Project Numbers: LDA - 1001

GFS - 1003

DESIGN OF WPI MIXED-USE FACILITY FOR GATEWAY PARK

A Major Qualifying Project Proposal

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Civil Engineering

by

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Abstract

The project investigated preliminary design layouts as well as structural frame and construction plan for Lot 3commercial building of the Gateway Park expansion at Worcester Polytechnic Institute. A structural design, including an additional floor featuring an open-style conference center, was established following studies of structural steel and reinforced concrete alternatives. Elements of the foundation system were also designed. A phased construction plan, project schedule and cost estimate were prepared and submitted as project deliverables.

Capstone Design Statement

The project team's overall objective was to provide a conceptual design that is structurally sound, cost effective and maximizes the inclusion of multi-use space. A structural frame and foundation designs were investigated in the structural facet of the engineering design. In the construction management aspect, the project team proposed a project construction timeline, construction plan and cost estimate. Various alternatives to the facility were considered by the project team, but a proposed open-style lecture hall and conference center with no interior columns was investigated on an additional floor.

The design and construction planning of the four-story building introduced many obstacles in completion of the team's Major Qualifying Project. Some of the challenges that we identified follow the standards set forth in the ABET General Criterion Curriculum. The standards state that students "must be prepared for engineering practice," and recognize "realistic constraints" that are involved with a real-world project (Criteria for Accrediting Engineering Programs/ABET). This section of the report will address specific constraints that apply to the project, including issues involving economics, constructability, the environment and sustainability,

Economic

From an economic standpoint, a general cost analysis was done for the project including cost implications of alternative approaches in design and construction. The overall goal for this facility from the economic standpoint was to provide a constant and healthy stream of revenue to both Worcester Polytechnic Institute and the Worcester Business Development Commission. A preliminary cost estimate was calculated by referencing similar designs from previously constructed buildings of similar size, shape and purpose. Cost implications of alternative concepts were explored when possible. These cost comparisons also provided an understanding of scale and what appropriate values might be in a real-life design scenario.

Constructability

Considerations to standardize sizes and materials enhanced the effort to maximize repeatability, especially when choosing member sizes in both the structural steel and reinforced concrete alternatives. The concept of constructability is to advance designs that enable the generation of an effective and logical construction plan. The construction plan encompassed the order in which materials should be delivered to the site and the order in which they were added to the facility. Seemingly trivial, the procurement of equipment and materials can help or burden the project's schedule.

Another issue of constructability that was a difficult obstacle was accommodating the mixed-use aspect of the facility. The group needed to address and consider complications such as separating the school from the remainder of the building while isolating each wet laboratory workspace to be its own cell within the building.

Environmental and Sustainability

As WPI has committed to future buildings to be environmentally friendly, environmental and sustainability issues will certainly be a major focus for the project. Difficulties could include issues surrounding WPI's attempt to acquire "Silver" LEED certification, EPA "brownfield" site conditions and maximizing flexible space. The project team incorporated as many environmentally friendly systems as possible but also considered the restrictions of these aforementioned systems and their effect on the total cost of construction.

Health and Safety

Both the design and construction phases complied with all local, state and federal building, health and safety codes. Health and Safety considerations were met through the proper application of building code provisions. Structural design was governed by the *International Building Code*. This standard is customary for construction projects throughout the United States.

Social, Ethical and Political

Social, ethical and political problems are closely associated, and they can delay or stop projects altogether if the proposed development falls out of favor. No doubt a project of this magnitude would have a great impact on the local community, especially the surrounding old mill district. Depending on the kind of tests that are being conducted (stem cell research, animal testing, etc.), ethical issues could arise within the community if the public thinks that the development does more harm than good. However, the proposed building could ensure it's a positive addition to the community by enhancing education and the interest of the Massachusetts Academy students in the field of mathematics and sciences, and acting as a catalyst for community growth in the area around Gateway Park. The Gateway Park expansion would provide thousands of jobs in both the short-term and long-term and invigorate continued growth and opportunity to Worcester. By continuing WPI's pledge for sustainability and environmental friendly buildings through the "Silver" LEED certification, the community would be less inclined to worry about long-term ramifications to the environment. Overall, the Lot 3 building will contribute far more positive than negative effects on the city of Worcester and its local community; therefore, most social, ethical and political issues will be at a minimum.

Authorship

All aspects of this project were equally worked on by the three members on the team with a few exceptions. The following chapters were completed by the person below.

4.2 Reinforced Concrete

-Thomas Zajac Jr.

4.3 Structural Steel

-Rens F. Hayes IV

5. Foundation Design

-Thomas Zajac Jr.

6. Schedule & Construction Plan

-Paul F. Galligan

7. Cost Estimate

-Paul F. Galligan

The signatures below indicate acceptance of the above.

Paul F. Galligan

Rens F. Hayes IV

Thomas Zajac, Jr.

Date: December 14, 2009

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1. Introduction

Worcester Polytechnic Institute, with its lasting commitment to redefining education and research, brought Gateway Park to the Worcester community in 2005. Gateway Park provides a foundation for scientists, scholars, students, and entrepreneurs to research and prosper (Gateway Park, 2008). Life sciences, biotechnology, biochemical engineering companies and research programs will thrive in this 55-acre mixed-use destination. At the development's completion, there will be five life science buildings with roughly 500,000 square feet of adaptable lab space designed for researchers and entrepreneurs. As a whole, Gateway Park is designed to "foster innovation and create a smooth product pipeline from the lab to the marketplace." (Gateway Park, 2008)

Lot 3 of the Gateway campus, in particular, will accommodate a four-story, 80,000 square foot facility. The planned use of this space currently includes multiple life sciences companies, a wet laboratory training facility, leasable office space, and a local high school. The proposed tenants include Massachusetts Biomedical Initiatives, Blue Sky Biotech, Massachusetts Academy of Math and Sciences, and Highland Executive Suites. This facility will become a versatile and integral part of Gateway Park. This integration of business and education is a representation of the Gateway Park vision.

The project team's overall objective was to provide a preliminary structural design with an educated construction cost estimate and timeline corresponding to the concept of the proposed facility. The project team has identified key tasks that allowed for the fulfillment of these objectives. The tasks include the development process for the progression of structural design and construction management for Lot 3. Designs delivered to the project team featured partial floor layouts and basic structural bays. The preliminary design involved completing the proposed floor layouts considering both the needs of the tenants and the structural constraints. In the structural facet of the engineering design, structural frame and foundation design were investigated. In the construction management aspect, the project team proposed a project construction schedule and cost estimate. An open-style lecture hall and conference center with minimal interior columns on an additional floor was investigated as a project alternative. The entire proposal was completed with the LEED certification requirements in mind. It was demonstrated that the proposed facility may achieve “Silver” LEED certification without creating a significant financial burden on the parties involved in providing unnecessary environmentally friendly alternatives.

A substantial amount of background research was conducted to prepare for the preliminary design process. The history and vision of Gateway Park was investigated to better understand the context for the proposed development of the facility. Geotechnical reports, zoning implications and building requirements were explored to assure the design will be completed within the proper technical and regulatory constraints. LEED certification requirements and wet laboratory facilities were researched to gain a better understanding of the scope of the project. This background research has been documented in Chapter 2. Chapters 3 to 5 portray the project team’s approach to each aspect of the architectural and engineering design while Chapters 6 and 7 address the team’s approach to the construction management related components. The report concludes with a final recommendation for the proposed facility that the team believes would best benefit the Owner. As a capstone design experience, the project team incorporated previous coursework and field experience to address the real-world constraints of the construction process for Lot 3. It is the hope of the project group that this baseline can be used as a promotional and planning tool when the facility is actually designed for the next phase of the Gateway Park Development Plan.

2. Background

This chapter of the report involves the historical and non-technical information about the site that helped the project team gain a better, overall understanding of the design and construction planning of a mixed-use commercial building. Many times there are implications or limitations involving the history or current state of a site that are initially unknown to the project engineer and are only revealed during a thorough investigation. If the proper research is not conducted before the technical design begins, unforeseen problems could arise that would be costly to address and delay the project. Some of the non-technical areas that were investigated were history, current status and the future plans for Gateway Park; site specific information; zoning ordinances; LEED criteria; and similar mixed-use facilities.

2.1 Gateway Park

One of the ideals of Worcester Polytechnic Institute is its commitment to research and providing opportunities for individuals to freely explore their respective fields of study (www.wpi.edu/about). Fulfilling this goal in the fields of life sciences, biotechnology and biochemistry is Gateway Park, a joint venture between Worcester Polytechnic Institute and the Worcester Business Development Corporation. Work has already commenced on this 12-acre plot, and it will soon provide 500,000 square feet of lab space, loft condominiums and several thousand square feet of retail space right in the heart of Worcester (Hurd, 2009). In the near future, Gateway Park will become a pivotal part of the 55-acre Gateway Redevelopment District that intends to revitalize its neighborhood by redeveloping the surrounding area and creating up to two thousand high-wage occupations.

2.1.1 History of Gateway District

The Gateway District traces its roots to the manufacturing district of Worcester, Massachusetts. One of the premier companies to occupy the plot was the Washburn and Moen Manufacturing Company, a leading producer of steel wire founded in 1868. Although Washburn and Moen was an integral part of Gateway years ago, it left the surrounding area with considerable soil contamination shortly into the 20th century. This pollution classified Gateway as a "brownfield" site, a plot of land that is constructible but needs to be purged of its contaminants. (Welcome to Gateway Park, 2008)

March 2005 marked the advent of the Gateway Park redevelopment project. A $2.5 million grant from the United States Economic Development Administration allowed Worcester Polytechnic Institute and the Worcester Business Development Corporation (WBDC) to begin bringing Gateway Park to life by cleaning the brownfield sites and finding prospective developers.

2.1.2 Current Status of Gateway Park

In April 2007, WPI took its first step in creating a haven for life science study by completing the WPI Life Sciences and Bioengineering Center at Gateway Park. This 4-story facility is roughly 125,000 square feet of laboratory, conference and office space. It currently houses four WPI academic departments, several diverse research groups and modern conference rooms and offices. This building can be found in Figure 1. In addition, a multimillion dollar multi-story parking garage that services the Gateway Park area was completed in June 2007 (www.gatewayparkworcester.com). Since the erection of these buildings, there has not been much progress made in the sense of new construction. However, WPI has made significant strides in marketing the ideology and goals of the Gateway project. (Hurd, D'Anne, 2009)

Figure 1: WPI Life Sciences and Bioengineering Center

http://www.gatewayparkworcester.com/bioeng.html

Despite only one completed research facility, Gateway Park has been making a considerable impact on the biomedical research world. In September 2009, several researchers at the Life Sciences and Biotechnology Center received awards totaling over $1.3 million from the National Institutes of Health and the National Science Foundation. The awards were given for a variety of research topics ranging from engineering blood vessels and analyzing mechanical properties of heart valves to using stem-cells to restore function to damaged heart tissue. (“WPI Receives $1.3 million for Ongoing Life Science Research”, Press Release, September 24, 2009) Additionally, its accolades include the 2007 Phoenix Award, a national honor that recognizes developments that revitalize “brownfield” sites for new, productive uses.

Gateway has been contacted by various companies interested in leasing space in future buildings that will occupy the Gateway property. As of September 2009, Worcester Polytechnic Institute has approximately 60,000 square feet of lab and office space claimed in its next proposed building, an 80,000 square foot mixed-use laboratory and office center. (www.gatewayparkworcester.com)

2.1.3 The Future of Gateway Park

The future vision of Gateway is bold and bright. As mentioned before, the entire Gateway business venture will incorporate 500,000 square feet of laboratories as well as space for commercial and retail lease. In total, the Gateway Redevelopment District is a locality that has been selected to be rejuvenated from a former manufacturing region to a new, contributing part of Worcester.

The next phase of Gateway Park consists of a variety of buildings with individual uses that will contribute to the diversity of the Gateway District. Building 3 (see Figure 2 below) will be a mixed-use graduate housing development with retail spaces in the bottom floor. Scheduled to break ground in 2011, this structure will be closely related in usage to Founders Hall, a Worcester Polytechnic Institute undergraduate dormitory that supports living space on upper floors and a restaurant and convenience store on the ground floor. Building 4, a condominium complex with readily available parking, will provide living quarters within the boundaries of Gateway, blending in with the surrounding neighborhood. In addition to the condos in Building 4, Building 5 will consist of affordable market-rate condominiums and commercial and retail space. These facilities will be integrated into the surrounding neighborhood that includes the Courtyard by Marriott (Building 23) and WPI's Life Sciences and Bioengineering Center (Building 1).

Figure 2: Proposed Gateway Park Complex

(www.gatewayparkworcester.com)

From our interview with D'Anne Hurd, the Vice President of Business Development at Gateway, we learned about three buildings that will be the life science "backbone" of Gateway Park. Each of these buildings, (Buildings 6, 7 and 8) will be leased out for commercial use. They will mainly consist of leased "wet" laboratories and offices that will house companies focused on life science research. These facilities, 100,000 square feet, 80,000 square feet and 140,000 square feet, respectively, have attracted the likes of many international corporations looking to expand to a region with a more attractive cost of living and research than either Cambridge or Providence. Though no timeframe has been given to these facilities, WPI and the WBDC are looking to develop this area as soon as possible. (Hurd, 2009). An artist's rendition of what Gateway Park might look like can be seen in Figure 3.

Figure 3: Artists Rendition of Gateway Park

(www.gatewayparkworcester.com)

2.2 Building 7: "Lot 3" Prescott Street

Proposed to break ground in November 2009, Building 7 is an 80,000 square foot edifice to be located at the intersection of Prescott Street and Washburn Way. The exact address of this building is yet to be determined, but this project will reference it as the "Lot 3" building. As mentioned previously, this facility will consist mainly of "wet" laboratories that accommodate hands on experimental work using chemicals and organic compounds. One of the proposed tenants is Massachusetts Biomedical Initiatives, a non-profit biomedical corporation that has claimed 10,000 square feet of laboratories. Additionally, Blue Sky Biotech has expressed interest in expanding, and it has claimed 10,000 square feet to add offices and laboratories next to its headquarters in the Life Sciences and Bioengineering Center. Figure 4 illustrates a proposed floor plan featuring Blue Sky Biotech's added space. However, life science research companies are not the only tenants in the facility. The Massachusetts Academy of Math and Sciences, a local high school for exceptional students, has signed a lease for roughly 15,000 square feet to be housed on the ground floor, as shown in Figure 5. Also, Highland Executive Suites, an upscale office space leasing company has requested 10,000 square feet to fit out. (Hurd, 2009)

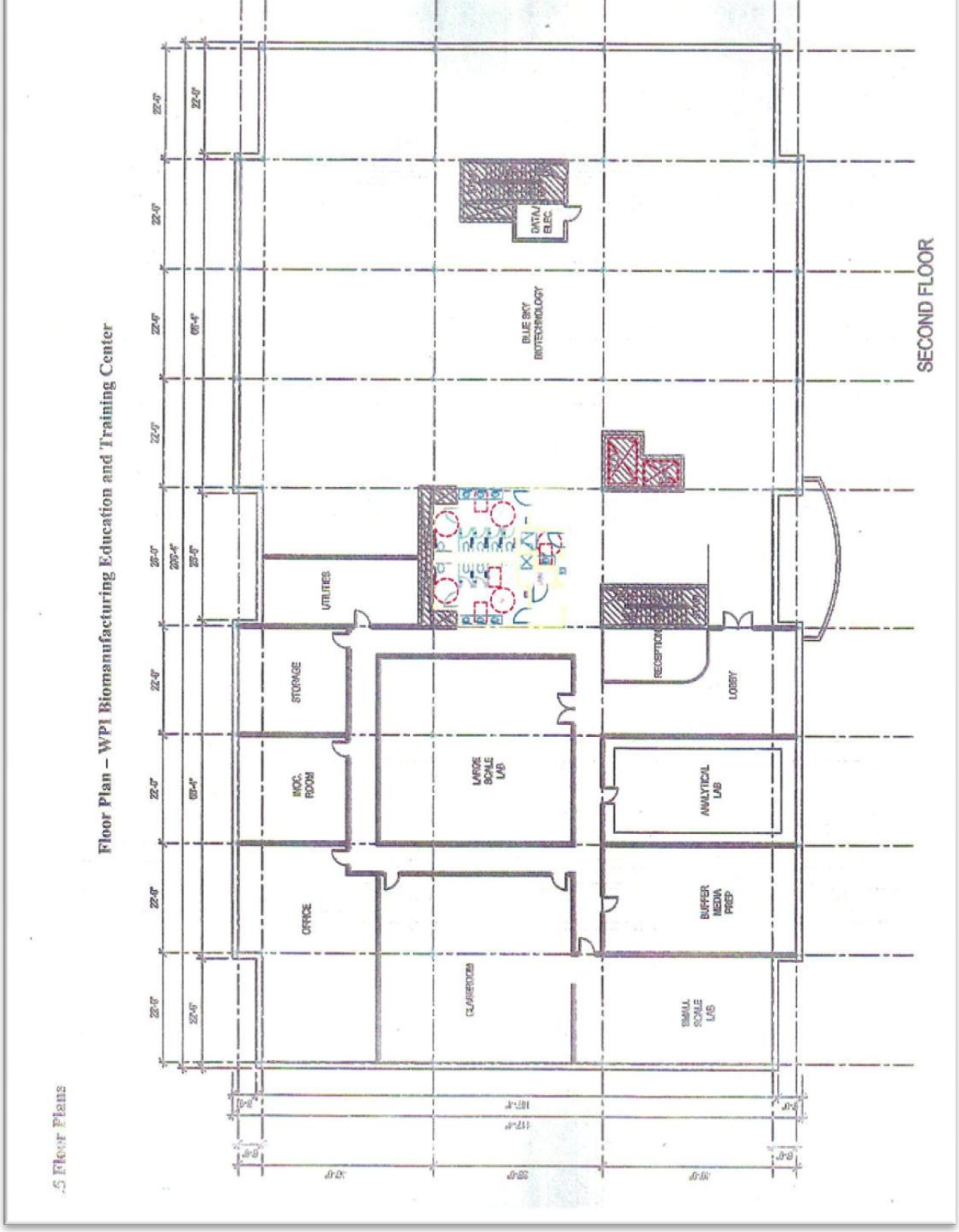


Figure 4: Floor Plan - WPI Biomanufacturing Education and Training Center

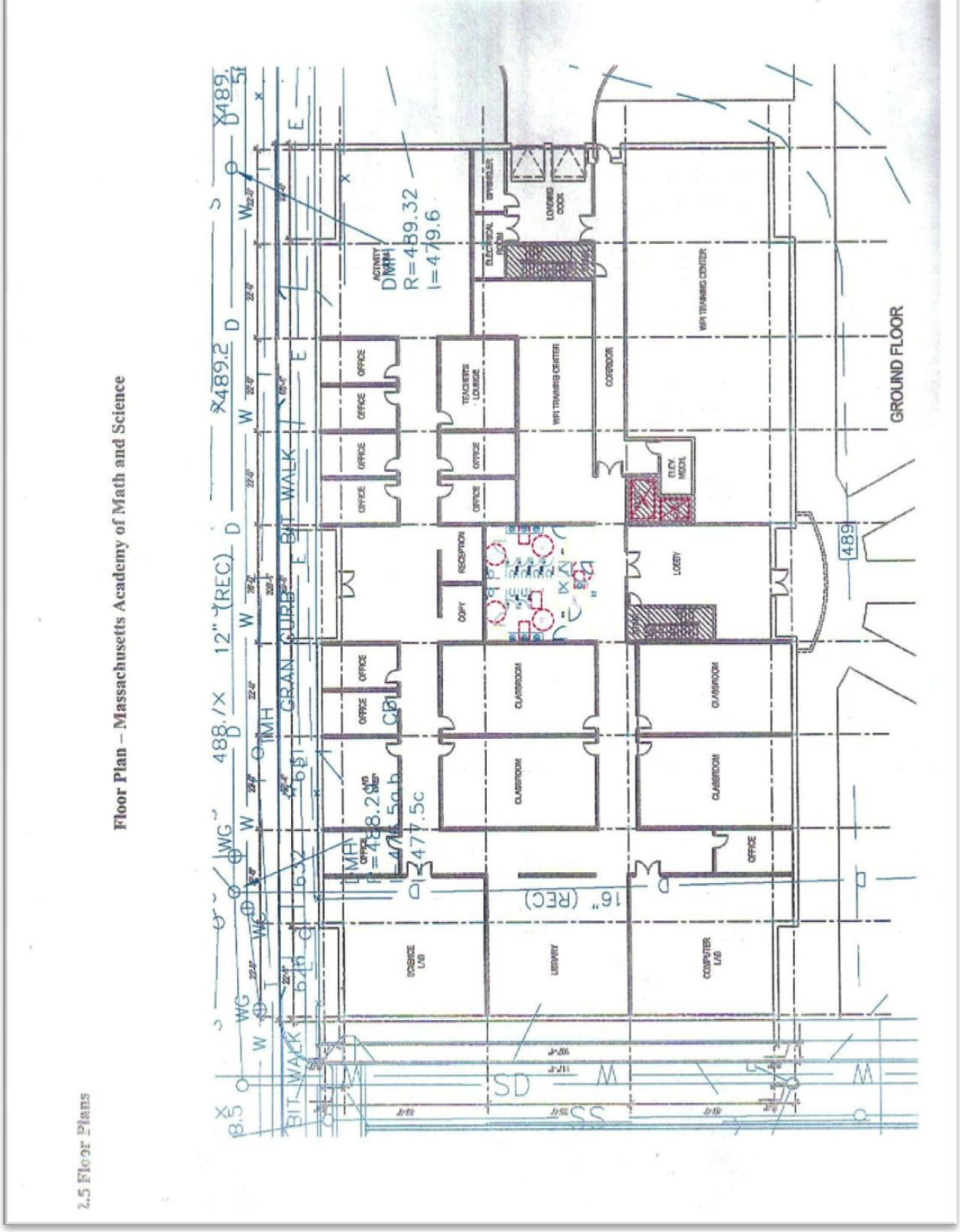


Figure 5: Floor Plan - Massachusetts Academy of Math and Science

Overall, the "Lot 3" building will become a versatile and integral part of Gateway Park. It has the ability to be used as an educational center as well as a means of profit; an ideal situation for Gateway Park as it moves forward in development.

2.2.1 Gateway Park: Soils and Geotechnical Report

In October 2005, a preliminary geotechnical report was done on the soils in Gateway Park by Maguire Group Inc., an architectural and engineering firm located in Foxborough, MA. It primarily focused on the soils around the proposed parking garage and the adjacent facilities and plaza. The report introduces the site history of Gateway as well as the regional topsoil and subsurface history of the adjoining area.

The report also outlines the testing programs and procedures done by the respective boring and soil testing companies. Overall, there were twenty five bore holes drilled in the Gateway area. These were strategically placed throughout the proposed Gateway layout to present the best possible estimation for the existing soil conditions. The borings were performed by New Hampshire Borings, Inc., and cylinders were forwarded to the firm of Paul B. Aldinger and Associates for soil testing. Groundwater location wells were excavated to establish the position of the groundwater table below the Gateway Park locale. (Maguire Group, 2005)

Soil data was collected and organized into five groups by proximity to a prospective structure that was projected to be built in 2005. These five groups include the plaza, building number 8, the present parking facility, the at-grade parking lot and the access road that will weave through the Gateway campus. These groups make up what is identified as the "Lower Site" of Gateway Park.

