common earth, off site storage	2019	Yes	1.020	A2010 110 2240	1517.76	SF	$0.00	$1.75	$0.00	$3,386.50
A2020 Basement Walls									$9,501.44	$41,367.30
8' wall, cast-in-place, direct chute, 8" thick	2019	Yes	1.020	A2020 110 5020	218	LF	$42.73	$148.83	$9,501.44	$41,367.30
B Shell									**$110,048.34**	**$158,518.37**
B10 Super Structure									**$16,116.87**	**$18,022.23**

B1010 Floor Construction								$11,424.71	$12,090.12
Wood joists, 2 x 10, 24" o.c.	2019	No	1.020	B1010 261 3400	2035	SF	$1.95	$1.81	$4,007.14	$4,696.27
Wood joists, 3 x 10, 24" o.c.	2019	No	1.020	B1010 261 5400	0	SF	$3.32	$1.93	$0.00	$0.00
Wood joists, 3 x 12, 24" o.c.	2019	No	1.020	B1010 261 5800	385	SF	$3.72	$2.20	$1,446.24	$1,079.93
Wood joists, 2 x 10, 24" o.c.	2019	No	1.020	B1010 261 3400	1081.28	SF	$1.95	$1.81	$2,129.16	$2,495.32
Wood joists, 2 x 12, 24" o.c.	2019	No	1.020	B1010 261 3800	177.23	SF	$2.18	$1.84	$390.15	$415.78
Wood joists, 3 x 10, 24" o.c.	2019	No	1.020	B1010 261 5400	343.53	SF	$3.32	$1.93	$1,151.70	$845.34
Wood joists, 3 x 12, 24" o.c.	2019	No	1.020	B1010 261 5800	343.53	SF	$3.72	$2.20	$1,290.46	$963.60
Columns	2019	No	1.020	B1010 210 2400	8334	SF	$0.12	$0.15	$1,009.88	$1,593.88
B1020 Roof Construction									$4,692.16	$5,932.10
3/12 slope, 2 x 10, 24" o.c.	2019	No	1.020	B1020 102 3800	2319.59	SF	$1.58	$1.62	$3,700.87	$4,791.11
3/12 slope, 2 x 12, 24" o.c.	2019	No	1.020	B1020 102 4200	542.36	SF	$1.81	$1.65	$991.29	$1,140.99
B20 Exterior Enclosure									**$91,158.23**	**$134,986.17**
B2010 Exterior Walls									$68,372.32	$125,107.35
Brick Veneer, 2x6 wood, 16" stud spacing, plain face	2019	No	1.020	B2010 129 4720	7241.58	SF	$9.35	$13.55	$68,372.32	$125,107.35
B2020 Exterior Windows									$20,816.80	$9,292.33
Window - 3' 0" x 2' 0" (vinyl clad, casement)	2019	Yes	1.020	B2020 108 1010	11	EA	$351.88	$192.10	$3,948.09	$2,694.20
Window - 4' 0" x 2' 0" (double-hung, insul. Glass)	2019	No	1.020	B2020 108 3000	5	EA	$485.00	$139.00	$2,448.77	$886.13
Window - 3' 0" x 6' 0"	2019	No	1.020	B2020 108 3600	8	EA	$510.00	$160.00	$4,119.98	$1,632.00
Window - 6' 0" x 3' 0"	2019	No	1.020	B2020 108 3600	20	EA	$510.00	$160.00	$10,299.96	$4,080.00
B2030 Exterior Doors									$1,969.11	$586.50
Combination Storm & Screen Wood Door, 3' x 7'	2019	No	1.020	B2030 210 2800	1	EA	$390.00	$92.00	$393.82	$117.30
Combination Storm & Screen Wood Door, 3' x 7'	2019	No	1.020	B2030 210 2800	3	EA	$390.00	$92.00	$1,181.47	$351.90
Combination Storm & Screen Wood Door, 3' x 7'	2019	No	1.020	B2030 210 2800	1	EA	$390.00	$92.00	$393.82	$117.30

B30 Roofing									**$2,773.23**	**$5,509.97**
B3010 Roof Coverings									$2,773.23	$5,509.97
Asphalt strip shingles, 4" slope, inorganic class A 210-235 lb./sq.	2019	Yes	1.020	B3010 140 1100	2861.95	SF	$0.95	$1.51	$2,773.23	$5,509.97
B3020 Roof Openings									$0.00	$0.00
C Interiors									**$134,687.52**	**$195,929.14**
C10 Interior Construction									**$57,459.96**	**$132,765.06**
C1010 Partitions									$29,376.73	$116,249.09
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2019	Yes	1.020	C1010 142 5100	2500	SF	$3.62	$11.46	$9,231.00	$36,528.75
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2019	Yes	1.020	C1010 142 5100	2644	SF	$3.62	$11.46	$9,762.71	$38,632.81
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2019	Yes	1.020	C1010 142 5100	2812	SF	$3.62	$11.46	$10,383.03	$41,087.54
C1020 Interior Doors									$15,288.37	$12,933.60
Solid Core Flush Door, Oak - 2' 6" x 6' 8"	2019	No	1.020	C1020 122 5200	1	EA	$475.00	$254.00	$479.66	$323.85
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	2019	No	1.020	C1020 120 3400	11	EA	$430.00	$292.00	$4,776.35	$4,095.30
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	2019	No	1.020	C1020 120 3400	11	EA	$430.00	$292.00	$4,776.35	$4,095.30
Solid Core Flush Door, Oak - 2' 6" x 6' 8"	2019	No	1.020	C1020 122 5200	1	EA	$475.00	$254.00	$479.66	$323.85
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	2019	No	1.020	C1020 120 3400	11	EA	$430.00	$292.00	$4,776.35	$4,095.30
C1030 Fittings									$12,794.85	$3,582.37

