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Integrated Structural and Fire Protection Considerations in Building Design

A Major Qualifying Project

Submitted to the Faculty of

Worcester Polytechnic Institute

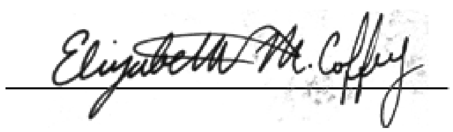
in partial fulfilment of the requirements for the

Degree in Bachelor of Science

in

Civil Engineering

By



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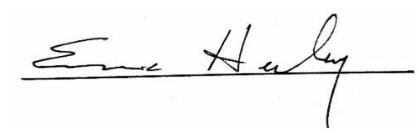

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Abstract

A five-story structure was created for modification to demonstrate the variations in design as a result of building codes, fire codes, and environmental factors. Environmental factors were considered in Boston, MA; Los Angeles, CA; and Miami, FL. Designs were evaluated based on estimated costs, and changes in the structural and fire protection layouts. This report includes structural and fire protection design calculations, architectural drawings, structural drawings, fire alarm drawings, and fire protection drawings for five different occupancy case studies.

Executive Summary

Introduction

A five-story structure was created for modification to demonstrate the variations in design as a result of building codes, fire codes, and environmental factors. Five design case studies were created and then altered for three geographic locations. These designs included a steel office building, a lightweight wood residential building, a lightweight wood and steel pedestal building with mercantile and residential uses, a steel office building with a two-story atrium, and a steel office building with an extended central corridor. Structural and fire protection designs were completed for each case based on the loading conditions, structure location, and building occupancies.

The goal of this project was to explore the differences in structural and fire protection design as a result of occupancy factors and geographical location. Design changes and the costs related to these variations were then explored.

Background

For the structural designs, the current edition of the *International Building Code (IBC)*, along with design specifications or standards from the *American Institute of Steel Construction (AISC)*, *American Society of Civil Engineers (ASCE)*, and *American Wood Council (AWC)* were used. *National Fire Protection Association (NFPA)* codes including *Life Safety Code (NFPA 101)*, *National Fire Alarm and Signaling Code (NFPA 72)*, and *Standard for the Installation of Sprinkler Systems (NFPA 13)* were references in designing the fire detection and suppression systems. *RS Means: Building Construction Cost Data* was used to determine line item costs of the structural and fire protection components within the designs.

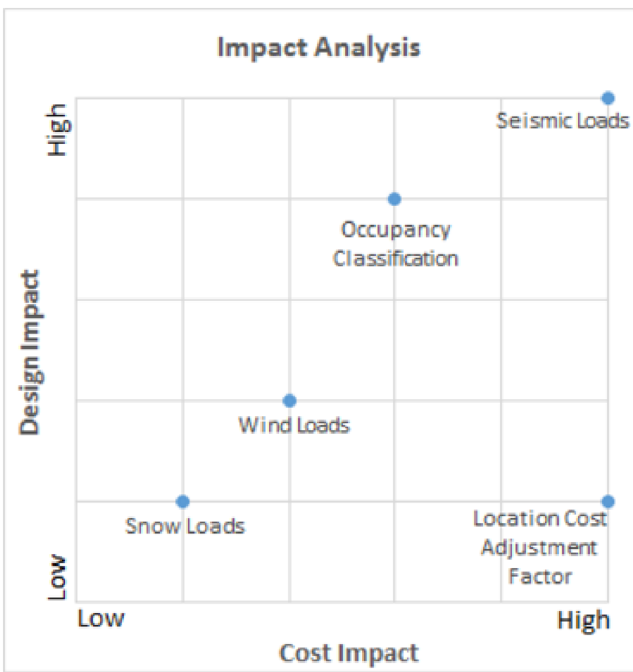
The structural and fire protection designs in this project were completed in compliance with the most recent *IBC* and *NFPA* codes, respectively. The structural designs were based on the 2015 edition of *IBC*. Fire detection designs were in compliance with the 2015 edition of *NFPA 101* and the 2016 edition of *NFPA 72*. Fire suppression designs utilized the criteria in the 2015 edition of *NFPA 101* and the 2016 edition of *NFPA 13*.

Results

Variations in structural design, fire protection system design, and costs were compiled upon completing the five different case studies in three geographic locations. For structural design, the most significant differences in the cases stemmed from the size of the frames required for the various lateral loading conditions. The spacing requirements for both the fire detection and suppression systems were consistent among the cases. The locations of devices, appliances, and sprinkler heads varied according to the occupancy classification of the structure and the architectural layouts of the rooms. The costs associated with each design were calculated with and without location factors and then compared to the base costs of the associated case study.

Summary and Conclusions

Throughout the course of this project, the effects of different environmental loading conditions, the occupancy classifications, and the cost factors associated with specific locations were considered and used within the design of the five case studies. These significant factors had an impact on both the structural and fire protection system designs for each case as well as the costs associated with each case.



The figure above is a visual depiction of the design and cost impacts of each significant factor considered.

Authorship

Within this report, the work was broken up categorically into structural design, fire protection design, and cost estimation. The team designed architectural layouts for business, residential, and mercantile occupancies.

Emma Healey was responsible for the structural design background, design criteria, and results sections. Emma designed the layout and sizing of structural wood and steel members through iterative calculation methods while staying within the sizing constraints presented by the architectural layouts of the structures. For each case, she designed structural frames to resist environmental loading conditions. Emma also completed the AutoCAD layouts for the structural designs.

Elizabeth Coffey was responsible for the fire protection design background, design criteria, and results sections. Elizabeth assisted Emma in the steel design for Case 1. She used a combination of heat transfer and hydraulic calculation methods to design and validate the fire detection and suppression systems. These designs took the geometry of the rooms, the intensity rating of the strobe light notification devices, the hazard classification of each occupancy, and the location of egress points into account. Elizabeth completed the AutoCAD designs for the architectural, fire alarm, fire protection layouts, and completed the final drawing set.

Both Elizabeth and Emma completed the cost estimation sections and the analysis of results.

We ascertain the above information to be correct and true.

Elizabeth Coffey

Emma Healey

Acknowledgements

We would like to thank Professor Lenard Albano for his assistance and insight throughout the course of this project. His knowledge of both structural and fire protection engineering was an invaluable resource in completing this project. We would like to extend additional thanks to Jess Rosewitz and Caitlin Burner for their assistance in wood design calculations and the steel design iteration flowchart respectively.

Capstone Design Statement

This Major Qualifying Project focused on the design and analysis of the structural and fire protection aspects of a hypothetical five-story structure. Courses in civil, structural, and fire protection engineering gave our team the tools to complete the engineering and design work for this project. The capstone design served as a bridge between school and the professional engineering workforce. The skills learned in the classroom were then applied to a real-world design problem. This project helped our team review the current code requirements and how these requirements vary under different design constraints. The main focuses of this project were:

Economic

A variety of cases were considered as final designs of the building. These cases differed in the structural and fire protection aspects of the design. By considering different design scenarios, a cost analysis was implemented for each case. From here, we determined the construction costs needed for each scenario and identified how each case differs. This allowed us to determine the structural and fire protection components that have the greatest cost impact.

Health and Safety

The use of building and fire codes is necessary in creating regulated, safe building and system designs. The *National Fire Protection Association 2015 (NFPA)* and the *International Building Code 2015 (IBC)* are two established codes used in the United States for design and construction. Both of these codes add different considerations that were taken into account when changing the building's use, material, and location. The most current editions of the *NFPA* and *IBC* codes (as of September 2016) were used to ensure that our designs are compliant on a national scale.

Manufacturability

The scope of the project considered a variety of different types of construction materials, designs, and calculations. Structural designs included standard sizes and designs for steel and wood members to limit costs for customization. In addition to structural considerations, the design was reconfigured to account for fire protection system layout. A full fire protection layout was designed for each case study as per *NFPA* and regional fire codes based on the occupancy types and hazard classifications. These designs included automatic suppression systems, heat and smoke detection devices, notification appliances, occupancy loads, and egress analysis.

Ethical

This project conforms to the *ASCE Code of Ethics* under *Canon 1: Hold Safety Paramount*. The designs within this project heavily consider lifesafety features and conformity of nationally recognized engineering standards. Everything that was designed for this project was in line with the constraints put forth by *NFPA* codes and the *IBC*.

Professional Engineering Licensure

In every discipline, there is a system of checks and balances to ensure high quality and professional work. In order to moderate the outputs from engineers throughout the country, the National Council of Examiners for Engineering and Surveying (NCEES) administer a nationally recognized set of exams. In the world of design, an engineer who takes and passes these exams is allowed to legally approve plans and declare the plans safe to implement and build. This responsibility is given to an engineer when they attain certification as a "Professional Engineer". This system allows for accountability of the designer if something fails, but also explicitly gives credit to them if they come up with a new and innovative design.

Achieving the status of a Professional Engineer is beneficial both professionally and personally. To acquire a PE license, an engineer must complete a rigorous process that includes earning a four-year college engineering degree from an ABET-accredited school and passing the Fundamentals of Engineering (FE) exam. Once this exam has been passed, the graduate becomes an Engineer in Training (EIT) and must work under a Professional Engineer (PE) for at least four years. To grow from the title of EIT to PE, the Engineer in Training must complete and pass a second, intensive, Principles and Practice of Engineering exam. Upon passing the exam, the EIT then becomes a PE for the state in which they took the exam. In order to practice in multiple states after receiving their license, the engineer must apply to each new state individually. Each state has different continuing education requirements to maintain a PE license.

Having a PE license can provide more opportunities for career growth and development because many companies view a PE as a sign of a determined and motivated individual. A licensed engineer can approve drawings and designs to be put forward onto projects, allowing the PE to take on more management roles and responsibilities. This gives the PE a high level of responsibility but also a high level of respect from peers and coworkers. Even in careers that do not require the use of a PE license, having the license showcases knowledge and drive to other professionals and clients. In addition to the professional benefits of a PE license, there is an increased pay scale for those with a license.

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Acronyms

Full Title	Acronym
American Institute of Steel Construction	AISC
American Society of Civil Engineers	ASCE
American Wood Council	AWC
Fire Alarm Control Panel	FACP
International Building Code	IBC
International Code Council	ICC
Load and Resistance Factor Design	LRFD
Major Qualifying Project	MQP
National Fire Protection Association	NFPA
Principles and Practice of Engineering Exam	PE Exam
Professional Engineer	PE
Worcester Polytechnic Institute	WPI

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1. Introduction

For decades, building and fire codes have improved safety in the built environment. As materials of construction and furnishings change, and predictive technology improves, the national codes and standards must reflect these changes. Although current codes provide a sufficient baseline for standard construction and protection, many significant changes in requirements are reactive to larger-scale incidents, rather than being proactive in nature.

An example of reactive changes is the code changes that occurred after the Station Nightclub fire in Warwick, RI in February 2003 (*NFPA*, 2003). This fire was caused by a pyrotechnic display that ignited highly flammable foam attached to the ceiling. After this fire occurred, many code sections, especially in *NFPA 1* and *NFPA 101* were added and revised. Many of the hundreds of deaths and injuries could have been prevented that night if the building and fire codes laid out more stringent design parameters for both existing and new buildings. This building had been inspected and was deemed code compliant at the time. After this incident, the importance of egress, fire spread through different materials, and increased training to Fire Marshals or equivalent Authorities Having Jurisdiction (AHJs) were all considered.

To explore this relationship and better understand the interaction of codes, a series of case studies was considered. Two 5-story tall control buildings were designed for commercial occupancy and residential occupancy. From these control buildings, a series of alterations were made and the significance of required code changes was considered. These code considerations included both structural and fire protection elements, as well as environmental criteria (such as seismic and wind loads based on location). Once full system designs were completed for each case study, a comprehensive comparison of the different cases using factors including lifesafety, differences in code requirements, and estimated construction costs was completed.

Once these two control buildings were designed, three additional cases were created by varying different aspects of the control cases. One of these cases was a hybrid of the two control cases by using a steel pedestal construction. The second variation was the alteration of the lobby of a control case to contain an atrium. The third variation was an extended version of a control case by doubling the length of the hallway. These cases all had design ramifications due to the differences in each building. A range of occupancies suited to each case was also chosen. From here, the case studies were each considered in three different geographic locations, and designs were changed according to load constraints, local building codes, and local fire codes.

As these cases were designed and considered, the changes in building and fire code requirements and restrictions were explored between each structure and location. These modifications were then noted and the necessary designs were made and implemented. The modifications were then explored to determine the monetary significance to the design by completing a structural and fire protection cost analysis for each case. As the costs were changed for each case, trends were identified in these changes and it was determined if the root change was because of architectural and structural differences between the cases, or if it was more a factor of geographic location of the structure.

This report outlines and details what goes into a structural and fire protection design process and the conclusions that can be draw from design considerations and post-design analysis. The beginning of the report provides the reader with background information on structural and fire protection design and code requirements. After this, the project scope and description is included followed by the design criteria used in the system and building layouts. After this, the final layouts are included in addition to final calculation results. Finally, a summary of the analysis of the design cases and conclusions drawn from these designs are detailed.

2. Background

The structures designed in this project were based on the layout of an existing building that was completed in 2011. This project uses the specifications in the *International Building Code* (2015) and the *National Fire Protection Association Codes* (2015 through 2017 depending on the code cycle). From these specifications, five modified design cases were created to explore.

2.1 Initial Structure

The structure modified for the purposes of this projects was a five-story structure whose architectural design is based on Worcester Polytechnic Institute's (WPI's) East Hall. This building was completed in 2011 and was compliant with building and fire codes at that time. The case studies in this project were redesigned to current *IBC* and *NFPA* code provisions. The initial design was a residential steel structure but the building materials and architectural layouts were modified for each case study in this project.

2.2. Codes

When any type of structure is designed, various codes are used to ensure that the building will be safe for its occupants. Building codes include aspects such as loading conditions of the structure, occupancy classification and building usages, height and area constraints, M/E/P requirements, and information regarding different types of construction materials. This includes everything from concrete and steel, to glass and glazing and plastics. Building codes, such as the International Building Code, also include requirements for fire protection materials and systems, and means of egress. In addition to the fire protection requirements shown in building codes, the International Fire Code (IFC) and the *National Fire Protection Association* (*NFPA*) discuss fire codes exclusively. These national codes can be adopted into law on a state-by-state basis as a whole or with state amendments. For the scope of this project, the International Building Code (*IBC*) and the *National Fire Protection Association* (*NFPA*) codes and standards were used.

2.2.1 Building Codes

The *IBC* is a series of model building codes released by the International Code Council (ICC) every three years. It has been adopted throughout the United States with certain amendments and adaptations enacted by individual states. The 2015 edition contains 35 chapters and 13 amendments. For the purposes of this project, the *IBC 2015* were used.

2.2.1.1 Structural Design

The building of a structure has many code provisions and reference standards regarding the structural design, which are covered in Chapter 16 of the *IBC*. These design criteria include loading conditions, risk categories, the required strength, and design factors for different types of structures to decrease the risk and limit the consequences of structural failure.

Structures have different load combinations depending on their location and what environmental factors will affect it. *ASCE 7-10*, Chapter 2 presents seven Load Combination equations for Load and Resistance Factor Design (LRFD) as listed in Table 1.

Table 1:ASCE 7-10 LRFD Load Combination Equations

LRFD Load Combinations	**Environment Factor Equations**
Load Combination 1	$1.4D$
Load Combination 2	$1.2D + 1.6L + 0.5(L_r \text{ or } R \text{ or } S)$
Load Combination 3	$1.2D + 1.6(L_r \text{ or } R \text{ or } S) + (L \text{ or } 0.5W)$
Load Combination 4	$1.2D + 1.6W + L + 0.5(L_r \text{ or } R \text{ or } S)$
Load Combination 5	$1.2D + 1.0E + L + 0.2S$
Load Combination 6	$0.9D + 1.0W$
Load Combination 7	$0.9D + 1.0E$

These equations use a combination of different dead and live loads in conjunction with various factors of safety. These loads are Dead (D), Live (L), Roof Live (L_r), Rain Load (R), Snow Load, (S), Wind Load (W), and Seismic Load (E). The Governing Load combination is determined by the greatest loading effect on the structure.

2.2.1.1.1 Risk Category

All buildings and structures are assigned a risk category based on the nature of the occupancy. There are 4 risk categories that range from low risk storage facilities (Risk I), to facilities of high importance, such as emergency shelters and toxic material storage (Risk IV).

This project considered a Risk II building which is the classification for miscellaneous structures that do not fall into risk categories I, III, or IV.

Risk Categories are given to all structures based on their hazard to human life in the event of failure (*IBC 1604.5*, 2015). Higher values indicate that more conservative design factors should be used for the structure. This allows for more resilience of the structure against environmental changes. Structures such as hospitals, aviation control towers, and power generating facilities are categorized as Risk IV due to their importance. Any structure that is categorized as Risk I is anything that "represent a low hazard to human life in the event of failure," (*IBC Table 1604.5*, 2015).

The Risk Categories are used when developing factors of safety for different load types. The loads which use these factors are lateral loads such as wind and seismic forces. Wind and seismic are dynamic forces that have the ability to damage a structure so a structure requires a more conservative design to combat these forces. Snow loading is less dynamic than wind and seismic loading. It is also considered a gravity load which requires increased load bearing capabilities instead of increased structural stiffness.

2.2.1.1.2 Wind

Section 1609 of *IBC 2015* covers wind loads that must be considered in structural design. These loads are determined in accordance with Chapter 26 of *ASCE 7-10* (*IBC 1609*, 2015).

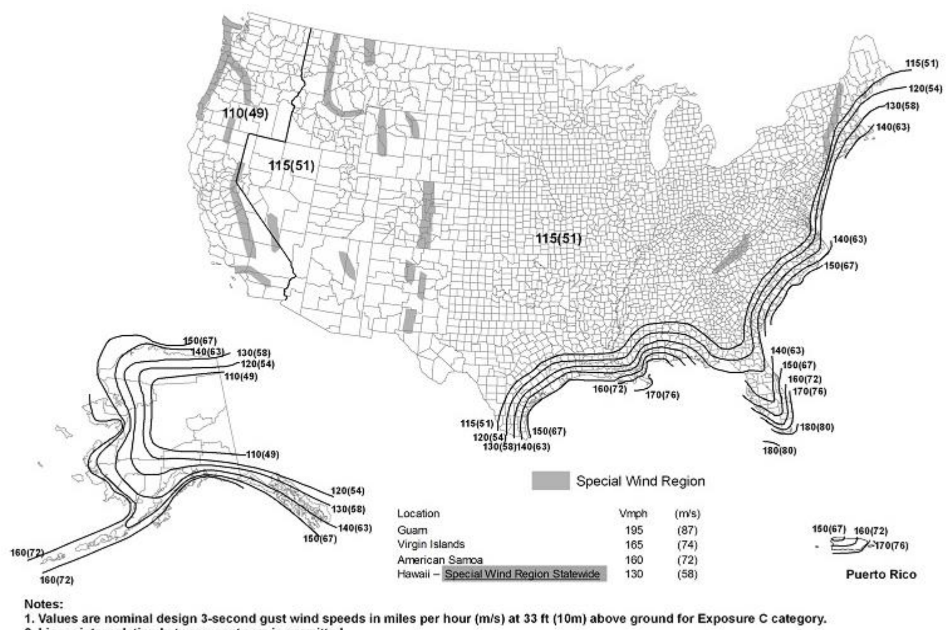


Figure 1: Ultimate Design Wind Speeds for Risk Category II Buildings and Other Structures (IBC 1609, 2015)

Wind loading varies throughout the country based on the weather patterns in the region. The ultimate design wind speed, V_{ult}, is determined by the wind loads shown in the map in Figure 1. This map is Figure 1609.3(1) from *IBC 2015* which is used for Risk Category II Buildings. The contours on the map indicate the ultimate wind speeds, ranging from 100-200 mph. Most regions use 100 mph or 105 mph as the standard V_{ult} but regions on the east coast and the Gulf of Mexico have higher values and a larger range due to the increased risk of hurricane force winds.

2.2.1.1.3 Seismic

IBC 2015 discusses seismic forces and loading in Section 1613: Earthquake Loads. Seismic forces must be considered for all structures except for those with incidental human occupancy, as well as detached dwellings. As the structures under study do not fulfill either of these requirements, they were designed per the Maximum Considered Earthquake. The map in Figure 2 shows the Ground Motion Response Acceleration for 1-Second Spectral Response.

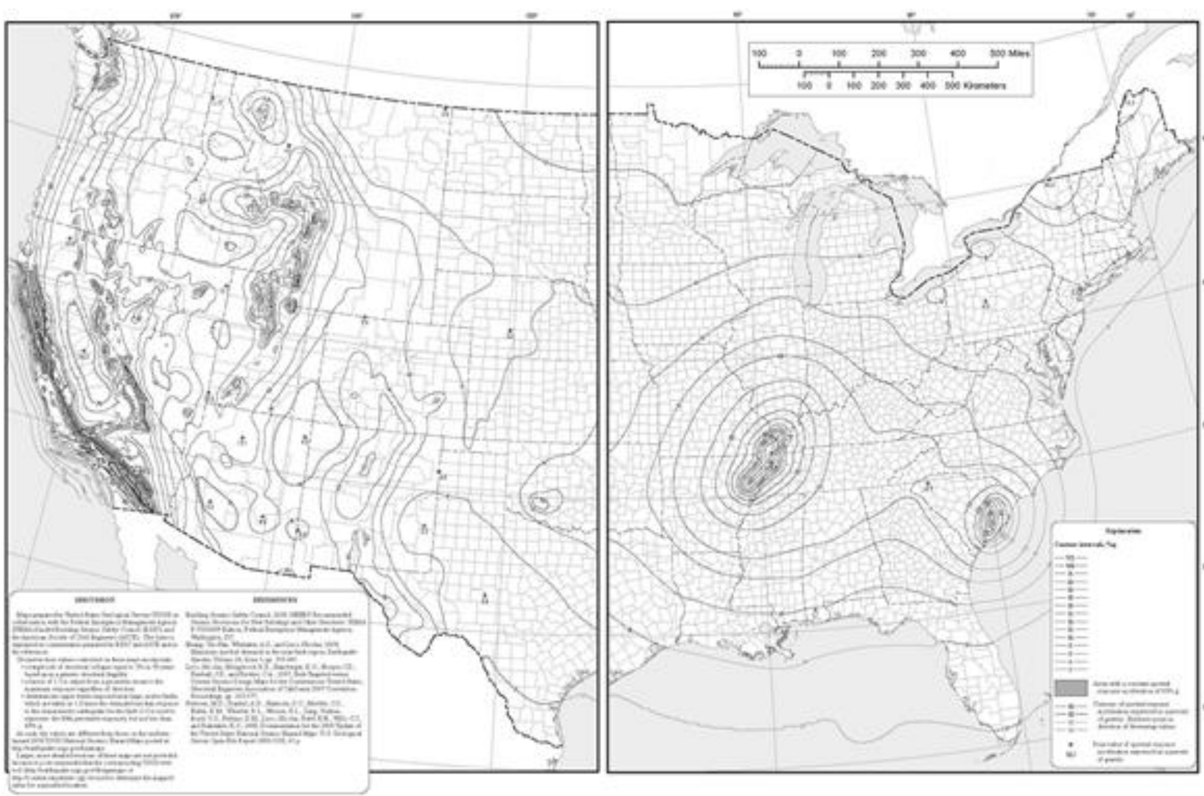


Figure 2: Risk-Targeted Maximum Considered Earthquake Ground Motion Response Accelerations for the Conterminous United States of 1-Second Spectral Response Acceleration (5% of Critical Damping), Site Class B (IBC 1613, 2015)

Similar to Wind Loads, these values vary across the United States, depending on both historic occurrence and intensity. These values, as well as the Risk Category of the structures were defined, and a Seismic Design Category, A, B, C, or D, was assigned to the buildings.

2.2.1.1.4 Snow

Section 1608 of the *IBC* pertains to information about snow loading. Snow loads are considered to be a gravity load that is added onto the roof of a structure. This value is given in pounds per square foot so it can be added into the dead and live load already considered on the structure. Like wind and seismic loads, snow loads vary geographically, as seen in Figure 3. These loads also vary at different elevations. The values given on the chart are to be considered for structures at or near sea level, and the values in parentheses are the upper elevation limits.

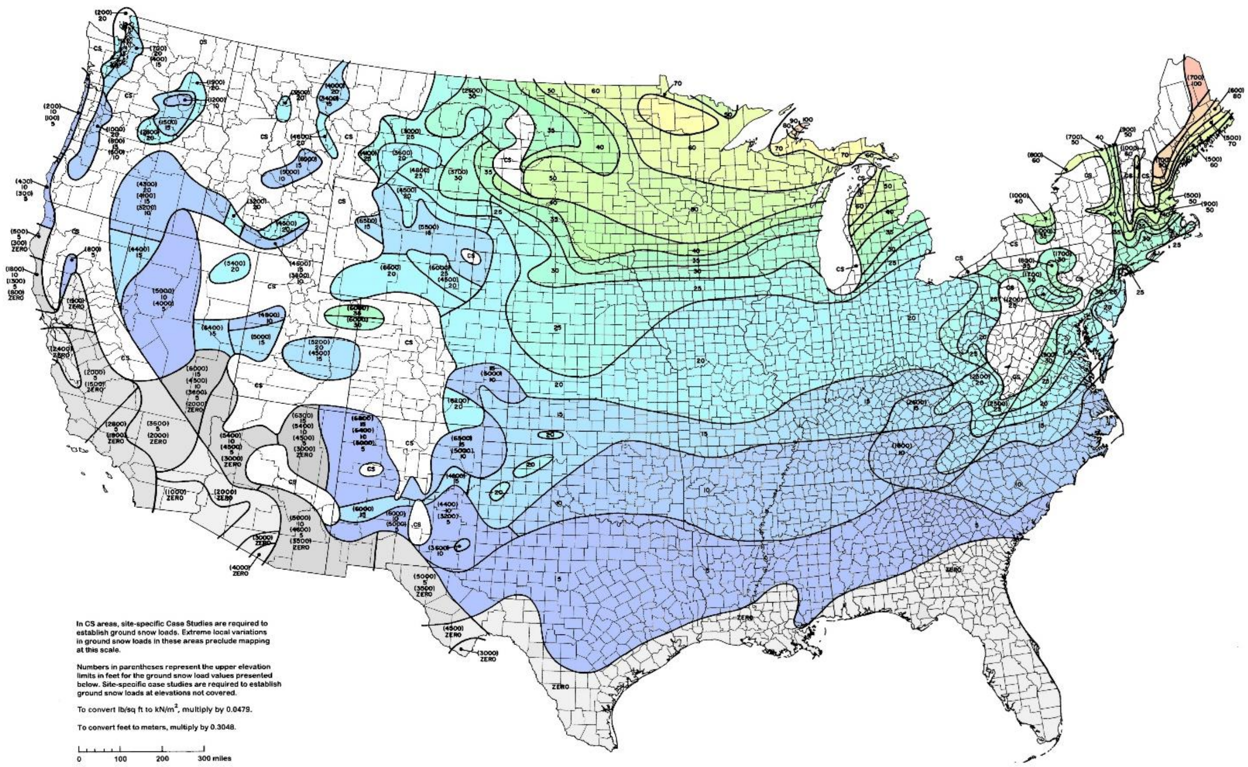


Figure 3: Ground Snow Loads, for the United States (psf) (IBC 1608, 2015)

2.2.1.2 Building Occupancy

Building Occupancy is broken up by the *IBC* into ten different subgroups depending on the intended use for the facility. There are different structural limitations associated with each occupancy type and different live loading values must be considered in the design. The occupancy types include Assembly, Business, Educational, Factory and Industrial, High Hazard, Institutional, Mercantile, Residential, Storage, Utility, and Miscellaneous. Some of these groups are subcategorized in order to add specifications needed for variations. These specifications are used for individualized cases with additional special considerations under one main category. For example, a single-family dwelling and a high-rise apartment building are both considered residential, but need to be designed very differently due to height, building material, and number of occupants. The three occupancies that should be noted for this project are Business: Group B (*IBC 2015, Section 304*), Mercantile: Group M (*IBC 2015, Section 309*), and Residential: Group R-2 (*IBC 2015, Section 310.4*) (Table 2).

Similar to the *IBC*, the *NFPA* codes dictate different occupancy classifications depending on the use of the building. For fire protection, the occupancy classification is used to determine the type and intensity of sprinkler system needed in the building, as well as the spacing required for detection devices such as smoke and heat detectors.

Table 2: Description of Occupancy Types

Occupancy Type	**Group**	**Description**	**Examples**
Business	B	Offices and professional use, including storage of records and accounts. Classified if any portion is used for business.	office facilities, banks, car washes, laboratories, outpatient clinics
Mercantile	M	Display, storage, and sale of merchandise.	department stores, drug stores, gas stations, retail, sales rooms
Residential	R-2	Facilities with areas used for sleeping purposes that are not classified as Institutional (Group I).	transient sleeping units (apartments, dormitories, religious living facilities)

2.2.2 Fire Codes

The *National Fire Protection Association* (*NFPA*) is an organization that writes and revises codes and standards for use in fire protection design at both state and municipal levels.

These codes and standards are typically adopted by local governments and amended if stricter codes are desired. Each *NFPA* code is revised and released in a three-year cycle, and the local government determines which version is used. *NFPA 1 (Fire Code)*, *NFPA 13 (Standard for the Installation of Sprinkler Systems)*, *NFPA 72 (National Fire Alarm and Signaling Code)*, and *NFPA 101 (Life Safety Code)* were the primary codes used for the fire protection systems designed in this project.

2.2.2.1 Fire Protection Systems

Fire protection systems are designed and implemented to mitigate the effects of a fire hazard. According to *NFPA 1 [Section 3.3.120]*, a fire hazard is defined as “any situation, process, material, or condition that, on the basis of applicable data, can cause a fire or explosion or that can provide a ready fuel supply to augment the spread or intensity of a fire or explosion, all of which pose a threat to life or property.” Fire detection and suppression systems are used to protect both the lifesafety of building occupants and emergency responders, and to mitigate property loss or damages. These systems are implemented in a variety of occupancy classifications including mercantile, business, commercial, and residential.

2.2.2.1.1 Fire Detection Systems

Fire detection systems are used in both sprinklered and unsprinklered structures. A detector is defined as “a device suitable for connection to a circuit that has a sensor that responds to a physical stimulus such as gas, heat or smoke” *[NFPA 72; Section 3.3.66]*. These systems detect fire signatures within a room and notify the occupants of a potentially dangerous fire scenario. For system design, characteristics such as the physical size and occupancy type of the building are taken into consideration to determine the ambient conditions occurring in the building. For example, if there is a room with a high ceiling, smoke detectors may have to be placed closer together. Another example could be using linear heat detection along storage shelves in a warehouse as opposed to only placing heat detectors at the ceiling level.

2.2.2.1.2 Fire Suppression Systems

Similar to fire detection systems, the design criteria for a fire suppression system is based upon design areas, occupancy types, and hazard classifications of the building. These suppression systems are used to limit the spread of flames and damage caused by fire. Fire suppression systems include water-based, foam application, and inert gas injection, depending on the space being protected. For a typical residential or commercial occupancy, a water-based automatic sprinkler system is typically proficient because the type of fire is not likely to be extremely fast-growing and is not usually oil-based. Foam suppression systems are typically used where the threat of chemical or oil-based fires is high, and inert gas injection systems are most common in areas with expensive or delicate electronics that would be damaged by water or foam.

2.2.2.2 Egresses

NFPA 1; Section 3.3.177 defines means of egress as "a continuous and unobstructed way of travel from any point in a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit, (3) the exit discharge." Egress must be considered to determine if the number and size of stairways is appropriate for the occupant load. When calculating the permitted occupancy of specific rooms and entire buildings, an egress analysis is required. This analysis uses criteria such as the corridor lengths, door widths, stair risers, and similar factors to determine how many people can safely exit a building in a timely manner during an emergency.

2.2.2.3 Stairs

Stairs are considered in accordance with *NFPA 101* for egress analysis. The riser, tread, and width of a stair may have significant impacts upon egress requirements and occupancy loads. Currently, stairs are the main means of egress from a multistory building; this makes the quantity and characteristics of staircases within a building instrumental in fire safety design. Appendix G shows the drawing set produced during this project with the architectural layouts that were designed. In these architectural layouts, there are four sets of stairs in Cases 1-4 and six sets of stairs in Case 5. This design shows a direct correlation between the number of suites within the building and the number of stairs included in the design.

2.2.2.4 Occupancy Types

As discussed in Section 2.2.1.2, *IBC* and *NFPA* codes have similar occupancy classifications, but both must be considered within a design. An occupancy as defined by *NFPA 1; Section 3.3.183* is "the purpose for which a building or other structure, or part thereof, is used or intended to be used". Classification of building usage helps to determine the fire detection and protection systems appropriate for the space based on the typical fuel loads present in different occupancies.

2.2.2.5 Hazard Classes

A hazard rating is "the numerical rating of the health, flammability, self-reactivity, and other hazards of the material including its reaction with water" [*NFPA 1; Section 3.3.143*; Hazard Rating*]. Similar to occupancy types, the hazard classification helps the designer determine the appropriate levels and ratings of fire protection systems within a structure. When designing a fire protection system, a "design fire" is typically estimated based upon the combustibility of materials within a building. This design fire allows for estimating a worst case scenario heat release rate and growth time of a fire. The method of using a design fire for a specific occupancy is a performance-based approach in the sense that the response is tailored to the specific hazard at hand. For some systems, this can be a prescriptive design based on NFPA codes, and in other systems, the design fire may directly influence the spacing of detectors and discharge criteria of suppression systems.

2.2.2.6 Stratification

When structures contain a room or area where the ceiling level is above one story in height, a phenomenon called "stratification" may occur [*NFPA 72; Section 3.3.277*]. Typically, the smoke in a fire creates a ceiling jet that begins at the ceiling above the fire and moves outward from that space, heating up the ceiling and surrounding combustibles. In larger spaces, the air being entrained into the fire and the smoke layer has the potential to cool the smoke down to the temperature of the surrounding air. This is dependent upon the geometry of the compartment, the fuel being combusted, the air flow in the room, the ambient temperature, and a variety of other environmental factors within the room. Designs are in these types of spaces typically compensate for potential stratification by using alternate methods to smoke, heat, or fire detection than the typical ceiling-mounted smoke detector.

2.3 Structure Types

The *IBC 2015* has specific chapters dedicated to different types of building materials and the minimum requirements and limitations for each. Chapters 19-26 include concrete, aluminum, masonry, steel, wood, glass and glazing, gypsum boards, and plastic. For the design and analysis of the proposed structure, steel (Chapter 22) and wood (Chapter 23) structural framing systems were used. Building construction type was also considered for fire resistance rating in the sprinkler system design [*NFPA 13*]. The system protection area limitations vary based on the occupancy hazard type as dictated in *NFPA 13; Section 8.2.1*. These occupancy hazard types are based on the intended uses of a space and the expected fire size for that space. A "system protection area" has been determined and recorded in *NFPA 13* for each hazard classification. The protection area is used as a sample area of sprinkler operation for feasible worst case scenario fires in a specific type of space. Having these protection area limitations allow the designer to ensure that there will be enough water and pressure in a system for operation during a fire. Table 3 shows the different system protection area limitations based on occupancy type as indicated in *NFPA 13*.

Table 3: System Protection Area Limitations for Occupancy Types

Occupancy Type	System Protection Area Limitations
Light Hazard	52,000 ft^2
Ordinary Hazard	52,000 ft^2
Extra Hazard	40,000 ft^2
Storage	40,000 ft^2

2.3.1 Steel Frame

Steel is one of the most desirable structural frame materials for mercantile, commercial, and large-scale residential buildings. It is a high-strength material with a wide range of design flexibility and accommodate large bay sizes. Because of these characteristics, both architects and engineers benefit from using steel in construction. In addition, in areas with local access to steel manufacturing, steel is less expensive than concrete and it can be built much quicker due to a lack of curing time. Steel is also not affected by weather during construction. This is beneficial when building in locations with harsh winters.

2.3.2 Lightweight Wood Frame

Wood framing can be used in Risk I and II type buildings. It is particularly favorable for residential construction due to its inexpensive nature. Although lumber comes in certain standard width and height dimensions, the lengths can be easily modified on site which makes wood a more forgiving construction material than steel. Wood is much more susceptible to environmental changes which affects the time of year and location wood can be constructed in. Building codes also affect the constructability of wood. The *IBC 2015* limits construction to five stories but many local codes add their own restrictions making it a less desirable material for many types of structures.

2.3.3 Pedestal with Wood Frame

Structures do not necessarily need to be constructed of only one building material. Wood can only be used for construction to a limited height, because of this, it is sometimes built on top of a stronger, less combustible, base material. The base material could be concrete walls, steel columns, or a combination of both to create the “pedestal”. All materials used in these structures must be in compliance with the building codes.

2.4 Special Conditions

When a building does not conform to traditional design, considerations of its variations must be accounted for. Designs may include unique structural or aesthetic elements that have an effect on how the code is interpreted and implemented. Examples of special conditions that were considered in this project are atriums and non-traditional fire doors.

2.4.1 Atrium

As defined in *NFPA 101; Section 3.3.27*, an atrium is a “large-volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; an elevator hoistway; an escalator opening; or as a utility shaft used for plumbing, electrical, air-conditioning, or communications facilities." Atriums are a common design element in larger buildings to open the interior space and provide interest points to a structure. Because atriums are not uncommon, there are specific areas of the code that detail the variations in treatment required. These specific criteria typically address smoke control and detection as well as automatic sprinkler protection or other suppression techniques. Including an atrium is a concern in the design of a structure because there is less division between levels which allows for fire and smoke to spread more easily.

2.4.2 Accordion-Type Fire Doors

The code must adapt and change with improvements and expansion of technology. A double accordion-type fire door has been around for decades *[Won Door]* but has recently been rising in popularity as building owners value the aesthetic of an open space over a bay of traditional fire doors. These doors function through a heat or smoke detection system that triggers their release from a recess in the wall. After closure is triggered, this moveable wall will automatically extend to the opposite wall on a ceiling track. The concerns for appliances like these mainly extend to the compartmentalization speed and the robustness to function under emergency conditions.

2.5 Cost Estimating

Before a construction project begins, the overall cost of the project is estimated. These estimates are based on standards for cost estimating and cost analysis. *RS Means Building Construction Cost* was used as a source of product cost data and was utilized for cost compilation and analysis. Estimating is completed using a method called "takeoff" and then the total project is priced per square foot of the structure. Some aspects of a project must be determined using takeoff but others can be more generalized by estimating per square foot. When there is insufficient data in the design specifications, elements including electrical wiring, HVAC, and plumbing can be generalized to cost per square foot. There are benefits and drawbacks of using takeoff versus cost per area, therefore both methods are initially considered for every product to achieve the most accurate price.

2.5.1 Takeoff

Estimating using the "takeoff" method involves determining how much of a specific material is going to be used and then multiplying by the cost per unit. For example, steel is estimated using this method by pricing per linear foot of each piece size. This method was used in estimating the cost of each steel design case. When materials are measured using takeoff, a certain amount of buffer is calculated in to ensure that the amount does not come up short. Takeoff can be calculated by hand, but there are also software programs available that can do many of these calculations at once, expediting the process.

2.5.2 Square Footage

When pricing a job using area estimation, only certain aspects are included in this cost. Labor is one of the items that is estimated per square foot. Other items such as wiring and plumbing can be estimated using square footage because many structures built for the same uses have similar amounts of these items per square foot. These items were estimated in the design cases because there was not enough information to do a takeoff. This type of estimating can be less precise than takeoff because each amount of product is not being calculated throughout the entire building, but it is generally accurate enough that estimators use it as a way to assist in establishing their bid.

2.6 Conclusion

Through the design and analysis of both structural and fire protection systems, the relationship and use of codes for varying occupancy and structural characteristics will be explored. Many different portions of *IBC* and *NFPA* codes and standards were consulted to complete this project. Discussion of the results includes the relative cost effectiveness of each design as well as the interactions between various code provisions and requirements. This was completed through analysis of five different cases located in Boston, Miami, and Los Angeles, and exploring variations in structural and fire protection system design.

3. Problem Statement

Throughout this project, different structural factors were investigated for their effect on the design of structural members and fire protection systems. The design variations were based on steel and wood construction materials. For each different case study, the structural design utilized either a steel or wood structural base with a variety of design features that affected the architectural, structural, and fire protection layouts. The fire protection system design included a sprinkler layout, smoke detection, notification devices, heat detection, and smoke control systems where appropriate. The design criteria for each case is shown in Table 4.

The first case was a 5-story, commercial occupancy. This structure was designed using steel beam and girder framing with a slab floor. Dead and live loads associated with the occupancies and the mass of structural members were considered in the design of the frame. Brick facade walls were used for the exterior enclosure. Due to these structural decisions, the building was classified as Construction Type II (B). Type B refers to the structural steel members that do not have a fire protective coating. The office space in this structure was classified as a Light Hazard Occupancy in accordance with *NFPA 13; Chapter 5*, and fire protection systems were designed appropriately to these criteria with special considerations given to spaces such as mechanical rooms.

The second case is a 5-story, residential occupancy. This structure was designed using a light frame wood configuration. Dead loads and live loads associated with the structural members and residential occupancies were considered in this design. Exterior paneling was used in this case. With these structural elements and wood composition, this building was classified as Construction Type V (A). As a residential occupancy, none of the structural wood members were exposed to the living space. The residential spaces within the building were classified as a Light Hazard Occupancy with the mechanical spaces classified as Ordinary Hazard 1 (*NFPA 13; Chapter 5*).

For Cases 3-5, design variations were added to Cases 1 and 2 by using the basic steel and wood design layouts. Case 3 combined structural steel and wood with a pedestal design containing mercantile and residential occupancies. Case 4 considered the design variations necessary if a two story atrium was located on the ground floor of a steel office building, and Case 5 contained an extended central hallway within a steel office building. With each variation, required changes for the structural components of the building were noted, and incorporated, and any differences in necessary fire protection systems were implemented. Upon completion of these designs, a breakdown of variable construction costs was conducted for each case. Depending on the material or component being considered, an analysis was conducted in cost per unit floor area or cost per item.

All cases were then compared on the criteria of cost, occupancy use, building and fire code requirements, and design simplicity. From here, strategies were proposed to improve the performance and ease of future design in each area.

Table 4: Case Study Descriptions

Case Number	Primary Occupancy Type	Structural System and Enclosure	Construction Type	Fire Protection
Case 1: Structural Steel Office Building	Commercial (Office Use) *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade	Construction Type II	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 2: Lightweight Wood Construction Residential Building	Residential *Light Hazard*	Lightweight Wood Exterior Vinyl Siding	Construction Type V (A)	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 3: Mixed Occupancy	Mercantile Ground Level, Residential Above *Ordinary Hazard (Group 2)*	Steel Pedestal with Lightweight Wood Concrete Slab Floor Exterior Vinyl Siding	Construction Type V (A)	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 4: Central Atrium with Horizontal Fire Doors	Commercial *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade Altered Wall Design	Construction Type II (B)	Sprinkler System, Detection and Alarm Systems, Smoke Control System, Egress Analysis, Horizontal Fire Doors
Case 5: Additional Building Wings	Commercial *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade	Construction Type II (B)	Sprinkler System, Detection and Alarm Systems, Egress Analysis, Horizontal Fire Doors

3.1 Integration of Structural Design and Fire Protection System Design

In a typical design process, the architectural layout is created first, followed by the structural elements of the building with an integrated HVAC layout, and the fire protection systems would be designed last. For this project, the structural, architectural, and fire protection design components influenced one another and grew co-dependently. The general parameters for the building, such as location, occupancy type, and size, were determined at the beginning. Design considerations within the structure such as the story height and corresponding drop ceiling height, the stairway locations, and other structural features were greatly influenced by the projected fire protection design.

Fire protection system design typically depends on the layout and projected usage of a space. Influencing the structural and architectural layout of a building with fire protection considerations from the beginning was both a hindrance and a positive strategy. It was difficult to design a fire protection system for a layout that was prone to changing. The full extent of the architectural layout was also unknown at the time of the fire protection designs. This process of designing and changing the fire protection layouts as architectural features are altered could represent a more accurate portrayal of what may happen when working in industry as building owners change their minds about certain features in their construction project.

The design elements influenced by fire protection were put in place to increase the cohesiveness between the layout and the proposed lifesafety protection of the building. In this way, it was very beneficial to base the designs on each other as they were still in incipient stages. Design decisions like the height of the drop ceiling allowed for ample room for sprinkler piping and electrical conduit, while the use of acoustic ceiling tiles (ACT) would create a more pleasing aesthetical choice for both sprinkler head installation and smoke detectors and notification systems. Another example of this co-dependent design was in considering the atrium and options to retain the surrounding walkways as viable egress routes. Utilization of horizontal fire or smoke doors gave the leniency to not require a different primary egress route.

Intertwining the structural, architectural, and fire protection designs allowed for both aesthetic and lifesafety components to be considered from the beginning. By making these designs interdependent, one aspect of the structure did not interfere with the intended outcome of a different discipline's design.

3.2 Design Considerations and Alterations

As the design process of this project developed, some of the Cases were modified or eliminated. In the initial proposal, there were two Control Cases and five modified cases for a total of seven cases. Cases I and II remained the same as in the initial proposal but were no longer considered “control cases” because they were no longer the basis of the remaining cases. Case III was originally defined with commercial space on the first floor and residential on the subsequent floors. This was changed to include a mercantile space on the first floor instead of a commercial space because it would increase the hazard class from Light to Ordinary Hazard Group 2. All other cases were Light Hazard so this change added variety to the hazard classes, and as a result, allowed for more modifications in the Fire Protection design.

The final modification that was made was combining the case including an atrium with the case including accordion-style fire doors. In spaces with atriums, one of the most critical issues in the Fire Protection design is the compartmentalization of the smoke to prevent it from reaching the upper floors through means of the open atrium. Accordion-style fire doors are a useful solution to this issue so the two cases were combined to create a more cohesive modification and solution. In addition to the modifications, the case including Alternative Flooring Systems was removed from this project. This Case would be interesting to pursue further but it was not cohesive with the other cases in this project so it was removed. After all of the modification were made, the final project included five case studies.

4. Design Criteria

The cases in this project were created to provide a variety of both structural and fire protection conditions. The main construction materials used in these cases were structural steel and lightweight wood. Having these two variations in construction design allowed for a breadth of different design considerations.

4.1 Structural Design

The structural design for each case was created by superimposing the structural members over the architectural drawing of the building. Each floor was laid out identically in AutoCAD to maximize the efficiency of the design. The architectural layout was considered in each design layout to ensure the columns would not obstruct doors or hallways and to maximize the number of columns located within walls.

4.1.1 Steel Design

Various design iterations were performed until all beam members were of a reasonable size. The beam spacing needed to be reduced because the initial spacing was unable to support the weight of the flooring system while maintaining a reasonable size. In the first design, the beams in Section 4 of Figure 4 were over 25 feet in length.

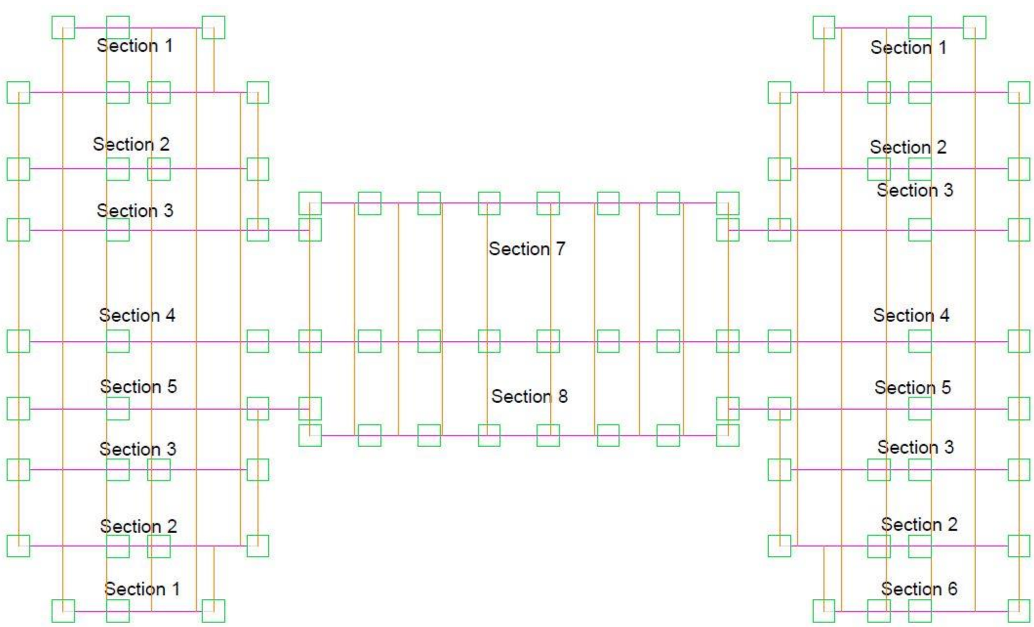


Figure 4: Beam Layout Version 1

A beam of this length would deflect excessively which caused it to have a web larger than the 24 inch desired for the ceiling depth. To remedy this, another row of columns was added to the other side of the hallway which divided the 25-foot span in half (Figure 5).

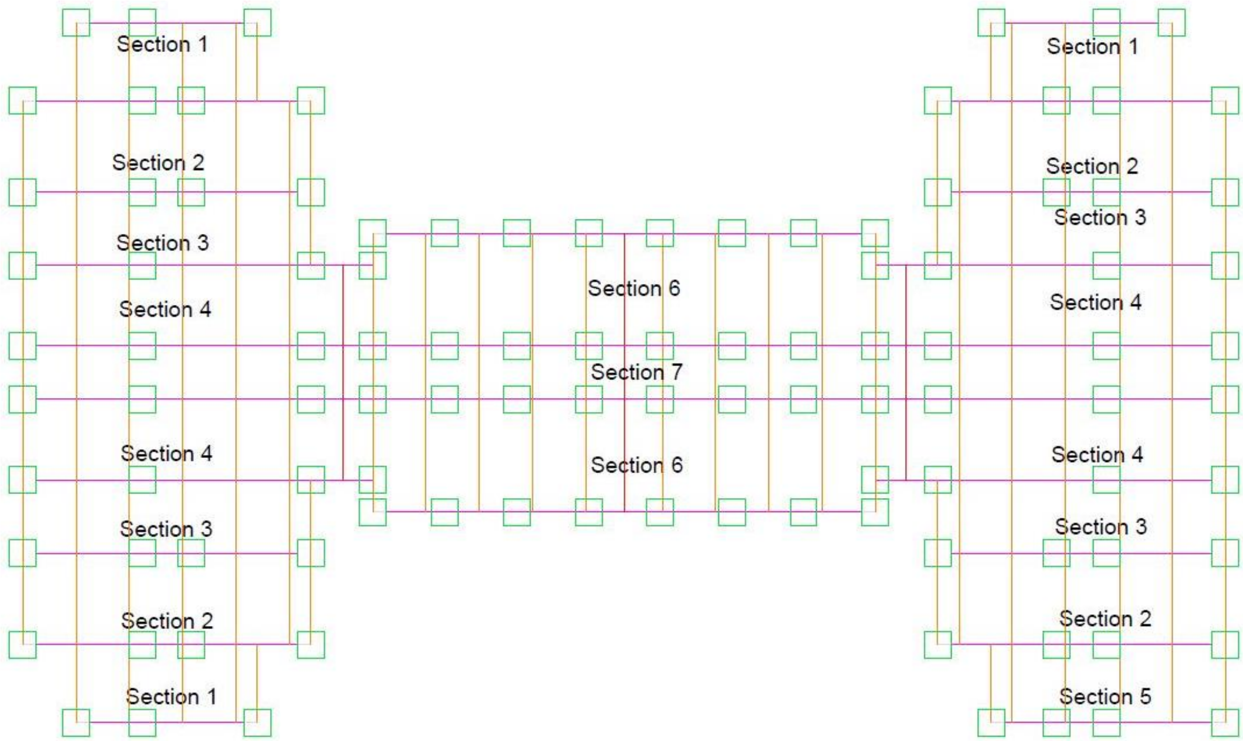


Figure 5: Beam Layout Version 2

However, this design was not able to be used because the beams in Section 6 of Figure 5 were almost 22 feet in length which also caused too much like deflection, similar to Section 4 from the first design iteration. The two areas on the side of the structure had adequate beam lengths so the beams and girders were rotated 90° to make the beams run horizontally through the center hallway of the structure. This design had adequate sized girders but the beams in Section 7, Figure 6 were sized at W24x62 in the condition that did not include environmental loads, which was the same depth as the ceiling.

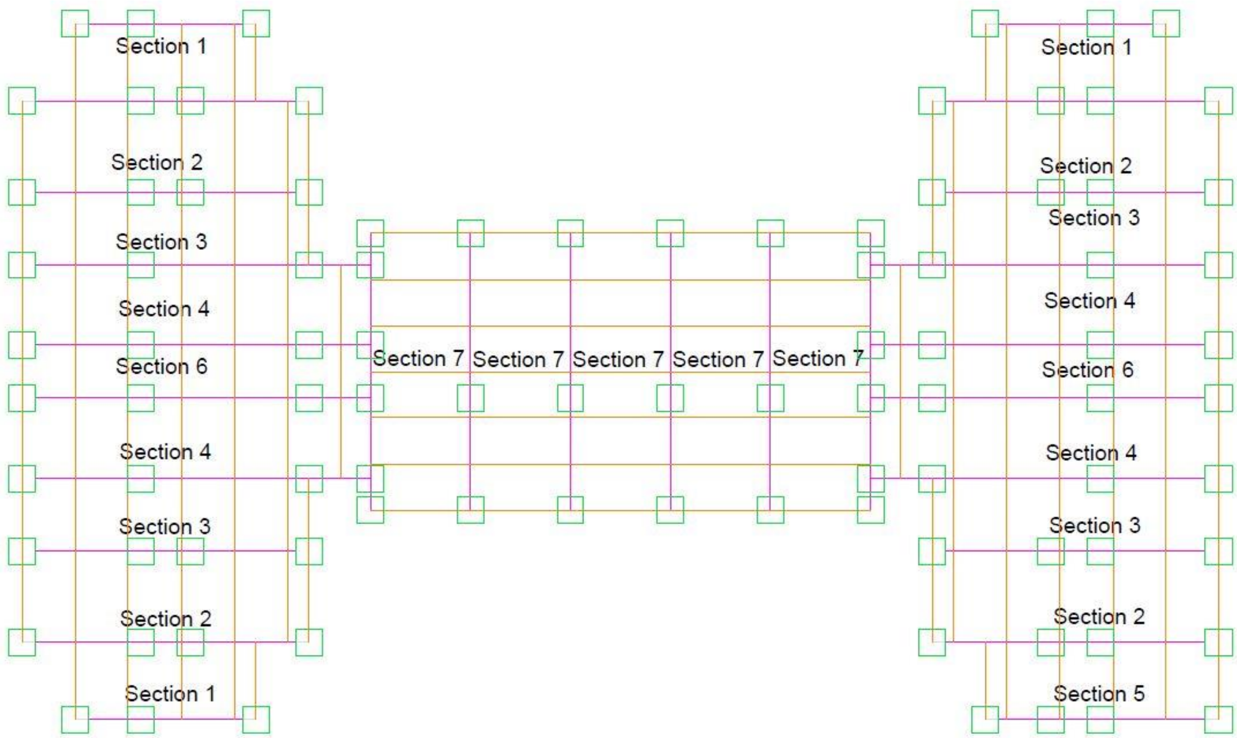


Figure 6: Beam Layout Version 3

To create more clearance in the ceiling for MEP, another row of columns was added to the center of the structure which reduced the Section 7 beams to W14x26 which gave 10 inches of clearance (Figure 7).

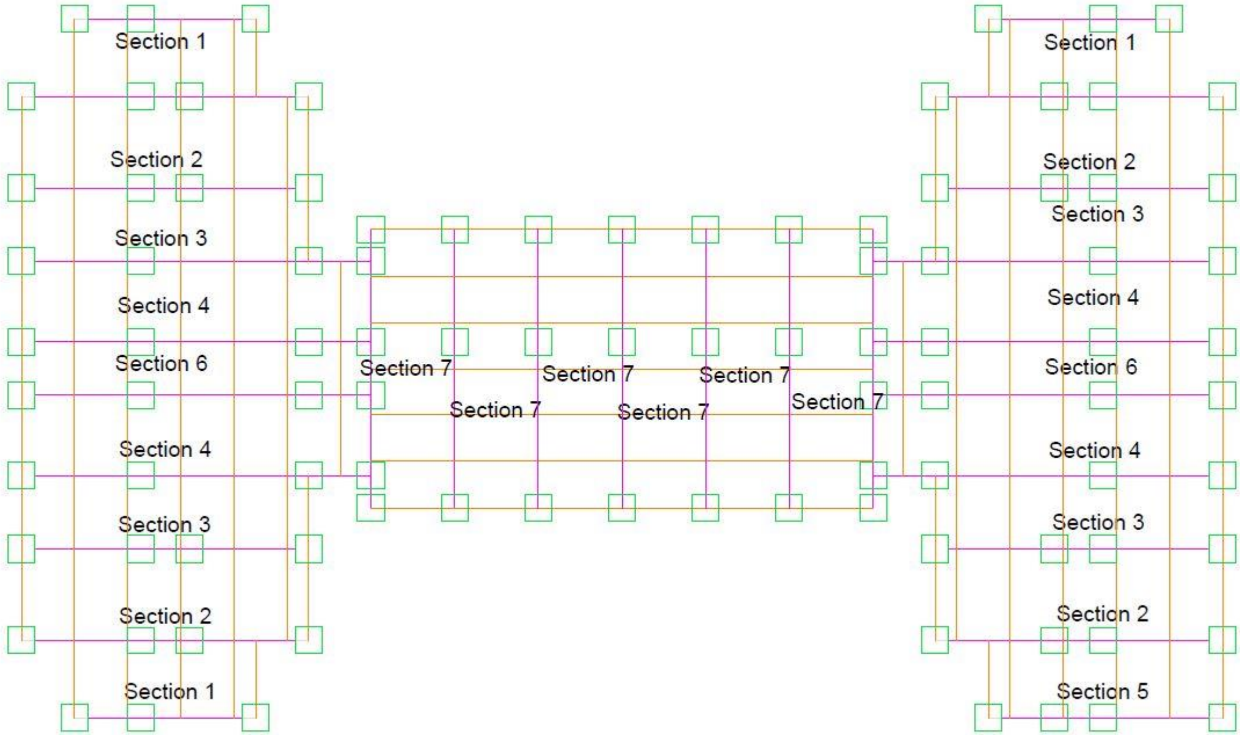


Figure 7: Beam Layout Version 4

Throughout the design process, each section of beams was calculated first taking into account dead and live loads for the appropriate structure type (See Table 5).

Table 5: Case 1 Loading Conditions

Dead Load	
Reinforced Concrete	43 lb./ft^2
Steel Decking	2.75 lb./ft^2
MEP	10 lb./ft^2
Finishes	5 lb./ft^2
Live Load	
Office	50 lb./ft^2
Concentrated Load	
Office	2000 lb.

For the Geographical cases, the snow loads were considered as well. Beam sizes were selected and then reevaluated to include their self-weight. The floors with the same layout were assumed to have the same beam sizes except for the roof which had different loading applied to it. Girders were calculated next using the same dead and live loads as the beams but also including the dead weight caused by the beams located in the tributary area of the girder. Columns were designed last using the first floor layout and including the dead, self, and live loads of the four overlying floors plus the dead, live, and snow loads from the roof.

4.1.2 Lightweight Wood Design

Lightweight wood design was completed using a less methodical approach than steel design because each individual member did not need to be analyzed. For this design, calculation checks were done for floor joists, load-bearing wall systems, and glued laminated beams. Each of these types was checked using the longest member in the structure and then used as a typical dimension throughout the rest of the building. The dead and live loads listed in Table 6 were used for these calculations.

Table 6: Case 2 Loading Conditions

Dead Load	
3/4” OSB Plywood	2.5 lb./ft^2
2x6 Framing	1.7 lb./ft^2
2x10 Framing	2.9 lb./ft^2
2x12 Framing	3.5 lb./ft^2
MEP	10 lb./ft^2
Finishes	5 lb./ft^2
Roofing System	20 lb./ft^2
Live Load	
Apartment Rooms	40 lb./ft^2
Roof	20 lb./ft^2

In lightweight wood construction, the floor members are spaced closer to each other than in steel design. Wood has less strength than steel so more members are required to carry the different loading conditions. Having more members reduces the tributary area of each piece, thus reducing the weight being carried across the member. In this design, the longest joist size was found to be 14 feet 7.5 inches in length. An assumed member size was chosen and then checked for bending, shear, and deflection to ensure adequate sizing.

Wall systems were calculated in the same manner as the joists where the longest unbraced wall span was determined and a typical calculation was done to determine the size of the wall joists. These walls were designed with the same joist and spacing as the floors. This allows for the floor and wall joists to line up and carry loads throughout the structure from the roof into the foundation.

Some open areas between load bearing walls needed support for the floor joists because without them, the joists would be too long and deflect from the dead loads. These intermediate beams were designed with the same dead loads as the joists in addition to the weight of the floor joists on it. These beams were designed as glued laminated members which are much stronger than a typical wood beam.

4.1.3 Pedestal Design

The pedestal design combined the techniques used for the steel and lightweight wood designs into one structure. Only the first floor of the structure was constructed with steel members, decking, and reinforced concrete. Because of this, the floor system was designed in the same manner as the previous steel design, using apartment live loads instead of office (Table 6). The columns in this design were different than previously designed because instead of supporting a system of exclusively steel members, the dead weight on these columns was one floor system of steel, three floors and four walls of lightweight wood, and one lightweight wood roof. The second through fifth floors are constructed of wood and were designed using the same methods listed previously for lightweight wood construction.

4.2 Fire Protection: Detection System Design

For a fire detection system, spacing requirements were based on the size of the room, the type of hazard in the area, and the rating of the detection or notification device. In light and ordinary hazard occupancies like the case studies considered herein, smoke detectors were required in most of the rooms. These detectors typically were spaced with a 20ft by 20ft area of coverage. The final spacing determination was based on the manufacturer's data sheets of the specific products, but *NFPA 72; Section 17.7.3.2.3.1* states that spot type smoke detectors may have a maximum spacing of 30ft. In locations where smoke detectors were not permitted, like mechanical spaces, heat detectors were used based on the area of the space. Manual pull stations were located within five feet from exterior exits and placed at 40ft spacing in corridors.

The fire notification system for these cases consist of speaker strobe notification devices. The spacing of these notification devices were dependent upon the strobe's candela rating. These values were shown in *NFPA 72*; *Table 18.5.5.4.1(a)*. Different candela ratings were required for different room areas. The rating was based on the values shown in Figure 8 below. Speakers were integrated into the notification devices, and intelligibility was considered for larger spaces such as the lobby.

Table 18.5.5.4.1(a) Room Spacing for Wall-Mounted Visible Appliances

Maximum Room Size		Minimum Required Light Output [Effective Intensity (cd)]	
ft	m	One Light per Room	Four Lights per Room (One Light per Wall)
20 × 20	6.10 × 6.10	15	NA
28 × 28	8.53 × 8.53	30	NA
30 × 30	9.14 × 9.14	34	NA
40 × 40	12.2 × 12.2	60	15
45 × 45	13.7 × 13.7	75	19
50 × 50	15.2 × 15.2	94	30
54 × 54	16.5 × 16.5	110	30
55 × 55	16.8 × 16.8	115	30
60 × 60	18.3 × 18.3	135	30
63 × 63	19.2 × 19.2	150	37
68 × 68	20.7 × 20.7	177	43
70 × 70	21.3 × 21.3	184	60
80 × 80	24.4 × 24.4	240	60
90 × 90	27.4 × 27.4	304	95
100 × 100	30.5 × 30.5	375	95
110 × 110	33.5 × 33.5	455	135
120 × 120	36.6 × 36.6	540	135
130 × 130	39.6 × 39.6	635	185

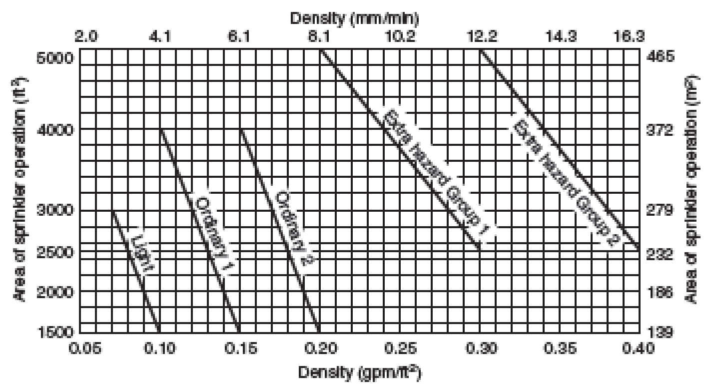
NA: Not allowable.

Figure 8: Taken from NFPA 72; Table 18.5.5.4.1(a)

4.3 Fire Protection: Suppression System Design

A wet-pipe sprinkler suppression system was used to protect the structures in all of the case studies. Two significant design assumptions for these systems were that concealed spaces within the drop ACT ceiling was not considered public access and therefore was not sprinklered, and that light fixtures within the structures were not considered obstructions to the sprinkler heads. Depending on the occupancy type, the design requirements for the sprinkler systems varied. The cases included a commercial occupancy, a residential occupancy, and a mercantile occupancy. These occupancy types all fell within light and ordinary hazard occupancies and were designed accordingly.

The primary design considerations for occupancy classification was the design density and area used for spacing and flow requirements. These density/area curves were found in *NFPA 13; Figure 11.2.3.1.1* (shown below as Figure 9). Light hazard occupancies included the commercial and residential cases. These occupancies typically require smaller amounts of water to suppress a fire. A density of 0.10 gpm/ft^2 over a design area of 1500 ft^2 was used for the light hazard occupancies. Ordinary hazard occupancies included mercantile areas and storefronts; these were additionally characterized as an ordinary hazard "Group 2". For these occupancies, more pressure and flow was required to suppress a fire, so a density of 0.20 gpm/ft^2 over a design area of 1500ft^2 was used for the cases that had ordinary hazard occupancy.



'RE 11.2.3.1.1 *Density/Area Curves.*

Figure 9: Taken from NFPA 13; Figure 11.2.3.1.1

Hydraulic calculations were completed to determine the overall pressure and water demands of the sprinkler system. These calculations can be shown in the *NFPA 13* format in Appendix E. To complete these calculations, the sprinkler k-factor (5.7), the area of coverage, and the design density must be considered. Appendix E has design areas highlighted within each case study and the correlating equations for each step of the calculation.

In some geographic locations, additional design considerations were made for seismic bracing of sprinkler piping. For these cases, the type of pipe, size of pipe, and geographic seismic characteristics were considered in determining the spacing required for these braces. A program called TOL-Brace was used to calculate and confirm the correct components for areas with seismic activity. This program uses geographic-specific seismic values and the length, size, and material of sprinkler piping to determine the spacing of seismic bracing and the fastening components that were required for the hangers. The two largest factors that go into this calculation is the seismic value for short periods of a specific geographic location, and the projected weight of water within a span of sprinkler pipe.

4.4 Cost Analysis

For each Design Case, a simple cost analysis was done in order to compare the costs difference in various locations as a result of the structural and fire protection alterations required of each city. All of the items listed in Table 7 were taken from line items in *RS Means 2016: Construction Costs*.

Table 7: Cost Analysis Values from Building Construction Cost Data RS Means 2015

Section	Item Type	Cost per Unit	Unit
Structural			
Structural Shapes	Beams	$3900	Ton
	Girders	$3900	Ton
	Columns	$3900	Ton
Rough Carpentry	Stud Walls, 2x6 10ft	$2.37	SF
	Roof Joists, 2x10	$2.00	SF
	Roof Joists, 2x12	$2.48	SF
	Floor Joists, 2x12	$2.48	SF
	Beam, 6 ¾” x 24”	$42.60	LF
Fire Alarm: Detection/Notification			
	Spot-Type Smoke Detectors	$110.00	Ea.
	Rate of Rise Heat Detector	$51.00	Ea.
	Linear Beam Smoke Detectors	$200.00	Ea.
	Manual Pull Stations	$83.50	Ea.
	Strobe and Horn Notification	$152.00	Ea.
Fire Suppression: Suppression			
	15000SF or more (Exposed Wet)	$3.56	SF

The items considered in the analysis were simplified to include only items that would vary with changes in the structural and fire protection designs. For example, the steel was included because different member sizes would change the cost but the steel decking was not included because the structure maintains the same surface area regardless of the location. Each case had the base cost calculated for the gravity load model, and then the variations for each structure were calculated and compared to the initial cost. In addition to the variations caused by material changes, the location factors for each city were included in the cost to show the differences in construction costs that need to be considered when building in different locations.

4.5 Geographical Analysis and Environmental Loads

The initial design of each case was developed without any considerations of environmental loading conditions. Member sizes were established from the dead load conditions created by the structure itself and the live loads associated with the designated use of the structure. Across the United States wind, seismic, and snow loads, and the fire protection codes vary from location to location. Varying the location altered the structural designs for each case. Figures 1, 2, and 3 were used to determine the magnitudes of the environmental loads associated with each location.

Seismic Loading was found using the following series of equations to solve for the total force acting on the entire story of the structure. The values in Table 8 were taken from *ASCE 7-10* and *IBC 2015* and used in the equations. The weight of the structure was an estimated value where it was assumed that each floor weighed 125 pounds per square foot and the roof weighed 75 pounds per square foot. Once the force per story was calculated, it was divided amongst the frames dependent on how much load they would carry. The full set of calculations can be found in Appendix C.

$$C_s = \frac{S_{DS}}{RI}$$

$$V = W * C_s$$

$$C_{vi} = \frac{w_i h_i}{\sum_1^5 w_i h_i}$$

$$w_i = weight\ of\ story;\ h_i = height\ of\ story$$

$$F_i = C_{vi} * V$$

Wind Loading was found using the series of equations below to determine the total wind force on each face of the building. The values used for these equations are indicated in Table 9. First the static wind pressure, q_s was calculated using the U.S customary units formula. This was used in the formula for the velocity wind pressure at different heights above the ground. In this equation, the variable for the exposure coefficients changes as the height of the structure increases. The velocity wind pressure q_z was the used to determine the design wind pressure, p, on a particular face of the structure which in turn was multiplied by the length of the building and the tributary floor height, 10 feet, to determine the wind force acting on each story. The full set of calculations can be found in Appendix C.

Table 8: Seismic Calculation Values

Variable	Boston	Miami	Los Angeles
ρ	1	1	1.3
S_{DS}	0.23	0.04	1.60
R	3	3	3
I	1	1	1
W(kips)	14066	14066	14066

$$q_s = 0.00256V$$

$$q_z = q_s I K_z K_{zt} K_d$$

$$p = q_z G C_p$$

$$Force = L * (tributary\ floor\ height = 10) * p$$

Table 9: Wind Calculation Values

Variable		Boston	Miami	Los Angeles
Wind Velocity, V		108 mph	139 mph	85 mph
Occupancy Importance Factor, I		1	0.77	1
Velocity Pressure Exposure Coefficient, K_z	10’	0.57	0.57	0.57
	20’	0.62	0.62	0.62
	30’	0.70	0.70	0.70
	40’	0.76	0.76	0.76
	50’	0.81	0.81	0.81
Velocity Pressure Exposure Coefficient, K_z Least Horizontal Dimension	10’	0.70	0.70	0.70
	20’	0.70	0.70	0.70
	30’	0.70	0.70	0.70
	40’	0.76	0.76	0.76
	50’	0.81	0.81	0.81
Topographic Factor, K_{zt}		1	1	1
Wind Directionality Factor, K_d		1	1	1
Gust Factor, G		0.85	0.85	0.85
External Pressure Coefficient, C_p		1	1	1
Length of Building, N-S		225.67 ft.	225.67 ft.	225.67 ft.
Length of Building, E-W		131.38 ft.	131.38 ft.	131.38 ft.

In order to carry lateral loads, structures have frames placed throughout the structure which are designed to carry the additional loading. To design these frames, the lateral loading first was divided amongst the different frames. The lateral loads acting on each individual frame was determined by designing the structure in RISA-3D and applying a 1-kip point load to the top of the structure. The displacement was then used to calculate the stiffness of the frame in kips per inch. This was then multiplied by the quantity of the frame type used in the structure and used to find the percentage of total stiffness the frame carried. These stiffness percentages were multiplied by the total force per story to determine the forces acting upon each story of each different frame. From here, the loads for wind and seismic were analyzed separately for each location in RISA-3D. The calculated loads were applied to each story and the frame was analyzed to determine the displacement caused by the forces. The maximum displacement was determined to be the height divided by 500 which is 1.2 inches. Each frame was analyzed and the maximum deflection of the top story was compared to the allowable deflection. If the limit was exceeded, each frame was redesigned using the design method in Table 10.