In reading the geotechnical report, there is no information that directly pertains to the "Lot 3" building. However, there are three boring logs, designated as MGI-08, MGI-11 and MGI-14, very close to the proposed building that will provide the group with enough subsurface information with which to design foundations. As Figure 6 shows, MGI-8 is located between "Lot 3" and proposed Building number 2 near Prescott Street. MGI-11 is located within the plaza at the midpoint of the eastern exterior wall of "Lot 3". Lastly, MGI-14 is located off of the northeastern corner of the facility, closest to the existing Life Science and Biotechnology Center. (Maguire Group, 2005)

In looking at the boring logs done in 2005, the soil conditions seem to be consistent throughout the project site. The profiles are principally medium to very dense sand with a little bit of silt. Small amounts of gravel appear in MGI-14, the closest boring log to the Life Sciences Center. Lastly, the water table seems to appear at a depth of 11.5' to 12' in all boring logs examined. Uniform conditions like those found in the preliminary geotechnical report tend to provide a stable foundation base and facilitate the design of concrete footings.

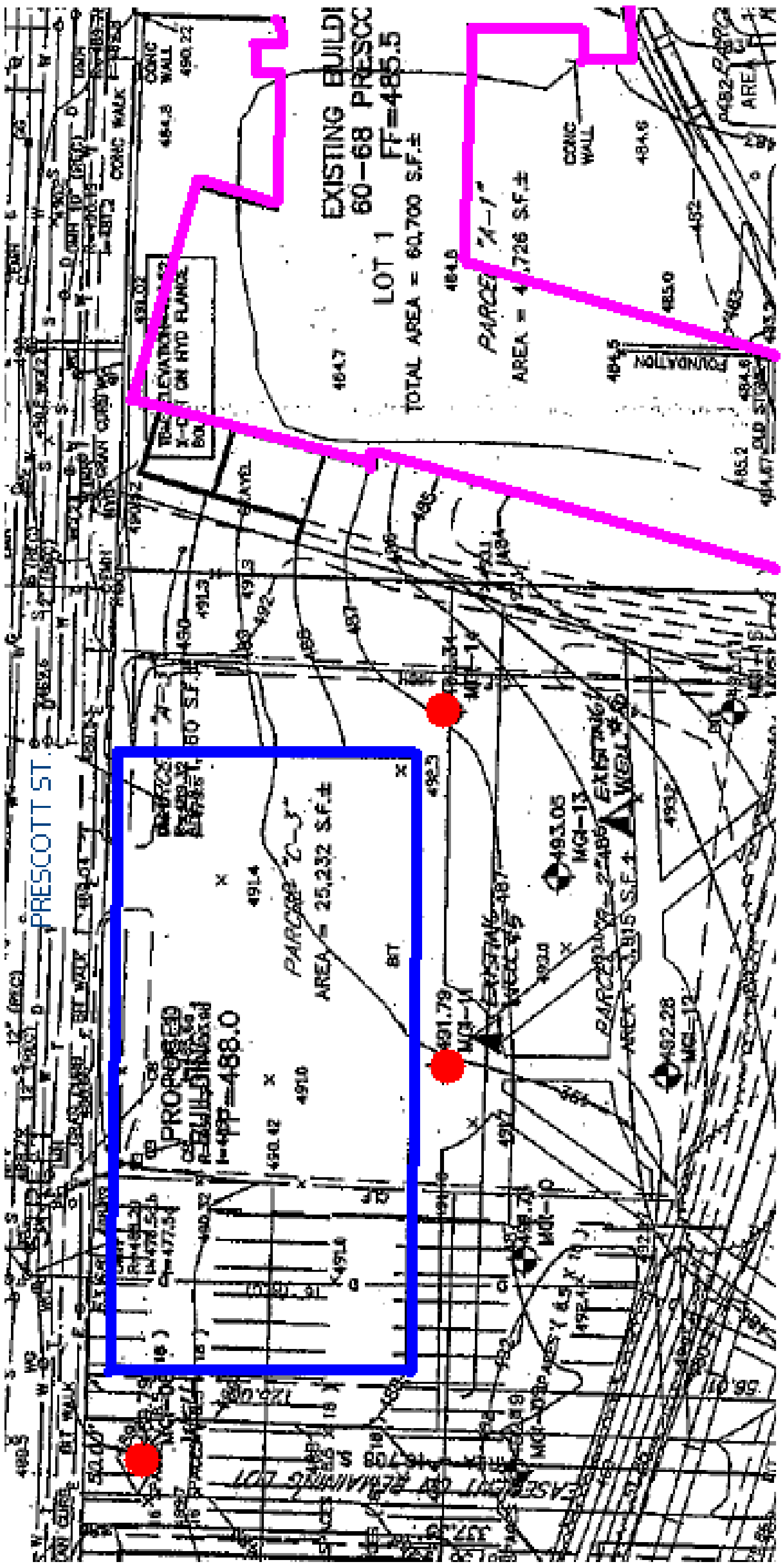


Figure 6: Location of Gateway Soil Borings

2.2.2 Zoning Ordinance of the City of Worcester

Land use and zoning laws regulate the use and development of real estate. Zoning is the most common form of land-use regulations. Municipalities use zoning regulations and restrictions to control and direct the development of property within their jurisdiction. In addition, easements and eminent domain are two legal issues related to land use. An easement allows the holder to use property that he or she does not actually own or possess for purposes such as a road or utility access. The government's power to take private land (while providing compensation) for public use is known as eminent domain. (Land Use & Zoning, 2009)

Various geographic areas, or zones, are restricted to certain uses and development such as residential and commercial. These zones are then subdivided by additional use restrictions. These subdivisions may include industrial, light-industrial, commercial, light-commercial, agricultural, single-family residential, multi-unit residential, schools, and other purposes. Zoning laws may affect issues such as parking, setbacks, floor area ratios, lot size, height restrictions, etc. Therefore, entrepreneurs and business owners need to be aware of zoning regulations when looking to set up, expand, or relocate business establishments. (Zoning Ordinances Law & Legal, 2008)

Municipalities use zoning as a primary technique to manage the future development of community, protect neighborhoods, concentrate business (retail and industrial), and even channel traffic. As a result, homeowners in a residential zone do not have to worry about a gas station going up next door; however, a home-based business may not be in accordance with residential zoning restrictions if it requires signs or frequent traffic from customers. Similarly, a factory in an industrial zone does not have to worry about noise complaints from residential neighbors. This prevents neighbors, both business oriented and residential, from having a disagreement about regulations. Each Municipality has its own visions and goals portrayed by specific Zoning Ordinances. Lot 3, located on Prescott Street, is restricted by the specifications set forth by the Zoning Ordinance of the City of Worcester.

The Zoning Ordinance of the City of Worcester (ZOCW) states its objective of promoting the health, safety and general welfare of the public while complying with Worcester's plans for progress and growth. To satisfy this objective, the ZOCW is devised to encourage the appropriate use of land. The function of the ZOCW can be defined by the following six characteristics:

- Creates and maintains an environment in which people can fulfill the social, economic and other needs of present and future generations.
- Facilitates transportation, water supply, drainage, sewerage, schools, parks, open space, lights and other public requirements.
- Encourages economic development and housing suitable for the present and future needs.
- Protects against: overcrowding of land; air and water pollution; use of land incompatible with nearby uses; undue intensity of noise; danger and congestion in transportation; and loss of life, health, or property from fire, floor panic or other dangers.
- Protects natural environment including its scenic and aesthetic qualities.
- Promotes the preservation of historical/architectural significant land uses.

The administrative authority of the ZOCW is the Director of Code Enforcement, who will withhold a building permit for a structure in violation of the Ordinance. An investigation or inspection will be made of the pertaining property if the Director of Code Enforcement has any reason to believe the ZOCW has been compromised. Any person or organization violating the Ordinance may be fined no more than three hundred dollars for each offense, but a violation is considered to be a new offense each day it is not corrected. There is, however, the right for any person to appeal a violation and apply for a variance or special permit. The Special Permit Granting Authority (SPGA) is either the Zoning Board of Appeals (ZBA) or the Planning Board depending on the context of the permit request. Special permits are usually granted given the benefits outweigh the adverse effects to the city or neighborhood. It is also important to note that permits are acquired before the start of construction. (Zoning Ordinance of the City of Worcester, 2008)

For the purpose of the ZOCW, the city was divided into a number of districts: Residence, Business, Industrial, Manufacturing, Institutional, Airport, and Overlay Districts as well as Open Space Zones. "Lot 3" of Gateway Park is located in the Business District, specifically BG-6.0: Business, General. The school, research laboratories, and offices planned to be located at Lot 3 are all in accordance with the specifications of this zoning district. A more complete description of permitted uses by zoning districts in terms of residential, business, manufacturing, and general uses can be found in Appendix A. This table from the 2008 ZOCW verifies all intended uses on Lot 3 are in accordance.

Each zoning district also has restrictions on the dimensions of the building, lot, and where the building sits on the lot. This helps control the aesthetics and open space of a particular neighborhood. One of the primary specifications noted for BG-6.0 is the maximum floor area ratio (FAR). There can be no more than 6 square feet of building per 1 square foot of land. A required rear yard setback of at least 10 linear feet is also noted. An interesting observation is the ZOCW does not specify a height restriction for zone BG-6.0. The FAR suggests that buildings maybe six stories or more height. The City Planning Board, however, takes the surrounding area into consideration. In other words, a skyscraper would seem out of place if it was neighboring only four-story buildings. An additional floor space premium of 600 square feet per parking space added is allowed where off-street parking is provided on-site or within 1,000 feet of the building. (ZOCW, 2008)

Lot 3 also lies within the Mixed Use Overlay Zone. The intent of each mixed-use development is to contain a variety of land uses. It is specifically defined as a development "characterized by two or more significant revenue producing uses, such as retail, office, residential, hotel/ motel, entertainment/cultural/recreational which are mutually supporting, exhibit physical and functional integration and are developed in conformance with a coherent plan." (ZOCW, 2008) There are some additional limitations to Lot 3 because it lies within the mixed-use overlay zone. One single development may not constitute more than 75% of the gross floor area.   This means that the leasable lab space must be less than 75% of the proposed facility. Much of this leasable lab space along with some of the education space will most likely be restricted to public access and require a key or badge to enter. Recreational or open space must constitute at least 5% of the gross floor area. This open space is characterized as an area that is free and accessible to the public for activities and/or amenities.   Although there will be certain security restrictions, this open space can be partially accounted for in the use of the fifth floor odeum, classrooms and lecture halls for community events. Lastly, it is important to abide by the most restrictive limitations, whether it is a BG-6.0 or mixed-use overlay zone detail. (ZOCW, 2008)

2.3 Design and Loading Combinations

The *International Building Code (IBC)* is a model regulatory document that defines general requirements for structural design. Strength, serviceability, analysis and occupancy are categories used to help set these requirements. Capacity and deflection limitations are set to prevent structural member failure as well as provide a structure suitable for service. A complete analysis must be completed on a structure to assure the applied loading is distributed properly through the structural frame, foundation and surrounding soil. Lastly, occupancy refers to the appropriateness of the design for the given solution. The *IBC* was used instead of the MA Building Code for broader experience and expectations that differences with the MA Building Code are not significant. (IBC, 2006)

The *IBC* and *Minimum Design Loads for Buildings and Other Structures (ASCE 7)* were used to determine all concerning loading combinations. Of the seven basic loading combinations explored, the most critical were used for designing the structural frame. These combinations included several horizontal and vertical effects involving factored combinations of dead, live, rain, snow, wind and seismic loads. *ASCE 7* was also vital in determining the specifications for stair and elevator design. These requirements are further discussed in the design portion of this document. (ASCE 7, 2000)

2.4 Leadership in Energy and Environmental Design

To fulfill its commitment to sustainability, Worcester Polytechnic Institute has pledged to design and construct buildings with Leadership in Energy and Environmental Design (LEED) certification in mind. Since its commitment to sustainability, the university has constructed three buildings that have achieved some level of LEED accreditation. WPI’s first LEED certified building was the undergraduate admissions facility, the Bartlett Center. This building, which stands adjacent to WPI's quadrangle, was completed and registered as a LEED certified facility in 2006. Following the Bartlett Center was the WPI Life Sciences and Bioengineering Center. Registered in 2007, this was the Institute's second LEED certified building and first in Gateway Park. The latest addition to Worcester Polytechnic Institute's LEED certified structures is East Hall, a state-of-the-art undergraduate dormitory that holds a "Gold" certification. East Hall serves as Worcester Polytechnic Institute's proudest accomplishment in sustainable design, holding one of the only green roofs in the Worcester area. (WPI Sustainability, 2008)

2.4.1 LEED Certification

Leadership in Energy and Environmental Design is an initiative started by the United States Green Building Council (USGBC) that strives to rate buildings and communities that have committed to design and build with energy efficiency, water conservation and emission reduction in mind. It accomplishes this goal by promoting building products that are environmentally friendly or locally obtained. Additionally, it establishes protocols and procedures for owners to maintain during construction and occupancy. Within the last year, the USGBC upgraded LEED to "v3", an updated and more extensive certification program. This program evolved to a prorated system based on gradual point increments for increased performance. (USGBC, 2009)

LEED is internationally recognized as one of the premier sustainability evaluation systems available for developers and property owners. It uses an objective-based point system to designate different levels of sustainability: Certified, Silver, Gold and Platinum. Each related point is grouped into a category. When the building is complete and ready to be examined for certification, a team of LEED Accredited Professionals will determine the point total based on construction procedures, current equipment and future building protocol. The sum of these point totals equates to the facility's sustainability level. (USGBC, 2009) Table 1 shows the LEED Accreditation categories and possible point totals. A sample checklist can be found below in Figure 7, while the full project specific LEED checklist can be found in Appendix 10.10.

Table 1: LEED Categories and Possible Points

LEED CATEGORIES & POSSIBLE POINTS	
Category	**Points**
Sustainable Sites	26
Water Efficiency	10
Energy & Atmosphere	35
Materials & Resources	14
Indoor Environmental Quality	15
Innovation in Design	6
Regional Priority	4

One of the categories that LEED focuses on is "Sustainable Sites". This rating category encourages owners to build upon previously developed land, create regionally appropriate landscaping, control stormwater runoff and minimize construction-related pollution (www.usgbc.org). These initiatives encourage the healthy use of the land on which the building is constructed. Another category, "Water Efficiency," focuses on wiser use of potable water in the building and landscaping that is environmentally friendly in regards to runoff dispersion. Items that can be used towards LEED accreditation points include efficient water fixtures and appliances as well as designated runoff wetland areas and permeable pavement.

The "Energy and Atmosphere" division is one of the broader point categories. This category encompasses building emissions and electricity, two very important aspects of environmental concern. It promotes the use of lighting systems with the capability of automatically turning off when not in use. Additionally, it encourages the use of clean, renewable sources of energy as a source of power that produces minimal emissions. Another category, “Materials & Resources” plays a large part in LEED accreditation. LEED encourages the use of locally grown or fabricated construction materials, such as lumber, drywall or structural framing, when selecting components that will be part of the facility. “Materials and Resources” also focuses on the reduction of waste and the use of recycled materials throughout the construction process.

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS PROJECT CHECKLIST

Sustainable Sites		**26 Possible Points**
☑ Prerequisite 1	Construction Activity Pollution Prevention	Required
☐ Credit 1	Site Selection	1
☐ Credit 2	Development Density and Community Connectivity	5
☐ Credit 3	Brownfield Redevelopment	1
☐ Credit 4.1	Alternative Transportation—Public Transportation Access	6
☐ Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
☐ Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
☐ Credit 4.4	Alternative Transportation—Parking Capacity	2
☐ Credit 5.1	Site Development—Protect or Restore Habitat	1
☐ Credit 5.2	Site Development—Maximize Open Space	1
☐ Credit 6.1	Stormwater Design—Quantity Control	1
☐ Credit 6.2	Stormwater Design—Quality Control	1
☐ Credit 7.1	Heat Island Effect—Nonroof	1
☐ Credit 7.2	Heat Island Effect—Roof	1
☐ Credit 8	Light Pollution Reduction	1
Water Efficiency		**10 Possible Points**
☑ Prerequisite 1	Water Use Reduction	Required
☐ Credit 1	Water Efficient Landscaping	2-4
☐ Credit 2	Innovative Wastewater Technologies	2
☐ Credit 3	Water Use Reduction	2-4

Figure 7: LEED Checklist 2009 (www.usgbc.org)

The previous four categories are the major divisions that incorporate most of a building’s sustainable features. LEED also includes divisions such as “Locations and Linkages” and “Awareness & Education” that focus on the transportation of building tenants and the education of the tenants, respectively. It should be noted that these divisions do not necessarily pertain to the construction or components of the building yet still provide valuable accreditation points. (USGBC, 2009)

As a result of Worcester Polytechnic Institute's sustainability pledge, Leadership in Energy and Environmental Design becomes a significant part of any development project within WPI's campus. Additionally, sustainability is one of the most attractive revenue tools for companies and developers alike. The ability to invest in a sustainable initiative sends positive messages about the identity of a corporation, big or small. (Shireman, 2005)

2.5 Similar Facilities

This section will discuss similar facilities that will be of use to the project team in comparing floor layouts, wet lab space, construction timelines, and cost estimates. As previously mentioned, the Gateway Park Lot 3 building will be a mixed-use facility consisting of commercial laboratory, office and educational space. In the alternative design, the addition of a fifth floor that provides an open-area conference or meeting space will be investigated. The project team has identified the WPI Life Sciences and Biotechnology Center and the Charles River Laboratories Building 21 as two buildings that have specific components that are similar to those of the proposed building.

The WPI Life Sciences and Biotechnology Center was the first Gateway Park building and was completed in April 2007. This state of the art facility houses four WPI academic departments, several diverse research groups, and modern conference rooms and offices. Examining laboratory layouts in this building will help the project team finalize similar designs for the proposed building. Also, adjacencies between lab, educational and office space will be investigated to determine effectiveness and overall feasibility. Once the final design for the proposed building's layout is completed, the project group will use the cost per square foot for the current building's lab, office and educational space in order to develop a cost estimate for the proposed building.

Charles River Laboratories (CRL) is an emerging biotechnology and pharmaceutical drug development corporation that is headquartered in Wilmington, Massachusetts. One of the group members worked on a project in the summer of 2009 involving the design of a 100,000 square foot facility mainly comprised of laboratory and office support space. The CRL facility will use estimates from previously built CRL facilities around the world to develop a total cost estimate. By comparing CRL cost estimates with the WPI Life Sciences and Biotechnology Center, the project team will be able to accurately gain a total cost per square foot for the proposed building.

As with previous sections in this chapter, the study of similar facilities helped the project team better understand non-technical areas involved with the design and construction planning of a mixed-use facility. Through its detailed background research, the project team established itself a foundation of knowledge and was prepared for the implications and limitations that might have possibly arose during the technical areas of the project. Anticipation and knowledge of these potential problems helped avoid any unnecessary delays or redoing design work.

3. Architectural Design & Layout

In the group's first meeting with D'Anne Hurd, the project team was provided with architectural layouts developed by Kavanagh Advisory Group and Cubellis Inc. that illustrated the first three floors of the Lot 3 complex. Although functional spaces for Mass Academy and MBI were laid out in significant detail, the rest of the building had designated spaces but no set layouts. It was at the discretion of the project team to devise typical layouts for the non-detailed laboratory and office spaces. To make sure that the building's layouts were practical, the project team researched typical architectural layouts for laboratory and executive office spaces. To visualize each space, the group used a three-dimensional architectural modeling program named REVIT that allowed the team to visualize and quantify materials and spaces in the building. In addition to the building description given by D'Anne Hurd, the team considered an alternative design that consisted of a fifth floor with conference rooms and a space designated for large functions similar to the hall located on the top floor of WPI's Campus Center.

3.1 Given Layouts and Designed Layouts

As mentioned previously, the project team was provided with layouts for two of the prospective tenants that would be working in the Lot 3 facility. The Mass Academy layout was set up similar to a typical high school with classroom and laboratories on one side of the building, and offices and a workshop area on the other. The walls and partitions throughout the floor were congruent with the structural frame and column locations. Massachusetts Biomedical Initiatives used an open floor layout as the facility dictates more laboratory area, classrooms and minimal office space. It was understood that the layouts distributed by D'Anne Hurd accommodated all objectives and needs of the respective tenants. However, aside from the two layouts that were provided, it was up to the project team's discretion as to the floor layouts for the remaining spaces.

To gain a better understanding of typical laboratory set ups, the team requested a tour of laboratory space in WPI's Life Sciences and Bioengineering Center. Professor Pins allowed us to tour his personal laboratory space under the supervision of Sahil Bhagat, a WPI undergraduate research assistant. Our visit was very helpful in that we saw support space for client needs, typical laboratory layouts, construction materials used, equipment placement and column placement.

To develop a basic floor plan for the executive office spaces, the team decided to emulate offices that the team had visited in the past. Attractive features within the office were incorporated where possible. One of the major features requested by D'Anne Hurd was a central area with a photocopier and fax machine that would service all of the offices within the suite. The team's architectural design incorporated this request with offices that line the exterior of the building while the central space was designated for support services such as document reproduction capabilities. The design was also consistent with the office spaces researched by the group.

As the team discovered, the preliminary structural scheme established for the Mass Academy and MBI layouts helped in designing the architectural layouts for the office space. Where possible, the team aligned walls and partitions where columns and girders would be present. Additionally, depending on the usage of floor space, the team was able to justify in certain instances the placement of a column within the middle of a room. For instance, it is not practical to place a column in the middle of a classroom due to visual concerns. On the contrary, the laboratory tour showed the team that columns in laboratories are not a hindrance to the tenants and can sometimes be used as wall backing for cabinets and shelves. To satisfy structural considerations, the anticipated locations of cross and diagonal bracing for lateral load resistance were considered in door and wall placements.

3.2 Architectural Modeling

To aid in visualizing the actual three-dimensional concept of the facility, the project team decided to use the three-dimensional Building Information Modeling software system REVIT. REVIT is architectural and structural modeling software that generates layouts that allow the observer to understand how the building will "look". It is an object-based modeling system, meaning typical construction materials such as concrete, brick and glass are selected in designing the building. This capability demonstrates a more realistic model of the building and aids in quantity takeoffs.

As shown in Figure 8, the team's proposed laboratory floor space (located on the left) consisted of a U-shaped hallway starting by the lobby entrance. Wall locations were selected based upon wall placements in the lower floors and also to divide up large areas if applicable. The first rooms along the hallway were designated to be offices and cubicles for the researchers. As the corridor wraps around the interior of the facility, the space transforms from office space to laboratory space. Typical laboratory space consists of open areas with laboratory benches parallel to one another. Rooms that will be designated for laboratory use will incorporate benches along the interior walls with fume hoods alongside each workstation. The center area that is surrounded by the laboratories and offices will be used for storage, dark rooms and other tenant fit out. This layout is consistent with the layout observed in our tour of the Life Sciences and Bioengineering Center.