Partitions, shower stall, single wall, painted steel, 2'-8" x 2'-8"	2019	No	1.020	C1030 110 1500	3	EA	$990.00	$296.00	$2,999.11	$1,132.20
Toilet partitions, cubicles, floor and ceiling anchored, stainless steel	2019	No	1.020	C1030 110 6000	6	EA	$1,375.00	$250.00	$8,330.85	$1,912.50
Grab bar, 1-1/2" diam, 36" long	2019	No	1.020	C1030 710 0150	6	EA	$52.00	$31.50	$315.06	$240.98
Dispenser, towel, flush mounted with waste receptacle	2019	No	1.020	C1030 710 0130	3	EA	$375.00	$62.50	$1,136.03	$239.06
Bulletin board, cork sheets, no frame, 1/4" thick	2019	No	1.020	C1030 520 0010	8	SF	$1.71	$5.65	$13.81	$57.63
C20 Stairs									**$12,117.60**	**$3,315.00**
C2010 Stair Construction									$12,117.60	$3,315.00
Wood, prefab box type, oak treads, wood rails 3'-6" wide, 14 risers	2019	No	1.020	C2010 110 1120	5	Flights	$2,400.00	$520.00	$12,117.60	$3,315.00
C2020 Stair Finishes									$0.00	$0.00
C30 Interior Finishes									**$65,109.97**	**$59,849.08**
C3010 Wall Finishes									$2,272.23	$13,998.58
Basement - roller work, primer & 1 coat	2019	Yes	1.020	C3010 230 0120	5000	SF	$0.14	$0.69	$714.00	$4,398.75
1st floor - roller work, primer & 1 coat	2019	Yes	1.020	C3010 230 0120	5288	SF	$0.14	$0.69	$755.13	$4,652.12
2nd floor - roller work, primer & 1 coat	2019	Yes	1.020	C3010 230 0120	5624	SF	$0.14	$0.69	$803.11	$4,947.71
C3020 Floor Finishes									$44,739.12	$23,590.65
Carpet tile, nylon, fusion bonded, 24oz	2019	Yes	1.020	C3020 410 0060	7286.096	SF	$3.72	$1.02	$27,646.36	$9,475.57
Ceramic tile, thin set, 4-1/4" x 4-1/4"	2019	No	1.020	C3020 410 1720	630.96	SF	$6.50	$5.50	$4,141.43	$4,424.61
Underlayment, plywood, 3/4" thick	2019	No	1.020	C3020 410 2370	7917.056	SF	$1.62	$0.96	$12,951.32	$9,690.48
C3030 Ceiling Finishes									$18,098.61	$22,259.84

Suspended Ceilings - 5/8" fiberglass board, 24" x 48"	2019	Yes	1.020	C3030 210 5800	7126	SF	$2.49	$2.45	$18,098.61	$22,259.84
D Services									**$386,621.61**	**$415,431.03**
D10 Conveying									**$0.00**	**$0.00**
D1010 Elevators & Lifts									$0.00	$0.00
D1020 Escalators & Moving Walks									$0.00	$0.00
D1090 Other Conveying Systems									$0.00	$0.00
D20 Plumbing									**$204,664.30**	**$27,247.91**
D2010 Plumbing Fixtures									$11,123.49	$15,961.44
Toilet, floor mount, two piece close coupled	2019	Yes	1.020	D2010 110 2000	6	EA	$705.71	$913.14	$4,318.95	$6,985.52
Kitchen sink w/ trim, countertop, PE on CI, 32" x 21" double bowl	2019	Yes	1.020	D2010 410 1800	1	EA	$765.77	$1,019.94	$781.09	$1,300.42
Shower, fiberglass one piece, three walls, 36" square	2019	No	1.020	D2010 710 1800	6	EA	$715.00	$915.00	$4,332.04	$6,999.75
Drinking fountain, one bubbler, wall mounted, semi-recessed, stainless steel	2019	No	1.020	D2010 810 2040	1	EA	$1,675.00	$530.00	$1,691.42	$675.75
D2020 Domestic Water Distribution									$188,832.60	$8,191.88
Electric water heater, commercial, 1500 gal, 480 KW 1970 GPH	2019	No	1.020	D2020 240 2500	1	EA	$187,000.00	$6,425.00	$188,832.60	$8,191.88
D2030 Sanitary Waste									$0.00	$0.00
D2040 Rain Water Drainage									$657.02	$1,884.05
Roof drain systems, 4" diam, 10' high	2019	Yes	1.020	D2040 210 2040	1	EA	$480.48	$1,068.00	$490.09	$1,361.70
(for each additional foot, add)	2019	No	1.020	D2040 210 2080	14.375	LF	$11.50	$28.50	$166.93	$522.35
D2090 Other Plumbing Systems									$4,051.19	$1,210.54