Table 10: Frame Design Iteration Method

	Original Member	New Member	Member Type
1	W14x22	W14x26	Beam
2	W14x26	W16x31	Beam
3	W16x31	W18x35	Beam
4	W18x35	W18x40	Beam
5	W12x40	W12x50	Column
6	N/A	W12x16	Cross Beam
7	W12x16	W14x22	Cross Beam
8	W12x50	W12x65	Column
9	W18x40	W21x44	Beam
10	W12x65	W14x82	Column
11	Add additional cross beams		Cross Beam
12	W14x82	W14x109	Column
13	W14x22	W14x26	Cross Beam
14	W21x44	W21x62	Beam
15	X-shapes cross beams		Cross Beam
16	W14x109	W14x120	Column
17	W14x26	W16x31	Cross Beam
18	W16x31	W18x35	Cross Beam
19	W21x62	W21x68	Beam
20	W14x120	W14x132	Column
21	W18x35	W18x40	Cross Beam
22	W14x132	W14x145	Column
23	W21x68	W24x68	Beam
24	W14x145	W14x176	Column

4.5.1 Los Angeles, California

The first site location to be considered was Los Angeles, California which is located in the Southwest of the country. This region is located on a fault line so high levels of seismic loading must be considered. The wind forces in this region are less significant than the seismic loading so the seismic loads govern the required lateral loading. California has snow loading at higher altitudes but Los Angeles is close enough to sea level and has a climate and elevation that the snow loading can be considered as zero. The values used in the calculations for Los Angeles were taken from ASEC 7-10 and are in Table 11.

Table 11: Calculation Values for Los Angeles from ASCE 7-10

Item	Values	Unit
Address	2975 Wilshire Boulevard	-
Soil Classification	C	-
Seismic Design Category	D	-
Redundancy (ρ)	1.3	-
S_{DS}	1.603	%g
Wind Velocity (V_{asd})	85	mph
Wind Importance Factor	1	-
Exposure Category	B	-
Snow Load	0	psf

The designs of Case 2 and Case 3 were partially or completely lightweight wood construction. A structure of this height and area cannot be built in Los Angeles, California in accordance with the city's building code. *The Los Angeles Building Code* is a series of amendments to the 2013 *California Building Code (CBC)*. In Chapter 5: General Building Heights and Areas of the *CBC,* Table 503 indicates the floor area per story and story limits for different types of construction. For an R-2 type structure of Type V-A construction, the structure is limited to three stories at up to 18,000 square feet per story. Type V-B is even more restrictive, limiting construction to two stories at up to 12,000 square feet. The residential structure designed in Case 2 and 3 are five stories at 19,000 square feet so this structure could not be constructed in Los Angeles, California due to its noncompliance with local and state building codes.

4.5.2 Miami, Florida

The next site location considered was Miami, Florida which is located in the Southeast of the country. This region is located on the Atlantic Ocean in an area prone to hurricanes so high levels of lateral loading caused by wind must be considered. There are minimal seismic forces in this region so even though they were included in the design, the wind loading was the driving force for lateral effects. Similar to California, no snow loading was considered but unlike California, the snow loading is considered zero at all elevations in this region. The values used in the calculations for Miami were taken from ASEC 7-10 and are in Table 12.

Miami is located in a hurricane zone with wind velocity of 139 miles per hour. As a result of this, wood is not a desirable construction material for the size of structure designed in Case 2 and 3. Unlike California however, Florida does not have specified limits in their building code for construction height limits for different building materials. The American Wood Council (AWC) does have recommended floor areas and structure heights for wood construction for structures in 140 mph winds and Exposure Category B. This guide states that the structure should not be greater than 33 feet in height and for irregular structures with an aspect ratio of 1.5, no larger than 80 feet by 60 feet. The structure in the design is several times larger than these limits that were set forth, indicating that wood would not be able to be used in this structure. However, this guide is intended to be used for “Wood Frame Construction in High Wind Areas for One- and Two-Family Dwellings,” which is not the nature of the building in the design. Since there are no limits specifically indicated in the Florida or Miami building codes that permit the construction of a lightweight wood structure of this height and area, it was deemed unsafe to pursue the designs for Case 2 and 3 in Florida without further knowledge of the area.

Table 12: Calculation Values for Miami from ASCE 7-10

Item	Values	Unit
Address	745 SW 3rd Street	-
Soil Classification	D	-
Seismic Design Category	A	-
Redundancy (ρ)	1	-
S_{DS}	0.044	%g
Wind Velocity (V_{asd})	139	mph
Wind Importance Factor	1	-
Exposure Category	B	-
Snow Load	0	psf

4.5.3 Boston, Massachusetts

The final site location considered was Boston, Massachusetts which is located in the northeast of the country. This region was the most difficult to calculate because all three loading conditions must be considered. Even though Massachusetts is not located on a major fault line, there is still minor seismic loading that must be considered. In addition, much of Boston is located on land created by filling in the ocean with soil. These areas must be treated with greater seismic consideration so the location of the structure was placed outside of this region. Wind loading is minimal throughout most of the country but it is more substantial in this location due to its proximity to the Atlantic Ocean. Of the three locations selected, Boston has the largest snow load to consider because it is much further north than the other two locations. The values used in the calculations for Los Angeles were taken from ASEC 7-10 and are in Table 13.

Table 13: Calculation Values for Boston from ASCE 7-10

Item	Values	Unit
Address	165 Tremont Street	-
Soil Classification	D	-
Seismic Design Category	B	-
Redundancy (ρ)	1	-
S_{DS}	0.23	%g
Wind Velocity (V_{asd})	108	mph
Wind Importance Factor	1	-
Exposure Category	B	-
Snow Load	50	psf

5.0 Results

Five cases were designed with different building materials and uses and then relocated to three major cities across the United States. These designs were chosen to show how a variety of minor changes in a structure can have large implications on the structural and fire protection designs. Each design has unique characteristics that change what needs to be considered in the design process. These designs were then reanalyzed in three different locations to demonstrate how environmental factors can have large effects on the design of a structure. By changing the use and location, the variations of the needs of a structure as well as the impact of the local building codes can be analyzed. In addition, a cost analysis of the five structures was done in the three locations as well as with a base cost. These costs only included the variable costs such as steel members and quantity of smoke detectors. This made it possible to show a direct comparison between the costs in the different locations.

5.1 Case 1: Steel Office Building

The first case being considered is a five-story, steel frame structure. For the initial analysis, only the occupancy live loads and structural dead load were considered. Additional designs were prepared for three different locations which considered environmental loads as well. This structure was designed as an open concept office space with executive offices and a conference room, break room, and reception area in each suite. Partitions were designed to allow space for up to six tenants per floor. Each floor contains two elevators, two bathrooms, and four stairways. These stairways were used in egress analysis of calculated occupant load per *NFPA 101*. The architectural layout of this case can be found in Appendix G.

5.1.1 Structural Design

The structural design for Case 1 was composed of a series of beams, girders, and columns as seen in Figure 10.

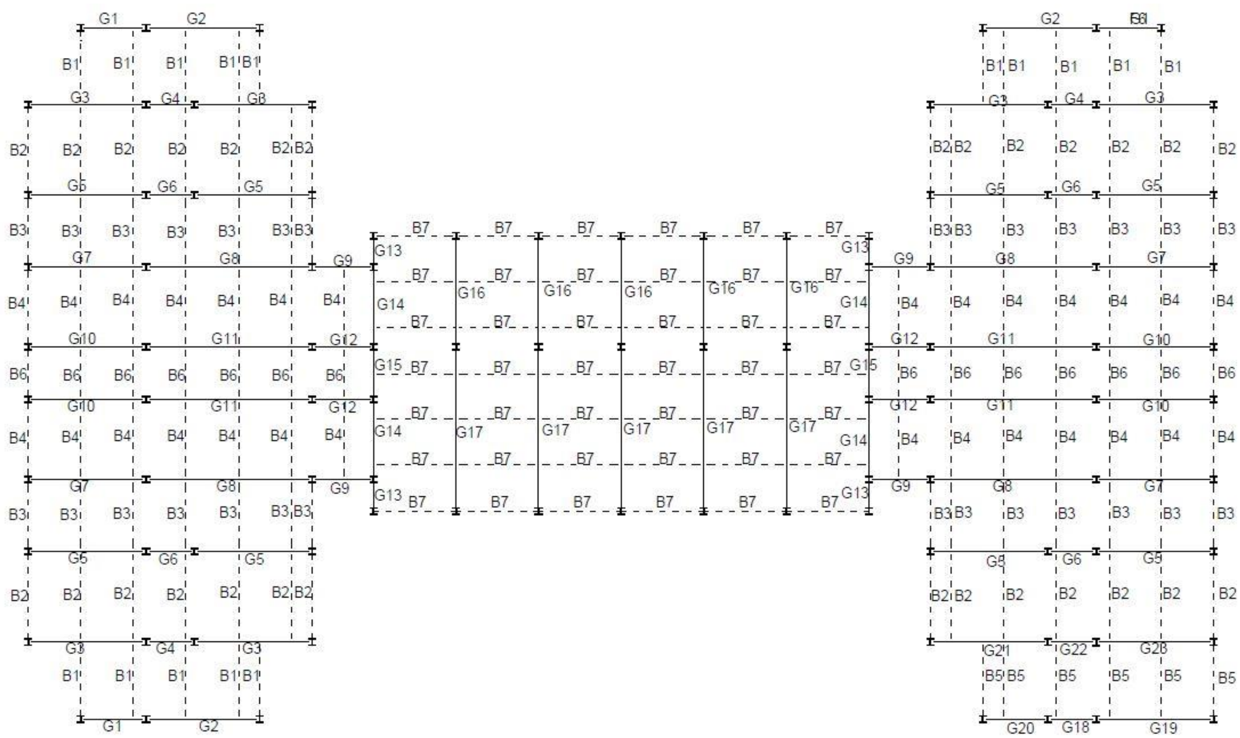


Figure 10: Case 1 Structural Framing Plan

Figure 10 shows the first floor framing plan and the subsequent floors are designed in the same manner. Girders run from North to South in the end sections and run East to West in the longer middle hallway. For the initial gravity load design, the members were all defined to support dead and live loads only. The member sizes for this design can be found in Appendix G. It can be noted that all beam and girder sizes were designed to be a minimum size of W12x16 to reduce the risk of problems arising due to slenderness of members. When lateral loading was introduced to the design, eight frames (Figure 11) were introduced into the structural layout. These frames were designed to resist the wind and seismic loading conditions of the three areas and the values varied for the different locations so the frames were modified to the appropriate size for each loading condition. The final frame design for each location can be found in Appendix B.

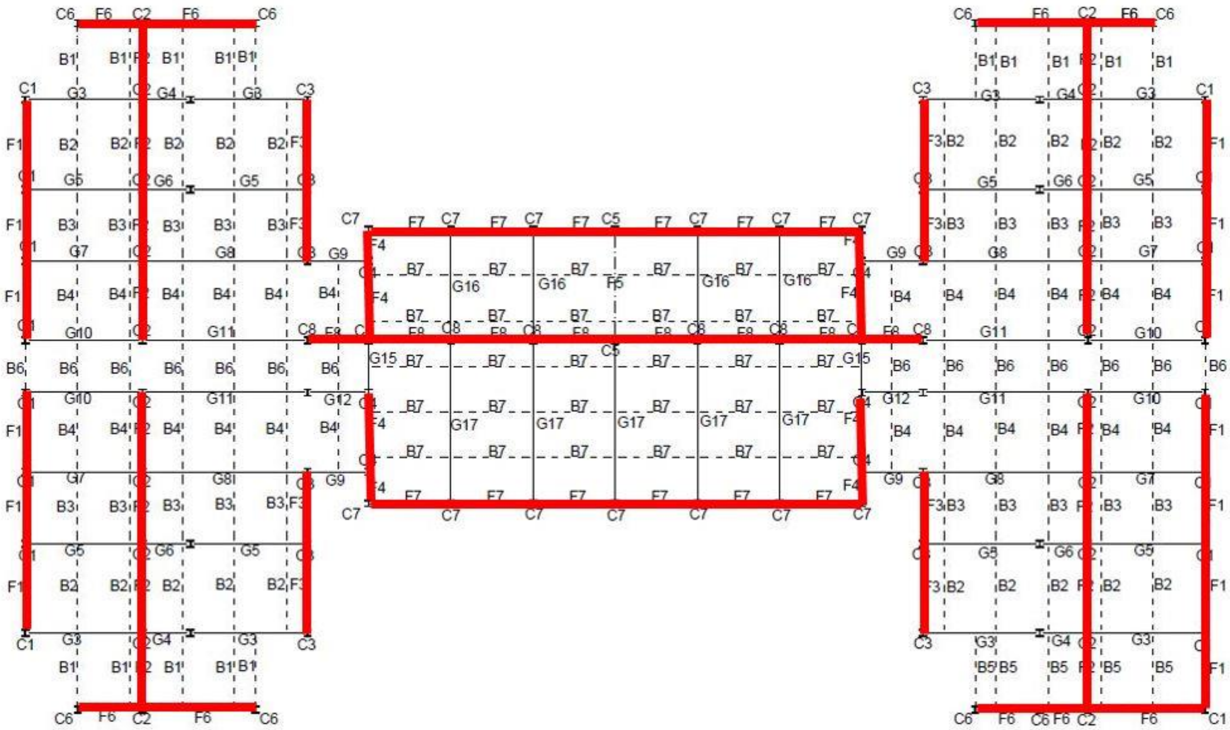


Figure 11: Case 1 Structural Layout with Frames

5.1.2 Fire Protection: Detection System Design

For Case 1, the required detection devices and notification appliances included smoke detection throughout, heat detection in the elevator machine room, manual pull stations, and speaker/strobe notification appliances throughout all occupied spaces. The layout for this case can be found in Appendix G and in Figures 12 and 13.

Figure 12: Fire Alarm Design - Case 1, Floor 1

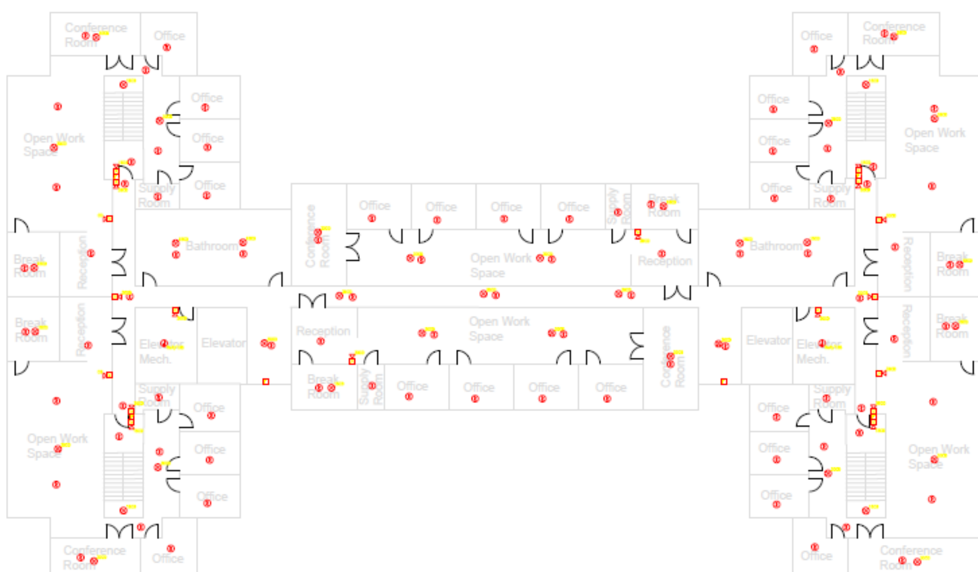


Figure 13: Fire Alarm Design – Case 1, Floors 2-5

The design spacing in Case 1 for the ceiling-mounted smoke detectors was 30ft by 30ft. This is a standardized spacing for smoke detectors for ceilings that are only one story high. This spacing can be seen on the drawings throughout as the typical spacing for the office space, lobby, work areas, restrooms, etc. In this design, heat detectors were only prescribed for use in the elevator machine room to minimize potential of false alarms from mechanical function within the building.

As per *NFPA 72*, there was a maximum of 200 ft. spacing between manual pull stations. These devices were placed in the path of egress in all areas. This made the design slightly more conservative than the code requirements, but because of the size and the number of exits, it was prudent to include more manual pull stations. A combination of wall-mounted and ceiling-mounted speaker/strobe appliances were laid out with a design area of coverage of 30 ft. x 30ft. Designing all the rooms to have ceiling-mounted notification allowed for flexibility within rooms if furniture were to be moved or for the space use to change. The two-directional wall-mounted notification appliances were beneficial for the uniform spacing and proximity to doors in many cases.

In office design it is presumed that the occupants have familiarity with the building and their own office space; therefore, the layout did not include notification appliances directly in the executive offices. The only occupied rooms that are separate from the general tenant space are 4 executive offices and the break room.

The elevator shafts were protected by a single sprinkler head at the base/top of the shaft. This will act as a heat detector and be linked to an automatic shutoff of elevator function in the case of actuation. The areas above the acoustic ceiling tiles (ACT) were not included in the scope of detection coverage since these spaces are concealed and will not be used for storage. The quantities of the aforementioned devices appliances are listed in Table 14.

Table 14: Case 1 Fire Detection Device and Appliance Count

Floor	Smoke Detector	Heat Detector	Pull Station	Horn/Strobe
1	81	2	7	51
2	87	2	6	55
3	87	2	6	55
4	87	2	6	55
5	87	2	6	55

5.1.3 Fire Protection: Suppression System Design

This office building was classified as a light hazard occupancy for the suppression system design. With a light hazard occupancy classification, one single sprinkler riser can supply systems that are up to 52,000 ft^2 in area. The water density and design area requirements of this system will be 0.10 gpm/ft^2 over 1,500 ft^2. This system was designed to have pendent K5.6 sprinklers throughout. The typical sprinkler head spacing in Case 1 was 10ft by 12ft. As per *NFPA 13*, no spacing exceeded 15ft between sprinkler heads. Each sprinkler head covered a maximum of 130 ft^2. Although the typical spacing was 10ft by 12ft, depending on the geometry of the room, this spacing throughout was not possible. Figures 14 and 15 show the sprinkler layout in Case 1. The number of sprinkler heads used in this design are also shown in Table 15.

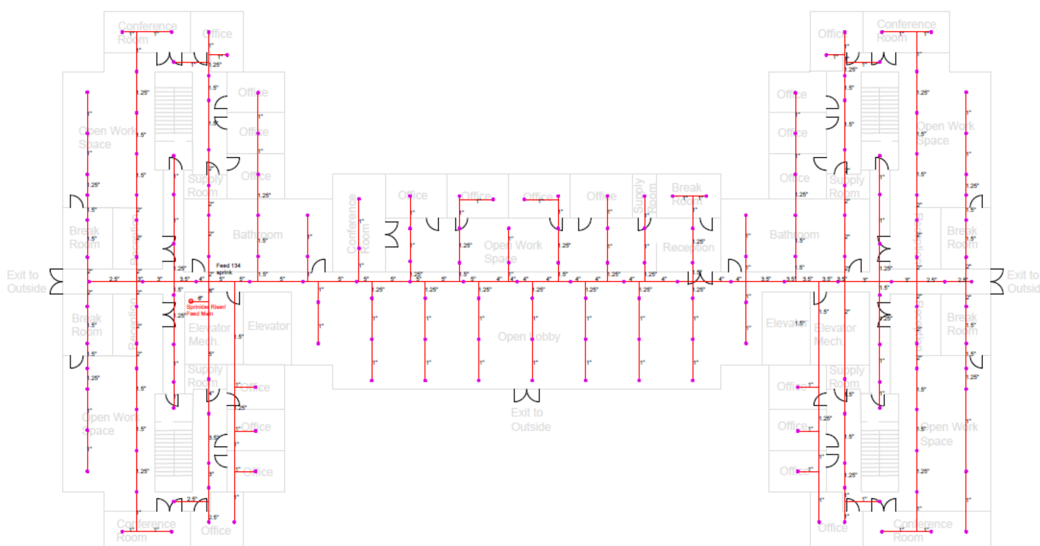


Figure 14: Fire Protection Design - Case 1, Floor 1

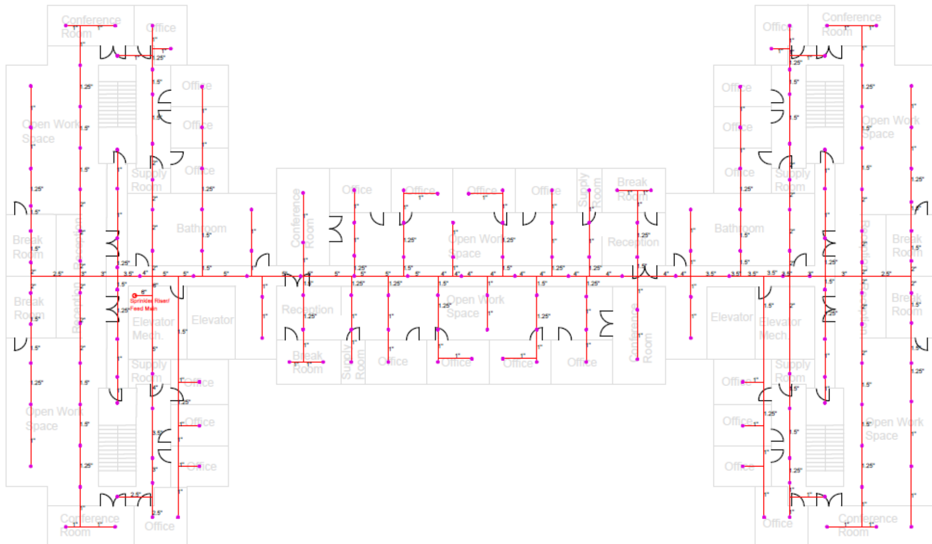


Figure 15: Fire Protection Design - Case 1, Floor 2

Table 15: Case 1 Sprinkler Head Count

Floor	Pendent K-5.6 Sprinkler
1	187
2	190
3	190
4	190
5	190

For a business occupancy, the design fire was simplified to a medium growth fire. This simplification incorporated the assumption of an alpha growth value of 0.011728 kW/s^2 over a growth time of 300 seconds. Refer to Section 2.2.2.1 Fire Protection Systems for more information on design requirements and to Figure 16 below for typical fire growth values. With these assumptions, at a spacing of 10ft by 12ft, and a heat rating of 135°F, the expected sprinkler activation time for the typical area in this occupancy would be approximately 13 seconds.

TABLE B.2.3.2.3.6 *Power Law Heat Release Rates*

Fire Growth Rate	*Growth Time (t_g)*	*α (kW/sec^2)*	*α (Btu/sec^3)*
Slow	$t_g \geq 400$ sec	$\alpha \leq 0.0066$	$\alpha \leq 0.0063$
Medium	$150 \leq t_g < 400$ sec	$0.0066 < \alpha \leq 0.0469$	$0.0063 < \alpha \leq 0.0445$
Fast	$t_g < 150$ sec	$\alpha > 0.0469$	$\alpha > 0.0445$

Figure 16: Power Law Heat Release Rates [NFPA 13; Table B.2.3.2.3.6]

There was no change in suppression design when the environmental loads prescribed for Boston and Miami were considered. Because of the seismic loads present in Los Angeles, additional seismic bracing was required to hang the sprinkler piping at a spacing of 30ft. This bracing absorbs movement and stabilizes the sprinkler pipe to account for the seismic forces.

The required water flow and pressure for this system is 168gpm at 50psi using a hydraulic calculation method for a design area of 1500 ft^2. These calculations and the design area are shown in Appendix E.

5.1.4 Cost Analysis

Construction costs for Case 1 were determined with the variable items listed in Table 16. Each cost has slight variations from the base cost due to more materials being used as well as the location factors which were included in each location. As you can see in this chart, the location factor for Boston is greater than those for Los Angeles and Miami which gives an immediate mark up to the project, regardless of the changes in member sizes. The location factor for Miami is 1 so any changes in the costs for Miami from the Base Cost are due to changes in the sizes of structural members.

Table 16: Case 1 Cost Analysis

Item Type	Base Cost	Boston	Los Angeles	Miami
Location Factor	-	1.37	1.08	1.00
Structural				
Beams	$463,000	$488,000	$385,000	$356,000
Girders	$409,000	$491,000	$379,000	$351,000
Columns	$246,000	$706,000	$847,000	$311,000
Frame	-	$524,000	$621,000	$304,000
Brace	-	$132,000	$557,000	$8,760
Total	$1,120,000	$2,340,000	$2,790,000	$1,330,000
Fire Alarm: Detection/Notification				
Spot-Type Smoke Detectors	$110.00 ea. $47,200 total	$64,700	$51,000	$47,200
Rate of Rise Heat Detector	$51.00 ea. $510 total	$699	$551	$510
Linear Beam Smoke Detectors	N/A	N/A	N/A	N/A
Manual Pull Stations	$83.50 ea. $2,580 total	$3,530	$2,790	$2,580
Strobe and Horn Notification	$152.00 ea. $49,600 total	$67,900	$53,500	$49,600
Total	$99,900	$137,000	$108,000	$99,900
Fire Suppression: Suppression				
15000SF or more (Exposed Wet)	$3.56 per SF $339,000 total	$465,000	$366,000	$339,000
Total Cost	**$1,560,000**	**$2,940,000**	**$3,260,000**	**$1,770,000**

5.2 Case 2: Lightweight Wood Residential

The second case considered was a five-story, lightweight wood residential building. Similar to the first case, the structure was first designed for only structural dead load and residential live load. As indicated in Section 4.5.1 and 4.5.2, wood structures of this size cannot be constructed in Los Angeles or Miami so this case was only considered in Boston. This structure was designed as a residential apartment building with 12 apartments per floor. On every level, there are ten apartments with three bedrooms and one bathroom, and two studio-style apartments with one bathroom. Each floor contains two elevators, and four stairways. The architectural layout of this case can be found in Appendix H.

5.2.1 Structural Design

The structural design for Case 2 consisted of floor joists, load bearing walls, and support beams as shown in Figure 17. As can be seen in floor plan, the floor joists were spaced at a typical 16” on center and then placed in the orientation that minimized the member length.

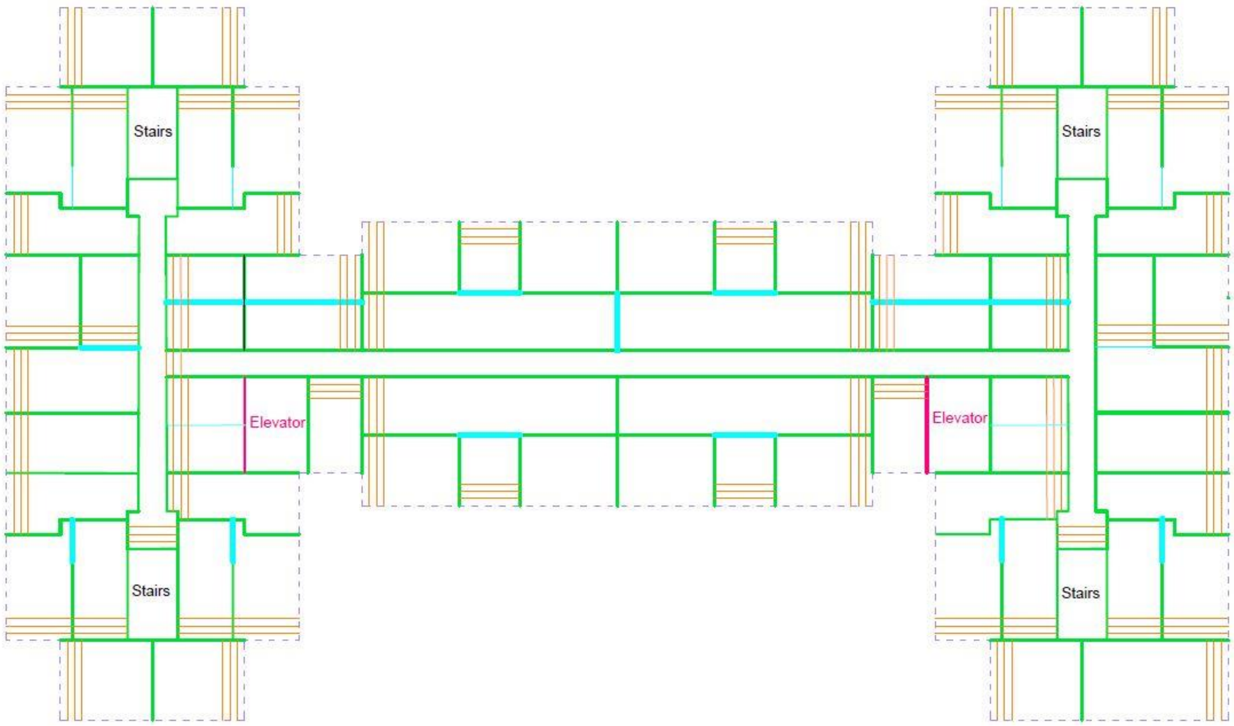


Figure 17: Case 2 Floor Layout

Since only one location, Boston, was considered, the resulting designs for the Base Case and Boston were very similar with only minor changes to the roof due to snow loading. The floor plan in Figure 17 shows the first floor but the same layout was used for all floors. A typical member size was chosen for the wall joists, floor joists, roof joists, and support beams and can be seen in Table 17. Complete calculations for this case can be found in Appendix B.

Table 17: Case 2 Wood Members

Member Type	Member Size (Gravity)	Member Size (Boston)
Wall Joist	2x6	2x6
Floor Joist	2x12 at 16” O.C.	2x12 at 16” O.C.
Roof Joist	2x10 at 16” O.C.	2x12 at 16” O.C.
Support Beam	6.75” x 24” glu-lam beam	6.75” x 24” glu-lam beam

5.2.2 Fire Protection: Detection System Design

The layout of Case 2 (Figure 18 and 19) reflects the differences in fire alarm notification requirements between residential occupancies and business occupancies. Smoke detectors are located throughout, but the bedrooms and bathroom do not require horn/strobe appliances. These appliances are located in the main living areas such as the living room and the kitchen. Table 18 denotes the number of devices and appliances used in each floor of this design.

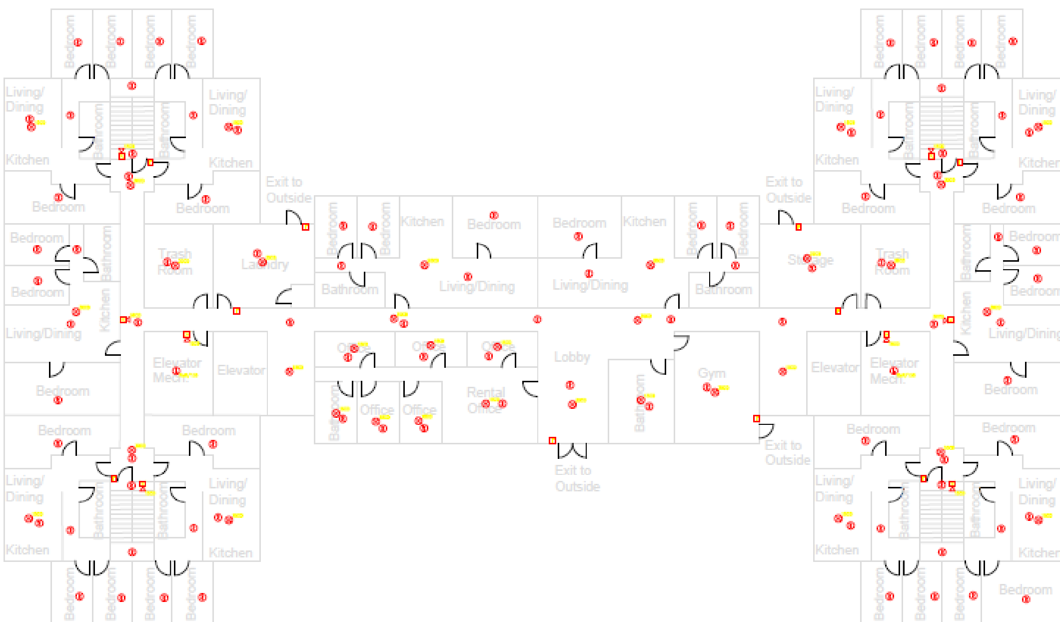


Figure 18: Fire Alarm Design - Case 2, Floor 1

Table 18: Case 2 Fire Detection Device and Appliance Count

Floor	Smoke Detector	Heat Detector	Pull Station	Horn/Strobe
1	93	2	10	42
2	93	2	6	34
3	93	2	6	34
4	93	2	6	34
5	93	2	6	34

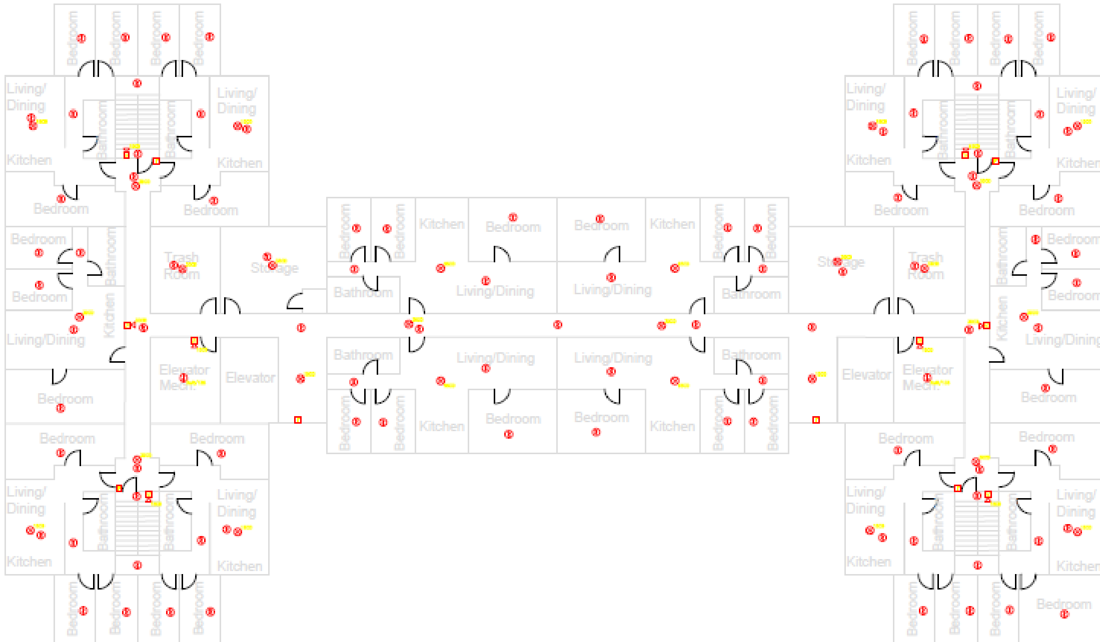


Figure 19: Fire Alarm Design - Case 2, Floors 2-5

5.2.3 Fire Protection: Suppression System Design

According to *NFPA 13*, residential buildings are classified as a light hazard occupancy. The same requirements as Case 1 apply to this case due to the similarities in water density, flow, and pressure requirements within the system. The branchline layout varied significantly due to the difference in architectural room layout. These layouts can be seen below and in *Figures 20 and 21*. The number of sprinkler heads used in this design are also shown below in *Table 19*.

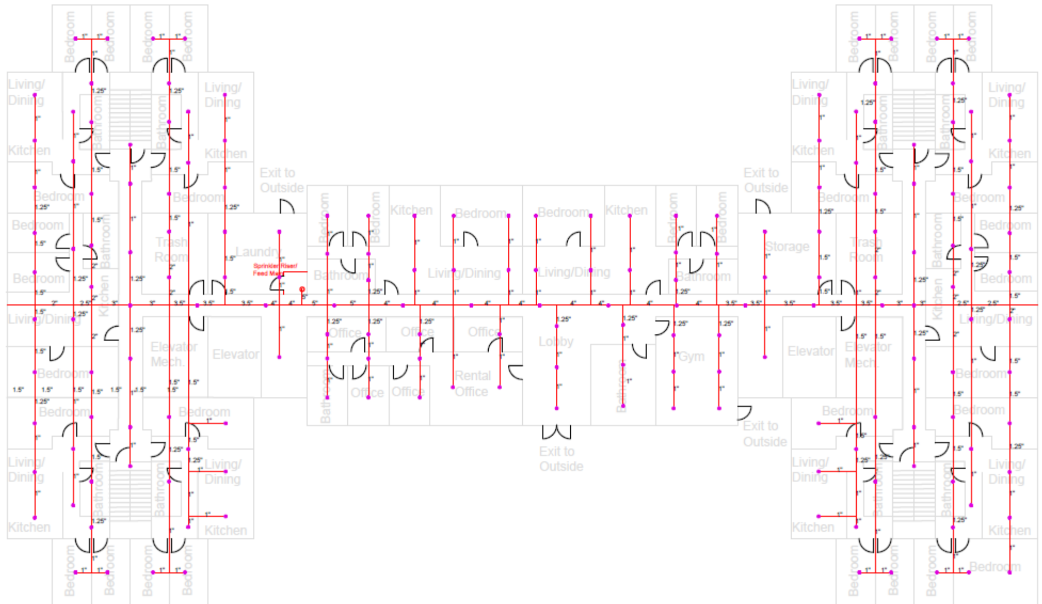


Figure 20: Fire Protection Design - Case 2, Floors 1

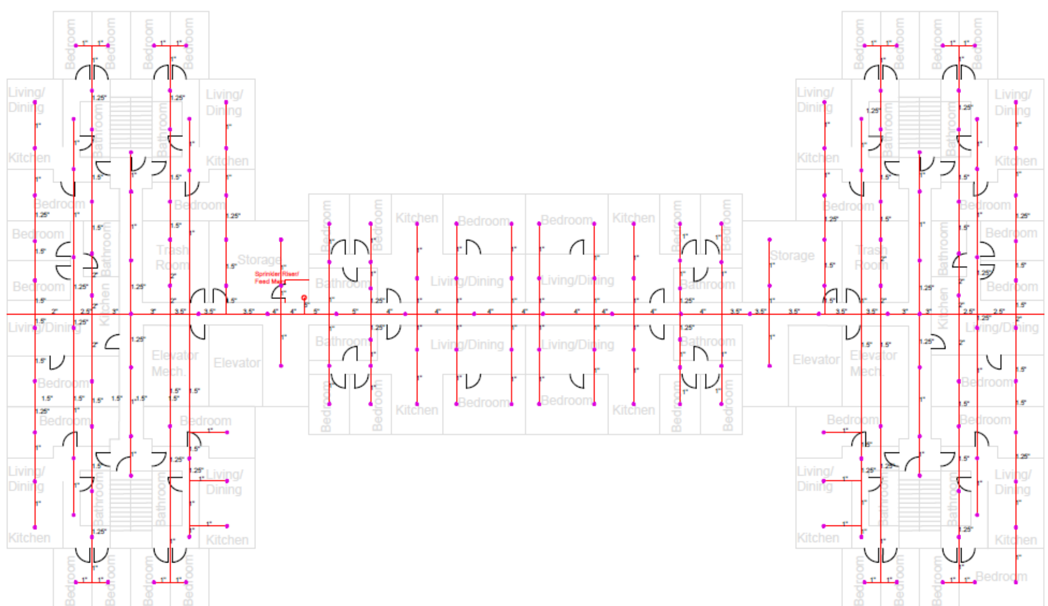


Figure 21: Fire Protection Design - Case 2, Floors 2-5

Table 19: Case 2 Sprinkler Head Count

Floor	Pendent K-5.6 Sprinkler
1	180
2	180
3	180
4	180
5	180

Because of structural factors within the building codes, this wood design was not considered in Los Angeles or Miami. In Boston, because of the geographic seismic activity, and the bracing being attached to wood decking, seismic sprinkler bracing would be required every 40ft. This bracing absorbs movement and stabilizes the sprinkler pipe to account for the seismic forces.

The required water flow and pressure for this system is 177gpm at 56psi using a hydraulic calculation method for a design area of 1500 ft^2. These calculations and the design area are shown in Appendix E.

5.2.4 Cost Analysis

The cost breakdown of Case 2 can be seen in Table 20. Only one geographic location was analyzed so this cost analysis is a comparison between the Base Case and the one location considered. The structural cost of Case 2 was very similar for the gravity load and geographical cases, with most of the variance being due to the location factor of Boston.

Table 20: Case 2 Cost Analysis

Item Type	Base Cost	Boston
Location Factor	-	1.37
Structural		
Stud Walls, 2x6 10ft	$352,000	$482,000
Floor Joists, 2x12	$189,000	$259,000
Roof Joists, 2x10	$38,100	-
Roof Joists, 2x12	-	$64,700
Support Beam	$48,800	$66,900
Total	$628,000	$873,000
Fire Alarm: Detection/Notification		
Spot-Type Smoke Detectors	$110.00 ea. $51,150 total	$70,100
Rate of Rise Heat Detector	$51.00 ea. $510 total	$700
Linear Beam Smoke Detectors	N/A	N/A
Manual Pull Stations	$83.50 ea. $2,840 total	$3,890
Strobe and Horn Notification	$152.00 ea. $27,100 total	$37,200
Total	$81,600	$112,000
Fire Suppression: Suppression		
15000SF or more (Exposed Wet)	$3.56 per SF $339,000 total	$465,000
Total Cost	**$1,050,000**	**$1,450,000**

5.3 Case 3: Steel Pedestal Mixed Occupancy

The third case considered was a five-story, mixed-use building with steel and lightweight wood construction. Similar to the first case, the structure was first designed only with structural dead load and residential live load. As indicated in Section 4.5.1 and 4.5.2, wood structures of this size cannot be constructed in Los Angeles or Miami so this case was only considered in Boston. This structure was designed as a mixed-use building with 12 apartments on floors two through five and flexible mercantile spaces on the first floor that can accommodate up to four tenants. On each apartment level, there are ten apartments with three bedrooms and one bathroom, and two studio-style apartments with one bathroom. The mercantile floor contains the four storefronts as well as two public bathrooms. Each floor contains two elevators, and four stairways. The architectural layout of this case can be found in Appendix I.

5.3.1 Structural Design

The structural design for Case 3 was a combination of the designs used in Case 1 and Case 2. Floor 1 of Case 3 had the same layout of structural steel beams, girders, and columns as Case 1 but with smaller members due to the smaller dead and live loads created by apartments on Floor 2 instead of offices. In addition, smaller columns could be used because the dead load from the subsequent wood floors have a lower weight than steel members. The breakdown of member sizes can be seen in Appendix H. Because the steel of the structure only reaches 10 feet tall, frames were not designed in the geographical iteration of this case. Instead, a system of tie downs was used to join the four wood floors as well as to connect the wood floors to the concrete slab on top of the steel. For floors 2-4 and the roof, the same design as Case 2 was used.

5.3.2 Fire Protection: Detection System Design

The fire alarm spacing in Case 3 was consistent with the spacing requirements used in cases 1 and 2. Larger candela ratings in the horn/strobe appliances were able to be used for increased spacing in the larger retail areas of the fire floor. Because of the open space, fewer smoke detectors were used in the first floor than the rest of the building. The device count can be found in table 21. The differences in device placement demonstrated the juxtaposition of mercantile versus residential occupancies and how partition walls within a building affected the overall required notifiers and detection devices used in one system. Figures 22 and 23 show the first floor alarm system layout and the typical layout for the residential floors above.

Figure 22: Fire Alarm Design - Case 3, Floor 1

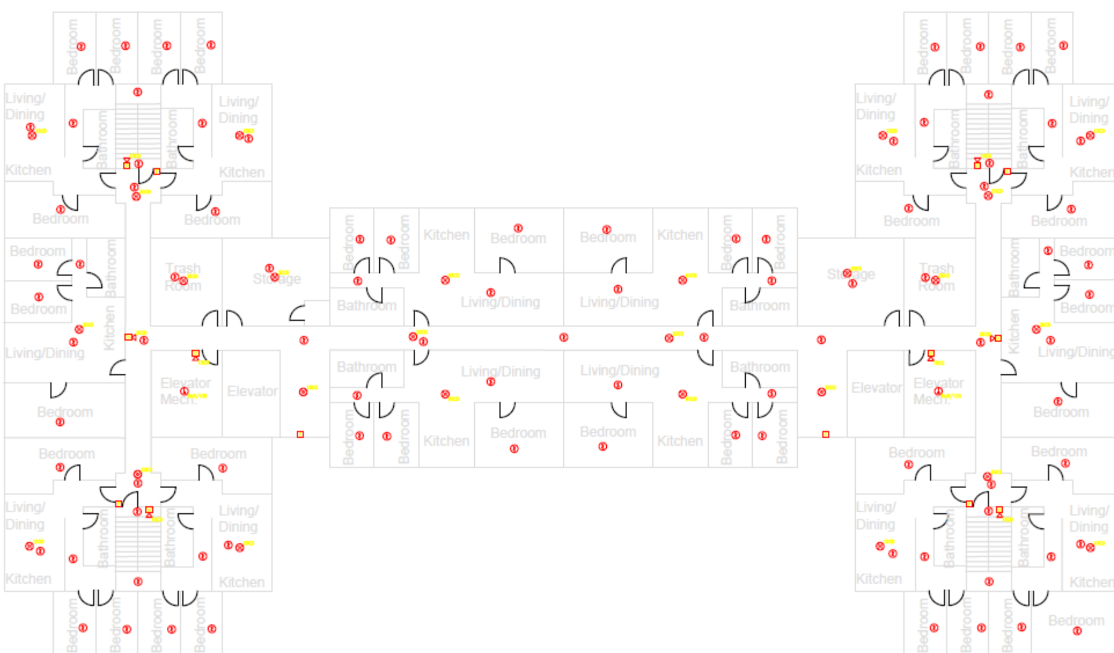


Figure 23: Fire Alarm Design - Case 2, Floors 2-5

Table 21: Case 3 Fire Detection Device and Appliance Count

Floor	Smoke Detector	Heat Detector	Pull Station	Horn/Strobe
1	57	2	7	49
2	93	2	6	34
3	93	2	6	34
4	93	2	6	34
5	93	2	6	34

5.3.3 Fire Protection: Suppression System Design

Mercantile occupancies present a higher hazard than residential or commercial occupancies. This meant that instead of having a design water flow density of 0.1 gpm/ft^2, the first floor of this building required a system that could provide a design density of 0.2 gpm/ft^2. This did not affect the placement of the sprinkler heads since the area of coverage was still 130ft^2, but it did change the water requirements in the hydraulic calculations. Sprinkler layouts are shown in Figures 24 and 25 and the quantity per floor are in Table 22.

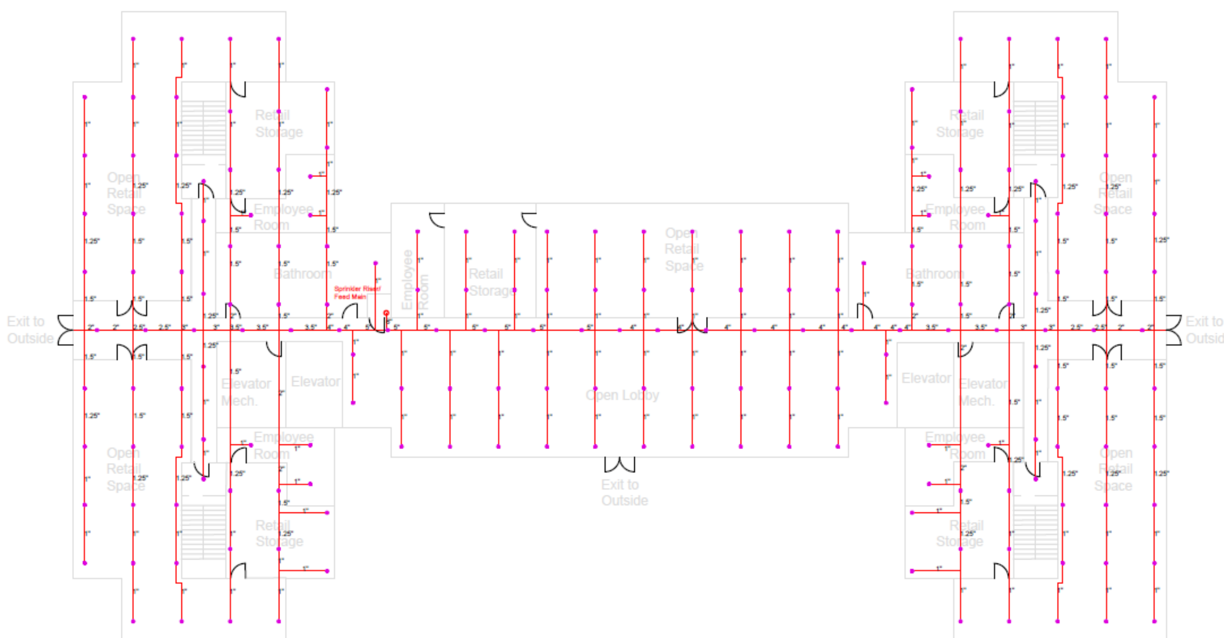


Figure 24: Fire Protection Design - Case 3, Floor 1

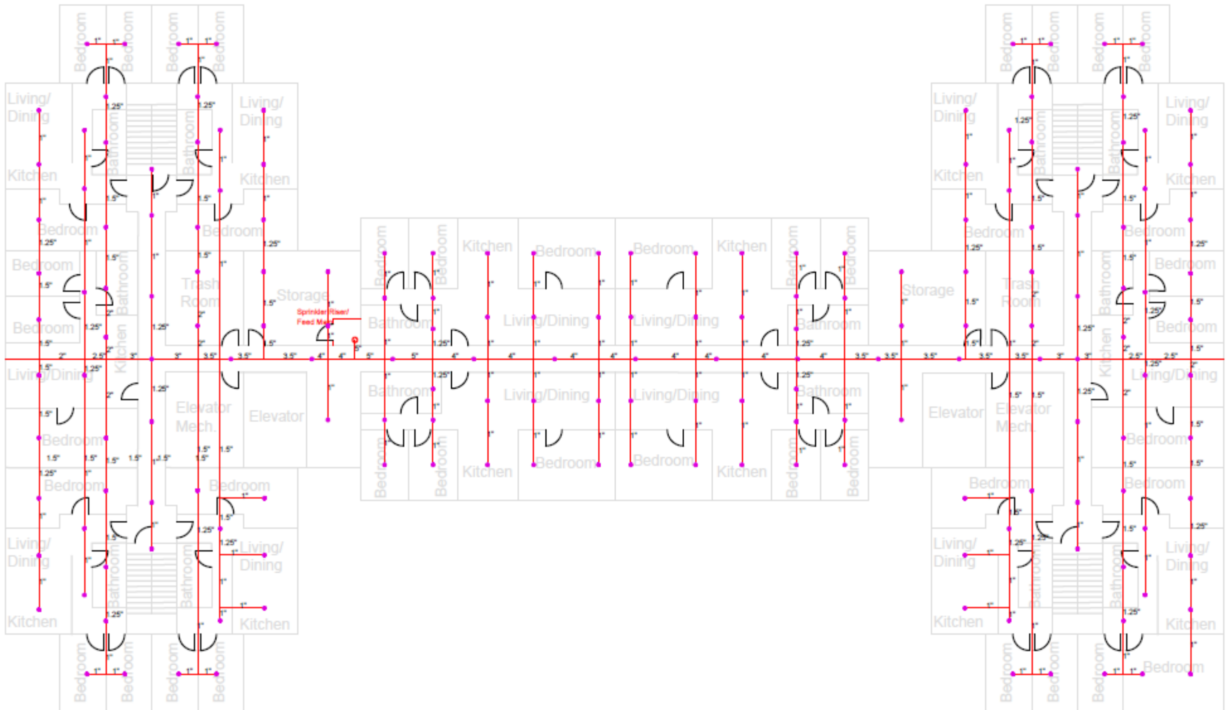


Figure 25: Fire Protection Design - Case 3, Floors 2-5

Table 22: Case 3 Sprinkler Head Count

Floor	Pendent K-5.6 Sprinkler
1	194
2	180
3	180
4	180
5	180

Because the majority of this building was wood construction, it would have required seismic bracing similar to Case 2 of 40ft spacing in Boston. With the larger design density, floor one of this case required a water flow and pressure of 346gpm at 138psi. This would be the governing flow and pressure requirements because, even taking the elevation into consideration, the water requirements for the fifth floor of this building in a light hazard area was a flow of 177gpm at a pressure of 56psi. These calculations and the design area are shown in Appendix E.

5.3.4 Cost Analysis

The structural cost of Case 3 is itemized in Table 23. This cost was greater than the cost of Case 2 because it was not entirely wood construction but less than Case 1 because there was only one floor of steel. In a pedestal design, the structural cost is more expensive than complete wood construction but is significantly less expensive than steel. This design also had less expensive Fire Alarm systems because the mercantile space on the first floor did not require as many devices as the apartment rooms in the floors above.

Table 23: Case 3 Cost Analysis

Item Type	Base Cost	Boston
Location Factors	-	1.37
Structural		
Beams	$94,700	$130,000
Girders	$86,300	$118,000
Columns	$49,100	$67,300
Stud Walls, 2x6 10ft	$282,000	$386,000
Floor Joists, 2x12	$142,000	$195,000
Roof Joists, 2x10	$38,100	-
Roof Joists, 2x12	-	$64,700
Support Beam	$29,300	$40,100
Total	$722,000	$1,000,000
Fire Alarm: Detection/Notification		
Spot-Type Smoke Detectors	$110.00 ea. $47,200 total	$64,700
Rate of Rise Heat Detector	$51.00 ea. $510 total	$700
Linear Beam Smoke Detectors	N/A	
Manual Pull Stations	$83.50 ea. $2,590 total	$3,550
Strobe and Horn Notification	$152.00 ea. $28,200 total	$38,600
Total	$78,500	$108,000
Fire Suppression: Suppression		
15000SF or more (Exposed Wet)	$3.56 per SF $339,000 total	$465,000
Total Cost	**$1,140,000**	**$1,573,000**

5.4 Case 4: Atrium with Accordion-Type Fire Doors

Case 4 is designed in a similar manner to Case 1 as a 5-story steel structure with an atrium spanning floors 1 and 2. For the initial analysis, the structure was designed considering only the gravity loads but then lateral loads from three locations were considered as well. This structure was designed as an open concept office space with executive offices and conference room in each suite. Partitions were designed to allow space for up to four tenants in floors three through five and three tenants in floors one and two. Each floor contains two elevators, two bathrooms, and six stairways. These stairways were used in egress analysis of predicted occupant load. The architectural layout of this case can be found in Appendix K.

5.4.1 Structural Design

The structural design for Case 4 was similar to Case 1 on floors 2-4 and the roof. Since the structure was designed with the same column, beam, and girder layout, these floors did not need a separate analysis and the structural steel framing from Case 1 was used. The atrium on Floor 1 caused changes in the design of some of the members directly around the open area. Girders in this area were shortened but because they were cantilevered, their tributary length was considered to the end of the member instead of halfway to the next column. The frame layout and member sizing from Case 1 were used again in Case 4 because none of the frames interrupted the open area of the atrium. The first floor layout of this case can be seen in Figure 26.

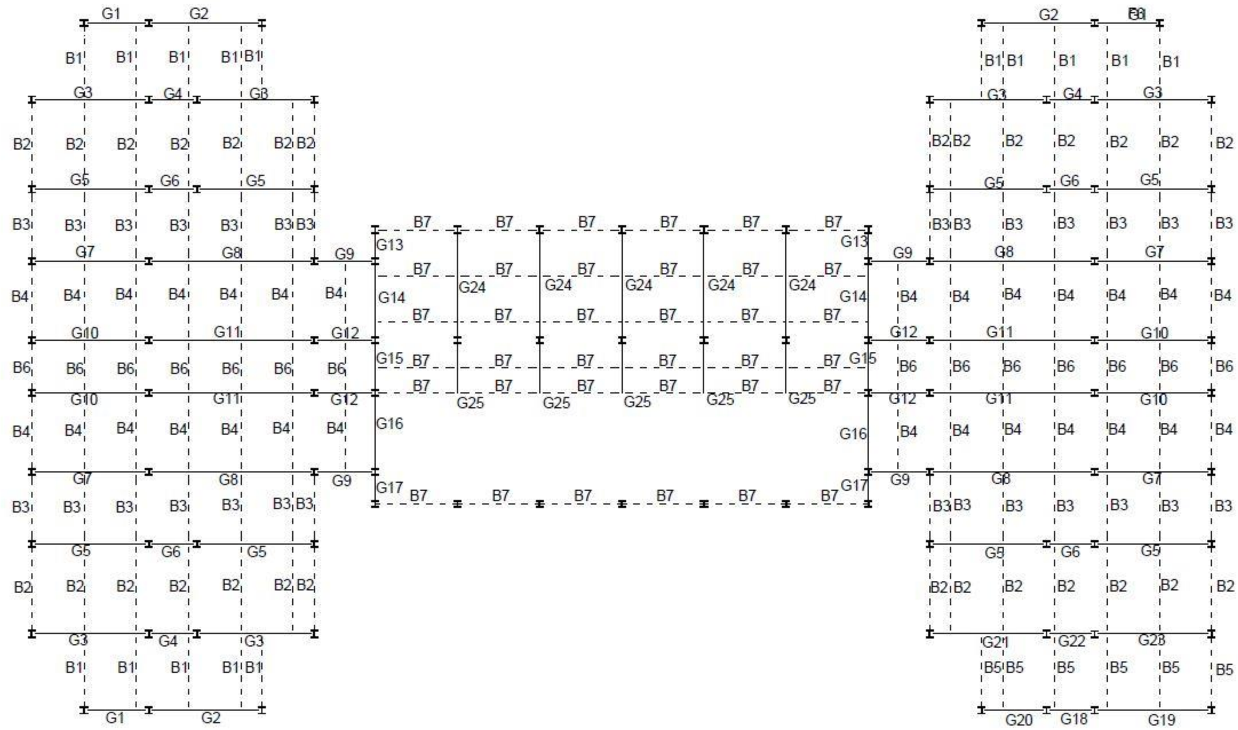


Figure 26: Case 4 Floor Layout

5.4.2 Fire Protection: Detection System Design

Case 4 provided insight into the effect higher ceilings can have on fire alarm design. To ensure that smoke was being reliably detected, even in the case of stratification within the atrium, linear beam smoke detection was implemented in this design. Typically, smoke detector placement is not reduced in areas with 20ft high ceilings. This design does not enclose the atrium however and this could become a problem when detecting smoke and activating sprinklers. To include another layout protective measure within this design, a performance-based option of using horizontal fire doors as smoke protection surrounding the atrium was explored. This would use the linear beam smoke detection devices to activate the doors and prevent the spread of smoke to corridors on the second floor as well as preventing fire spread. The layouts for the first floor, second floor, and typical upper-level floors are shown in Figures 27, 28, and 29.

Figure 27: Fire Alarm Design - Case 4, Floor 1

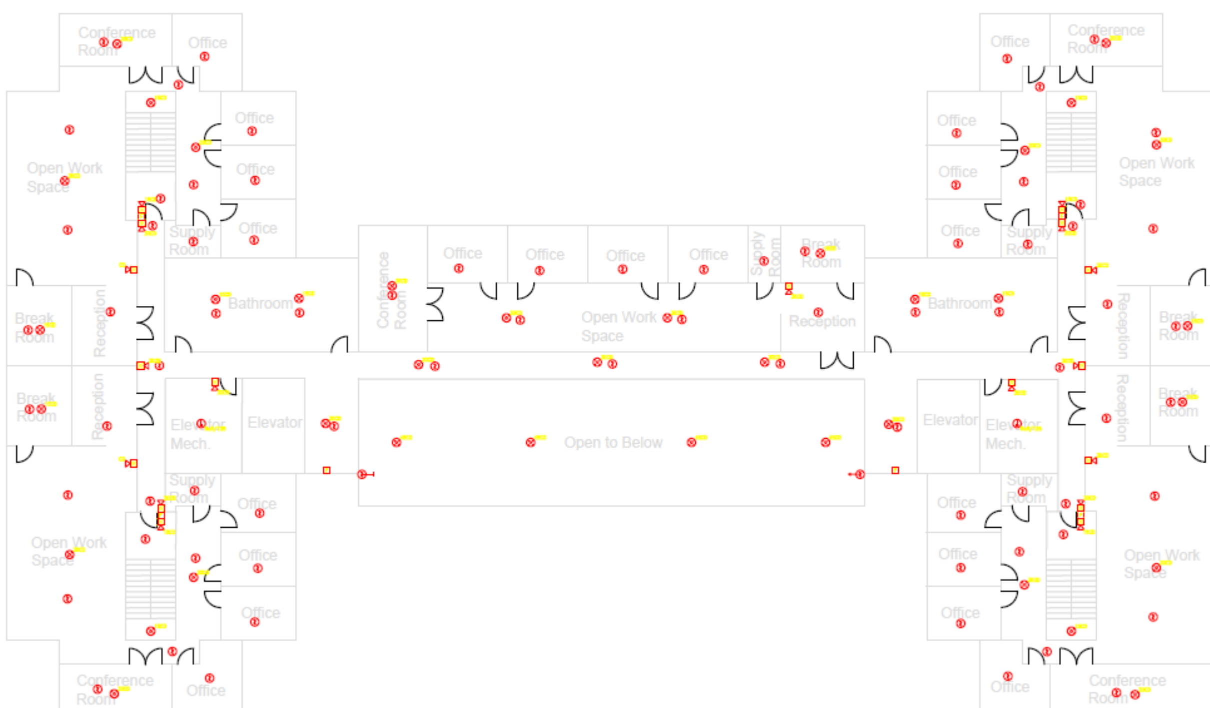


Figure 28: Fire Alarm Design - Case 4, Floor 2

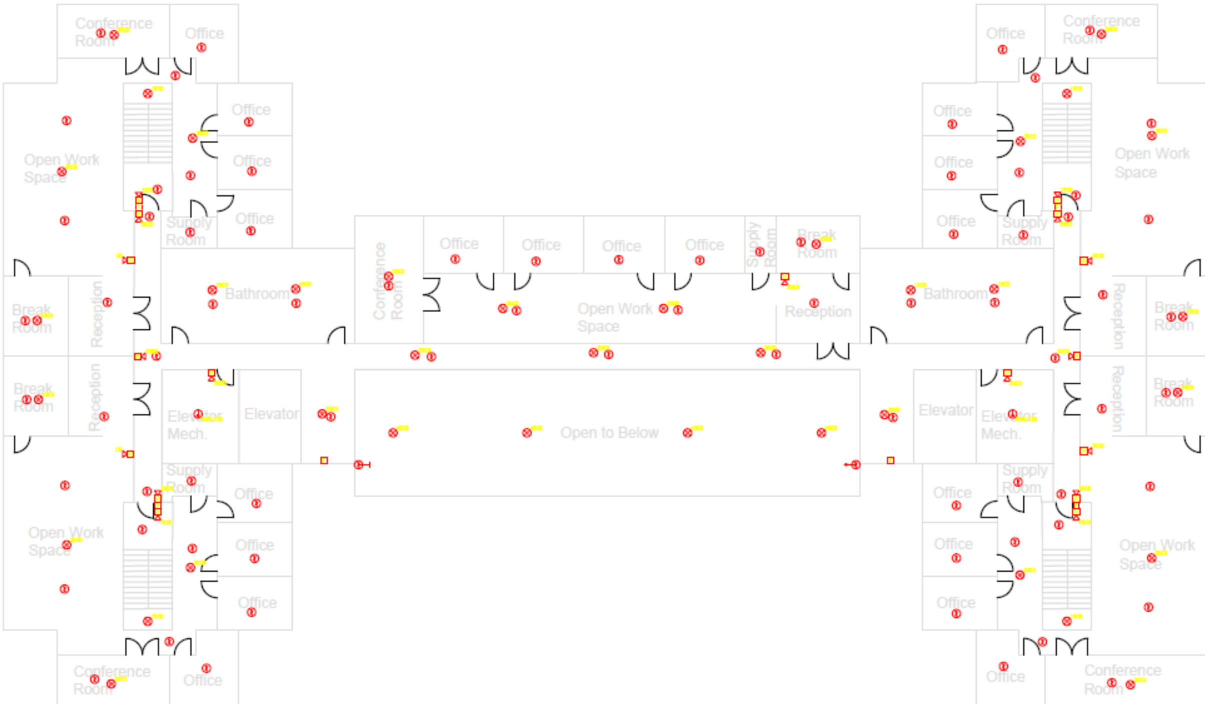


Figure 29: Fire Alarm Design - Case 4, Floors 3-5

Table 24: Case 4 Fire Detection Device and Appliance Count

Floor	Smoke Detector	Linear Beam Smoke Detector	Heat Detector	Pull Station	Horn/Strobe
1	77	1	2	7	52
2	77	1	2	6	56
3	87	0	2	6	55
4	87	0	2	6	55
5	87	0	2	6	55

5.4.3 Fire Protection: Suppression System Design

The sprinkler layout criteria for this case was very similar to that of Case 1. The only differences were in the physical placement of branchlines within the atrium. The layouts for Case 4 are shown in Figure 30, 31, and 32. Because the atrium is only 20ft high, special considerations were not made for sprinkler head spacing or alternative methods of suppression.

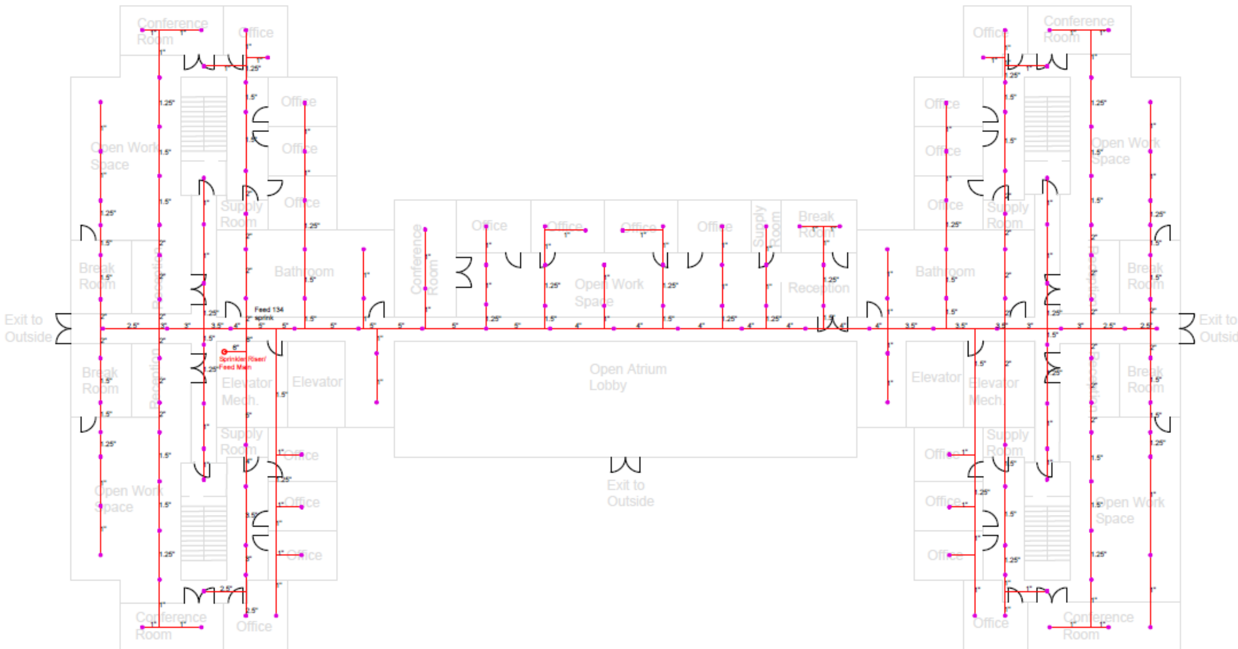


Figure 30: Fire Protection Design - Case 3, Floors 2-5

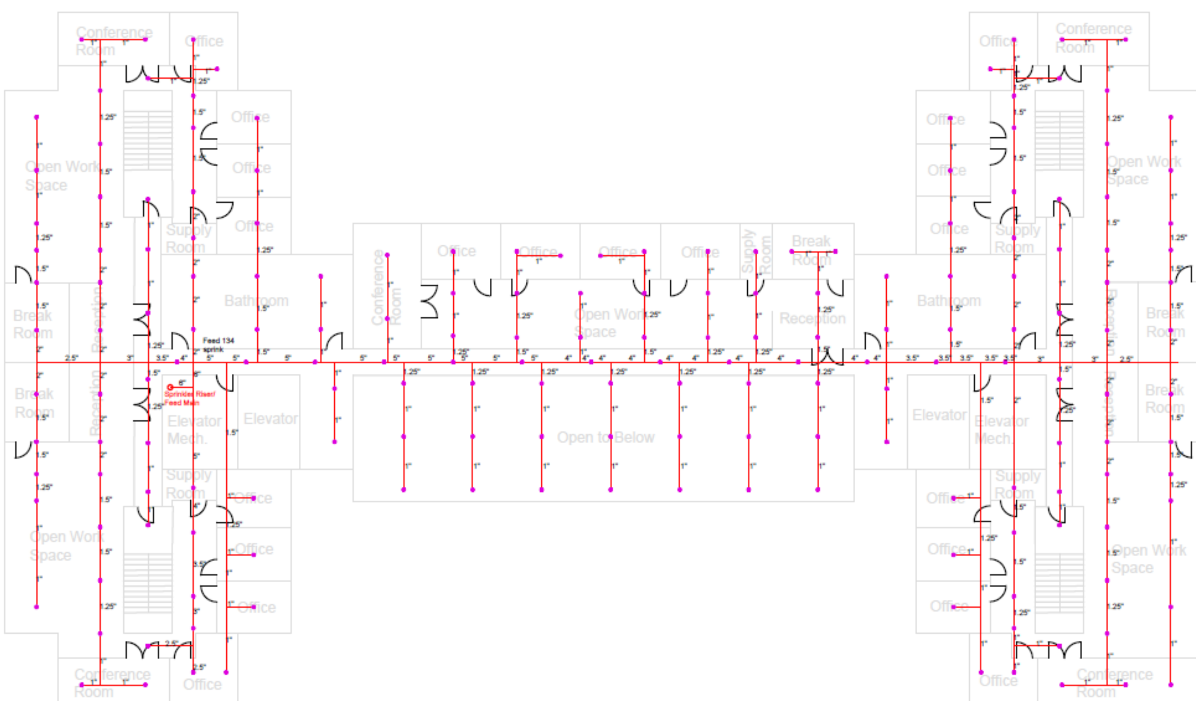


Figure 31: Fire Protection Design - Case 3, Floors 2-5

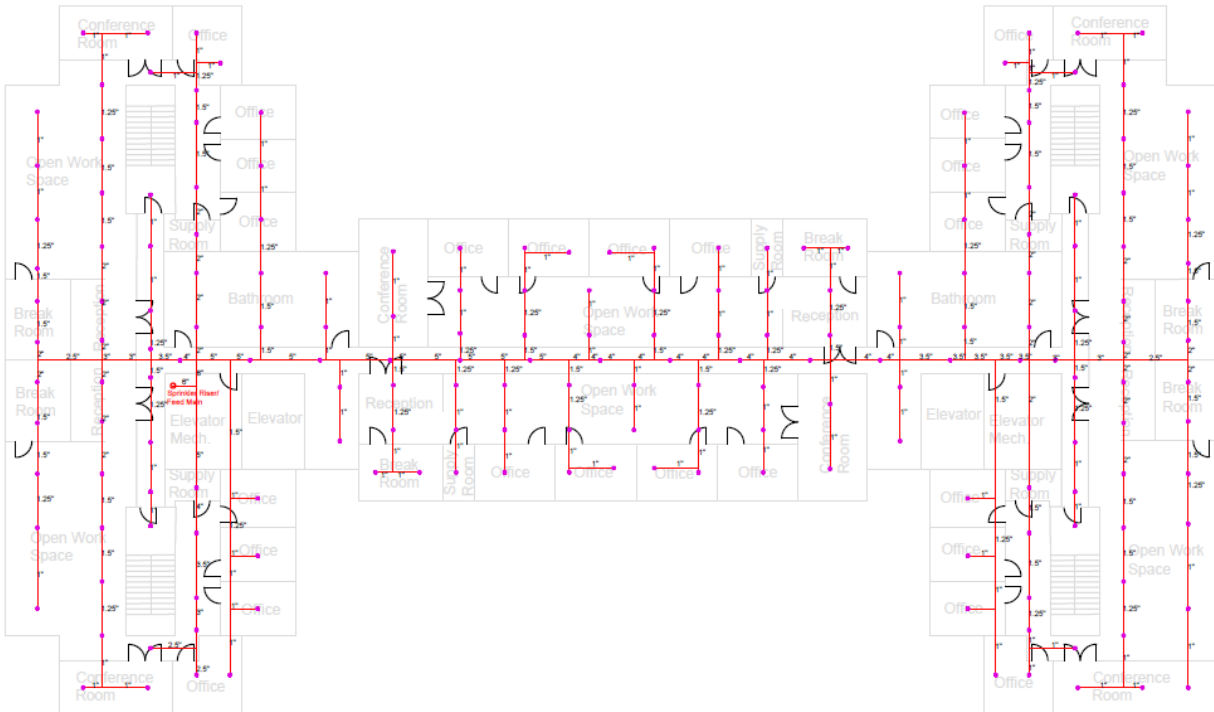


Figure 32: Fire Protection Design - Case 3, Floors 2-5

Table 25: Case 4 Sprinkler Head Count

Floor	Pendent K-5.6 Sprinkler
1	160
2	181
3	190
4	190
5	190

Seismic loads present in Los Angeles would require additional seismic bracing at a spacing of 30ft. The required water flow and pressure for this system is 168gpm at 50psi. These calculations and the design area are shown in Appendix E. The quantity of sprinklers per floor are listed in Table 25.