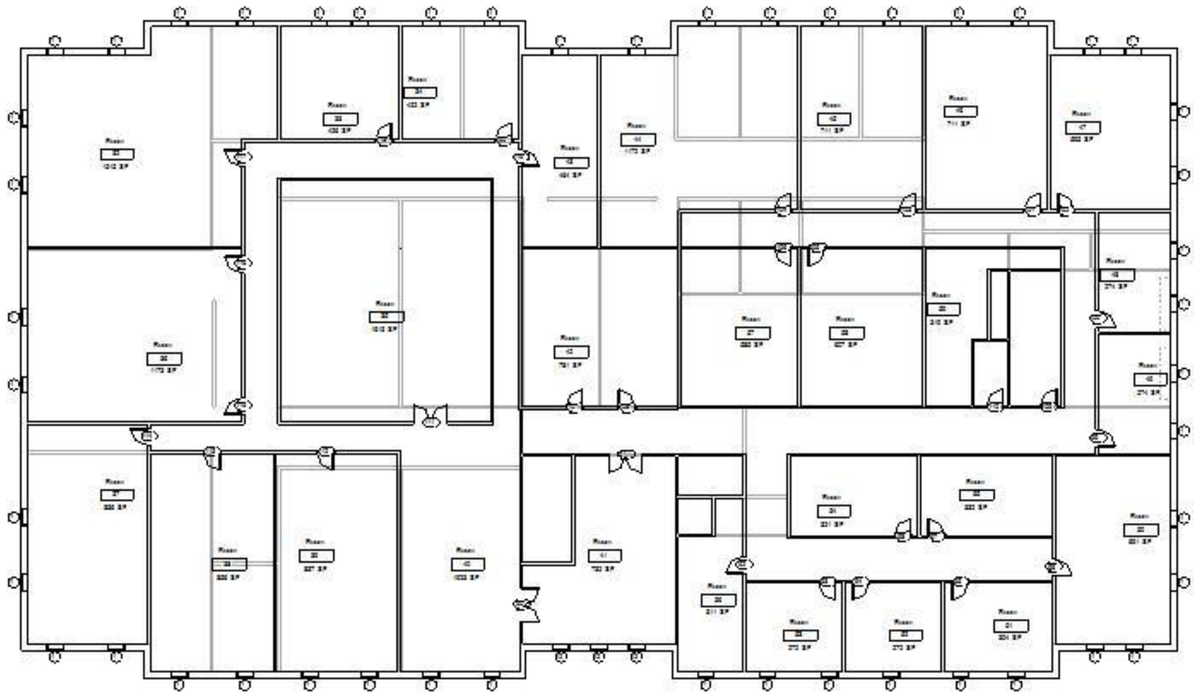


Figure 8: Laboratory & Office Architectural Layout

In selecting the exterior walls of the facility, the team tried to match the existing exteriors of the surrounding facilities. The WPI Life Sciences and Bioengineering Center uses brick as an exterior with large windows. This same design was used for Lot 3. The exterior was selected as Brick on Metal Stud. This façade is less expensive than other brick façades and also matches the surrounding facilities, blending the building into the Gateway campus. The selected windows tried to emulate the size, periodic placement and shape of the windows in the Life Sciences and Bioengineering Center. A three-dimensional view of the facility can be seen in Figure 9.

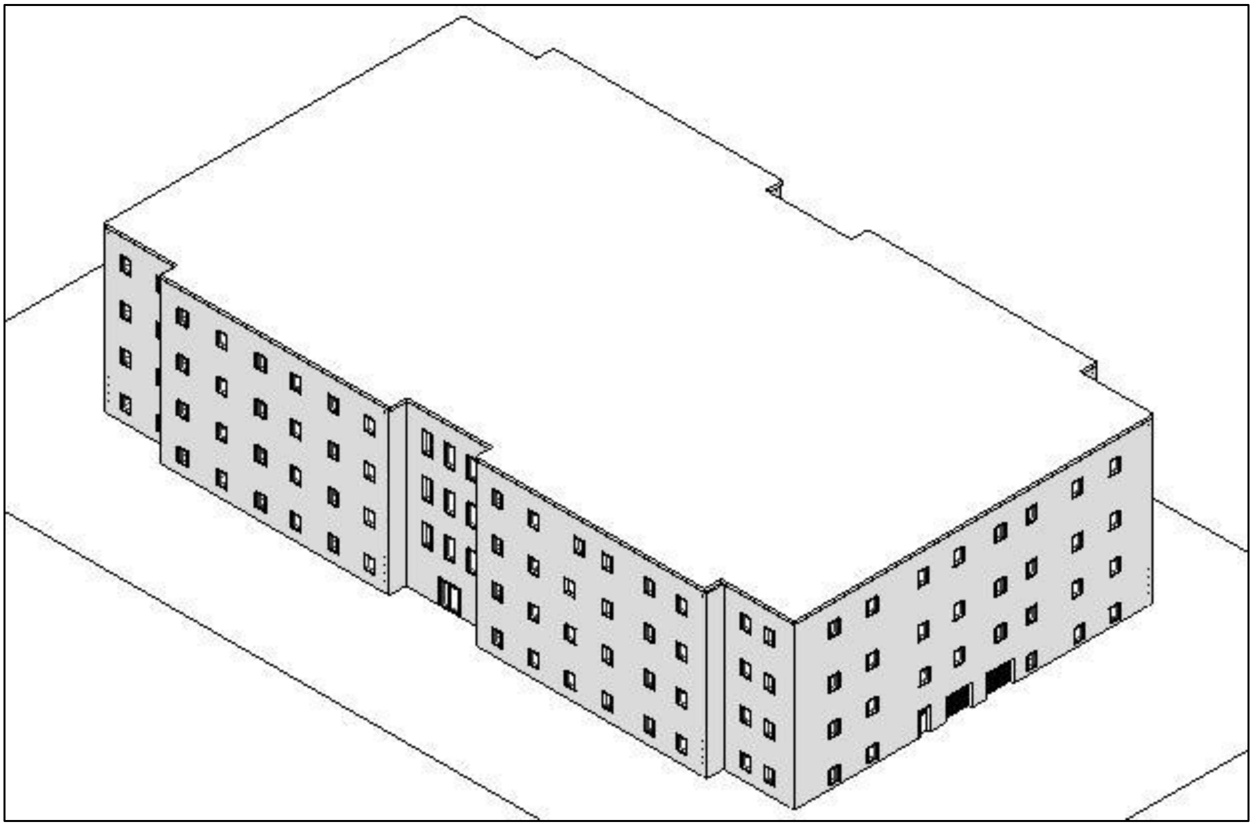


Figure 9: 3-Dimensional View of Gateway Mixed Use Facility

3.3 Alternate Approach: 5th Floor Conference Center/Odeum

The initial proposal for Gateway Park "Lot 3" building is four 20,000 sq ft floors mainly consisting of laboratory or educational space. It was expressed to the project team that alternate designs involving a fifth floor could be considered if there was a need. Wet labs are designed, built and fitted to a certain specification. Equipment, HVAC and MEP systems, and other characteristics of a lab are built for its intended purpose. To change or alter the space in order to use it for another purpose would be expensive and time consuming. The most obvious use of an additional floor would be wet lab space similar to the underlying floors; though, building additional lab space could be a risk to the owner if the space cannot be filled. Another option is to shell out all or part of the top floor, that is, not to include any interior walls and develop the space at a later date. However, empty space is not a revenue producer.

Figure 10: Fifth Floor Alternative Design Architectural Layout

While much of the first four floors of the proposed building already has detailed preliminary design, the project team proposed a fifth floor that features an open-style conference center or odeum along with small meeting rooms and additional office space.   No such similar flexible or open space was found in the initial designs of the building. As shown in Figure 10, half the floor would be dedicated to conference rooms, but the other half would be an open-style conference center. This space serves as a general assembly area that would have the capabilities to house events from small lectures to large conferences and conventions.   The meeting space would have the capabilities to house student groups, local community groups, small business meetings, lectures, etc. With its modern feel and newest technology, this space certainly would attract numerous types of users and garner consistent revenue. The conference center side of the floor consists of limited interior columns to not only maximize open space, but also ensures that it could more easily be transformed into additional laboratory space. Flexible and open space highly complements the laboratory space currently planned and gives the building an additional feature that would make it more attractive to prospective tenants.

With the addition of the “odeum” alternative, the overall cost estimate had to be adjusted and can be found in Chapter 7. The estimate reflected additional structural framing, wall space and MEP equipment that would make up the supplementary floor space. The structural changes reflected dead and live loads that must be considered with the open-area floor. Although the floor will be originally planned for the open-area “odeum,” the frame of the building was designed to support the worst-case scenario of its use. The structural design, cost estimates and construction schedule reflect these changes.

4. Structural Design

One of principle deliverables of our project is the structural design of the building. The structural bays were coordinated with the layout of the building, or in this case the laboratory space and school. Adjustments were made to the bays if specific layouts are necessary. The frame was made up of a grid with repeating standard structural bays. Special areas, such as elevators, were handled separately. Included in the structural system are bay sizes, shape and size of structural members, floor compositions and curtain walls. These elements were established to resist gravity and lateral loads as appropriate. The gravity load design was completed for two frames: one of structural steel and one of reinforced concrete. The structural steel frame was chosen for further design based on cost per square foot, local availability of material and constructability considerations, such as erection and fabrication. The steel system was then designed for lateral loading with necessary adjustments being made to framing members. Next, the project team designed standard connections or reinforcement details for the structural frame. Once the structural frame was finalized, the project group performed the foundation design to determine the necessary footing sizes to adequately transfer the load from the structural frame to the supporting ground. Engineering calculations were prepared by the project team and supported through the use of spreadsheets and simulation programs such as RISA.

4.1 Structural Bay Layout

Before commencing the design of the structural components, structural bay layouts were finalized. The predetermined floor layouts from the proposed tenants guided the location of columns and the arrangement of structural bays. The project team also visited the WPI Life Sciences and Biotechnology Center to get a view the floor layouts of lab space. The floor layout for the lab space was relatively simple and flexible since the space could adapt to column placement.

4.2 Reinforced Concrete

The project group prepared hand structural design calculations for a typical bay of a reinforced concrete frame. In all reinforced concrete bay designs, a superimposed dead load of 7.5 pounds per square foot was assumed for mechanical equipment, floor coverings and ceilings. Similarly, the design of the typical bay accounted for the use of laboratory space, in which a live load of 125 pounds per square was assumed. Loads were calculated based on the requirements of the *ASCE Minimum Design Loads for Buildings and Other Structures* (ASCE 1997). The group's initial idea was to design a one-way slab with a T-beam-girder gravity load system for a typical bay of 35' x 22'. This design would be helpful in determining the thickness and weight of the members in regards to the anticipated issues listed above. Preliminary analysis of the floor layouts and the resulting structural bays yielded that the members carrying loads over the span would most likely be too thick or too heavy for the practical use of a reinforced concrete frame. The weight of the members would increase cost of the members themselves and the supporting columns and footings; the thickness would leave little to no room for MEP piping and wires and cause the ceiling height to change.

The group also considered other options for a reinforced concrete frame such as the use of precast floor planks, joist construction, or using additional T-beams to better distribute load on girders. Joist construction was chosen for further investigation as it was determined to be the easiest way to determine whether any type of concrete design was feasible. The joist construction featured the same bay size and loading conditions as the one-way slab design above.

As a result of the analysis of differing methods discussed above, reinforced concrete was not a viable option for the structural frame of the proposed building.

4.2.1 One- Way Slab, T-Beam and Girder Design

Design of a one-way slab according to specifications in ACI 318 resulted in a floor that was 6 inches thick. Specifically, a minimum height was determined based upon the type of support and the corresponding span (ACI Table 9.5a). Figure 11 shows the T-beam spacing and bay size layout for a typical section of the building. The stem of the T-beam was calculated to be eight inches wide by seventeen inches deep. Next, the supporting girders were designed and found to be sixteen inches wide by twenty eight inches thick. Both the beam and girder design were completed in accordance with ACI 9.5 in order to avoid deflection concerns. As a result of the heavy live load conditions and the long spans, when the slab was combined with the thickness of the girder, the total floor system was nearly three feet deep.

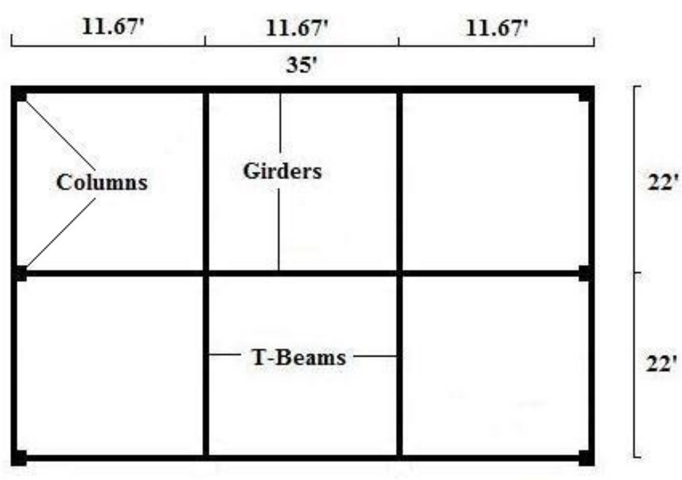


Figure 11: Typical Bay for Reinforced Concrete Frame

The first step in the design of the one-way floor slab was to estimate the floor thickness based upon the span between columns. A trial size of six inches was estimated in accordance with ACI 318-08. Next, the dead and live loads were calculated based upon the trial unfactored loads and using two different loading combinations. The purpose of the strength reduction factor is to allow for the probability of under-strength members due to variations in material strengths and dimensions, and to allow for in accuracies in design equations (ACI 9.3.2.1). After a strength reduction factor was chosen based upon the slab being tension controlled, the slab thickness was analyzed to make sure it was adequate for the moment. The slab thickness was then analyzed to make sure it was adequate for shear. Finally, the reinforcement for one-way slabs was considered using the ACI Moment Coefficients and found to require No. 4 bars on top and bottom at twelve and sixteen inches on center respectively.

The T-beam was designed based upon the trial factored loads acting on the beam. A strength reduction factor was applied to the resistance side of the equation. The loads were then multiplied by load factors to establish the governing combination. The next step was choosing the actual size of the beam stem. As shown in Figure 12, a beam with a width of eight inches and a depth of seventeen inches was selected along with the use of No. 3 stirrups based on the required shear capacity in accordance with ACI 318-08. The effective slab width and the effective T-beam flange width were calculated in accordance with ACI 8.12.2. The effective flange width was determined based on the beam span, spacing and slab thickness. The flexural steel reinforcement was designed once the new dead load and moments were calculated. As Figure 13 illustrates, two #8 bars were used on top and six #8 bars on the bottom of the T-beam to meet requirements so no steel was required in the slab. The bars in the top of the beam are compression steel. After defining the steel for shear reinforcement, the last step was to calculate the bar cutoffs and lap splicing.

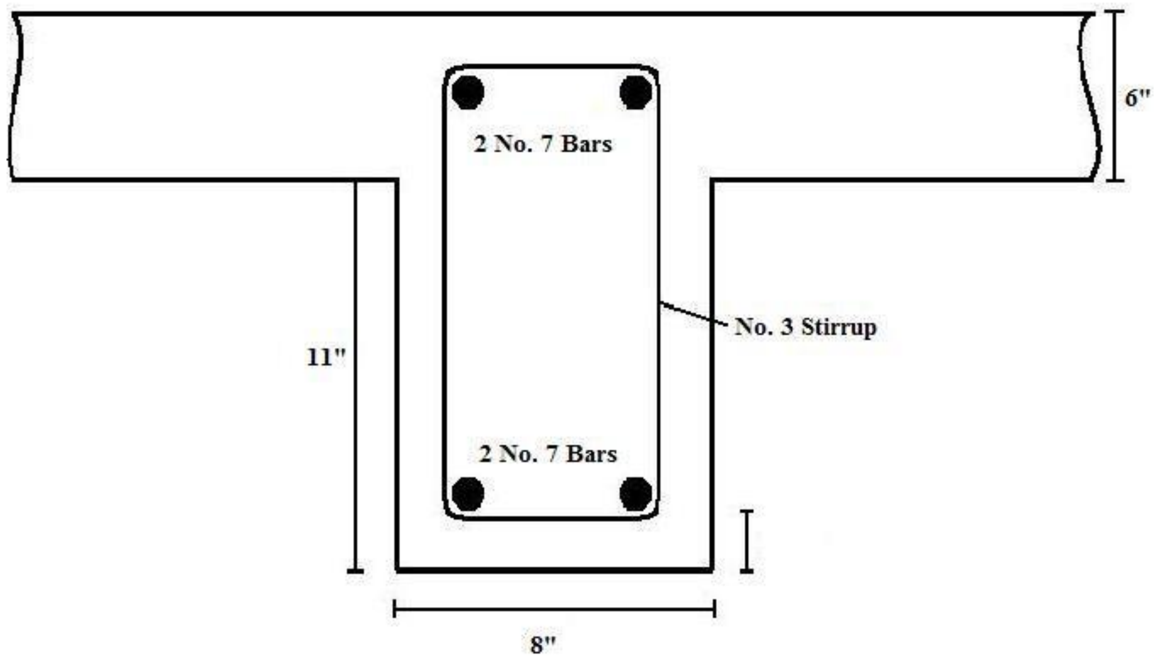


Figure 12: Typical Slab and T-Beam Design for Reinforced Concrete Frame

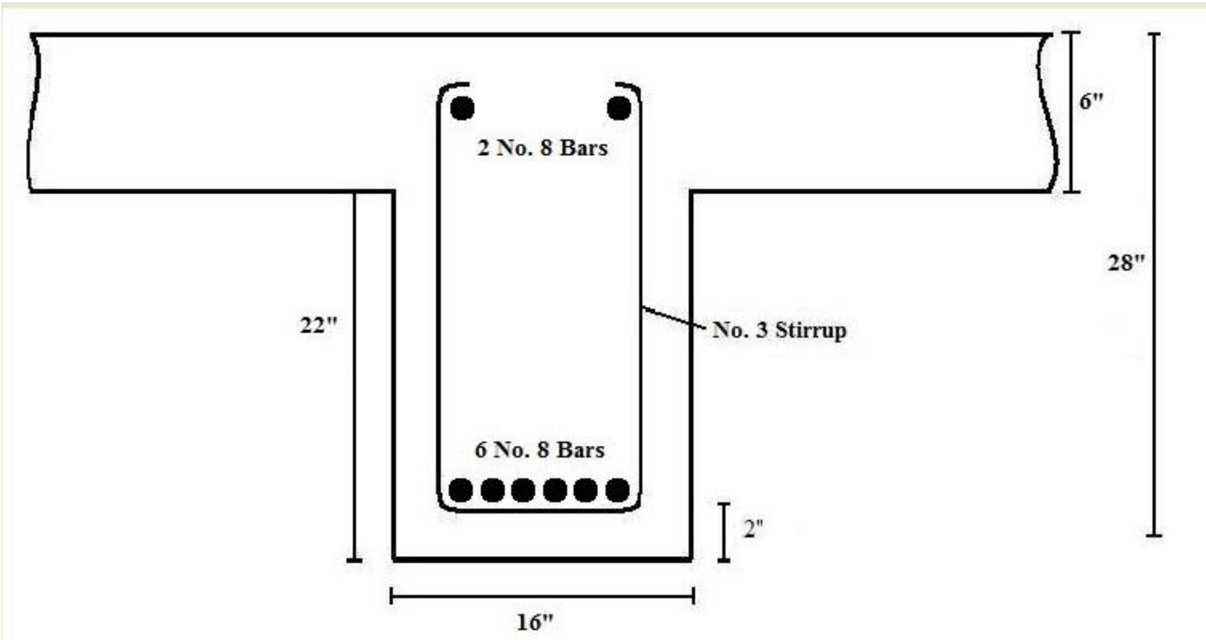


Figure 13: Typical Girder Design for Reinforced Concrete Frame

The girder was designed to support the loads of the one-way slab and T-beams. The use of a T-beam girder design was used to reduce the extension of the member below the slab. First, the dead load of the member was estimated and the factored moment was calculated. As shown in Figure 13, the trial size of the girder was determined to have a width of sixteen inches and a depth of twenty-eight inches in accordance with ACI 318-08. Once the size of the girder was determined, the design load was recalculated using the proper dead load of the girder. After the design moment was revised, the required area of reinforcing steel was calculated, and the bars were selected. As shown in Figure 13, two No. 8 bars and six No 8. bars were used on the top and bottom, respectively. Finally, No. 3 stirrups were used in accordance with the design for shear.

4.2.2 Joist Construction Design

The joist construction analysis features a joist floor system that is comprised of a continuous slab, beam and girder. The design was based upon a similar system in the WPI Kaven Hall Student Lounge. The reason for analyzing this system was that it might be able to reduce the depth of construction within the bays by better distributing loads from the slab and joists to the girders. In order to help accomplish this task, more joists were used and were spaced thirty inches apart. A continuous slab was estimated at 4.5 inches based upon the calculated moment and ACI Table 9.5. Welded wire fabric (4 x 12 – W3.5 x W2) was used for shrinkage and temperature control.

Based upon ACI 9.5a, the joist was estimated to be 20" deep below the bottom of the slab and 7" wide. After recalculating the dead load and loading combinations, maximum negative and positive moments were calculated. In accordance with ACI 7.7.1c, a minimum cover of ¾"was estimated. The reinforcement bars were then selected based upon the calculation for the required area of steel. The joist will need two #8 bars and one #6 truss bar on the bottom and 1 # 8 bar on top. The shear capacity of the joists were also analyzed and found to need to be tapered 2.5" at 3' from the end of the joist in order to meet the minimum requirement. This was done in accordance with Fig 10.11.1 in *Reinforced Concrete Design* (Wang, 2007). Finally, the embedment and development lengths of the bars were checked in accordance with ACI 12.11.3. This involved examining the joists at the support and at the mid-span.

The last step in the joist construction design was to design the girder that will carry the loads from the slab and joists to the columns. The girders were found to be 20" wide and 32" deep. The size of the girder can be attributed to the heavy loading conditions, the 35' span, and the weight of the 15 joists in the bay. Furthermore, the girder design ultimately failed because the member did not meet the minimum width for the amount of reinforcement bars that were needed. If the width was increased, the member would either be too heavy and fail in shear capacity, or would be using reinforcement bars that are typically used for columns only.

4.2.3 Design Problems with the Reinforced Concrete Frame

After the design of a typical bay with slab, beam and girder bay completed, it was evident that the preliminary analysis was correct and further design of the reinforced concrete frame was not pursued. In the preliminary analysis, the project group discussed the practicality of designing the structural frame with reinforced concrete because size of the bay and, more specifically, the thirty-five foot column-to-column span that the girder would traverse were design concerns. As was mentioned while discussing the floor layouts, the structural bays had been previously established by the architect and the functional layout, and altering those designs would have adversely affected the partial floor layouts the project group received. The combination of the slab and girder thickness was nearly three feet and would be too large. The depth of the floor system would not allow room for mechanical, electrical and plumbing equipment to be properly placed in the proposed suspended ceiling without significantly altering the height of the ceiling itself. One way to work around this problem would be to not have any piping or wiring running perpendicular to the girders and simply paint the concrete for an interior finish. Another option would be to have the perpendicular systems running through holes cast in the girder. However, such plans to alter or avoid all girders would most likely cause design problems or involve inefficiencies in the MEP systems. This is something that would not be practical or cost effective.

The analysis of other bays would generate similar results that suggested against further pursuing the design of a reinforced concrete frame because those spans are larger than the typical

35’ x 22’ bay analyzed above. This would only increase the loads carried by the girders and increase their thickness even more. Finally, the project group has presented an alternative approach to the architect’s design that includes an additional floor that will feature an open-style, large conference or lecture hall. This hall will feature a 115’ x 88’ bay and would be far too long of a span for a reinforced concrete floor system to practically carry loads to the columns.