Storage Tanks	2019	No	1.020	Rain Harvesting Supplies (n.d.)	14	EA	$229.25	$67.82	$4,051.19	$1,210.54
D30 HVAC									**$105,092.52**	**$175,196.74**
D3010 Energy Supply									$28,848.43	$50,208.17
Apartment Building Heating - Fin Tube Radiation - 10,000 SF area, 100,000 CF volume	2019	Yes	1.020	D3010 510 1760	8343	SF	$3.39	$4.72	$28,848.43	$50,208.17
D3020 Heat Generating Systems									$76,244.09	$124,988.57
Small heating systems, hydronic, electric boilers, hot water, 3 floors, 9,700 SF, 410 MBH	2019	No	1.020	D3020 102 1480	8343	SF	$9.05	$11.75	$76,244.09	$124,988.57
D3030 Cooling Generating Systems									$0.00	$0.00
D3050 Terminal & Package Units									$0.00	$0.00
D40 Fire Protection									**$52,531.74**	**$46,237.16**
D4010 Sprinklers									$37,995.67	$32,762.96
On-off multicycle sprinkler system, ordinary hazard, one floor, 10,000 SF	2019	No	1.020	D4010 390 1080	8343	SF	$4.51	$3.08	$37,995.67	$32,762.96
D4020 Standpipes									$8,886.24	$7,777.50
Wet standpipe risers, Class I, steel, black, sch. 40, 10' height, 4" diam., one floor	2019	No	1.020	D4020 310 0560	1	Floors	$5,900.00	$3,750.00	$5,957.82	$4,781.25
Additional floors	2019	No	1.020	D4020 310 0580	2	Floors	$1,450.00	$1,175.00	$2,928.42	$2,996.25
D4030 Fire Protection Specialties									$0.00	$0.00
D4090 Other Fire Protection Systems									$5,649.83	$5,696.70
Rate of temperature rise detector	2019	No	1.020	D4090 910 0060	32	EA	$57.50	$89.50	$1,858.03	$3,651.60
Multizone (4) control station with batteries	2019	No	1.020	D4090 910 0470	1	EA	$3,325.00	$1,425.00	$3,357.59	$1,816.88

Battery standby power 10" x 10" x 17"	2019	No	1.020	D4090 901 0640	1	EA	$430.00	$179.00	$434.21	$228.23
D50 Electrical									**$24,333.04**	**$166,749.22**
D5010 Electrical Service & Distribution									$2,942.65	$4,553.15
3 phase, 4 wire, 120/208 V, 60 A	2019	Yes	1.020	D5010 120 0220	1	EA	$501.10	$1,252.55	$511.12	$1,597.00
Panelboard, 100A, 1 stories, 25' horizontal	2019	Yes	1.020	D5010 250 1020	1	EA	$2,383.85	$2,318.55	$2,431.53	$2,956.15
D5020 Lighting and Branch Wiring									$21,390.39	$81,306.18
Receptacle, 20 per 1000 SF, 2.4 W per 1000 SF	2019	No	1.020	D5020 110 0720	8343	SF	$1.47	$4.24	$12,384.40	$45,102.26
Wall switch, 5.0 per 1000 SF	2019	No	1.020	D5020 130 0360	8343	SF	$0.22	$1.11	$1,853.45	$11,807.43
T8, energy saver, 32 watt lamps, 0.8 watt per SF, 20 FC, 5 fixtures per 1000 SF (bedrooms, bathrooms, corridors, storage)	2019	No	1.020	D5020 210 0500	7,761.70	SF	$0.78	$2.11	$6,113.45	$20,880.90
T8, energy saver, 32 watt lamps, 1.6 watt per SF, 40 FC, 10 fixtures per 1000 SF (common rooms)	2019	No	1.020	D5020 210 0520	415.08	SF	$1.55	$4.14	$649.68	$2,191.02
T8, energy saver, 32 watt lamps, 60 FC, 15 fixtures per 1000 SF (kitchen)	2019	No	1.020	D5020 210 0540	166.22	SF	$2.32	$6.25	$389.41	$1,324.57
D5030 Communications & Security									$0.00	$0.00
NONE										
D5090 Other Electrical Systems									$0.00	$80,889.89
Photovoltaic Solar Panel System - Construction	2019	Yes	1.020		26119	W	$0.00	$3.47	$0.00	$115,556.99
Photovoltaic Solar Panel System	2019	Yes	1.020		26119	W	$0.00	-$1.04	$0.00	-$34,667.10
E Equipment & Furnishings									**$29,556.03**	**$20,178.92**

E10 Equipment									**$0.00**	**$0.00**
E1010 Commercial Equipment									$0.00	$0.00
E1020 Institutional Equipment									$0.00	$0.00
E1030 Vehicular Equipment									$0.00	$0.00
E1040 Other Equipment									$0.00	$0.00
E20 Furnishings									**$29,556.03**	**$20,178.92**
E2010 Fixed Furnishings									$0.00	$0.00
E2020 Movable Furnishings									$29,556.03	$20,178.92
Dormitory furniture, desk top (built-in), laminated plastic, 30" deep, deluxe	2019	Yes	1.020	E2020 220 0210	119	LF	$53.50	$29.78	$6,493.83	$4,518.37
Dressing unit, built-in, deluxe	2019	Yes	1.020	E2020 220 0230	99.17	LF	$228.00	$123.86	$23,062.20	$15,660.55
F Special Construction & Demolition									**$219.94**	**$17,374.21**
F10 Special Construction									**$0.00**	**$0.00**
F1010 Special Structures									$0.00	$0.00
F1020 Integrated Construction									$0.00	$0.00
F1030 Special Construction Systems									$0.00	$0.00
F1040 Special Facilities									$0.00	$0.00
F1050 Special Controls and Instrumentation									$0.00	$0.00
F20 Selective Building Demolition									**$219.94**	**$17,374.21**
F2010 Building Elements Demolition									$0.00	$14,471.88
Building Demolition - Small buildings or single buildings - wood	2019	No	1.020	02 41 16.13 0700	36,614.49	CF	$0.00	$0.31	$0.00	$14,471.88