5.4.4 Cost Analysis

The structural cost of Case 4 is broken down in Table 26. This case had a very similar cost to Case 1 because the structures are the same size, have the same structural layout, and have the same building use. Case 4 was slightly less expensive however, because there was less material needed in the 2000 square foot area of the atrium. The cost of the fire protection and detection systems were less expensive than Case 1 because even though the design criteria were the same for both structures in Floors 2-5, the open area of the atrium eliminated some of the system required. In addition, the extra ceiling height in the atrium did not require additional fire protection design which could have increased the cost.

Table 26: Case 4 Cost Analysis

Item Type	Base Cost	Boston	Los Angeles	Miami
Location Factors	-	1.37	1.08	1.00
Structural				
Beams	$455,000	$479,000	$378,000	$350,000
Girders	$310,000	$395,000	$303,000	$280,000
Columns	$246,000	$706,000	$847,000	$311,000
Frame	-	$524,000	$621,000	$304,000
Brace	-	$132,000	$557,000	$8,760
Total	$1,010,000	$2,240,000	$2,710,000	$1,250,000
Fire Alarm: Detection/Notification				
Spot-Type Smoke Detectors	$110.00 ea. $45,700 total	$62,600	$49,300	$45,700
Rate of Rise Heat Detector	$51.00 ea. $510 total	$700	$550	$510
Linear Beam Smoke Detectors	$200.00 ea. $400 total	$550	$440	$400
Manual Pull Stations	$83.50 ea. $2,590 total	$3,550	$2,800	$2,590
Strobe and Horn Notification	$152.00 ea. $41,500 total	$56,900	$44,900	$41,500
Total	$90,700	$125,000	$98,000	$90,700
Fire Suppression: Suppression				
15000SF or more (Exposed Wet)	$3.56 per SF $332,000 total	$458,000	$359,000	$332,000
Total Cost	**$1,430,000**	**$2,820,000**	**$3,160,000**	**$1,670,000**

5.5 Case 5: Effects of Extended Central Hallway

Case 5 is designed in a similar manner to Case 1 as a 5-story steel structure but the center hallway is twice the length. In addition, there are two additional sets of stairs in the center of the extended hallway. For the initial analysis, the structure was designed considering only the gravity loads but then lateral loads from three locations were considered as well. This structure was designed as an open concept office space with executive offices and conference room in each suite. Partitions were designed to allow space for up to eight tenants per floor. Each floor contains two elevators, two bathrooms, and six stairways. These stairways were used in egress analysis of predicted occupant load. The architectural layout of this case can be found in Appendix K.

5.5.1 Structural Design

The structural design for Case 5 was also similar to Case 1 but with additional steel members in the extended hallway (Figure 33).

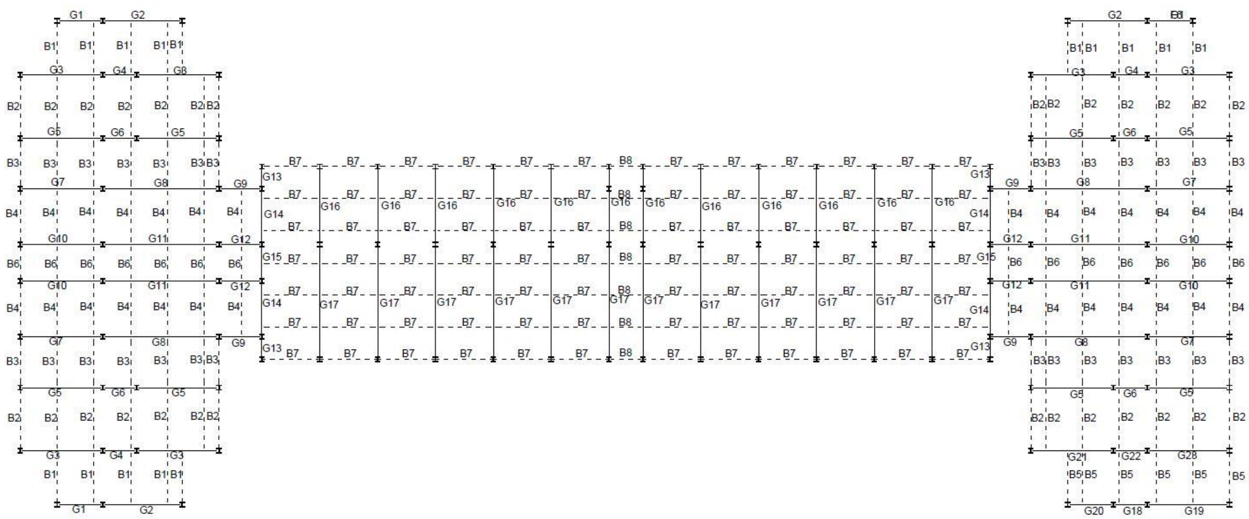


Figure 33: Case 5 Floor Layout

Beams, girders, and columns for this structural have the same design as Case 1 with the exception of beam type 8 which was added for this case. An additional calculation was required to size this member. Because of the extended hallway, more frames were added to the center of the structure (Figure 34).

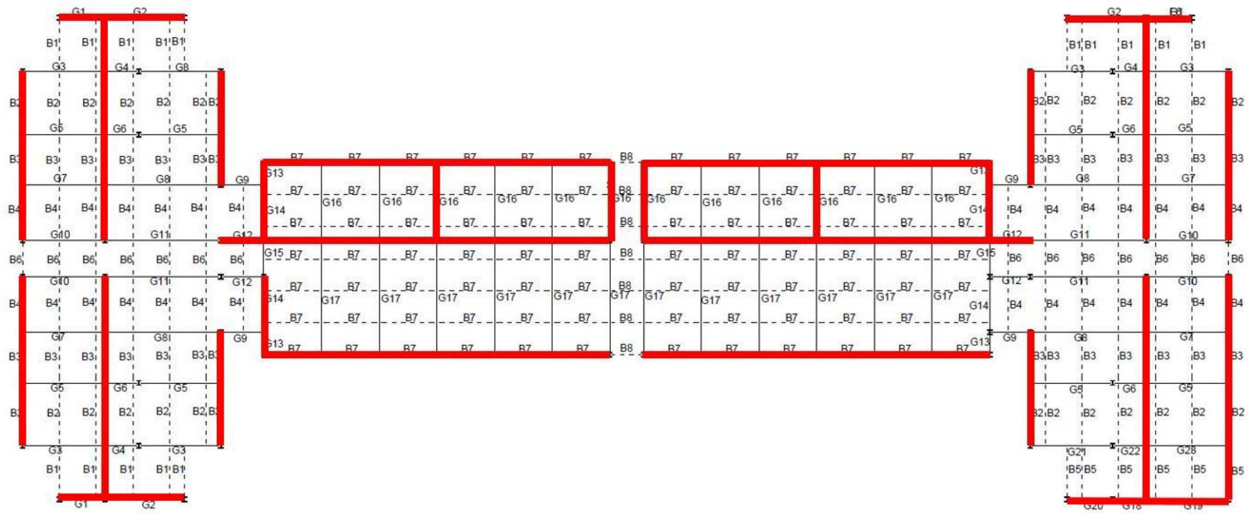


Figure 34: Case 5 Structural Layout with Frame

These additional frames carried some of the stiffness of the structure so new member sizes were designed for each frame type to carry the different percentage of the load. In addition to changing the percentage of load carried by each member, the lateral loads were larger because of the increased length and weight of the structure. For Case 5, Frame 7 carried a large portion of the load so larger members and more cross beams were required (Figure 35). A sample frame calculation and full results can be found in Appendix C.

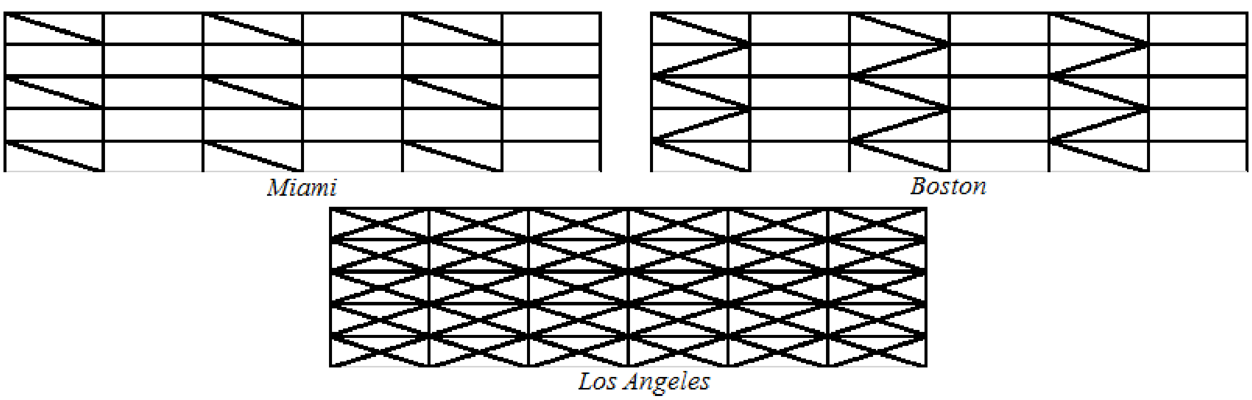


Figure 35: Case 5 Frame 7 for Geographic Locations

5.5.2 Fire Protection: Detection System Design

Case 5 is the same fire alarm design as Case 1 with an extended corridor. This required more fire safety devices and appliances than the previous four cases, but the spacing and locations remained consistent. The layouts are shown in Figures 36 and 37 and the quantities of the fire devices and appliances are shown in Table 27.

Figure 36: Fire Alarm Design - Case 5, Floor 1

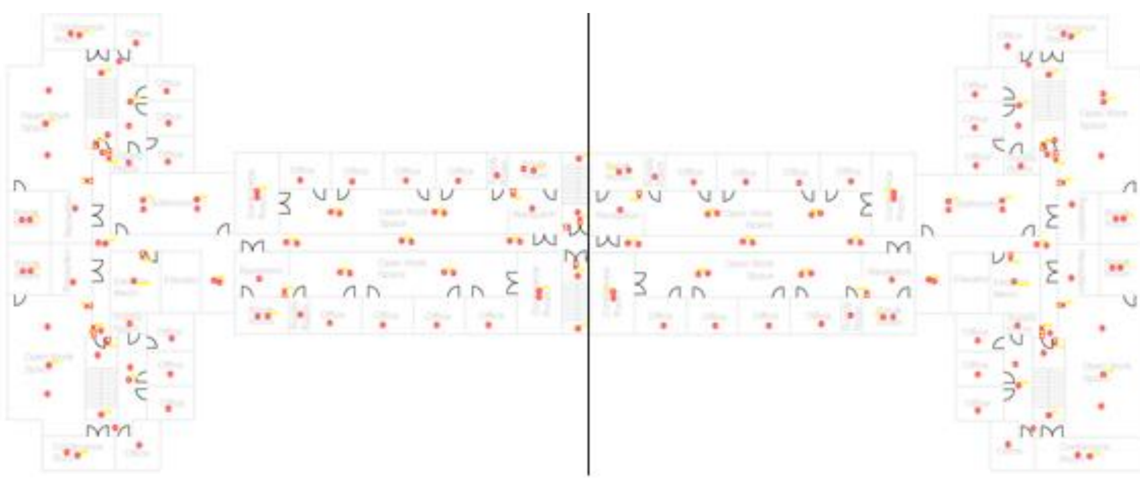


Figure 37: Fire Alarm Design - Case 5, Floors 2-5

Table 27: Case 5 Fire Detection Device and Appliance Count

Floor	Smoke Detector	Heat Detector	Pull Station	Horn/Strobe
1	102	2	9	70
2	112	2	6	74
3	112	2	6	74
4	112	2	6	74
5	112	2	6	74

5.5.3 Fire Protection: Suppression System Design

Even though Case 5 is such a large structure, it would still be classified as a light hazard occupancy. Similar to the fire alarm layouts, the fire protection layouts are also consistent with Case 1. The differences lie in the location of the riser and the additional branchlines to accommodate the width of the building. Figures 38 and 39 are layouts of the sprinkler system for this case and Table 28 indicates the number of sprinklers per floor.

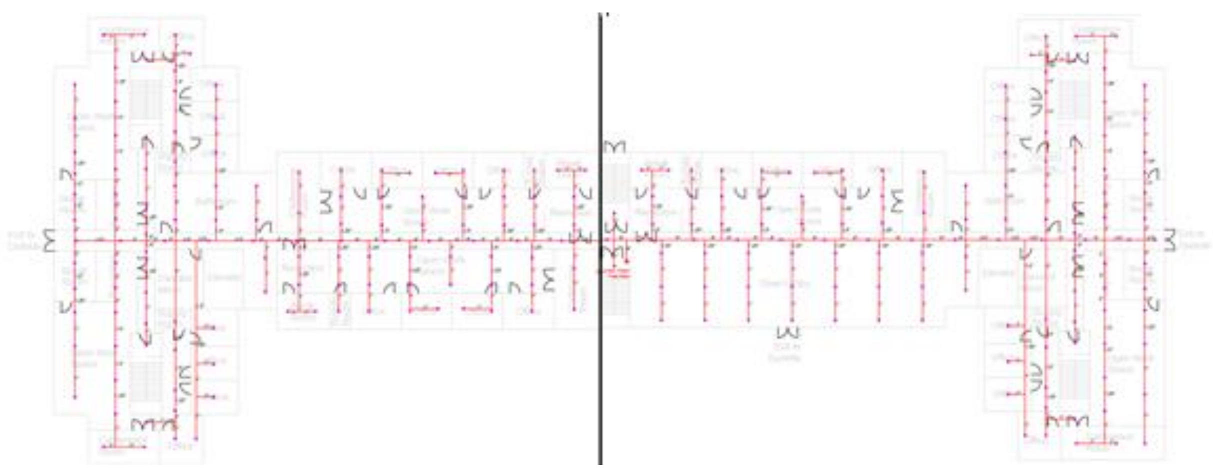


Figure 38: Fire Protection Design - Case 5, Floor 1

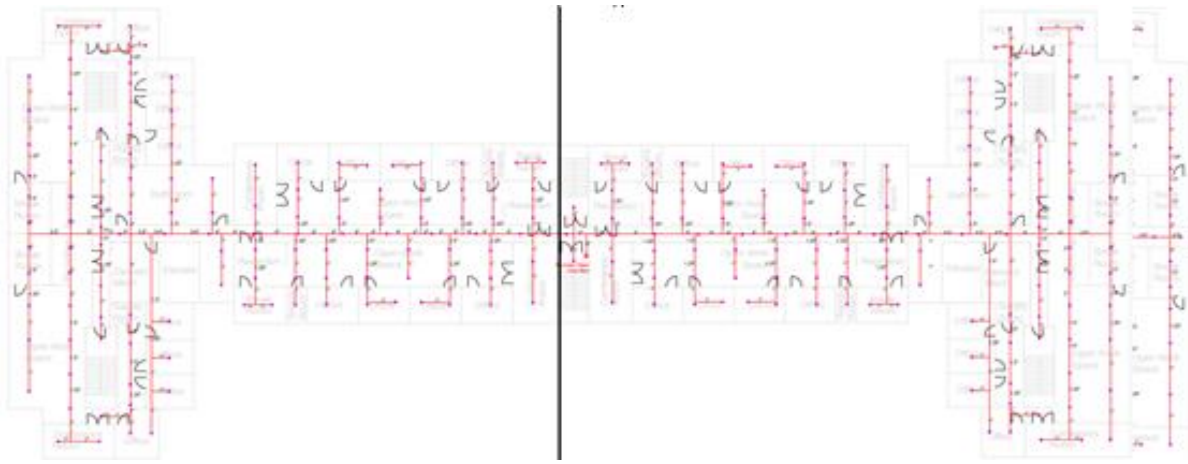


Figure 39: Fire Protection Design - Case 5, Floors 2-5

Table 28: Case 5 Sprinkler Head Count

Floor	Pendent K-5.6 Sprinkler
1	251
2	250
3	250
4	250
5	250

Seismic bracing would be required in Los Angeles at a spacing of 30ft. Because the riser was located in the center of building for this case, the required water flow and pressure for this system were very similar to Cases 1 and 4 with a flow of 168gpm at 50psi. These calculations and the design area are shown in Appendix E.

5.5.4 Cost Analysis

The cost breakdown of Case 5 is in Table 29. This case was the most expensive case because of the larger area of the building. A larger area required a more expansive fire protection system which in turn increased the cost. In addition, the increased number of steel members in the extended hallway doubled the cost of that set of beams, girders, and columns. With the longer structure, more frames were also required which increased the cost of these members, as well as the cross-braces.

Table 29: Case 5 Cost Analysis

Item Type	Base Cost	Boston	Los Angeles	Miami
Location Factor	-	1.37	1.08	1.00
Structural				
Beams	$577,000	$625,000	$493,000	$456,000
Girders	$557,000	$673,000	$519,000	$481,000
Columns	$292,000	$845,000	$1,020,000	$369,000
Frame	-	$634,000	$767,000	$358,000
Brace	-	$173,000	$918,000	$45,900
Total	$1,450,000	$2,950,000	$3,720,000	$1,710,000
Fire Alarm: Detection/Notification				
Spot-Type Smoke Detectors	$110.00 ea. $60,500 total	$82,900	$65,400	$60,500
Rate of Rise Heat Detector	$51.00 ea. $510 total	$700	$550	$510
Linear Beam Smoke Detectors	N/A	N/A	N/A	N/A
Manual Pull Stations	$83.50 ea. $2,800 total	$3,800	$3,000	$2,800
Strobe and Horn Notification	$152.00 ea. $55,700 total	$76,300	$60,100	$55,700
Total	$120,000	$168,000	$129,000	$120,000
Fire Suppression: Suppression				
15000SF or more (Exposed Wet)	$3.56 per SF $436,000 total	$597,000	$471,000	$436,000
Total Cost	**$2,010,000**	**$3,720,000**	**$4,320,000**	**$2,270,000**

6.0 Discussion

This project provided insight into the effects that various environmental loading conditions, occupancy classifications, and geographic cost considerations had on different structural and fire protection designs. Within this analysis, the implications that different components of this project had on the design and costs of the overall product were considered. Comparison of the costs of Cases 1 through 5 demonstrated the effects that architectural, structural, and geographic variations had on the overall cost. A summary of the cases can be seen in Table 30.

Table 30: Design Case Summary

Case Number	Primary Occupancy Type	Structural System, Enclosure, Construction Type	Fire Protection
Case 1: Structural Steel Office Building	Commercial (Office Use) *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade Construction Type II	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 2: Lightweight Wood Construction Residential Building	Residential *Light Hazard*	Lightweight Wood Exterior Vinyl Siding Construction Type V (A)	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 3: Mixed Occupancy	Mercantile Ground Level, Residential Above *Ordinary Hazard (Group 2)*	Steel Pedestal with Lightweight Wood Concrete Slab Floor Exterior Vinyl Siding Construction Type V (A)	Sprinkler System, Detection and Alarm Systems, Egress Analysis
Case 4: Central Atrium with Horizontal Fire Doors	Commercial *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade Altered Wall Design Construction Type II (B)	Sprinkler System, Detection and Alarm Systems, Smoke Control System, Egress Analysis, Horizontal Fire Doors
Case 5: Additional Building Wings	Commercial *Light Hazard*	Steel Frame Concrete Slab Floor Brick Façade Construction Type II (B)	Sprinkler System, Detection and Alarm Systems, Egress Analysis, Horizontal Fire Doors

6.1 Impact Analysis

A qualitative impact analysis was completed by considering the design and cost implications of various factors. For this analysis the effects of environmental loading conditions, the occupancy classifications, and the location cost adjustment factor were ranked based on the impact on final designs and costs. A visual depiction of the impact analysis can be found below in Figure 40.

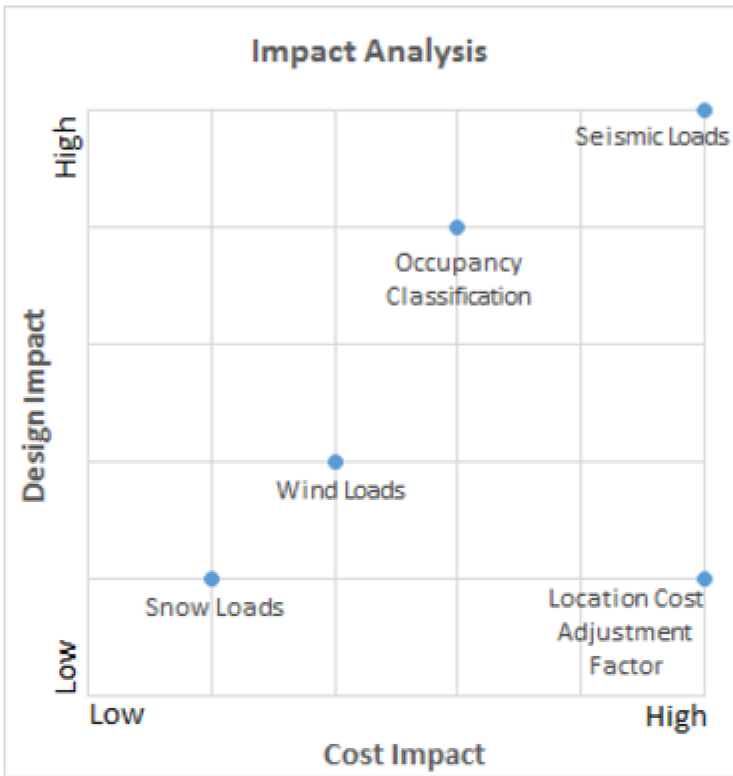


Figure 40: Impact Analysis

The snow loading conditions presented in the geographic-specific cases only had an effect when the structures were located in Boston. The snow loading condition required marginal increases in the member sizes for the roof framing for the Boston location. This change was fairly trivial for both the design and cost impacts.

Wind loads had a negligible impact to the designs in the Boston and Los Angeles locations. In Miami, minimal changes were required within the structural frame design to account for the wind loading condition. These changes presented a slight cost impact when compared to the costs associated with the design loading conditions.

The occupancy classification of the various cases had a significant effect on the structural, architectural, and fire protection and detection systems. The occupancy of a building inherently changes the layout of the rooms and, consequently, the location of fire detection, notification, and suppression systems. This directly affects cost with the increase or decrease of the number of required devices and appliances.

The location cost adjustment factor from RS Means had a significant effect on the overall cost of the building in all of the cases, but had no impact on the designs. This adjustment factor skewed the final location-based costs. Boston has a very large adjustment factor (1.37), whereas Los Angeles and Miami both have smaller factors (1.08 and 1.00 respectively). This made Boston appear to be significantly more expensive than what the base construction costs and systems components would suggest.

Seismic loading conditions had the most significant impact on both the designs and the costs of all the cases. All of the steel cases in Boston and Los Angeles required the design of seismic framing. Seismic framing was also designed for Cases 2 and 3 in Boston. Seismic bracing for sprinkler piping was also required in Boston and Los Angeles. These factors created additional design considerations and increased the cost of the overall building.

6.2 Cost Analysis

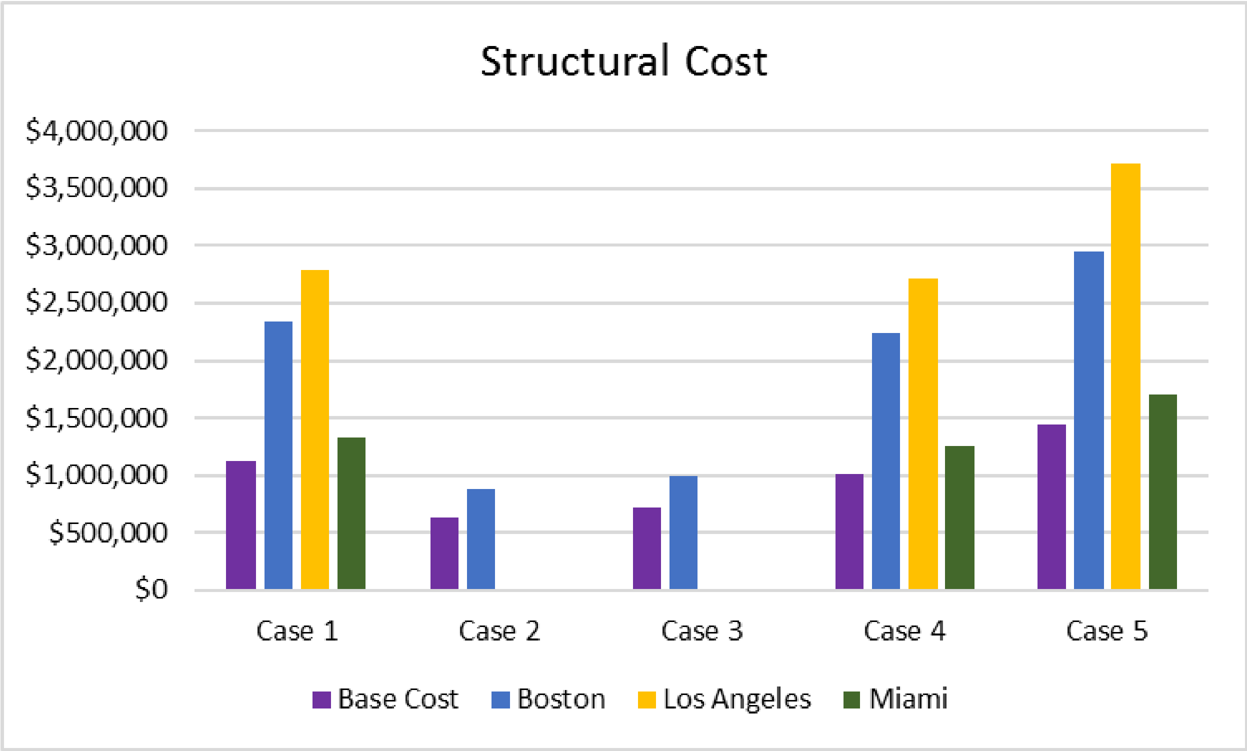


Figure 41: Structural Cost Comparison

The structural cost of each of the cases varied for each geographic location compared to the Base Cost. As can be seen in Figure 41, the costs for Case 1 and Case 4 are very similar for each scenario which is due to the similarities in their structures. Case 5 is the most expensive case due to the extended hallway which required more structural materials to be used. Case 2 and Case 3 had very similar base costs because they were the two structures that used lightweight wood construction. Case 2 is slightly less expensive because it had entirely wood construction and Case 3 had one floor of steel. The cost for Los Angeles was always the most expensive due to the large amounts of steel required for each of the frames. The frames in Boston had much smaller member sizes and less cross bracing than the Los Angeles frames but the location factor in Boston was much larger which made the costs end up being closer. In the Miami scenarios, the frames were not much larger than the original design and the location factor was equal to 1, so the cost for Miami did not increase by much compared to the Base Cost in each case.

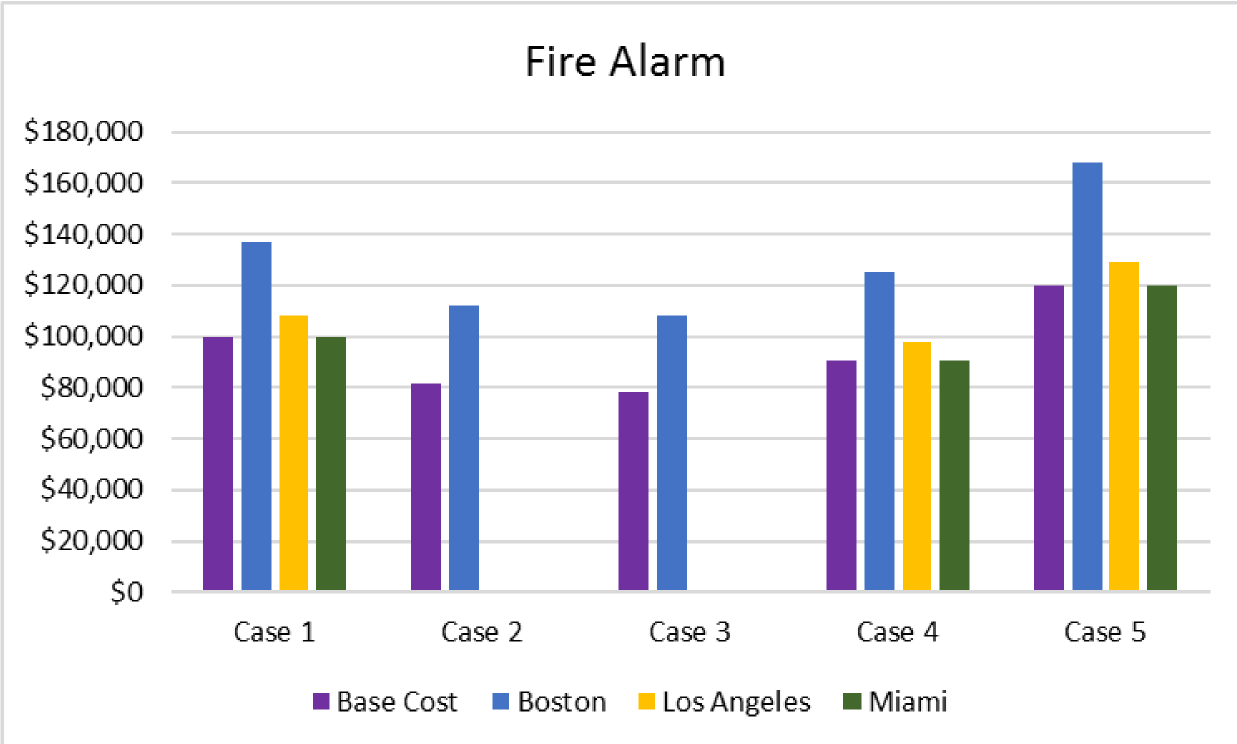


Figure 42: Fire Alarm Cost Comparison

The cost for the Fire Alarm system was more varied than the suppression system but was still very similar across the different cases (Figure 42). Cases 1 and 4 required similar number of detection devices and notification appliances because the structural layouts of the offices were similar. Cases 2 and 3 had apartments that required less devices and appliances than the offices so the cost of these two cases were lower than Case 1 and 4. Case 3 is slightly less expensive than Case 2 because the open layout of the mercantile spaces on the first floor required less devices and appliances than the apartments on the first floor of Case 2. Case 5 is the most expensive case because the larger area of the overall building required more devices and appliances, thus driving up the price.

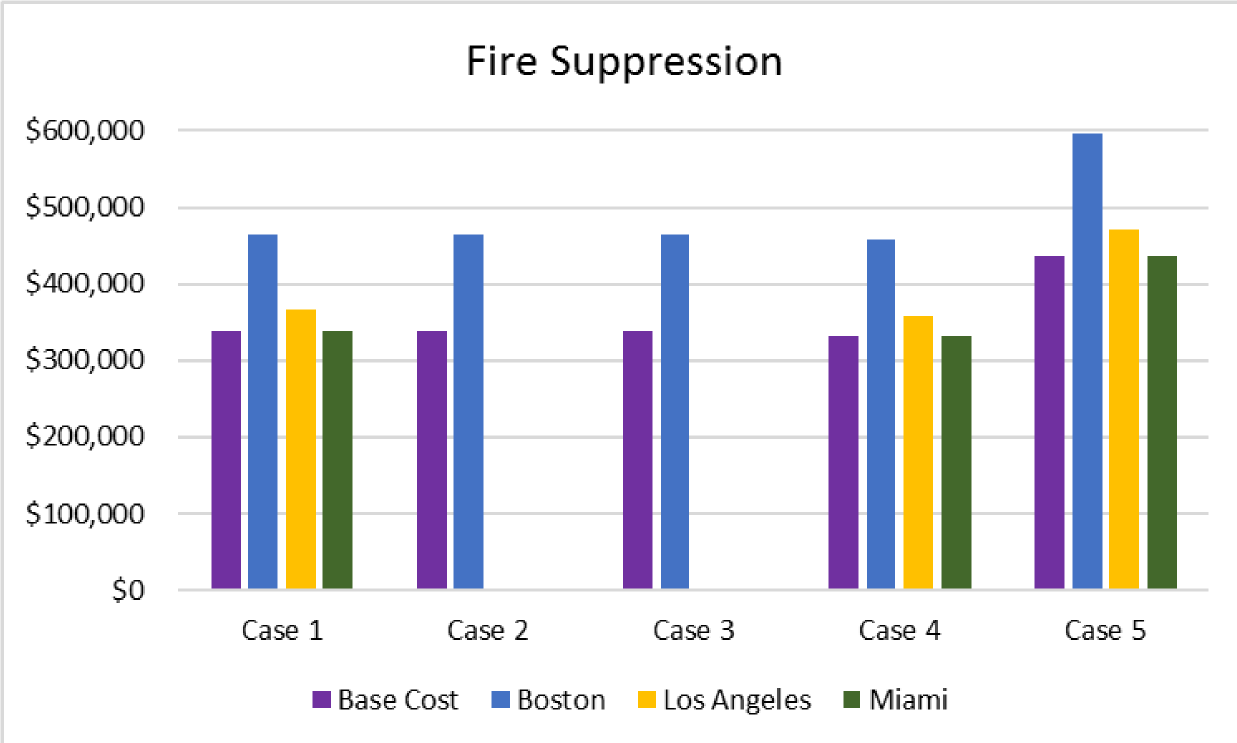


Figure 43: Fire Suppression Cost Comparison

The cost of Fire Suppression systems is based on square footage so as a result, the costs for Cases 1-4 are the same. Case 5 is the only structure with an increased cost because the extended hallway increased the square footage of the building. In each case, the costs for each location are also the same with the variation from the Base Cost coming from the Location Factor.

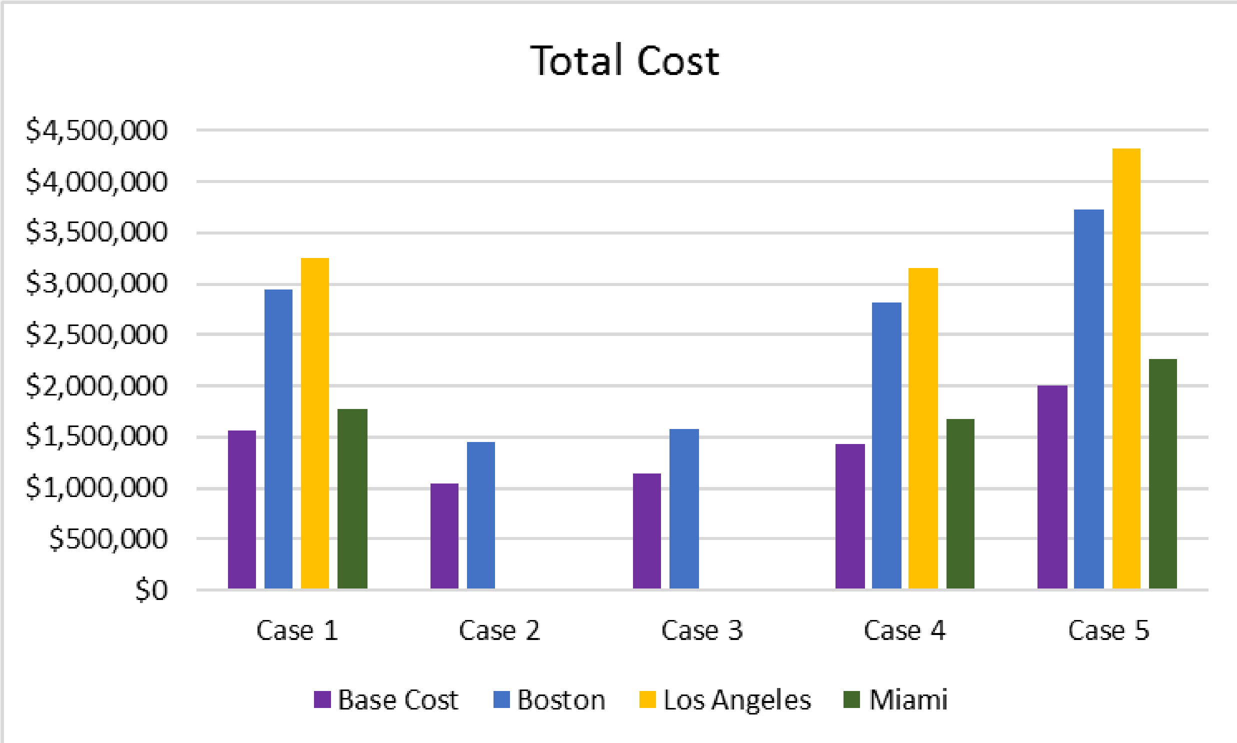


Figure 44: Total Overall Cost Comparison

The total costs of each case have similar trends to the structural costs. This is because the fire detection and suppression costs were very similar in each case and they were much less expensive than the structural materials. As a result, the costs in each case were driven by the cost of the structural design.

7.0 Summary and Conclusions

In this project, five cases were designed with different structural materials and occupancy types. The goal of this project was to explore variations within fire protection and structural system design, and to identify their effects on cost and design requirements in relation to national codes. Each of these cases was then modified to fit the environmental loads from three locations, Boston, Los Angeles, and Miami. Fire protection systems and structural designs were created for each cases in each location. A cost analysis was then done for each of these cases and compared to analyze the effects that different structural designs, fire protection systems, and locations had on the overall cost.

7.1 Design Work

This project focuses primarily on basic variations of a typical structure to gather information on the changes required for the structural and fire protection designs. As a result, only critical aspects, such as steel member sizes and sprinkler locations, were designed. To expand on this project, one case could be chosen and designed in further depth. A deeper study could be used to determine the cost impacts of other systems. Components of this more extensive design may include structural details such as foundation and roof. Wall depths and window locations could also be specified. This would become a governing factor in the location and the sizing of steel members. Full mechanical and HVAC systems could also be included for a more complete structure and would have an effect on the location of fire protection systems as well as the structural decisions such as steel member locations and sizing. Addressable versus analog fire alarms could be further explored, as well as the effect of Fire Alarm Control Panel (FACP) zoning on the building's system and panel annunciation in the case of emergency response.

The structural design of each of these structures was calculated based on gravity and lateral loading conditions. Members were then chosen as the least weight solution. As a result, the member sizes may pose challenged for specifying connections. A further analysis of the steel design could be done to design the connections required and revise the member sizes to promote economical and efficient connections. Important strategies include using similar connection details as much as possible, minimizing the number of pieces in the connections, and avoiding stiffeners and reinforcing plates. This would improve the constructability of the overall design. In addition to connections, baseplates could be designed for the columns which would have an effect on the overall design due to lateral loading, as well as the cost due to larger plates being required for larger columns. When reviewing the frame design for the Los Angeles geographic cases, smaller spacing between the columns may be explored to determine if that would reduce the amount of cross bracing required for this structure.

The fire protection systems for these cases were designed with conservative assumptions and calculations. By doing so, larger pipes were required. If a component cost analysis were completed rather than estimation per square foot of system, these larger pipes would drive up the cost. A redesign of the system could be completed with fire compartmentalization of the office suites and apartments. This may lead to a design where fewer sprinkler heads and detection devices are required as well as fewer egress requirements. In addition to redesigning the systems, local fire codes and their effects on the design could be explored. For this project, NFPA codes were used for each case. If the local fire codes and amendments used in Boston, Los Angeles, and Miami were applied, some of the design criteria may have been more lenient than national codes, and some of the local codes may have required extremely strict, more conservative designs. Additional geographic considerations could be explored with the water demand for each system and the local water supplies. This would dictate whether a fire pump and additional water sources would be required.

7.2 Cost Analysis

Cost analyses done in this project were based on values from RS Means for the structural and fire protection systems. This data did give an estimate of the cost of each structure sufficient for comparison, but it could be analyzed further for a more accurate, complete cost. For example, there were no connections or baseplates in the structural cost analysis even though these components would increase the overall price. Additionally, the sprinkler system cost was analyzed based on square footage. A more specific cost analysis could be completed using the sprinkler pipe lengths, sprinkler head count, and valve specifications. In addition to more specific material estimates, local availability of materials and local labor costs could be explored; giving a more in-depth cost analysis of each case.

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Appendices

Appendix A: Project Proposal

1. Introduction

For decades, building and fire codes have improved safety in the built environment. As materials of construction and furnishing change, and predictive technology improves, the national codes and standards must reflect these changes. Although current codes provide a sufficient baseline for standard construction and protection, many significant improvements are reactive to larger-scale incidents, rather than being proactive in nature.

To explore this relationship and better understand the interaction of codes, a series of case studies will be considered. Two 5-story tall control buildings will be designed for commercial occupancy and residential occupancy. From these control buildings, a series of alterations will be made and the significance of required code changes will be considered. These code considerations will include both structural and fire protection elements, as well as geographic criteria (such as seismic and wind loads based on location). Once full system designs for each case study are completed, there will be a comprehensive comparison of the different cases using factors including lifesafety, differences in code requirements, and estimated design costs.

2. Background

2.1 Initial Structure

The structure modified for the purposes of this projects will be a five-story structure whose architectural design is based on Worcester Polytechnic Institute's (WPI's) East Hall. It was completed in 2011 so it complies with building and fire codes and has the correct number of floors for the purposes of this project. The structure will have a steel frame as the initial condition but will have modification made to the design and building materials.

2.2. Codes

When any type of structure is designed, various codes are used to ensure that the building will be safe for its occupants. Building codes include aspects such as loading conditions of the structure, occupancy classification and building usages, height and area constraints, M/E/P requirements, and information regarding different types of construction materials. This includes everything from concrete and steel, to glass and glazing and plastics. Building codes also include information about fire protection materials and systems, and means of egress. However, there are some codes that just include information regarding fire protection. For the scope of this project, the International Building Code (IBC) and the National Fire Protection Association (NFPA) codes will be used.

2.2.1 Building Codes

IBC is a series of building codes released by the International Code Council (ICC) every three years. It has been adopted throughout the United States with certain amendments and adaptations enacted by individual states. The 2015 edition contains 35 chapters and 13 amendments. For the purposes of this project, the IBC 2015 will be used. The use of former editions will be noted if required.

2.2.1.1 Structural Design

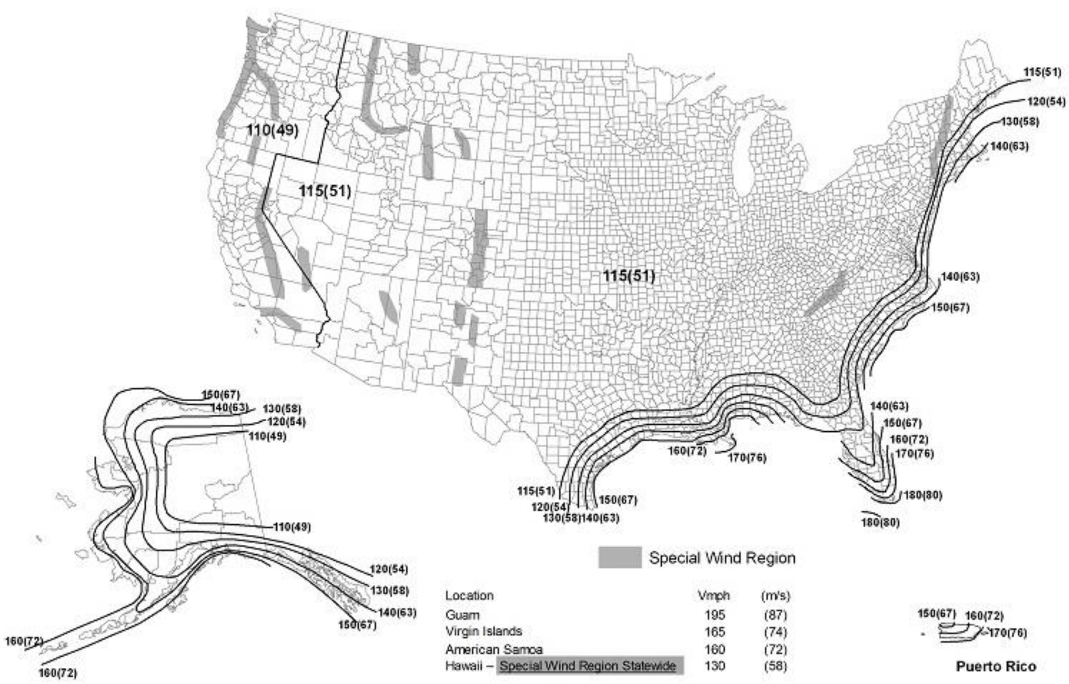
The building of a structure has many code provisions and reference standards regarding the structural design, which are covered in Chapter 16 of IBC. These design criteria include loading conditions, risk categories, the required strength, and design factors for different types of structures to decrease the risk of structural failure.

2.2.1.1.1 Risk Category

All buildings and structures are assigned a risk category based on the nature of the occupancy. There are 4 risk categories that range from low risk storage facilities (Risk I), to facilities of high importance, such as emergency shelters and toxic material storage (Risk IV). We are considering a Risk II building which is the classification for miscellaneous structures that do not fall into risk categories I, III, or IV.

2.2.1.1.2 Wind

Section 1609 of IBC 2015 covers wind loads that must be considered in structural design. These loads are determined by Chapter 26 of *ASCE 7-10*. Wind loading varies throughout the country based on the weather patterns in the region. The ultimate design wind speed, V_{ult}, is determined by the wind loads shown in the map figure below.



Notes:
1. Values are nominal design 3-second gust wind speeds in miles per hour (m/s) at 33 ft (10m) above ground for Exposure C category.
2. Linear interpolation between contours is permitted.
3. Islands and coastal areas outside the last contour shall use the last wind speed contour of the coastal area.
4. Mountainous terrain, gorges, ocean promontories, and special wind regions shall be examined for unusual wind conditions.
5. Wind speeds correspond to approximately a 7% probability of exceedance in 50 years (Annual Exceedance Probability = 0.00143, MRI = 700 Years).

FIGURE 1609.3(1) ULTIMATE DESIGN WIND SPEEDS, V_{ult}, FOR RISK CATEGORY II BUILDINGS AND OTHER STRUCTURES

This map is Figure 1609.3(1) from IBC 2015 which is used for Risk Category II Buildings. The lines on the map indicate the ultimate wind loads, ranging from 100-200 mph. Most regions use 100 mph or 105 mph as the standard V_{ult} but regions on the east coast and the Gulf of Mexico have higher values and a larger range due to the increased risk of hurricane force winds.

2.2.1.1.3 Seismic

The IBC 2015 discusses seismic forces and loading in Section 1613: Earthquake Loads. Seismic forces must be considered for all structures except for those with incidental human occupancy, as well as detached dwellings. As the structure being analyzed does not fulfill either of these requirements, it will be designed per the Maximum Considered Earthquake. The map below shows the Ground Motion Response Acceleration for 1-Second Spectral Response.

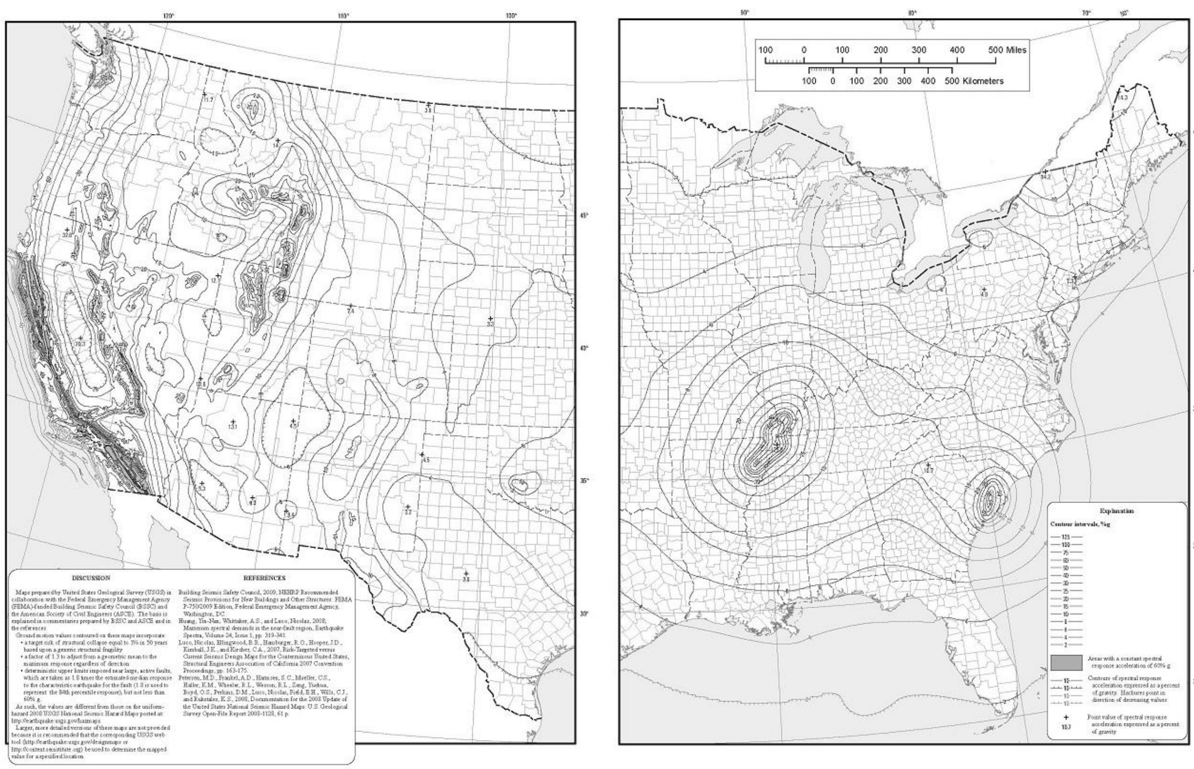


FIGURE 1613.3.1(2) RISK-TARGETED MAXIMUM CONSIDERED EARTHQUAKE (MCE_R) GROUND MOTION RESPONSE ACCELERATIONS FOR THE CONTERMINOUS UNITED STATES OF 1-SECOND SPECTRAL RESPONSE ACCELERATION (5% OF CRITICAL DAMPING), SITE CLASS B

Similar to Wind Loads, these values vary across the United States, depending on both historic occurrence and intensity. These values as well as the Risk Category of the structure are analyzed and a Seismic Design Category, A, B, C, or D, is assigned to the building.

2.2.1.2 Building Occupancy

Building Occupancy is broken up by the IBC into ten different subgroups depending on the intended use for the facility. These include Assembly, Business, Educational, Factory and Industrial, High Hazard, Institutional, Mercantile, Residential, Storage, Utility, and Miscellaneous. Some of these groups are subcategorized in order to add specifications needed for variations. These specifications are used for individualized cases with additional special considerations under one main category. For example, a single family dwelling and a high-rise apartment building are both considered residential, but need to be designed very differently due to height, building material, and number of occupants. The three occupancies that should be noted for this project are Business: Group B (IBC 2015, Section 304), Mercantile: Group M (IBC 2015, Section 309), and Residential: Group R-2 (IBC 2015, Section 310.4).

2.2.1.2.1 Business: Group B

Business Occupancy encompasses structures for offices and professional use, including storage of records and accounts. Structures are classified as this occupancy if any portion is used for business. Business classification includes office facilities, banks, car washes, laboratories, outpatient clinics, and others.

2.2.1.2.2 Mercantile: Group M

Mercantile Occupancy is for buildings intended for the display, storage, and sale of merchandise. Such facilities include department stores, drug stores, gas stations, retail, and sales rooms.

2.2.1.2.3 Residential: Group R-2

Facilities with areas used for sleeping purposes that are not classified as Institutional (Group I) are considered a Residential Occupancy. Group R is broken in 4 subcategories covering varying lengths of stay and number of residents. Group R-2 covers transient sleeping units including apartments, dormitories, and religious living facilities.

2.2.2 Fire Codes

The National Fire Protection Association (NFPA) is an organization that writes and revises codes and standards for use in fire protection design at both state and municipal levels. These codes and standards are typically adopted by local governments and amended if stricter codes are desired. Each NFPA code is revised and released in a three-year cycle and the local government determines which version is used. NFPA 1 (Fire Code), NFPA 13 (Standard for the Installation of Sprinkler Systems), NFPA 72 (National Fire Alarm and Signaling Code), and NFPA 101 (Life Safety Code) will be the primary codes used as a standard for fire protection systems designed in this project.

2.2.2.1 Fire Protection Systems

Fire protection systems are designed and implemented to mitigate the effects of a fire hazard. According to NFPA 1 [3.3.120], a fire hazard is defined as "any situation, process, material, or condition that, on the basis of applicable data, can cause a fire or explosion or that can provide a ready fuel supply to augment the spread or intensity of a fire or explosion, all of which pose a threat to life or property." Fire detection and suppression systems are used to protect both the lifesafety of building occupants and emergency responders, and to mitigate property loss or damages. These systems are implemented in a variety of occupancy classifications including mercantile, business, commercial, and residential.

2.2.2.1.1 Fire Detection Systems

Fire detection systems are used in both sprinklered and unsprinklered structures. A detector is defined as "a device suitable for connection to a circuit that has a sensor that responds to a physical stimulus such as gas, heat or smoke" [*NFPA 72; Section 3.3.66*]. For system design, characteristics such as the physical size and occupancy type of the building are taken into consideration.

2.2.2.1.2 Fire Suppression Systems

Similar to fire detection systems, the design criteria for a fire suppression system is based upon design areas, occupancy types, and hazard classifications of the building. Fire suppression systems include water-based, foam application, and inert gas injection depending on the space being protected. For a typical residential or commercial occupancy, a water-based automatic sprinkler system is typically proficient.

2.2.2.2 Egresses

NFPA 1; 3.3.177 defines means of egress as "a continuous and unobstructed way of travel from any point in a building or structure to a public way consisting of three separate and distinct parts: (1) the exit access, (2) the exit, (3) the exit discharge." When calculating the permitted occupancy of specific rooms and entire buildings, an egress analysis is required. This analysis uses criteria such as the corridor lengths, door widths, stair risers, and similar factors to determine how many people can safely exit a building in a timely manner during an emergency.

2.2.2.3 Stairs

Stairs are considered in accordance with NFPA 101 for egress analysis. The riser, tread, and width of a stair may have significant impacts upon egress requirements and occupancy loads. Currently, stairs are the main means of egress from a multistory building, this makes the quantity and characteristics of staircases within a building instrumental in a design.

2.2.2.4 Occupancy Types

IBC and NFPA have similar occupancy classifications, but both must be considered within a design. An occupancy as defined by NFPA 1; 3.3.183 is "the purpose for which a building or other structure, or part thereof, it used or intended to be used". Classification of building usage helps to determine the appropriate fire detection and protection systems appropriate for the space.

2.2.2.5 Hazard Classes

A hazard rating is "the numerical rating of the health, flammability, self-reactivity, and other hazards of the material including its reaction with water" [NFPA 1; 3.3.143*; Hazard Rating]. Similar to occupancy types, the hazard classification helps the designer determine the appropriate levels and rating of fire protection systems within a structure. When designing a fire protection system, a "design fire" is typically estimated based upon the combustibility of materials within a building. This design fire allows for estimating a worst case scenario heat release rate and growth time of a fire.

2.3 Structure Types

The IBC 2015 has specific chapters dedicated to different types of building materials and the codes and limitations for each. Chapters 19-26 include concrete, aluminum, masonry, steel, wood, glass and glazing, gypsum boards, and plastic. For the analysis of the theoretical structure, steel (Chapter 22), wood (Chapter 23), and concrete (Chapter 19) will be used. Building construction type will also be considered for fire resistance rating in the sprinkler system design [NFPA 13].

2.3.1 Steel Frame

Steel is one of the most desirable structural frame materials for mercantile, commercial, and large-scale residential buildings. It is a high strength material with a wide range of design flexibility. Because of these characteristics, both architects and engineers benefit from using steel in construction. In addition, in areas with local access to steel manufacturing, steel is less expensive than concrete and it can be built much quicker due to a lack of curing time. Steel is also not effected by weather during construction. This is beneficial when building in locations with harsh winters.

2.3.2 Pedestal with Wood Frame

Structures do not necessarily need to be constructed of only one building material. Wood framing can be used in Risk I and II type buildings, with regards to seismic classification. It is particularly favorable for residential construction due to its inexpensive nature. Wood can only be used for construction to a limited height, because of this, it is sometimes built on top of a stronger base material. This is considered “pedestal” construction. All materials used in these structures must be in compliance with the building codes.

2.4 Special Conditions

When a building does not conform to traditional design, considerations of these variations must be accounted for. Designs may include unique structural or aesthetic elements that have an effect on how the code is interpreted and implemented. Examples of special conditions that we will be considering are atriums and non-traditional fire doors.

2.4.1 Atrium

As defined in NFPA 3.3.27, an atrium is a "large-volume space created by a floor opening or series of floor openings connecting two or more stories that is covered at the top of the series of openings and is used for purposes other than an enclosed stairway; an elevator hoistway; an escalator opening; or as a utility shaft used for plumbing, electrical, air-conditioning, or communications facilities." Atriums are a common design element in larger buildings to open the interior space and provide interest points to a structure. Because atriums are not uncommon, there are specific areas of the code that detail the variations in treatment required. These specific criteria typically address smoke control and detection as well as automatic sprinkler protector or other suppression techniques.

2.4.2 Accordion-Type Fire Doors

The code must adapt and change with improvements and expansion of technology. A double accordion-type fire door has been around for decades [source Won Door] but has recently been rising in popularity as building owners value the aesthetic of an open space over a bay of traditional fire doors. These doors function through a heat or smoke detection system that triggers their release from a recess in the wall. After this is triggered, this moveable wall will automatically extend to the opposite wall on a ceiling tract. The concerns for appliances like these mainly extend to the compartmentalization speed and the robustness to function under emergency conditions. Non-traditional fire doors like this must be considered in a case by case basis to determine the effectiveness of the system and if it will pose a problem to the structural elements of the building. These doors may impact the structural design when replacing a load bearing wall containing traditional swing-type fire doors.

2.5 Cost Estimating

Before a construction project begins, the overall cost of the project is estimated. These estimates are based on standards for cost estimating and cost analysis. RS Means will be used as a source of product cost data, and UniFormat will be utilized as an organization system for cost compilation and analysis. Estimating is completed using a method called "takeoff" and then the total project is priced per square foot of the structure. Some aspects of a project must be determined using takeoff but others can be more generalized by estimating per square foot. When there is insufficient data in the design specifications, elements including electrical wiring, HVAC, and plumbing can be generalized to cost per square foot. There are benefits and drawbacks of using takeoff versus cost per area, therefore both methods are initially considered for every product to achieve the most accurate price.

2.5.1 Takeoff

Estimating using the "takeoff" method involves determining how much of a specific material is going to be used and then multiplying by the cost per unit. Steel is estimated using this method by pricing per linear foot of each piece size. This method will be used in estimating the cost of each steel design case. When materials are measured using takeoff, a certain amount of buffer is calculated in to ensure that the amount does not come up short. Takeoff can be calculated by hand, but there are also software programs available that can do many of these calculations at once, expediting the process.

2.5.2 Square Footage

When pricing a job using area estimation, only certain aspects are included in this cost. Labor is one of the items that is estimated per square foot. Other items such as wiring and plumbing can be estimated using square footage because many structures built for the same uses have similar amounts of these items per square foot. These items will be estimated in the design cases because there is not enough information to do a takeoff. This type of estimating can be less precise than takeoff because each amount of product is not being calculated throughout the entire building, but it is generally accurate enough that estimators use it as a way to assist in establishing their bid.

2.6 Conclusion

Through analysis of both structural and fire protection systems, the relationship and use of codes for varying occupancy and structural characteristics will be explored. Many different portions of IBC and NFPA codes and standards will be consulted to complete this analysis.

Discussion will include the relative cost effectiveness of each design as well as the interactions between various code types. This will be completed through analysis of different cases exploring variations in structural and fire protection system design.

3. Capstone Design Statement

This Major Qualifying Project focused on the design and analysis of the structural and fire protection aspects of a theoretical five-story structure. Courses in civil, structural, and fire protection engineering gave our team the tools to complete the engineering and design work for this project. The capstone design serves as a bridge between school and the professional engineering workforce. The skills that had been learned in the classroom were able to be applied to a real-world design problem. This project will help our team review the current code requirements and how they vary under different design constraints. The main focuses of this project were:

3.1 Economic

A variety of cases are being considered as final designs of the building. These cases differed in the structural and fire protection aspects of the design. By considering different design scenarios, a cost analysis can be implemented for each case. From here, we will be able to determine the cost of the materials needed for each scenario and identify how each case differs. This will allow us to determine the structural and fire protection components that have the greatest cost impact.

3.2 Health and Safety

The use of building and fire codes is necessary in creating regulated, safe building and system designs. The National Fire Protection Association (NFPA) and the International Building Code (IBC) are two established codes used in the United States for design and construction. Both of these codes add different considerations that must be taken into account when changing the building's use, material, and location. We will be using NFPA and IBC codes to ensure that our designs are compliant on a national scale.

3.3 Manufacturability

The scope of project considered a variety of different types of construction materials, designs, and calculations. In addition to pure structural considerations, the design was reconfigured to account for fire protection system layout. A full fire protection layout was designed for each case study as per NFPA and regional fire codes based on the occupancy types and hazard classifications. These designs included automatic suppression systems, heat and smoke detection devices, notification appliances, occupancy loads, and egress analysis.

3.4 Sustainability

As part of our results, we will be looking into the longevity and sustainability of each design. As large scale events occur, codes are reevaluated and updated based on safety and new technologies available. By looking at a variety of case studies, we will be reviewing the strengths and potential weaknesses in each design. This critical look at the designs will aid in determining the sustainability of each case from a code and material perspective.

4. Professional Engineering Licensure

Achieving the status of a Professional Engineer is beneficial both professionally and personally. To acquire a PE, an engineer must complete a rigorous process that includes completing a four-year college degree and taking the Fundamentals of Engineering (FE) exam. Once this exam has been passed, the graduate becomes an Engineer in Training (EIT) and must work under a Professional Engineer (PE) for at least four years. To move from the title of EIT to PE, the Engineer in Training must complete and pass a second intensive Principles and Practice of Engineering exam. This PE exam grants PE status to the engineer in the state that they took it in. In order to practice in multiple states after receiving their license, the engineer must apply to each new state individually. Each state has different continuing education requirements to maintain a PE license.

Having a PE license can provide more opportunities for career growth and development because many companies view a PE as a sign of a determined and motivated individual. A licensed engineer can approve drawings and designs to be put forward on to projects. This gives you a high level of responsibility but also a high level of respect from peers and coworkers. Even in a careers that do not require the use of a PE license, having the license will showcase your knowledge and drive to other professionals and clients. In addition to the professional benefits of a PE license, there is an increased pay scale for those with a license.

5. Scope and Methodology

Case	Number of Stories	Occupancy Type	"Special" Characteristics and Conditions	Principle Responsibility	Scope	References	Programs or Software
Case 1: Control I	5	Commercial	Control Building	Coffey & Healey	Modify East Hall CAD Floor Plans		AutoCAD
				Coffey	Design Fire Protection Systems for Commercial Use	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout of Building	IBC (2015), AISC 14th ed.	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	
Case 2: Control II	5	Residential	Control Building	Coffey & Healey	Modify East Hall CAD Floor Plans		AutoCAD
				Coffey	Design Fire Protection Systems for Commercial Use	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout of Building	IBC (2015), AWC (2012)	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	

Case 3: Mixed Occupancy	5	Commercial /Mercantile on Bottom Floor, Residential Above	Multiple Occupancy Types	Coffey & Healey	Modify Control Case Drawings (Denote locations such as office space, residential space, retail, etc.)		AutoCAD
				Coffey	Design Fire Protection Systems based on Occupancy	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout of Building and Identify Changes from Control	IBC (2015), AISC 14th ed.	
				Coffey & Healey	Identify Differences between Original Use/Renovation	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	
Case 4: Inclusion of an Atrium	5	Commercial	Atrium requires alternative code application and smoke control	Coffey & Healey	Modify Case I Drawings to include Atrium from Floors 1-2		AutoCAD
				Coffey	Design Fire Protection Systems for Commercial Use (include considerations for smoke control)	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016),	

						NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout of Building (including differences in load bearing due to open atrium design)	IBC (2015), AISC 14th ed.	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	
Case 5: Horizontal Fire Door vs. Traditional Swing Fire Door	5	Commercial	Use of "new technology" (example: Won Door) compared to a bay of fire doors	Coffey & Healey	Modify Case I Drawings to include horizontal fire doors in open areas (elevator bays, staircases, etc.)		AutoCAD
				Coffey	Design Fire Protection Systems for Commercial Use (take fire doors into account)	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout (Differences between having a load-bearing set of doors versus a ceiling track accordion fold door).	IBC (2015), AISC 14th ed.	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	

Case 6: Effects of Additional Wings on Building	5	Commercial	Long corridors' effect on egress	Coffey & Healey	Modify Case I Drawings to include additional wings on building		AutoCAD
				Coffey	Design Fire Protection Systems for Commercial Use	NFPA 1 (2015), NFPA 13 (2016), NFPA 72 (2016), NFPA 101 (2015)	
				Coffey	Confirm Egress Compliance	NFPA 101 (2015)	
				Healey	Design Structural Layout (Design for Lateral Load)	IBC (2015), AISC 14^{th} ed.	
				Coffey & Healey	Develop Cost Estimate (per square foot)	RS Means	
Case 7: Alternative Floor Systems	5	Commercial	Steel Decking, Precast Concrete, etc. Loading conditions and fire resistance	Coffey & Healey	Investigate effect on price per square foot from Control Case I	ACI (2014), AISC 14^{th} ed.	