4.3 Structural Steel Design

The design of the structural steel frame began with developing the loading conditions, due to both gravitational and lateral loading. A steel and concrete floor system, composed of a concrete slab on steel decking, infill beams and girders, as well as columns, was designed to support the gravitational loads. Once the gravity system was determined, the lateral load resisting system was considered. A braced structural frame was designed to allow for simple connections, which reduce costs of fabrication and erection. The determined floor layouts accommodate the required space for a braced frame design. The final aspects investigated for the structural steel design included base plates, column splices, and connections.

4.3.1 Concrete Slab and Steel Decking Design

Developing the concrete slab and steel decking system is the first step in structural component design. This particular system is composed of a continuous concrete slab and decking system that is supported by the underlying beams and girders. First, code requirements were investigated to assure the design would be acceptable. *IBC* provisions specify a minimum 3” concrete floor slab for type 1 construction to provide a 2-hour fire rating. The project team decided to use a 4.5 inch floor slab to comply with the building code and to better resist deflection and vibration. Next, a steel deck was determined to complete the composite slab system. A 2” LOK-Floor design table from CMC Joist & Deck was utilized for the design. For constructability purposes, the project team decided upon an unshored floor system. A 22 gage 2”LOK-Floor deck as shown in Figure 14, with a maximum unshored clear span of 8.14 feet for 2-span applications was selected. (2” LOK-Floor, 2009) Considering the largest tributary width of an infill beam is 7 feet, the maximum unshored clear span length is suitable. The 4.5” concrete slab on a 2” corrugated deck will have ¾” inch shear studs at a length of 3.5”. These dimensions abide by the *AISC* Specification I3.2c(1) as each shear stud extends 1.5” above the steel deck and maintains a 1” clearance below the top of the concrete slab. It is also notable that the concrete slab extends more than 2 inches above the steel deck.

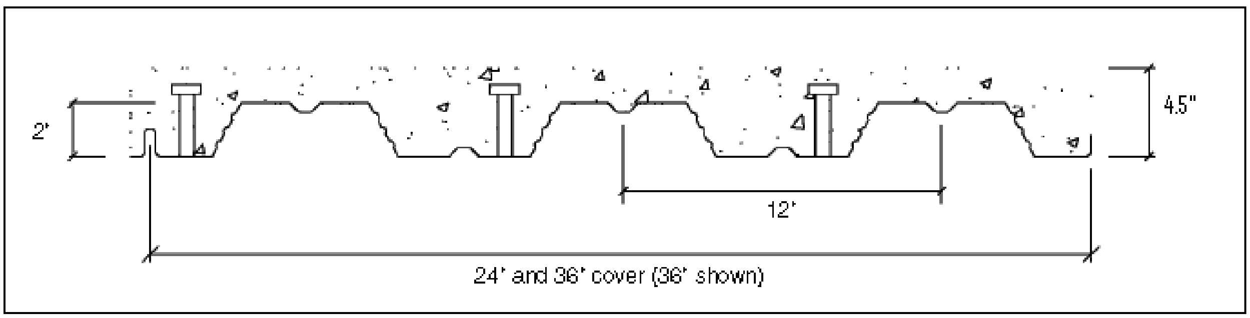


Figure 14: 2" LOK-FLOOR Decking with 4.5" Concrete Slab
(www.njb-united.com)

4.3.2 Composite Infill Beams and Girders

The loading due to gravity, shown in Table 2, was investigated to begin the composite floor design for infill beams and girders, and the calculations are presented in Appendix 10.5.1. The typical dead loads considered in this investigation included the concrete slab, floor decking and insulation, MEP, and suspended ceilings. When investigating the live loads of lab space, no standard was found. The project team decided to use 125 psf, which is the minimum design load of Light Manufacturing from *ASCE 7.* A snow load of 50 psf and a wind speed of 100 mph were also determined from *ASCE 7* for Worcester, MA. It is also important to include the actual steel beam weight in the dead load calculation. The floor layout considerations led to three typical structural bays: 35’ x 22’, 40’ x 22’, and 35’x 28’. Each structural bay has five infill beams spanning 35, 40 and 35 feet, respectively. As a result, the maximum tributary width of an infill beam is 7 feet, and 5.5 feet in most cases.

Table 2: Typical Loading Considerations

Dead Loads			**Live Loads**	
Concrete Slab (145 pcf)	60 psf		Light Manufacturing	125 psf
Floor Decking & Insulation	10 psf			
MEP	5 psf		**Snow Load**	20 psf
Suspended Ceilings	2 psf			
Total	77 psf		**Wind Load**	100 mph

Each floor member, both beams and girders, was designed as a composite system with the floor slab. A composite floor system is formed when shear studs are used to connect the top flange of the beam or girder to the concrete floor slab. As a result, the floor slab becomes an integral part of the beam and enhances the beam’s performance. One of the advantages of a composite floor system is that it uses the concrete and steel to their respective strengths. The concrete slab is in compression, which makes use of the concrete’s high compressive strength. A large percent of the steel section is kept in tension, which is also very advantageous. As a result, less steel is required for the same loading and spans as a noncomposite floor structure. A composite floor system also has greater stiffness and less deflection than noncomposite sections. The only disadvantage of a composite floor system is the additional cost of furnishing and installing the shear studs, which may exceed the cost reductions from use of smaller steel members in spans that are short and lightly loaded. (McCormac, 2008)

In the design of each floor member, the moment capacity and deflection were investigated during service considerations as well as during unshored construction. The investigation during construction was conducted by referencing Table 3-2 and Table 3-3 of the *AISC Manual*. It is important to note that the steel beam is the only supporting member during the unshored construction investigation because the system will not act compositely before the concrete is cured. Flange and web local buckling are checked with data from Table 1-1 of the *AISC Manual*. It is assumed that the formwork provides sufficient support to prevent lateral torsional buckling. As for the composite beam design, Tables 3-19 and 3-20 of the *AISC Manual* were referenced to assure the design was completed with sufficient moment capacity and within the deflection limitations. The maximum allowable deflections were 1.5 inches and length/360 for unshored construction and service capacity, respectively. In addition, the depth and web thickness of the steel beams were investigated to assure the system had adequate shear capacity.

Plan views of a few typical bays are shown in Figure 15, Figure 16 and Figure 17. Figure 15 displays a 22' by 40' bay with five W21x44 beams spanning 40 feet. These beams are significantly larger than those in Figure 16 where W18x35 beams span 35 feet. It is important to note that each beam has a tributary width of 5.5 feet. As for Figure 17, the W18x40 beams have a tributary width of seven feet, which justifies the increase from 35 to 40 pounds per linear foot over a 35-foot span.

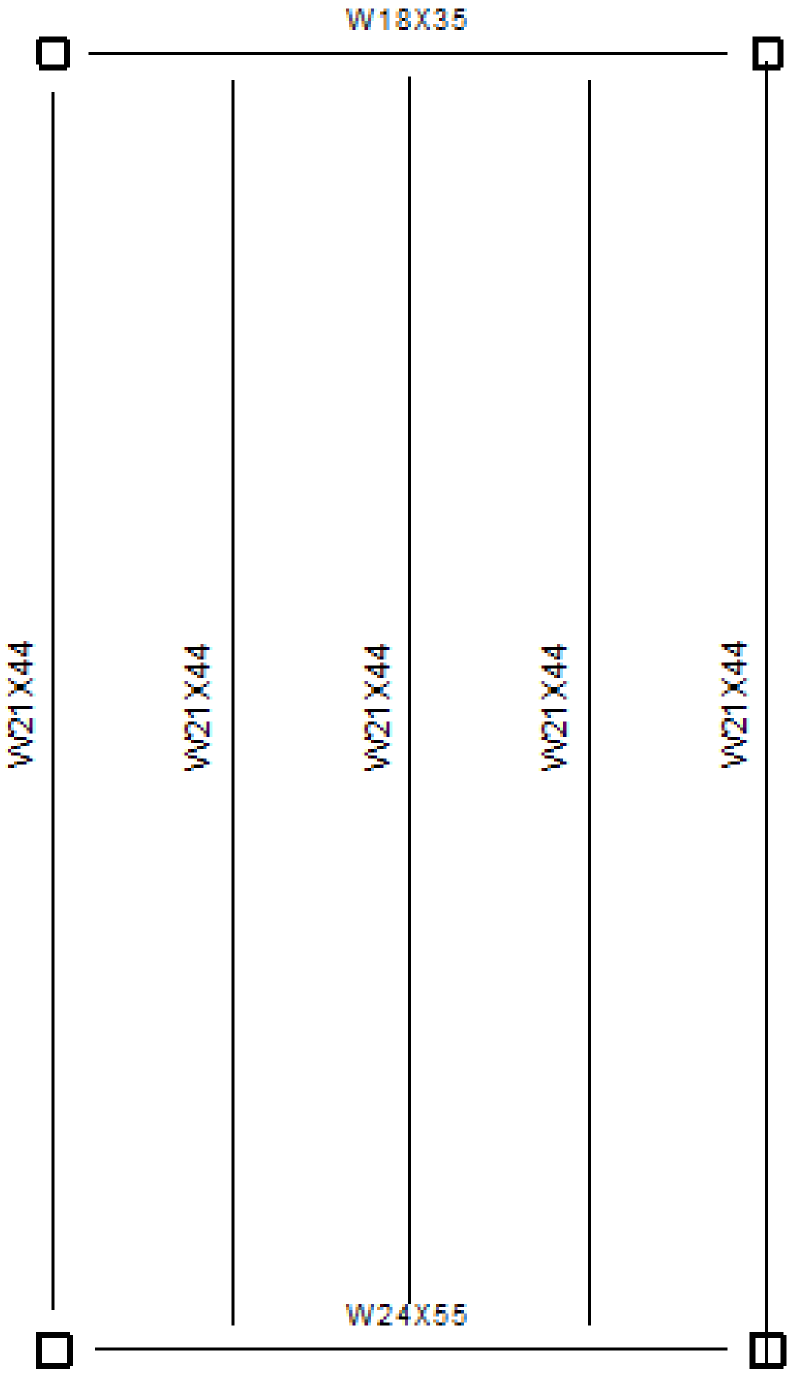


Figure 15: 22' x 40' Exterior Bay

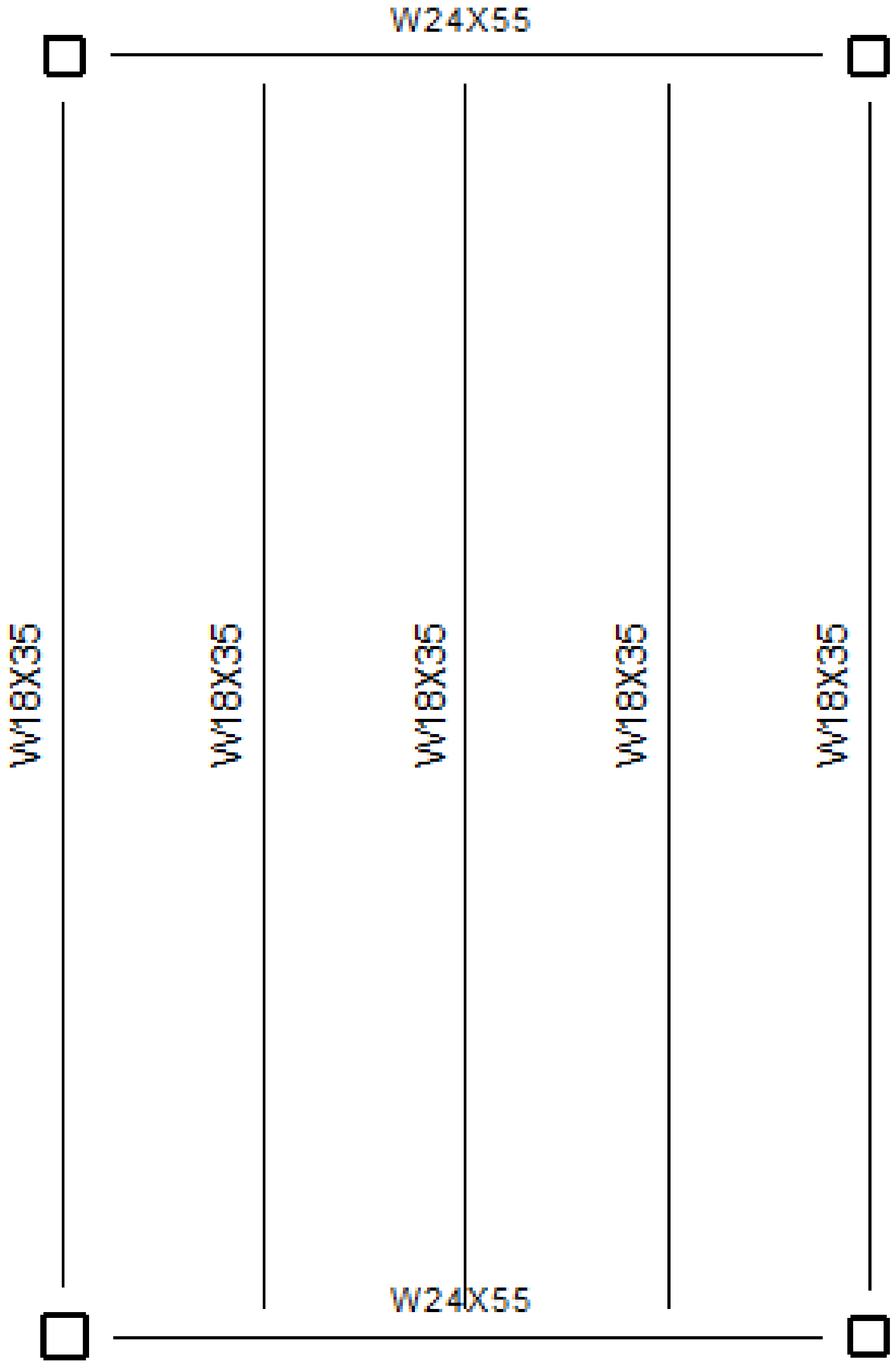


Figure 16: 22' x 35' Interior Bay

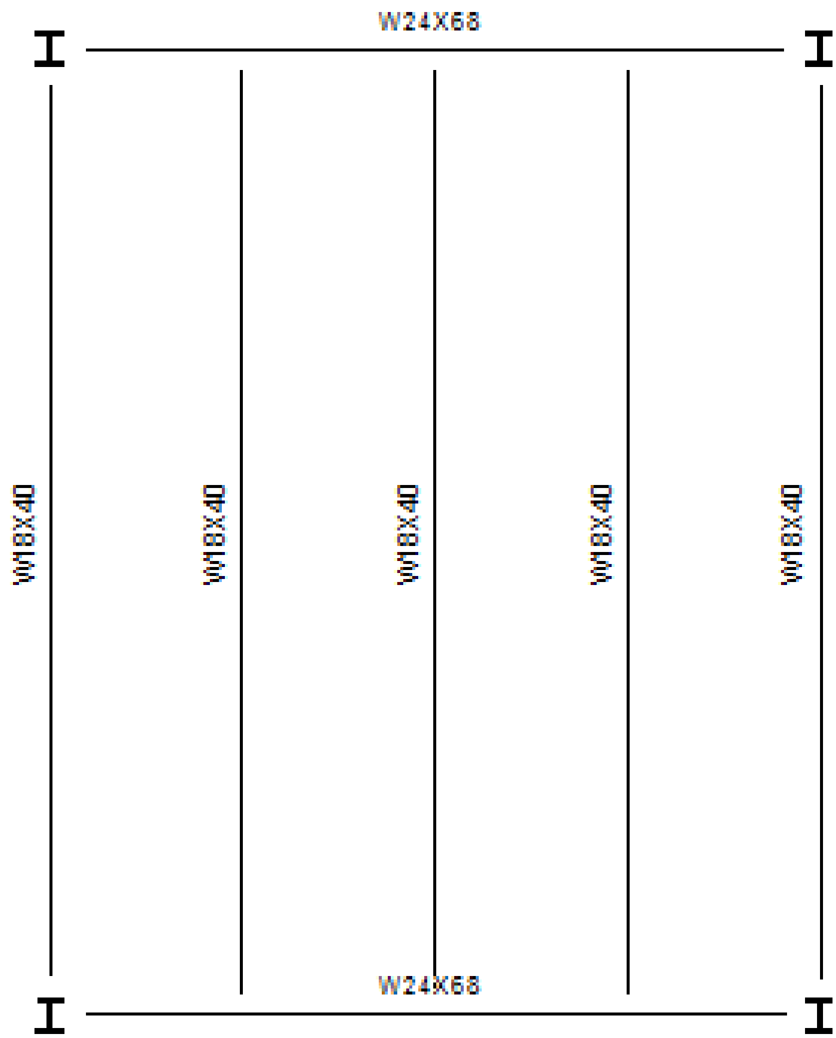


Figure 17: 28' x 35' Interior Bay

4.3.3 Column Design

Columns that are a part of the lateral force resisting system must withstand gravity, wind and seismic loads. The remaining columns are referred to as leaning columns and are only required to withstand gravity loads. The typical gravity loads used are the same as those used in the composite beam design. Each interior, side and corner column was designed according to their respective tributary area coupled with the gravity loads. An example calculation is shown in Appendix 10.5.2. All columns were designed to be non-slender using Table 4-4 of the AISC

Manual. Figure 18 and Figure 19 show two typical column lines in the building design. The 12-foot centerline dimension, Figure 21 in Section 4.3.4, between each floor will provide a desirable clear height of at least nine feet between the drop ceiling and floor construction. The floor system should only reach a height of six inches, leaving 2.5 feet of usable space above the drop ceiling for structural members and MEP systems.

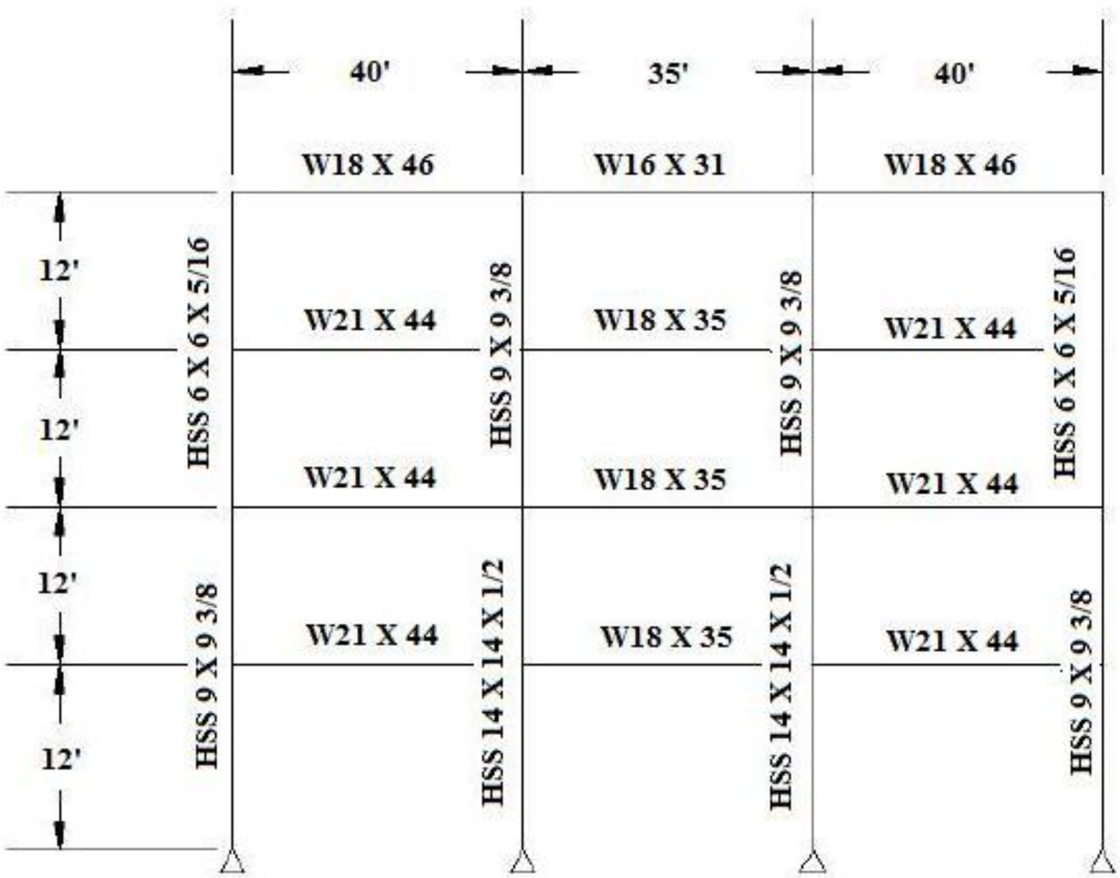


Figure 18: Typical Column Line 1

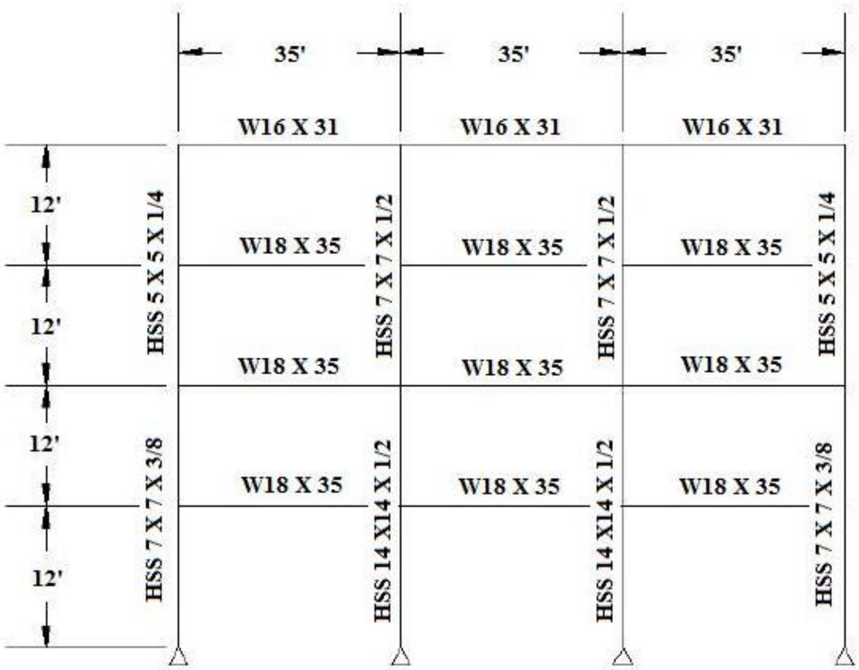


Figure 19: Typical Column Line 2

Since the initial building design called for a four-story building, the project team decided to design primarily square HSS shaped columns. The most efficient compression member is one that has a constant radius of gyration. Round HSS tubing has a constant radius of gyration with square HSS tubing being the next-most-efficient compression member. The flat faces of the HSS tubing, however, allow for simple and quick connections. (McCormac, 2008) This essentially governed the project team's decision to use square HSS tubing for columns.

The project team decided to fabricate each four-story column from two sections. The splice in the column would occur just above the second story, or right above the third floor. There were a few reasons behind this decision. First, this design will ease and accelerate the erection process because additional structural support would be required for columns spanning 63 feet during construction. The two-story sections will also reduce the cost of each column. For instance, the first story bears more load that the third or fourth story columns and is therefore larger and more expensive. As for the location of the break, the splice between the base and upper column section will not interfere with the connection between the base column and the third story floor system.