F2020 Hazardous Components Abatement									$219.94	$2,902.33
OSHA Testing - Certified technician - Maximum	2016	No	1.082	02 82 13.45 0110	1	Day	$0.00	$300.00	$0.00	$405.91
OSHA Testing - Industrial hygenist - Maximum	2016	No	1.082	02 82 13.45 0130	1	Day	$0.00	$400.00	$0.00	$541.22
Asbestos sampling and PCM analysis, NIOSH 7400, max.	2016	No	1.082	02 82 13.45 0210	3	Ea	$22.00	$107.00	$88.41	$434.33
Cleaned area samples - PCM air sample analysis, NIOSH 7400, maximum	2016	No	1.082	02 82 13.45 1000	3	Ea	$2.20	$107.00	$8.84	$434.33
Spray exposed substrate with surfractant (bridging)	2016	No	1.082	02 82 13.46 0300	12	LF	$0.60	$1.71	$9.64	$27.76
Spray encapsulate polyethylene sheeting	2016	No	1.082	02 82 13.46 1000	16.78	SF	$0.40	$0.43	$8.99	$9.76
Roll down polyethylene sheeting	2016	No	1.082	02 82 13.46 1100	16.78	SF	$0.00	$0.43	$0.00	$9.76
Bag polyethylene sheeting	2016	No	1.082	02 82 13.46 1500	3	EA	$1.00	$8.55	$4.02	$34.71
Fine clean exposed substrate, with nylon brush	2016	No	1.082	02 82 13.46 2000	16.78	SF	$0.00	$1.43	$0.00	$32.47
Wet wipe substrate	2016	No	1.082	02 82 13.46 2500	16.78	SF	$0.00	$0.71	$0.00	$16.12
Vacuum surfaces, fine brush	2016	No	1.082	02 82 13.46 2600	16.78	SF	$0.00	$0.53	$0.00	$12.03
Remove portable decontamination facility	2016	No	1.082	02 82 13.46 4100	3	EA	$13.35	$107.00	$53.65	$434.33
HEPA vacuum, shampoo carpeting	2016	No	1.082	02 82 13.46 5000	0	SF	$0.10	$0.71	$0.00	$0.00
Final cleaning of protected surfaces	2016	No	1.082	02 82 13.46 9000	1532.62	SF	$0.00	$0.16	$0.00	$331.79
Collect and bag bulk material, 3 CF. bags, by hand	2016	No	1.082	02 82 13.47 0100	1	EA	$0.84	$8.55	$1.13	$11.57
Double bag and decontaminate	2016	No	1.082	02 82 13.47 1000	1	EA	$0.84	$3.56	$1.13	$4.82
Containerize bagged material in drums, per 3 CF. drum	2016	No	1.082	02 82 13.47 2000	1	EA	$18.55	$4.28	$24.85	$5.79

Cart bags 50' to dumpster	2016	No	1.082	02 82 13.47 5000	1	EA	$0.00	$2.14	$0.00	$2.90
Disposal charges, not including haul, maximum	2016	No	1.082	02 82 13.47 5020	0.029	CY	$0.00	$355.00	$0.00	$13.93
Asbestos encapsulation with sealants - pipes to 12" diameter	2016	No	1.082	02 82 13.48 0310	12	LF	$1.20	$8.55	$19.29	$138.82
G Building Sitework									**$11,087.09**	**$43,892.82**
G10 Site Preparation									**$0.00**	**$0.00**
G1010 Site Clearing									$0.00	$0.00
G1020 Demolition and Relocations									$0.00	$0.00
G1030 Site Earthwork									$0.00	$0.00
G1040 Hazardous Waste Remediation									$0.00	$0.00
G20 Site Improvements									**$11,087.09**	**$43,892.82**
G2010 Roadways									$0.00	$0.00
G2020 Parkings Lots									$0.00	$0.00
G2030 pedestrian Paving									$1,111.32	$2,279.56
Concrete sidewalk, 4" thick, 4" gravel base, 4' wide	2019	Yes	1.020	G2030 120 1600	110.50	LF	$9.86	$16.18	$1,111.32	$2,279.56
G2040 Site Development									$9,975.77	$41,613.26
Wood deck, treated lumber, 2" x 8" joists @ 16" O.C., 2" x 6" decking - for porch and accessibility ramp to first floor	2019	Yes	1.020	G2040 910 1000	353.13	SF	$4.10	$10.24	$1,476.77	$4,610.40
8' wall, cast-in-place, direct chute, 8" thick	2019	Yes	1.020	A2020 110 5020	195	LF	$42.73	$148.83	$8,499.00	$37,002.86
G2050 Landscaping									$0.00	$0.00
G30 Site Mechanical Utilities									**$0.00**	**$0.00**
G3010 Water Supply									$0.00	$0.00
G3020 Sanitary Sewer									$0.00	$0.00

G3030 Storm Sewer		$0.00	$0.00
G3040 Heating Distribution		$0.00	$0.00
G3050 Cooling Distribution		$0.00	$0.00
G3060 Fuel Distribution		$0.00	$0.00
G3070 Other Site Mechanical Utilities		$0.00	$0.00
G40 Site Electrical Utilities		**$0.00**	**$0.00**
G4010 Electrical Distributions		$0.00	$0.00
G4020 Site Lighting		$0.00	$0.00
G4030 Site Communications and Security		$0.00	$0.00
G4050 Other Site Electrical Utilities		$0.00	$0.00
G50 Other Site Construciton		**$0.00**	**$0.00**
G5010 Service and Pedestrian Tunnels		$0.00	$0.00
G5020 Other Site Systems and Equipment		$0.00	$0.00

Table 69. Life expectancy costs for new construction

			Unit Costs (unadjusted)		Total Costs (adjusted)		Life Expectancy (Years)	Cost / Year
Individual Activities	**Units**	**UOM**	**Material**	**Installation**	**Material**	**Installation**		
A Substructure					**$42,184.36**	**$79,039.94**		
A10 Foundation					**$32,682.92**	**$34,286.14**		
A1010 Standard Foundations					$23,660.35	$23,211.34		
Load 25K, soil capacity 2 KSF, 3'-0" sq. x 12" deep	4	ea	$62.49	$163.88	$254.96	$835.79	110	$9.92
Load 50K, soil capacity 3 KSF, 4'-6" sq. x 12" deep	7	ea	$133.26	$280.35	$951.48	$2,502.12	110	$31.40