6. Schedule

Term	Dates	Milestones	Weekly Goals	Notes
A Term	9/19 - 9/25	First Proposal Submittal (September 23rd)	Finish all sections of the project proposal	
	9/26 - 10/2			
	10/3 - 10/9			
	10/10 - 10/13	End of Term Submittal (October 15th)		
B Term	10/24 - 10/30		-Review working draft and solidify design approach	
	10/31 - 11/6		-Structural calculation spreadsheet for Case 1 completed -Identify additional design case studies to consider	Contact Kristen Bigda (NFPA)
	11/7 - 11/13	Complete Case Study Drawings (including Fire Detection and Notification appliance design)	-Complete audit and code review of all cases for compliance	
	11/14 - 11/20		-Complete sprinkler activation time spreadsheets	
	11/21 - 12/4	Complete Sprinkler Design for all Case Studies	-Complete structural calculations for Case 2	Decide whether or not to include a concrete structure case
	12/5 - 12/11		-Complete structural calculations for Cases 3-7	
	12/12 - 12/15	End of Term Submittal (Paper to Date and All Calculations)		
C Term	1/12 - 1/22		-Complete cost analysis on structural and fire protection components of design	

			-Compare Cases in regards to design criteria and associated costs	
	1/23 - 1/29		-Compile calculations and drawings -Compare Cases in regards to design criteria and associated costs	
	1/30 - 2/5	First Full Draft Submittal (February 3rd)	-Format report -Write initial project conclusions	
	2/6 - 2/12		-Continue analysis and comparisons of Case Studies	
	2/13 - 2/19		-Continue analysis and comparisons of Case Studies -Update discussion and conclusions	
	2/20 - 2/26		-Continue analysis and comparisons of Case Studies -Update discussions and conclusions	
	2/27 - 3/3	Submit Final Project	-Finalize formatting	

References

"International Building Code". International Code Council. 2015

"Fire Code". NFPA 1. 2015

"Standard for the Installation of Sprinkler Systems". NFPA 13. 2016

"National Fire Alarm and Signaling Code". NFPA 72. 2016

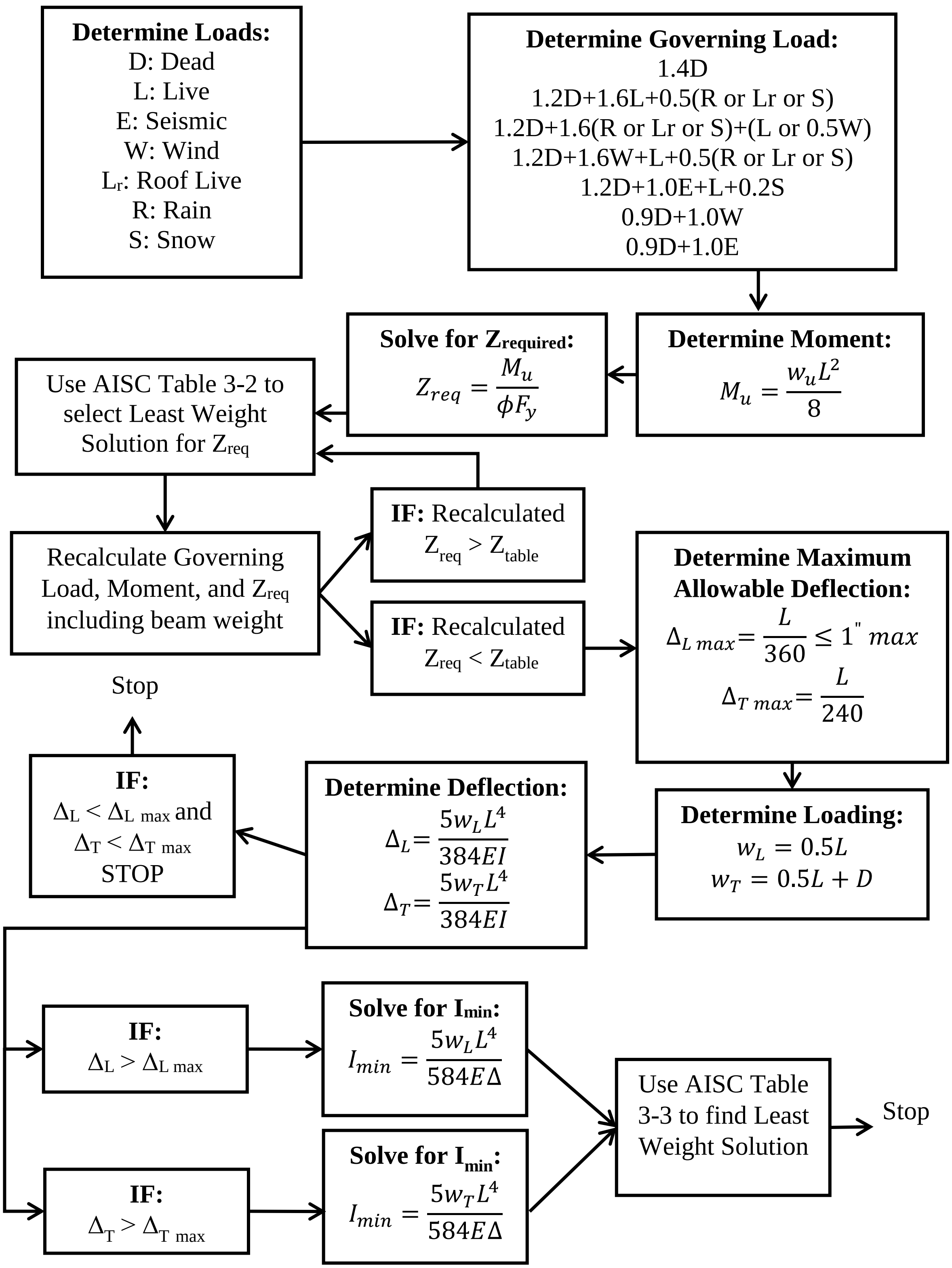
"Life Safety Code". NFPA 101. 2015

"What is a PE?" National Society of Professional Engineers. NSPE. 2016

https://www.nspe.org/resources/licensure/what-pe

Appendix B: Structural Design Sample Calculation

Steel Design



Case 1											
Gravity Loads			**Los Angeles, California**			**Miami, Florida**			**Boston, Massachusetts**		
Label	**Size**	**Length (ft)**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**
B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63
B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21
B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71
B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13
B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63
B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00
B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71
B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63
B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21
B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71
B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W14x22	15.13
B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63
B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00
B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71
G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40
G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60
G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40
G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21
G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40
G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21
G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40
G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60
G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67
G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40
G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60
G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67
G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04
G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19
G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00
G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21
G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13
G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21
G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00
G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40
G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40
G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21
G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40
G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40
G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W14x22	21.60
G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x30	22.40
G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21

G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x30	22.40
G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21
G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x26	22.40
G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60
G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67
G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x26	22.40
G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60
G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67
G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04
G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19
G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00
G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x26	21.21
G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x62	31.13
G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21
G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W14x22	22.00
G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40
G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x30	22.40
G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21
G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x30	22.40
F1	-	-	F1*	W21x62	-	F1	W18x40	-	F1*	W21x44	-
F2	-	-	F2*	W21x62	-	F2	W18x40	-	F2*	W21x44	-
F3	-	-	F3*	W21x62	-	F3*	W18x40	-	F3*	W21x44	-
F4	-	-	F4*	W21x62	-	F4	W14x22	-	F4*	W18x40	-
F5	-	-	F5*	W21x68	-	F5*	W18x40	-	F5*	W21x44	-
F6	-	-	F6*	W21x62	-	F6	W14x26	-	F6*	W21x44	-
F7	-	-	F7*	W21x62	-	F7	W14x26	-	F7*	W21x44	-
F8	-	-	F8*	W21x62	-	F8	W14x22	-	F8*	W14x22	-
C1	-	-	C1	W14x109	-	C1	W12x50	-	C1	W14x82	-
C2	-	-	C2	W14x120	-	C2	W12x40	-	C2	W14x82	-
C3	-	-	C3	W14x120	-	C3	W12x50	-	C3	W14x82	-
C4	-	-	C4	W14x109	-	C4	W12x40	-	C4	W12x50	-
C5	-	-	C5	W14x132	-	C5	W12x50	-	C5	W14x82	-
C6	-	-	C6	W14x109	-	C6	W12x40	-	C6	W14x65	-
C7	-	-	C7	W14x109	-	C7	W12x40	-	C7	W14x82	-
C8	-	-	C8	W14x120	-	C8	W12x40	-	C8	W12x40	-
			* = Cross-Bracing			* = Cross-Bracing			* = Cross-Bracing		

General Cost								
Label	Weight	Length (ft)	Cost/ton	# per Floor	# of Floors	Total	Length	Total Cost
Beams								
B1	19	14.63	3100.00	15	4	60	878	$25842
B2	40	17.21	3100.00	28	4	112	1927	$119495
B3	19	13.71	3100.00	28	4	112	1535	$45216
B4	22	15.13	3100.00	28	4	112	1694	$57765
B5	19	14.63	3100.00	6	4	24	351	$10337
B6	16	10.00	3100.00	14	4	56	560	$13888
B7	26	15.71	3100.00	42	4	168	2639	$106363
B1R	16	14.63	3100.00	15	1	15	219	$5441
B2R	35	17.21	3100.00	28	1	28	482	$26139
B3R	16	13.71	3100.00	28	1	28	384	$9519
B4R	22	15.13	3100.00	28	1	28	424	$14441
B5R	16	14.63	3100.00	6	1	6	88	$2176
B6R	16	10.00	3100.00	14	1	14	140	$3472
B7R	22	15.71	3100.00	42	1	42	660	$22500
							Total Cost	$462594
Girder								
G1	16	12.40	3100.00	3	4	12	149	$3689
G2	22	21.60	3100.00	3	4	12	259	$8840
G3	35	22.40	3100.00	6	4	24	538	$29159
G4	16	9.21	3100.00	3	4	12	111	$2740
G5	35	22.40	3100.00	8	4	32	717	$38879
G6	16	9.21	3100.00	4	4	16	147	$3654
G7	31	22.40	3100.00	4	4	16	358	$17218
G8	68	31.60	3100.00	4	4	16	506	$53297
G9	16	11.67	3100.00	4	4	16	187	$4629
G10	31	22.40	3100.00	4	4	16	358	$17218
G11	62	31.60	3100.00	4	4	16	506	$48595
G12	16	11.67	3100.00	4	4	16	187	$4629
G13	16	6.04	3100.00	4	4	16	97	$2397
G14	16	15.19	3100.00	4	4	16	243	$6026
G15	16	10.00	3100.00	2	4	8	80	$1984
G16	31	21.21	3100.00	5	4	20	424	$20381
G17	68	31.13	3100.00	5	4	20	623	$65612
G18	16	9.21	3100.00	1	4	4	37	$913
G19	26	22.00	3100.00	1	4	4	88	$3546
G20	16	12.40	3100.00	1	4	4	50	$1230
G21	35	22.40	3100.00	1	4	4	90	$4860
G22	16	9.21	3100.00	1	4	4	37	$913
G23	35	22.40	3100.00	1	4	4	90	$4860
G1R	16	12.40	3100.00	3	1	3	37	$922
G2R	16	21.60	3100.00	3	1	3	65	$1607
G3R	22	22.40	3100.00	6	1	6	134	$4582

G4R	16	9.21	3100.00	3	1	3	28	$685
G5R	22	22.40	3100.00	8	1	8	179	$6110
G6R	16	9.21	3100.00	4	1	4	37	$913
G7R	22	22.40	3100.00	4	1	4	90	$3055
G8R	55	31.60	3100.00	4	1	4	126	$10777
G9R	16	11.67	3100.00	4	1	4	47	$1157
G10R	22	22.40	3100.00	4	1	4	90	$3055
G11R	55	31.60	3100.00	4	1	4	126	$10777
G12R	16	11.67	3100.00	4	1	4	47	$1157
G13R	16	6.04	3100.00	4	1	4	24	$599
G14R	16	15.19	3100.00	4	1	4	61	$1507
G15R	16	10.00	3100.00	2	1	2	20	$496
G16R	22	21.21	3100.00	4	1	4	85	$2893
G17R	55	31.13	3100.00	4	1	4	125	$10614
G18R	16	9.21	3100.00	1	1	1	9	$228
G19R	19	22.00	3100.00	1	1	1	22	$648
G20R	16	12.40	3100.00	1	1	1	12	$307
G21R	22	22.40	3100.00	1	1	1	22	$764
G22R	16	9.21	3100.00	1	1	1	9	$228
G23R	22	22.40	3100.00	1	1	1	22	$764
							Total Cost	$409118
Columns								
C	33	10	3100	96	5	480	4800	$245520
							Total Cost	$1117232

	Weight (Lb/ft)									Total Cost		
Label	Los Angeles	Miami	Boston	Length (ft)	Cost/ ton	# per Floor	# of Floors	Total	Length	Los Angeles	Miami	Boston
Beams												
B1	19	19	19	14.63	3100	15	4	60	878	$25842	$25842	$25842
B2	40	40	40	17.21	3100	20	4	80	1377	$85353	$85353	$85353
B3	19	19	19	13.71	3100	20	4	80	1097	$32297	$32297	$32297
B4	22	22	22	15.13	3100	24	4	96	1452	$49513	$49513	$49513
B5	19	19	19	14.63	3100	5	4	20	293	$8614	$8614	$8614
B6	16	16	16	10.00	3100	14	4	56	560	$13888	$13888	$13888
B7	26	26	26	15.71	3100	30	4	120	1885	$75974	$75974	$75974
B1R	16	16	16	14.63	3100	15	1	15	219	$5441	$5441	$5441
B2R	35	35	35	17.21	3100	20	1	20	344	$18671	$18671	$18671
B3R	16	16	16	13.71	3100	20	1	20	274	$6799	$6799	$6799
B4R	22	22	22	15.13	3100	24	1	24	363	$12378	$12378	$12378
B5R	16	16	16	14.63	3100	5	1	5	73	$1814	$1814	$1814
B6R	16	16	16	10.00	3100	14	1	14	140	$3472	$3472	$3472
B7R	22	22	22	15.71	3100	30	1	30	471	$16071	$16071	$16071
Total Cost without Location Factors										$356127	$356127	$356127
Total Cost with Location Factors										$384618	$356127	$487895
Girders												
G1	16	16	16	12.40	3100	0	4	0	0	$	$	$
G2	22	22	22	21.60	3100	0	4	0	0	$	$	$
G3	35	35	35	22.40	3100	6	4	24	538	$29159	$29159	$29159
G4	16	16	16	9.21	3100	3	4	12	111	$2740	$2740	$2740
G5	35	35	35	22.40	3100	8	4	32	717	$38879	$38879	$38879
G6	16	16	16	9.21	3100	4	4	16	147	$3654	$3654	$3654
G7	31	31	31	22.40	3100	4	4	16	358	$17218	$17218	$17218
G8	38	38	38	31.60	3100	4	4	16	506	$29784	$29784	$29784
G9	16	16	16	11.67	3100	4	4	16	187	$4629	$4629	$4629
G10	31	31	31	22.40	3100	4	4	16	358	$17218	$17218	$17218
G11	62	62	62	31.60	3100	4	4	16	506	$48595	$48595	$48595
G12	16	16	16	11.67	3100	2	4	8	93	$2315	$2315	$2315
G13	16	16	16	6.04	3100	0	4	0	0	$	$	$
G14	16	16	16	15.19	3100	0	4	0	0	$	$	$
G15	16	16	16	10.00	3100	2	4	8	80	$1984	$1984	$1984
G16	31	31	31	21.21	3100	4	4	16	339	$16305	$16305	$16305
G17	68	68	68	31.13	3100	5	4	20	623	$65612	$65612	$65612
G18	16	16	16	9.21	3100	0	4	0	0	$	$	$
G19	26	26	26	22.00	3100	0	4	0	0	$	$	$
G20	16	16	16	12.40	3100	1	4	4	50	$1230	$1230	$1230
G21	35	35	35	22.40	3100	1	4	4	90	$4860	$4860	$4860
G22	16	16	16	9.21	3100	1	4	4	37	$913	$913	$913
G23	35	35	35	22.40	3100	1	4	4	90	$4860	$4860	$4860
G1R	16	16	16	12.40	3100	0	1	0	0	$	$	$
G2R	16	16	22	21.60	3100	0	1	0	0	$	$	$

G3R	22	22	30	22.40	3100	6	1	6	134	$4582	$4582	$6248
G4R	16	16	16	9.21	3100	3	1	3	28	$685	$685	$685
G5R	22	22	30	22.40	3100	8	1	8	179	$6110	$6110	$8331
G6R	16	16	16	9.21	3100	4	1	4	37	$913	$913	$913
G7R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G8R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777
G9R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G10R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G11R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777
G12R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G13R	16	16	16	6.04	3100	0	1	0	0	$	$	$
G14R	16	16	16	15.19	3100	0	1	0	0	$	$	$
G15R	16	16	16	10.00	3100	2	1	2	20	$496	$496	$496
G16R	22	22	26	21.21	3100	4	1	4	85	$2893	$2893	$3419
G17R	55	55	62	31.13	3100	5	1	5	156	$13267	$13267	$14956
G18R	16	16	16	9.21	3100	0	1	0	0	$	$	$
G19R	19	19	22	22.00	3100	0	1	0	0	$	$	$
G20R	16	16	16	12.40	3100	1	1	1	12	$307	$307	$307
G21R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
G22R	16	16	16	9.21	3100	1	1	1	9	$228	$228	$228
G23R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
Total Cost without Location Factors										$350942	$350942	$358711
Total Cost with Location Factors										$379017	$350942	$491434
Frames												
F1*	62	40	44	14.63	3100	1	5	5	73	$7030	$4535	$4989
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F2*	62	40	44	14.63	3100	4	5	20	293	$28119	$18141	$19955
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F3*	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
F4*	62	22	40	6.04	3100	4	5	20	121	$11612	$4120	$7492
	62	22	40	15.19	3100	4	5	20	304	$29190	$10358	$18833
F5*	68	40	44	21.21	3100	4	5	20	424	$44707	$26298	$28928
F6*	62	26	44	9.21	3100	1	5	5	46	$4425	$1855	$3140
	62	26	44	22.00	3100	4	5	20	440	$42284	$17732	$30008
	62	26	44	12.40	3100	4	5	20	248	$23825	$9991	$16908
F7*	62	26	44	15.71	3100	12	5	60	943	$90584	$37987	$64285
F8*	62	22	22	15.71	3100	6	5	30	471	$45292	$16071	$16071
	62	22	22	11.67	3100	2	5	10	117	$11215	$3979	$3979
Total Cost without Location Factors										$574688	$303589	$382361
Total Cost with Location Factors										$620663	$303589	$523834

Columns												
C	33	33	33	10	3100	8	5	40	400	$20460	$20460	$20460
C1	109	50	82	10	3100	17	5	85	850	$143608	$65875	$108035
C2	120	40	82	10	3100	20	5	100	1000	$186000	$62000	$127100
C3	120	50	82	10	3100	12	5	60	600	$111600	$46500	$76260
C4	109	40	50	10	3100	6	5	30	300	$50685	$18600	$23250
C5	132	50	82	10	3100	2	5	10	100	$20460	$7750	$12710
C6	109	40	65	10	3100	8	5	40	400	$67580	$24800	$40300
C7	109	40	82	10	3100	13	5	65	650	$109818	$40300	$82615
C8	120	40	40	10	3100	8	5	40	400	$74400	$24800	$24800
Total Cost without Location Factors										$784610	$311085	$515530
Total Cost with Location Factors										$847379	$311085	$706276
Cross Beams												
	Weight (Lb/ft)					**Length/ Bay**				**Total Cost**		
Label	**Los Angeles**	**Miami**	**Boston**	**Length (ft)**	**Cost/ ton**	**Los Angeles**		**Miami**	**Boston**	**Los Angeles**	**Miami**	**Boston**
X1	26	-	22	19.90	3100	199		-	59.7	$32079	-	$8143
	26	-	-	16.97	3100	169.7		-	-	$27356	-	-
	26	-	22	18.13	3100	181.3		-	54.39	$29226	-	$7419
X2	26	-	22	17.72	3100	177.2		-	53.16	$28565	-	$7251
	26	-	-	19.9	3100	99.5		-	-	$16039	-	-
	26	-	22	16.97	3100	169.7		-	50.91	$27356	-	$6944
	26	-	-	18.13	3100	90.65		-	-	$14613	-	-
X3	35	16	22	19.9	3100	199		59.7	59.7	$43183	$5922	$8143
	35	-	22	16.97	3100	169.7		-	33.94	$36825	-	$4629
X4	26	-	-	11.68	3100	116.8		-		$18828	-	-
	26	-	26	18.18	3100	181.8		-	54.54	$29306	-	$8792
X5	35	26	26	23.45	3100	234.5		70.35	70.35	$12722	$2835	$2835
X6	26	-	22	15.93	3100	159.3		-	47.79	$25679	-	$6519
	26	-	22	23.45	3100	234.5		-	70.35	$37801	-	$9596
X7	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-
	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-
	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-

X8	26	-	22	15.37	3100	76.85	-	46.11	$3097	-	$1572
	26	-	-	18.63	3100	93.15	-	-	$3754	-	-
	26	-	22	18.63	3100	93.15	-	55.89	$3754	-	$1906
	26	-	-	18.63	3100	93.15	-	-	$3754	-	-
	26	-	22	18.63	3100	93.15	-	55.89	$3754	-	$1906
	26	-	-	18.63	3100	93.15	-	-	$3754	-	-
	26	-	22	18.63	3100	93.15	-	55.89	$3754	-	$1906
	26	-	-	15.37	3100	76.85	-	-	$3097	-	-
Total Cost without Location Factors									$515715	$8757	$96619
Total Cost with Location Factors									$556972	$8757	$132368
Total Cost of Design without Location Factors									$2582083	$1330501	$1709348
Total Cost of Design with Location Factors									$2788650	$1330501	$2341807

Case 3											
Gravity Loads			**Los Angeles, California**			**Miami, Florida**			**Boston, Massachusetts**		
Label	**Size**	**Length (ft)**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**
B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63
B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21
B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71
B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13
B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63
B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00
B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71
G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40
G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60
G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40
G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21
G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40
G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21
G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40
G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60
G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67
G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40
G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60
G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67
G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04
G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19
G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00
G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21
G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13
G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21
G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00
G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40
G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40
G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21
G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40

Label	Weight	Length (ft)	Cost/ton	# per Floor	# of Floors	Total	Length	Total Cost
Beams								
B1	19	14.63	3100.00	15	1	15	219	$6461
B2	40	17.21	3100.00	28	1	28	482	$29874
B3	19	13.71	3100.00	28	1	28	384	$11304
B4	22	15.13	3100.00	28	1	28	424	$14441
B5	19	14.63	3100.00	6	1	6	88	$2584
B6	16	10.00	3100.00	14	1	14	140	$3472
B7	26	15.71	3100.00	42	1	42	660	$26591
							Total Cost	$94726
Girder								
G1	16	12.40	3100.00	3	1	3	37	$922
G2	22	21.60	3100.00	3	1	3	65	$2210
G3	35	22.40	3100.00	6	1	6	134	$7290
G4	16	9.21	3100.00	3	1	3	28	$685
G5	35	22.40	3100.00	8	1	8	179	$9720
G6	16	9.21	3100.00	4	1	4	37	$913
G7	31	22.40	3100.00	4	1	4	90	$4304
G8	68	31.60	3100.00	4	1	4	126	$13324
G9	16	11.67	3100.00	4	1	4	47	$1157
G10	31	22.40	3100.00	4	1	4	90	$4304
G11	62	31.60	3100.00	4	1	4	126	$12149
G12	16	11.67	3100.00	4	1	4	47	$1157
G13	16	6.04	3100.00	4	1	4	24	$599
G14	16	15.19	3100.00	4	1	4	61	$1507
G15	16	10.00	3100.00	2	1	2	20	$496
G16	31	21.21	3100.00	5	1	5	106	$5095
G17	68	31.13	3100.00	5	1	5	156	$16403
G18	16	9.21	3100.00	1	1	1	9	$228
G19	26	22.00	3100.00	1	1	1	22	$887
G20	16	12.40	3100.00	1	1	1	12	$307
G21	35	22.40	3100.00	1	1	1	22	$1215
G22	16	9.21	3100.00	1	1	1	9	$228
G23	35	22.40	3100.00	1	1	1	22	$1215
							Total Cost	$86318
Columns								
C	33	10	3100	96	1	96	960	$49104
							Total Cost	$230148

Case 4											
Gravity Loads			**Los Angeles, California**			**Miami, Florida**			**Boston, Massachusetts**		
Label	**Size**	**Length (ft)**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**	**Label**	**Size**	**Length**
Floor 1											
B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63
B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21
B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71
B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13
B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63
B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00
B7	W12x22	15.71	B7	W12x22	15.71	B7	W12x22	15.71	B7	W12x22	15.71
Floor 2-4											
B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63
B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21
B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71
B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13
B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63
B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00
B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71
Roof											
B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63
B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21
B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71
B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W14x22	15.13
B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63
B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00
B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71
Floor 1											
G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40
G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60
G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40
G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21
G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40
G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21
G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40
G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60
G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67
G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40
G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60
G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67
G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04
G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19
G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00
G16	W12x16	15.19	G16	W12x16	15.19	G16	W12x16	15.19	G16	W12x16	15.19
G17	W12x16	6.04	G17	W12x16	6.04	G17	W12x16	6.04	G17	W12x16	6.04

G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21
G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00
G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40
G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40
G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21
G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40
G24	W16x31	21.21	G24	W16x31	21.21	G24	W16x31	21.21	G24	W16x31	21.21
G25	W14x26	10.00	G25	W14x26	10.00	G25	W14x26	10.00	G25	W14x26	10.00
Floor 2-4											
G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40
G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60
G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40
G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21
G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40
G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21
G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40
G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60
G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67
G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40
G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60
G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67
G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04
G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19
G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00
G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21
G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13
G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21
G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00
G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40
G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40
G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21
G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40
Roof											
G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40
G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W14x22	21.60
G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x30	22.40
G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21
G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x30	22.40
G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21
G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x26	22.40
G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60
G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67
G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x26	22.40
G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60
G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67

G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04
G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19
G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00
G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x26	21.21
G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x62	31.13
G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21
G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W14x22	22.00
G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40
G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x30	22.40
G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21
G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x30	22.40
F1	-	-	F1*	W21x62	-	F1	W18x40	-	F1*	W21x44	-
F2	-	-	F2*	W21x62	-	F2	W18x40	-	F2*	W21x44	-
F3	-	-	F3*	W21x62	-	F3*	W18x40	-	F3*	W21x44	-
F4	-	-	F4*	W21x62	-	F4	W14x22	-	F4*	W18x40	-
F5	-	-	F5*	W21x68	-	F5*	W18x40	-	F5*	W21x44	-
F6	-	-	F6*	W21x62	-	F6	W14x26	-	F6*	W21x44	-
F7	-	-	F7*	W21x62	-	F7	W14x26	-	F7*	W21x44	-
F8	-	-	F8*	W21x62	-	F8	W14x22	-	F8*	W14x22	-
C1	-	-	C1	W14x109	-	C1	W12x50	-	C1	W14x82	-
C2	-	-	C2	W14x120	-	C2	W12x40	-	C2	W14x82	-
C3	-	-	C3	W14x120	-	C3	W12x50	-	C3	W14x82	-
C4	-	-	C4	W14x109	-	C4	W12x40	-	C4	W12x50	-
C5	-	-	C5	W14x132	-	C5	W12x50	-	C5	W14x82	-
C6	-	-	C6	W14x109	-	C6	W12x40	-	C6	W14x65	-
C7	-	-	C7	W14x109	-	C7	W12x40	-	C7	W14x82	-
C8	-	-	C8	W14x120	-	C8	W12x40	-	C8	W12x40	-
			* = Cross-Bracing			* = Cross-Bracing			* = Cross-Bracing		

Case 4 General Cost								
Label	Weight	Length (ft)	Cost/ton	# per Floor	# of Floors	Total	Length	Total Cost
Beams								
Floor 1								
B1	19	14.63	3100.00	15	1	15	219	$6461
B2	40	17.21	3100.00	28	1	28	482	$29874
B3	19	13.71	3100.00	28	1	28	384	$11304
B4	22	15.13	3100.00	28	1	28	424	$14441
B5	19	14.63	3100.00	6	1	6	88	$2584
B6	16	10.00	3100.00	14	1	14	140	$3472
B7	22	15.71	3100.00	36	1	36	566	$19286
Floor 2-4								
B1	19	14.63	3100.00	15	3	45	658	$19382
B2	40	17.21	3100.00	28	3	84	1446	$89621
B3	19	13.71	3100.00	28	3	84	1152	$33912
B4	22	15.13	3100.00	28	3	84	1271	$43324
B5	19	14.63	3100.00	6	3	18	263	$7753
B6	16	10.00	3100.00	14	3	42	420	$10416
B7	26	15.71	3100.00	42	3	126	1979	$79772
Roof								
B1R	16	14.63	3100.00	15	1	15	219	$5441
B2R	35	17.21	3100.00	28	1	28	482	$26139
B3R	16	13.71	3100.00	28	1	28	384	$9519
B4R	22	15.13	3100.00	28	1	28	424	$14441
B5R	16	14.63	3100.00	6	1	6	88	$2176
B6R	16	10.00	3100.00	14	1	14	140	$3472
B7R	22	15.71	3100.00	42	1	42	660	$22500
							Total Cost	$455289
Girder								
Floor 1								
G1	16	12.40	3100.00	3	1	3	37	$922
G2	22	21.60	3100.00	3	1	3	65	$2210
G3	35	22.40	3100.00	6	1	6	134	$7290
G4	16	9.21	3100.00	3	1	3	28	$685
G5	35	22.40	3100.00	8	1	8	179	$9720
G6	16	9.21	3100.00	4	1	4	37	$913
G7	31	22.40	3100.00	4	1	4	90	$4304
G8	68	31.60	3100.00	4	1	4	126	$13324
G9	16	11.67	3100.00	4	1	4	47	$1157
G10	31	22.40	3100.00	4	1	4	90	$4304
G11	62	31.60	3100.00	4	1	4	126	$12149
G12	16	11.67	3100.00	4	1	4	47	$1157
G13	16	6.04	3100.00	2	1	2	12	$300
G14	16	15.19	3100.00	2	1	2	30	$753

G15	16	10.00	3100.00	2	1	2	20	$496
G16	16	15.19	3100.00	2	1	2	30	$753
G17	16	6.04	3100.00	2	1	2	12	$300
G18	16	9.21	3100.00	1	1	1	9	$228
G19	26	22.00	3100.00	1	1	1	22	$887
G20	16	12.40	3100.00	1	1	1	12	$307
G21	35	22.40	3100.00	1	1	1	22	$1215
G22	16	9.21	3100.00	1	1	1	9	$228
G23	35	22.40	3100.00	1	1	1	22	$1215
G24	31	21.21	3100.00	5	1	5	106	$5095
G25	26	10.00	3100.00	5	1	5	50	$2015
Floor 2-4								
G1	16	12.40	3100.00	3	3	9	112	$2767
G2	22	21.60	3100.00	3	3	9	194	$6630
G3	35	22.40	3100.00	6	3	18	403	$21870
G4	16	9.21	3100.00	3	3	9	83	$2055
G5	35	22.40	3100.00	8	3	24	538	$29159
G6	16	9.21	3100.00	4	3	12	111	$2740
G7	31	22.40	3100.00	4	3	12	269	$12913
G8	68	31.60	3100.00	4	3	12	379	$39973
G9	16	11.67	3100.00	4	3	12	140	$3472
G10	31	22.40	3100.00	4	3	12	269	$12913
G11	62	31.60	3100.00	4	3	12	379	$36446
G12	16	11.67	3100.00	4	3	12	140	$3472
G13	16	6.04	3100.00	4	3	12	73	$1798
G14	16	15.19	3100.00	4	3	12	182	$4520
G15	16	10.00	3100.00	2	3	6	60	$1488
G16	31	21.21	3100.00	4	3	12	255	$12229
G17	68	31.13	3100.00	4	3	12	374	$39367
G18	16	9.21	3100.00	1	3	3	28	$685
G19	26	22.00	3100.00	1	3	3	66	$2660
G20	16	12.40	3100.00	1	3	3	37	$922
G21	35	22.40	3100.00	1	3	3	67	$3645
G22	16	9.21	3100.00	1	3	3	28	$685
G23	35	22.40	3100.00	1	3	3	67	$3645
Roof								
G1R	16	12.40	3100.00	3	1	3	37	$922
G2R	16	21.60	3100.00	3	1	3	65	$1607
G3R	22	22.40	3100.00	6	1	6	134	$4582
G4R	16	9.21	3100.00	3	1	3	28	$685
G5R	22	22.40	3100.00	8	1	8	179	$6110
G6R	16	9.21	3100.00	4	1	4	37	$913
G7R	22	22.40	3100.00	4	1	4	90	$3055
G8R	55	31.60	3100.00	4	1	4	126	$10777
G9R	16	11.67	3100.00	4	1	4	47	$1157

G10R	22	22.40	3100.00	4	1	4	90	$3055
G11R	55	31.60	3100.00	4	1	4	126	$10777
G12R	16	11.67	3100.00	4	1	4	47	$1157
G13R	16	6.04	3100.00	4	1	4	24	$599
G14R	16	15.19	3100.00	4	1	4	61	$1507
G15R	16	10.00	3100.00	2	1	2	20	$496
G16R	22	21.21	3100.00	4	1	4	85	$2893
G17R	55	31.13	3100.00	4	1	4	125	$10614
G18R	16	9.21	3100.00	1	1	1	9	$228
G19R	19	22.00	3100.00	1	1	1	22	$648
G20R	16	12.40	3100.00	1	1	1	12	$307
G21R	22	22.40	3100.00	1	1	1	22	$764
G22R	16	9.21	3100.00	1	1	1	9	$228
G23R	22	22.40	3100.00	1	1	1	22	$764
							Total Cost	$309901
Columns								
C	33	10	3100	96	5	480	4800	$245520
							Total Cost	$1010710

	Weight (Lb/ft)									Total Cost		
Label	Los Angeles	Miami	Boston	Length (ft)	Cost/ ton	# per Floor	# of Floors	Total	Length	Los Angeles	Miami	Boston
Beams												
Floor 1												
B1	19	19	19	14.63	3100	15	1	15	219	$6461	$6461	$6461
B2	40	40	40	17.21	3100	20	1	20	344	$21338	$21338	$21338
B3	19	19	19	13.71	3100	20	1	20	274	$8074	$8074	$8074
B4	22	22	22	15.13	3100	24	1	24	363	$12378	$12378	$12378
B5	19	19	19	14.63	3100	5	1	5	73	$2154	$2154	$2154
B6	16	16	16	10.00	3100	14	1	14	140	$3472	$3472	$3472
B7	22	22	22	15.71	3100	24	1	24	377	$12857	$12857	$12857
Floor 2-4												
B1	19	19	19	14.63	3100	15	3	45	658	$19382	$19382	$19382
B2	40	40	40	17.21	3100	20	3	60	1033	$64015	$64015	$64015
B3	19	19	19	13.71	3100	20	3	60	823	$24223	$24223	$24223
B4	22	22	22	15.13	3100	24	3	72	1089	$37135	$37135	$37135
B5	19	19	19	14.63	3100	5	3	15	219	$6461	$6461	$6461
B6	16	16	16	10.00	3100	14	3	42	420	$10416	$10416	$10416
B7	26	26	26	15.71	3100	30	3	90	1414	$56980	$56980	$56980
Roof												
B1R	16	16	16	14.63	3100	15	1	15	219	$5441	$5441	$5441
B2R	35	35	35	17.21	3100	20	1	20	344	$18671	$18671	$18671
B3R	16	16	16	13.71	3100	20	1	20	274	$6799	$6799	$6799
B4R	22	22	22	15.13	3100	24	1	24	363	$12378	$12378	$12378
B5R	16	16	16	14.63	3100	5	1	5	73	$1814	$1814	$1814
B6R	16	16	16	10.00	3100	14	1	14	140	$3472	$3472	$3472
B7R	22	22	22	15.71	3100	30	1	30	471	$16071	$16071	$16071
Total Cost without Location Factors										$349991	$349991	$349991
Total Cost with Location Factors										$377990	$349991	$479488
Girders												
Floor 1												
G1	16	16	16	12.40	3100	0	1	0	0	$	$	$
G2	22	22	22	21.60	3100	0	1	0	0	$	$	$
G3	35	35	35	22.40	3100	6	1	6	134	$7290	$7290	$7290
G4	16	16	16	9.21	3100	3	1	3	28	$685	$685	$685
G5	35	35	35	22.40	3100	8	1	8	179	$9720	$9720	$9720
G6	16	16	16	9.21	3100	4	1	4	37	$913	$913	$913
G7	31	31	31	22.40	3100	4	1	4	90	$4304	$4304	$4304
G8	68	68	68	31.60	3100	4	1	4	126	$13324	$13324	$13324
G9	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G10	31	31	31	22.40	3100	4	1	4	90	$4304	$4304	$4304
G11	62	62	62	31.60	3100	4	1	4	126	$12149	$12149	$12149
G12	16	16	16	11.67	3100	2	1	2	23	$579	$579	$579
G13	16	16	16	6.04	3100	0	1	0	0	$	$	$

G14	16	16	16	15.19	3100	0	1	0	0	$	$	$
G15	16	16	16	10.00	3100	2	1	2	20	$496	$496	$496
G16	16	16	16	15.19	3100	0	1	0	0	$	$	$
G17	16	16	16	6.04	3100	0	1	0	0	$	$	$
G18	16	16	16	9.21	3100	0	1	0	0	$	$	$
G19	26	26	26	22.00	3100	0	1	0	0	$	$	$
G20	16	16	16	12.40	3100	0	1	0	0	$	$	$
G21	35	35	35	22.40	3100	1	1	1	22	$1215	$1215	$1215
G22	16	16	16	9.21	3100	1	1	1	9	$228	$228	$228
G23	35	35	35	22.40	3100	1	1	1	22	$1215	$1215	$1215
G24	31	31	31	21.21	3100	4	1	4	85	$4076	$4076	$4076
G25	26	26	26	10.00	3100	4	1	4	40	$1612	$1612	$1612
Floor 2-4												
G1	16	16	16	12.40	3100	0	3	0	0	$	$	$
G2	22	22	22	21.60	3100	0	3	0	0	$	$	$
G3	35	35	35	22.40	3100	6	3	18	403	$21870	$21870	$21870
G4	16	16	16	9.21	3100	3	3	9	83	$2055	$2055	$2055
G5	35	35	35	22.40	3100	8	3	24	538	$29159	$29159	$29159
G6	16	16	16	9.21	3100	4	3	12	111	$2740	$2740	$2740
G7	31	31	31	22.40	3100	4	3	12	269	$12913	$12913	$12913
G8	38	38	38	31.60	3100	4	3	12	379	$22338	$22338	$22338
G9	16	16	16	11.67	3100	4	3	12	140	$3472	$3472	$3472
G10	31	31	31	22.40	3100	4	3	12	269	$12913	$12913	$12913
G11	62	62	62	31.60	3100	4	3	12	379	$36446	$36446	$36446
G12	16	16	16	11.67	3100	4	3	12	140	$3472	$3472	$3472
G13	16	16	16	6.04	3100	0	3	0	0	$	$	$
G14	16	16	16	15.19	3100	0	3	0	0	$	$	$
G15	16	16	16	10.00	3100	2	3	6	60	$1488	$1488	$1488
G16	31	31	31	21.21	3100	4	3	12	255	$12229	$12229	$12229
G17	68	68	68	31.13	3100	5	3	15	467	$49209	$49209	$49209
G18	16	16	16	9.21	3100	0	3	0	0	$	$	$
G19	26	26	26	22.00	3100	0	3	0	0	$	$	$
G20	16	16	16	12.40	3100	1	3	3	37	$922	$922	$922
G21	35	35	35	22.40	3100	1	3	3	67	$3645	$3645	$3645
G22	16	16	16	9.21	3100	1	3	3	28	$685	$685	$685
G23	35	35	35	22.40	3100	1	3	3	67	$3645	$3645	$3645
Roof												
G1R	16	16	16	12.40	3100	0	1	0	0	$	$	$
G2R	16	16	22	21.60	3100	0	1	0	0	$	$	$
G3R	22	22	30	22.40	3100	6	1	6	134	$4582	$4582	$6248
G4R	16	16	16	9.21	3100	3	1	3	28	$685	$685	$685
G5R	22	22	30	22.40	3100	8	1	8	179	$6110	$6110	$8331
G6R	16	16	16	9.21	3100	4	1	4	37	$913	$913	$913
G7R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G8R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777

G9R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G10R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G11R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777
G12R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G13R	16	16	16	6.04	3100	0	1	0	0	$	$	$
G14R	16	16	16	15.19	3100	0	1	0	0	$	$	$
G15R	16	16	16	10.00	3100	2	1	2	20	$496	$496	$496
G16R	22	22	26	21.21	3100	4	1	4	85	$2893	$2893	$3419
G17R	55	55	62	31.13	3100	5	1	5	156	$13267	$13267	$14956
G18R	16	16	16	9.21	3100	0	1	0	0	$	$	$
G19R	19	19	22	22.00	3100	0	1	0	0	$	$	$
G20R	16	16	16	12.40	3100	1	1	1	12	$307	$307	$307
G21R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
G22R	16	16	16	9.21	3100	1	1	1	9	$228	$228	$228
G23R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
Total Cost without Location Factors										$280189	$280189	$287958
Total Cost with Location Factors										$302605	$280189	$394503
Frames												
F1*	62	40	44	14.63	3100	1	5	5	73	$7030	$4535	$4989
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F2*	62	40	44	14.63	3100	4	5	20	293	$28119	$18141	$19955
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F3*	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
F4*	62	22	40	6.04	3100	4	5	20	121	$11612	$4120	$7492
	62	22	40	15.19	3100	4	5	20	304	$29190	$10358	$18833
F5*	68	40	44	21.21	3100	4	5	20	424	$44707	$26298	$28928
F6*	62	26	44	9.21	3100	1	5	5	46	$4425	$1855	$3140
	62	26	44	22.00	3100	4	5	20	440	$42284	$17732	$30008
	62	26	44	12.40	3100	4	5	20	248	$23825	$9991	$16908
F7*	62	26	44	15.71	3100	12	5	60	943	$90584	$37987	$64285
F8*	62	22	22	15.71	3100	6	5	30	471	$45292	$16071	$16071
	62	22	22	11.67	3100	2	5	10	117	$11215	$3979	$3979
Total Cost without Location Factors										$574688	$303589	$382361
Total Cost with Location Factors										$620663	$303589	$523834
Columns												
C	33	33	33	10	3100	8	5	40	400	$20460	$20460	$20460
C1	109	50	82	10	3100	17	5	85	850	$143608	$65875	$108035
C2	120	40	82	10	3100	20	5	100	1000	$186000	$62000	$127100
C3	120	50	82	10	3100	12	5	60	600	$111600	$46500	$76260
C4	109	40	50	10	3100	6	5	30	300	$50685	$18600	$23250

C5	132	50	82	10	3100	2	5	10	100	$20460	$7750	$12710
C6	109	40	65	10	3100	8	5	40	400	$67580	$24800	$40300
C7	109	40	82	10	3100	13	5	65	650	$109818	$40300	$82615
C8	120	40	40	10	3100	8	5	40	400	$74400	$24800	$24800
Total Cost without Location Factors										$784610	$311085	$515530
Total Cost with Location Factors										$847379	$311085	$706276
Cross Beams												
	Weight (Lb/ft)					**Length/ Bay**				**Total Cost**		
Label	**Los Angeles**	**Miami**	**Boston**	**Length (ft)**	**Cost/ ton**	**Los Angeles**		**Miami**	**Boston**	**Los Angeles**	**Miami**	**Boston**
X1	26	-	22	19.90	3100	199		-	59.7	$32079	-	$8143
	26	-	-	16.97	3100	169.7		-	-	$27356	-	-
	26	-	22	18.13	3100	181.3		-	54.39	$29226	-	$7419
X2	26	-	22	17.72	3100	177.2		-	53.16	$28565	-	$7251
	26	-	-	19.9	3100	99.5		-	-	$16039	-	-
	26	-	22	16.97	3100	169.7		-	50.91	$27356	-	$6944
	26	-	-	18.13	3100	90.65		-	-	$14613	-	-
X3	35	16	22	19.9	3100	199		59.7	59.7	$43183	$5922	$8143
	35	-	22	16.97	3100	169.7		-	33.94	$36825	-	$4629
X4	26	-	-	11.68	3100	116.8		-		$18828	-	-
	26	-	26	18.18	3100	181.8		-	54.54	$29306	-	$8792
X5	35	26	26	23.45	3100	234.5		70.35	70.35	$12722	$2835	$2835
X6	26	-	22	15.93	3100	159.3		-	47.79	$25679	-	$6519
	26	-	22	23.45	3100	234.5		-	70.35	$37801	-	$9596
X7	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-
	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-
	31	-	22	18.63	3100	186.3		-	93.15	$17903	-	$6353
	31	-	-	18.63	3100	186.3		-	-	$17903	-	-
X8	26	-	22	15.37	3100	76.85		-	46.11	$3097	-	$1572
	26	-	-	18.63	3100	93.15		-	-	$3754	-	-
	26	-	22	18.63	3100	93.15		-	55.89	$3754	-	$1906
	26	-	-	18.63	3100	93.15		-	-	$3754	-	-
	26	-	22	18.63	3100	93.15		-	55.89	$3754	-	$1906
	26	-	-	18.63	3100	93.15		-	-	$3754	-	-
	26	-	22	18.63	3100	93.15		-	55.89	$3754	-	$1906
	26	-	-	15.37	3100	76.85		-	-	$3097	-	-
Total Cost without Location Factors										$515715	$8757	$96619
Total Cost with Location Factors										$556972	$8757	$132368
Total Cost of Design without Location Factors										$2505194	$1253612	$1632459
Total Cost of Design with Location Factors										$2705610	$1253612	$2236469

Case 5											
Gravity Loads			Los Angeles, California			Miami, Florida			Boston, Massachusetts		
Label	Size	Length (ft)	Label	Size	Length	Label	Size	Length	Label	Size	Length
B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63	B1	W12x19	14.63
B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21	B2	W18x40	17.21
B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71	B3	W12x19	13.71
B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13	B4	W14x22	15.13
B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63	B5	W12x19	14.63
B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00	B6	W12x16	10.00
B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71	B7	W14x26	15.71
B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63	B1R	W12x16	14.63
B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21	B2R	W18x35	17.21
B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71	B3R	W12x16	13.71
B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W12x22	15.13	B4R	W14x22	15.13
B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63	B5R	W12x16	14.63
B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00	B6R	W12x16	10.00
B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71	B7R	W14x22	15.71
G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40	G1	W12x16	12.40
G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60	G2	W14x22	21.60
G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40	G3	W18x35	22.40
G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21	G4	W12x16	9.21
G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40	G5	W18x35	22.40
G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21	G6	W12x16	9.21
G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40	G7	W16x31	22.40
G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60	G8	W24x68	31.60
G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67	G9	W12x16	11.67
G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40	G10	W16x31	22.40
G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60	G11	W24x62	31.60
G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67	G12	W12x16	11.67
G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04	G13	W12x16	6.04
G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19	G14	W12x16	15.19
G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00	G15	W12x16	10.00
G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21	G16	W16x31	21.21
G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13	G17	W24x68	31.13
G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21	G18	W12x16	9.21
G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00	G19	W14x26	22.00
G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40	G20	W12x16	12.40
G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40	G21	W18x35	22.40
G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21	G22	W12x16	9.21
G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40	G23	W18x35	22.40
G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40	G1R	W12x16	12.40
G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W12x16	21.60	G2R	W14x22	21.60
G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x22	22.40	G3R	W14x30	22.40
G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21	G4R	W12x16	9.21
G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x22	22.40	G5R	W14x30	22.40

G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21	G6R	W12x16	9.21
G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x22	22.40	G7R	W14x26	22.40
G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60	G8R	W21x55	31.60
G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67	G9R	W12x16	11.67
G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x22	22.40	G10R	W14x26	22.40
G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60	G11R	W21x55	31.60
G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67	G12R	W12x16	11.67
G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04	G13R	W12x16	6.04
G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19	G14R	W12x16	15.19
G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00	G15R	W12x16	10.00
G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x22	21.21	G16R	W14x26	21.21
G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x55	31.13	G17R	W21x62	31.13
G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21	G18R	W12x16	9.21
G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W12x19	22.00	G19R	W14x22	22.00
G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40	G20R	W12x16	12.40
G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x22	22.40	G21R	W14x30	22.40
G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21	G22R	W12x16	9.21
G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x22	22.40	G23R	W14x30	22.40
F1	-	-	F1*	W21x62	-	F1	W18x40	-	F1*	W21x44	-
F2	-	-	F2*	W21x62	-	F2	W18x40	-	F2*	W21x44	-
F3	-	-	F3*	W21x62	-	F3*	W18x40	-	F3*	W21x44	-
F4	-	-	F4*	W21x62	-	F4	W14x22	-	F4*	W18x40	-
F5	-	-	F5*	W21x68	-	F5*	W18x40	-	F5*	W21x44	-
F6	-	-	F6*	W21x62	-	F6	W14x26	-	F6*	W21x44	-
F7	-	-	F7*	W21x62	-	F7	W14x26	-	F7*	W21x44	-
F8	-	-	F8*	W21x62	-	F8	W14x22	-	F8*	W14x22	-
C1	-	-	C1	W14x109	-	C1	W12x50	-	C1	W14x82	-
C2	-	-	C2	W14x120	-	C2	W12x40	-	C2	W14x82	-
C3	-	-	C3	W14x120	-	C3	W12x50	-	C3	W14x82	-
C4	-	-	C4	W14x109	-	C4	W12x40	-	C4	W12x50	-
C5	-	-	C5	W14x132	-	C5	W12x50	-	C5	W14x82	-
C6	-	-	C6	W14x109	-	C6	W12x40	-	C6	W14x65	-
C7	-	-	C7	W14x109	-	C7	W12x40	-	C7	W14x82	-
C8	-	-	C8	W14x120	-	C8	W12x40	-	C8	W12x40	-
			* = Cross-Bracing			* = Cross-Bracing			* = Cross-Bracing		

Case 5 General Costs								
Label	**Weight**	**Length (ft)**	**Cost/ton**	**# per Floor**	**# of Floors**	**Total**	**Length**	**Total Cost**
Beams								
B1	19	14.63	3100.00	15	4	60	878	$25842
B2	40	17.21	3100.00	28	4	112	1927	$119495
B3	19	13.71	3100.00	28	4	112	1535	$45216
B4	22	15.13	3100.00	28	4	112	1694	$57765
B5	19	14.63	3100.00	6	4	24	351	$10337
B6	16	10.00	3100.00	14	4	56	560	$13888
B7	26	15.71	3100.00	84	4	336	5279	$212726
B8	16	9.21	3100.00	7	4	28	258	$6395
B1R	16	14.63	3100.00	15	1	15	219	$5441
B2R	35	17.21	3100.00	28	1	28	482	$26139
B3R	16	13.71	3100.00	28	1	28	384	$9519
B4R	22	15.13	3100.00	28	1	28	424	$14441
B5R	16	14.63	3100.00	6	1	6	88	$2176
B6R	16	10.00	3100.00	14	1	14	140	$3472
B7R	22	15.71	3100.00	42	1	42	660	$22500
B8R	16	9.21	3100.00	7	1	7	64	$1599
							Total Cost	$576952
Girder								
G1	16	12.40	3100.00	3	4	12	149	$3689
G2	22	21.60	3100.00	3	4	12	259	$8840
G3	35	22.40	3100.00	6	4	24	538	$29159
G4	16	9.21	3100.00	3	4	12	111	$2740
G5	35	22.40	3100.00	8	4	32	717	$38879
G6	16	9.21	3100.00	4	4	16	147	$3654
G7	31	22.40	3100.00	4	4	16	358	$17218
G8	68	31.60	3100.00	4	4	16	506	$53297
G9	16	11.67	3100.00	4	4	16	187	$4629
G10	31	22.40	3100.00	4	4	16	358	$17218
G11	62	31.60	3100.00	4	4	16	506	$48595
G12	16	11.67	3100.00	4	4	16	187	$4629
G13	16	6.04	3100.00	4	4	16	97	$2397
G14	16	15.19	3100.00	4	4	16	243	$6026
G15	16	10.00	3100.00	2	4	8	80	$1984
G16	31	21.21	3100.00	12	4	48	1018	$48915
G17	68	31.13	3100.00	12	4	48	1494	$157468
G18	16	9.21	3100.00	1	4	4	37	$913
G19	26	22.00	3100.00	1	4	4	88	$3546
G20	16	12.40	3100.00	1	4	4	50	$1230
G21	35	22.40	3100.00	1	4	4	90	$4860
G22	16	9.21	3100.00	1	4	4	37	$913
G23	35	22.40	3100.00	1	4	4	90	$4860

G1R	16	12.40	3100.00	3	1	3	37	$922
G2R	16	21.60	3100.00	3	1	3	65	$1607
G3R	22	22.40	3100.00	6	1	6	134	$4582
G4R	16	9.21	3100.00	3	1	3	28	$685
G5R	22	22.40	3100.00	8	1	8	179	$6110
G6R	16	9.21	3100.00	4	1	4	37	$913
G7R	22	22.40	3100.00	4	1	4	90	$3055
G8R	55	31.60	3100.00	4	1	4	126	$10777
G9R	16	11.67	3100.00	4	1	4	47	$1157
G10R	22	22.40	3100.00	4	1	4	90	$3055
G11R	55	31.60	3100.00	4	1	4	126	$10777
G12R	16	11.67	3100.00	4	1	4	47	$1157
G13R	16	6.04	3100.00	4	1	4	24	$599
G14R	16	15.19	3100.00	4	1	4	61	$1507
G15R	16	10.00	3100.00	2	1	2	20	$496
G16R	22	21.21	3100.00	12	1	12	255	$8678
G17R	55	31.13	3100.00	12	1	12	374	$31841
G18R	16	9.21	3100.00	1	1	1	9	$228
G19R	19	22.00	3100.00	1	1	1	22	$648
G20R	16	12.40	3100.00	1	1	1	12	$307
G21R	22	22.40	3100.00	1	1	1	22	$764
G22R	16	9.21	3100.00	1	1	1	9	$228
G23R	22	22.40	3100.00	1	1	1	22	$764
							Total Cost	$556521
				Columns				
C	33	10	3100	114	5	570	5700	$291555
							Total Cost	$1425027

	Weight (Lb/ft)									Total Cost		
Label	Los Angeles	Miami	Boston	Length (ft)	Cost/ ton	# per Floor	# of Floors	Total	Length	Los Angeles	Miami	Boston
Beams												
B1	19	19	19	14.63	3100	15	4	60	878	$25842	$25842	$25842
B2	40	40	40	17.21	3100	20	4	80	1377	$85353	$85353	$85353
B3	19	19	19	13.71	3100	20	4	80	1097	$32297	$32297	$32297
B4	22	22	22	15.13	3100	24	4	96	1452	$49513	$49513	$49513
B5	19	19	19	14.63	3100	5	4	20	293	$8614	$8614	$8614
B6	16	16	16	10.00	3100	14	4	56	560	$13888	$13888	$13888
B7	26	26	26	15.71	3100	60	4	240	3770	$151947	$151947	$151947
B8	16	16	16	9.21	3100	7	4	28	258	$6395	$6395	$6395
B1R	16	16	16	14.63	3100	15	1	15	219	$5441	$5441	$5441
B2R	35	35	35	17.21	3100	20	1	20	344	$18671	$18671	$18671
B3R	16	16	16	13.71	3100	20	1	20	274	$6799	$6799	$6799
B4R	22	22	22	15.13	3100	24	1	24	363	$12378	$12378	$12378
B5R	16	16	16	14.63	3100	5	1	5	73	$1814	$1814	$1814
B6R	16	16	16	10.00	3100	14	1	14	140	$3472	$3472	$3472
B7R	22	22	22	15.71	3100	60	1	60	943	$32143	$32143	$32143
B8R	16	16	16	9.21	3100	7	1	7	64	$1599	$1599	$1599
Total Cost without Location Factors										$456167	$456167	$456167
Total Cost with Location Factors										$492660	$456167	$624948
Girders												
G1	16	16	16	12.40	3100	0	4	0	0	$	$	$
G2	22	22	22	21.60	3100	0	4	0	0	$	$	$
G3	35	35	35	22.40	3100	6	4	24	538	$29159	$29159	$29159
G4	16	16	16	9.21	3100	3	4	12	111	$2740	$2740	$2740
G5	35	35	35	22.40	3100	8	4	32	717	$38879	$38879	$38879
G6	16	16	16	9.21	3100	4	4	16	147	$3654	$3654	$3654
G7	31	31	31	22.40	3100	4	4	16	358	$17218	$17218	$17218
G8	38	38	38	31.60	3100	4	4	16	506	$29784	$29784	$29784
G9	16	16	16	11.67	3100	4	4	16	187	$4629	$4629	$4629
G10	31	31	31	22.40	3100	4	4	16	358	$17218	$17218	$17218
G11	62	62	62	31.60	3100	4	4	16	506	$48595	$48595	$48595
G12	16	16	16	11.67	3100	2	4	8	93	$2315	$2315	$2315
G13	16	16	16	6.04	3100	0	4	0	0	$	$	$
G14	16	16	16	15.19	3100	0	4	0	0	$	$	$
G15	16	16	16	10.00	3100	2	4	8	80	$1984	$1984	$1984
G16	31	31	31	21.21	3100	8	4	32	679	$32610	$32610	$32610
G17	68	68	68	31.13	3100	12	4	48	1494	$157468	$157468	$157468
G18	16	16	16	9.21	3100	0	4	0	0	$	$	$
G19	26	26	26	22.00	3100	0	4	0	0	$	$	$
G20	16	16	16	12.40	3100	1	4	4	50	$1230	$1230	$1230
G21	35	35	35	22.40	3100	1	4	4	90	$4860	$4860	$4860
G22	16	16	16	9.21	3100	1	4	4	37	$913	$913	$913

G23	35	35	35	22.40	3100	1	4	4	90	$4860	$4860	$4860
G1R	16	16	16	12.40	3100	0	1	0	0	$	$	$
G2R	16	16	22	21.60	3100	0	1	0	0	$	$	$
G3R	22	22	30	22.40	3100	6	1	6	134	$4582	$4582	$6248
G4R	16	16	16	9.21	3100	3	1	3	28	$685	$685	$685
G5R	22	22	30	22.40	3100	8	1	8	179	$6110	$6110	$8331
G6R	16	16	16	9.21	3100	4	1	4	37	$913	$913	$913
G7R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G8R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777
G9R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G10R	22	22	26	22.40	3100	4	1	4	90	$3055	$3055	$3610
G11R	55	55	55	31.60	3100	4	1	4	126	$10777	$10777	$10777
G12R	16	16	16	11.67	3100	4	1	4	47	$1157	$1157	$1157
G13R	16	16	16	6.04	3100	0	1	0	0	$	$	$
G14R	16	16	16	15.19	3100	0	1	0	0	$	$	$
G15R	16	16	16	10.00	3100	2	1	2	20	$496	$496	$496
G16R	22	22	26	21.21	3100	8	1	8	170	$5786	$5786	$6838
G17R	55	55	62	31.13	3100	12	1	12	374	$31841	$31841	$35893
G18R	16	16	16	9.21	3100	0	1	0	0	$	$	$
G19R	19	19	22	22.00	3100	0	1	0	0	$	$	$
G20R	16	16	16	12.40	3100	1	1	1	12	$307	$307	$307
G21R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
G22R	16	16	16	9.21	3100	1	1	1	9	$228	$228	$228
G23R	22	22	30	22.40	3100	1	1	1	22	$764	$764	$1041
									Total Cost without Location Factors	$480570	$480570	$491228
									Total Cost with Location Factors	$519015	$480570	$672983
Frames												
F1*	62	40	44	14.63	3100	1	5	5	73	$7030	$4535	$4989
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F2*	62	40	44	14.63	3100	4	5	20	293	$28119	$18141	$19955
	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
	62	40	44	15.13	3100	4	5	20	303	$29070	$18755	$20631
F3*	62	40	44	17.21	3100	4	5	20	344	$33074	$21338	$23472
	62	40	44	13.71	3100	4	5	20	274	$26347	$16998	$18698
F4*	62	22	40	6.04	3100	4	5	20	121	$11612	$4120	$7492
	62	22	40	15.19	3100	4	5	20	304	$29190	$10358	$18833
F5*	68	40	44	21.21	3100	4	5	20	424	$44707	$26298	$28928
F6*	62	26	44	9.21	3100	1	5	5	46	$4425	$1855	$3140
	62	26	44	22.00	3100	4	5	20	440	$42284	$17732	$30008
	62	26	44	12.40	3100	4	5	20	248	$23825	$9991	$16908
F7*	62	26	44	15.71	3100	24	5	120	1885	$181168	$75974	$128571

F8*	62	22	22	15.71	3100	12	5	60	943	$90584	$32143	$32143
	62	22	22	11.67	3100	2	5	10	117	$11215	$3979	$3979
Total Cost without Location Factors										$710564	$357647	$462717
Total Cost with Location Factors										$767409	$357647	$633923
Columns												
C	33	33	33	10	3100	8	5	40	400	$20460	$20460	$20460
C1	109	50	82	10	3100	17	5	85	850	$143608	$65875	$108035
C2	120	40	82	10	3100	20	5	100	1000	$186000	$62000	$127100
C3	120	50	82	10	3100	12	5	60	600	$111600	$46500	$76260
C4	109	40	50	10	3100	6	5	30	300	$50685	$18600	$23250
C5	132	50	82	10	3100	5	5	25	250	$51150	$19375	$31775
C6	109	40	65	10	3100	8	5	40	400	$67580	$24800	$40300
C7	109	40	82	10	3100	24	5	120	1200	$202740	$74400	$152520
C8	120	40	40	10	3100	12	5	60	600	$111600	$37200	$37200
Total Cost without Location Factors										$945423	$369210	$616900
Total Cost with Location Factors										$1021056	$369210	$845153

Cross Beams											
	Weight (Lb/ft)					**Length/ Bay**			**Total Cost**		
Label	**Los Angeles**	**Miami**	**Boston**	**Length (ft)**	**Cost/ ton**	**Los Angeles**	**Miami**	**Boston**	**Los Angeles**	**Miami**	**Boston**
X1	35	16	22	19.90	3100	199	59.7	99.5	$43183	$5922	$13572
	35	-	-	16.97	3100	169.7	-	-	$36825	-	-
	35	16	22	18.13	3100	181.3	54.39	90.65	$39342	$5395	$12365
X2	26	16	22	17.72	3100	177.2	53.16	53.16	$28565	$5273	$7251
	26	-	-	19.9	3100	199	-	-	$32079	-	-
	26	16	22	16.97	3100	169.7	50.91	50.91	$27356	$5050	$6944
	26	-	-	18.13	3100	181.3	-	-	$29226	-	-
X3	40	16	22	19.9	3100	199	59.7	59.7	$49352	$5922	$8143
	40	-	22	16.97	3100	169.7	-	33.94	$42086	-	$4629
X4	35	-	-	11.68	3100	116.8	-		$25346	-	-
	35	-	22	18.18	3100	181.8	-	54.54	$39451	-	$7439
X5	40	16	22	23.45	3100	234.5	70.35	117.3	$14539	$1745	$3998
X6	26	-	-	15.93	3100	79.65	-	-	$12840	-	-
	26	-	22	23.45	3100	234.5	-	70.35	$37801	-	$9596
X7	40	16	22	18.63	3100	186.3	55.89	93.15	$46202	$5544	$12706
	40	-	-	18.63	3100	186.3	-	-	$46202	-	-
	40	16	22	18.63	3100	186.3	55.89	93.15	$46202	$5544	$12706
	40	-	-	18.63	3100	186.3	-	-	$46202	-	-
	40	16	22	18.63	3100	186.3	55.89	93.15	$46202	$5544	$12706
	40	-	-	18.63	3100	186.3	-	-	$46202	-	-

X8	26	-	22	15.37	3100	153.7	-	46.11	$12388	-	$3145
	26	-	-	18.63	3100	186.3	-	-	$15016	-	-
	26	-	22	18.63	3100	186.3	-	55.89	$15016	-	$3812
	26	-	-	18.63	3100	186.3	-	-	$15016	-	-
	26	-	22	18.63	3100	186.3	-	55.89	$15016	-	$3812
	26	-	-	18.63	3100	186.3	-	-	$15016	-	-
	26	-	22	18.63	3100	186.3	-	55.89	$15016	-	$3812
	26	-	-	15.37	3100	153.7	-	-	$12388	-	-
Total Cost without Location Factors									$850074	$45941	$126634
Total Cost with Location Factors									$918080	$45941	$173489
Total Cost of Design without Location Factors									$3442797	$1709535	$2153646
Total Cost of Design with Location Factors									$3718221	$1709535	$2950495

Wood Calculations

Wall Column Design | L_{max}: 47'-2" | Tributary Width: 7'-9⅛"

Dead Load: 17 lb/ft² (16")(7'-9⅛") + 1.7 lb/ft² (10 ft)(47'-2")(4 floor) = 3207 lb
Live Load: 40 lb/ft² (16")(7'-9⅛") = 414 lb
Snow Load: 50 lb/ft² (16")(7'-9⅛") = 517 lb

Critical Load Combinations (no snow)

$$\frac{1.4D}{0.6} = \boxed{7906\ \text{lb}} \qquad \frac{1.2D + 0.5S}{0.6} = 6777\ \text{lb}$$

$$\frac{1.2D + 1.6L + 0.5S}{0.8} = 5910\ \text{lb} \qquad \frac{1.2D + 1.6S + L}{0.8} = 5600\ \text{lb}$$

Geographic

$$\frac{1.4D}{0.6} = \boxed{7906\ \text{lb}} \qquad \frac{1.2D + 0.5S}{0.6} = 7208\ \text{lb}$$

$$\frac{1.2D + 1.6L + 0.5S}{0.8} = 6234\ \text{lb} \qquad \frac{1.2D + 1.6S + L}{0.8} = 6635\ \text{lb}$$

Section Properties

Length: 10 ft
Depth: 5.5 in
Width: 1.5 in
Area: 8.25 in²

Design Values

F_c = 1600 psi
E = 1600,000 psi
E_{min} = 580,000 psi
c = 0.8

$C_F = 1.0$, $C_M = 1.0$, $C_t = 1.0$, $C_T = 1.0$

$C_i = 1.0$, $\lambda = 0.8$, $\phi_c = 0.9$, $\phi_s = 0.85$

$K_{Fc} = \frac{2.16}{\phi_c}$, $K_{FE} = \frac{1.5}{\phi_s}$

Calculations

$K_e = 1.0$
$l_e = K_e \cdot \text{Length} = 120\ \text{in}$

$E'_{min} = \phi_s K_{F\text{-}E} E_{min} C_M C_t C_i C_T$
$= 870,000\ \text{psi}$

$$F_{cE} = 0.822 \frac{E'_{min}}{\left(\frac{l_e}{\text{Depth}}\right)^2} = 0.822 \frac{870,000\ \text{psi}}{\left(\frac{120}{5.5}\right)^2} = 1502\ \text{psi}$$

$$F_c^* = \lambda \phi_c \cdot F_c K_{F\text{-}c} C_M C_t C_F C_i = 2765\ \text{psi}$$

$$\alpha_c = \frac{F_{cE}}{F_c^*} = \frac{1502}{2765} = 0.543$$

$$C_p = \left(\frac{1+\alpha_c}{2 \cdot c}\right) - \sqrt{\left(\frac{1+\alpha_c}{2 \cdot c}\right)^2 - \frac{\alpha_c}{c}} = 0.463$$

$$F'_c = \lambda \phi_c K_{F\text{-}c} F_c C_M C_t C_F C_i C_p = 1281\ \text{psi}$$

$$f_c = \frac{P_{load}}{\text{Area}} = \frac{7906\ \text{lb}}{8.25\ \text{in}^2} = 958\ \text{psi} \qquad F'_c > f_c$$

2x6 @ 16" OC

Glued Laminated Beam

$L_{max} = 21'-8''$

Dimensions

width: 6 3/4"
depth: 24"

dead load: 21.4 lb/ft² (4'-5 1/8") = 94.74 lb/ft
Live Load: 40 lb/ft² (4'-5 1/8") = 177.1 lb/ft

$W_{factored} = 1.2D + 1.6L = (1.2 \times 94.74) + (1.6 \times 177.1) = 397$ lb/ft

Area = 162 in²
$I_x = 7776$ in⁴
$S_x = 648$ in³

$F_{bx} = 2400$ psi
$F_{vx} = 215$ psi

$E_x = 1,800,000$ psi
$E_{xmin} = 930,000$ psi

$E_y = 1,600,000$ psi
$E_{ymin} = 780,000$ psi

$C_{Fu} = 1.07$
$C_m = 1.0$
$C_t = 1.0$

$\phi_b = 0.85$, $\phi_s = 0.85$
$\phi_v = 0.75$, $\lambda = 0.8$

$K_{F-Fb} = \frac{2.16}{\phi_b}$, $K_{F-E} = \frac{1.5}{\phi_s}$
$K_{F-Fv} = \frac{2.16}{\phi_v}$

$$M = \frac{wL^2}{8} = \frac{397 \text{ lb/f} (21'-8'')^2}{8} = 23,296 \text{ lb-ft} = 279,554 \text{ lb-in}$$

$$f_{bi} = \frac{M}{S_x} = \frac{279,554 \text{ lb-in}}{648 \text{ in}^3} = 431.4 \text{ psi}$$

Design Calculations

$$C_v = \left(\frac{21 \text{ ft}}{24'-8''}\right)^{0.1} \left(\frac{12 \text{ in}}{24 \text{ in}}\right)^{0.1} \left(\frac{5.125 \text{ in}}{6.75 \text{ in}}\right)^{0.1} = 0.905$$

$$\frac{L_{ux}}{Depth} = \frac{21'-8''}{2'} = 10.8$$

$$l_e = 1.63(21'-8'') + 3(2') = 495.8 \text{ in}$$

$$E'_{min} = K_{F-E}\, \phi_s\, E_{ymin}\, C_M C_t = \left(\frac{1.5}{0.85}\right) 0.85 (780000 \text{ psi})(1)(1) = 1,170,000 \text{ psi}$$

$$R_B = \sqrt{l_e \frac{d}{b^2}} = \sqrt{(495.8 \text{ in}) \frac{24 \text{ in}}{(6.75)^2}} = 16.16$$

$$F_{bE} = 1.20 \frac{E'_{min}}{R_B^2} = 1.20 \frac{(1,170000 \text{ psi})}{16.16^2} = 5,376 \text{ psi}$$

$$F_b^* = \lambda K_{F-Fb}\, \phi_b\, F_b C_m C_t = (0.8) \frac{2.16}{0.85} (0.85)(2400 \text{ psi})(1)(1) = 4147 \text{ psi}$$

$$\alpha_b = \frac{F_{bE}}{F_b^*} = \frac{5376}{4147} = 1.296$$

$$C_L = \left(\frac{1+\alpha_b}{1.9}\right) - \sqrt{\left(\frac{1+\alpha_b}{1.9}\right)^2 - \frac{\alpha_b}{0.95}}$$

$$= \left(\frac{1+1.296}{1.9}\right) - \sqrt{\left(\frac{1+1.296}{1.9}\right)^2 - \frac{1.296}{0.95}} = 0.898$$

$C_L < C_V$ ∴ C_L governs

Bending Check

- Major Axis : $F_{b_1} = \lambda K_{F-F_b} \Phi_b F_{bx} C_m C_t C_L$
$= 0.8\left(\frac{2.16}{\Phi_b}\right)(\Phi_b)(2400\,psi)(1)(1)(0.898) = 3724\,psi$

$f_{b_1} = 431.4 < F_{b_1} = 3724\,psi$ ✓

Shear Check

$F'_v = \lambda K_{F-F_v} \Phi_v F_v C_m C_t$
$= 0.8\left(\frac{2.16}{\Phi_v}\right)\Phi_v(215\,psi)(1.0)(1.0) = 372\,psi$

$V'_r = \left(\frac{2}{3}\right)F'_v\,bd = \left(\frac{2}{3}\right)372\,psi\,(6.75\,in)(24\,in) = 40{,}176\,lb$

$V_{load} = \frac{wL}{2} = \frac{(397\,lb/ft)(21'\text{-}8")}{2} = 4{,}301\,lb$

$V_{load} < V'_r$ ✓

Deflection Check

$\frac{L_{max}}{360} = 0.722\,in$

$\Delta = \frac{5wL^4}{384EI} = \frac{5(397\,lb/ft)(21'\text{-}8\,in)^4}{384(1{,}800{,}000\,psi)(7776\,in^4)} = 0.14\,in$ ✓

Beam Size is acceptable

Roof Joist Check | L_{max}: 14'-7½" | 2x10

Length: 14'-7½"	width: 1.50 in	$C_m = 1.0$	$C_i = 1.0$
Fb: 1050 psi	depth: 9.25 in	$C_r = 1.15$	$\phi_b = 0.85$
Fv: 175 psi	Sx: 21.39 in³	$C_t = 1.0$	$\phi_v = 0.75$
E: 1,600,000 psi	Ix: 98.93 in³	$C_F = 1.0$	$\lambda = 0.8$

Dead Load: 30 lb/ft² (16") = 40 lb/ft
Live Load: 20 lb/ft² (16") = 26.7 lb/ft

$w = 1.2D + 1.6L = 1.2(40) + 1.6(26.7) = 90.7$ lb/ft

$M_{load} = \frac{wL^2}{8} = \frac{90.7 \text{ lb/ft} (14'\text{-}7\tfrac{1}{2}")^2}{8} = 29{,}089$ lb·in $= 2424$ lb·ft

Bending Check

$F'b = \lambda K_{F\text{-}Fb} \phi_b F_b C_m C_t C_r C_F = 0.8\left(\frac{2.16}{0.85}\right)(0.85)(1050\text{psi})(1)(1)(1.15)(1)$
$= 2087$ psi

$f_b = \frac{M_{load}}{S_x} = \frac{29{,}089 \text{ lb·in}}{21.39 \text{ in}^3} = 1360$ psi $f_b < F'b$ ✓

Shear Check

$F'v = \lambda K_{F\text{-}Fv} \phi_v F_v C_m C_t C_i = 0.8\left(\frac{2.16}{0.75}\right)0.75(175\text{psi})(1)(1)(1)$
$= 302$ psi

$V_{load} = \frac{wL}{2} = \frac{90.7(14\text{-}7\tfrac{1}{2})}{2} = 663$ lb

$V'_r = \left[\left(\tfrac{2}{3}\right)F'v\, b d_n\right]\left(\frac{d_n}{d}\right)^2 = \left[\left(\tfrac{2}{3}\right)302\text{psi}(1.5)(7.25\text{in})\right]\left[\frac{7.25}{9.25}\right]^2$
$= 1347$ lb $V_{load} < V'_r$ ✓

Deflection Check

$\Delta = \frac{5wL^4}{384EI} = \frac{5(66.7 \text{ lb/ft})(14'\text{-}7\tfrac{1}{2})^4}{384(1{,}600{,}000\text{psi})(98.93\text{ in}^4)} = 0.4335$ in

$0.4335 < 0.488$ ✓   **2x10 @ 16" OC**

Roof + Snow => 2x12

Dead Load: 80 lb/ft² (16") = 106.7 lb/ft

$w = 1.2D + 1.6L = 1.2(106.7) + 1.6(26.7) = 170.7$ lb/ft

$M_{load} = \frac{wL^2}{8} = \frac{170.7 \text{ lb/ft} (14\text{-}7\tfrac{1}{2})^2}{8} = 54{,}756$ lb-in $= 4563$ lb-ft

Bending: $f_b = \frac{54756 \text{ lb·in}}{31.64 \text{ in}^3} = 1731$ psi $f_b < F'b$ ✓

Shear: $V_{load} = \frac{170.7(14\text{-}7\tfrac{1}{2})}{2} = 1248$ lb $V_{load} < V'_r = 1891$ lb ✓

Deflection: $\Delta = \frac{5(133 \text{ lb/ft})(14\text{-}7\tfrac{1}{2})^4}{384(1{,}600{,}000\text{psi})(178\text{ in}^4)} = 0.482$ in $\Delta < \Delta_{max} = 0.488$ in ✓

2x12 @ 16" OC

Floor Joist Check — L_{max} : 14'-7½" — 2" x 12"

Length: 14'-7½"	Width: 1.50 in	C_m = 1.0	C_i = 1.0
F_b : 1050 psi	Depth: 11.25 in	C_r = 1.15	ϕ_b = 0.85
F_v : 175 psi	S_x = 31.64 in³	C_t = 1.0	ϕ_v = 0.75
E : 1,600,000 psi	I_x = 177.98 in⁴	C_F = 1.0	λ = 0.8

Dead Load: 17.5 lb/ft² (16") = 23.33 lb/ft
Live Load: 40.0 lb/ft² (16") = 53.33 lb/ft

$w = 1.2D + 1.6L = 1.2(23.33) + 1.6(53.33) = 113.3$ lb/ft

$M_{load} = \frac{wL^2}{8} = \frac{113.3(14'\text{-}7\tfrac{1}{2}")^2}{8} = 36{,}361$ lb·in $= 3030$ lb·ft

Bending Check

$\frac{\text{Depth nominal}}{\text{Width nom.}} = \frac{12}{2} = 6 \quad \therefore \quad C_L = 1.0$

$F_b' = \lambda K_{F\text{-}Fb} \phi_b F_b C_m C_t C_r C_F = 0.8\left(\frac{2.16}{0.85}\right)(0.85)(1050\text{psi})(1)(1)(1.15)(1)$
$= 2087$ psi

$f_b = \frac{M_{load}}{S_x} = \frac{36{,}361 \text{ lb·in}}{31.64 \text{ in}^3} = 1{,}149$ psi $\quad f'_b < F_b$ ✓

Shear Check

$F'_v = \lambda K_{F\text{-}Fv} \phi_v F_v C_m C_t C_i = 0.8\left(\frac{2.16}{0.75}\right)(0.75)(175\text{psi})(1)(1)(1)$
$= 302$ psi

$V_{load} = \frac{wL}{2} = \frac{113.3 \text{ lb/ft} (14'\text{-}7\tfrac{1}{2}")}{2} = 829$ lb

Depth notch = 9.25 in $\quad \therefore$ notch = 2 in

$V'_r = \left[\left(\frac{2}{3}\right) F'_v b d_n\right]\left(\frac{d_n}{d}\right)^2 = \left[\left(\frac{2}{3}\right) 302\text{psi}(1.5\text{in})(9.25\text{in})\right]\left(\frac{9.25}{11.25}\right)^2$
$= 1891$ lb

$V_{load} < V'_r$ ✓

Deflection Check

$\frac{\text{Length}}{360} = 0.488$ in

$\Delta = \frac{5wL^4}{384EI_x} = \frac{5(76.67 \text{ lb/ft})(14'\text{-}7\tfrac{1}{2}")^4}{384(1600000\text{psi})(177.98\text{in}^4)} = 0.277$ in

$0.277 < 0.488$ ✓

2" x 12" @ 16" O.C. is acceptable.