4.3.4 Alternative Design: 5th Floor Odeum

As an alternative design, the project team recommended adding a fifth floor to the building. Half of the floor would be occupied by additional lab space, but the other half is something that is unique and useful. The alternative design includes an odeum, as shown in Figure 20, which spans 88 feet by 115 feet with no interior columns. The remaining structural design will now incorporate this alternative design concept. The same loading combinations apply on the 5th floor as the other floors to provide the most flexible space. The roof above the odeum, however, spans from the column left of the entrance to the left side of the building and covers an area of 9900 square feet with no interior columns. The beams will span 88 feet with tributary widths of five feet to total 20 infill beams.

The project team first investigated W-Shaped members for the large span. A W33x118 was determined to be adequate, but extremely heavy and expensive. As a result, open-web steel joists were investigated. Design tables from the *Steel Joist Institute* aided our design for the roof span above the odeum. (Canam Steel Corp, 1997) A 48LH16 longspan steel joist was selected. This joist is only 42 pounds per linear foot and has a depth of 48 inches. The obvious advantage of the joist is the lighter deadweight of 42 PLF instead of the 118 PLF of the W-Shape. On the other hand, the joist has a depth of 48 inches compared to the beam depth of 33 inches. The project team considered both options, but selected the open-web joists as the best option. The depth was only 15 more inches to use the lighter weight joists rather than the heavy w-shaped beam. The additional load on the columns and the pricing of twenty 118 PLF beams would obviously cost more than the additional 15 inches of interior wall, exterior enclosures, and other vertical pipes needed to accommodate the deeper member.

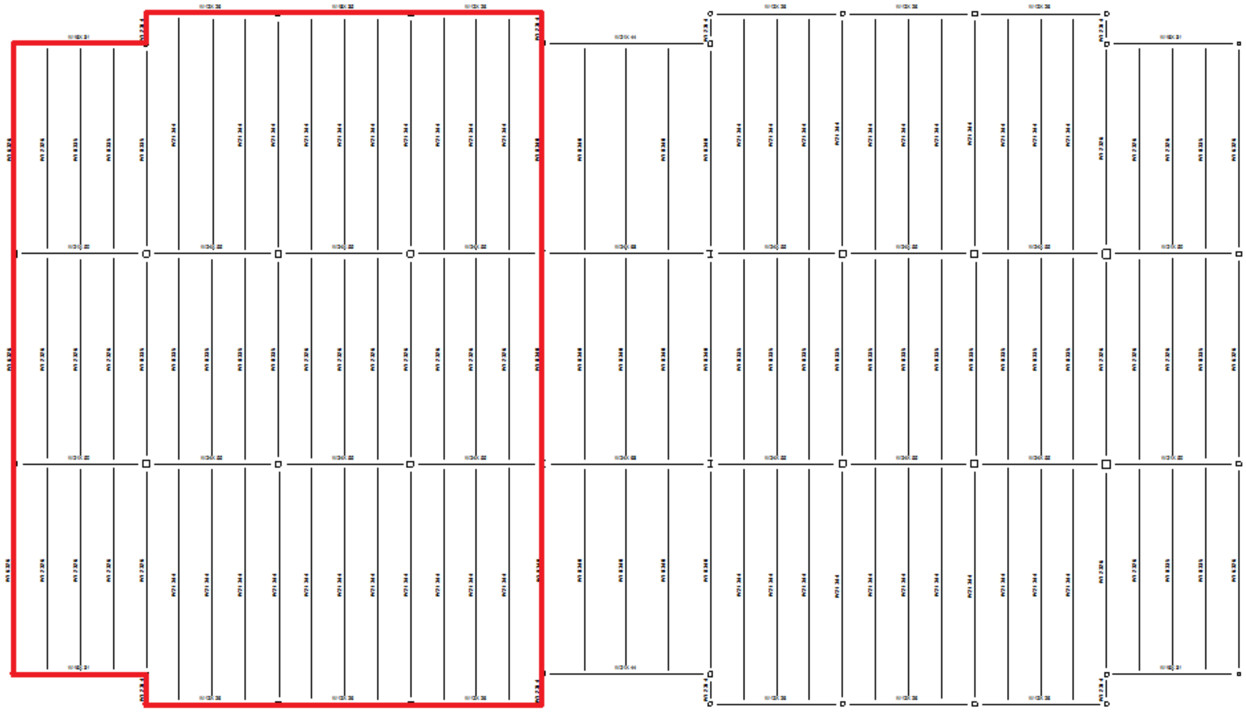


Figure 20: Odeum Location

The additional floor and new design for the large roof span also affected the column sizes. It is important to note that the column splices will remain at the same location. The upper section of the column will extend for a third floor. The columns supporting the large span of the odeum obviously acquire a much larger tributary area and, in turn, larger loads. The 48-inch depth of the girder joist also requires a taller column to provide sufficient clear height in the odeum. The project team decided a 15-foot centerline dimension would provide adequate clear floor height of at least nine feet as depicted in Figure 21. The effective length of the columns on the top floor supporting the odeum is considerably larger than the other floors, but will not govern the member size because the design loads are less than those for the column segments spanning the third floor. In addition, the height of the 5th floor in all areas besides that of the odeum will remain at 12 feet.

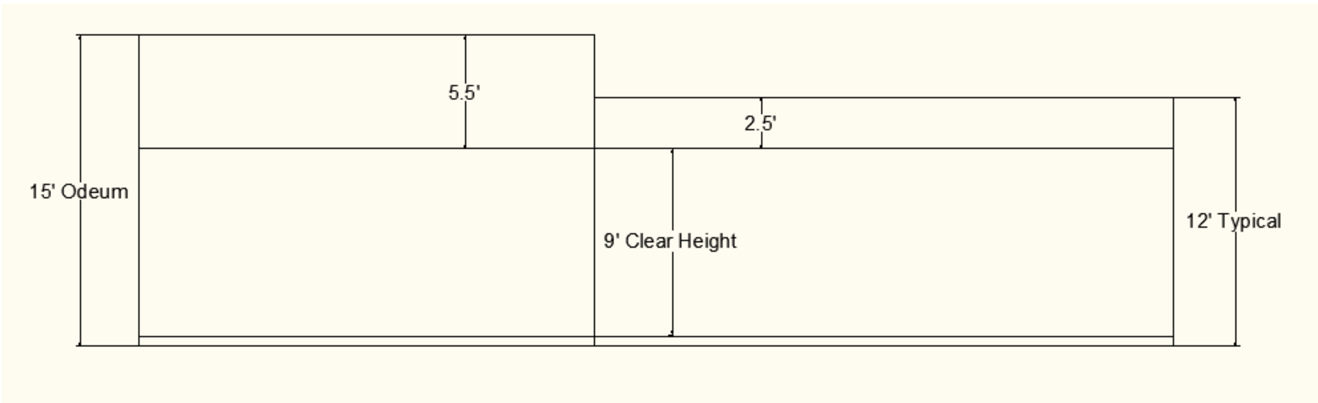


Figure 21: Ceiling Clear Height

4.3.5 Lateral Load Resisting System

In addition to the gravity loads, the project team also inspected wind and earthquake loads. These loads exert lateral forces on the building that need to be accounted for. Both braced and unbraced frames were considered, but the project team determined the braced frames to be most suitable for Lot 3. Braced frames utilize diagonal members and simple connections, which are very cost effective because the methods of fabrication and erection are faster and easier. Unbraced frames require fixed end connections that can be difficult and time consuming because the connections are complex. However, unbraced frames are used to open up floor space whereas a braced frame may interfere with layout considerations. The project team determined a braced frame would not interfere with the proposed floor layouts from the tenants. The locations of the braced frames in the building are shown in Figure 22.

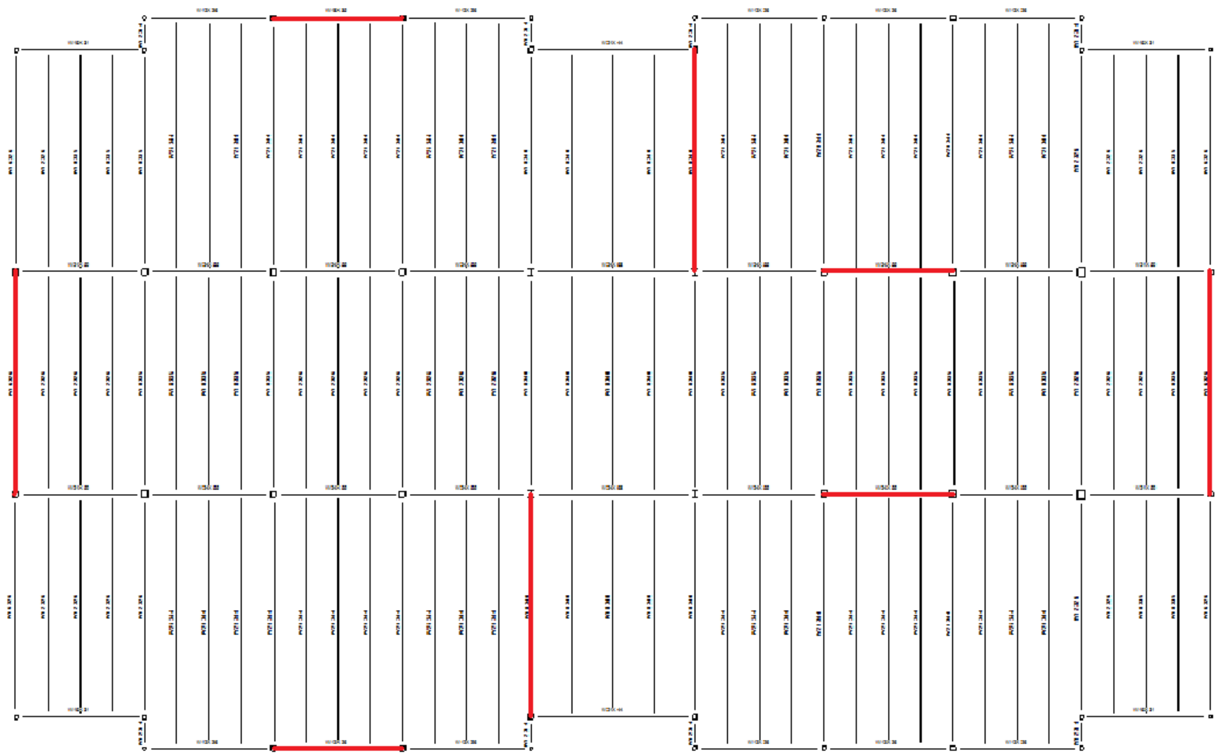


Figure 22: Braced Frame Locations

The wind loads were determined to be the governing lateral forces in accordance with *ASCE 7*. These loads were distributed along each floor line according to their respective tributary area. The forces in each frame member were calculated using the method of joints. When designing the braced frame in Figure 23, these governing loads were divided by four because four braced frames would support the lateral forces in each direction as shown in Figure 22. The resulting axial forces in each diagonal member spanning the 22’ bays are noted in Table 3. These member forces were calculated by method of joints. The forces in the diagonal members were then analyzed using Table 4-4 of the AISC Manual to determine adequate HSS shapes. The factored column forces due to wind were then added to their respective loading due to gravity. Changes were made as necessary. The project team decided to specifically design the braced frame in Figure 23 to allow for possible entry ways through the specific walls to better accommodate alterations in floor layout.

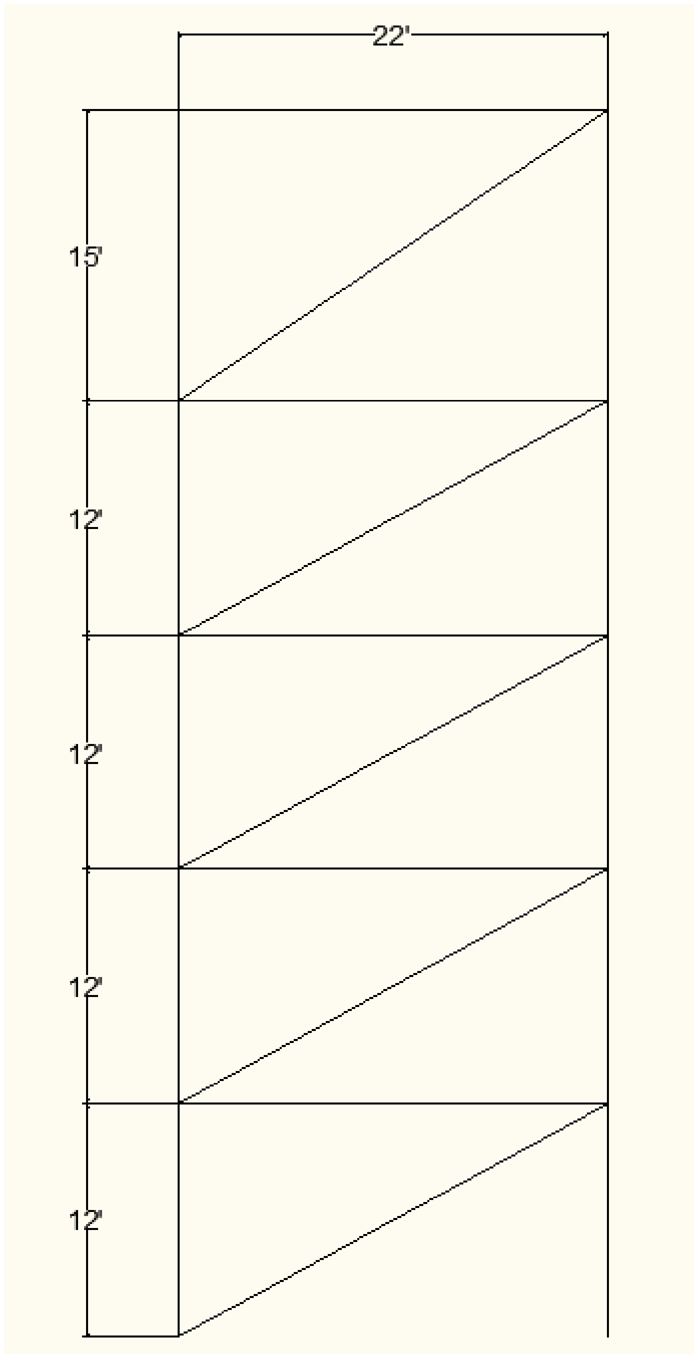


Figure 23: Braced Frame 22' Span

Table 3: Diagonal Brace Design for 22' Span

1ST FLOOR		
Pu =	28	Kips
KL =	25	Ft
Brace	**ΦPn (kips)**	**Wt (plf)**
HSS5x5x3/16	31.6	12
SECOND FLOOR		
Pu	22.5	Kips
KL =	25	ft
Brace	**ΦPn (kips)**	**Wt (plf)**
HSS5x5x3/16	31.6	12
THIRD FLOOR		
Pu =	17	Kips
KL =	25	ft
Brace	**ΦPn (kips)**	**Wt (plf)**
HSS4x4x1/4	19.6	12.2
FOURTH FLOOR		
Pu =	11	Kips
KL =	25	ft
Brace	**ΦPn (kips)**	**Wt (plf)**
HSS4x4x1/4	19.6	12.2
FIFTH FLOOR		
Pu =	5.1	Kips
KL =	26.6	ft
Brace	**ΦPn (kips)**	**Wt (plf)**
HSS4x4x1/4	19.6	12.2

4.3.6 Stair Design

The proposed building has two typical staircases as a means of egress. One staircase is located toward the south side of the building in the middle bay, and the other is located towards the east side. Each staircase will span from the 1st floor to the fifth floor. Figure 24 depicts the dimensions of a typical two-flight staircase. The width of the staircase is suitable by *IBC* standards with the 48-inch dimension between handrails and uniform stair treads. The stair is surrounded by a concrete masonry unit (CMU wall). A W12x14 beam spanned ten feet between the two CMU walls at each landing for added support to a pre-designed stair system. These beams were designed to hold dead loads including the concrete slab, decking and insulation, MC 12x10.6 stringers (assumed) and ceiling material as well as a live load of 125 psf. The beams were designed to hold a live load of 125 psf, even though *ASCE 7* specifies 100psf, because the rest of the building was built to that capacity requirement. The floor decking on each landing will be supported by the W12x14 beam along with 4”x4”x3/8” angles along the CMU wall. These angles will be secured to the wall using concrete wedge anchors.

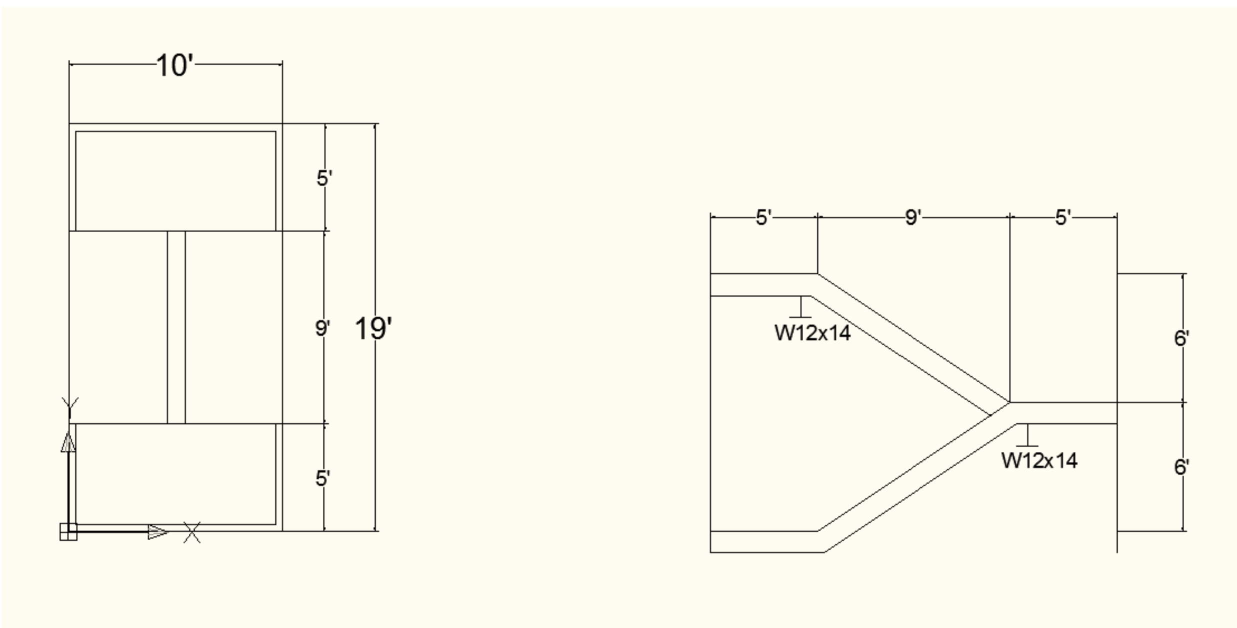


Figure 24: Typical Two-Flight Staircase

4.3.7 Elevator Design

There are many regulations that need to be met when designing an elevator shaft. It is an integral part of the building as it is a means of handicap transportation. First, the deflection limits are extremely small as it is important for the elevator shaft to stay true for the mechanical aspect of the elevator to work properly. These deflection limits include a girder deflection limit of length divided by 1666 and a lateral sway for columns of length divided by 500. (Building Design & Construction Handbook, 2000) Elevators shall also be designed to meet the force and displacement requirements due to seismic loading as described in Sections 13.2.1 and 13.2.2 of *ASCE 7.* As for the capacity of the car, a 3,000-pound elevator was chosen as it was recommended for office building, hotels, and stores. (Architects Studio Companion, 2002) This was the most logical choice as the three buildings aforementioned share similar elements with the mixed-use facility on Lot 3. Figure 25 depicts the bay with the 8' by 8' elevator shaft. The total design load for the W12x16 sheave beam included the summation of the weight of the car and a live load of 75 psf multiplied by 100% to account for impact and the counterbalance. This value was then added to the estimated weight of 1,000 pounds for the cable system as well as roof dead and live load to accumulate to 17.2 kips. As for lateral loading, a value of 4.6 kips due to seismic conditions was calculated in accordance with *ASCE 7*. This value was derived considering the location of the building, weight of the car, and design loading for the car. This force was then applied to the elevator shaft that is braced on three sides, the fourth left clear for the door opening. Every brace was determined to be an HSS5x5x3/8 tubing to assure rigidity in the structure. Each member can withstand an axial load of 138 kips. It is also important to note, the columns were also designed to meet the loading and deflection limitations mentioned above.

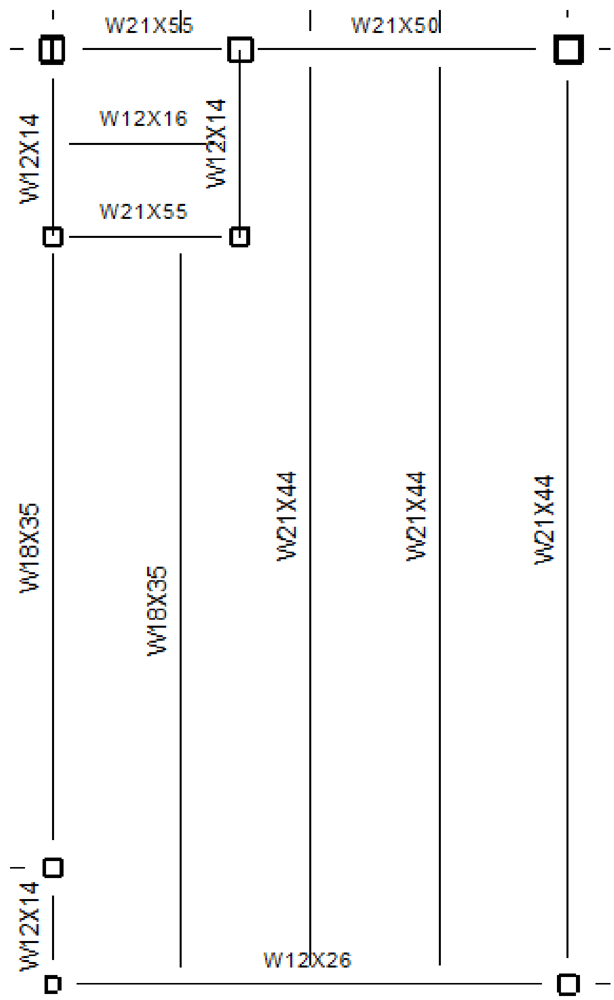


Figure 25: 22' x 40' Bay including 8' x 8' Elevator Shaft

4.3.8 Base Plate Design

Base plates are required to disperse the load from the column over a sufficient area to limit the stresses in the concrete footing. Since the columns for Lot 3 are not extremely large, welding the base plate to the column is the most sensible approach. The design procedure for base plate size was obtained from *Structural Steel Design* and used A36 steel for base plate material in the sample calculations shown in Appendix 10.5.2. Base plate dimensions determined for columns supporting the braced frames are shown in Table 4. The W14x132 and W12x120 columns are the most load bearing columns in the building. This directly correlated with the base plate dimensions over 20 inches and thickness exceeding 2 inches. For constructability purposes, a 14" x 14" x 1" base plate could be used for both Col 1 (Side 3) and Col 2 (Side2). A 14" x 14" x 1.375" base plate could also be used for both Col 3 (Corn2) and Col 3 (Corn3).