Load 20KLF, soil capacity 3 KSF, 96" wide x 24" deep, reinf.	218	LF	$102.00	$71.50	$22,453.91	$19,873.43	110	$384.79
A1020 Special Foundations								
A1030 Slab on Grade					$9,022.57	$11,074.80		
6" slab-on-grade, non-industrial, reinforced	2488.86	SF	$3.59	$3.49	$9,022.57	$11,074.80	71	$283.06
A20 Basement Construction					**$9,501.44**	**$44,753.80**		
A2010 Basement Excavation					$0.00	$3,386.50		
Excavate and Fill, 1000 SF, 4' sand, gravel, or common earth, off site storage	1517.76	SF	$0.00	$1.75	$0.00	$3,386.50	110	$30.79
A2020 Basement Walls					$9,501.44	$41,367.30		
8' wall, cast-in-place, direct chute, 8" thick	218	LF	$42.73	$148.83	$9,501.44	$41,367.30	110	$462.44
B Shell					**$110,048.34**	**$158,518.37**		
B10 Super Structure					**$16,116.87**	**$18,022.23**		
B1010 Floor Construction					$11,424.71	$12,090.12		
Wood joists, 2 x 10, 24" o.c.	2035	SF	$1.95	$1.81	$4,007.14	$4,696.27	90	$96.70
Wood joists, 3 x 10, 24" o.c.	0	SF	$3.32	$1.93	$0.00	$0.00	90	$0.00
Wood joists, 3 x 12, 24" o.c.	385	SF	$3.72	$2.20	$1,446.24	$1,079.93	90	$28.07
Wood joists, 2 x 10, 24" o.c.	1081.28	SF	$1.95	$1.81	$2,129.16	$2,495.32	90	$51.38
Wood joists, 2 x 12, 24" o.c.	177.23	SF	$2.18	$1.84	$390.15	$415.78	90	$8.95
Wood joists, 3 x 10, 24" o.c.	343.53	SF	$3.32	$1.93	$1,151.70	$845.34	90	$22.19
Wood joists, 3 x 12, 24" o.c.	343.53	SF	$3.72	$2.20	$1,290.46	$963.60	90	$25.05
Columns	8334	SF	$0.12	$0.15	$1,009.88	$1,593.88	69	$37.74
B1020 Roof Construction					$4,692.16	$5,932.10		
3/12 slope, 2 x 10, 24" o.c.	2319.59	SF	$1.58	$1.62	$3,700.87	$4,791.11	74	$114.76
3/12 slope, 2 x 12, 24" o.c.	542.36	SF	$1.81	$1.65	$991.29	$1,140.99	74	$28.81
B20 Exterior Enclosure					**$91,158.23**	**$134,986.17**		
B2010 Exterior Walls					$68,372.32	$125,107.35		

Brick Veneer, 2x6 wood, 16" stud spacing, plain face	7241.58	SF	$9.35	$13.55	$68,372.32	$125,107.35	86	$2,249.76
B2020 Exterior Windows					$20,816.80	$9,292.33		
Window - 3' 0" x 2' 0" (vinyl clad, casement)	11	EA	$351.88	$192.10	$3,948.09	$2,694.20	37	$179.52
Window - 4' 0" x 2' 0" (double-hung, insul. Glass)	5	EA	$485.00	$139.00	$2,448.77	$886.13	37	$90.13
Window - 3' 0" x 6' 0"	8	EA	$510.00	$160.00	$4,119.98	$1,632.00	37	$155.46
Window - 6' 0" x 3' 0"	20	EA	$510.00	$160.00	$10,299.96	$4,080.00	37	$388.65
B2030 Exterior Doors					$1,969.11	$586.50		
Combination Storm & Screen Wood Door, 3' x 7'	1	EA	$390.00	$92.00	$393.82	$117.30	31	$16.49
Combination Storm & Screen Wood Door, 3' x 7'	3	EA	$390.00	$92.00	$1,181.47	$351.90	31	$49.46
Combination Storm & Screen Wood Door, 3' x 7'	1	EA	$390.00	$92.00	$393.82	$117.30	31	$16.49
B30 Roofing					**$2,773.23**	**$5,509.97**		
B3010 Roof Coverings					$2,773.23	$5,509.97		
Asphalt strip shingles, 4" slope, inorganic class A 210-235 lb./sq.	2861.95	SF	$0.95	$1.51	$2,773.23	$5,509.97	74	$111.94
B3020 Roof Openings					$0.00	$0.00		
C Interiors					**$134,687.52**	**$195,929.14**		
C10 Interior Construction					**$57,459.96**	**$132,765.06**		
C1010 Partitions					$29,376.73	$116,249.09		
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2500	SF	$3.62	$11.46	$9,231.00	$36,528.75	39	$1,173.33
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2644	SF	$3.62	$11.46	$9,762.71	$38,632.81	39	$1,240.91
Plaster Partition, Wood Framing, 2x4 @24" o.c., 1/2" gypsum lath, opposite face same	2812	SF	$3.62	$11.46	$10,383.03	$41,087.54	39	$1,319.76
C1020 Interior Doors					$15,288.37	$12,933.60		