Appendix C: Lateral Loading Sample Calculation

Seismic

$$C_s = \frac{S_{DS}}{\frac{R}{I}}$$

$$V = C_s * W$$

$$C_{vi} = \frac{w_x h_x^k}{\sum_{i=1}^{n} w_i h_i^k}$$

$$F_i = C_{vi} * V$$

$$F_x = \frac{F_i K_F}{N}$$

S_{DS}: short-period design response acceleration

R: Response modification factor, 3

I: Importance Factor

Cs: Seismic response coefficient

V: total base shear

W: total weight of structure

w_x: weight of floor, x

h_x^k: height of floor, x

C_{vi}: vertical distribution factor

F_i: total seismic force

F_x: Force per frame, x

K_F: Frame stiffness

N: quantity of frame type

Boston Seismic Calculations (Case 1 & 4)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	0.23	0.11	0.07	3	1	0.08	-	10951	840	2381	10	1	309481	0.08	64.58	9.58	10.20	7.06	3.65	3.61
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	20	1	309481	0.15	129.16	19.15	20.40	14.11	7.30	7.22
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	30	1	309481	0.23	193.75	28.73	30.60	21.17	10.96	10.83
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	40	1	309481	0.31	258.33	38.31	40.80	28.23	14.61	14.44
1	0.23	0.11	0.07	3	1	0.08		10951	840	1428	50	1	309481	0.23	193.75	28.73	30.60	21.17	10.96	10.83

																Frame 6	Frame 7	Frame 8
1	0.23	0.11	0.07	3	1	0.08	-	10951	840	2381	10	1	309481	0.08	64.58	5.62	19.42	14.50
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	20	1	309481	0.15	129.16	11.25	38.84	28.99
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	30	1	309481	0.23	193.75	16.87	58.26	43.49
1	0.23	0.11	0.07	3	1	0.08		10951	840	2381	40	1	309481	0.31	258.33	22.50	77.68	57.98
1	0.23	0.11	0.07	3	1	0.08		10951	840	1428	50	1	309481	0.23	193.75	16.87	58.26	43.49

Miami Seismic Calculations (Case 1 & 4)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	0.04	0.03	0.02	3	1	0.01	-	10951	161	2381	10	1	309481	0.08	12.35	1.83	1.95	1.35	0.70	0.69
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	20	1	309481	0.15	24.71	3.66	3.90	2.70	1.40	1.38
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	30	1	309481	0.23	37.06	5.50	5.85	4.05	2.10	2.07
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	40	1	309481	0.31	49.42	7.33	7.81	5.40	2.79	2.76
1	0.04	0.03	0.02	3	1	0.01		10951	161	1428	50	1	309481	0.23	37.06	5.50	5.85	4.05	2.10	2.07

																Frame 6	Frame 7	Frame 8
1	0.04	0.03	0.02	3	1	0.01	-	10951	161	2381	10	1	309481	0.08	12.35	1.08	3.71	2.77
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	20	1	309481	0.15	24.71	2.15	7.43	5.55
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	30	1	309481	0.23	37.06	3.23	11.14	8.32
1	0.04	0.03	0.02	3	1	0.01		10951	161	2381	40	1	309481	0.31	49.42	4.30	14.86	11.09
1	0.04	0.03	0.02	3	1	0.01		10951	161	1428	50	1	309481	0.23	37.06	3.23	11.14	8.32

Los Angles Seismic Calculations (Case 1 & 4)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	10	1	309481.25	0.08	450.11	66.75	71.10	49.18	25.45	25.16
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	20	1	309481.25	0.15	900.22	133.49	142.20	98.36	50.90	50.32
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	30	1	309481.25	0.23	1350.33	200.24	213.29	147.54	76.35	75.47
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	40	1	309481.25	0.31	1800.44	266.98	284.39	196.72	101.81	100.63
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	1428	50	1	309481.25	0.23	1350.33	200.24	213.29	147.54	76.35	75.47

																Frame 6	Frame 7	Frame 8
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	10	1	309481.25	0.08	450.11	39.20	135.34	101.03
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	20	1	309481.25	0.15	900.22	78.39	270.68	202.06
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	30	1	309481.25	0.23	1350.33	117.59	406.03	303.09
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	2381	40	1	309481.25	0.31	1800.44	156.79	541.37	404.12
1.3	1.60	0.74	0.85	3	1	0.53	0.14	10951	5851	1428	50	1	309481.25	0.23	1350.33	117.59	406.03	303.09

Boston Seismic Calculations (Case 5)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	0.23	0.11	0.07	3	1	0.08	-	14066	1078	3058	10	1	397508	0.08	82.95	11.65	12.41	8.58	4.44	4.39
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	20	1	397508	0.15	165.90	23.30	24.82	17.17	8.88	8.78
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	30	1	397508	0.23	248.85	34.95	37.23	25.75	13.33	13.17
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	40	1	397508	0.31	331.81	46.60	49.64	34.34	17.77	17.56
1	0.23	0.11	0.07	3	1	0.08		14066	1078	1835	50	1	397508	0.23	248.85	34.95	37.23	25.75	13.33	13.17

																Frame 6	Frame 7	Frame 8
1	0.23	0.11	0.07	3	1	0.08	-	14066	1078	3058	10	1	397508	0.08	82.95	3.96	27.32	20.40
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	20	1	397508	0.15	165.90	7.91	54.64	40.79
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	30	1	397508	0.23	248.85	11.87	81.97	61.19
1	0.23	0.11	0.07	3	1	0.08		14066	1078	3058	40	1	397508	0.31	331.81	15.83	109.29	81.58
1	0.23	0.11	0.07	3	1	0.08		14066	1078	1835	50	1	397508	0.23	248.85	11.87	81.97	61.19

Miami Seismic Calculations (Case 5)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	0.04	0.03	0.02	3	1	0.01	-	14066	206	3058	10	1	397508	0.08	15.87	2.23	2.37	1.64	0.85	0.84
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	20	1	397508	0.15	31.74	4.46	4.75	3.28	1.70	1.68
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	30	1	397508	0.23	47.61	6.69	7.12	4.93	2.55	2.52
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	40	1	397508	0.31	63.48	8.91	9.50	6.57	3.40	3.36
1	0.04	0.03	0.02	3	1	0.01		14066	206	1835	50	1	397508	0.23	47.61	6.69	7.12	4.93	2.55	2.52

																Frame 6	Frame 7	Frame 8
1	0.04	0.03	0.02	3	1	0.01	-	14066	206	3058	10	1	397508	0.08	15.87	0.76	5.23	3.90
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	20	1	397508	0.15	31.74	1.51	10.45	7.80
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	30	1	397508	0.23	47.61	2.27	15.68	11.70
1	0.04	0.03	0.02	3	1	0.01		14066	206	3058	40	1	397508	0.31	63.48	3.03	20.91	15.61
1	0.04	0.03	0.02	3	1	0.01		14066	206	1835	50	1	397508	0.23	47.61	2.27	15.68	11.70

Los Angeles Seismic Calculations (Case 5)

	Sds	Sd1	S1	R	I	Cs	check	W (kips)	V (kips)	wi (kips)	hi (feet)	k	numerator (k-ft.)	Cvi	Fi (kips)	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	10	1	397508	0.08	578.13	81.19	86.49	59.83	30.96	30.60
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	20	1	397508	0.15	1156.27	162.38	172.97	119.65	61.92	61.21
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	30	1	397508	0.23	1734.40	243.58	259.46	179.48	92.88	91.81
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	40	1	397508	0.31	2312.54	324.77	345.95	239.30	123.84	122.41
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	1835	50	1	397508	0.23	1734.40	243.58	259.46	179.48	92.88	91.81

																Frame 6	Frame 7	Frame 8
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	10	1	397508	0.08	578.13	27.57	190.42	142.14
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	20	1	397508	0.15	1156.27	55.15	380.84	284.29
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	30	1	397508	0.23	1734.40	82.72	571.26	426.43
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	3058	40	1	397508	0.31	2312.54	110.30	761.68	568.58
1.3	1.60	0.74	0.85	3	1	0.53	0.14	14066	7516	1835	50	1	397508	0.23	1734.40	82.72	571.26	426.43

Wind

$$q_s = 0.00256 * V^2$$

$$q_z = q_s * K_z$$

$$p = q_z * C_p * G$$

$$F = L * p * h$$

$$F_x = F * K_F$$

q_s: static wind pressure

V: wind velocity

q_z: velocity wind pressure at height z

K_z: exposure factor

p: design wind pressure on a particular face of a building

G: gust factor, 0.85

C_p: external pressure coefficient, 1.0

L: building length

F: total force

h: tributary height

F_x: Force per frame, x

K_F: Frame stiffness

Boston Wind Calculations (Case 1 & 4)

Floor	Wind Velocity	qs	Exposure	qz	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	108	29.86	0.57	17.02	14.47	225.67	32647	4.84	5.16	3.57	1.85	1.82
2	108	29.86	0.62	18.51	15.74	225.67	35511	5.27	5.61	3.88	2.01	1.98
3	108	29.86	0.66	19.71	16.75	225.67	37802	5.61	5.97	4.13	2.14	2.11
4	108	29.86	0.70	20.90	17.77	225.67	40093	5.95	6.33	4.38	2.27	2.24
5	108	29.86	0.76	22.69	19.29	225.67	21765	3.23	3.44	2.38	1.23	1.22
								Frame 6	**Frame 7**	**Frame 8**		
1	108	29.86	0.70	20.90	17.77	131.38	23341	2.03	7.02	5.24		
2	108	29.86	0.70	20.90	17.77	131.38	23341	2.03	7.02	5.24		
3	108	29.86	0.70	20.90	17.77	131.38	23341	2.03	7.02	5.24		
4	108	29.86	0.70	20.90	17.77	131.38	23341	2.03	7.02	5.24		
5	108	29.86	0.76	22.69	19.29	131.38	12671	1.10	3.81	2.84		

Miami Wind Calculations (Case 1 & 4)

Floor	Wind Velocity	qs	Exposure	qz	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	139	49.46	0.57	28.19	23.96	225.67	54079	8.02	8.54	5.91	3.06	3.02
2	139	49.46	0.62	30.67	26.07	225.67	58823	8.72	9.29	6.43	3.33	3.29
3	139	49.46	0.66	32.64	27.75	225.67	62618	9.29	9.89	6.84	3.54	3.50
4	139	49.46	0.70	34.62	29.43	225.67	66413	9.85	10.49	7.26	3.76	3.71
5	139	49.46	0.76	37.59	31.95	225.67	36053	5.35	5.69	3.94	2.04	2.02
								Frame 6	**Frame 7**	**Frame 8**		
1	139	49.46	0.70	34.62	29.43	131.38	38663	3.37	11.63	8.68		
2	139	49.46	0.70	34.62	29.43	131.38	38663	3.37	11.63	8.68		
3	139	49.46	0.70	34.62	29.43	131.38	38663	3.37	11.63	8.68		
4	139	49.46	0.70	34.62	29.43	131.38	38663	3.37	11.63	8.68		
5	139	49.46	0.76	37.59	31.95	131.38	20989	1.83	6.31	4.71		

Los Angeles Wind Calculations (Case 1 & 4)

Floor	Wind Velocity	qs	Exposure	qz	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	85	18.50	0.57	10.54	8.96	225.67	20223	3.00	3.19	2.21	1.14	1.13
2	85	18.50	0.62	11.47	9.75	225.67	21997	3.26	3.47	2.40	1.24	1.23
3	85	18.50	0.66	12.21	10.38	225.67	23416	3.47	3.70	2.56	1.32	1.31
4	85	18.50	0.70	12.95	11.01	225.67	24835	3.68	3.92	2.71	1.40	1.39
5	85	18.50	0.76	14.06	11.95	225.67	13482	2.00	2.13	1.47	0.76	0.75
								Frame 6	Frame 7	Frame 8		
1	85	18.50	0.70	12.95	11.01	131.38	14458	1.26	4.35	3.25		
2	85	18.50	0.70	12.95	11.01	131.38	14458	1.26	4.35	3.25		
3	85	18.50	0.70	12.95	11.01	131.38	14458	1.26	4.35	3.25		
4	85	18.50	0.70	12.95	11.01	131.38	14458	1.26	4.35	3.25		
5	85	18.50	0.76	14.06	11.95	131.38	7849	0.68	2.36	1.76		

Boston Wind Calculations (Case 5)

Floor	Wind Velocity	qs	Exposure	qz	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	108	29.86	0.57	17.02	14.47	329.21	47627	6.69	7.12	4.93	2.55	2.52
2	108	29.86	0.62	18.51	15.74	329.21	51805	7.28	7.75	5.36	2.77	2.74
3	108	29.86	0.66	19.71	16.75	329.21	55147	7.74	8.25	5.71	2.95	2.92
4	108	29.86	0.70	20.90	17.77	329.21	58489	8.21	8.75	6.05	3.13	3.10
5	108	29.86	0.76	22.69	19.29	329.21	31751	4.46	4.75	3.29	1.70	1.68
								Frame 6	Frame 7	Frame 8		
1	108	29.86	0.70	20.90	17.77	131.38	23341	1.11	7.69	5.74		
2	108	29.86	0.70	20.90	17.77	131.38	23341	1.11	7.69	5.74		
3	108	29.86	0.70	20.90	17.77	131.38	23341	1.11	7.69	5.74		
4	108	29.86	0.70	20.90	17.77	131.38	23341	1.11	7.69	5.74		
5	108	29.86	0.76	22.69	19.29	131.38	12671	0.60	4.17	3.12		

Miami Wind Calculations (Case 5)

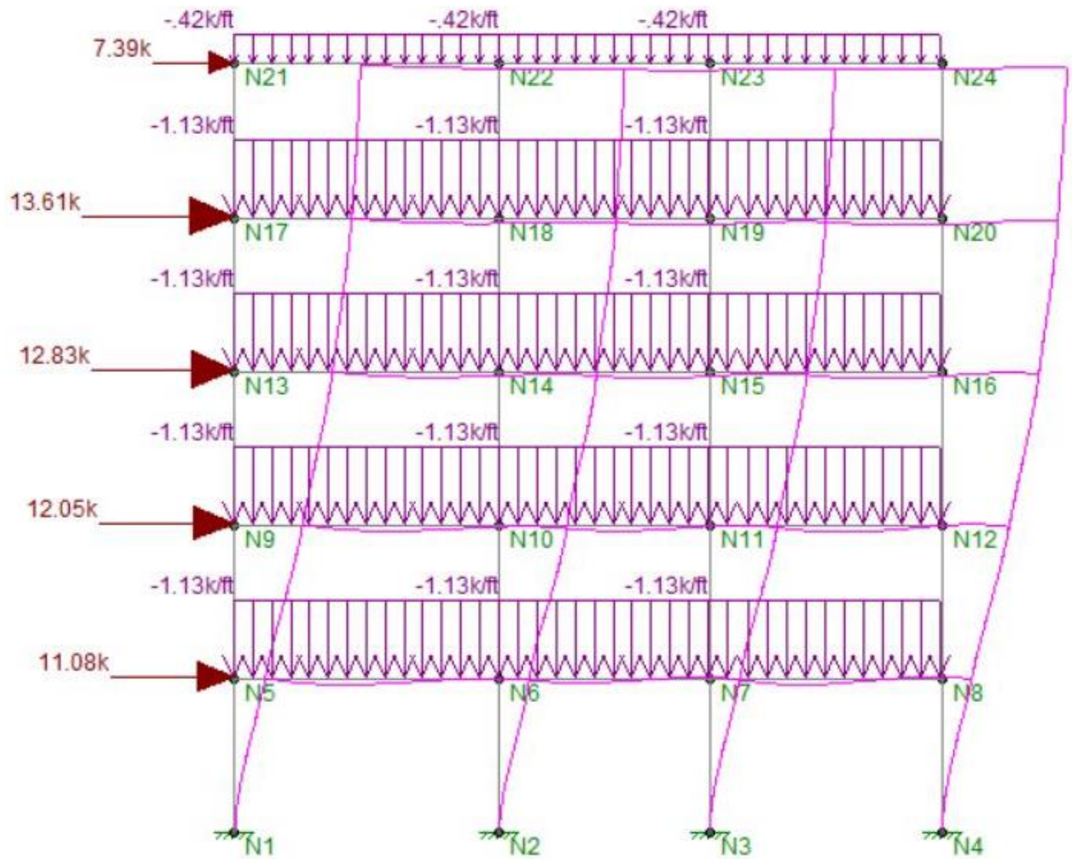
Floor	Wind Velocity	qs	Exposure	qz	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	139	49.46	0.57	28.19	23.96	329.21	78892	11.08	11.80	8.16	4.22	4.18
2	139	49.46	0.62	30.67	26.07	329.21	85813	12.05	12.84	8.88	4.60	4.54
3	139	49.46	0.66	32.64	27.75	329.21	91349	12.83	13.67	9.45	4.89	4.84
4	139	49.46	0.70	34.62	29.43	329.21	96885	13.61	14.49	10.03	5.19	5.13
5	139	49.46	0.76	37.59	31.95	329.21	52595	7.39	7.87	5.44	2.82	2.78
								Frame 6	Frame 7	Frame 8		
1	139	49.46	0.70	34.62	29.43	131.38	38663	1.84	12.73	9.51		
2	139	49.46	0.70	34.62	29.43	131.38	38663	1.84	12.73	9.51		
3	139	49.46	0.70	34.62	29.43	131.38	38663	1.84	12.73	9.51		
4	139	49.46	0.70	34.62	29.43	131.38	38663	1.84	12.73	9.51		
5	139	49.46	0.76	37.59	31.95	131.38	20989	1.00	6.91	5.16		

Los Angeles Wind Calculations (Case 5)

Floor	Wind Velocity	q_s	Exposure	q_z	p	Building Length	Total Force	Frame 1	Frame 2	Frame 3	Frame 4	Frame 5
1	85	18.50	0.57	10.54	8.96	329.21	29501	4.14	4.41	3.05	1.58	1.56
2	85	18.50	0.62	11.47	9.75	329.21	32089	4.51	4.80	3.32	1.72	1.70
3	85	18.50	0.66	12.21	10.38	329.21	34159	4.80	5.11	3.53	1.83	1.81
4	85	18.50	0.70	12.95	11.01	329.21	36230	5.09	5.42	3.75	1.94	1.92
5	85	18.50	0.76	14.06	11.95	329.21	19668	2.76	2.94	2.04	1.05	1.04
								Frame 6	Frame 7	Frame 8		
1	85	18.50	0.70	12.95	11.01	131.38	14458	0.69	4.76	3.55		
2	85	18.50	0.70	12.95	11.01	131.38	14458	0.69	4.76	3.55		
3	85	18.50	0.70	12.95	11.01	131.38	14458	0.69	4.76	3.55		
4	85	18.50	0.70	12.95	11.01	131.38	14458	0.69	4.76	3.55		
5	85	18.50	0.76	14.06	11.95	131.38	7849	0.37	2.59	1.93		

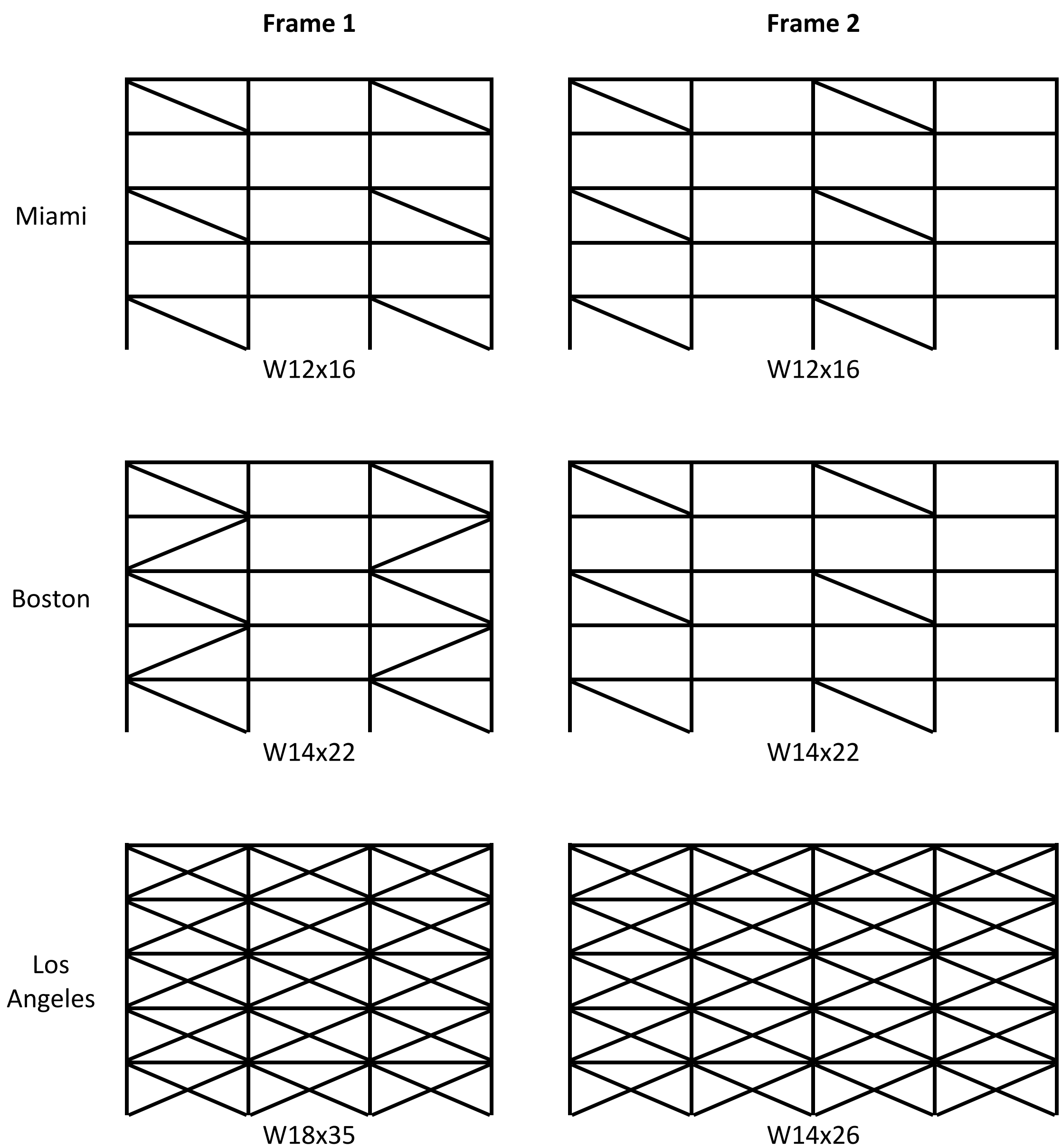
RISA-3D

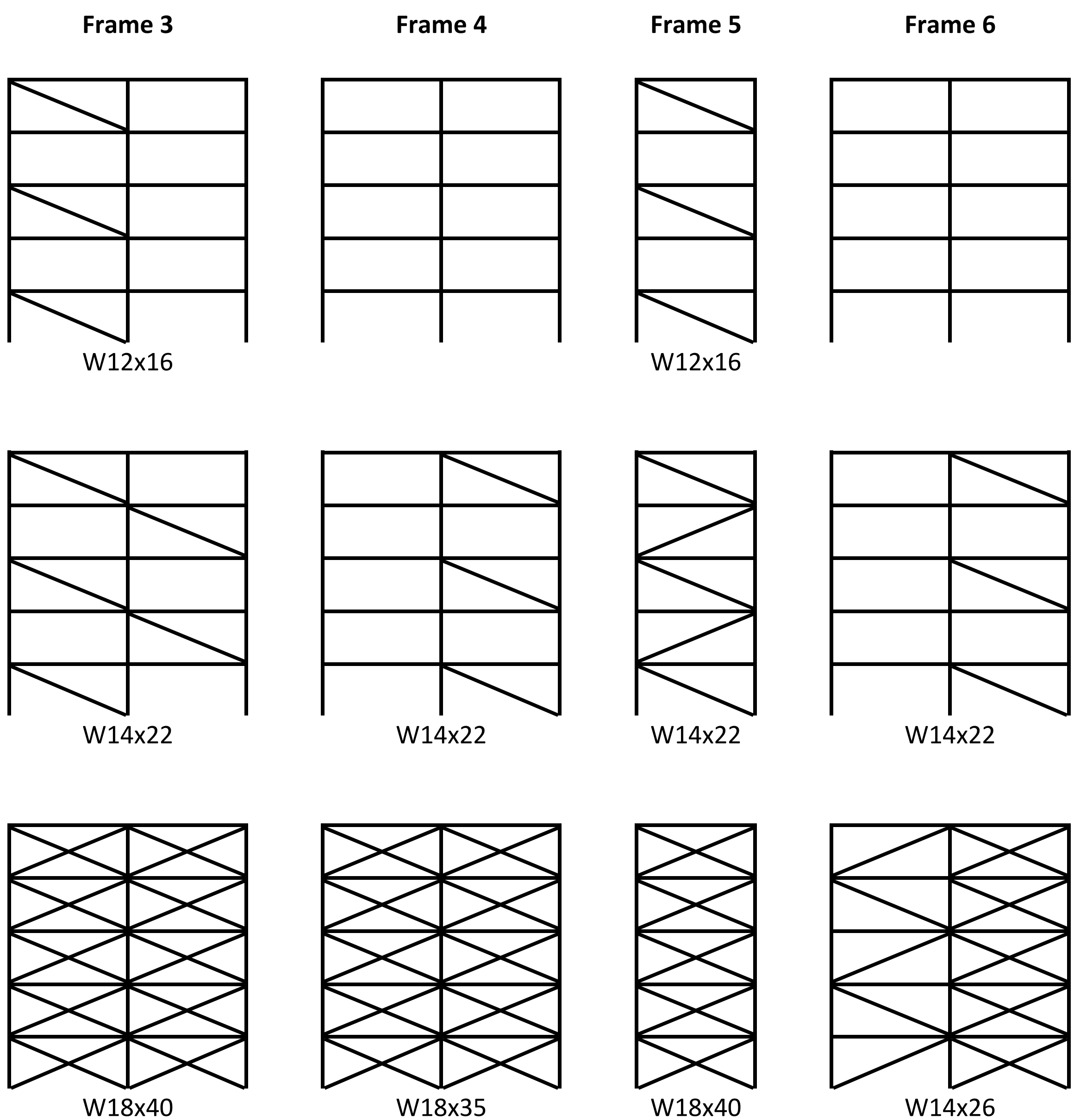
For the lateral load analysis, RISA-3D was used by modeling the frame using the originally designed members and redesigning them based on deflection. The dead and live loads were added to the model and the end supports were considered to be fixed. Each floor had a lateral load from the wind or seismic calculation applied to it and the model was solved for deflection. The frame in the example is Frame 1 from Case 1 with wind loading in Miami, Florida. The deflection shown has a magnification factor of 40X so the deflection appears to be more significant. Then, the maximum lateral deflection in the X-direction was identified and compared to the maximum lateral deflection of the structure. If the sway of the structure exceeded the allowable lateral deflection, the frame was redesigned with new member sizes and reanalyzed.



Joint Label	X [in]	Y [in]
N21	2.45	-.014
N22	2.444	-.105
N23	2.439	-.086
N24	2.436	-.067

Frame Summary




Frame 3
Frame 4
Frame 5
Frame 6
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W12x16
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W14x22
W14x22
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W18x40
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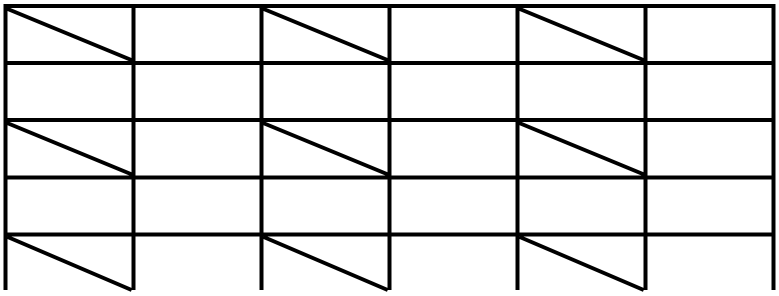
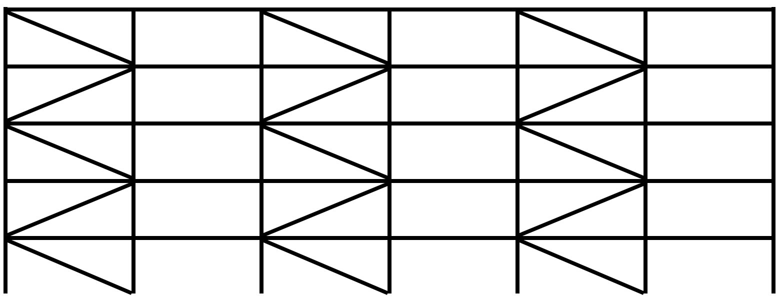
W18x40
W14x26

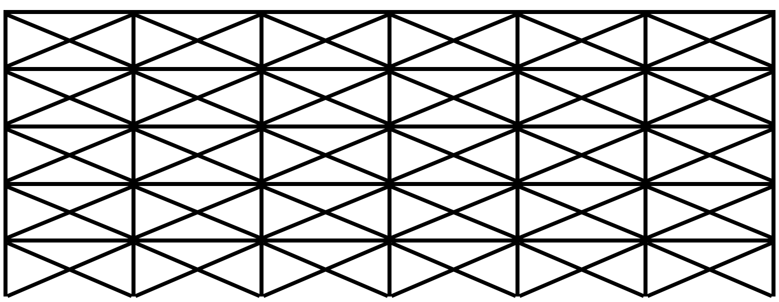
Frame 7



W12x16

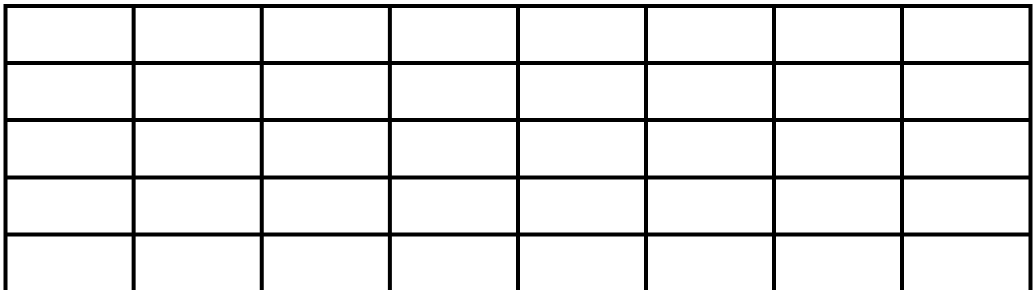


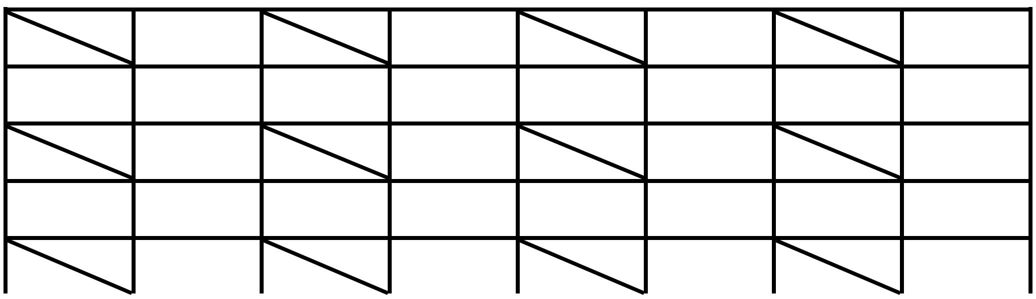
W14x22



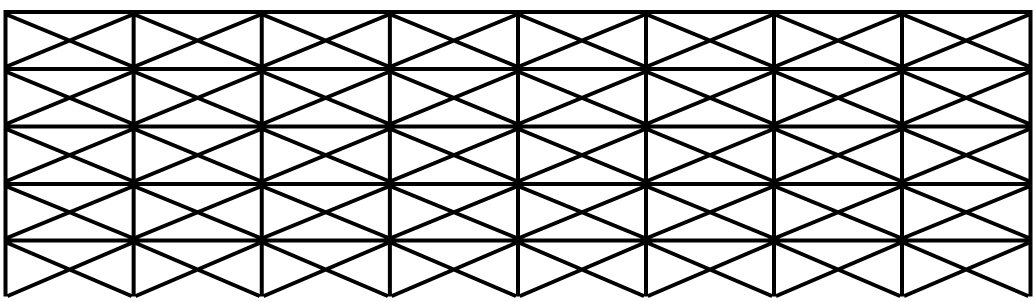
W18x40

Frame 8





W14x22



W14x26

Appendix D: Egress Analysis Sample Calculation

NFPA 101; Table 7.3.1.2; 7.3.3.2

Sample for Case 1:

Stairway Capacity:

$C = Capacity$

$W_n = Nominal\ Width\ of\ Stairs = 56in$

$$C = 146.7 + \left(\frac{W_n - 44}{0.218}\right)$$

$$C = 146.7 + \left(\frac{56 - 44}{0.218}\right)$$

$C = 202\ persons$

4 Stairways→ Allowable Occupancy = 808 persons

Case 1: Floor 1			
Occupancy Use	**Occupant Load Factor (ft^2/person)**	**Applicable Areas**	**Total Area (ft^2)**
Business Use	100	Open Work Space ($860ft^2$) Reception ($200ft^2$)	5300
Concentrated Business Use	50	Conference Room ($300ft^2$) Personal Offices ($160ft^2$)	4700
Storage (in other than storage and mercantile occupancies)	500	Supply Room ($64ft^2$)	320
Less Concentrated Use, Without Fixed Seating	15net	Open Lobby ($2200ft^2$)	~600
Concentrated use, without fixed seating	7net	Break Room ($170ft^2$)	~500

*Net occupant load factor only considers the area that is explicitly used

Occupant Load:

$$C = \left(\frac{5300}{100}\right) + \left(\frac{4700}{50}\right) + \left(\frac{320}{500}\right) + \left(\frac{600}{15}\right) + \left(\frac{500}{7}\right)$$

$C = 259\ persons$

Acceptable: 259 Occupant Load < 808 Allowable Capacity

Appendix E: Hydraulic System Sample Calculation

Case 1 (Floor 5) and Case 4 (Floor 5) Hydraulic Calculations

Material: Black Steel Schedule 40 Piping (C=120)
Design Area: 1500 ft^2
Design Density: 0.1 gpm/ft^2
Typical Area of Coverage: 120 ft^2
Sprinkler K-Factor: 5.6

Design Area:
NFPA 13HB; Figure A.23.4.4

$$N = \frac{Design\ Area}{Area\ per\ Sprinkler}$$

$$N = \frac{1500ft^2}{120ft^2}$$

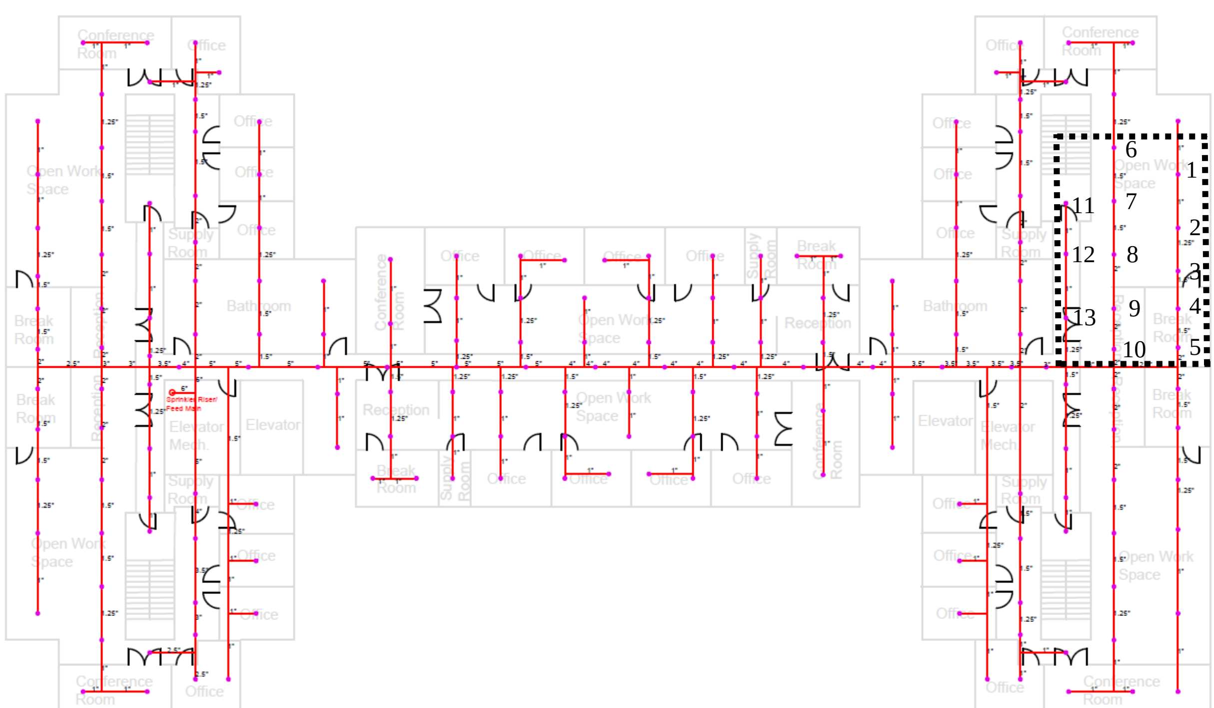
$N = 12.5\ Sprinklers$ → 13 Sprinklers

$$N_{Branchline} = \frac{1.2\sqrt{A}}{S}$$

$$N_{Branchline} = \frac{1.2\sqrt{1500ft^2}}{10}$$

$N_{Branchline} = 4.65\ Sprinklers$ → 5 Sprinklers

Required Flow and Pressure:
168gpm at 50psi



Location		Flow (gpm)	Pipe Size (in)	Fittings and Devices		Pipe Equivalent Length (ft)		Friction Loss		Required Pressure (psi)	Notes	
1	q		1		L	10	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2	
									Pf	0.50578018	Pt=	4.591837
					T	10					Height of Elevation	
2	q	12.64363	1.25		L	8	C	120	Pt	5.09761692	$q=k\sqrt{P_t}$	
									Pe	0	q	12.64363
	Q	24.64363	1.38		F		p	0.050361				
									Pf	0.40288906		
					T	8					Height of Elevation	
3	q	13.13377	1.5		L	7	C	120	Pt	5.50050598	$q=k\sqrt{P_t}$	
									Pe	0	q	13.13377
	Q	37.77739	1.61		F		p	0.052395				
									Pf	0.36676538		
					T	7					Height of Elevation	
4	q	13.56457	1.5		L	7.25	C	120	Pt	5.86727136	$q=k\sqrt{P_t}$	
									Pe	0	q	13.56457
	Q	51.34197	1.61		F		p	0.092424				
									Pf	0.67007473		
					T	7.25					Height of Elevation	
5	q	14.31821	2		L	3.66	C	120	Pt	6.53734609	$q=k\sqrt{P_t}$	
									Pe	0	q	14.31821
	Q	65.66018	2.067	1E	F	5	p	0.043147				
									Pf	0.37365577		
					T	8.66					Height of Elevation	
CM1	q	0	2.5		L	12	C	120	Pt	6.91100187	$q=k\sqrt{P_t}$	
									Pe	0	q	0
	Q	65.66018	2.469	1T	F	12	p	0.018159				
									Pf	0.43580826		
					T	24					Height of Elevation	
6	q		1.5		L	10	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.61		F		p	0.006279			Pt=(Q/k-factor)^2	
									Pf	0.06279086	Pt=	4.591837
					T	10					Height of Elevation	
7	q	12.08177	1.5		L	10	C	120	Pt	4.65462759	$q=k\sqrt{P_t}$	
									Pe	0	q	12.08177
	Q	24.08177	1.61		F		p	0.022779				
									Pf	0.22778997		
					T	10					Height of Elevation	
8	q	12.37387	2		L	10	C	120	Pt	4.88241756	$q=k\sqrt{P_t}$	
									Pe	0	q	12.37387
	Q	36.45564	2.067		F		p	0.014528				
									Pf	0.14528129		
					T	10					Height of Elevation	
9	q	12.55662	2		L	7.5	C	120	Pt	5.02769885	$q=k\sqrt{P_t}$	
									Pe	0	q	12.55662
	Q	49.01225	2.067		F		p	0.025119				
									Pf	0.18839524		
					T	7.5					Height of Elevation	
10	q	12.78971	2		L	3.33	C	120	Pt	5.21609408	$q=k\sqrt{P_t}$	
									Pe	0	q	12.78971
	Q	61.80196	2.067		F		p	0.038574				
									Pf	0.12845277		
					T	3.33					Height of Elevation	
CM2	q	0	3		L	9	C	120	Pt	12.691357	$q=k\sqrt{P_t}$	
									Pe	0	q	0
	Q	127.4621	3.068	1T	F	15	p	0.021509				
									Pf	0.51621906		
					T	24					Height of Elevation	

11	q		1		L	9.5	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)		
									Pe	0	Q=	12	
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2		
									Pf	0.48049117	Pt=	4.591837	
					T	9.5					Height of Elevation		
12	q	12.61222	1		L	12	C	120	Pt	5.07232791	q=k√Pt		
									Pe	0	q	12.61222	
	Q	24.61222	1.049		F		p	0.191032	Pf	2.29238126			
					T	12					Height of Elevation		
13	q	15.19728	1.25		L	9.25	C	120	Pt	7.36470916	q=k√Pt		
									Pe	0	q	15.19728	
	Q	39.8095	1.38		F		p	0.122297	Pf	1.13125161			
					T	9.25					Height of Elevation		
CM3	q	0	3		L	8.5	C	120	Pt	21.7035368	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	3.068		F		p	0.035563	Pf	0.30228583			
					T	8.5					Height of Elevation		
CM4	q	0	3.5		L	24	C	120	Pt	22.0058226	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	3.548		F		p	0.017521	Pf	0.42050919			
					T	24					Height of Elevation		
CM5	q	0	4		L	61	C	120	Pt	22.4263318	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	4.026		F		p	0.009468	Pf	0.57753593			
					T	61					Height of Elevation		
CM6	q	0	5		L	40.5	C	120	Pt	23.0038678	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	5.047	1E	F	12	p	0.003149	Pf	0.16533757			
					T	52.5					Height of Elevation		
RISER	q	0	6		L	6.5	C	120	Pt	23.1692053	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	6.065	1E	F	14	p	0.001287	Pf	0.02638471			
					T	20.5					Height of Elevation		
BOR	q	0	6		L	60	C	120	Pt	23.19559	q=k√Pt		
									Pe	25.98	q	0	
	Q	167.2716	6.065	1BV; 1GV; 1SCV	F	45	p	0.001287	Pf	0.13514118			
					T	105					Height of Elevation		60
									Pt	49.3107312			

Case 2 (Floor 5) and Case 3 (Floor 5) Hydraulic Calculations

Material: Black Steel Schedule 40 Piping (C=120)
Design Area: 1500 ft^2
Design Density: 0.1 gpm/ft^2
Area of Coverage: 120 ft^2
Sprinkler K-Factor: 5.6

Design Area:

$$N = \frac{Design\ Area}{Area\ per\ Sprinkler}$$

$$N = \frac{1500ft^2}{120ft^2}$$

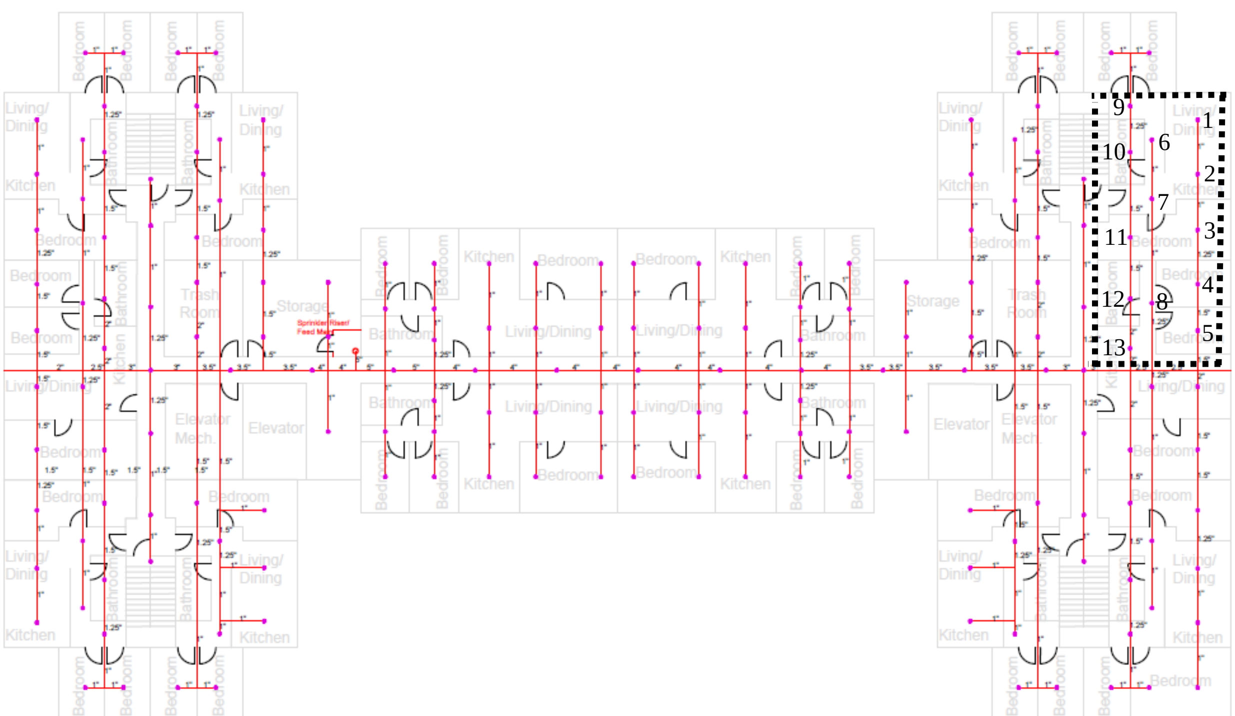
$$N = 12.5\ Sprinklers \rightarrow \text{13 Sprinklers}$$

$$N_{Branchline} = \frac{1.2\sqrt{A}}{S}$$

$$N_{Branchline} = \frac{1.2\sqrt{1500ft^2}}{10}$$

$$N_{Branchline} = 4.65\ Sprinklers \rightarrow \text{5 Sprinklers}$$

Required Flow and Pressure:
177gpm at 56psi



Location	Flow (gpm)		Pipe Size (in)	Fittings and Devices	Pipe Equivalent Length (ft)		Friction Loss		Required Pressure (psi)		Notes	
1	q		1		L	10	C	120	Pt	4.591836735	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2	
									Pf	0.505780181	Pt=	4.591837
					T	10					Height of Elevation	
2	q	12.64362553	1		L	10	C	120	Pt	5.097616915	q=k√Pt	
									Pe	0	q	12.64363
	Q	24.64362553	1.049		F		p	0.191483				
									Pf	1.914829077		
					T	10					Height of Elevation	
3	q	14.82937309	1.25		L	10	C	120	Pt	7.012445992	q=k√Pt	
									Pe	0	q	14.82937
	Q	39.47299862	1.61		F		p	0.056829				
									Pf	0.568285185		
					T	10					Height of Elevation	
4	q	15.41855148	1.5		L	8.5	C	120	Pt	7.580731177	q=k√Pt	
									Pe	0	q	15.41855
	Q	54.8915501	1.61		F		p	0.104591				
									Pf	0.88902752		
					T	8.5					Height of Elevation	
5	q	16.29759592	1.5		L	7.25	C	120	Pt	8.469758698	q=k√Pt	
									Pe	0	q	16.2976
	Q	71.18914602	1.61	1E	F	4	p	0.169191				
									Pf	1.903395923		
					T	11.25					Height of Elevation	
CM1	q	0	2.5		L	8.5	C	120	Pt	10.37315462	q=k√Pt	
									Pe	0	q	0
	Q	71.18914602	2.469	1T	F	12	p	0.021088				
									Pf	0.432309502		
					T	20.5					Height of Elevation	
6	q		1		L	10.83	C	120	Pt	4.591836735	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2	
									Pf	0.547759936	Pt=	4.591837
					T	10.83					Height of Elevation	
7	q	12.69558	1		L	19.25	C	120	Pt	5.13959667	q=k√Pt	
									Pe	0	q	12.69558
	Q	24.69558	1.049		F		p	0.19223				
									Pf	3.700435276		
					T	19.25					Height of Elevation	
8	q	16.65002708	1.25		L	12.33	C	120	Pt	8.840031946	q=k√Pt	
									Pe	0	q	16.65003
	Q	41.34560708	1.38		F		p	0.131171				
									Pf	1.617332805		
					T	12.33					Height of Elevation	
CM2	q	0	3		L	9	C	120	Pt	21.26282887	q=k√Pt	
									Pe	0	q	0
	Q	112.5347531	3.068	1T	F	15	p	0.017082				
									Pf	0.409976645		
					T	24					Height of Elevation	

9	q		1.25		L	8.5	C	120	Pt	4.591836735	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
											Pt=(Q/k-factor)^2	
	Q	12	1.38		F		p	0.013302	Pf	0.113069692	Pt=	4.591837
					T	8.5					Height of Elevation	
10	q	12.14684591	1.5		L	15.75	C	120	Pt	4.704906427	q=k√Pt	
									Pe	0	q	12.14685
	Q	24.14684591	1.61		F		p	0.022893	Pf	0.360564887		
					T	15.75					Height of Elevation	
11	q	12.60369709	1.5		L	11.25	C	120	Pt	5.065471314	q=k√Pt	
									Pe	0	q	12.6037
	Q	36.750543	1.61		F		p	0.049791	Pf	0.560146456		
					T	11.25					Height of Elevation	
12	q	13.28229548	2		L	9	C	120	Pt	5.62561777	q=k√Pt	
									Pe	0	q	13.2823
	Q	50.03283848	2.067		F		p	0.026096	Pf	0.234860257		
					T	9					Height of Elevation	
13	q	13.55671756	2		L	4	C	120	Pt	5.860478026	q=k√Pt	
									Pe	0	q	13.55672
	Q	63.58955604	2.067		F		p	0.040664	Pf	0.162655486		
					T	4					Height of Elevation	
CM3	q	0	3		L	17	C	120	Pt	27.69593903	q=k√Pt	
									Pe	0	q	0
	Q	176.1243091	3.068		F		p	0.039123	Pf	0.665092699		
					T	17					Height of Elevation	
CM4	q	0	3.5		L	28.5	C	120	Pt	28.36103173	q=k√Pt	
									Pe	0	q	0
	Q	176.1243091	3.548		F		p	0.019275	Pf	0.549342896		
					T	28.5					Height of Elevation	
CM5	q	0	4		L	76.33	C	120	Pt	28.91037463	q=k√Pt	
									Pe	0	q	0
	Q	176.1243091	4.026		F		p	0.010416	Pf	0.795021437		
					T	76.33					Height of Elevation	
RISER	q	0	5		L	18	C	120	Pt	29.70539606	q=k√Pt	
									Pe	0	q	0
	Q	176.1243091	5.047	2E	F	24	p	0.003465	Pf	0.145511037		
					T	42					Height of Elevation	
BOR	q	0	6		L	60	C	120	Pt	29.8509071	q=k√Pt	
									Pe	25.98	q	0
	Q	176.1243091	6.065	1BV; 1GV; 1SCV	F	45	p	0.001416	Pf	0.148669581		
					T	105					Height of Elevation	60
									Pt	55.97957668		

Case 3 (Floor 1) Hydraulic Calculations

Material: Black Steel Schedule 40 Piping (C=120)
Design Area: 1500 ft^2
Design Density: 0.2 gpm/ft^2
Area of Coverage: 120 ft^2
Sprinkler K-Factor: 5.6

Design Area:

$$N = \frac{Design\ Area}{Area\ per\ Sprinkler}$$

$$N = \frac{1500ft^2}{120ft^2}$$

$N = 12.5\ Sprinklers$ → 13 Sprinklers

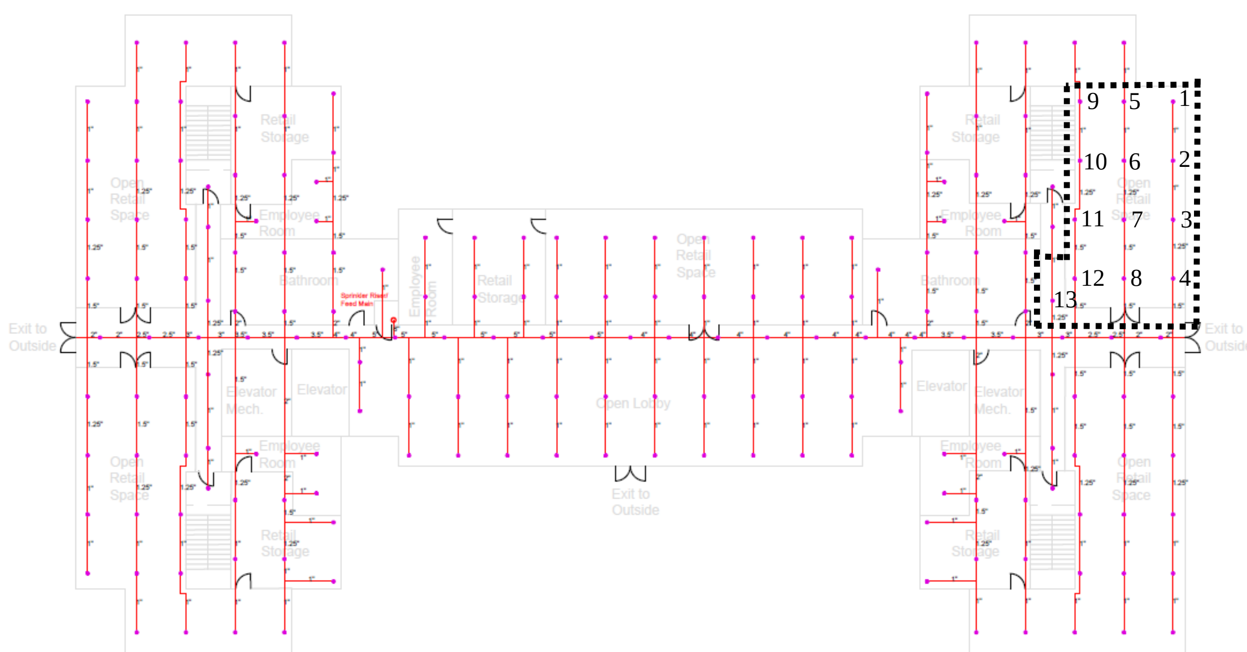
$$N_{Branchline} = \frac{1.2\sqrt{A}}{S}$$

$$N_{Branchline} = \frac{1.2\sqrt{1500ft^2}}{12}$$

$N_{Branchline} = 3.87\ Sprinklers$ → 4 Sprinklers

Required Flow and Pressure:

346gpm at 138psi



Location	Flow (gpm)		Pipe Size (in)	Fittings and Devices	Pipe Equivalent Length (ft)		Friction Loss		Required Pressure (psi)		Notes	
1	q		1		L	12	C	120	Pt	18.36734694	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	24
	Q	24	1.049		F		p	0.182334			Pt=(Q/k-factor)^2	
									Pf	2.188006185	Pt=	18.36735
					T	12					Height of Elevation	
2	q	25.3892866	1		L	12	C	120	Pt	20.55535312	q=k√Pt	
									Pe	0	q	25.38929
	Q	49.3892866	1.049		F		p	0.692942				
									Pf	8.315308022		
					T	12					Height of Elevation	
3	q	30.08959843	1.25		L	12	C	120	Pt	28.87066115	q=k√Pt	
									Pe	0	q	30.0896
	Q	79.47888503	1.38		F		p	0.439448				
									Pf	5.273379079		
					T	12					Height of Elevation	
4	q	32.72242505	1.5		L	12	C	120	Pt	34.14404023	q=k√Pt	
									Pe	0	q	32.72243
	Q	112.2013101	1.61	1E	F	4	p	0.392561				
									Pf	6.280977859		
					T	16					Height of Elevation	
CM1	q	0	2		L	10	C	120	Pt	40.42501808	q=k√Pt	
									Pe	0	q	0
	Q	112.2013101	2.067	1T	F	10	p	0.116263				
									Pf	2.325258125		
					T	20					Height of Elevation	
5	q		1		L	12	C	120	Pt	18.36734694	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	24
	Q	24	1.049		F		p	0.182334			Pt=(Q/k-factor)^2	
									Pf	2.188006185	Pt=	18.36735
					T	12					Height of Elevation	
6	q	25.3892866	1.25		L	12	C	120	Pt	20.55535312	q=k√Pt	
									Pe	0	q	25.38929
	Q	49.3892866	1.38		F		p	0.182248				
									Pf	2.186974998		
					T	12					Height of Elevation	
7	q	26.70579356	1.5		L	12	C	120	Pt	22.74232812	q=k√Pt	
									Pe	0	q	26.70579
	Q	76.09508016	1.61		F		p	0.191391				
									Pf	2.296688154		
					T	12					Height of Elevation	
8	q	28.0218406	1.5		L	12	C	120	Pt	25.03901628	q=k√Pt	
									Pe	0	q	28.02184
	Q	104.1169208	1.61		F		p	0.341842				
									Pf	4.102105192		
					T	12					Height of Elevation	
CM2	q	0	2.5		L	10	C	120	Pt	71.89139768	q=k√Pt	
									Pe	0	q	0
	Q	216.3182308	2.469	1T	F	15	p	0.164815				
									Pf	4.120384139		
					T	25					Height of Elevation	
9	q		1		L	12	C	120	Pt	18.36734694	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	24
	Q	24	1.049		F		p	0.182334			Pt=(Q/k-factor)^2	
									Pf	2.188006185	Pt=	18.36735
					T	12					Height of Elevation	
10	q	25.3892866	1.25		L	12	C	120	Pt	20.55535312	q=k√Pt	
									Pe	0	q	25.38929
	Q	49.3892866	1.38	2E	F	6	p	0.182248				
									Pf	3.280462497		
					T	18					Height of Elevation	
11	q	27.34028489	1.5		L	12	C	120	Pt	23.83581562	q=k√Pt	
									Pe	0	q	27.34028
	Q	76.72957149	1.61		F		p	0.194353				
									Pf	2.33224134		
					T	12					Height of Elevation	
12	q	28.64664494	1.5		L	12	C	120	Pt	26.16805696	q=k√Pt	
									Pe	0	q	28.64664
	Q	105.3762164	1.61		F		p	0.34953				
									Pf	4.194364522		
					T	12					Height of Elevation	

	q	0	3		L	9	C	120	Pt	106.3742033	q=k√Pt		
									Pe	0	q	0	
CM3	Q	321.6944473	3.068	1T	F	15	p	0.119244	Pf	2.861866597			
					T	24					Height of Elevation		
	q		1.25		L	7.5	C	120	Pt	18.36734694	Q=(Area of Coverage)(Density)		
									Pe	0	Q=	24	
13	Q	24	1.38		F		p	0.047955			Pt=(Q/k-factor)^2		
									Pf	0.359661573	Pt=	18.36735	
					T	7.5					Height of Elevation		
	q	0	3		L	5.5	C	120	Pt	127.9630784	q=k√Pt		
									Pe	0	q	0	
CM4	Q	345.6944473	3.068		F	0	p	0.136222	Pf	0.749223146			
					T	5.5					Height of Elevation		
	q	0	3.5		L	20	C	120	Pt	128.7123016	q=k√Pt		
									Pe	0	q	0	
CM5	Q	345.6944473	3.548		F		p	0.067114	Pf	1.342282369			
					T	20					Height of Elevation		
	q	0	4		L	65.5	C	120	Pt	130.0545839	q=k√Pt		
									Pe	0	q	0	
CM6	Q	345.6944473	4.026		F		p	0.036266	Pf	2.375418387			
					T	65.5					Height of Elevation		
	q	0	5		L	43.25	C	120	Pt	132.4300023	q=k√Pt		
									Pe	0	q	0	
CM7	Q	345.6944473	5.047	1E	F	12	p	0.012063	Pf	0.666490809			
					T	55.25					Height of Elevation		
	q	0	6		L	3.5	C	120	Pt	133.0964931	q=k√Pt		
									Pe	0	q	0	
RISER	Q	345.6944473	6.065	1E	F	14	p	0.00493	Pf	0.086275226			
					T	17.5					Height of Elevation		
	q	0	6		L	10	C	120	Pt	133.1827683	q=k√Pt		
									Pe	4.33	q	0	
BOR	Q	345.6944473	6.065	1BV; 1GV; 1SCV	F	45	p	0.00493	Pf	0.271150709			
					T	55					Height of Elevation		10
									Pt	137.7839191			

Case 5 (Floor 5) Hydraulic Calculations

Material: Black Steel Schedule 40 Piping
Design Area: 1500 ft^2
Design Density: 0.1 gpm/ft^2
Area of Coverage: 120 ft^2
Sprinkler K-Factor: 5.6

Design Area:

$$N = \frac{Design\ Area}{Area\ per\ Sprinkler}$$

$$N = \frac{1500ft^2}{120ft^2}$$

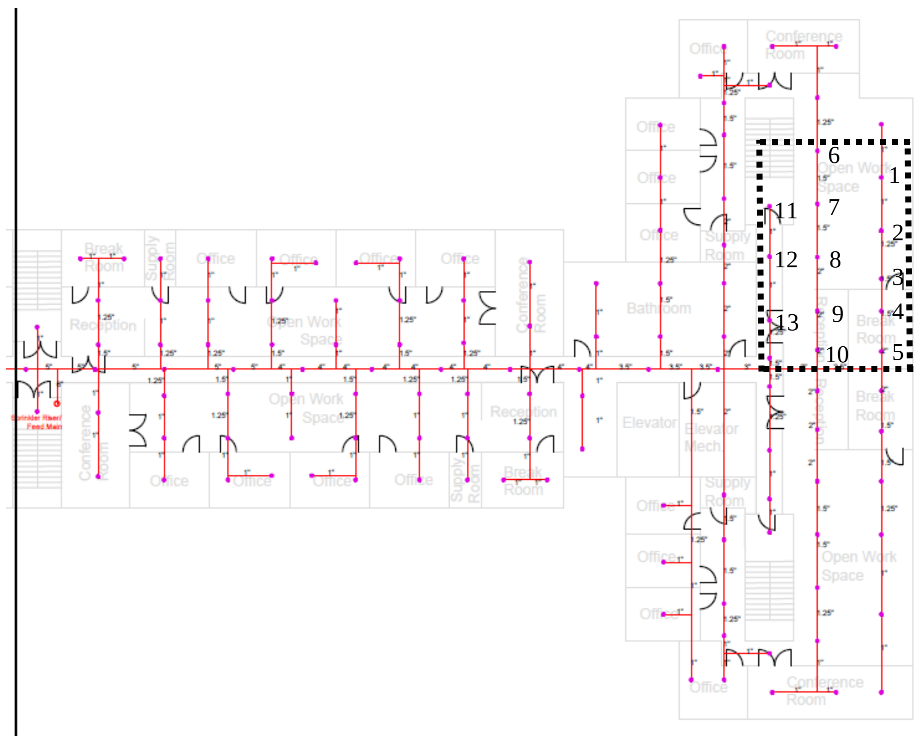
$N = 12.5\ Sprinklers$ → 13 Sprinklers

$$N_{Branchline} = \frac{1.2\sqrt{A}}{S}$$

$$N_{Branchline} = \frac{1.2\sqrt{1500ft^2}}{10}$$

$N_{Branchline} = 4.65\ Sprinklers$ → 5 Sprinklers

Required Flow and Pressure:
168gpm at 50psi



Location		Flow (gpm)	Pipe Size (in)	Fittings and Devices		Pipe Equivalent Length (ft)		Friction Loss		Required Pressure (psi)	Notes	
1	q		1		L	10	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2	
									Pf	0.50578018	Pt=	4.591837
					T	10					Height of Elevation	
2	q	12.64363	1.25		L	8	C	120	Pt	5.09761692	q=k√Pt	
									Pe	0	q	12.64363
	Q	24.64363	1.38		F		p	0.050361	Pf	0.40288906		
					T	8					Height of Elevation	
3	q	13.13377	1.5		L	7	C	120	Pt	5.50050598	q=k√Pt	
									Pe	0	q	13.13377
	Q	37.77739	1.61		F		p	0.052395	Pf	0.36676538		
					T	7					Height of Elevation	
4	q	13.56457	1.5		L	7.25	C	120	Pt	5.86727136	q=k√Pt	
									Pe	0	q	13.56457
	Q	51.34197	1.61		F		p	0.092424	Pf	0.67007473		
					T	7.25					Height of Elevation	
5	q	14.31821	2		L	3.66	C	120	Pt	6.53734609	q=k√Pt	
									Pe	0	q	14.31821
	Q	65.66018	2.067	1E	F	5	p	0.043147	Pf	0.37365577		
					T	8.66					Height of Elevation	
CM1	q	0	2.5		L	12	C	120	Pt	6.91100187	q=k√Pt	
									Pe	0	q	0
	Q	65.66018	2.469	1T	F	12	p	0.018159	Pf	0.43580826		
					T	24					Height of Elevation	
6	q		1.5		L	10	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)	
									Pe	0	Q=	12
	Q	12	1.61		F		p	0.006279			Pt=(Q/k-factor)^2	
									Pf	0.06279086	Pt=	4.591837
					T	10					Height of Elevation	
7	q	12.08177	1.5		L	10	C	120	Pt	4.65462759	q=k√Pt	
									Pe	0	q	12.08177
	Q	24.08177	1.61		F		p	0.022779	Pf	0.22778997		
					T	10					Height of Elevation	
8	q	12.37387	2		L	10	C	120	Pt	4.88241756	q=k√Pt	
									Pe	0	q	12.37387
	Q	36.45564	2.067		F		p	0.014528	Pf	0.14528129		
					T	10					Height of Elevation	
9	q	12.55662	2		L	7.5	C	120	Pt	5.02769885	q=k√Pt	
									Pe	0	q	12.55662
	Q	49.01225	2.067		F		p	0.025119	Pf	0.18839524		
					T	7.5					Height of Elevation	
10	q	12.78971	2		L	3.33	C	120	Pt	5.21609408	q=k√Pt	
									Pe	0	q	12.78971
	Q	61.80196	2.067		F		p	0.038574	Pf	0.12845277		
					T	3.33					Height of Elevation	
CM2	q	0	3		L	9	C	120	Pt	12.691357	q=k√Pt	
									Pe	0	q	0
	Q	127.4621	3.068	1T	F	15	p	0.021509	Pf	0.51621906		
					T	24					Height of Elevation	

11	q		1		L	9.5	C	120	Pt	4.59183673	Q=(Area of Coverage)(Density)		
									Pe	0	Q=	12	
	Q	12	1.049		F		p	0.050578			Pt=(Q/k-factor)^2		
									Pf	0.48049117	Pt=	4.591837	
					T	9.5					Height of Elevation		
12	q	12.61222	1		L	12	C	120	Pt	5.07232791	q=k√Pt		
									Pe	0	q	12.61222	
	Q	24.61222	1.049		F		p	0.191032					
									Pf	2.29238126			
					T	12					Height of Elevation		
13	q	15.19728	1.25		L	9.25	C	120	Pt	7.36470916	q=k√Pt		
									Pe	0	q	15.19728	
	Q	39.8095	1.38		F		p	0.122297					
									Pf	1.13125161			
					T	9.25					Height of Elevation		
CM3	q	0	3		L	8.5	C	120	Pt	21.7035368	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	3.068		F		p	0.035563					
									Pf	0.30228583			
					T	8.5					Height of Elevation		
CM4	q	0	3.5		L	24	C	120	Pt	22.0058226	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	3.548		F		p	0.017521					
									Pf	0.42050919			
					T	24					Height of Elevation		
CM5	q	0	4		L	61	C	120	Pt	22.4263318	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	4.026		F		p	0.009468					
									Pf	0.57753593			
					T	61					Height of Elevation		
CM6	q	0	5		L	40.5	C	120	Pt	23.0038678	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	5.047	1E	F	12	p	0.003149					
									Pf	0.16533757			
					T	52.5					Height of Elevation		
RISER	q	0	6		L	6.5	C	120	Pt	23.1692053	q=k√Pt		
									Pe	0	q	0	
	Q	167.2716	6.065	1E	F	14	p	0.001287					
									Pf	0.02638471			
					T	20.5					Height of Elevation		
BOR	q	0	6		L	60	C	120	Pt	23.19559	q=k√Pt		
									Pe	25.98	q	0	
	Q	167.2716	6.065	1BV; 1GV; 1SCV	F	45	p	0.001287					
									Pf	0.13514118			
					T	105					Height of Elevation		60
									Pt	49.3107312			

Appendix F: Seismic Bracing Sample Calculations (B-Line by Eaton, TOLBrace)

Seismic Bracing: Boston, Massachusetts

B-Line by Eaton, TOLBrace™ Fire 8.0 – FPWorksheet

2013 NFPA #13

Ss	=	0.23	Mapped spectral accelerations for short periods
Fpw	=	**Cp ***	**Wp**
Fpw	=	0.35	**Wp**

Per Section 9.3.5.9.6.1, longitudinal bracing may be required on branch lines, if the riser nipples are longer than 4 ft. and the following condition is met.

Braces are required if:

(Hr * Wp * Cp)/S >= Fy

Hr	=	2	length of riser nipple (in inches)
Wp	=	190	tributary weight (in pounds) for the branch line within the ZOI, including the riser nipple
Cp	=	0.5	seismic coefficient (calculated above)
S	=	0.1328	section modulus of riser nipple (1" Sch 40 = .1328, 1-1/4" Sch 40 = .2346, 1-1/2" Sch 40 = .3262, 2" Sch 40 = .4205)
Fy	=	30000	allowable yeild strength of 30,000 psi for steel

1431 >= 30000

If the number on the left is larger than the number on the right, you must add longitudinal braces to branch lines. If the number on the left is smaller, brace as usual.

Calculate Force Factor   Apply

Cases 1, 4, and 5

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec
100 Institute Road
Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

B-Line by EATON

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	40' 0" (12.19 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.35

Fastener Information

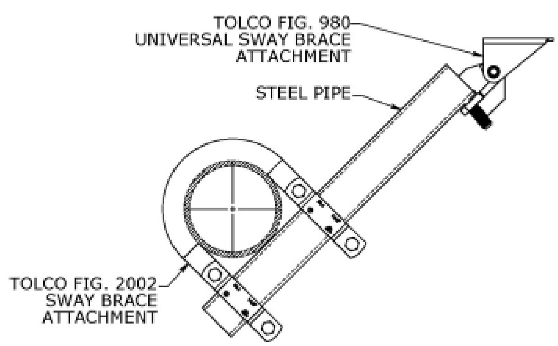
Fastener Orientation	NFPA Type A
Maximum Load	1600 lbs (726 kg)
Diameter	1/2n. (12 mm)
Length	N/A
Type	Bolt

Tolco Brace Components

Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Assembly Detail



Brace Identification on Plans Boston Cases 1, 4, and 5

Orientation of Brace Lateral

Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	40ft (12.2 m)	444 lbs (201 kg)
Percentage added for Fittings and Sprinklers	15%	67 lbs (30.39 kg)
Total Adjusted Load of all pipe within Zone of Influence		510 lbs (231 kg)

{Tol-Brace Verizon 8}

Cases 2 and 3

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec
100 Institute Road
Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

B-Line by EATON

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	40' 0" (12.19 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.35

Tolco Brace Components

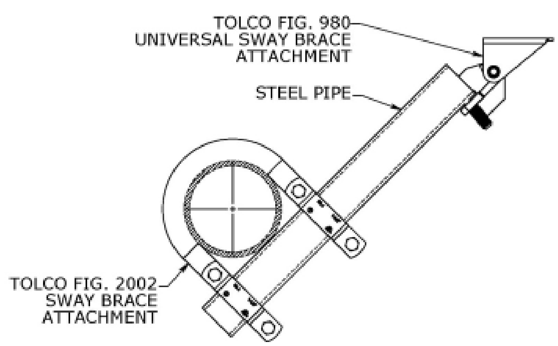
Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Fastener Information

Fastener Orientation	NFPA Type A
Maximum Load	565 lbs (256 kg)
Diameter	3/4in. (19 mm)
Length	Minimum 4x Wood Member
Type	Dual Through-Bolts - Fig.906

Assembly Detail



Brace Identification on Plans	Boston Cases 2 and 3
Orientation of Brace	Lateral

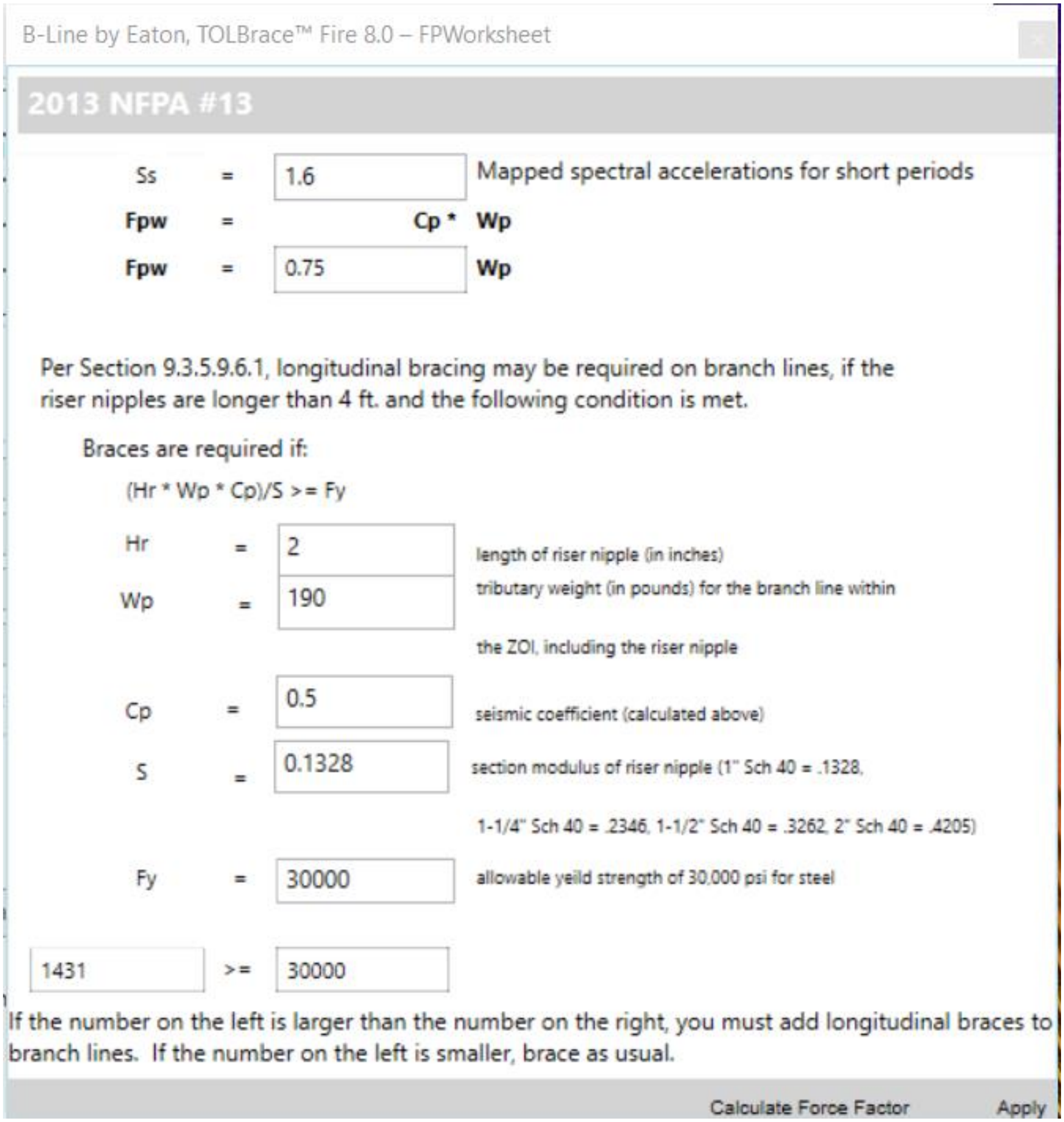
Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	40ft (12.2 m)	444 lbs (201 kg)
Percentage added for Fittings and Sprinklers	15%	67 lbs (30.39 kg)
Total Adjusted Load of all pipe within Zone of Influence		510 lbs (231 kg)

{Tol-Brace Verizon 8}

Seismic Bracing: Los Angeles, California



B-Line by Eaton, TOLBrace™ Fire 8.0 – FPWorksheet

2013 NFPA #13

Ss = 1.6 Mapped spectral accelerations for short periods

Fpw = **Cp * Wp**

Fpw = 0.75 **Wp**

Per Section 9.3.5.9.6.1, longitudinal bracing may be required on branch lines, if the riser nipples are longer than 4 ft. and the following condition is met.