Table 4: Column Base Plate Dimensions for Braced Frames

Location	Column	Length (in.)	Width (in.)	Thickness (in.)
Col 1 (Side2)	HSS12x12x1/2	17	17	1.5625
Col 1 (Side 3)	HSS12x12x3/8	14	14	1
Col 3 (Int2)	W14x132	23.5	22	2.4375
Col 3(Corn2)	HSS9x9x1/2	14	14	1.375
Col 3 (Int3)	W12x120	21.5	20	2.375
Col 3 (Corn3)	HSS8x8x1/2	13	13	1.375
Col 2 (Side2)	HSS12x12x3/8	13.5	13.5	0.875

4.3.9 Connections

Structural member connections are usually designed by the steel fabricator rather than the engineer. This allows the steel fabricator to detail the connections to suite their fabrication and erection capabilities. The engineer of record, however, is required to review, make necessary changes, and stamp the connection designs of the fabricator. For the purpose of this proposal, the project team decided to design the most widely used connections. Figure 26 depicts the detail of a single shear plate for the connection between a W24x55 girder and W18x35 beam. The fit up is shown in Figure 27Figure 27n which the plate is shop-welded to the W24x55 girder and bolted to a W18x35 beam in the field during erection. The typical bay including the

W18x35 beams and W24x55 girders can be seen previously in Figure 16. A325-N ¾" bolts were used for this connection design. The sample calculations for the design of this connection can be found in Appendix 10.5.3.

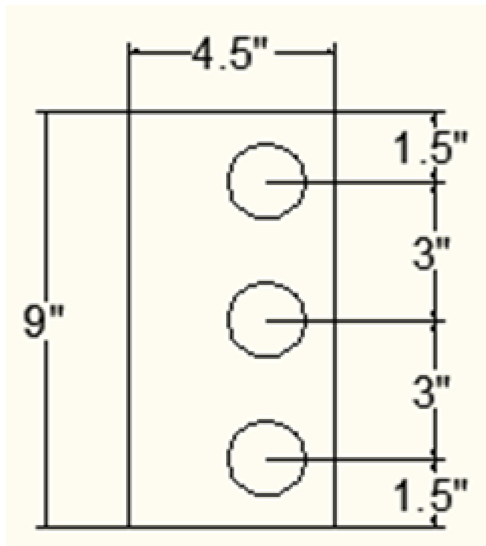


Figure 26: Typical Single Shear Plate Connection

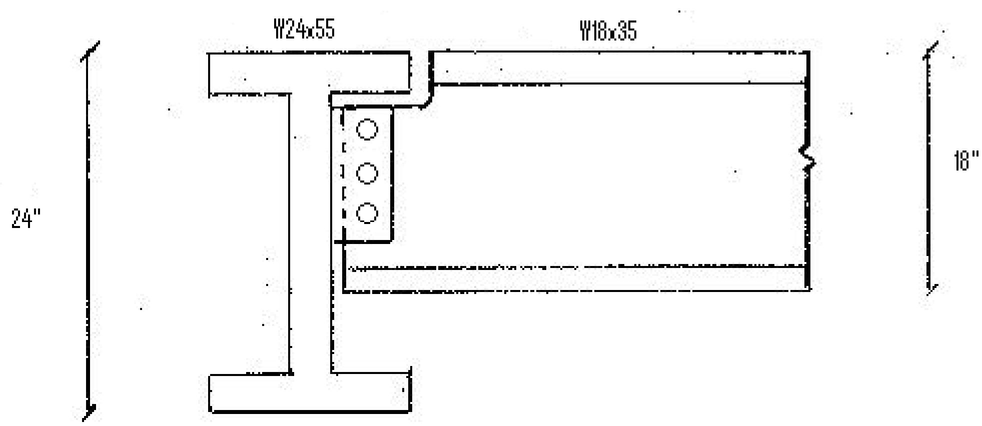


Figure 27: W24x55 Girder and W18x55 Beam Connection Fit Up

5. Foundation Design

The design of a superstructure may be accurate, have considered all possibilities and still fail because the substructure is incapable of distributing the applied loads to the supporting soil. Foundation design takes more into consideration than merely the loading from the columns. While the main part of the project focused on the structural frame and its alternate designs, a preliminary foundation plan was designed based upon maximum loads carried from the superstructure through the columns. The foundation design conducted by the project team consisted of the selection of foundation type, determination of the bearing capacity and the design for typical interior and exterior spread footings.

5.1 Selection of Foundation

Before any foundation design began, the type of foundation needed to be selected. The decision was between shallow or deep foundations. Shallow foundations are defined as those that transmit structural loads to the near-surface soils, while deep foundations transmit the loads well below the ground surface (Coduto 2001). There were several advantages accompanying the selection of a shallow foundation system that played smaller a role in the decision making process. Many of these advantages involved economics and constructability. For example, shallow foundations do not require expensive drilling with complicated equipment but rather just excavation. Another advantage of the site consisting of sand and gravel rather than mainly clay soils is that there is no need to pre-load the building footprint to combat future settlement. The selection of spread footings also had benefits of lower cost and a more straight forward design and constructability advantages than other methods.

The geotechnical report that was mentioned in the Background chapter allowed the team to better analyze the soil layers and the column loading of the structure. Based upon certain criteria, shallow foundations were chosen over deep foundations as the most practical type of foundation to use. The first criterion is that there is that the loading is significant but not so much that it requires a special design. Deep foundation are one type of special design and are necessary when upper soils are weak and/or the structural loads are high so that spread footings would be too large or cover too much area. Other criterion is the relatively shallow depth of the bedrock beneath the soil as the loads will react differently with the rock rather than the soil. The geotechnical report also yielded that the Gateway Park complex held a consistent groundwater table of eighteen feet beneath the surface. A higher or an inconsistent water table would have further complicated the design.

5.2 Bearing Capacity Considerations

Bearing pressure is the contact force per unit area along the bottom of the foundation. It defines the interface between a shallow foundation and the soil that supports it. Figure 28 shows Equation 5.1, by Codutto 2001, for the computation of bearing pressure, where q is the bearing pressure, P is the vertical column load, W_f is the weight of the foundation and any overlying soil, A is the base area of the foundation and u_D is the pore water pressure at the bottom of the foundation.

$$q = \frac{P + W_f}{A} - u_D$$

Figure 28: Equation 5.1 for Bearing Pressure (Codutto 2001)

The previous equation was used to establish a starting value for bearing pressure in the Codutto Bearing Capacity of Shallow Foundations Spreadsheet found in Figure 29. The spreadsheets were developed in order to aid in calculating the maximum allowable bearing pressure and designing the foundation system. The challenge in not using such an aid is that the allowable bearing pressure is needed to determine the initial width of the spread footing. Equation 5.1, shown in Figure 28, was essential in helping determine a good initial estimate. Knowing certain variables in the spreadsheet made it easy to use a "guess and check" philosophy. Some of these variables included the distance from the bottom of the foundation to the ground surface and from the surface to the groundwater level, and the factor of safety. This spreadsheet was then incorporated into the rest of the design through a linked spreadsheet, which will be discussed later, that determined the width, thickness and required reinforcement of the foundation.

BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date: December 14, 2009
Identification: **Typical Interior Spread Footing**

Input

Units of Measurement		
	E	SI or E
Foundation Information		
Shape	SQ	SQ, CI, CO, or RE
B =	14	ft
L =		ft
D =	4.5	ft
Soil Information		
c =	0	lb/ft^2
phi =	32	deg
gamma =	62.4	lb/ft^3
Dw =	18	ft
Factor of Safety		
F =	3	

Results

	Terzaghi		Vesic	
Bearing Capacity				
q ult =	17,458	lb/ft^2	19,149	lb/ft^2
q a =	5,819	lb/ft^2	6,383	lb/ft^2
Allowable Column Load				
P =	1,141	k	1,251	k

Copyright 2000 by Donald P. Coduto

Figure 29: Bearing Capacity Spreadsheet (Codutto 2001)

Another reason for using the spreadsheet allows for the comparisons between two formulas that have earned wide acceptance in the field: the Terzaghi and Vesić Bearing Capacity Formulas. The Vesić Bearing Capacity Formula is considered a more precise alternative to the Terzaghi model because it is a more developed equation, including fifteen individual factors relating to footing geometry, depth, load inclination, base inclination, and ground inclination. These individual factors were all added to further develop Terzaghi's basic formula. Also, it is applicable to a much wider variety of spread foundations, especially in terms of the type of loading and geometry. However, the Terzaghi Formula was used in this application because it met the basic needs of the project, and even more so because of a lack of the very specific data required by the Vesić formula.

5.3 Spread Footing Technical Design

This section considers the design of interior and exterior square footings supporting a single, centrally-located column. The purpose of a footing is to sustain shear and bending effects. Unlike other designs for bending in reinforced concrete members in which the flexural analysis is completed first, foundation design often beings with shear analysis. This is so because it is not cost effective to use shear resisting stirrups in most spread footings. Instead, the main source of shear resistance is from the concrete above the flexural reinforcement. As Figure 30 shows, the effective depth, d, had to be sufficient to provide sufficient shear capacity. This same effective depth was then used in the flexural analysis.

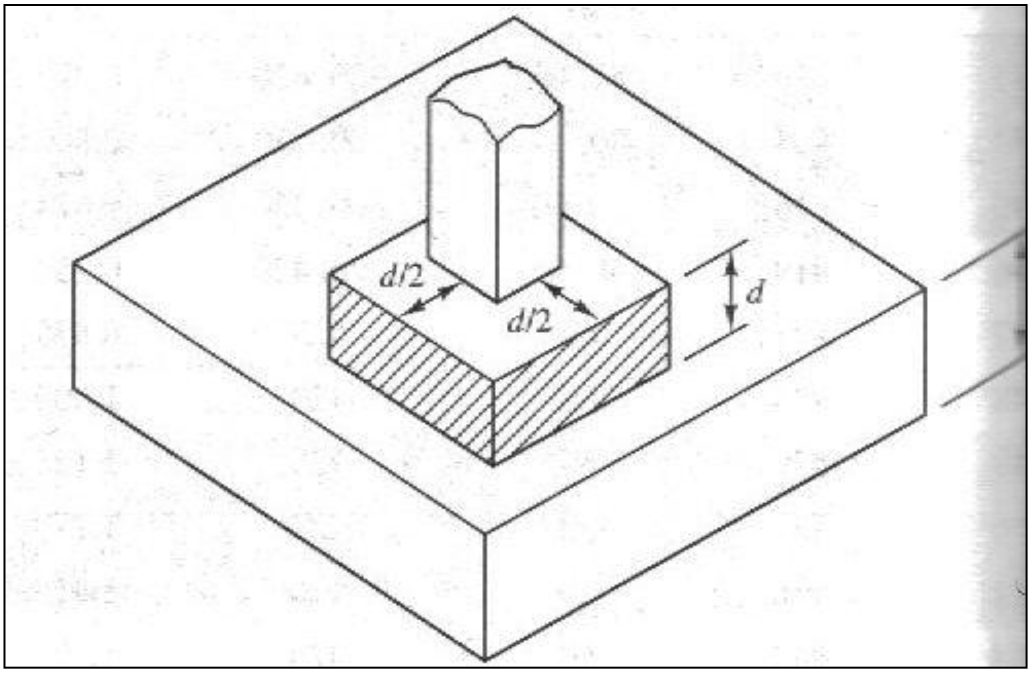


Figure 30: Two-way Shear Failure (Coduto 2001)

The two possible modes of shear failures are one-way shear and two-way shear. ACI 15.5, which discusses shear in footings, requires consideration of the more severe of these two condtions. In order for the design to be adequate for shear capacity, the factored shear force on the critical surface must be less than or equal to the nominal shear capacity on the critical surface multiplied by the resistance factor for shear strength. It was assumed that the nominal shear load capacity of the reinforcing steel is neglected. Additionally, only the two-way shear failure, shown in Figure 30, mode was considered because for as the columns did not have applied end moments or shear loads (Coduto 2001). For square footings supporting square or circular columns located in the interior of the footing, the nominal two-way shear capacity governs (ACI 11.11.1.2).

The spread footing design used loading conditions calculated from the structural steel columns discussed in Chapter 4. A typical design was completed using the worst-case scenario loading from one interior and one exterior column. Both designs were similarly conducted, with the only major difference being the heavier load of the interior column. The heavier load carried by the selected interior column can be attributed to the fact that it supported extra loading from the open-style odeum on the fifth floor and from the brace forces from the lateral load system. Once the unfactored loads were determined, a required width was determined based upon the minimum depth of embedment in Table 8.1 (Coduto 2001). After the factored load was determined, the required thickness was calculated based upon the two-way shear analysis mentioned above. This was done by assuming a required thickness and checking to see if the consequent design was adequate in shear capacity. Spreadsheets aided in the design process as they provided an efficient way to alter parameters and update the design calculations, such as effective thickness and width, to gain the desired results. These spreadsheets can be found in Appendix 10.6. Figure 31 below illustrates the design of a typical interior spread footing, the unfactored load, P, and its applied load on the column. Also shown are the final thickness, width and depth that were established for the square footings.

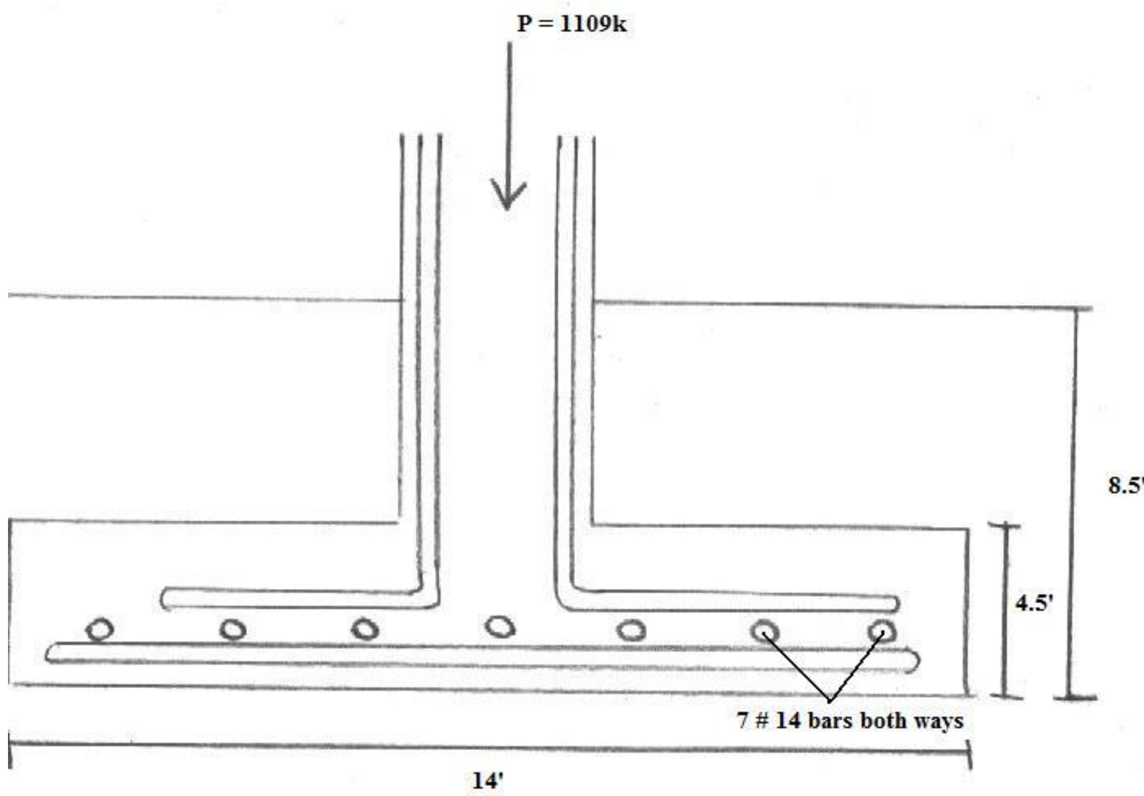


Figure 31: Typical Interior Spread Footing

Once the shear analysis was complete, the flexural analysis was conducted in order to determine the amount of reinforcement steel required. The amount of reinforcement steel required depends of the effective depth that was found in the shear analysis. Per Table 9.2 from Codutto 2001, the cantilever distance was calculated based upon the footing width, column width and base plate width. The factored bending moment at the critical section was calculated based upon the factored vertical load from the column, the cantilever length and the footing width. This bending moment was then used to determine the required area of reinforcement steel. For all foundation designs, the twenty-eight compressive strength of concrete and the yield strength of steel were assumed to be 4,000 psi and 60,000 psi, respectively. Once the minimum steel is checked, reinforcement bars are selected based upon Table 9.1: Design Data for Steel

Reinforcing Bars (Coduto 2001). As Figure 31 shows above, the design determined that the footing required seven #14 bars both ways. Finally, clear spacing between the bars and the development length were checked to support adequacy of the final design.

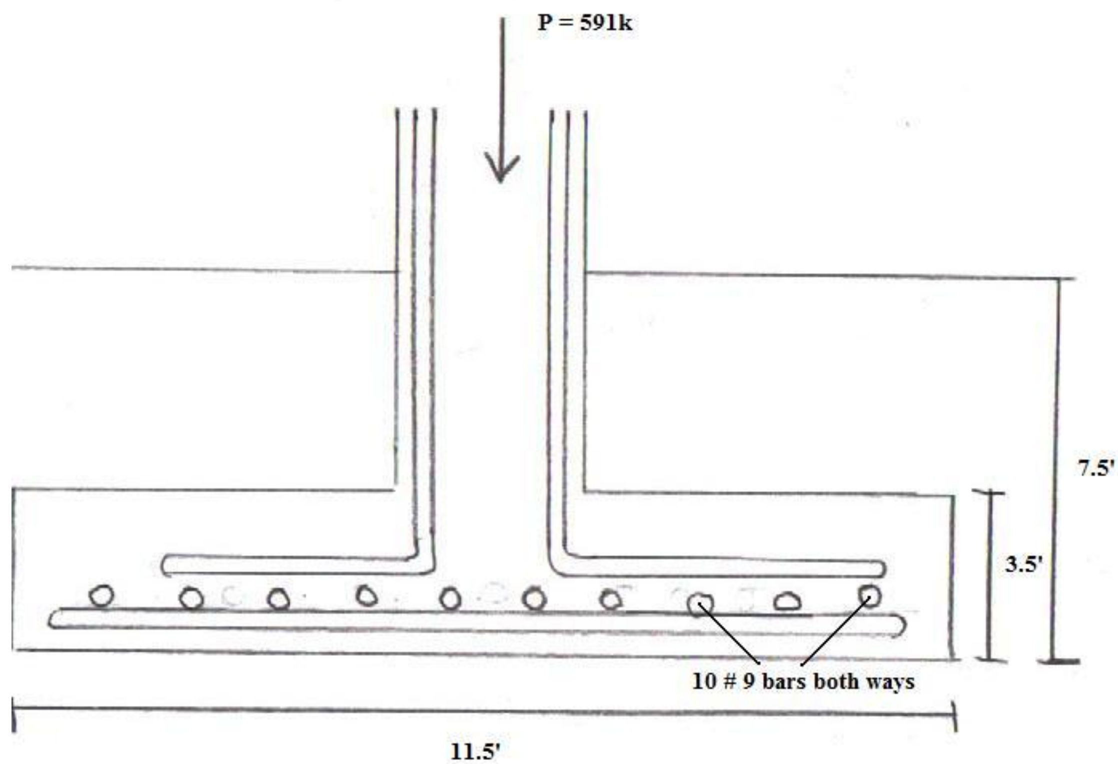


Figure 32: Typical Exterior Spread Footing

As mentioned above, the design of a typical exterior spread footing followed the same process as that of an interior spread footing. As shown in Figure 32, the difference in loading, over 400 kips, contributed to the exterior footing to be smaller. The footing was established to be three and a half feet thick, and eleven and a half feet by eleven and a half feet wide. For sufficient shear capacity, ten #9 reinforcement bars were used both ways.

5.4 Foundation System Considerations

The final foundation design required the use spread footings to distribute the load from each column to the surrounding soil. Thirty-two exterior spread footings and sixteen interior spread footings will comprise the foundation system. Although spread footings are widely accepted as the easiest and most cost effective type of footing, a brief investigation of different types of foundation systems was conducted. At the outset of the project, the team had the decision of whether or not to include a basement in the layout. One investigation that was pursued was a combined footing involving the use of interior, spread and exterior, continuous footings. Combined footings are treated differently from spread or continuous footings and involved a much more complex design process. Eventually, it was decided not to include a basement and design for a slab-on-grade. As a result, this eliminated the need for foundation walls and the need for the exterior continuous footings.

Exterior Spread Footings (sf)	4232	
Interior Spread Footings (sf)	3136	
Total Spread Footing Area(sf)	***7368***	
Total Gross Area per floor	*22237*	
Allowable Footing Area	**7412**	**OK**

Figure 33: Total Spread Footing Area vs. Allowable Footing Area

Another consideration that was briefly investigated but not ultimately used was a mat foundation. A mat foundation is another type of shallow foundation in which a very large spread footing usually encompasses the entire footprint of the structure. This type of system is generally used when the structural loads are so high or the soil conditions so poor that spread footings would be exceptionally large. As a general guideline, if spread footings would cover more than one-third of the building footprint area, a mat or deep foundation would most likely be more economical. As Figure 33 shows, the allowable footing area of 7,412 feet was just barely less than the total spread footing area of 7,368 feet. This means that the practical use of spread footings is close to its limit and any increase in the footing area would warrant a change to a matt or deep foundation system. Though foundations are designed after the superstructure, they are the first segment of a project to be constructed due to their importance in supporting the structure during construction as well as for decades into the future.

6. Schedule & Construction Plan

The project team developed a coordinated project schedule and construction plans that would reflect the expectations for an actual construction project. The project schedule was developed using the preliminary designs given to the project team. Additionally, the group considered typical construction activities and durations taken from similar construction projects as well as realistic constraints on building development. For instance, it is necessary for the structural frame to be completed before concrete can be placed for the slab on deck. Hand drawn construction plans detailing site entrances and storage areas were coordinated with the project schedule to give the reader visualizations of the construction site set up through various periods of production.

6.1 Project Scheduling

With any construction project, the General Contractor or Construction Manager must devise a project schedule that identifies construction activities and coordinates their respective execution. Activities and predecessors are selected based on the means and methods of construction that are appropriate for design and site conditions of the project. This document is typically one of the most important parts of a bid proposal as it allows the Owner to recognize the project's duration, understand cash-flow requirements and shows when the Owner can occupy the facility.

A construction schedule's "backbone" is its critical path. The critical path is a series of construction activities that when set in succession, dictate the duration of the project. To be critical, a construction activity must begin and finish on-time or the project will fall behind schedule. Each project's critical path incorporates different construction activities and durations. For instance, if a critical path activity has a duration of five days and it actually takes seven days to complete, the project will fall behind by two days unless remedial measures such as overtime and night shifts are taken. All other construction activities that are not on the critical path have "float". Float means that the construction activity has an allotted time greater than the expected duration in which the activity can be completed. For example, if an activity has a duration of five days with a float of three days, the activity can take up to eight days to complete without having an adverse impact on the overall schedule.

Like a cost estimate, developing a schedule combines "art" and science. The project team attempted to create a realistic experience of construction scheduling by examining similar facilities and available Contract Documents. A Contractor must examine comparable schedules and the Contract Documents to decide which construction activities will be included. If the Contract Documents are not complete, as in this case, the schedule must reflect activities that are taken from similar facilities.