Solid Core Flush Door, Oak - 2' 6" x 6' 8"	1	EA	$475.00	$254.00	$479.66	$323.85	31	$25.92
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	11	EA	$430.00	$292.00	$4,776.35	$4,095.30	31	$286.18
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	11	EA	$430.00	$292.00	$4,776.35	$4,095.30	31	$286.18
Solid Core Flush Door, Oak - 2' 6" x 6' 8"	1	EA	$475.00	$254.00	$479.66	$323.85	31	$25.92
Particle Core Flush Door, Oak - 3' 0" x 7' 0"	11	EA	$430.00	$292.00	$4,776.35	$4,095.30	31	$286.18
C1030 Fittings					$12,794.85	$3,582.37		
Partitions, shower stall, single wall, painted steel, 2'-8" x 2'-8"	3	EA	$990.00	$296.00	$2,999.11	$1,132.20	31	$133.27
Toilet partitions, cubicles, floor and ceiling anchored, stainless steel	6	EA	$1,375.00	$250.00	$8,330.85	$1,912.50	31	$330.43
Grab bar, 1-1/2" diam, 36" long	6	EA	$52.00	$31.50	$315.06	$240.98	31	$17.94
Dispenser, towel, flush mounted with waste receptacle	3	EA	$375.00	$62.50	$1,136.03	$239.06	31	$44.36
Bulletin board, cork sheets, no frame, 1/4" thick	8	SF	$1.71	$5.65	$13.81	$57.63	31	$2.30
C20 Stairs					**$12,117.60**	**$3,315.00**		
C2010 Stair Construction					$12,117.60	$3,315.00		
Wood, prefab box type, oak treads, wood rails 3'-6" wide, 14 risers	5	Flights	$2,400.00	$520.00	$12,117.60	$3,315.00	64	$241.13
C2020 Stair Finishes					$0.00	$0.00		
C30 Interior Finishes					**$65,109.97**	**$59,849.08**		
C3010 Wall Finishes					$2,272.23	$13,998.58		
Basement - roller work, primer & 1 coat	5000	SF	$0.14	$0.69	$714.00	$4,398.75	39	$131.10
1st floor - roller work, primer & 1 coat	5288	SF	$0.14	$0.69	$755.13	$4,652.12	39	$138.65
2nd floor - roller work, primer & 1 coat	5624	SF	$0.14	$0.69	$803.11	$4,947.71	39	$147.46
C3020 Floor Finishes					$44,739.12	$23,590.65		

Carpet tile, nylon, fusion bonded, 24oz	7286.096	SF	$3.72	$1.02	$27,646.36	$9,475.57	13	$2,855.53
Ceramic tile, thin set, 4-1/4" x 4-1/4"	630.96	SF	$6.50	$5.50	$4,141.43	$4,424.61	39	$219.64
Underlayment, plywood, 3/4" thick	7917.056	SF	$1.62	$0.96	$12,951.32	$9,690.48	51	$443.96
C3030 Ceiling Finishes					$18,098.61	$22,259.84		
Suspended Ceilings - 5/8" fiberglass board, 24" x 48"	7126	SF	$2.49	$2.45	$18,098.61	$22,259.84	24	$1,681.60
D Services					**$386,621.61**	**$415,431.03**		
D10 Conveying					**$0.00**	**$0.00**		
D1010 Elevators & Lifts					$0.00	$0.00		
D1020 Escalators & Moving Walks					$0.00	$0.00		
D1090 Other Conveying Systems					$0.00	$0.00		
D20 Plumbing					**$204,664.30**	**$27,247.91**		
D2010 Plumbing Fixtures					$11,123.49	$15,961.44		
Toilet, floor mount, two piece close coupled	6	EA	$705.71	$913.14	$4,318.95	$6,985.52	5	$2,260.89
Kitchen sink w/ trim, countertop, PE on CI, 32" x 21" double bowl	1	EA	$765.77	$1,019.94	$781.09	$1,300.42	5	$416.30
Shower, fiberglass one piece, three walls, 36" square	6	EA	$715.00	$915.00	$4,332.04	$6,999.75	5	$2,266.36
Drinking fountain, one bubbler, wall mounted, semi-recessed, stainless steel	1	EA	$1,675.00	$530.00	$1,691.42	$675.75	5	$473.43
D2020 Domestic Water Distribution					$188,832.60	$8,191.88		
Electric water heater, commercial, 1500 gal, 480 KW 1970 GPH	1	EA	$187,000.00	$6,425.00	$188,832.60	$8,191.88	20	$9,851.22
D2030 Sanitary Waste					$0.00	$0.00		
D2040 Rain Water Drainage					$657.02	$1,884.05		
Roof drain systems, 4" diam, 10' high	1	EA	$480.48	$1,068.00	$490.09	$1,361.70	74	$25.02
(for each additional foot, add)	14.375	LF	$11.50	$28.50	$166.93	$522.35	74	$9.31

D2090 Other Plumbing Systems					$4,051.19	$1,210.54		
Storage Tanks	14	EA	$229.25	$67.82	$4,051.19	$1,210.54	36	$146.16
D30 HVAC					**$105,092.52**	**$175,196.74**		
D3010 Energy Supply					$28,848.43	$50,208.17		
Apartment Building Heating - Fin Tube Radiation - 10,000 SF area, 100,000 CF volume	8343	SF	$3.39	$4.72	$28,848.43	$50,208.17	20	$3,952.83
D3020 Heat Generating Systems					$76,244.09	$124,988.57		
Small heating systems, hydronic, electric boilers, hot water, 3 floors, 9,700 SF, 410 MBH	8343	SF	$9.05	$11.75	$76,244.09	$124,988.57	20	$10,061.63
D3030 Cooling Generating Systems					$0.00	$0.00		
D3050 Terminal & Package Units					$0.00	$0.00		
D40 Fire Protection					**$52,531.74**	**$46,237.16**		
D4010 Sprinklers					$37,995.67	$32,762.96		
On-off multicycle sprinkler system, ordinary hazard, one floor, 10,000 SF	8343	SF	$4.51	$3.08	$37,995.67	$32,762.96	26	$2,721.49
D4020 Standpipes					$8,886.24	$7,777.50		
Wet standpipe risers, Class I, steel, black, sch. 40, 10' height, 4" diam., one floor	1	Floors	$5,900.00	$3,750.00	$5,957.82	$4,781.25	33	$325.43
Additional floors	2	Floors	$1,450.00	$1,175.00	$2,928.42	$2,996.25	33	$179.54
D4030 Fire Protection Specialties					$0.00	$0.00		
D4090 Other Fire Protection Systems					$5,649.83	$5,696.70		
Rate of temperature rise detector	32	EA	$57.50	$89.50	$1,858.03	$3,651.60	33	$166.96
Multizone (4) control station with batteries	1	EA	$3,325.00	$1,425.00	$3,357.59	$1,816.88	33	$156.80
Battery standby power 10" x 10" x 17"	1	EA	$430.00	$179.00	$434.21	$228.23	33	$20.07
D50 Electrical					**$24,333.04**	**$166,749.22**		