Braces are required if:

(Hr * Wp * Cp)/S >= Fy

Hr	=	2	length of riser nipple (in inches)
Wp	=	190	tributary weight (in pounds) for the branch line within the ZOI, including the riser nipple
Cp	=	0.5	seismic coefficient (calculated above)
S	=	0.1328	section modulus of riser nipple (1" Sch 40 = .1328, 1-1/4" Sch 40 = .2346, 1-1/2" Sch 40 = .3262, 2" Sch 40 = .4205)
Fy	=	30000	allowable yeild strength of 30,000 psi for steel

1431 >= 30000

If the number on the left is larger than the number on the right, you must add longitudinal braces to branch lines. If the number on the left is smaller, brace as usual.

Calculate Force Factor Apply

Cases 1, 4, and 5

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec | 100 Institute Road | Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

B-Line by EATON

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	30' 0" (9.14 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.75

Tolco Brace Components

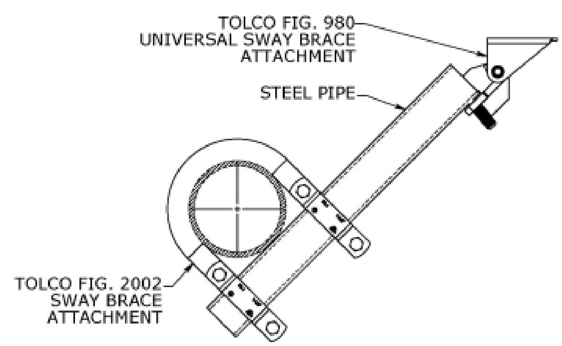
Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Fastener Information

Fastener Orientation	NFPA Type A
Maximum Load	1600 lbs (726 kg)
Diameter	1/2n. (12 mm)
Length	N/A
Type	Bolt

Assembly Detail



Brace Identification on Plans LA Cases 1, 4, and 5

Orientation of Brace Lateral

Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	30ft (9.1 m)	713 lbs (323 kg)
Percentage added for Fittings and Sprinklers	15%	107 lbs (48.54 kg)
Total Adjusted Load of all pipe within Zone of Influence		820 lbs (372 kg)

{Tol-Brace Verizon 8}

Cases 2 and 3

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec
100 Institute Road
Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

B-Line by EATON

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	20' 0" (6.1 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.75

Tolco Brace Components

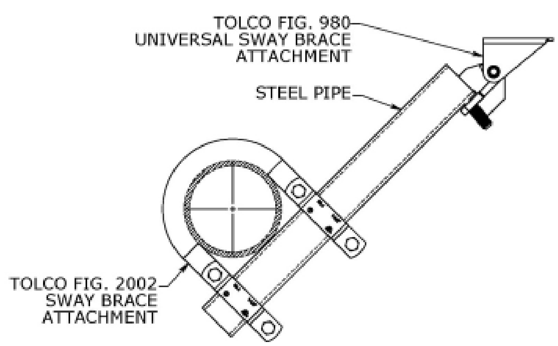
Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Fastener Information

Fastener Orientation	NFPA Type A
Maximum Load	565 lbs (256 kg)
Diameter	3/4in. (19 mm)
Length	Minimum 4x Wood Member
Type	Dual Through-Bolts - Fig.906

Assembly Detail



Brace Identification on Plans	LA Cases 2 and 3
Orientation of Brace	Lateral

Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	20ft (6.1 m)	475 lbs (215 kg)
Percentage added for Fittings and Sprinklers	15%	71 lbs (32.21 kg)
Total Adjusted Load of all pipe within Zone of Influence		547 lbs (248 kg)

{Tol-Brace Verizon 8}

Seismic Bracing: Miami, Florida

B-Line by Eaton, TOLBrace™ Fire 8.0 – FPWorksheet

2013 NFPA #13

Ss = 0.04 Mapped spectral accelerations for short periods

Fpw = Cp * Wp

Fpw = 0.35 **Wp**

Per Section 9.3.5.9.6.1, longitudinal bracing may be required on branch lines, if the riser nipples are longer than 4 ft. and the following condition is met.

Braces are required if:

(Hr * Wp * Cp)/S >= Fy

Hr	=	2	length of riser nipple (in inches)
Wp	=	190	tributary weight (in pounds) for the branch line within the ZOI, including the riser nipple
Cp	=	0.5	seismic coefficient (calculated above)
S	=	0.1328	section modulus of riser nipple (1" Sch 40 = .1328, 1-1/4" Sch 40 = .2346, 1-1/2" Sch 40 = .3262, 2" Sch 40 = .4205)
Fy	=	30000	allowable yeild strength of 30,000 psi for steel

1431 >= 30000

If the number on the left is larger than the number on the right, you must add longitudinal braces to branch lines. If the number on the left is smaller, brace as usual.

Calculate Force Factor Apply

Cases 1, 4, and 5

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec
100 Institute Road
Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	40' 0" (12.19 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.35

Tolco Brace Components

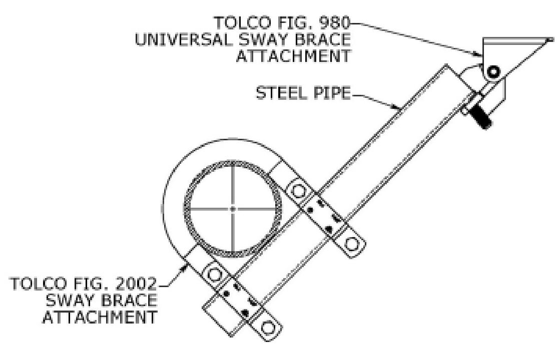
Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Fastener Information

Fastener Orientation	NFPA Type A
Maximum Load	1600 lbs (726 kg)
Diameter	1/2n. (12 mm)
Length	N/A
Type	Bolt

Assembly Detail



Brace Identification on Plans Miami Cases 1, 4, and 5

Orientation of Brace Lateral

Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	40ft (12.2 m)	444 lbs (201 kg)
Percentage added for Fittings and Sprinklers	15%	67 lbs (30.39 kg)
Total Adjusted Load of all pipe within Zone of Influence		510 lbs (231 kg)

{Tol-Brace Verizon 8}

Cases 2 and 3

Tol-Brace Seismic Calculations

Project Address: Integrated Structural and Fire Protec
100 Institute Road
Worcester, MA

Worcester Polytechnic Institu
100 Institute Road
Worcester, MA 01609

B-Line by EATON

Job # LDA - 1702

Calculations based on 2016 NFPA Pamphlet #13

Brace Information

Maximum Spacing	40' 0" (12.19 m)
Maximum Brace Length	13' 1" (4 m)
Bracing Material	2" Sch.40
Angle from Vertical	30° Min.
Least Rad. of Gyration	0.787" (20 mm)
L/R Value	200
Max Horizontal Load	3828 lbs (1736 kg)
Force Factor (Cp)	0.35

Fastener Information

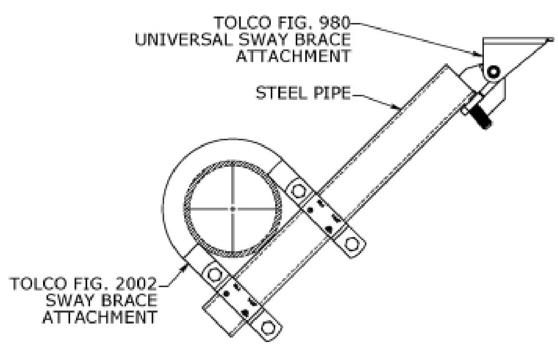
Fastener Orientation	NFPA Type A
Maximum Load	565 lbs (256 kg)
Diameter	3/4in. (19 mm)
Length	Minimum 4x Wood Member
Type	Dual Through-Bolts - Fig.906

Tolco Brace Components

Tolco Component Fig. Number	Adjusted Load
Fig. 2002 Clamp	1007 lbs (457 kg)
Fig.980 Universal Swivel	1007 lbs (457 kg)

*Calculation Based on CONCENTRIC Loading
*Please Note: These calculations are for Tolco components only. Use of any other components voids these calculations and the listing of the assembly.

Assembly Detail



Brace Identification on Plans Miami Cases 2 and 3

Orientation of Brace Lateral

Braced Pipe: 6" Sch.40 Steel Pipe

Load Information

Size and Type of Pipe	Total Length	Total Calculated Load
6" Sch.40 Steel Pipe (152.4 mm)	40ft (12.2 m)	444 lbs (201 kg)
Percentage added for Fittings and Sprinklers	15%	67 lbs (30.39 kg)
Total Adjusted Load of all pipe within Zone of Influence		510 lbs (231 kg)

{Tol-Brace Verizon 8}

Appendix G: Full Drawings Set

INTEGRATED STRUCTURAL AND FIRE PROTECTION DESIGN CONSIDERATIONS

KEY PLAN

NO.	REVISION	DATE

PROJECT
INTEGRATED STRUCTURAL AND FIRE PROTECTION DESIGN CONSIDERATIONS

ADDRESS
100 INSTITUTE ROAD
WORCESTER, MA 01609

PROJECT NO
LDA - 1702

DATE
March 1, 2017

DESIGN
ELIZABETH M. COFFEY
AND
EMMA T. HEALEY

DRAWN BY
ELIZABETH M. COFFEY
AND
EMMA T. HEALEY

CHECKED BY
LEONARD D. ALBANO

SCALE

TITLE
COVER SHEET

NUMBER
CS.1

SHEET
1 OF 60

INDEX OF DRAWINGS

SHEET NO.	DRAWING NO.	DRAWING TITLE
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9	FA.1.2	CASE 1 FIRE ALARM 2ND FLOOR (TYP.)
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54	FA.5.1.2	CASE 5 FIRE ALARM 1ST FLOOR – EAST
55	FA.5.2.1	CASE 5 FIRE ALARM 2ND FLOOR – WEST (TYP.)
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59	FP.5.2.1	CASE 5 FIRE PROTECTION 2ND FLOOR – WEST (TYP.)
60	FP.5.2.2	CASE 5 FIRE PROTECTION 2ND FLOOR – EAST (TYP.)

SYMBOLS LEGEND

	ADDRESSABLE PHOTOELECTRIC SMOKE DETECTOR
RoR/135	ADDRESSABLE COMBINATION RATE OF RISE / FIXED TEMPERATURE (135°F)
F	ADDRESSABLE DOUBLE-ACTION MANUAL FIRE ALARM BOX
CD	SPEAKER/STROBE NOTIFICATION APPLIANCE - WALL MOUNTED (CANDELA RATING AS NOTED)
CD	SPEAKER/STROBE NOTIFICATION APPLIANCE - CEILING MOUNTED (CANDELA RATING AS NOTED)
	LINEAR-BEAM SMOKE DETECTOR (TRANSMITTER)
	LINEAR-BEAM SMOKE DETECTOR (RECEIVER)
FACU	FIRE ALARM CONTROL UNIT
	SPRINKLER RISER
	SPRINKLER HEAD
	SPRINKLER PIPE
	BEAM
	GIRDER
	COLUMN

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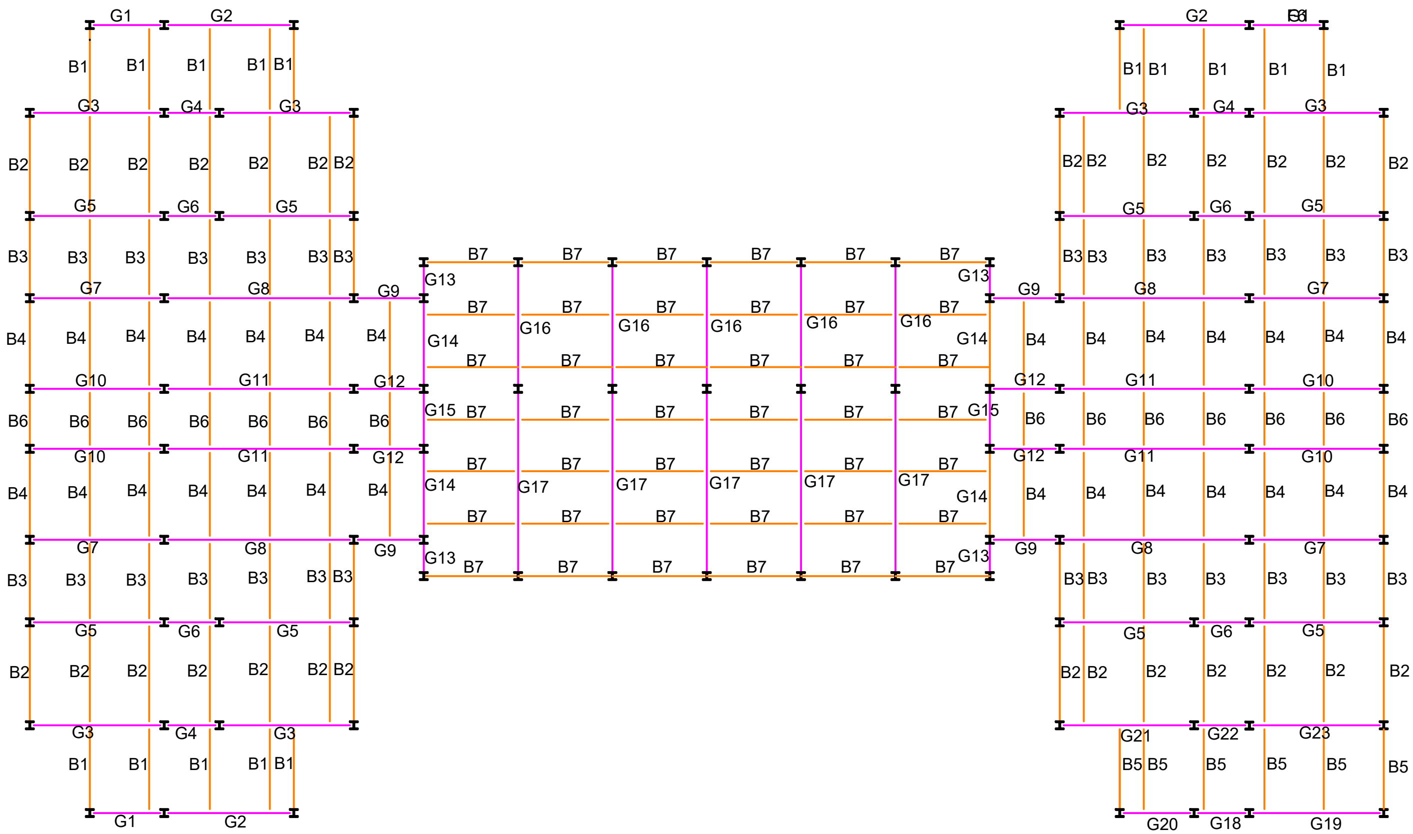
ELIZABETH M. COFFEY

CHECKED BY
LEONARD D. ALBANO

SCALE

TITLE
GENERAL NOTES AND LEGEND

NUMBER
G.1



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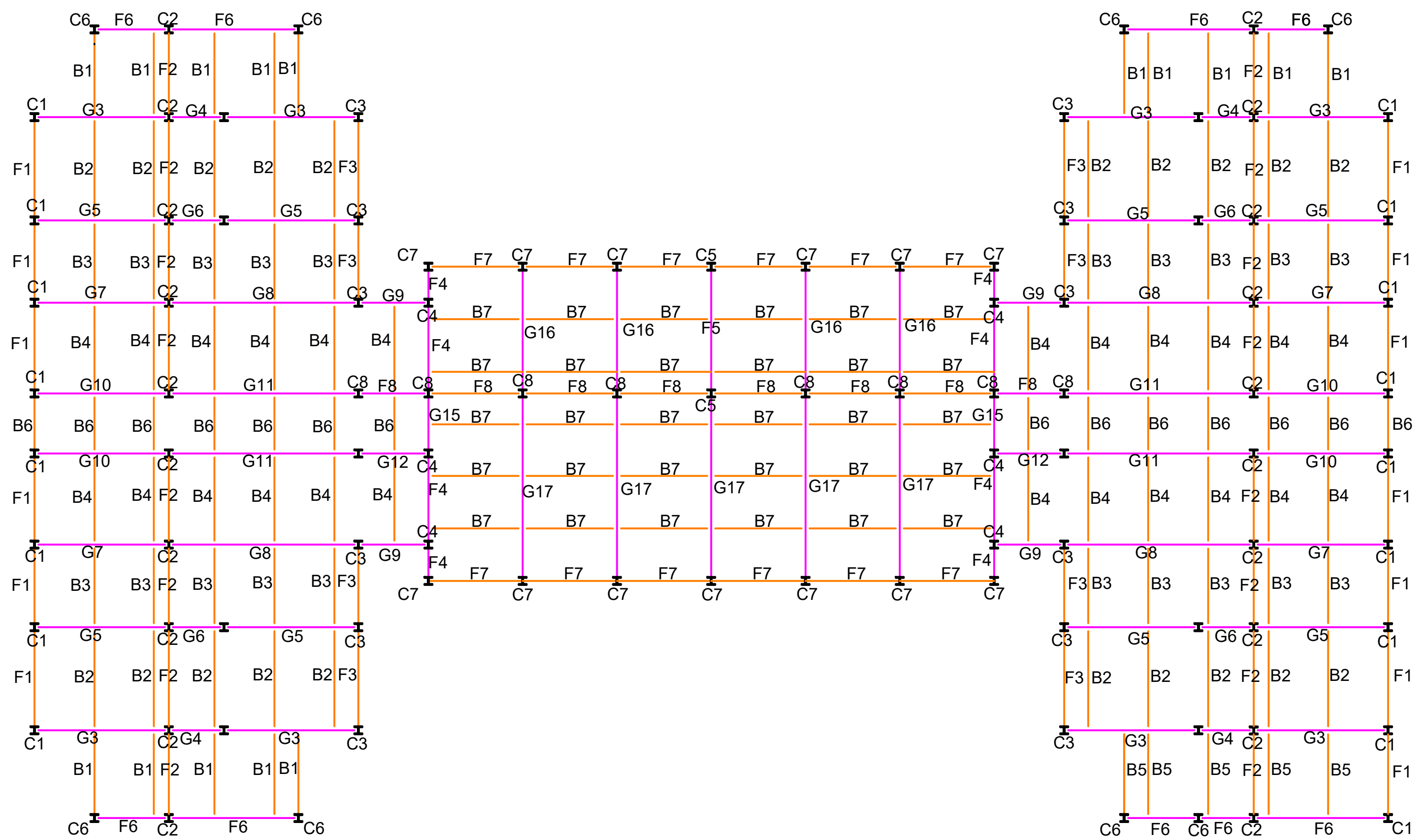
SCALE
$\frac{1}{32}'' = 1'$

TITLE
CASE 1
STRUCTURAL
(DESIGN LOADS)

NUMBER
S.1.1

SHEET
3 OF 60



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TITLE

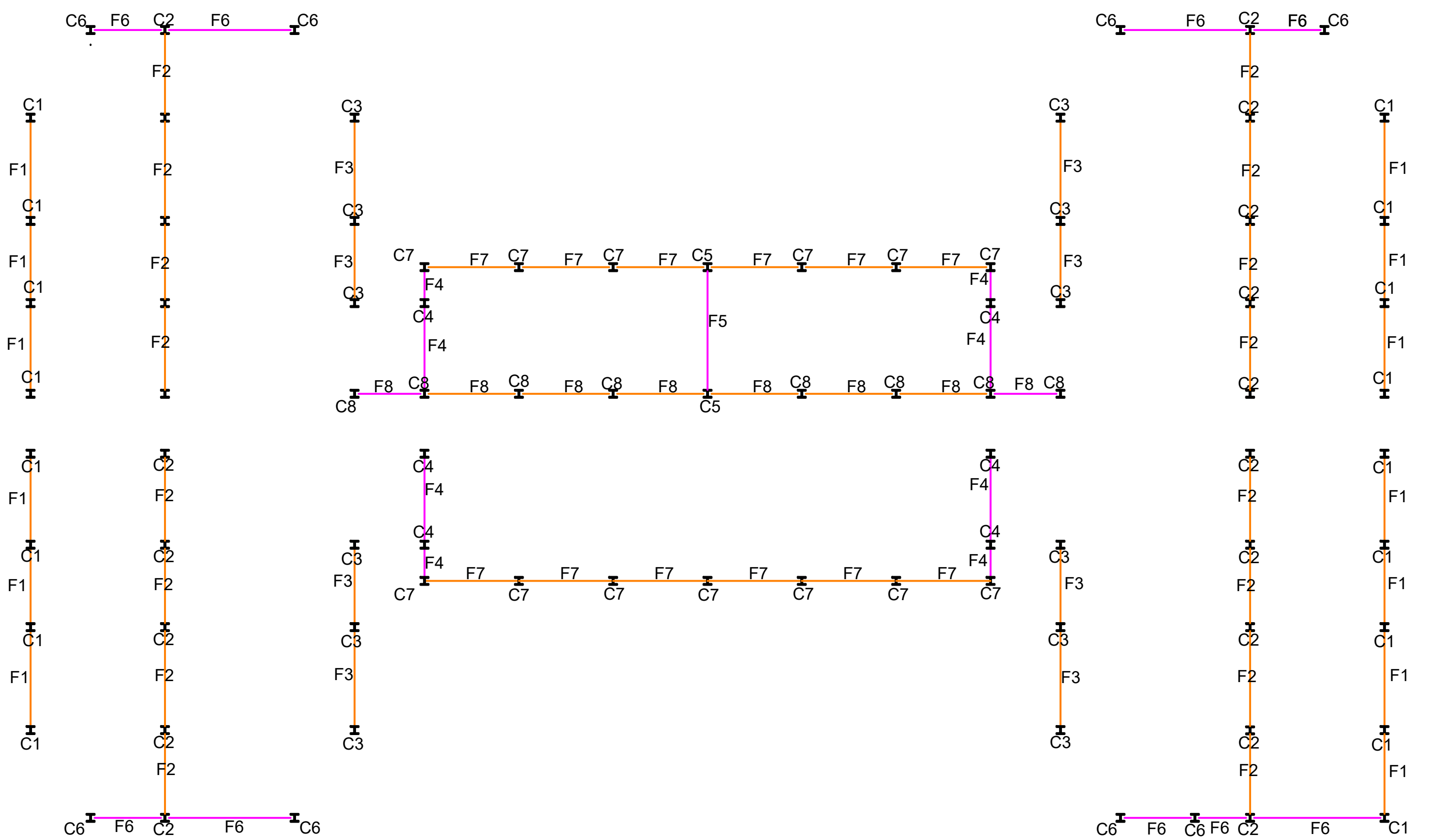
CASE 1
STRUCTURAL
(ENVIRONMENTAL LOADS)

NUMBER

S.1.2

SHEET

4 OF 60



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SCALE
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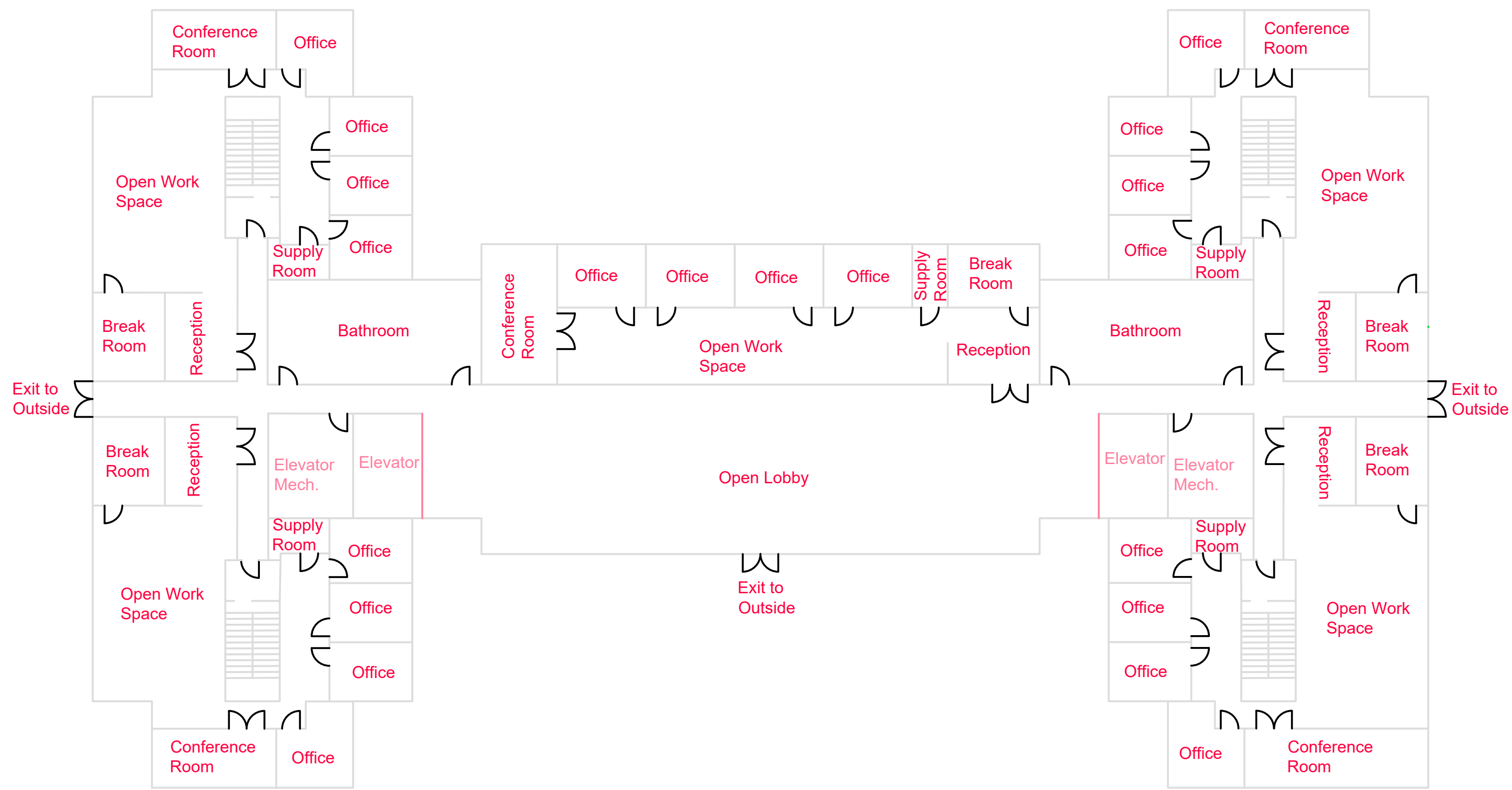
TITLE
CASE 1
STRUCTURAL
(FRAMES)

NUMBER
S.1.3

SHEET
5 OF 60



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SCALE
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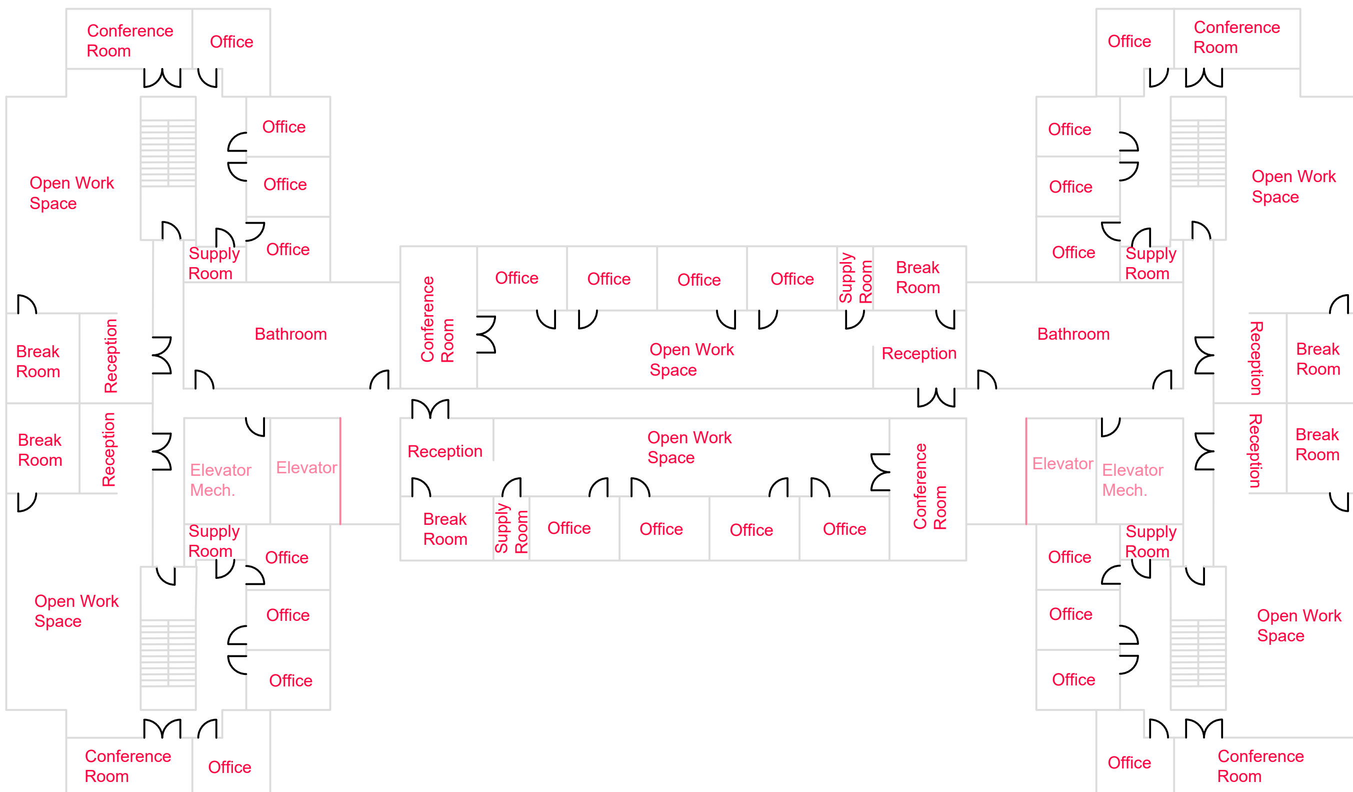
TITLE
CASE 1
ARCHITECTURAL
1ST FLOOR

NUMBER
A.1.1

SHEET
6 OF 60



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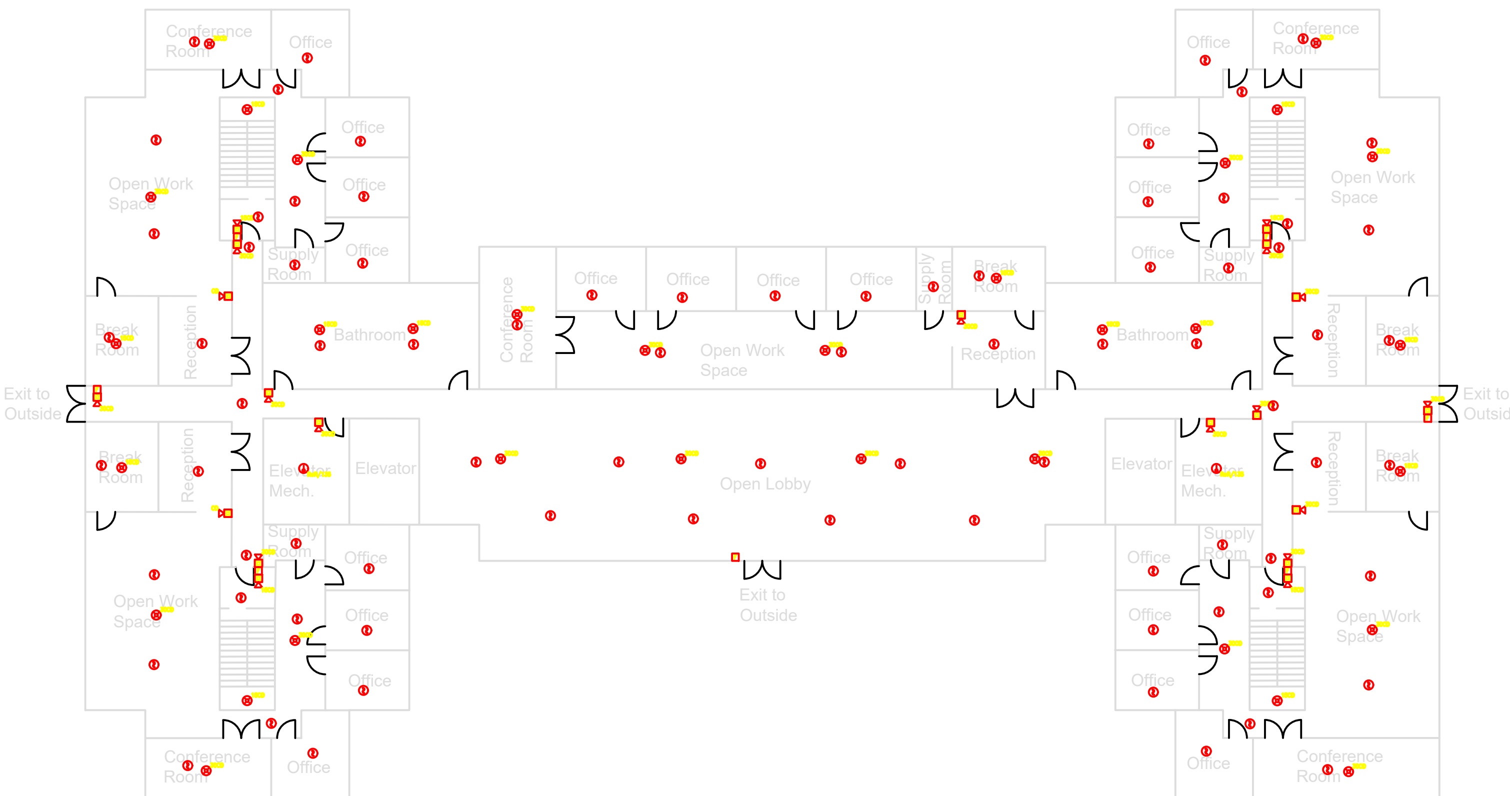
TITLE
CASE 1
ARCHITECTURAL
2ND FLOOR (TYP.)

NUMBER
A.1.2

SHEET
7 OF 60



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TITLE

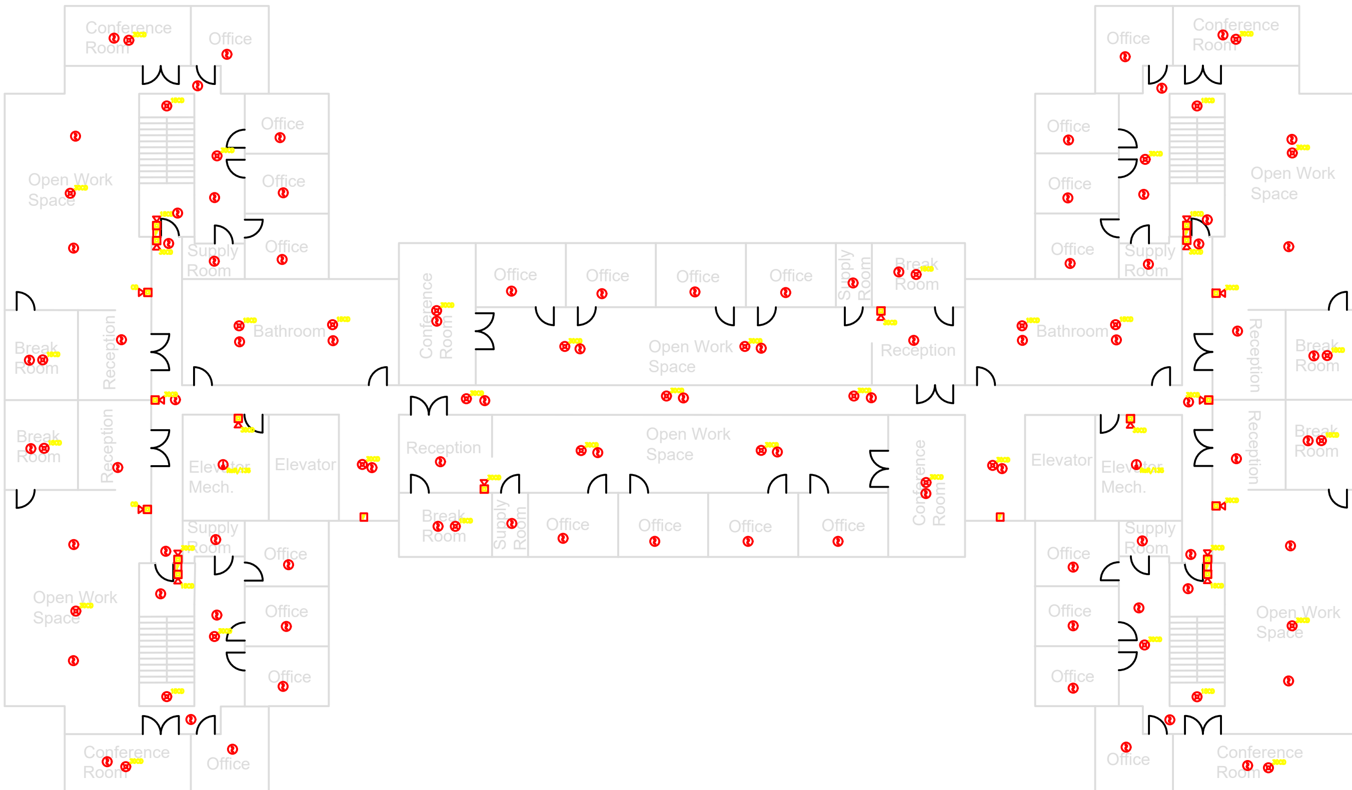
CASE 1
FIRE ALARM
1ST FLOOR

NUMBER

FA.1.1

SHEET

8 OF 60



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SCALE

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TITLE

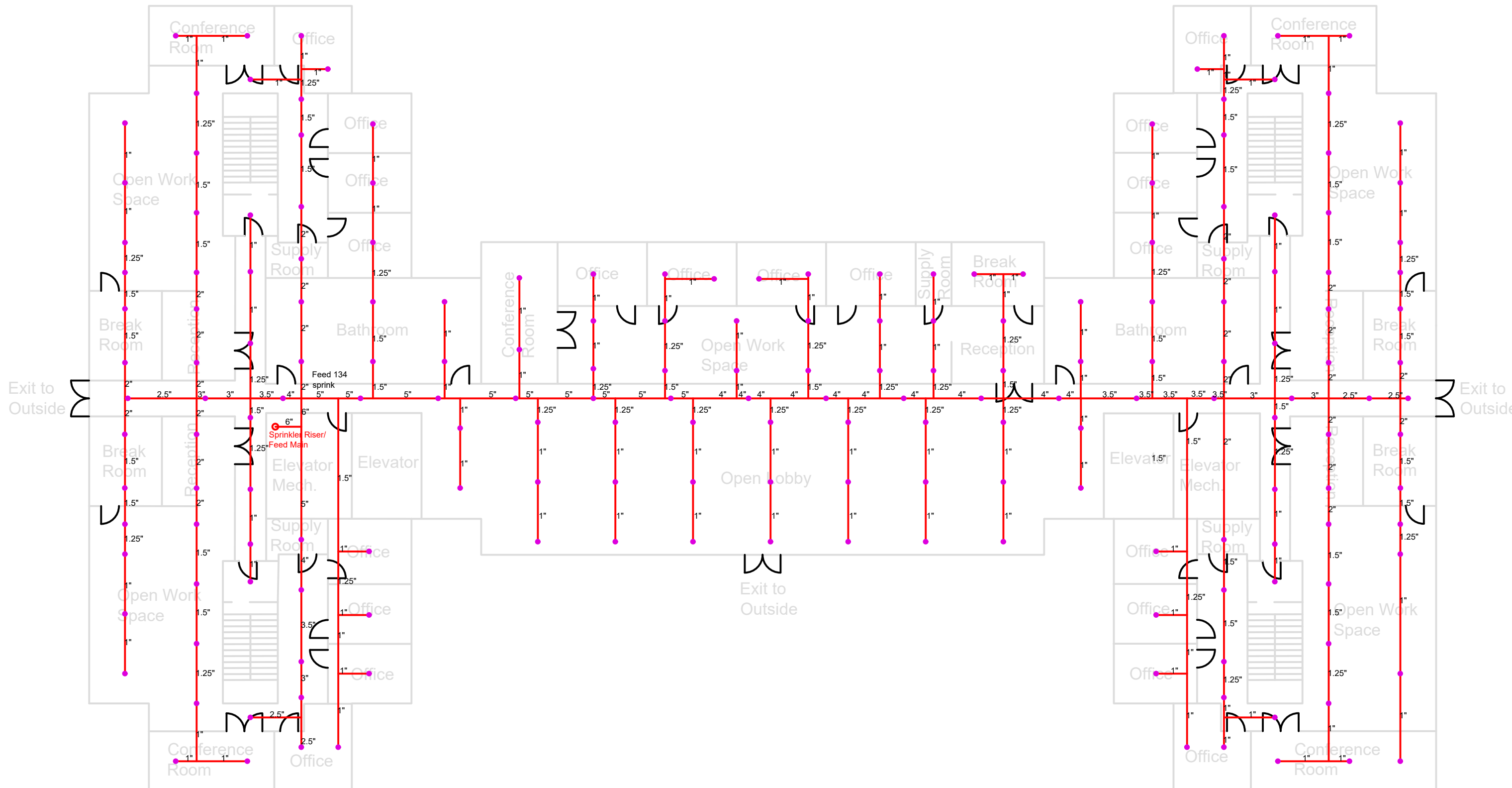
CASE 1
FIRE ALARM
2ND FLOOR (TYP.)

NUMBER

FA.1.2

SHEET

9 OF 60



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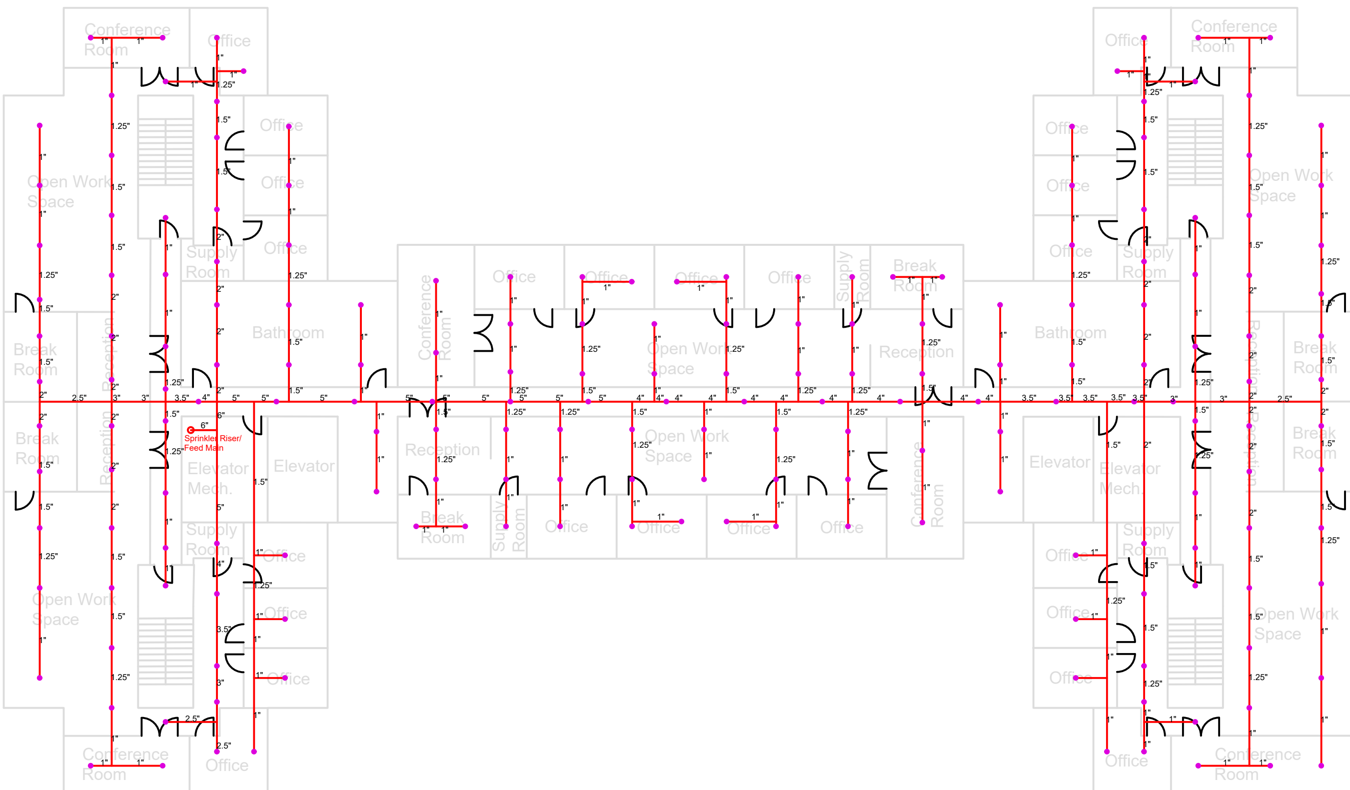
TITLE
CASE 1
FIRE PROTECTION
1ST FLOOR

NUMBER
FP.1.1

SHEET
10 OF 60



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TITLE

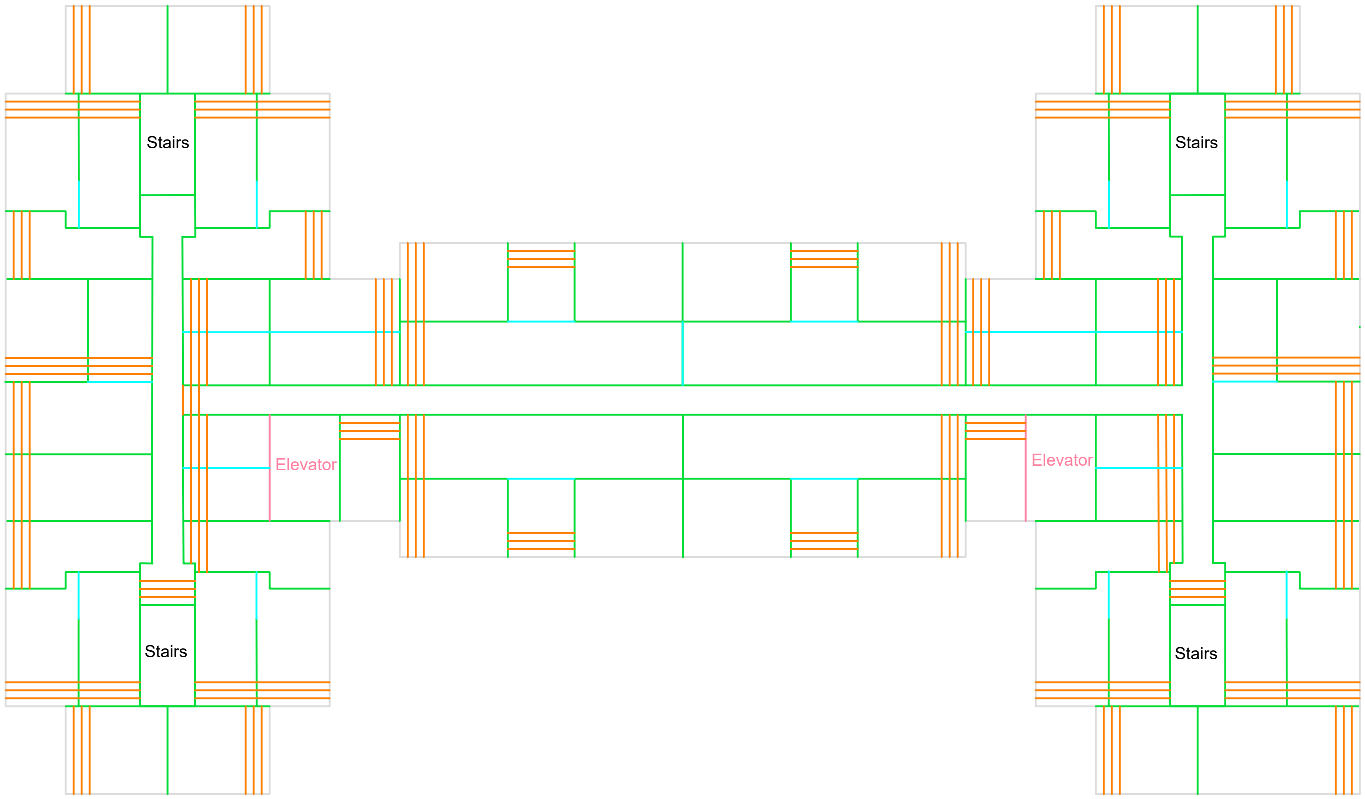
CASE 1
FIRE PROTECTION
2ND FLOOR (TYP.)

NUMBER

FP.1.2

SHEET

11 OF 60



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EMMA T. HEALEY

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SCALE

$\frac{1}{32}" = 1'$

TITLE

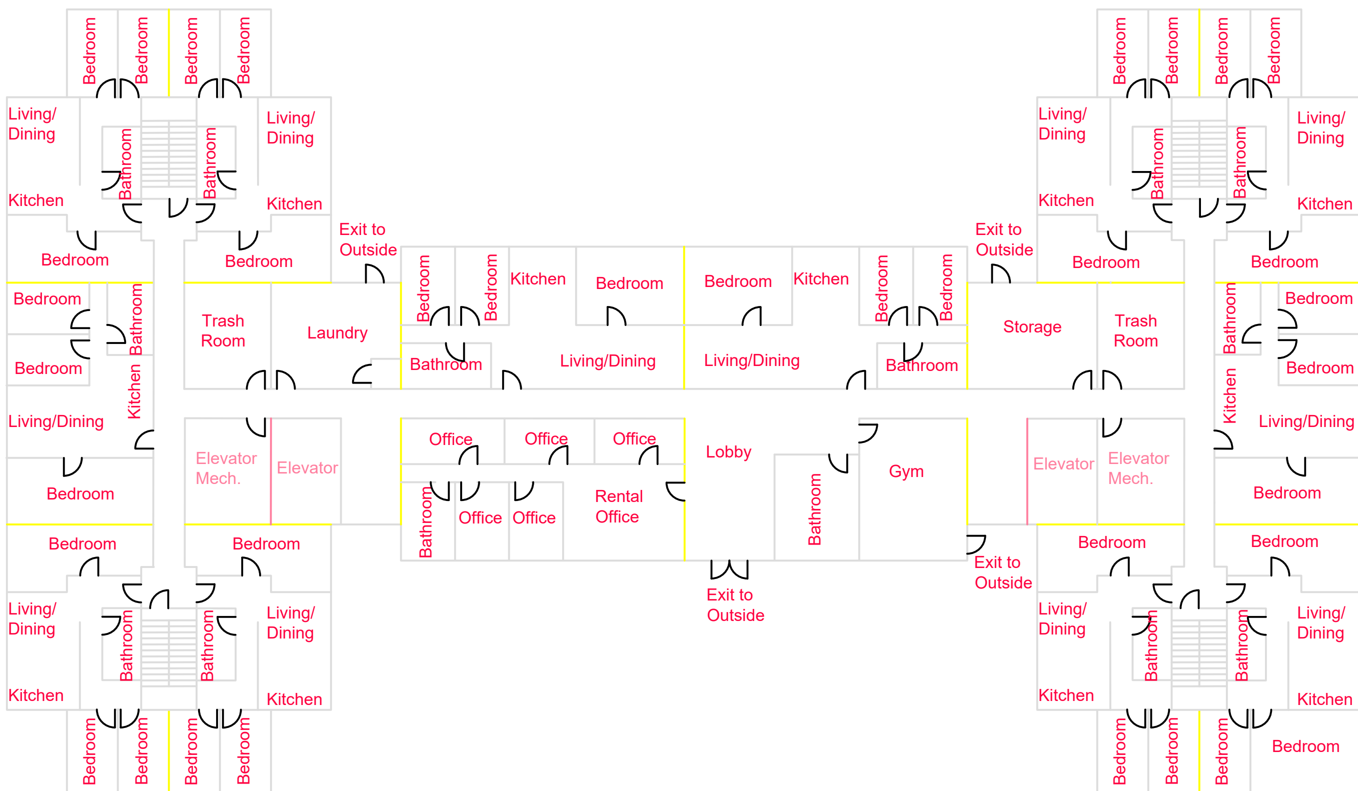
CASE 2
STRUCTURAL
(WOOD DESIGN)

NUMBER

S.2

SHEET

12 OF 60



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DRAWN BY
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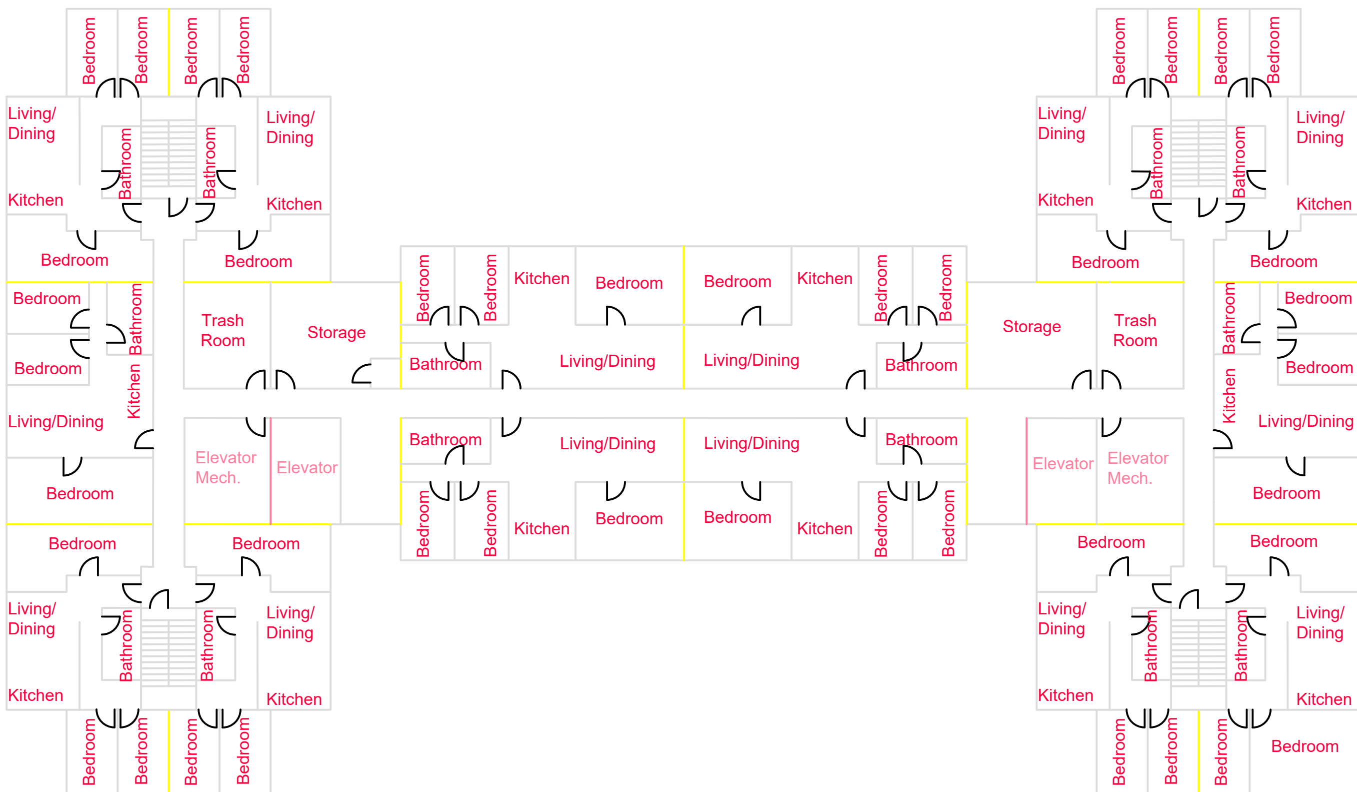
LEONARD D. ALBANO

SCALE
$\frac{1}{32}'' = 1'$

TITLE
CASE 2
ARCHITECTURAL
1ST FLOOR

NUMBER
A.2.1

SHEET
13 OF 60



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SCALE
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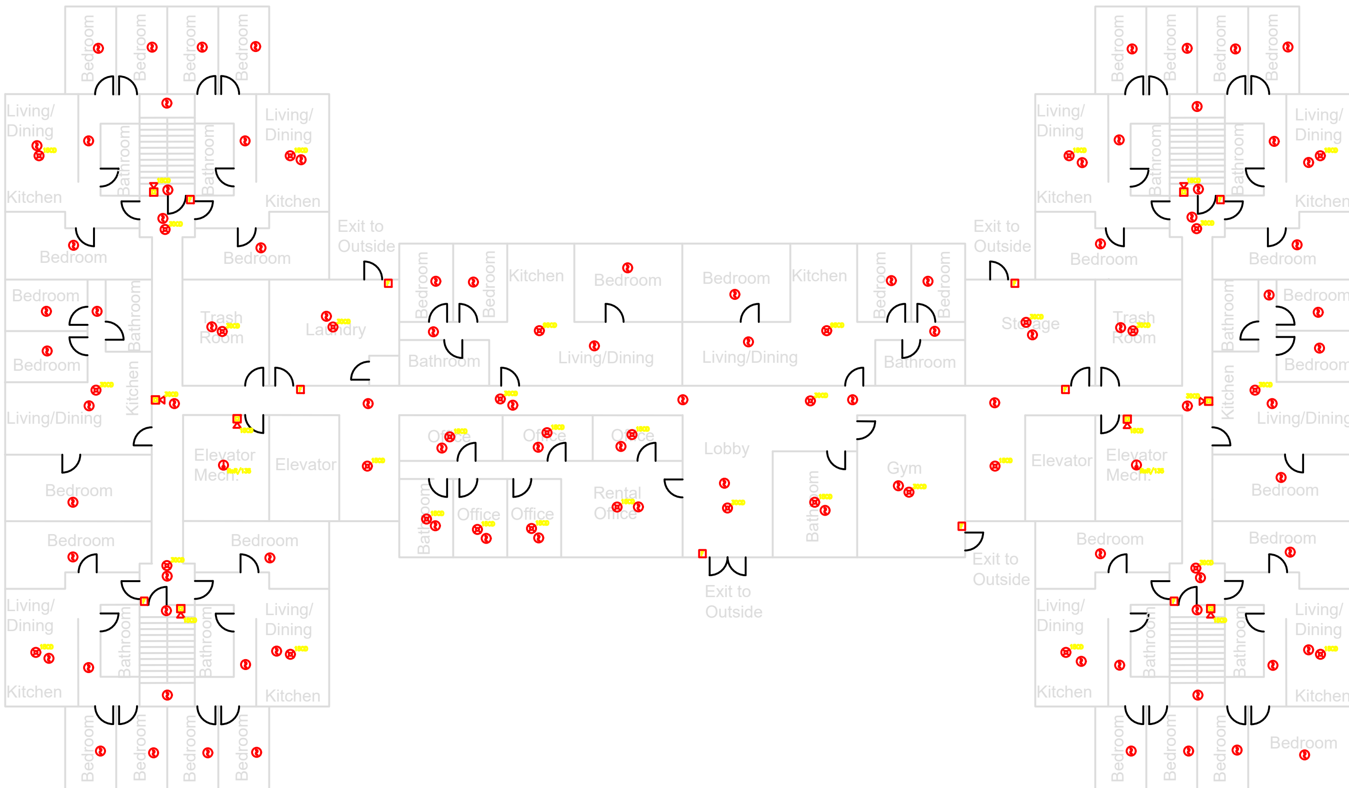
TITLE
CASE 2
ARCHITECTURAL
2ND FLOOR (TYP.)

NUMBER
A.2.2

SHEET
14 OF 60



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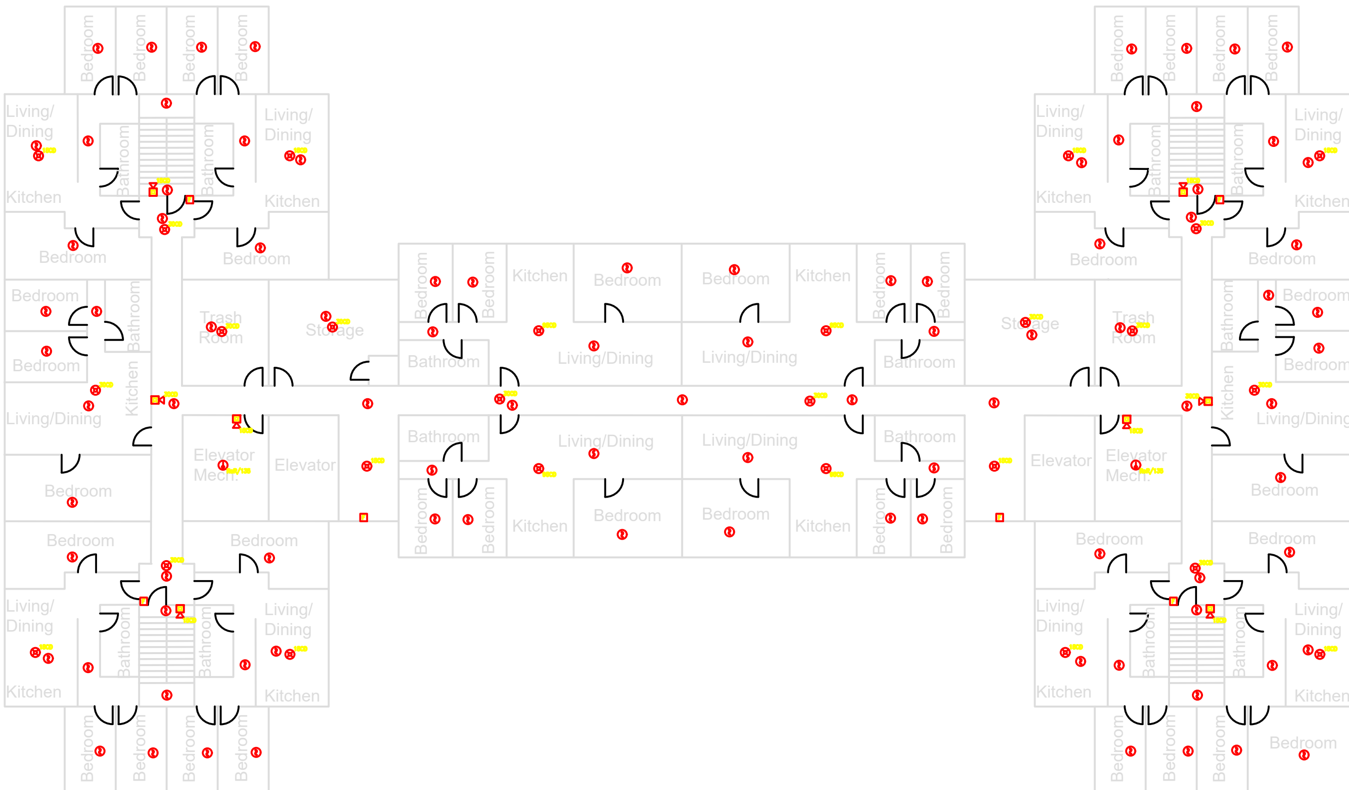
TITLE
CASE 2
FIRE ALARM
1ST FLOOR

NUMBER
FA.2.1

SHEET
15 OF 60



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TITLE

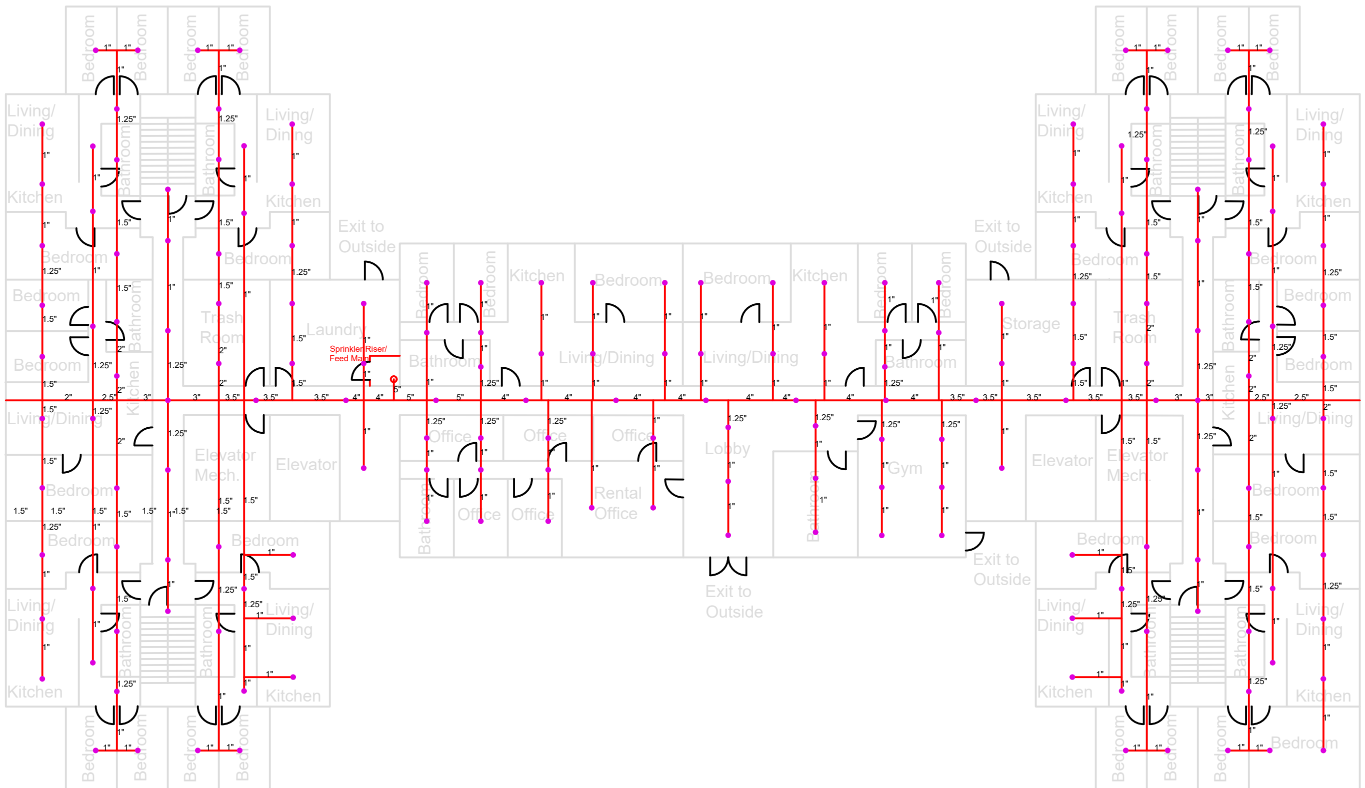
CASE 2
FIRE ALARM
2ND FLOOR (TYP.)