The group consulted schedules from two other projects to develop a unique schedule that reflects the facility. The first schedule considered was the schedule for the Bartlett Center, WPI's admissions and financial aid facility located on the quadrangle. This facility, though not similar in size or usage, gave the team a starting list of construction activities that could be used in the project. The team was hesitant to use activity durations based on the significant size and usage differences between the two facilities. The team's proposed facility encompassed two additional stories and almost 60,000 additional square feet, a significant factor to in considering activity durations.

The second schedule was the schedule for East Hall, WPI's new LEED accredited 100,000 square foot residence hall. The building, completed in 2008, has a similar shell, size and LEED accreditation. This project schedule also aided the group in defining durations, activities and green building activities by comparing building size and material quantities.

The project first created a spreadsheet outlining the 16 major CSI (Construction Specifications Institute) Masterformat Divisions as seen in Table 5 below. This method of construction organization is an industry standard and helps structure the construction schedule by trade. As construction activities were added, each was designated to the appropriate CSI Division.

Table 5: CSI Division List

CSI DIVISIONS	
01 PROJECT MANAGEMENT	09 FINISHES
02 EXCAVATION & SITEWORK	10 SPECIALTIES
03 CONCRETE	11 EQUIPMENT
04 MASONRY	12 FURNISHINGS
05 METALS	13 SPECIAL CONSTRUCTION
06 MILLWORK	14 CONVEYING SYSTEMS
07 THERMAL & MOISTURE PROTECTION	15 MECHANICAL
08 DOORS & WINDOWS	16 ELECTRICAL

The group discussed and selected project activities that would be included within the schedule and entered the activities into the spreadsheet under their respective CSI Divisions. Next, the team examined the schedule from the Bartlett Center that was developed by Gilbane Building Company. The team looked for activities that seemed to be within the scope of the facility such as brick installation, and the procurement and installation of precast concrete window sills. Again, the team added the activities to the spreadsheet. Table 6 shows an example of activities assigned to CSI Division 07, Thermal and Moisture Protection. The team then included the final activities and assigned durations using the schedule for WPI's East Hall. East Hall is measured at approximately 100,000 square feet, roughly 20,000 square feet larger than the Lot 3 facility. So, for Lot 3, similar construction activities were designated with durations of approximately 80% of their East Hall counterparts. Lastly, as the structural steel and foundation designs were completed, the team adjusted the initial durations based on the designed quantities of material using RS Means Construction Data. (*R.S. Means, Square Foot Cost Data Manual, 2009*) The entire set of construction activities organized by the CSI Division breakdown can be found in Appendix 10.8.

Table 6: Example Activity List

07 - THERMAL AND MOISTURE PROTECTION	
7	Fabricate and Deliver EPDM Roofing
7	Order White Membrane Roofing System
7	Fabricate and Deliver White Membrane
7	Dampproof and Insulate Foundation
7	Install Flashing & Roofing Ply
7	Install EPDM
7	Install White Membrane

The next step in the scheduling process was to upload the construction activities into Primavera Project Manager, a scheduling computer program that is widely used in the construction industry. The most useful tool in deciding the predecessors and successors for the project was the photographic progression of the Bartlett Center generated by a WPI Interactive Qualifying Project authored by Mustansir Jivanjee (Jivanjee, 2008). The graphical progression of construction activities helped the team to understand how and when activities from different trades could be completed concurrently. The ability to visualize and graphically manipulate the breadth of construction activities and durations helped identify a logical sequence for construction as seen in Figure 34 below.

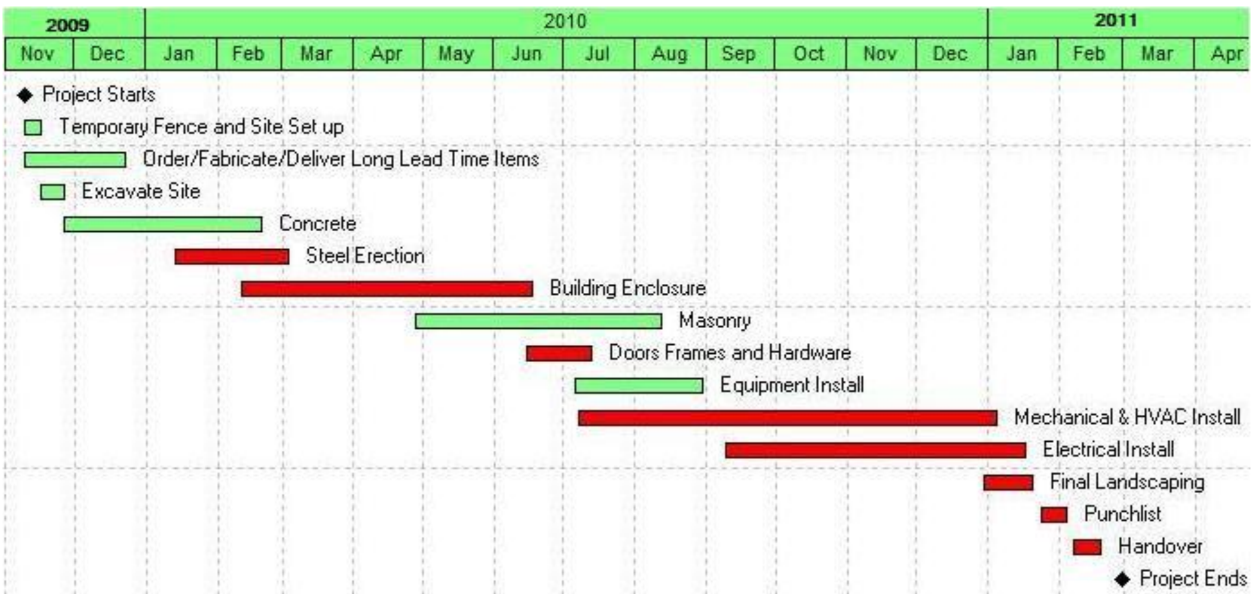


Figure 34: Abbreviated Construction Schedule

The construction project was slated to begin on November 15, 2009, as expressed by D'Anne Hurd, and finish on February 18, 2011. As seen in the abbreviated construction schedule above, a majority of the schedule's time is made up of five major activities: Concrete, Building Enclosure, Masonry, Mechanical & HVAC and Electrical Install. Concrete activities include processes such as placing foundations and slab on deck. The Building Enclosure phase includes erecting the scaffolding that will allow for exterior sheathing installation and bricklaying. Mechanical and Electrical Install coincide with each other due to the need for coordination between the two divisions. There are several periods of construction during the schedule in which there are multiple construction activities occurring at the same time. The construction site must be organized accordingly as these processes take place.

As with any construction project, the goal of the schedule was to complete all construction activities before the required Date of Completion. The target Date of Completion as provided by D'Anne Hurd in the given documents is March 2011. The project team's schedule, barring any delays, shows the issuance of the Certificate of Occupancy on February 18, 2011. This date of completion is practical based on the time of year in which the building will be completed. The team allowed a two week contingency for any setbacks. Typically, winter construction tends to cause unforeseen delays that negatively impact a construction project. In the team's meeting with D'Anne Hurd, the group learned that the estimated start time for the building was November 2009. Because of this start time, a considerable amount of the excavation and concrete work will be completed while in the winter months. Worcester winters are notorious for snow, ice and other unworkable conditions. These conditions can and will almost undoubtedly impact the project schedule by causing unforeseen delays and project inefficiency. Because of the probability of these delays, the team aimed to have the project completed approximately two weeks before March, 2011. The project team's overall construction schedule can be found in Appendix 10.7.1.

As previously mentioned, the proposed Lot 3 facility was to begin construction in November 2009. This date was encompassed by the academic terms in which the team completed the project and construction had not yet begun. To stay consistent with the information given to the project team, the group decided to stay with this start date even though construction had yet to start. 2008 and 2009 were difficult times within the construction industry. WPI was affected by this economy as the Lot 3 facility and the new WPI Athletic Center were pushed back.

6.1.1 Alternative Design Schedule

As the team completed the preliminary design of the alternative fifth floor design, the group noticed that the additional story would have a significant effect on the construction schedule of the project. The team estimated that the extra floor would add enough materials and labor to extend the duration of the project approximately one month. When the schedule was updated in Primavera, the estimated date of completion was extended to March 25, 2011. This date was congruent with the team's preliminary assessment of the project extension.

The construction activities most affected by the additional floor included shell construction, HVAC system installation, structural steel erection, and interior finishing systems. Activity durations affected by the supplementary floor were increased in proportion to their previous duration and relevance to the additional floor. For instance, paint and steel related durations were increased by just less than one fourth of their previous durations. These activity duration extensions were estimated while taking into account the extra floor space, room height, and partition density. However, activities like site excavation that have little to no pertinence to the extra story were left at their original duration.

The activities on the critical path of the project did not change much. The major activities such as site excavation, steel erection and exterior stud installation stayed on the critical path. This was not a surprising result as the majority of the activities within the critical path was relevant to the project and was assigned a duration extension. A full version of the alternative design construction schedule can be found in Appendix 10.7.2.

6.2 Construction Logistics

One of the many major issues that construction managers deal with during a construction project is site organization throughout the project's duration. Site superintendents must prioritize the use of space for various trades and materials through each phase of the project. To gain experience with this type of responsibility, the project team divided the schedule into 4 phases derived from the project schedule: Excavation, Structural Support/Framing, Building Enclosure, and Interior Fit-Out. Sketches of the construction site during the various stages of construction were made to accompany each phase in the process.

As seen in Figure 35 below, a major advantage of this building site is the wealth of space available for construction purposes. The project location has an open lot across the street for laydown areas and temporary on-site offices. Also, plenty of curbside space on the site and proximity to a major highway allow for the facilitation of material and equipment delivery. In major cities such as Worcester, the lack of open space can take a significant toll on the efficiency of the project. Fortunately, Lot 3 is located in an ideal spot. Additionally, the open space allows the temporary fencing and laydown areas to remain in relatively the same positions throughout the construction process, saving both time and money.

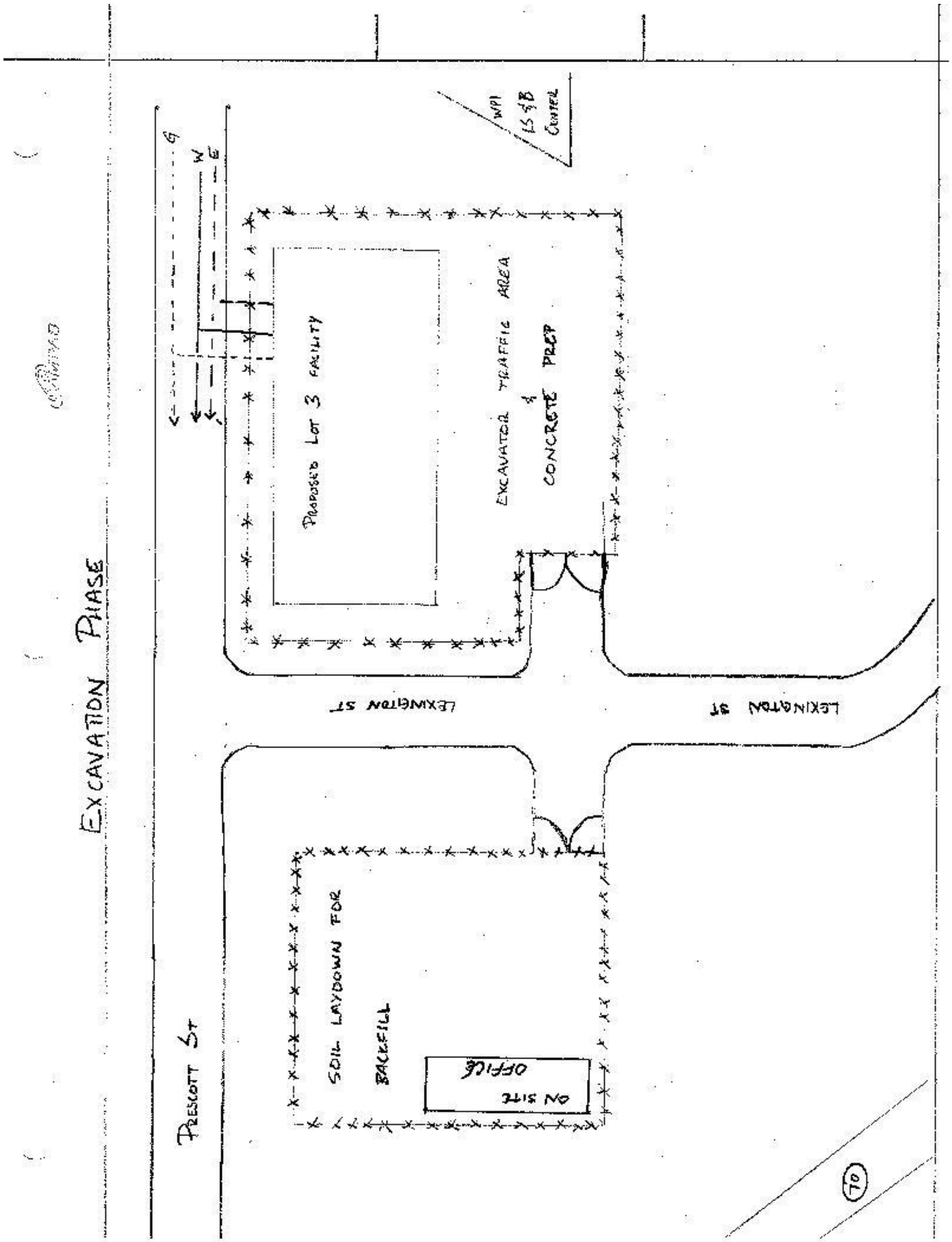


Figure 35: Site Logistics - Excavation Phase

During the Excavation Phase, there must be adequate room for the excavator to pick up soil and transport it to its dumping site on the other side of Lexington Street for backfill or removal. This transportation will have minimal impact on surrounding traffic as Lexington Street is a two-lane access road with minimal traffic. Excess soil that will not be used for backfill will be transported to an off-campus dumping zone that will accept the soil. Typically, there are two entrances to a construction site that is being excavated. However, the extensive space on the east side of the building should allow for room for vehicle maneuverability within the fenced off construction site. Additionally, the Excavation Stage sketch in Figure 35 illustrates the tapping points for the multiple utility sources that the project will use. The sources were determined from the Geotechnical Report provided by the Maguire Group for the Gateway area. A sample of this report can be found in Appendix 10.3.

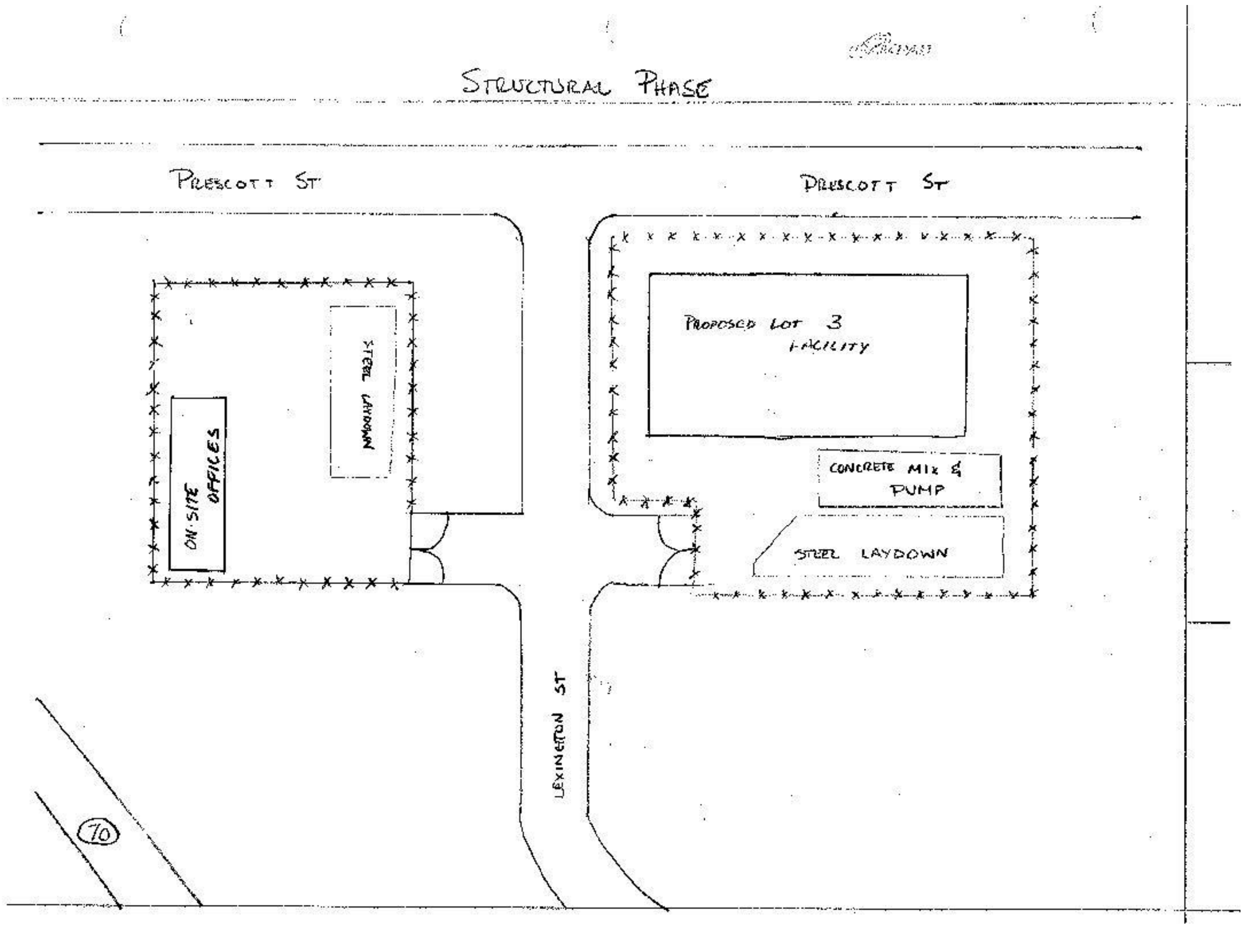


Figure 36: Site Logistics - Structural Phase

The Structural Phase shown in Figure 36 relies heavily on site organization. Placement of the foundation and erection of the structural frame are on the critical path of the construction schedule, and therefore must be prioritized accordingly. The construction superintendent should make sure that there is ample space around the formwork for the foundations for concrete trucks to place the needed concrete. Once the concrete has cured enough, the site will be ready for structural steel erection. The superintendent should make sure that the steel that will be erected first is placed within the temporary fencing on the east side of the facility. This will allow the crane operator to have easy access to the steel. Structural steel that will be placed in the upper sections of the facility will be designated to the unloading and storage area in the empty lot across Lexington Street. This storage area will be accessible to an on-site crane in addition to a crane designated for picking steel and transporting it across Lexington Street to the job site.

From a procurement standpoint, it is vital that the structural steel has been ordered with a sufficient lead time to satisfy the schedule. The order and fabrication of structural steel takes a considerable amount of time and must be taken into account during construction. The project team addressed this by assigning an appropriate duration for steel procurement. Typical steel beams can be ordered two weeks before their scheduled erection. For any specialized steel members, a one month lead time should be able to satisfy the construction schedule.

Similar to the Structural Phase, the Building Enclosure Phase, shown in Figure 37, will rely on planning by the superintendent to ensure that a laydown area for the exterior sheathing and the brick are carefully organized. Because the Building Enclosure Phase will involve work on the exterior of the building, it is vital that the scaffolding is delivered and erected on time. The exterior sheathing should be the first priority due to its placement in the schedule. The team laid out the temporary fencing so that there should be enough space around the facility to accommodate scaffolding that will support the bricklayers as they apply the brick and mortar.

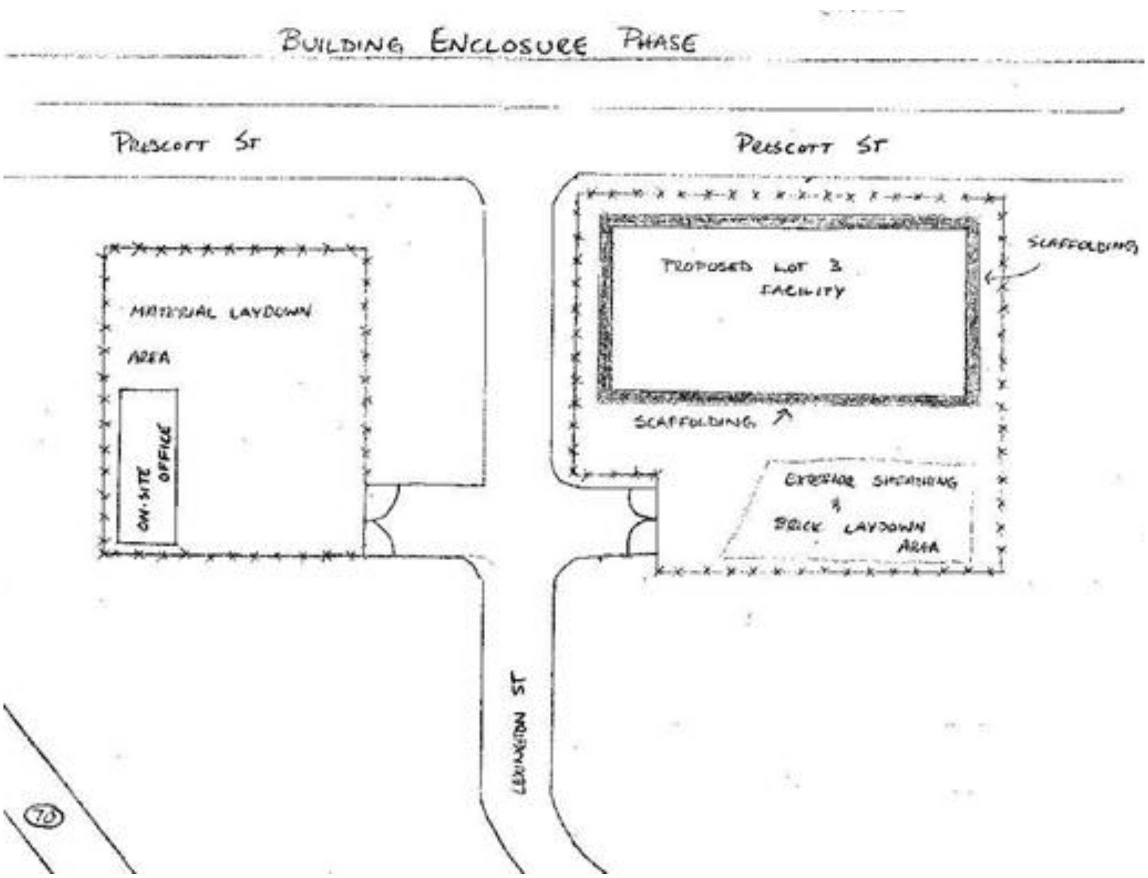


Figure 37: Site Logistics – Building Enclosure Phase

Lastly, the Interior Fit-Out Phase, shown below in Figure 38 will again need to consider the sequence in which interiors are to be installed as well as which materials will need to be shielded from the weather. Depending on when equipment arrives at the site, this may require renting weatherproof trailers to store the equipment and materials. If there is room in the constructed space, the Contractor may store materials and equipment in a secure area. The site should be organized in a way in which construction can efficiently take place.