D5010 Electrical Service & Distribution					$2,942.65	$4,553.15			
3 phase, 4 wire, 120/208 V, 60 A	1	EA	$501.10	$1,252.55	$511.12	$1,597.00		30	$70.27
Panelboard, 100A, 1 stories, 25' horizontal	1	EA	$2,383.85	$2,318.55	$2,431.53	$2,956.15		30	$179.59
D5020 Lighting and Branch Wiring					$21,390.39	$81,306.18			
Receptacle, 20 per 1000 SF, 2.4 W per 1000 SF	8343	SF	$1.47	$4.24	$12,384.40	$45,102.26		32	$1,796.46
Wall switch, 5.0 per 1000 SF	8343	SF	$0.22	$1.11	$1,853.45	$11,807.43		27	$505.96
T8, energy saver, 32 watt lamps, 0.8 watt per SF, 20 FC, 5 fixtures per 1000 SF (bedrooms, bathrooms, corridors, storage)	7,761.70	SF	$0.78	$2.11	$6,113.45	$20,880.90		16	$1,687.15
T8, energy saver, 32 watt lamps, 1.6 watt per SF, 40 FC, 10 fixtures per 1000 SF (common rooms)	415.08	SF	$1.55	$4.14	$649.68	$2,191.02		16	$177.54
T8, energy saver, 32 watt lamps, 60 FC, 15 fixtures per 1000 SF (kitchen)	166.22	SF	$2.32	$6.25	$389.41	$1,324.57		16	$107.12
D5030 Communications & Security					$0.00	$0.00			
NONE									
D5090 Other Electrical Systems					$0.00	$80,889.89			
Photovoltaic Solar Panel System - Construction	26119	W	$0.00	$3.47	$0.00	$115,556.99		25	$4,622.28
Photovoltaic Solar Panel System	26119	W	$0.00	-$1.04	$0.00	-$34,667.10		25	-$1,386.68
E Equipment & Furnishings					**$29,556.03**	**$20,178.92**			
E10 Equipment					**$0.00**	**$0.00**			
E1010 Commercial Equipment					$0.00	$0.00			
E1020 Institutional Equipment					$0.00	$0.00			
E1030 Vehicular Equipment					$0.00	$0.00			
E1040 Other Equipment					$0.00	$0.00			

E20 Furnishings					**$29,556.03**	**$20,178.92**		
E2010 Fixed Furnishings					$0.00	$0.00		
E2020 Movable Furnishings					$29,556.03	$20,178.92		
Dormitory furniture, desk top (built-in), laminated plastic, 30" deep, deluxe	119	LF	$53.50	$29.78	$6,493.83	$4,518.37	10	$1,101.22
Dressing unit, built-in, deluxe	99.17	LF	$228.00	$123.86	$23,062.20	$15,660.55	10	$3,872.27
F Special Construction & Demolition					**$219.94**	**$17,374.21**		
F10 Special Construction					**$0.00**	**$0.00**		
F1010 Special Structures					$0.00	$0.00		
F1020 Integrated Construction					$0.00	$0.00		
F1030 Special Construction Systems					$0.00	$0.00		
F1040 Special Facilities					$0.00	$0.00		
F1050 Special Controls and Instrumentation					$0.00	$0.00		
F20 Selective Building Demolition					**$219.94**	**$17,374.21**		
F2010 Building Elements Demolition					$0.00	$14,471.88		
Building Demolition - Small buildings or single buildings - wood	36,614.49	CF	$0.00	$0.31	$0.00	$14,471.88	110	$131.56
F2020 Hazardous Components Abatement					$219.94	$2,902.33		
OSHA Testing - Certified technician - Maximum	1	Day	$0.00	$300.00	$0.00	$405.91	110	$3.69
OSHA Testing - Industrial hygenist - Maximum	1	Day	$0.00	$400.00	$0.00	$541.22	110	$4.92
Asbestos sampling and PCM analysis, NIOSH 7400, max.	3	Ea	$22.00	$107.00	$88.41	$434.33	110	$4.75
Cleaned area samples - PCM air sample analysis, NIOSH 7400, maximum	3	Ea	$2.20	$107.00	$8.84	$434.33	110	$4.03
Spray exposed substrate with surfactant (bridging)	12	LF	$0.60	$1.71	$9.64	$27.76	110	$0.34