NUMBER

FA.2.2

SHEET

16 OF 60



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TITLE

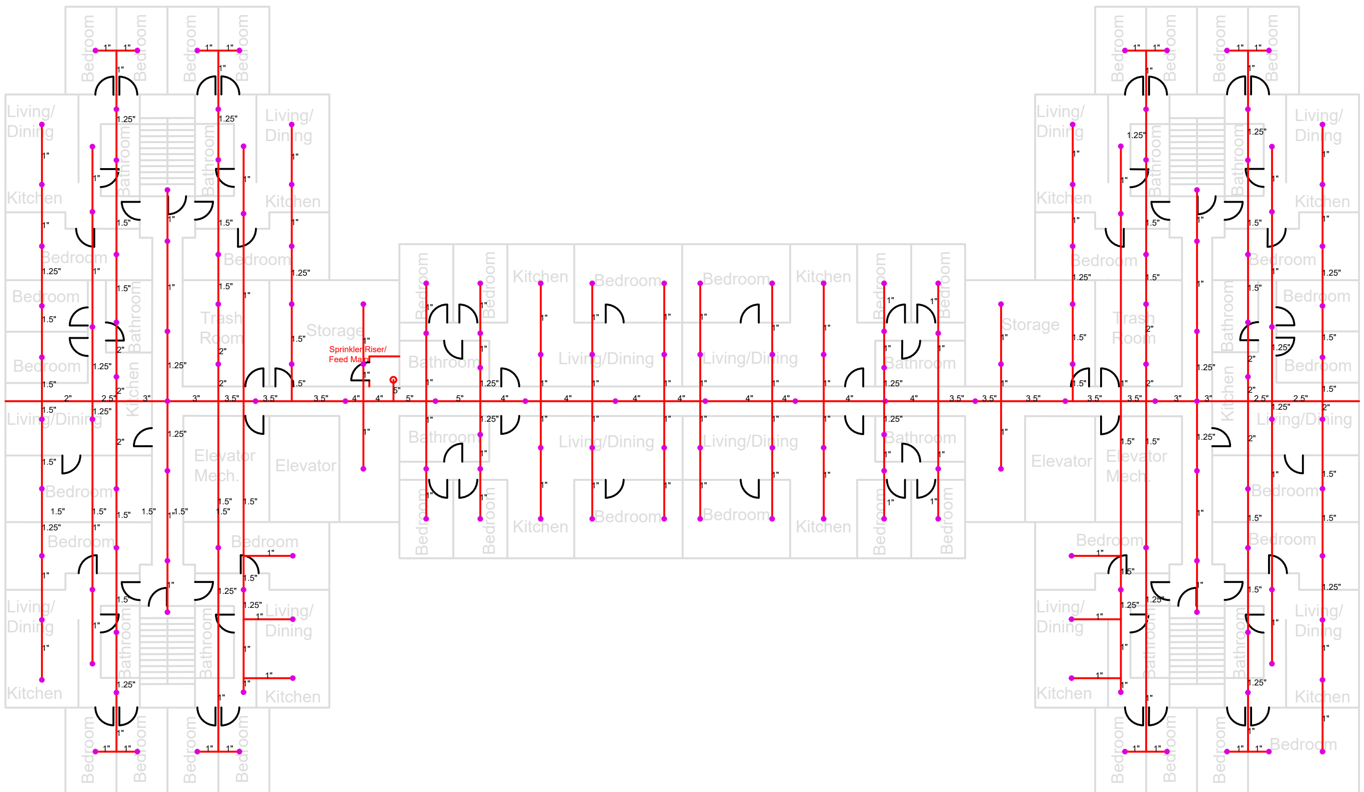
CASE 2
FIRE PROTECTION
1ST FLOOR

NUMBER

FP.2.1

SHEET

17 OF 60



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TITLE

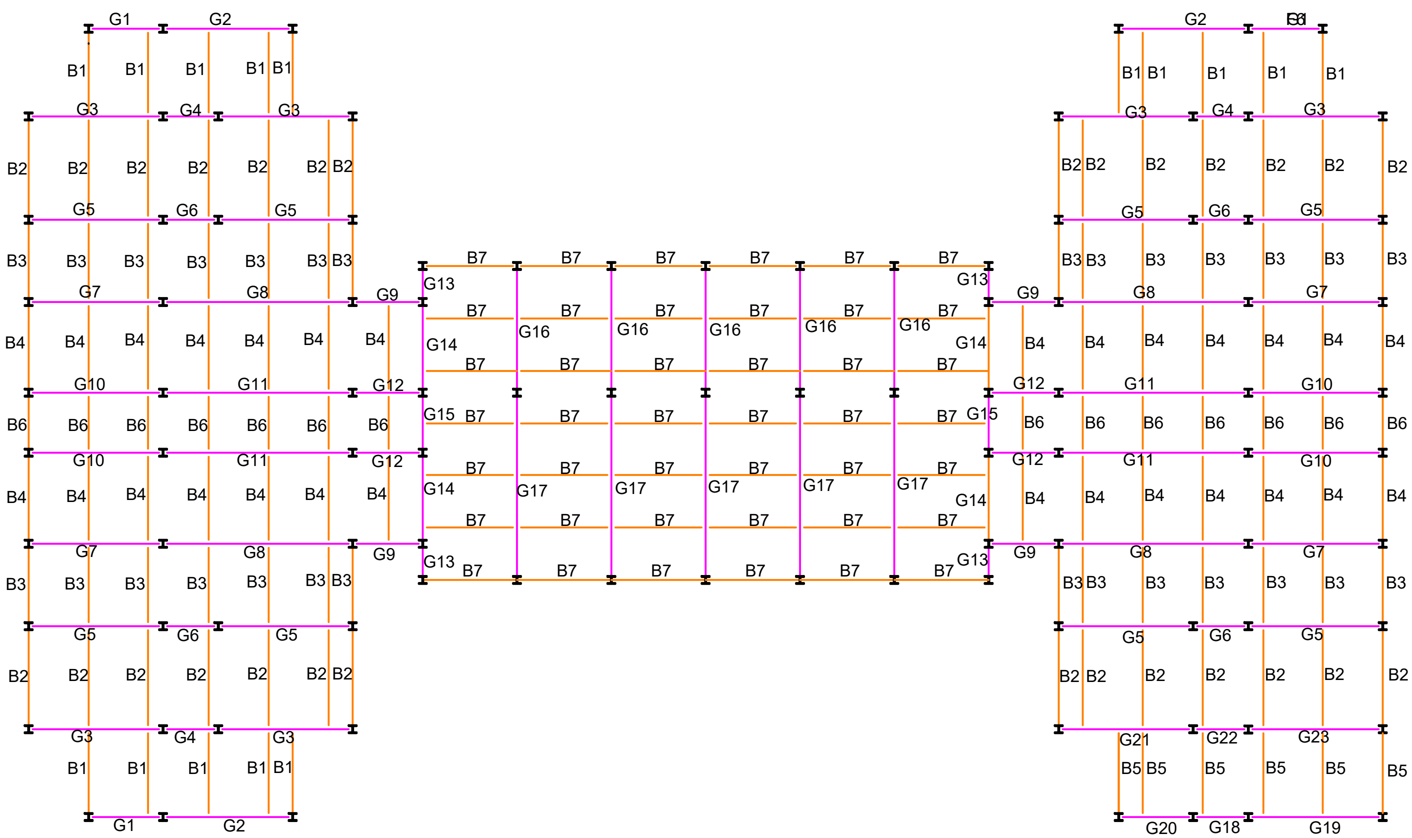
CASE 2
FIRE PROTECTION
2ND FLOOR (TYP.)

NUMBER

FP.2.2

SHEET

18 OF 60



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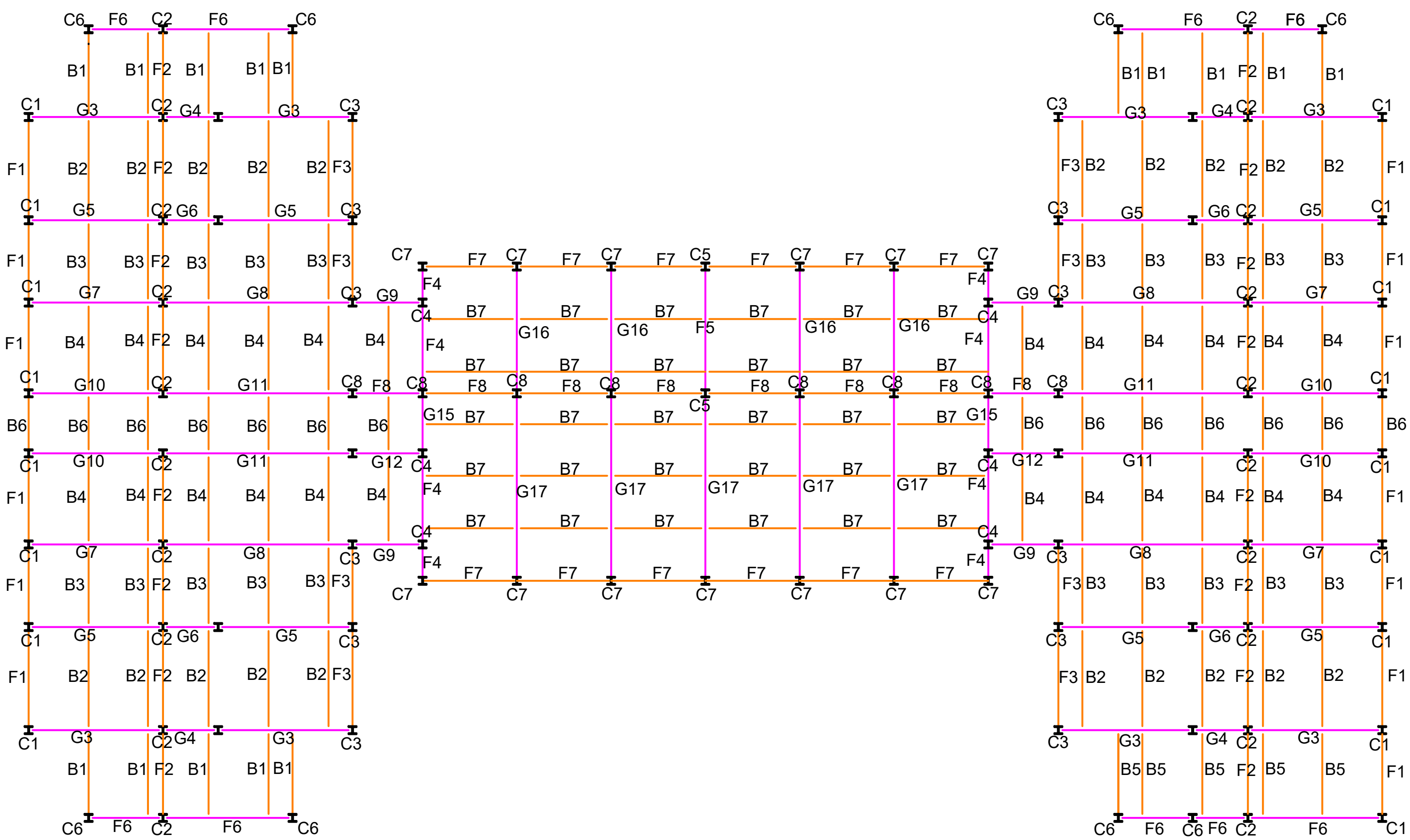
SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 3
STRUCTURAL
(DESIGN LOADS)

NUMBER
S.3.1

SHEET
19 OF 60



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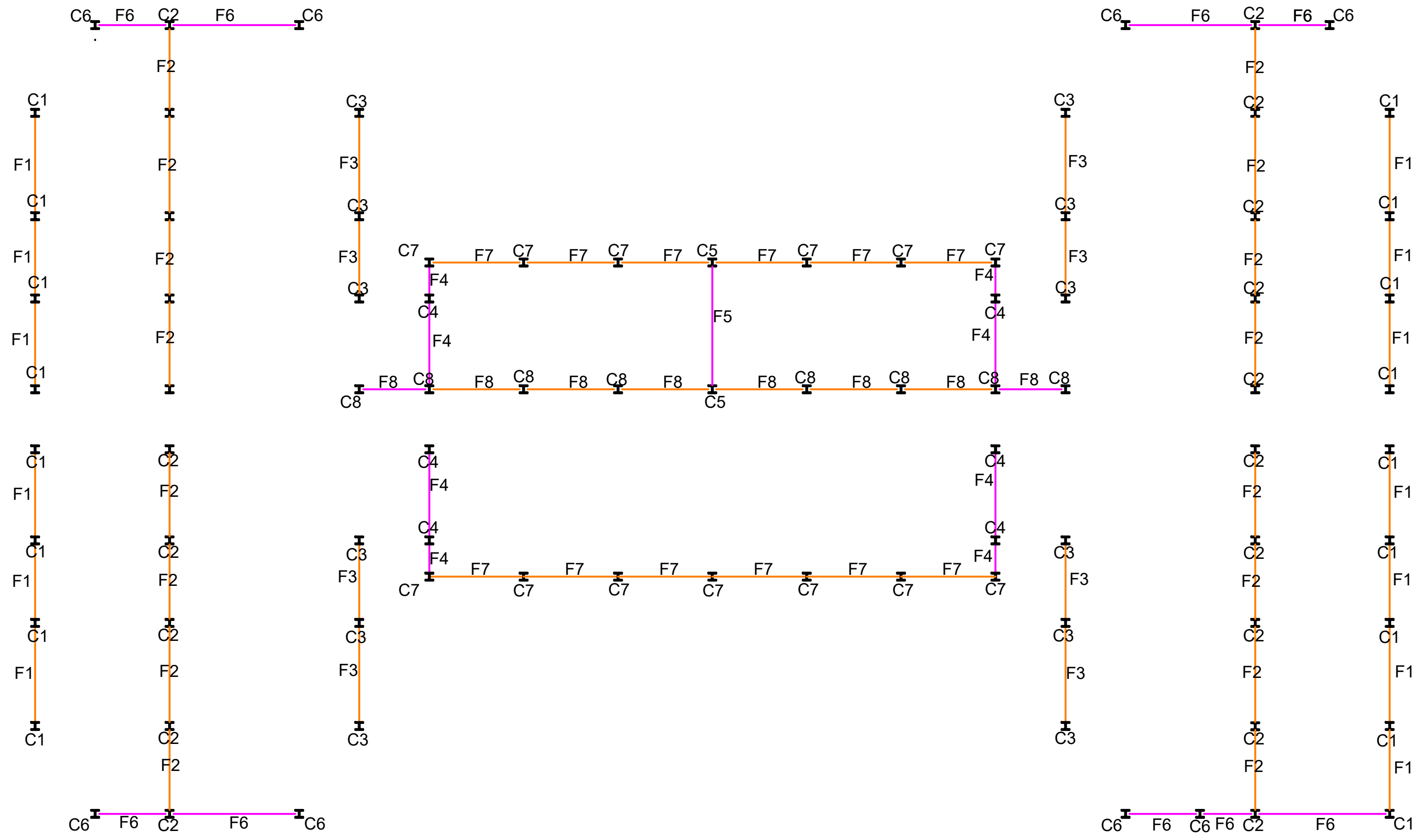
TITLE
CASE 3
STRUCTURAL
(ENVIRONMENTAL LOADS)

NUMBER
S.3.2

SHEET
20 OF 60



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SCALE

$\frac{1}{32}" = 1'$

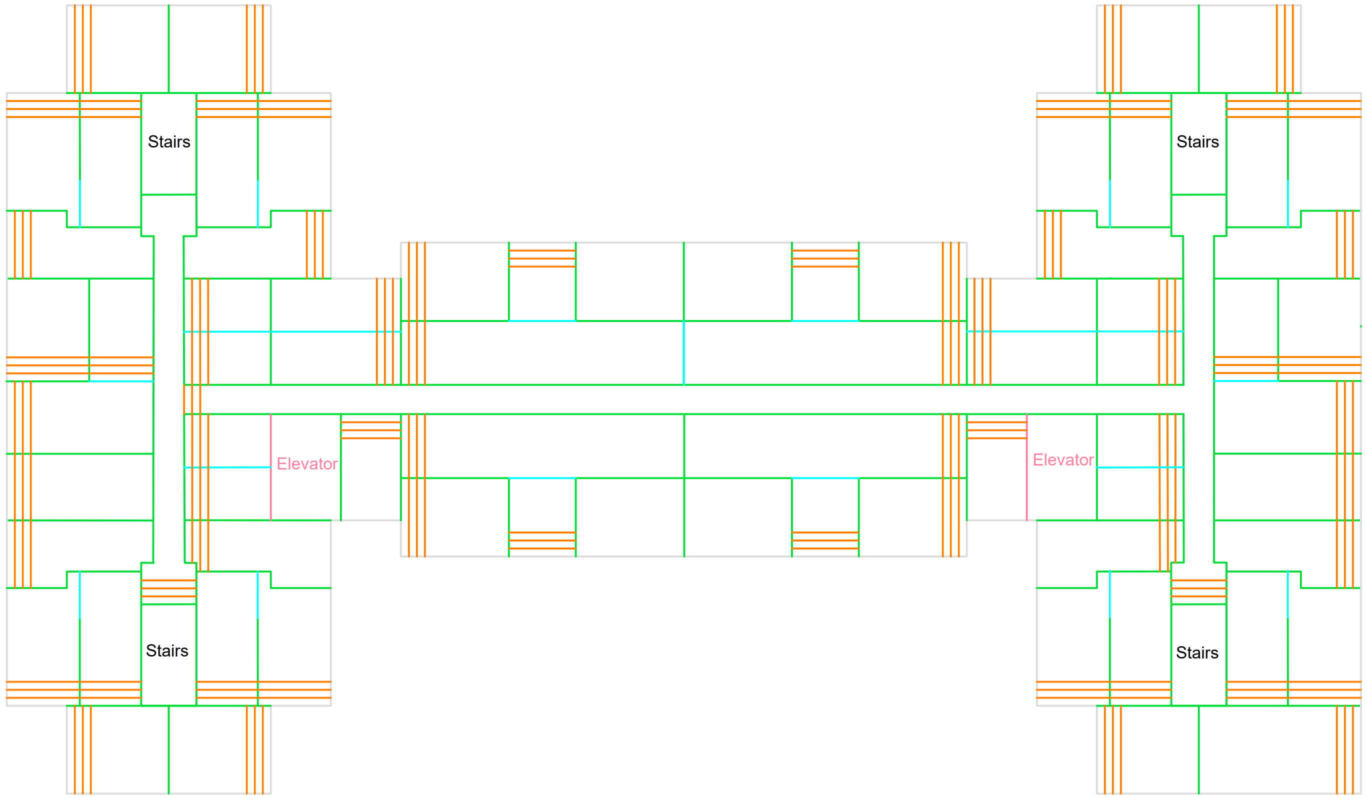
TITLE

CASE 3
STRUCTURAL
(FRAMES)

NUMBER

S.3.3

SHEET



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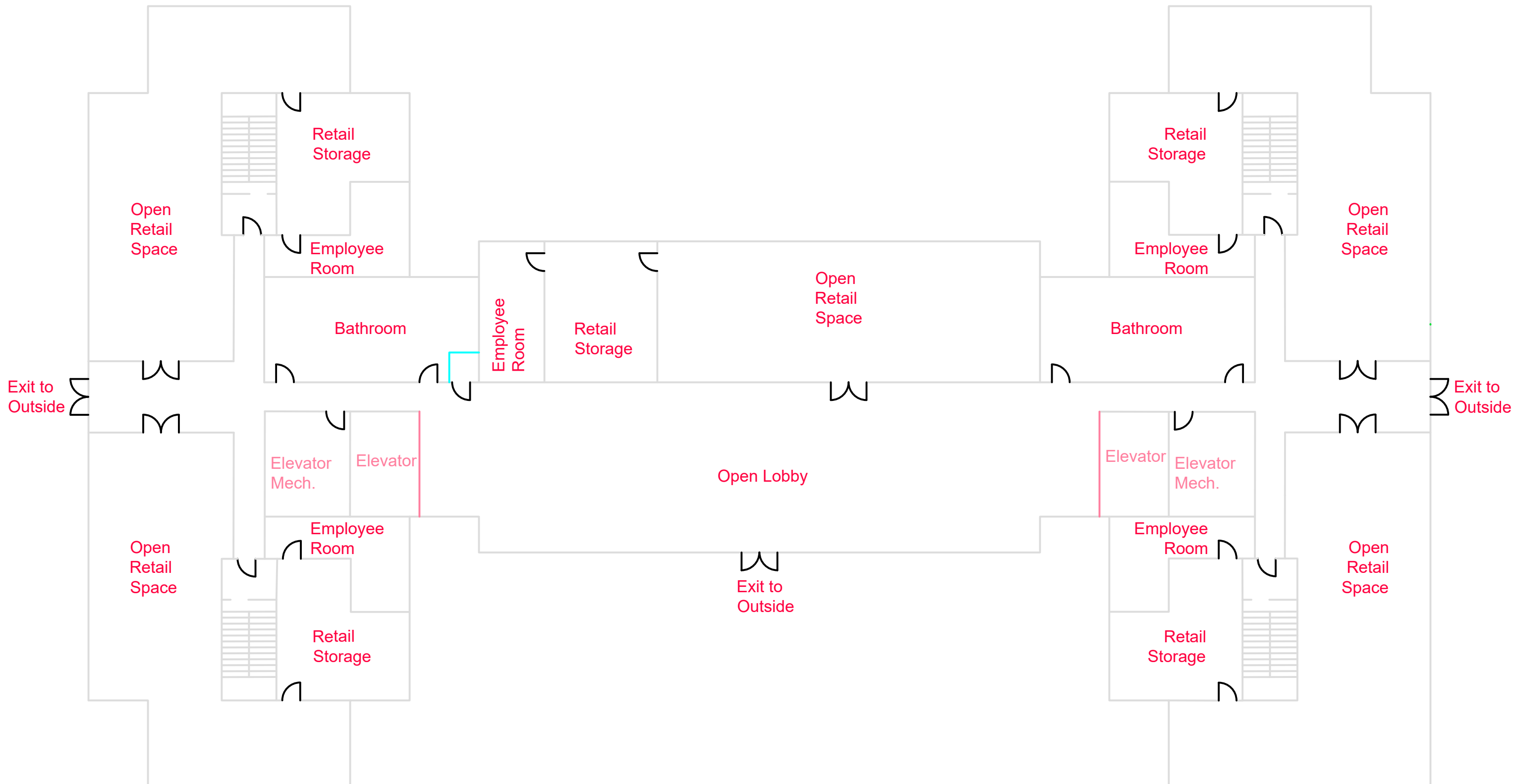
SCALE
$\frac{1}{32}" = 1'$

TITLE
CASE 3
STRUCTURAL
(WOOD DESIGN)

NUMBER
S.3.4

SHEET
22 OF 60



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WORCESTER, MA 01609

PROJECT NO
LDA - 1702

DATE
March 1, 2017

DESIGN
ELIZABETH M. COFFEY

DRAWN BY
ELIZABETH M. COFFEY

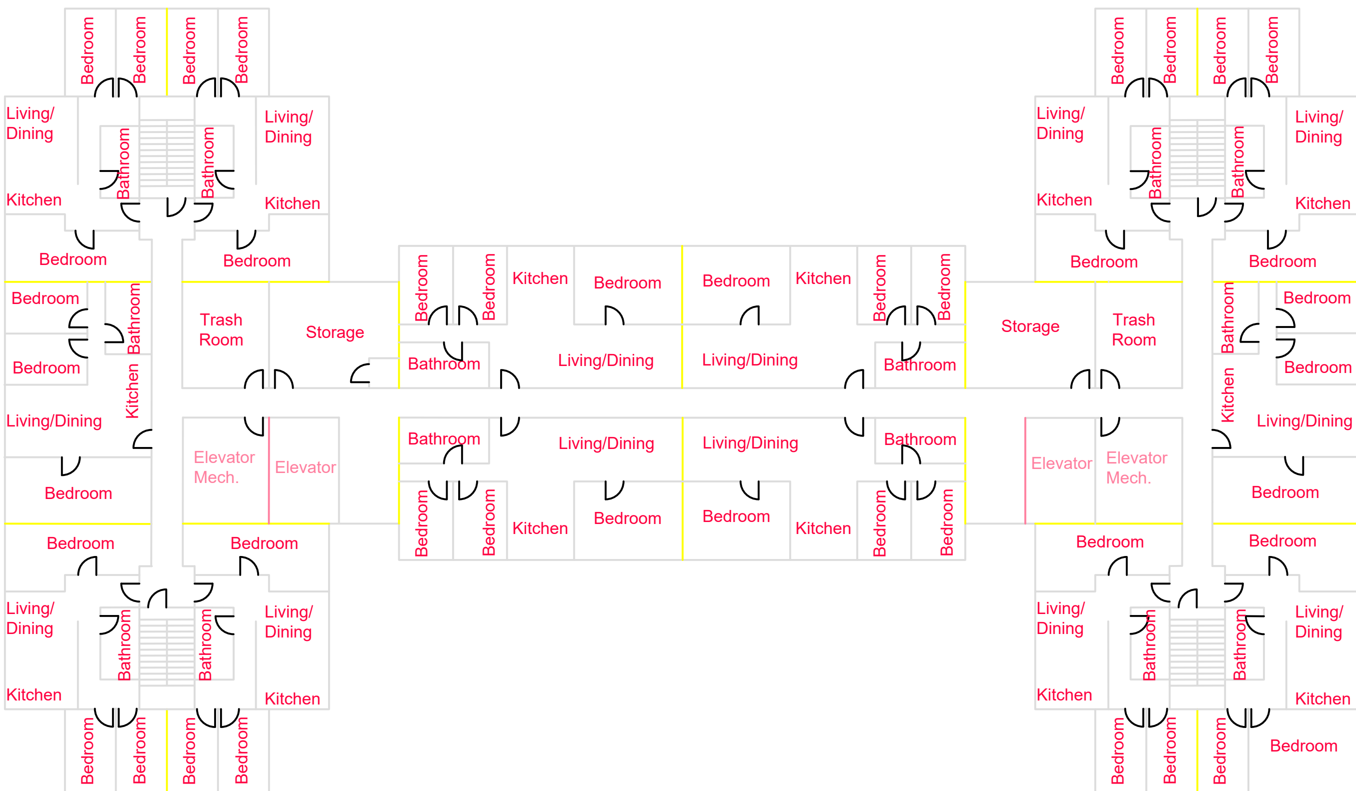
CHECKED BY
LEONARD D. ALBANO

SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 3
ARCHITECTURAL
1ST FLOOR

NUMBER
A.3.1

SHEET
23 OF 60



WORCESTER POLYTECHNIC INSTITUTE 1865

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SCALE

$\frac{1}{32}$" = 1'

TITLE

CASE 3
ARCHITECTURAL
2ND FLOOR (TYP.)

NUMBER

A.3.2

SHEET

24 OF 60

KEY PLAN

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SCALE

$\frac{1}{32}$" = 1'

TITLE

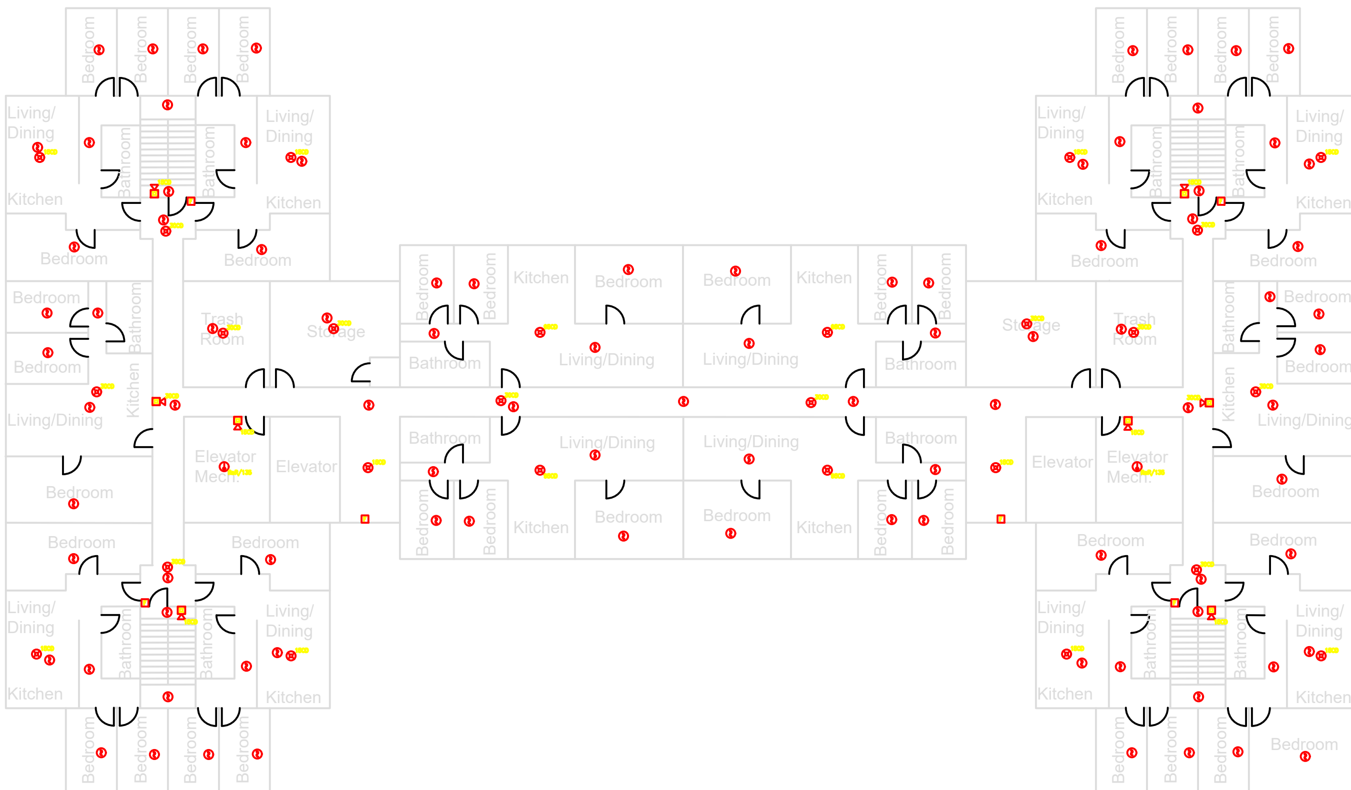
CASE 3
FIRE ALARM
1ST FLOOR

NUMBER

FA.3.1

SHEET

25 OF 60



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SCALE
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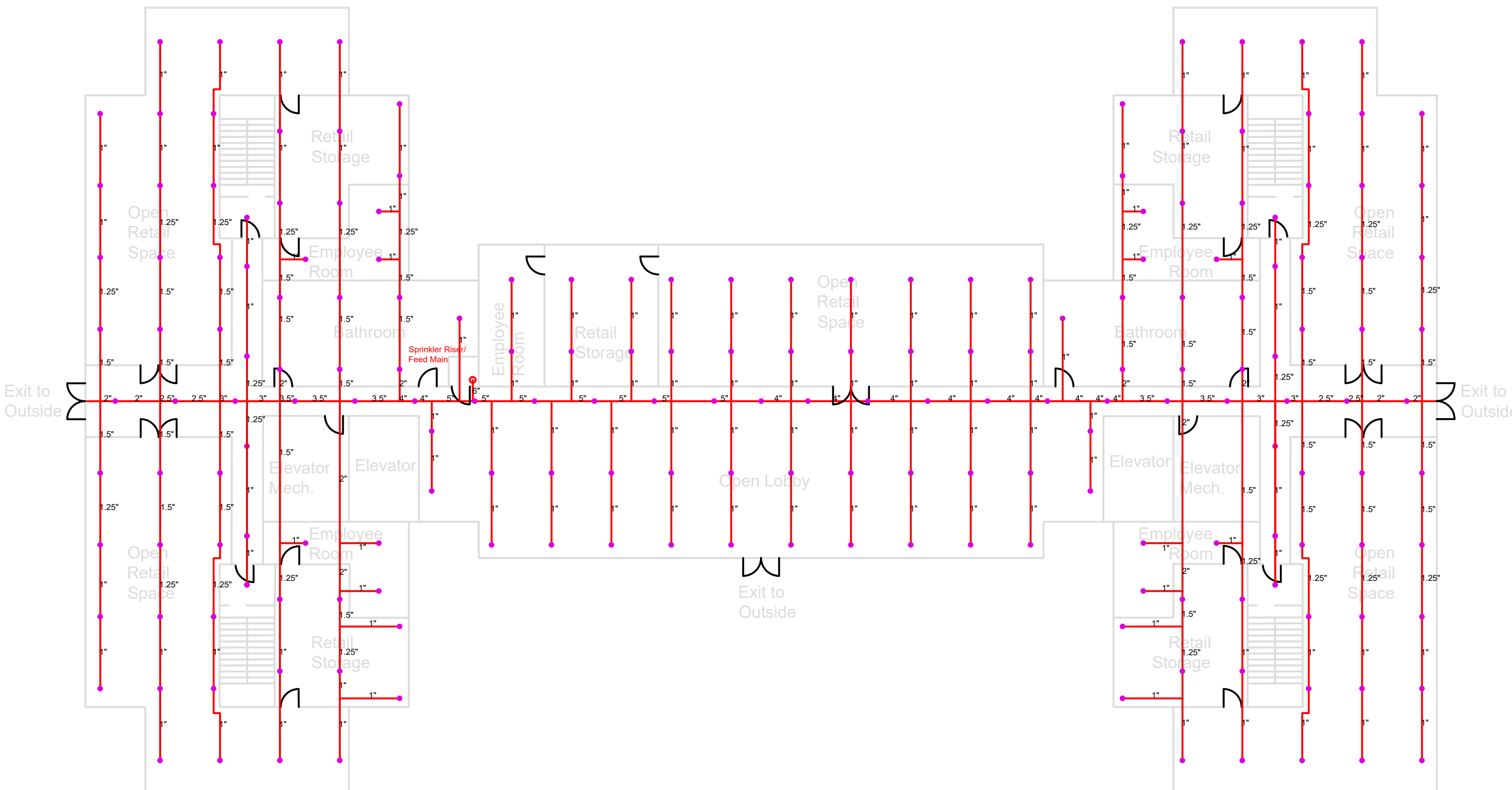
TITLE
CASE 3
FIRE ALARM
2ND FLOOR (TYP.)

NUMBER
FA.3.2

SHEET
26 OF 60



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SCALE

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TITLE

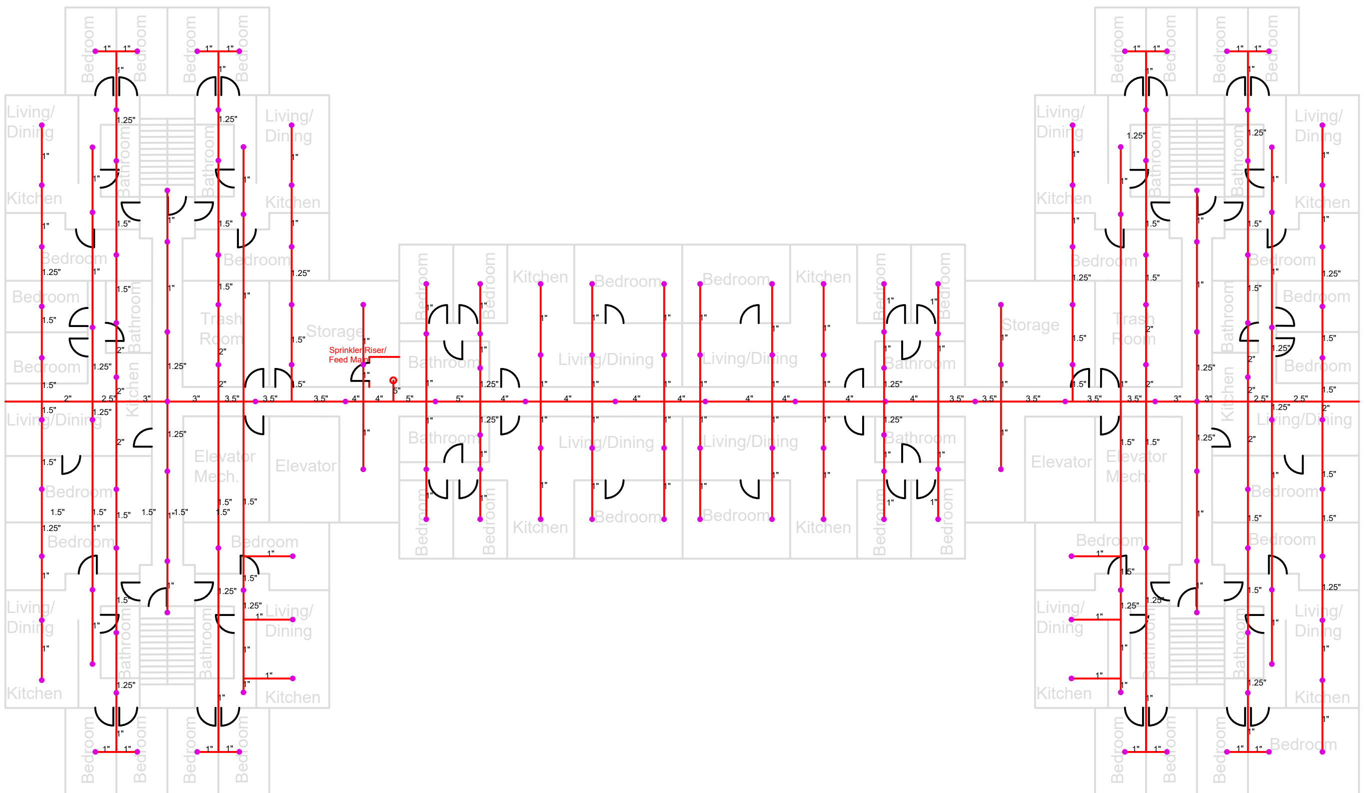
CASE 3
FIRE PROTECTION
1ST FLOOR

NUMBER

FP.3.1

SHEET

27 OF 60



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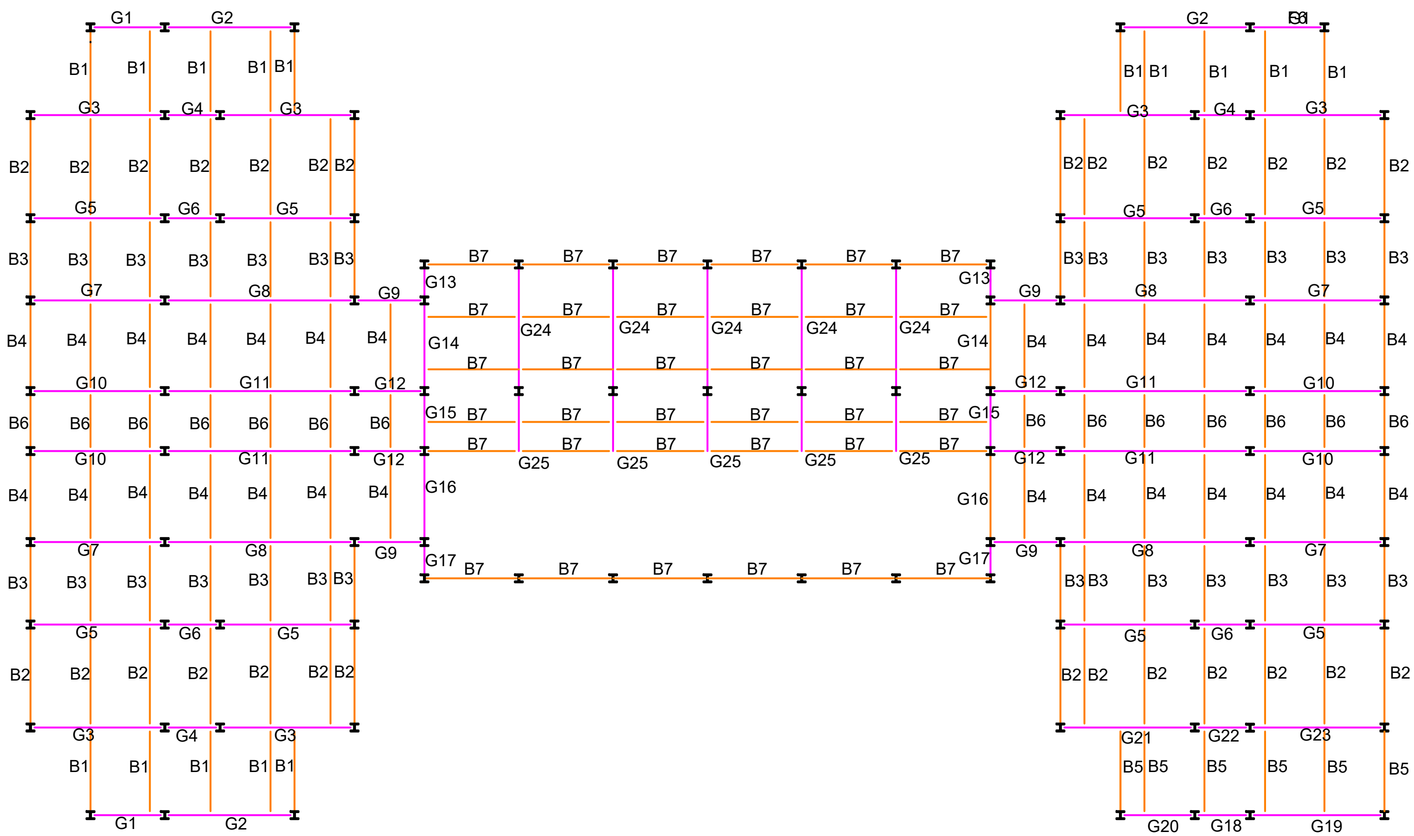
SCALE
$\frac{1}{32}" = 1'$

TITLE
CASE 3
FIRE PROTECTION
2ND FLOOR (TYP.)

NUMBER
FP.3.2

SHEET
28 OF 60



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DESIGN
EMMA T. HEALEY

DRAWN BY
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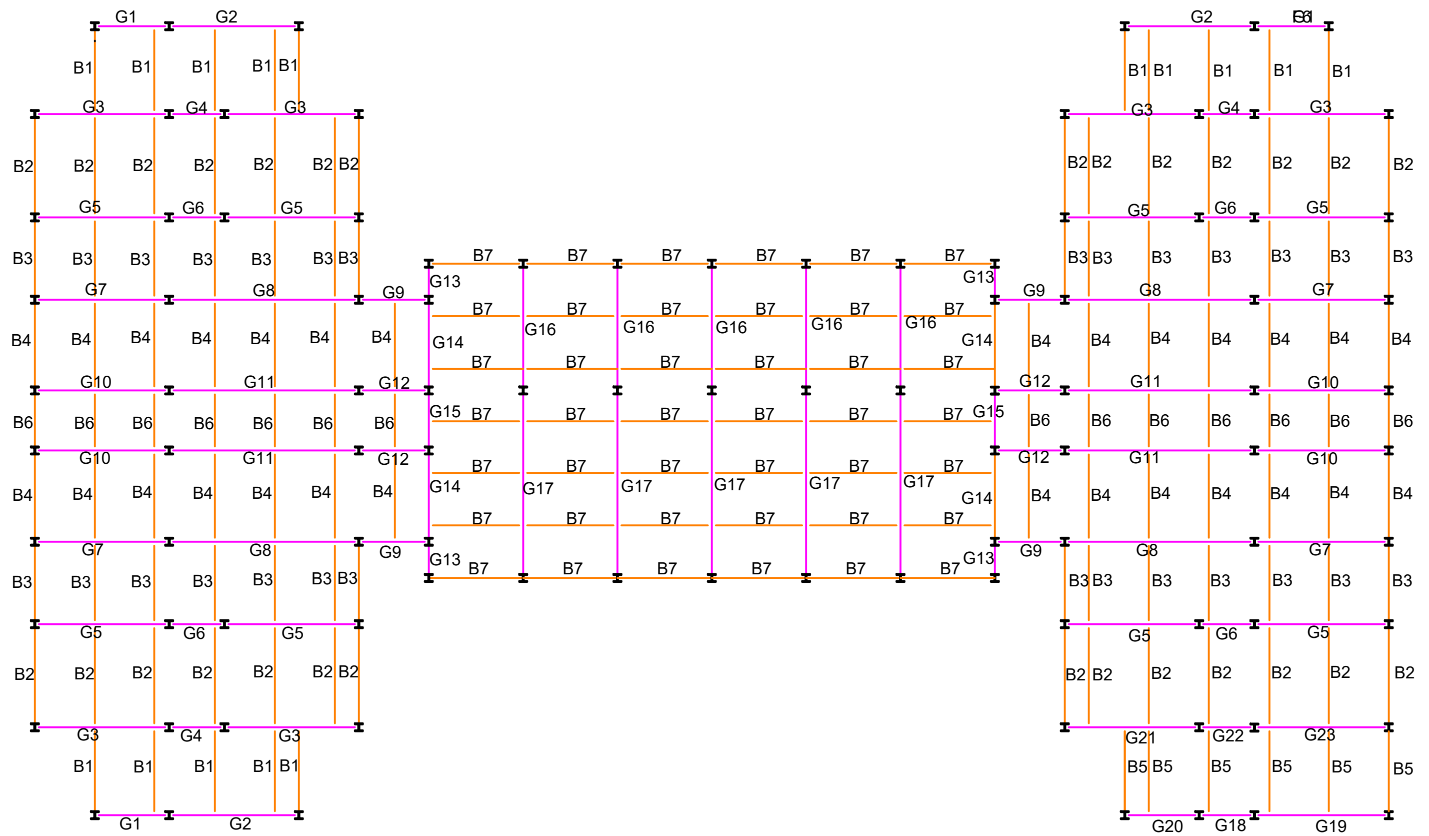
CHECKED BY
LEONARD D. ALBANO

SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 4
STRUCTURAL
(DESIGN LOADS F1)

NUMBER
S.4.1

SHEET
29 OF 60



INTEGRATED STRUCTURAL AND FIRE PROTECTION DESIGN CONSIDERATIONS

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WORCESTER, MA 01609

PROJECT NO: LDA - 1702

DATE: March 1, 2017

DESIGN: EMMA T. HEALEY

DRAWN BY: EMMA T. HEALEY

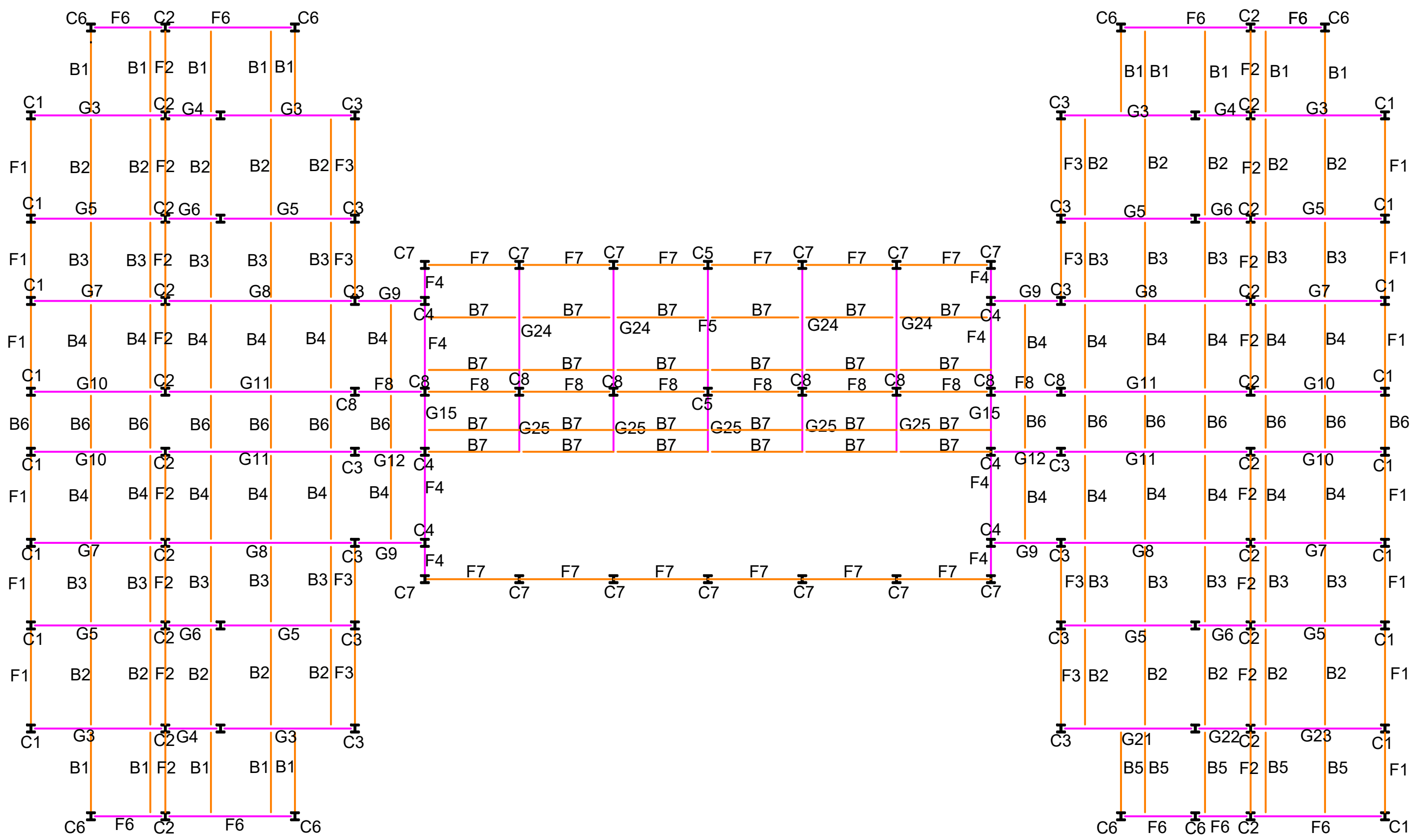
CHECKED BY: LEONARD D. ALBANO

SCALE: $\frac{1}{32}$" = 1'

TITLE: CASE 4 STRUCTURAL (DESIGN LOADS F2-5)

NUMBER: S.4.2

SHEET: 30 OF 60



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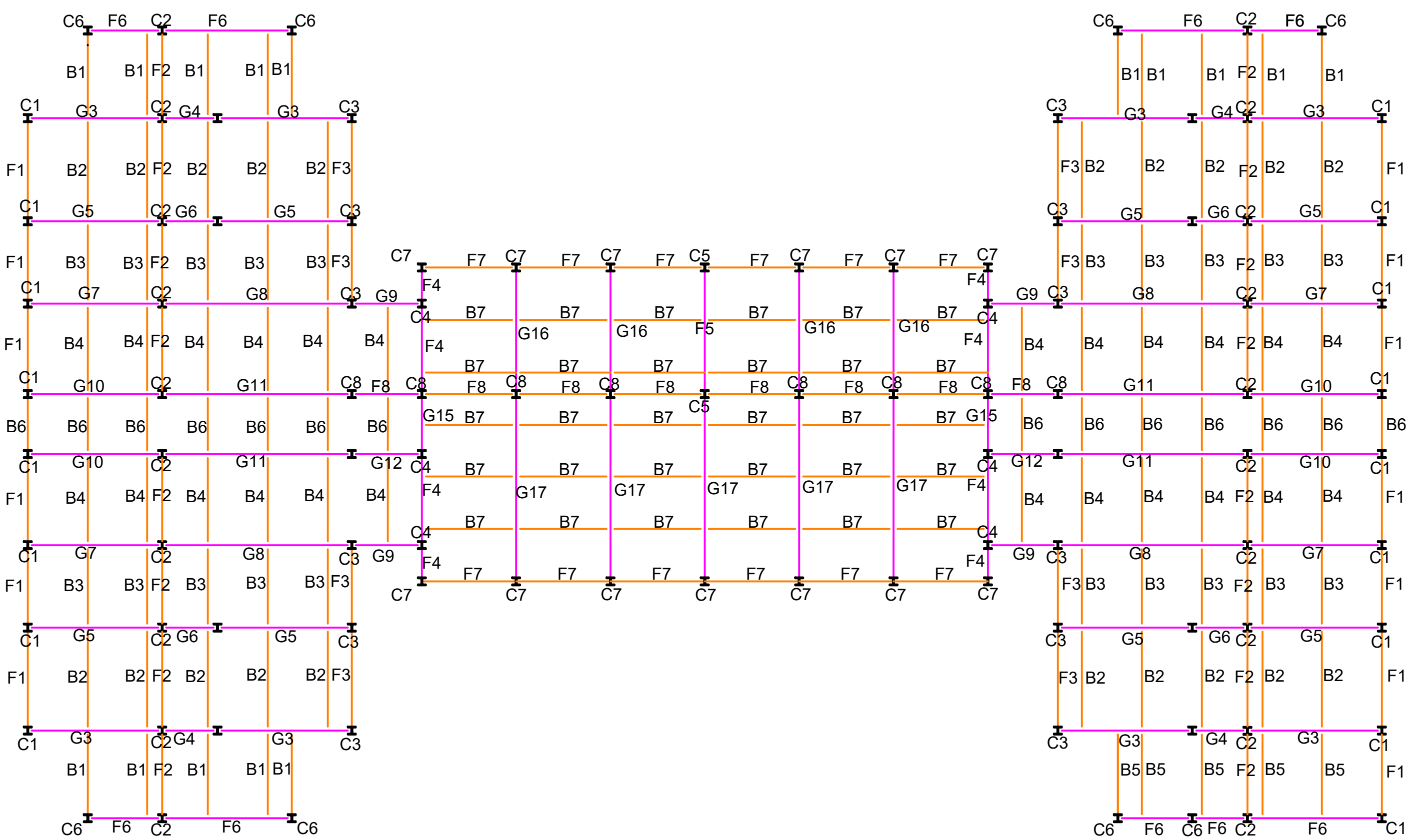
SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 4
STRUCTURAL
(ENVIRONMENTAL LOADS F1)

NUMBER
S.4.3

SHEET
31 OF 60



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SCALE

$\frac{1}{32}" = 1'$

TITLE

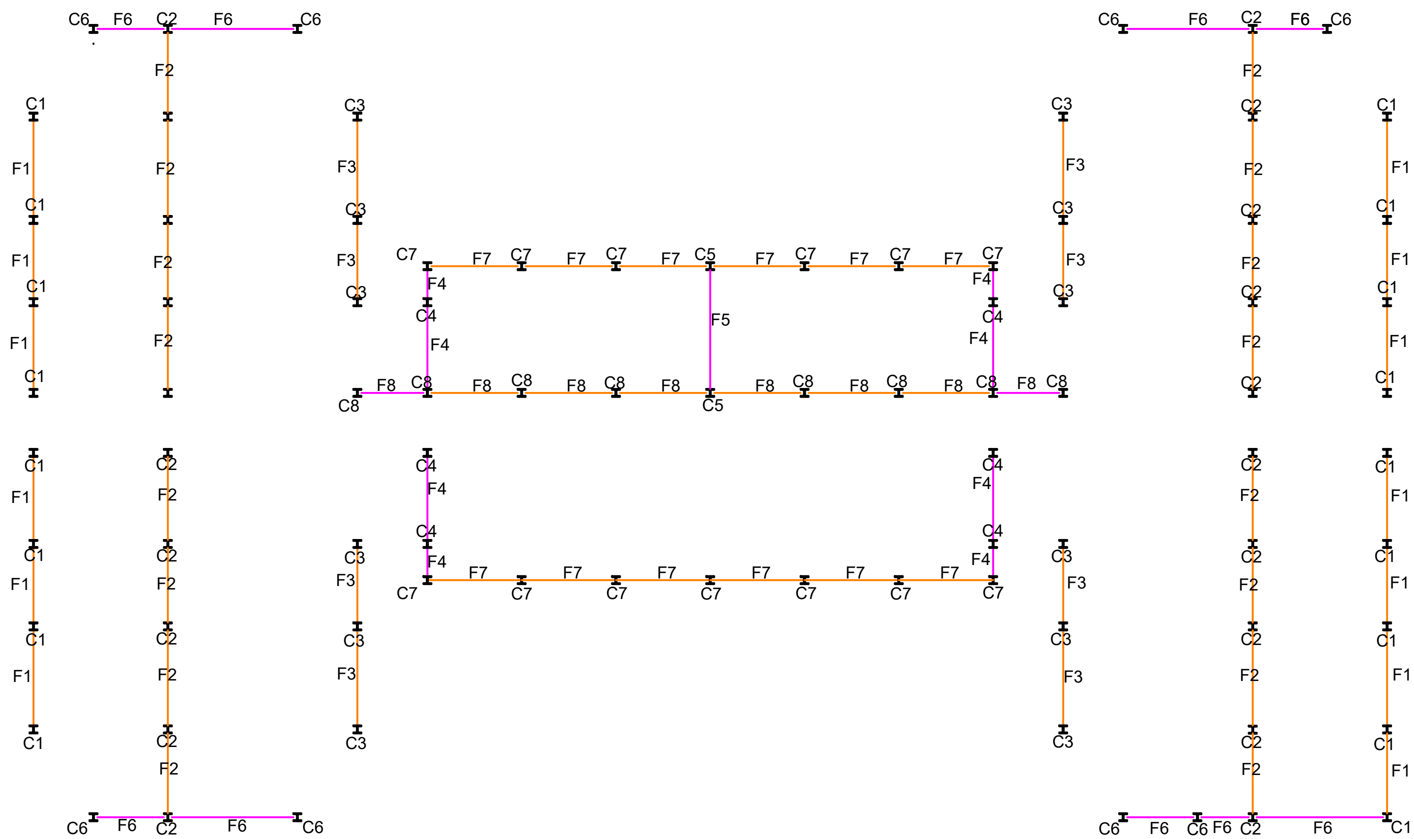
CASE 4
STRUCTURAL
(ENVIRONMENTAL LOADS F2-5)

NUMBER

S.4.4

SHEET

32 OF 60



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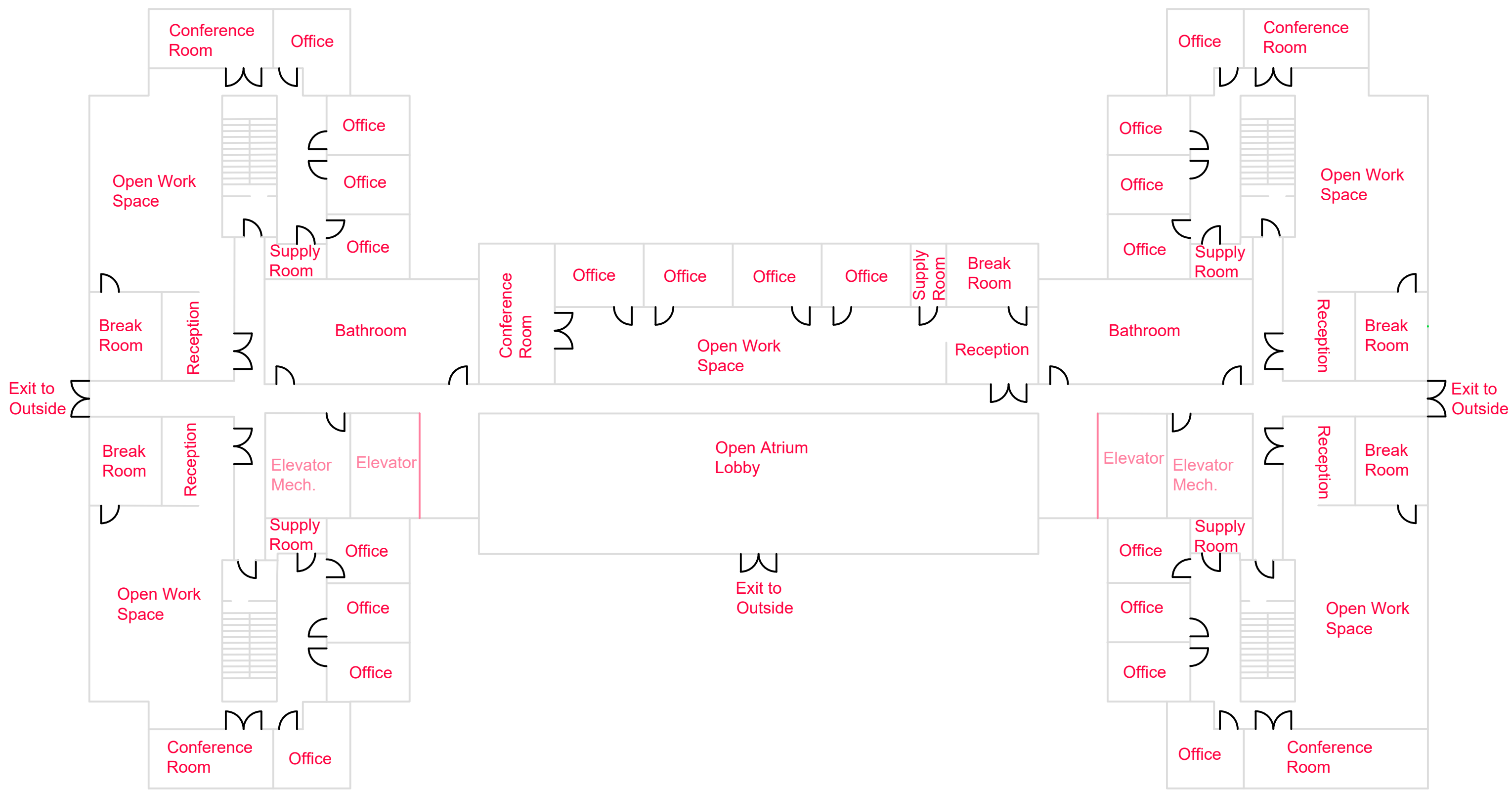
SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 4
STRUCTURAL
(FRAMES)

NUMBER
S.4.5

SHEET
33 OF 60



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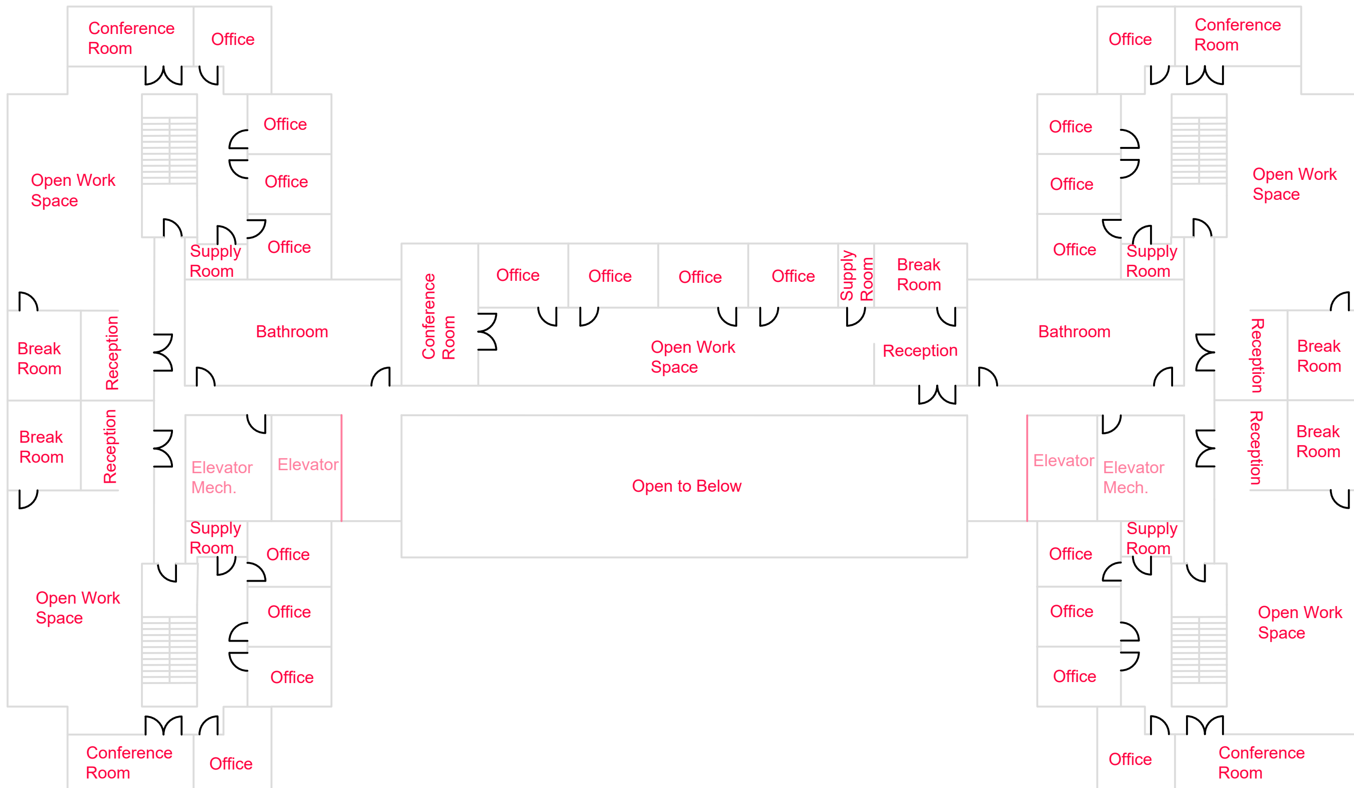
TITLE
CASE 4
ARCHITECTURAL
1ST FLOOR

NUMBER
A.4.1

SHEET
34 OF 60



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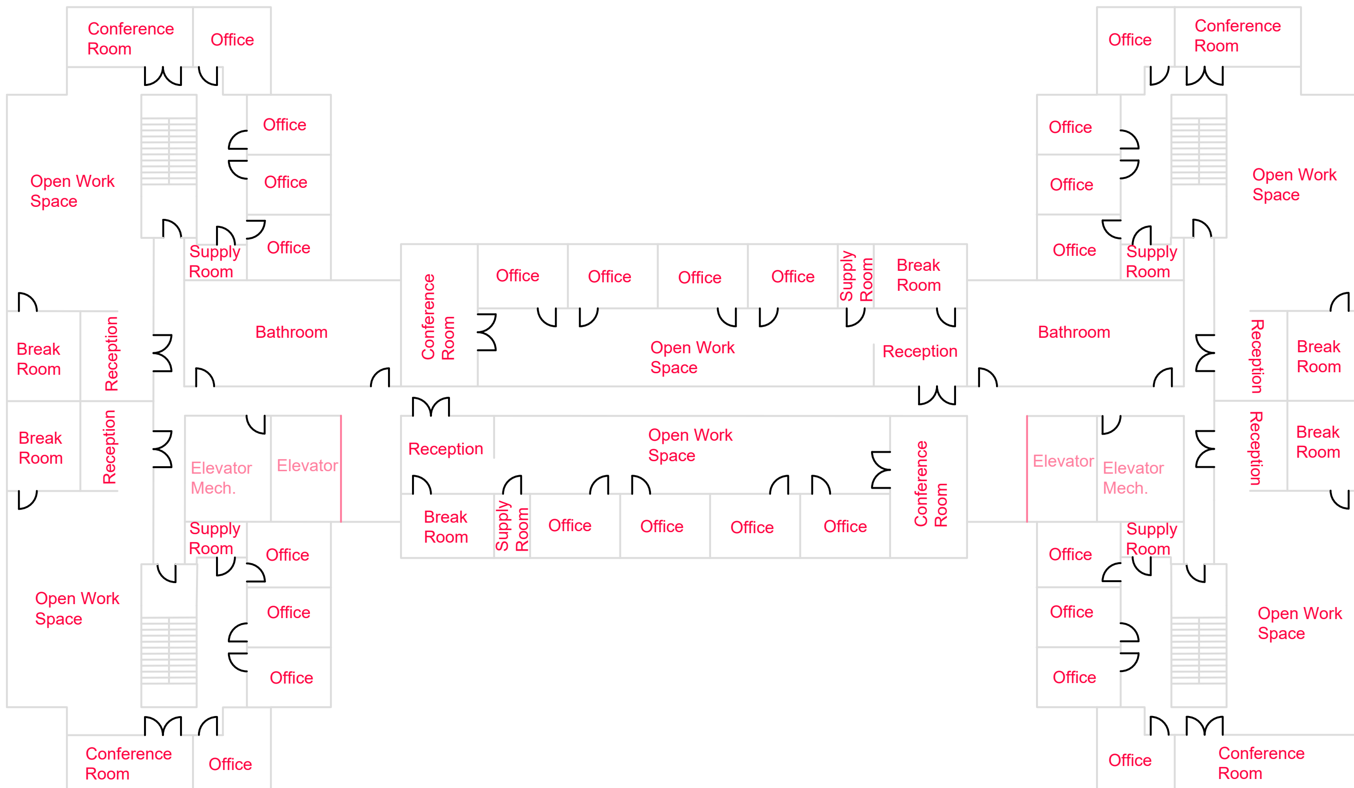
TITLE
CASE 4
ARCHITECTURAL
2ND FLOOR

NUMBER
A.4.2

SHEET
35 OF 60



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SCALE

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TITLE

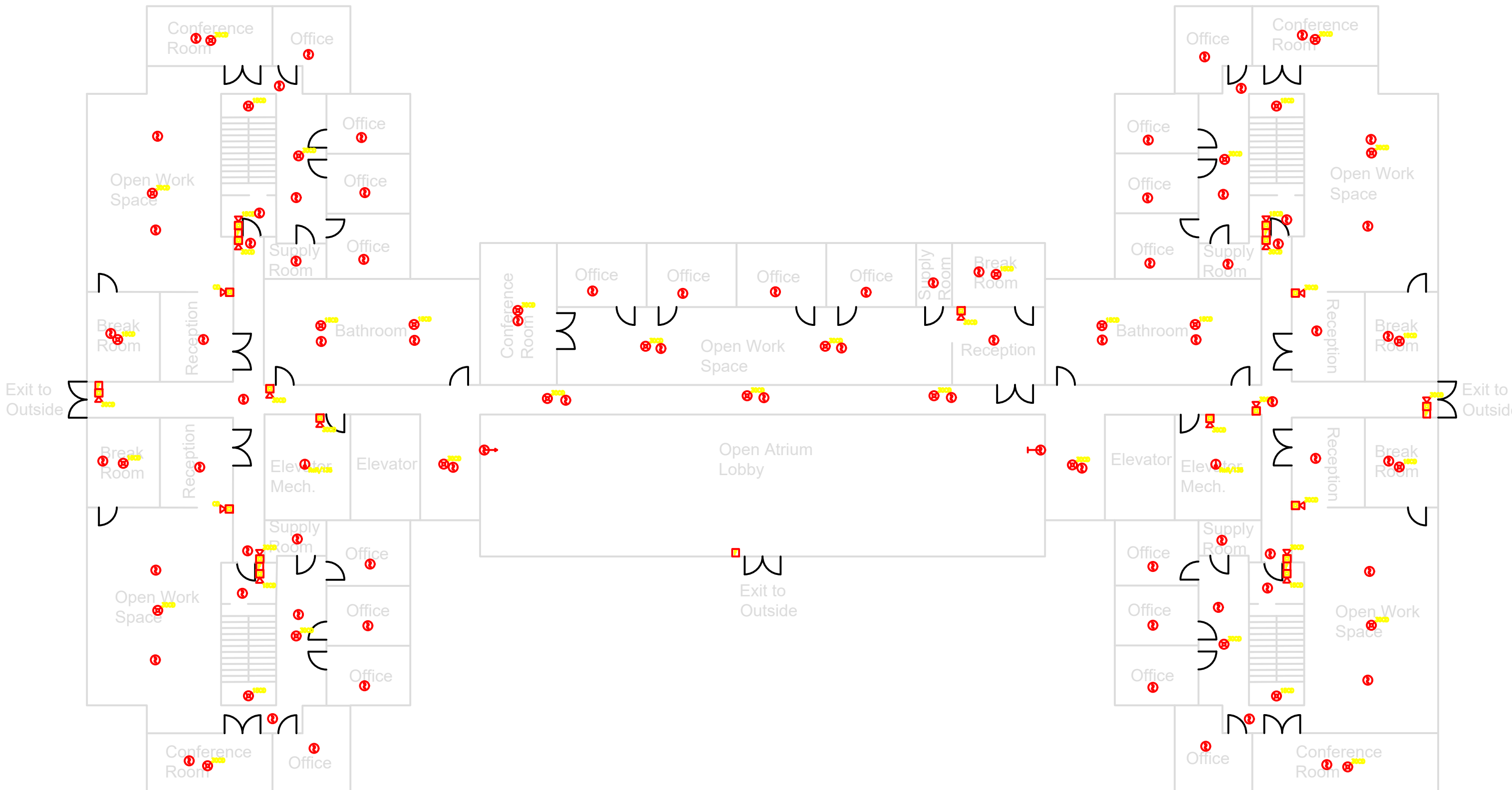
CASE 4
ARCHITECTURAL
3RD FLOOR (TYP.)