Spray encapsulate polyethylene sheeting	16.78	SF	$0.40	$0.43	$8.99	$9.76	110	$0.17
Roll down polyethylene sheeting	16.78	SF	$0.00	$0.43	$0.00	$9.76	110	$0.09
Bag polyethylene sheeting	3	EA	$1.00	$8.55	$4.02	$34.71	110	$0.35
Fine clean exposed substrate, with nylon brush	16.78	SF	$0.00	$1.43	$0.00	$32.47	110	$0.30
Wet wipe substrate	16.78	SF	$0.00	$0.71	$0.00	$16.12	110	$0.15
Vacuum surfaces, fine brush	16.78	SF	$0.00	$0.53	$0.00	$12.03	110	$0.11
Remove portable decontamination facility	3	EA	$13.35	$107.00	$53.65	$434.33	110	$4.44
HEPA vacuum, shampoo carpeting	0	SF	$0.10	$0.71	$0.00	$0.00	110	$0.00
Final cleaning of protected surfaces	1532.62	SF	$0.00	$0.16	$0.00	$331.79	110	$3.02
Collect and bag bulk material, 3 CF. bags, by hand	1	EA	$0.84	$8.55	$1.13	$11.57	110	$0.12
Double bag and decontaminate	1	EA	$0.84	$3.56	$1.13	$4.82	110	$0.05
Containerize bagged material in drums, per 3 CF. drum	1	EA	$18.55	$4.28	$24.85	$5.79	110	$0.28
Cart bags 50' to dumpster	1	EA	$0.00	$2.14	$0.00	$2.90	110	$0.03
Disposal charges, not including haul, maximum	0.029	CY	$0.00	$355.00	$0.00	$13.93	110	$0.13
Asbestos encapsulation with sealants - pipes to 12" diameter	12	LF	$1.20	$8.55	$19.29	$138.82	110	$1.44
G Building Sitework					**$11,087.09**	**$43,892.82**		
G10 Site Preparation					**$0.00**	**$0.00**		
G1010 Site Clearing					$0.00	$0.00		
G1020 Demolition and Relocations					$0.00	$0.00		
G1030 Site Earthwork					$0.00	$0.00		
G1040 Hazardous Waste Remediation					$0.00	$0.00		
G20 Site Improvements					**$11,087.09**	**$43,892.82**		
G2010 Roadways					$0.00	$0.00		
G2020 Parkings Lots					$0.00	$0.00		

G2030 pedestrian Paving					$1,111.32	$2,279.56		
Concrete sidewalk, 4" thick, 4" gravel base, 4' wide	110.50	LF	$9.86	$16.18	$1,111.32	$2,279.56	31	$109.38
G2040 Site Development					$9,975.77	$41,613.26		
Wood deck, treated lumber, 2" x 8" joists @ 16" O.C., 2" x 6" decking - for porch and accessibility ramp to first floor	353.13	SF	$4.10	$10.24	$1,476.77	$4,610.40	31	$196.36
8' wall, cast-in-place, direct chute, 8" thick	195	LF	$42.73	$148.83	$8,499.00	$37,002.86	81	$561.75
G2050 Landscaping					$0.00	$0.00		
G30 Site Mechanical Utilities					**$0.00**	**$0.00**		
G3010 Water Supply					$0.00	$0.00		
G3020 Sanitary Sewer					$0.00	$0.00		
G3030 Storm Sewer					$0.00	$0.00		
G3040 Heating Distribution					$0.00	$0.00		
G3050 Cooling Distribution					$0.00	$0.00		
G3060 Fuel Distribution					$0.00	$0.00		
G3070 Other Site Mechanical Utilities					$0.00	$0.00		
G40 Site Electrical Utilities					**$0.00**	**$0.00**		
G4010 Electrical Distributions					$0.00	$0.00		
G4020 Site Lighting					$0.00	$0.00		
G4030 Site Communications and Security					$0.00	$0.00		
G4050 Other Site Electrical Utilities					$0.00	$0.00		
G50 Other Site Construciton					**$0.00**	**$0.00**		
G5010 Service and Pedestrian Tunnels					$0.00	$0.00		
G5020 Other Site Systems and Equipment					$0.00	$0.00		

Table 70. Savings from replacing brick exterior with wood exterior

7241.58	Wall Area (SF)
$10.66	Cost of New Wall / SF (B2010 148 3400)
$77,195	New Cost of Wall
$169,149	Current Cost of Wall
$91,954	Total savings

Table 71. Cost components for replacing the wood frame with a steel frame

Individual Activities	Inflation Factor	MasterFormat Code	Units	UOM	Unit Costs		Total Costs	
					Material	Installation	Material	Installation
B Shell							**$244,640.41**	**$198,834.97**
B10 Super Structure							**$159,611.39**	**$34,678.52**
B1010 Floor Construction							$159,611.39	$34,678.52
Steel joists	1.020	B1010 241 1450	8334	SF	$3.57	$2.71	$30,043.95	$28,796.05
Columns	1.020	B1010 208 7800	546	VLF	$235.00	$8.45	$129,567.44	$5,882.47
B1020 Roof Construction							$14,132.09	$5,655.93
Roof	1.020	B1020 108 1600	2861.95	SF	$4.08	$1.36	$11,791.19	$4,962.62
w/ columns	1.020	B1020 108 1700	2861.95	SF	$0.81	$0.19	$2,340.90	$693.31
B20 Exterior Enclosure							**$68,123.71**	**$152,990.55**
B2010 Exterior Walls							$45,337.79	$143,111.72
Solid Brick Wall, Single Wythe, Common Bond	1.020	B2010 125 1000	7241.58	SF	$6.20	$15.50	$45,337.79	$143,111.72

Table 72. Life span calculations for replacing the wood frame with a steel frame

Individual Activities	Inflation Factor	MasterFormat Code	Units	UOM	Life Span (Years)	Cost / Year
B Shell						
B10 Super Structure						
B1010 Floor Construction						
Steel joists	1.020	B1010 241 1450	8334	SF	71	$828.73
Columns	1.020	B1010 208 7800	546	VLF	83	$1,631.93
B1020 Roof Construction						
Roof	1.020	B1020 108 1600	2861.95	SF	74	$226.40
w/ columns	1.020	B1020 108 1700	2861.95	SF	83	$36.56
B20 Exterior Enclosure						
B2010 Exterior Walls						
Solid Brick Wall, Single Wythe, Common Bond	1.020	B2010 125 1000	7241.58	SF	86	$2,191.27