NUMBER

A.4.3

SHEET

36 OF 60



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SCALE
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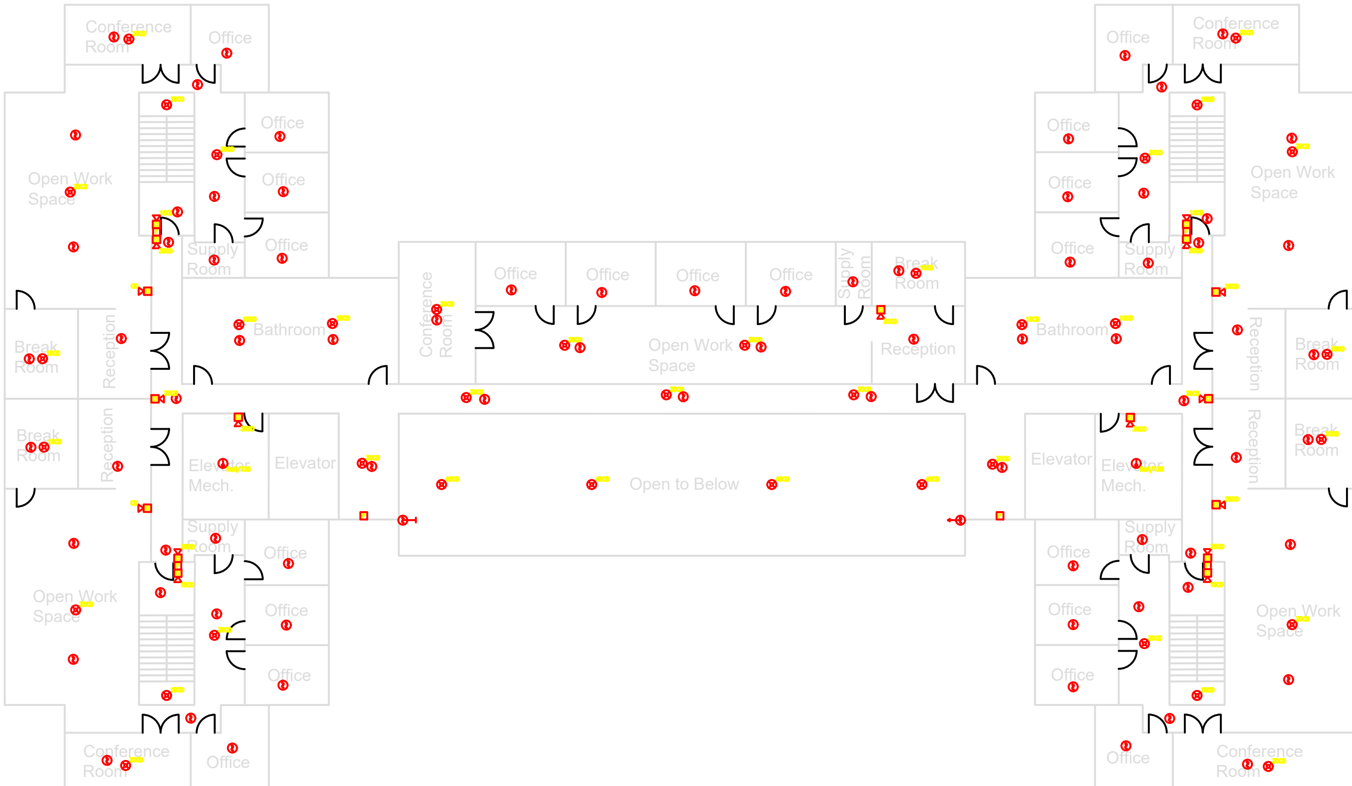
TITLE
CASE 4
FIRE ALARM
1ST FLOOR

NUMBER
FA.4.1

SHEET
37 OF 60



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SCALE

$\frac{1}{32}$" = 1'

TITLE

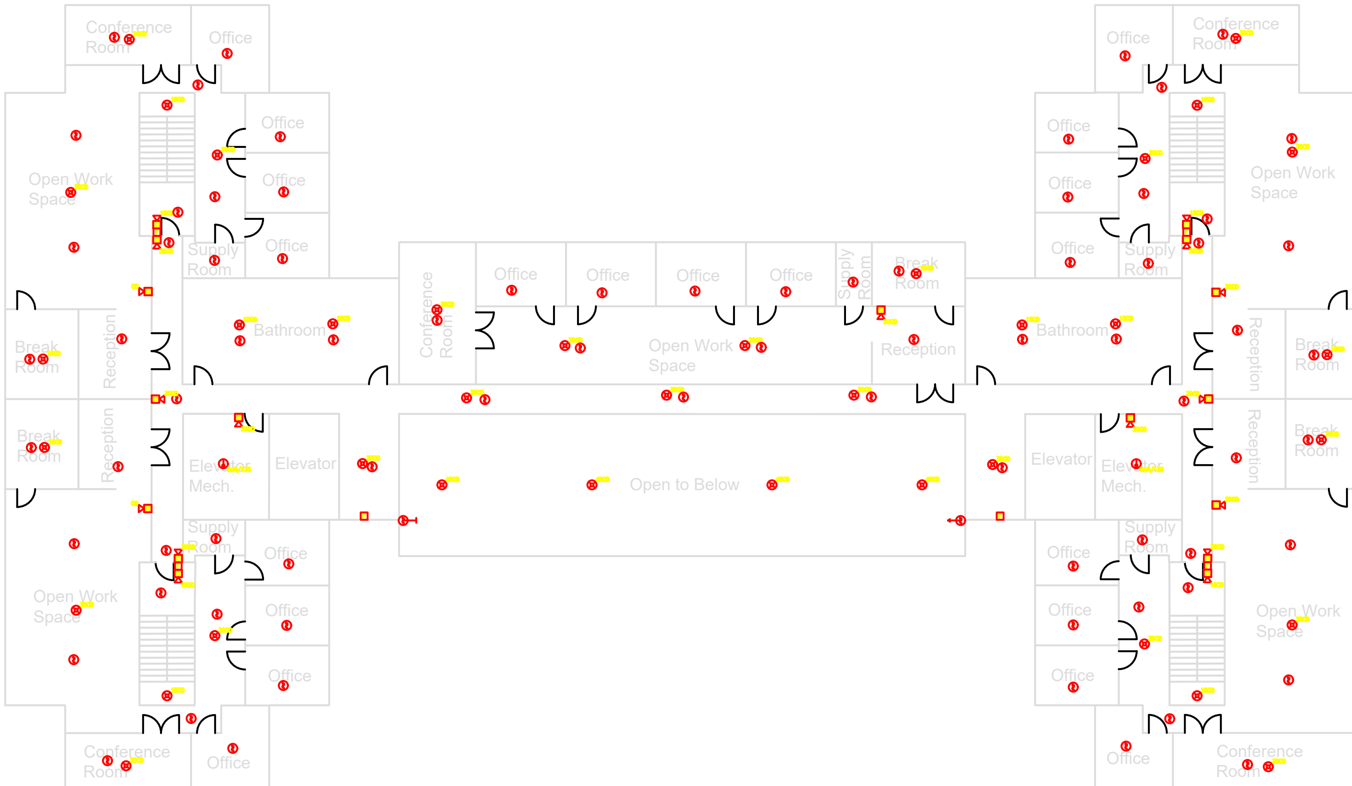
CASE 4
FIRE ALARM
2ND FLOOR

NUMBER

FA.4.2

SHEET

38 OF 60



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SCALE
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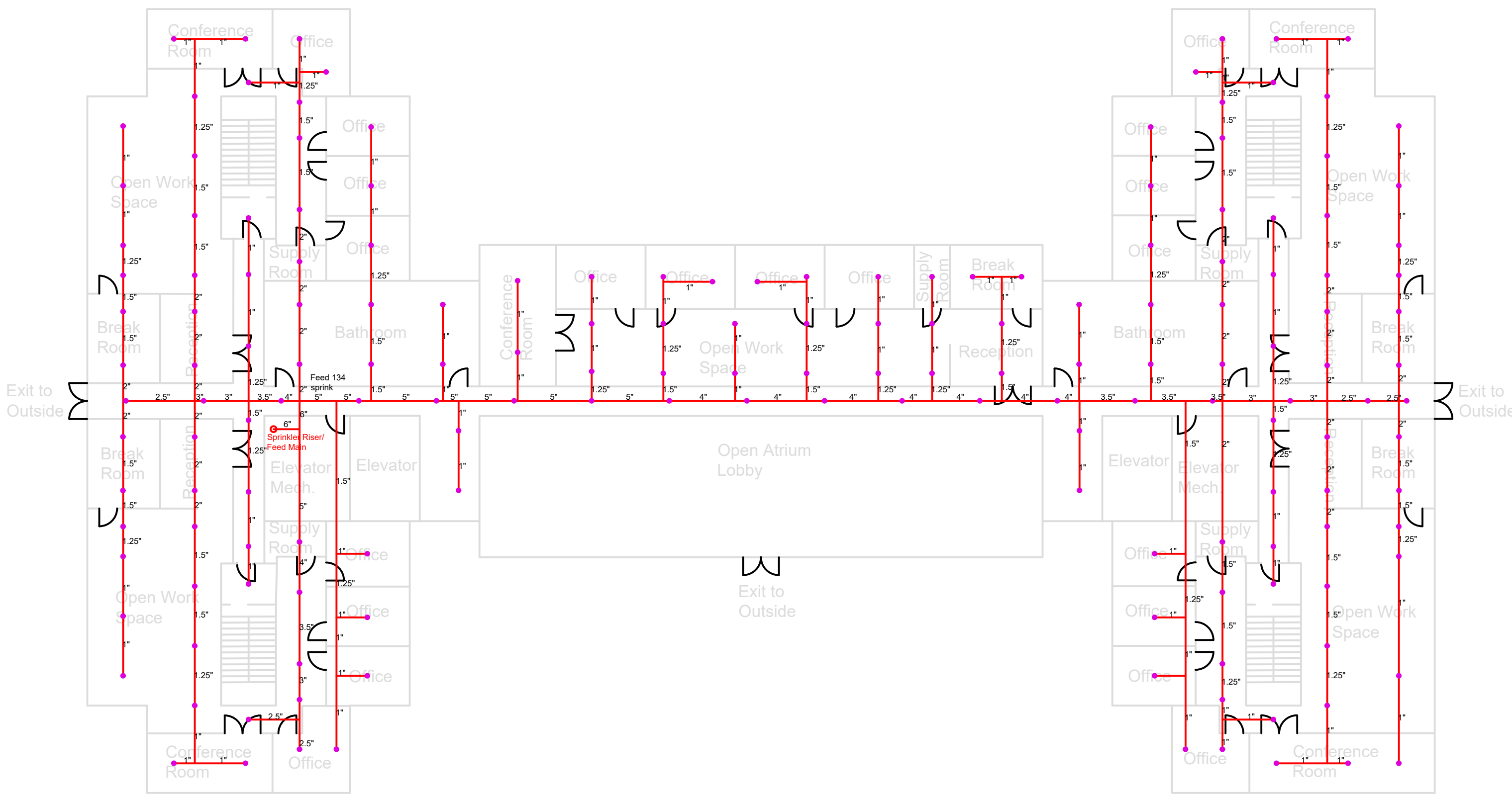
TITLE
CASE 4
FIRE ALARM
3RD FLOOR (TYP.)

NUMBER
FA.4.3

SHEET
39 OF 60



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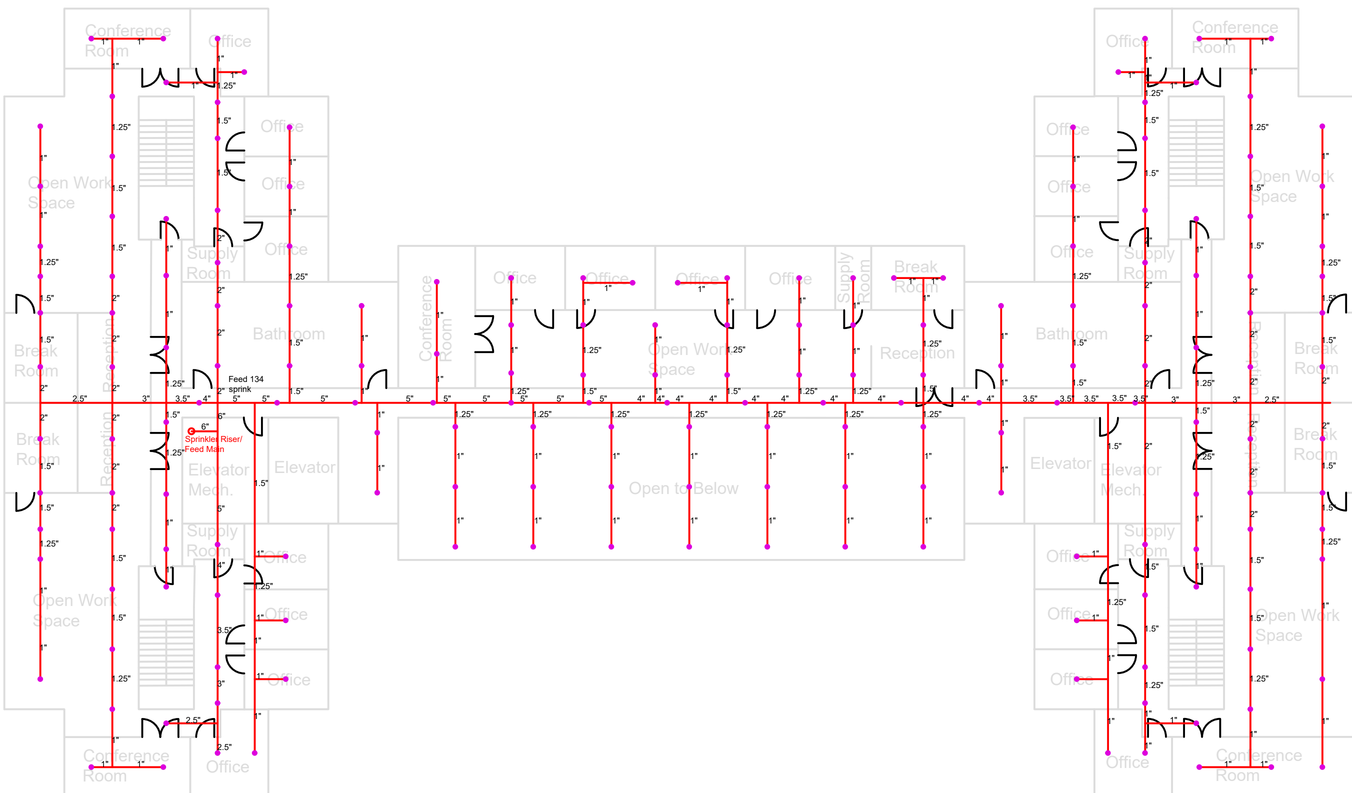
SCALE
$\frac{1}{32}" = 1'$

TITLE
CASE 4
FIRE PROTECTION
1ST FLOOR

NUMBER
FP.4.1

SHEET
40 OF 60



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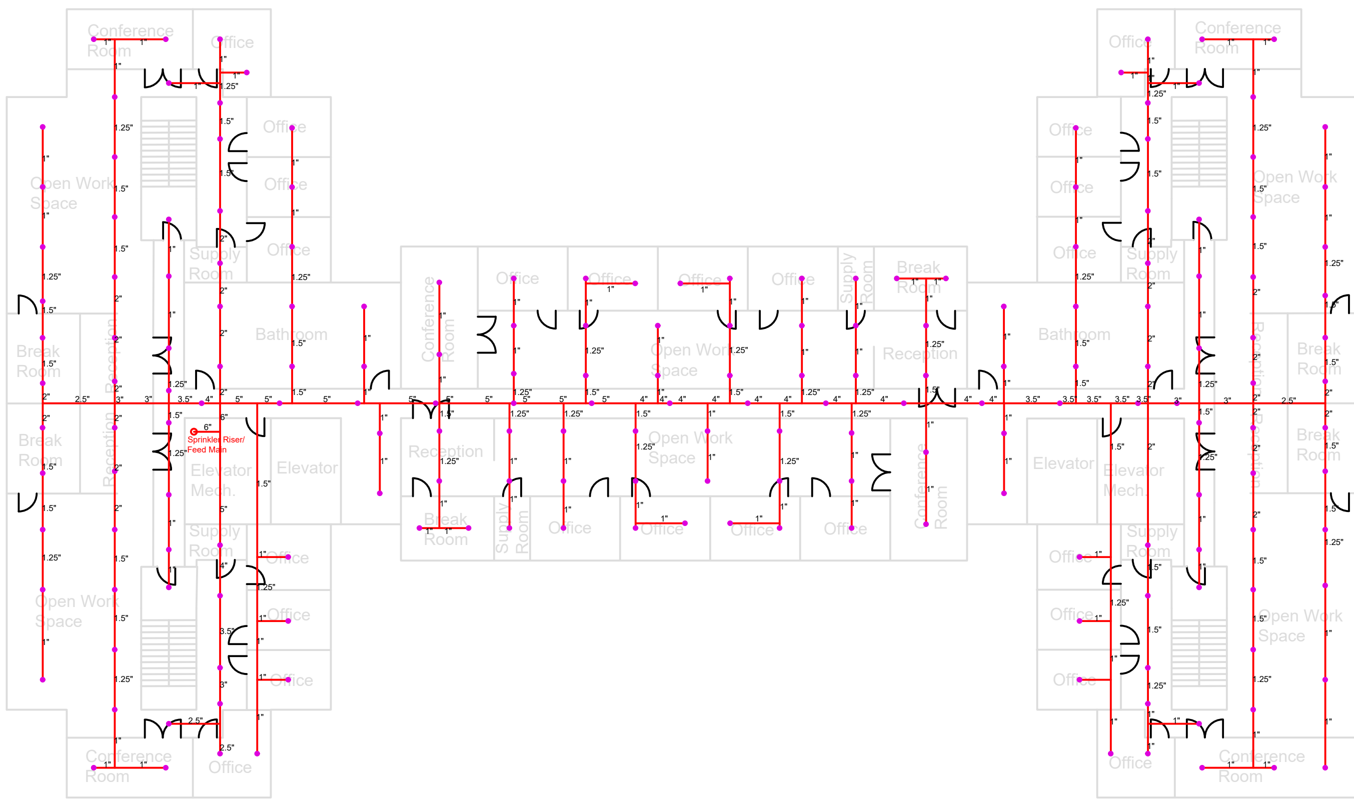
SCALE
$\frac{1}{32}'' = 1'$

TITLE
CASE 4
FIRE PROTECTION
2ND FLOOR

NUMBER
FP.4.2

SHEET
41 OF 60



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SCALE

$\frac{1}{32}" = 1'$

TITLE

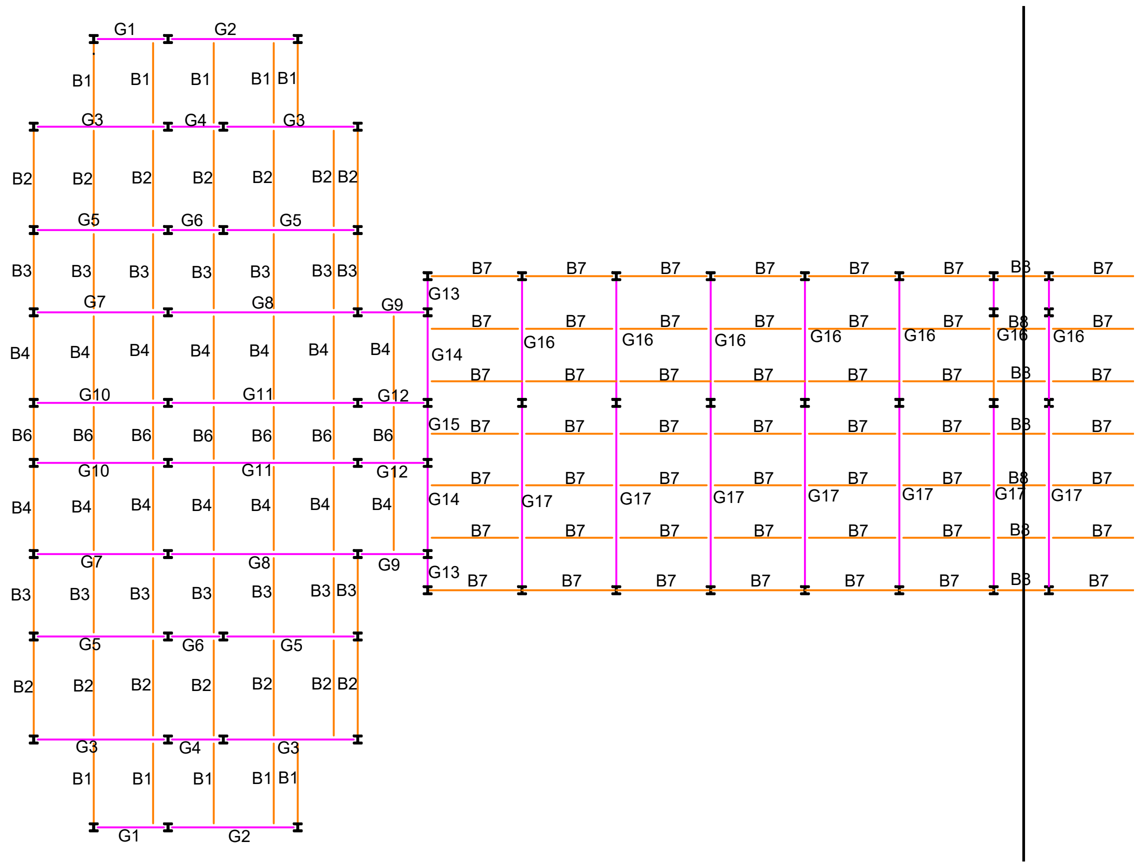
CASE 4
FIRE PROTECTION
3RD FLOOR (TYP.)

NUMBER

FP.4.3

SHEET

42 OF 60



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EMMA T. HEALEY

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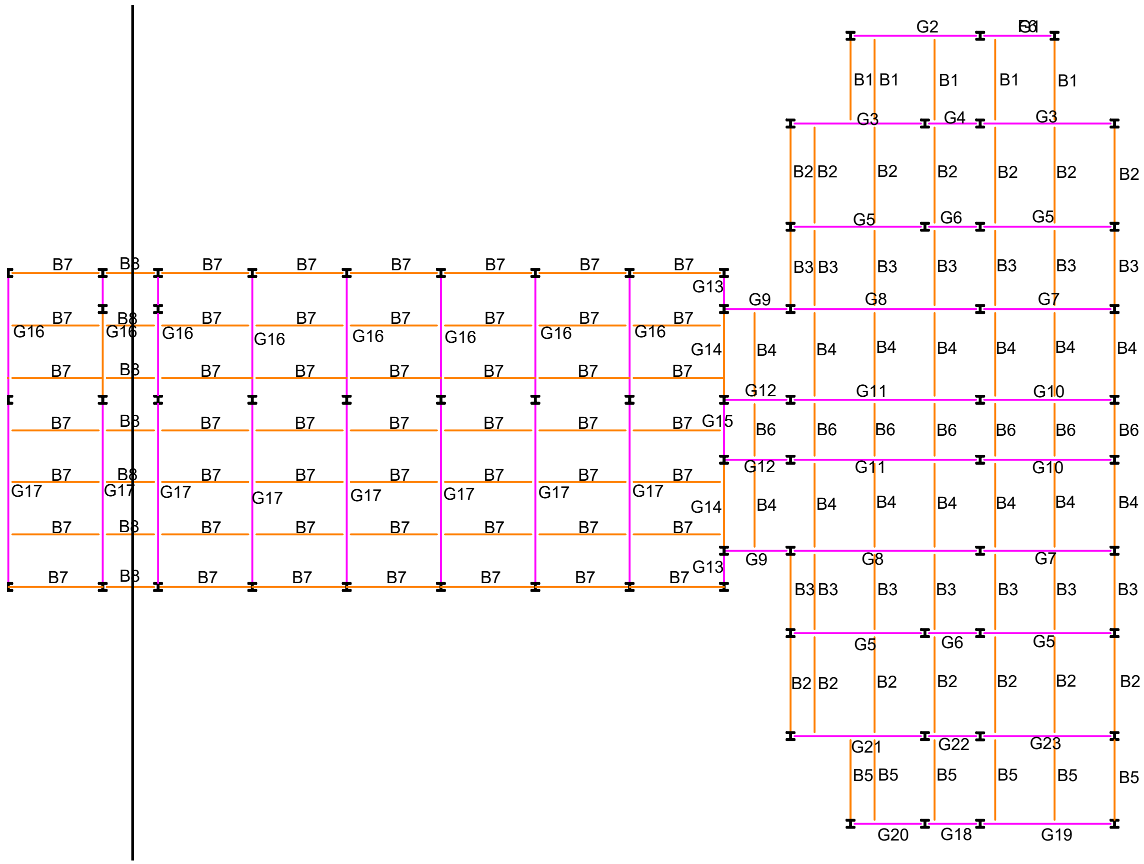
SCALE
$\frac{1}{32}$" = 1'

TITLE
CASE 5
STRUCTURAL
(DESIGN LOADS - WEST)

NUMBER
S.5.1.1

SHEET
43 OF 60



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SCALE

$\frac{1}{32}'' = 1'$

TITLE

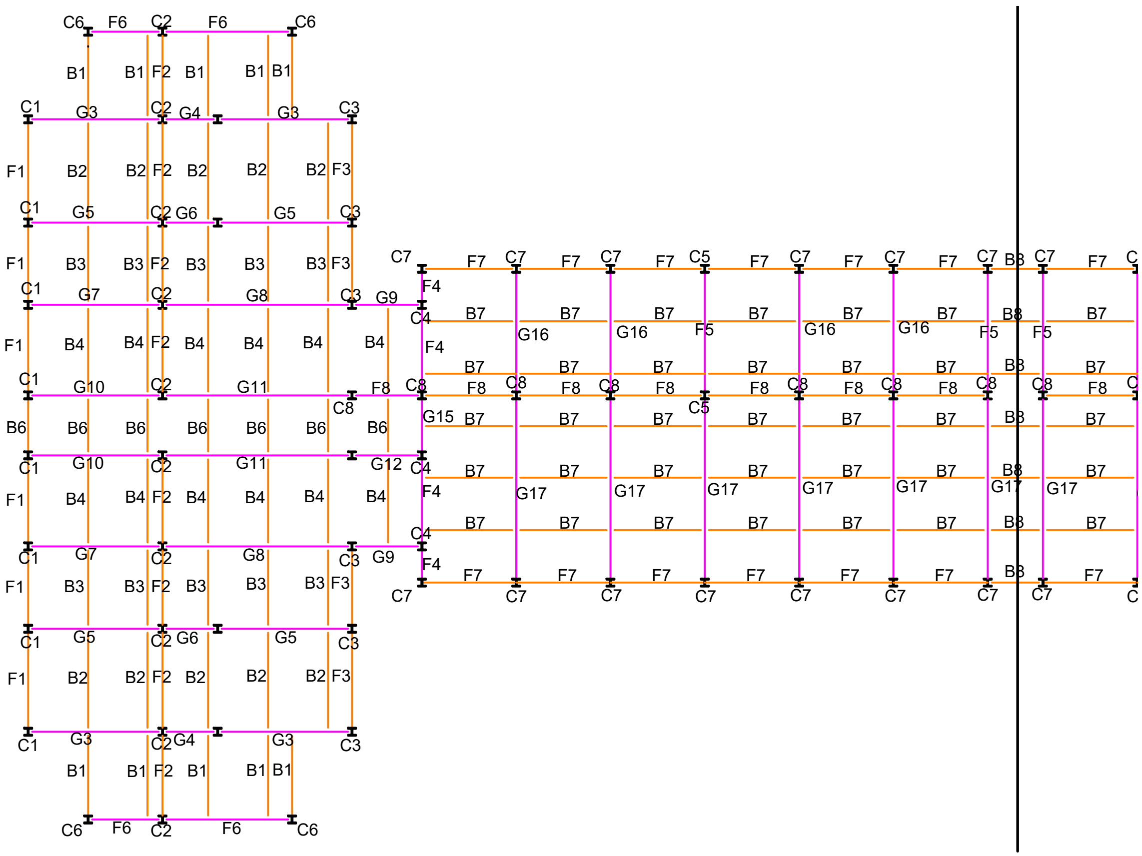
CASE 5
STRUCTURAL
(DESIGN LOADS - EAST)

NUMBER

S.5.1.2

SHEET

44 OF 60



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SCALE

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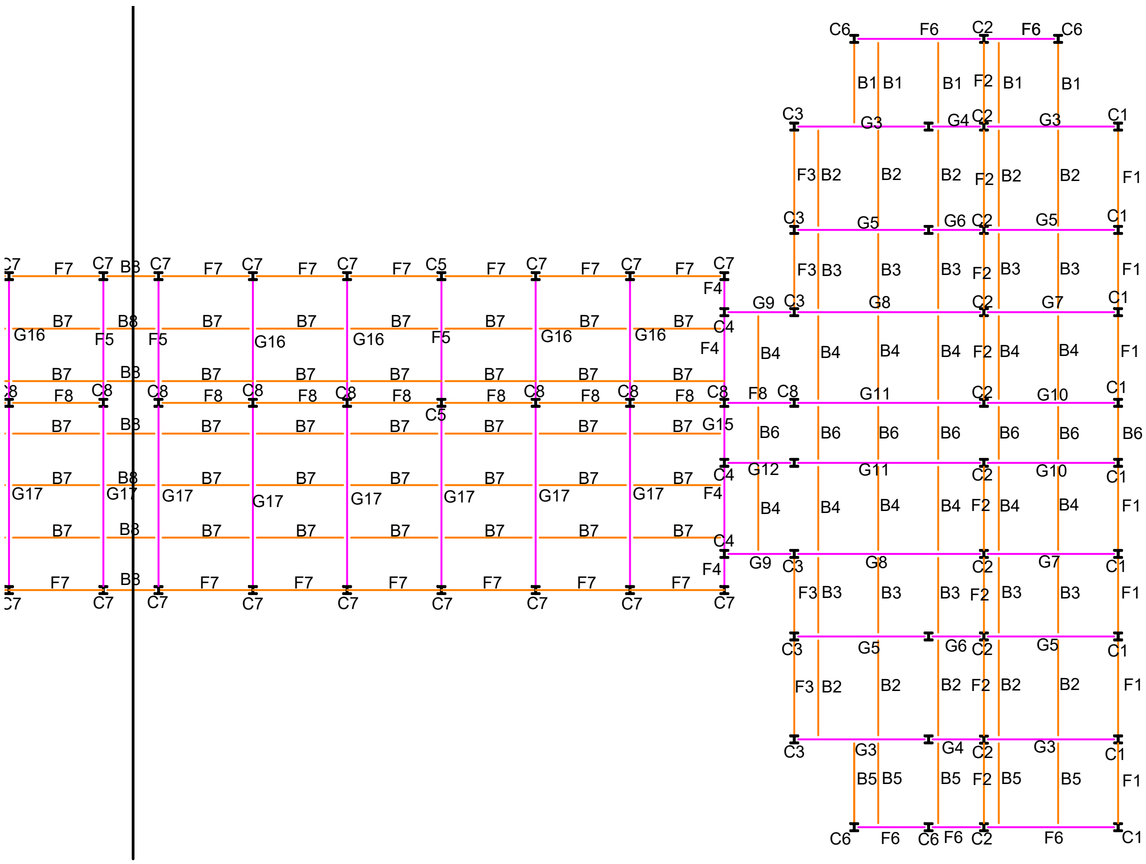
TITLE

CASE 5
STRUCTURAL
(ENVIRONMENTAL LOADS - WEST)

NUMBER

S.5.2.1

SHEET



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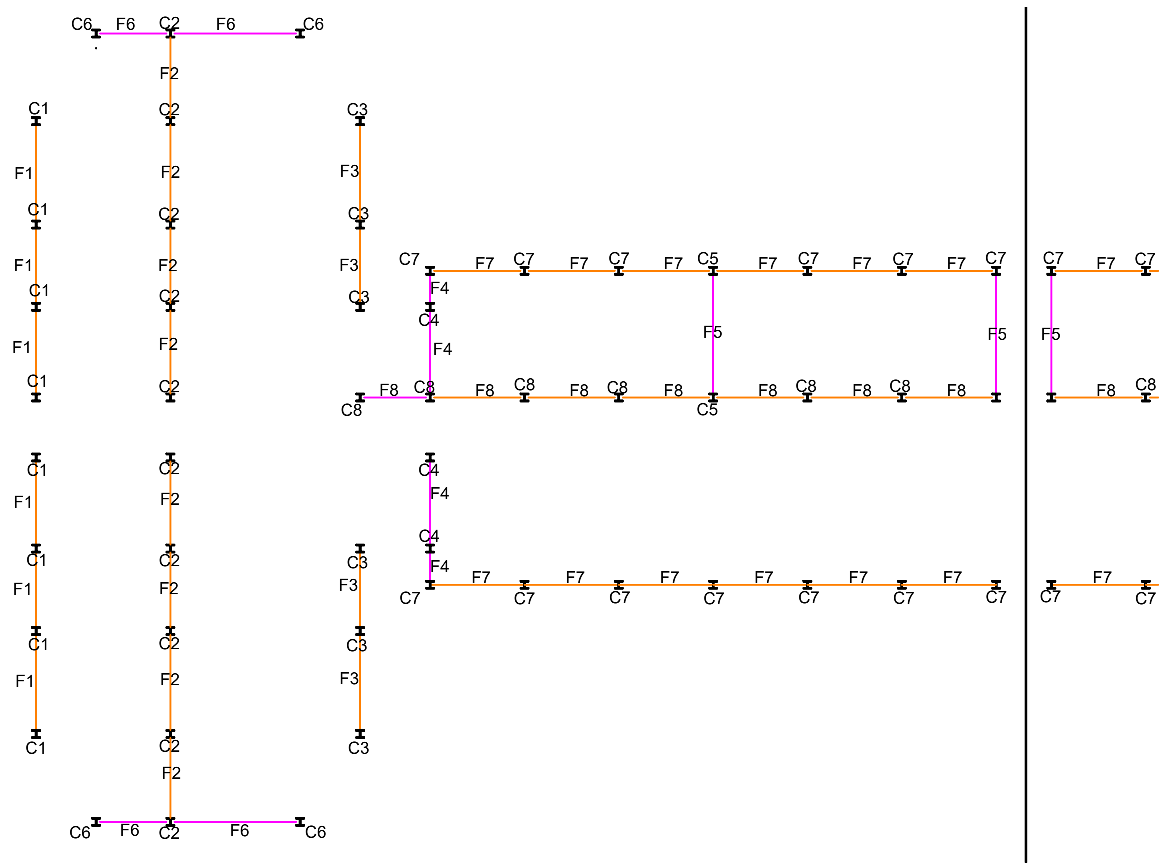
TITLE

CASE 5
STRUCTURAL
(ENVIRONMENTAL LOADS - EAST)

NUMBER

S.5.2.2

SHEET



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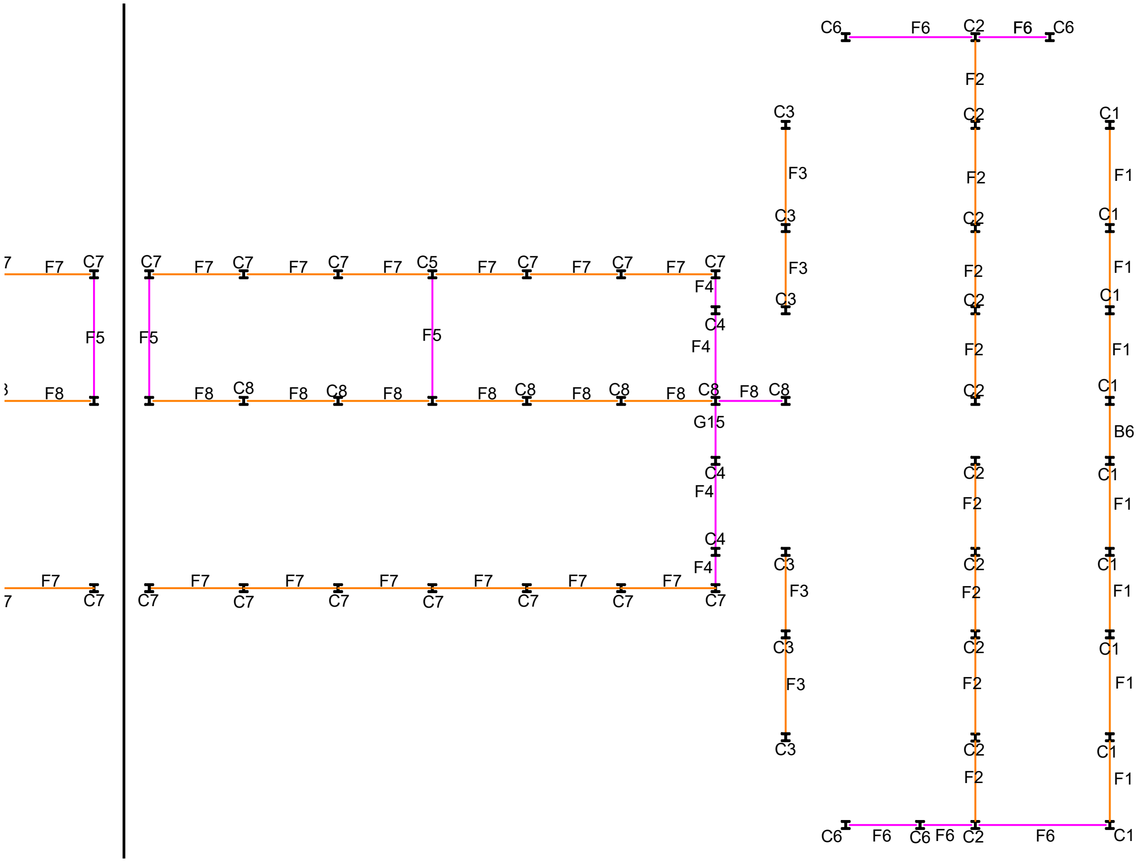
TITLE
CASE 5
STRUCTURAL
(FRAMES - WEST)

NUMBER
S.5.3.1

SHEET



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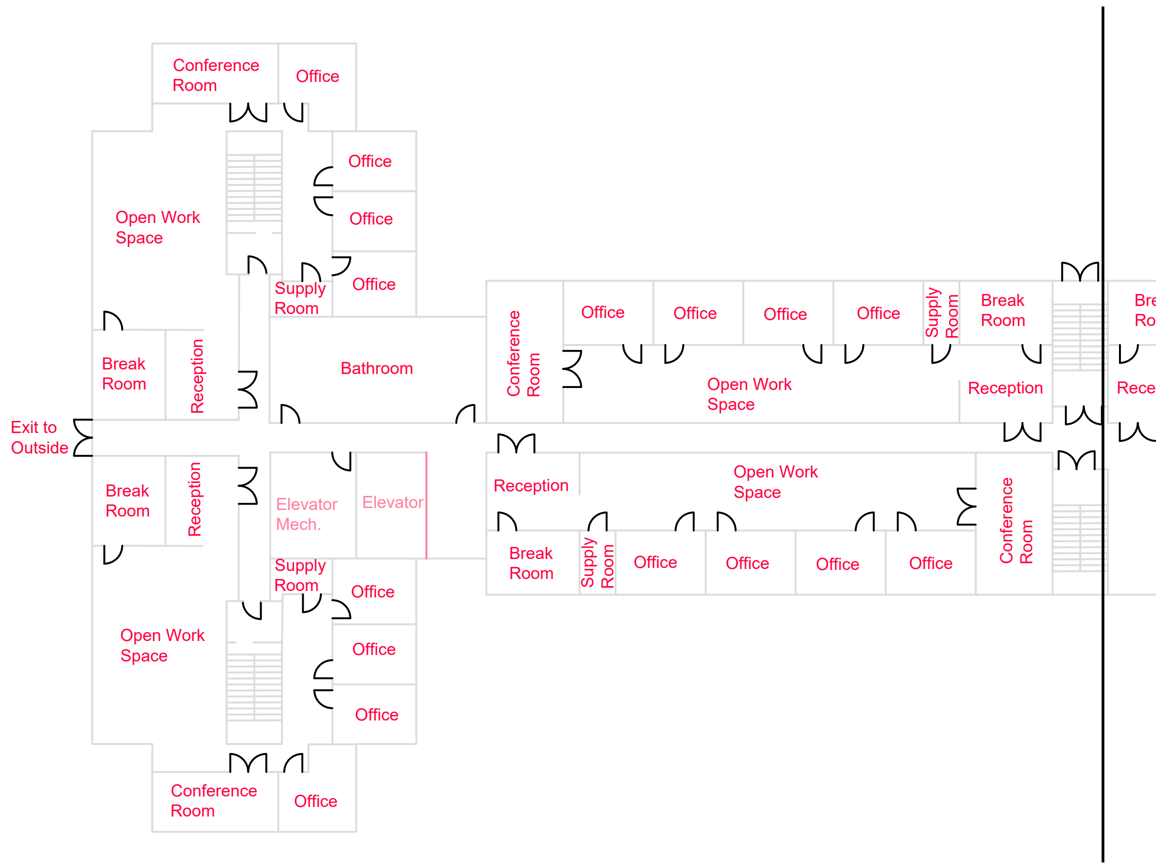
TITLE
CASE 5
STRUCTURAL
(FRAMES - EAST)

NUMBER
S.5.3.2

SHEET
48 OF 60



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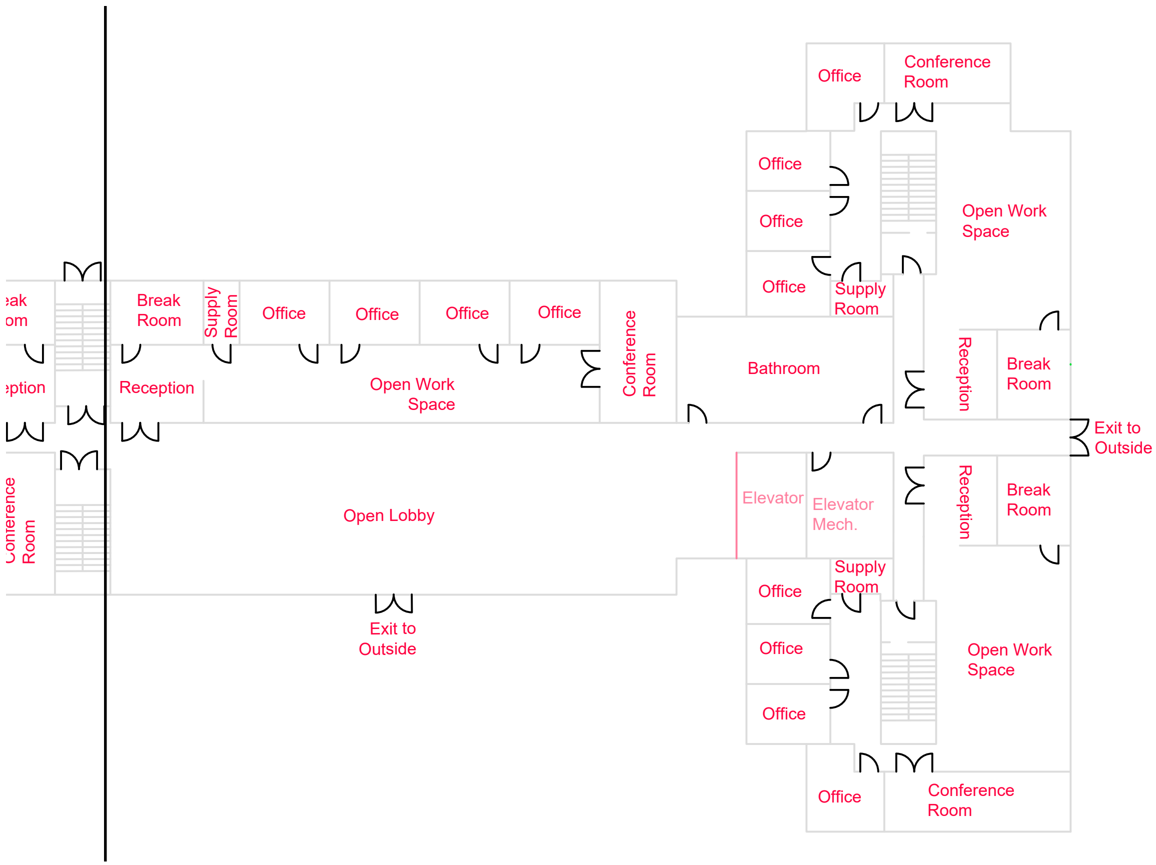
SCALE
$\frac{1}{32}'' = 1'$

TITLE
CASE 5
ARCHITECTURAL
1ST FLOOR - WEST

NUMBER
A.5.1.1

SHEET



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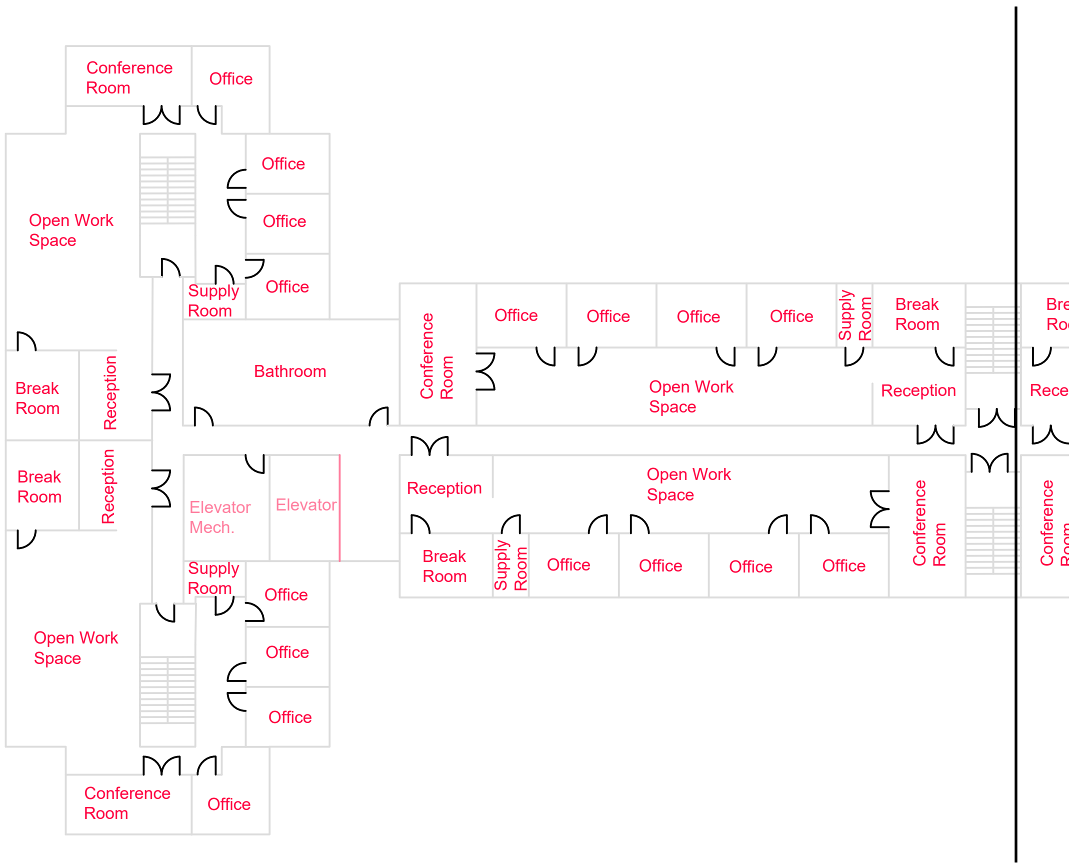
TITLE
CASE 5
ARCHITECTURAL
1ST FLOOR - EAST

NUMBER
A.5.1.2

SHEET
50 OF 60



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ELIZABETH M. COFFEY

DRAWN BY

ELIZABETH M. COFFEY

CHECKED BY

LEONARD D. ALBANO

SCALE

$\frac{1}{32}$" = 1'

TITLE

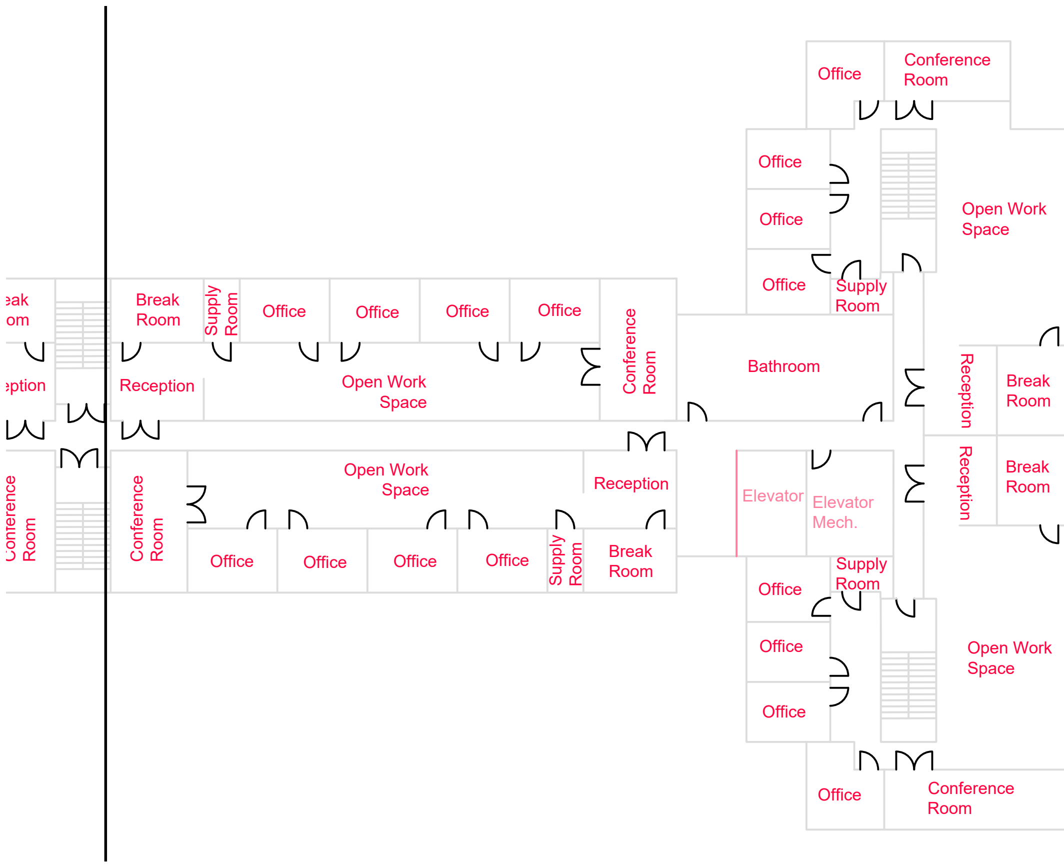
CASE 5
ARCHITECTURAL
2ND FLOOR - WEST
(TYP.)

NUMBER

A.5.2.1

SHEET

51 OF 60



KEY PLAN

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PROJECT
INTEGRATED STRUCTURAL AND FIRE PROTECTION DESIGN CONSIDERATIONS

ADDRESS
100 INSTITUTE ROAD
WORCESTER, MA 01609

PROJECT NO
LDA - 1702

DATE
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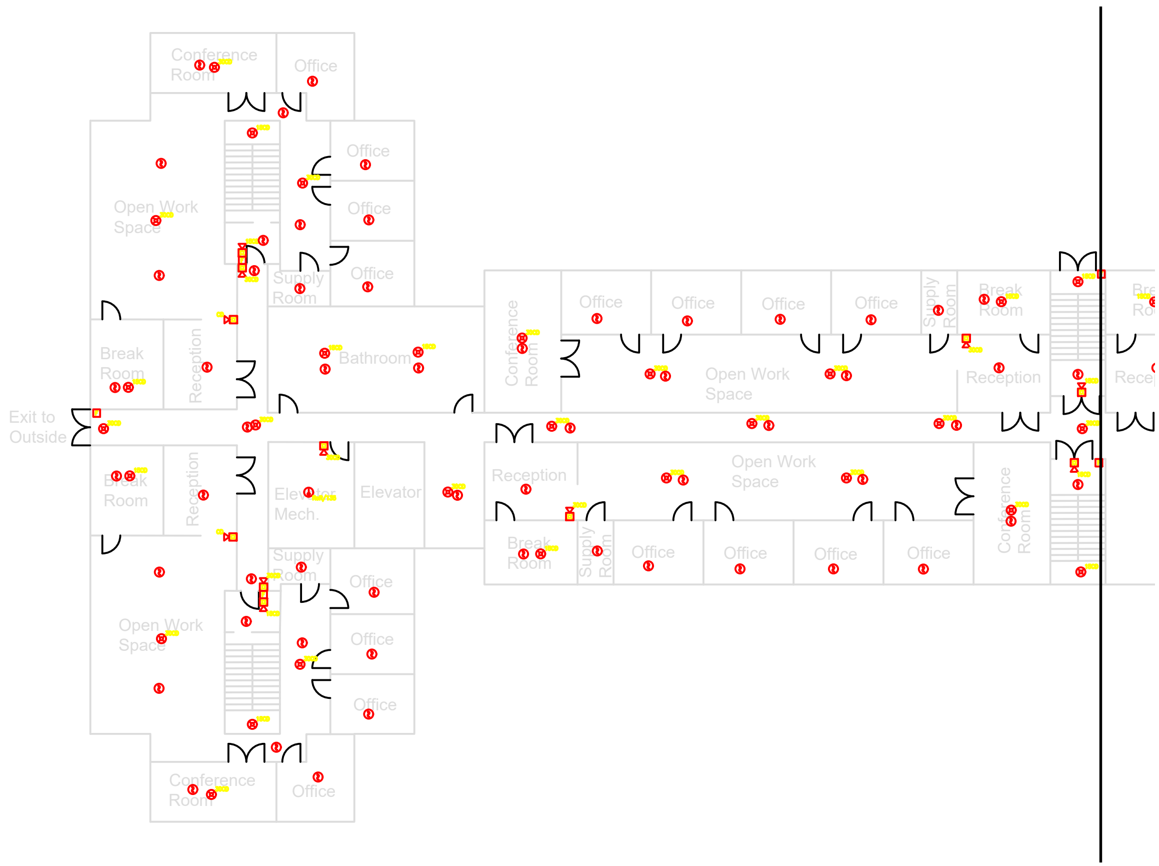
TITLE
CASE 5
ARCHITECTURAL
2ND FLOOR - EAST
(TYP.)

NUMBER
A.5.2.2

SHEET
52 OF 60



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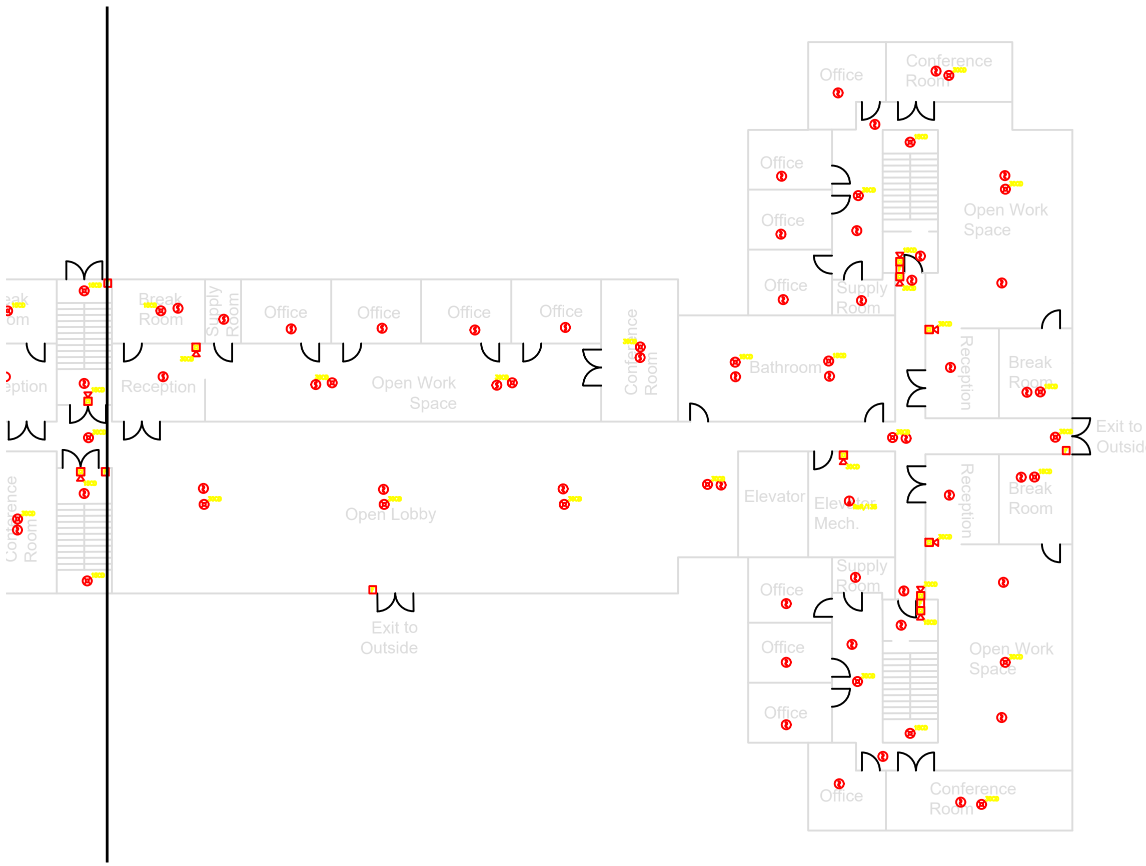
TITLE
CASE 5
FIRE ALARM
1ST FLOOR - WEST

NUMBER
FA.5.1.1

SHEET
53 OF 60



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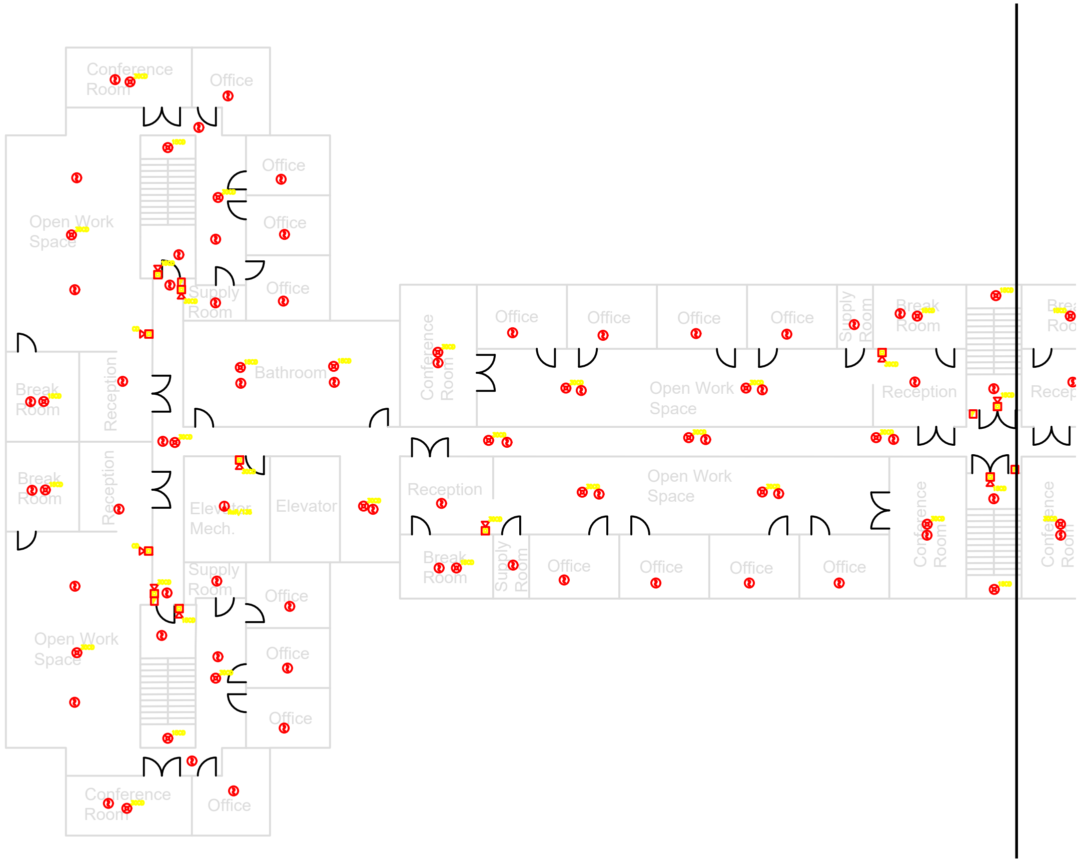
FIRE ALARM
1ST FLOOR - EAST

NUMBER

FA.5.1.2

SHEET



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TITLE

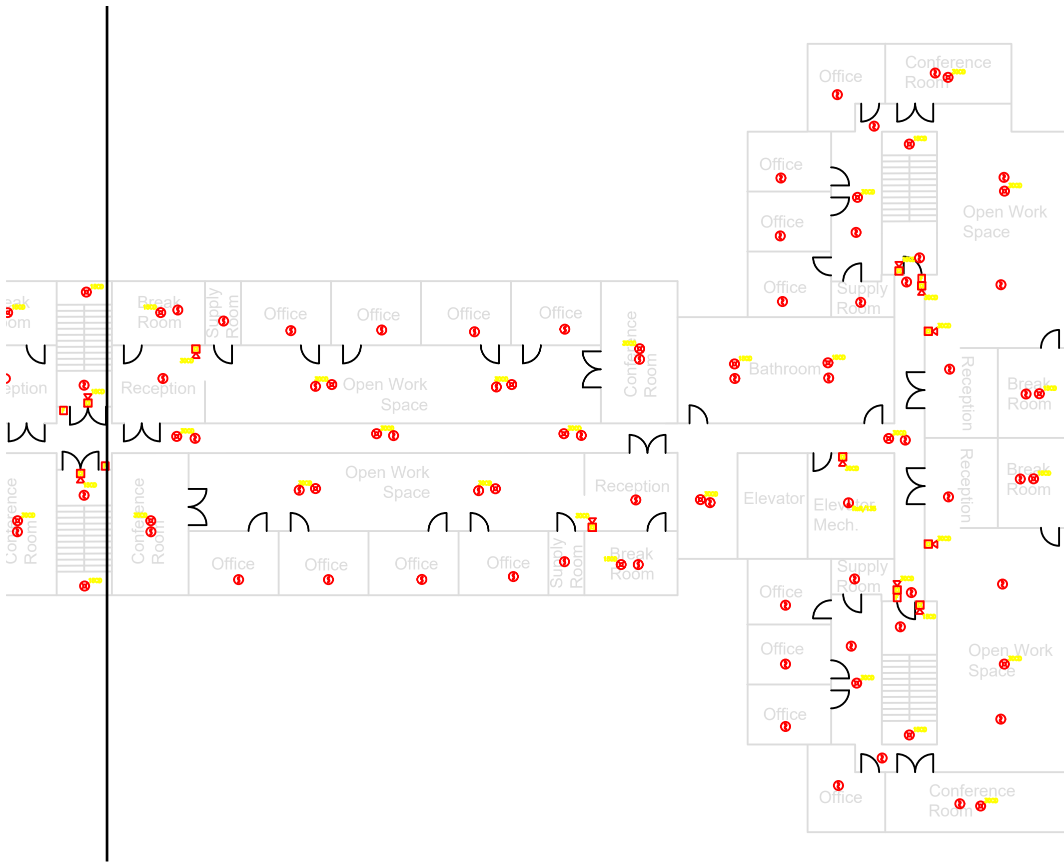
CASE 5
FIRE ALARM
2ND FLOOR - WEST
(TYP.)

NUMBER

FA.5.2.1

SHEET

55 OF 60



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TITLE

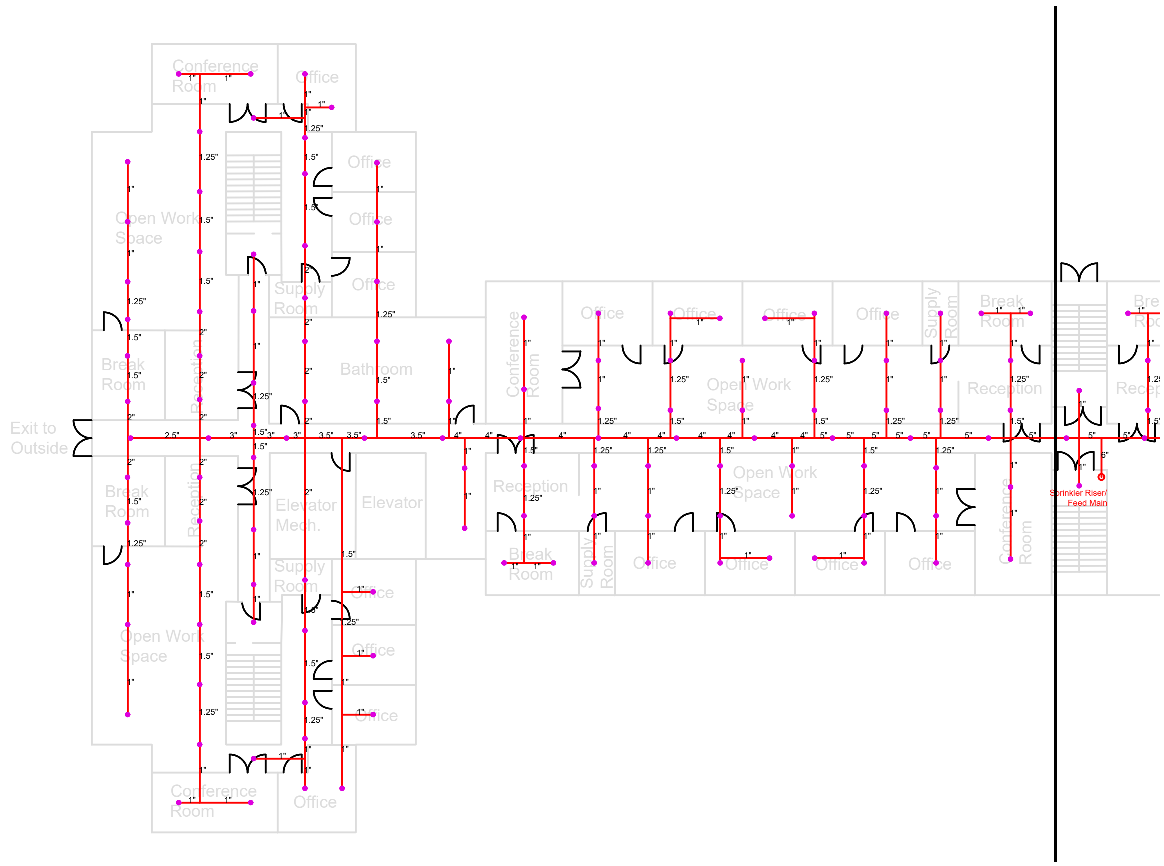
CASE 5
FIRE ALARM
2ND FLOOR - EAST
(TYP.)

NUMBER

FA.5.2.2

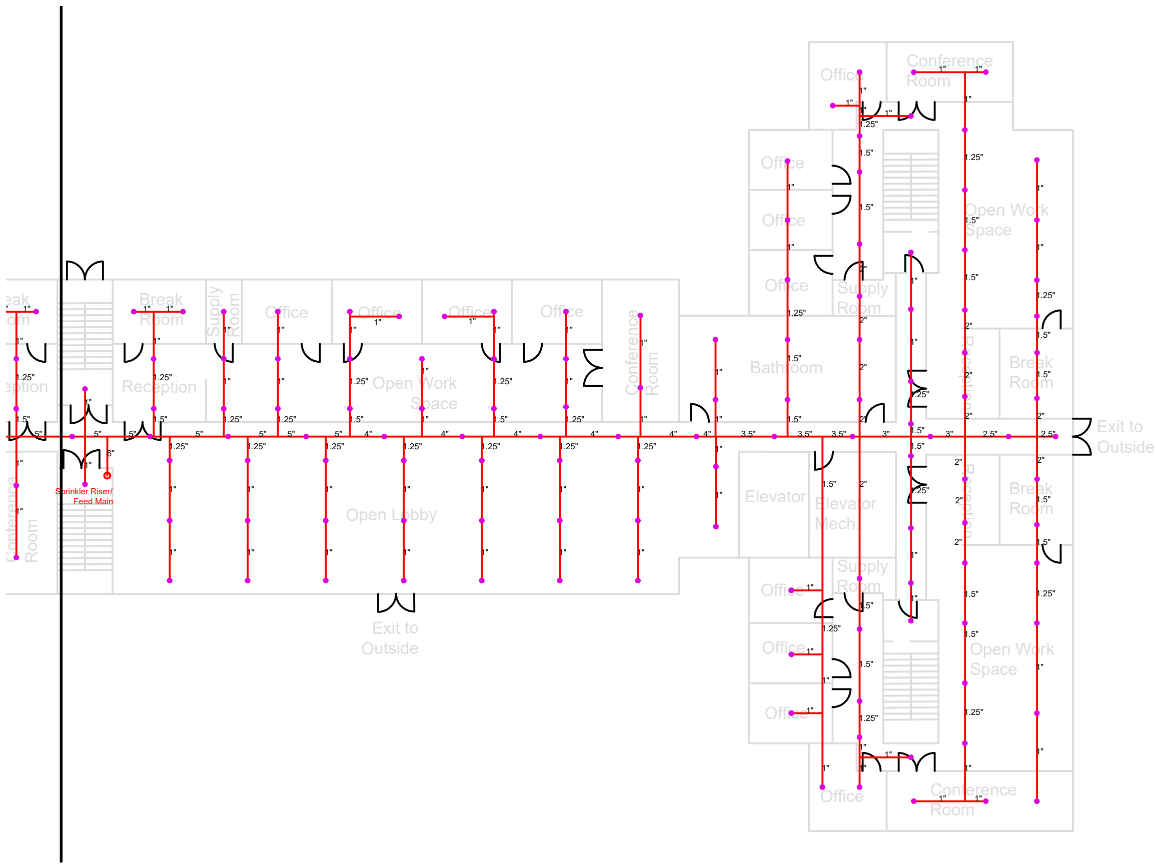
SHEET

56 OF 60



KEY PLAN	
PROJECT	INTEGRATED STRUCTURAL AND FIRE PROTECTION DESIGN CONSIDERATIONS
ADDRESS	100 INSTITUTE ROAD WORCESTER, MA 01609
PROJECT NO	LDA - 1702
DATE	March 1, 2017
DESIGN	ELIZABETH M. COFFEY
DRAWN BY	ELIZABETH M. COFFEY
CHECKED BY	LEONARD D. ALBANO
SCALE	$\frac{1}{32}$" = 1'
TITLE	CASE 5 FIRE PROTECTION 1ST FLOOR - WEST
NUMBER	FP.5.1.1
SHEET	57 OF 60

NO.	REVISION	DATE



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SCALE

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TITLE

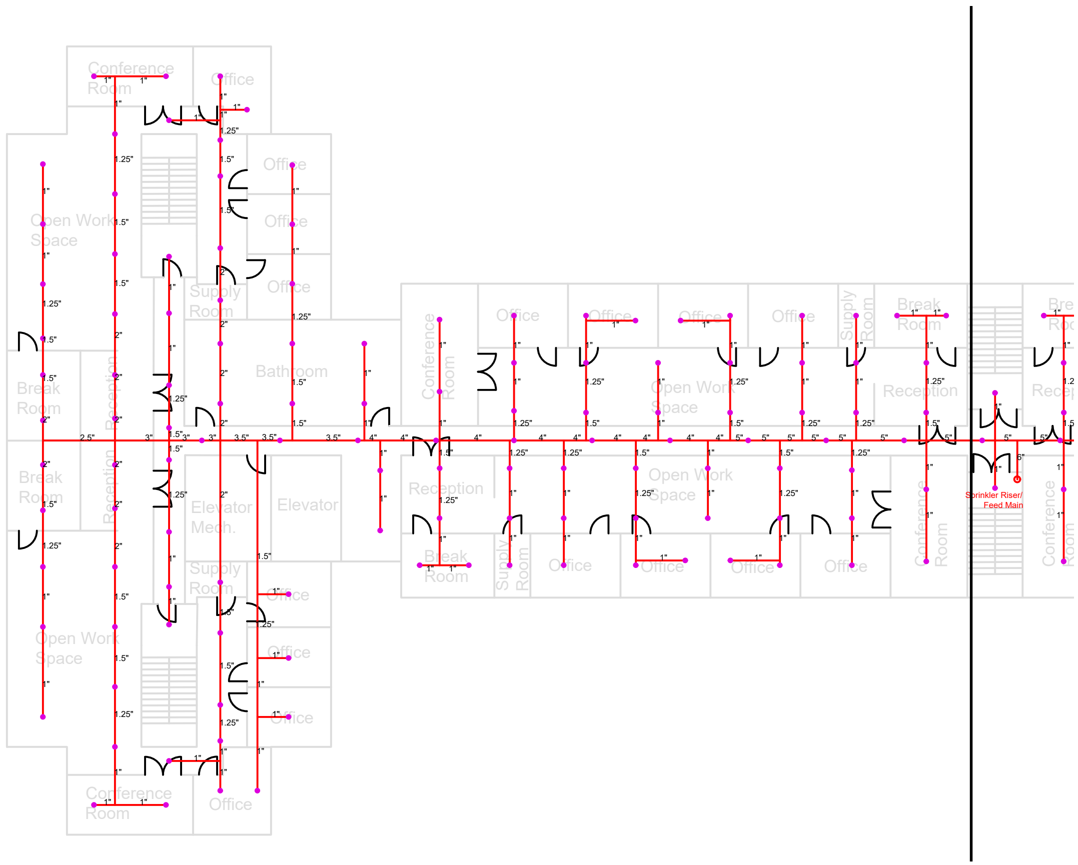
CASE 5
FIRE PROTECTION
1ST FLOOR - EAST

NUMBER

FP.5.1.2

SHEET

58 OF 60



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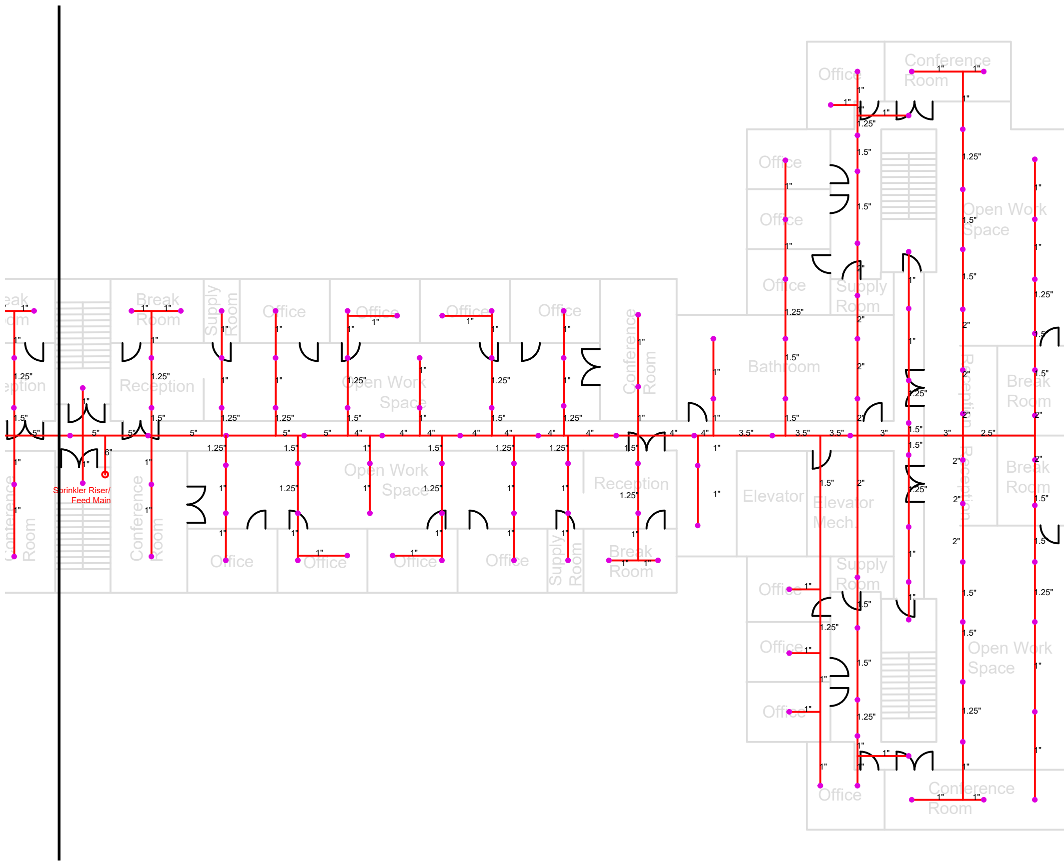
TITLE
CASE 5
FIRE PROTECTION
2ND FLOOR - WEST
(TYP.)

NUMBER
FP.5.2.1

SHEET
59 OF 60



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2ND FLOOR - EAST
(TYP.)

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SHEET

60 OF 60