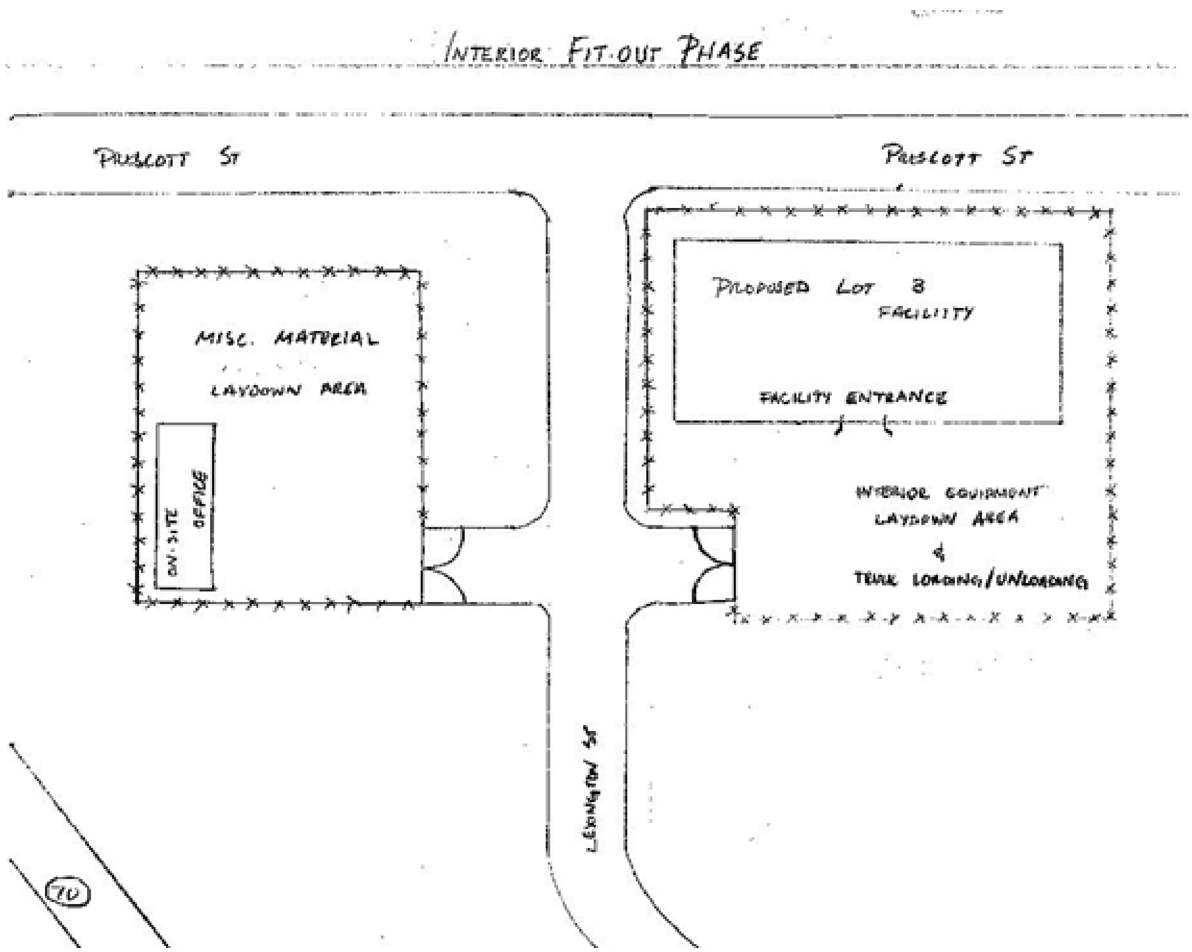


Figure 38: Site Logistics – Interior Fit-Out Phase

The sketches of these phases are consistent with sketches that will be submitted to the Owner and Architect at various instances during the construction project as bid documents and work plans. The priority within the phases will be dictated by the activities within the phase and the activities within the critical path. The construction plan sketches can be found in Appendix 10.9.

7. Cost Estimate

A preliminary cost estimate based on schematic designs was completed as a project deliverable. Over the course of the project, the team constructed two cost estimates each founded on a different stage of the building design. A preliminary cost estimate was calculated using facility square footages and RS Means construction cost per square foot values from the *RS Means Square Foot Cost Manual 2009*. Later, as the project developed, a cost estimate was based on the calculated materials and equipment for certain construction trades. Variables that influenced the price included the cost of equipment, labor, green construction, and materials. The cost estimate was prepared in a spreadsheet that was organized into separate categories of building construction based on the CSI Masterformat.

Where possible, the project team used the architectural modeling software REVIT to aid the cost estimate. REVIT Architecture has the capability to directly quantify items that are incorporated within the three-dimensional layouts such as windows, doors, wall surface areas, floor surface areas. Additionally, quantities of concrete, wood and steel can be calculated using the software. Actual quantities from the model were then used in the final cost estimate.

7.1 Stages of the Cost Estimate

Cost estimates follow a project from its earliest schematic stages to its final design. The project cost estimate becomes more refined as the project continues in its design process ultimately resulting in a final estimate that is the most accurate approximation of the final construction cost. Contractors are given complete construction drawings and specifications as a base to estimate and submit a bid for the whole construction cost of the facility. The project team emulated this process by determining the cost estimate using information prepared at various stages of the project as well as the drawings and information given by D’Anne Hurd.

The team was presented with the basic usages for the facility that aided in the preliminary square foot cost estimate. Additionally, the group was provided schematic design layouts that expressed basic architectural and structural layouts that aided the team in its cost estimate.

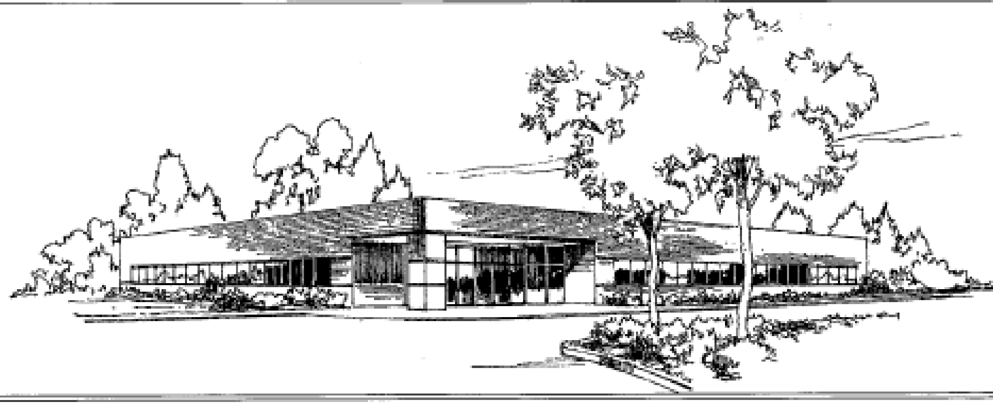
Preliminary cost estimates for buildings are based upon aggregating the costs of assemblies and systems on a square foot basis and give a very rough estimate for total building construction. These generally are good estimates but lack the accuracy, possibly ranging +/-30% of the final construction cost, with which to develop a cost estimate worthy of bidding. Cost estimates performed later in the design are refined versions of these estimates that quantify construction materials and systems. These estimates are the most accurate approximation of the construction cost, typically less than +/-10% of the final construction cost. These estimates are useful in developing bid amounts for prospective projects. (Oberlender, 2000)

7.1.1 Preliminary Estimate

The preliminary cost estimate was primarily based on square footage costs taken from *RS Means Square Foot Cost Data 2009* (*RS Means Square Foot Cost Data Manual, 2009*). The team, under the direction of D'Anne Hurd, understood the various uses of the facility and what percentage of the building each use would occupy. This information allowed the group to develop a schematic design and generate a cost estimate based on the building's size and use.

RS Means Square Foot Cost Data 2009 provides cost per square foot values for certain buildings based on past construction projects. A table is given with adjustment factors for building perimeter and height that allow the user to make the cost per square foot more particular to the project at hand. An example of this table is given below in Figure 39.

COMMERCIAL/INDUSTRIAL/ INSTITUTIONAL | **M.150** | **College, Laboratory**



Costs per square foot of floor area

Exterior Wall	S.F. Area	12000	20000	28000	37000	45000	57000	68000	80000	92000
	L.F. Perimeter	470	600	698	793	900	1060	1127	1200	1320
Face Brick with Concrete Brick Back-up	Steel Frame	269.45	221.50	199.45	185.55	178.55	171.60	165.95	161.65	159.00
	Bearing Walls	263.20	215.25	193.30	179.35	172.35	165.40	159.75	155.40	152.80
Decorative Concrete Block	Steel Frame	262.55	216.20	195.10	181.80	175.00	168.35	163.05	158.95	156.50
	Bearing Walls	256.55	210.25	189.10	175.85	169.05	162.40	157.10	153.00	150.45
Stucco on Concrete Block	Steel Frame	260.60	214.75	193.85	180.75	174.05	167.45	162.30	158.25	155.80
	Bearing Walls	254.65	208.75	187.90	174.75	168.05	161.50	156.30	152.30	149.80
Perimeter Adj., Add or Deduct	Per 100 L.F.	10.40	6.25	4.50	3.40	2.80	2.25	1.85	1.50	1.35
Story Hgt. Adj., Add or Deduct	Per 1 Ft.	1.80	1.45	1.20	1.06	0.95	0.90	0.80	0.65	0.65
For Basement, add $21.10 per square foot of basement area										

The above costs were calculated using the basic specifications shown on the facing page. These costs should be adjusted where necessary for design alternatives and owner's requirements. Reported completed project costs, for this type of structure, range from $151.00 to $282.00 per S.F.

Figure 39: Example RS Means Square Foot Estimate Table

(RS Means Square Foot Construction Data Manual, 2009)

One problem that the project team discovered was the lack of RS Means estimate values for mixed-use facilities that would be applicable to the group's project. RS Means only considers buildings with singular uses. To address this issue, the project team used a formula based on building usage percentages to develop the total building estimate. The formula is seen below.

$$\frac{Usage\ Square\ Footage}{Total\ Square\ Footage} = \%\ \text{Building Usage}$$

The team selected the three RS Means building types most closely related to the proposed building uses. They were "College Laboratory", "High School, 2-3 Story" and "Office, 2-4 Story". Each base estimate was taken at 80,000 square feet using a brick façade and structural steel. The team's next step was to adjust these values based on the geometry of the proposed facility. The proposed structure was exported from REVIT at 87,949 square feet of gross floor space and a building perimeter of 650 feet. It should be noted that all square foot estimates for the project used 87,949 square feet as a total amount. Height and perimeter adjustments were made to the respective values to ensure that the estimate reflected the building's height and footprint.

The resultant square foot estimate values were multiplied by the calculated square footages for each use to develop costs for each usage. For instance, the school space was calculated through REVIT at 21,987 square feet. This was multiplied by 171.50$/ft^2 to yield an estimated cost of the school section of the building of $3,770,770.50. Three separate calculations were totaled to generate a subtotal. Lastly, this subtotal was multiplied by a factor of 1.0316, the assumed multiplier for annual inflation between 2009 and 2010. (Oberlender, 2000) 2010 is the year in which the majority of construction will be taking place so it is necessary to account for the difference between the year of the estimated values and the year of construction, The subsequent values were multiplied by construction location factor (Worcester, MA) of 1.07 taken from RS Means. (*RS Means Square Foot Cost Data Manual, 2009*). The RS Means Square Foot Construction Estimate can be found in Table 7 below.

Table 7: RS Means Square Foot Estimate

BUILDING DATA	Laboratory SF	54968.00				
	School SF	21987.00				
	Office SF	10994.00				
	TOTAL	87949.00				
	Building Perimeter	647.20				
MULTIPLIERS	Location Factor	1.07				
	Inflation Factor	1.03				
SF COSTS BY USE	**Laboratory**					
	(RS Means "College Laboratory")					
	80000 SF					
	1200 LF					
		Means Value	**Perimeter Adj**	**Height Adj**		**$/SF**
		161.65	1.5*5	0.65*36		**177.55**
	School					
	(RS Means "School, High, 2-3 Story")					
	80000 SF					
	1200 LF					
		Means Value	**Perimeter Adj**	**Height Adj**		**$/SF**
	(interpolated)	161.20	2.5*5	1.9*12		**171.5**
	Office					
	(RS Means "Office, 2-4 Story")					
	80000 SF					
	580 LF					
		Means Value	**Perimeter Adj**	**Height Adj**		**$/SF**
		151.35	2.30	12.00		**165.65**
TOTALS	**LAB COST**	$ 9,759,568.40				
	SCHOOL COST	$ 3,770,770.50				
	OFFICE COST	$ 1,821,156.10				
	SUBTOTAL	$ 15,351,495.00				
	TOTAL	$ 16,945,000.14				

As seen above in Table 7, the RS Means cost per square foot estimate is $16,945,000. In the packets received from D'Anne Hurd, an "Estimated Private Investment" was given as $21,579,000. This latter estimate would include the cost of Architect's Fees for Design, a cost not included in the team's estimate. Typically, the design costs of a facility are 20% of the total construction cost. According to this assumption, the team's square foot estimate would decrease to about $17.2 million, which is reasonable for this type of facility. However, the project team recognized that the square foot estimate for a typical laboratory did not take into consideration the multiple floors. Although the height adjustment made up for some of this difference, it was very likely that the team's subsequent estimates would be more expensive than the RS Means square foot estimate.

7.1.2 CSI Uniformat II for Building Elements Cost Distribution

After using RS Means to generate a preliminary cost estimate for the facility, it is important to identify what elements of the structure accrued the most money in the construction cost. To examine these elements, the project team used the CSI Uniformat II to investigate the distribution of construction costs among building elements. CSI Uniformat II is a classification system that divides construction costs into eight broad categories: General Conditions, Substructure, Shell, Interiors, Services, Equipment & Furnishings, Special Construction and Demolition, and Sitework. Uniformat II helps users to assign costs into a framework that organizes the expenses of each element of a construction project. Table 8 below shows the Uniformat II breakdowns for each of the three respective building types examined by the group in RS Means.

Table 8: RS Means CSI Uniformat Breakdown

CSI UNIFORMAT	College Lab	High School	Office
Substructure	**11.30%**	**4.20%**	**4.40%**
Shell	**18.70%**	**36.40%**	**29.60%**
Superstructure	6.70%	15.70%	12.20%
Exterior Enclosure	7.70%	15.80%	15.80%
Roofing	4.30%	4.90%	1.60%
Superstructure	**23.30%**	**21.00%**	**22.70%**
Services	**45.60%**	**36.40%**	**43.30%**
Conveying	0.00%	0.50%	8.90%
Plumbing	17.10%	5.20%	2.80%
HVAC	14.50%	16.20%	11.80%
Fire Protection	1.90%	1.70%	2.80%
Electrical	12.10%	12.80%	17.00%
Equipment & Furnishings	**1.10%**	**2.00%**	**0%**
Special Construction	**0%**	**0%**	**0%**
Sitework	**0%**	**0%**	**0%**

RS Means Square Foot Cost Data has recognized this construction standard and incorporates a CSI Uniformat breakdown within its square foot cost estimate for each facility. The percentages shown above in Table 8 were taken from *RS Means Square Foot Cost Data* Uniformat Breakdowns for each of the three facilities. The project team used the CSI Uniformat breakdowns for each building type, as seen above in Table 8, to develop a unique set of Uniformat breakdown percentages for the mixed-use facility. The percentages were developed by using percentages from each RS Means category and formulating a comparable percentage for the respective category. Each percentage was then multiplied by the square foot estimate of $16.9 million, resulting in an associated category cost. The three Uniformat breakdowns from *RS Means Square Foot Data Manual* are shown above in Table 8 and the resultant project Uniformat breakdown with each cost association can be seen in Table 9 below.

Table 9: Gateway Mixed Use CSI Uniformat Breakdown

CSI UNIFORMAT	Gateway Facility	Associated Cost
Substructure	**4.00%**	$ 677,800.01
Shell	**30.00%**	$ 5,083,500.04
Superstructure	12.00%	
Exterior Enclosure	15.00%	
Roofing	3.00%	
Superstructure	**21.00%**	$ 3,558,450.03
Services	**44.00%**	$ 7,455,800.06
Conveying	5.00%	
Plumbing	10.00%	
HVAC	14.00%	
Fire Protection	2.00%	
Electrical	13.00%	
Equipment & Furnishings	**1.00%**	$ 169,450.00
Special Construction	**0.00%**	$ -
Sitework	**0.00%**	$ -

As seen in Table 8 the Uniformat breakdowns for each facility were similar. The "College Laboratory" had values that were dissimilar to the other facility types due to its height difference; however, the team was able to estimate the percentages with significant confidence.

Seeing that the Uniformat percentage breakdowns were comparable in each category, the team had little difficulty assigning percentages to the respective categories. Percentages rarely fluctuated from the initial numbers seen in the Uniformat Breakdowns. The team also made sure to incorporate realistic aspects of our project. For example, our building was designed without a basement, cutting the substructure costs. Additionally, the extensive laboratory space will create considerable costs associated with the HVAC and Electrical trades. Sitework and Special Construction did not have an impact on our Uniformat cost due to the limit of the scope of our project and the previous work that has made the project site ready for construction.

7.1.3 CSI Masterformat Cost Distribution

Lastly, the team developed a cost estimate using detailed "contractor" estimate combined with the approximated preliminary cost per square foot estimate. This estimate broke down the cost into specific construction materials and activities for the trades that were designed by the project team. The group used the CSI Masterformat structure to illustrate the cost estimate. Similar to the CSI Uniformat, the CSI Masterformat is designed to break down construction costs into categories; however, the Masterformat uses sixteen trade-specific classifications to structure the project information. This form of cost organization is beneficial to a Contractor in that the trade-specific categories are consistent with bid prepared by subcontractors.

Moving beyond the initial square foot estimates to identify and quantify the various construction materials that were going to be incorporated into the facility proved to be a significant challenge to the project team. The team attempted to quantify as many relevant construction materials as possible. Each CSI Division, with exception of Mechanical, Electrical and carpentry was examined in detail to indentify all applicable materials. Similar to the Preliminary Estimate, the team used literature from RS Means to establish unit cost values for respective quantities, and these were multiplied by appropriate inflation and location factors. It should be noted that these unit cost values incorporate labor and equipment factors.

Two Divisions, Concrete and Metals, specifically structural steel, were estimated differently from the rest of the Divisions because these Divisions included aspects of construction that were designed by the project team. The foundation design and structural design yielded designed quantities of materials for excavation, concrete and steel respectively that were imported from REVIT schedules into the cost estimate spreadsheet and quantified using RS Means values. An additional 10 % of the total steel cost was added for connections and anchor bolts. An example of the Metals Spreadsheet can be found below in Table 10.

Table 10: Gateway Mixed Use Facility Metals Estimate

ITEM	COST
Typical HSS Columns	$ 53,945.00
W Shape Beams (Floor)	$ 1,594,188.00
W Shape Beams (Roof)	$ 205,290.50
W Shape Columns	$ 45,018.73
Joist Girders	$ 28,665.00
Connections & Anchor Bolts	$ 192,710.72
Footing Reinforcement	$ 73,683.73
TOTAL METALS COST	$ 2,193,501.68

Costs for Mechanical and Electrical Divisions were estimated purely by square foot estimates from RS Means. The team used the building area usage percentages to adjust the RS Means multipliers to a single multiplier that could be multiplied by the building's gross square footage. The team decided that knowledge of these trades was limited and would be most accurately estimated by using a square foot cost. Table 11 below shows the team's estimate for Mechanical, Electrical and Plumbing expenses. It should be noted that the inflation factor for

Mechanical and Electrical reflects two years worth of inflation because the information was obtained from the 2008 version of *RS Means Construction Cost Data Manual.*

Table 11: MEP Cost Estimate

15-16 - MEP						
ITEM	**QUANTITY**	**UNITS**	**MEANS MULTIPLIER**	**INFLATION**	**LOCATION**	**TOTAL**
Mechanical & Electrical	87949	SF	63.9	1.0977953	1.07	$ 6,601,413.12
Plumbing	87949	SF	12.56	1.0315963	1.07	$ 1,219,309.90
						$ 7,820,723.02

Table 12 presents the Cost Estimate Summary with contributions from each CSI Masterformat Division and the total estimated cost.

Table 12: Gateway Mixed Use Facility Cost Estimate Summary

GATEWAY MIXED-USE FACILITY COST ESTIMATE SUMMARY		
DIVISION		
02 SITEWORK		$ 82,730.81
03 CONCRETE		$ 1,510,834.89
04 MASONRY		$ 1,358,276.88
05 METALS		$ 2,193,501.68
06 MILLWORK		$ 240,446.29
07 THERMAL & MOISTURE		$ 363,037.23
08 DOORS AND WINDOWS		$ 219,276.75
09 FINISHES		$ 1,374,222.21
10 SPECIALTIES		$ 84,789.44
11 EQUIPMENT		$ 3,166,736.47
12 FURNISHINGS		$ -
13 SPECIAL CONSTRUCTION		$ -
14 CONVEYING SYSTEMS		$ 292,507.34
15-16 MEP		$ 7,820,723.02
	TOTAL	$ 18,707,083.01

As expected, the majority of the construction cost was found in the mechanical, electrical and plumbing divisions. Laboratories require extensive HVAC equipment, driving up costs for this equipment. One division that contributed over $3 million, or 17% to the overall cost was Equipment. The Equipment division included appliances and furniture that would be included within the building. The most significant part of this division was the fit-out for the laboratory spaces. Due to the scope of the project, the team decided that a square foot estimate for laboratory equipment was more appropriate method of approximation.

The total construction cost shown in Table 12 is higher than the initial estimated square foot value presented in Table 7 which is based on square foot cost data provided by RS Means. As mentioned previously, the laboratory square foot estimate in RS Means did not take into account multiple floors. Because the majority of the building's usage is laboratory space, it makes sense that the square foot estimate would lower than a more detailed estimate. However, this preliminary information proved very useful to the project team as the square foot estimate provided a benchmark estimate for the facility.

The full CSI Masterformat Spreadsheet including the Metals Schedule and Takeoff can be found in Appendix 10.8.1.

7.1.4 Alternative Design Cost Estimate

In addition to the cost estimate for the Gateway Mixed Use facility, the project team developed a cost estimate that reflected the addition of a fifth floor with conference rooms and an odeum. The addition of this floor made a significant impact on the overall approximated cost, adding roughly $3 million to the original total yet decreased the cost per square foot from 212.7 $\$/ft^2$ to 197.2 $\$/ft^2$ due to the lack of laboratories on the fifth floor. The estimate was devised by constructing an additional three-dimensional REVIT model and exporting supplementary room areas, linear footages and other physical building information that would have an effect on the cost estimate. The team followed the same estimating approach regarding structural costs and square foot values for finishes and fit-outs as the previous estimate and made sure to use the same RS Means values in generating the project cost.

Several construction activities were affected by the addition of the fifth floor. The odeum requires an extensive amount of open space on the top floor justifying the need for long-span steel joists, adding significant cost to the structural steel. The total weight of steel for the four floor facility was 436.7 tons, or about 9.93 lbs/ft^2. The additional floor resulted in 559.0 tons, or about 10.2 lbs/ft^2. Additionally, interior finishes saw an increase in price with items such as flooring, drywall and paint gaining significant square footages. The cost of academic equipment such as chairs, discussion tables and projection apparatus also increased due to the presence of the odeum and workshop conference rooms. The project also saw an increase in mechanical, electrical and plumbing costs as the fifth floor adds ventilation and electrical requirements to the facility. However, these additional costs pale in comparison to the significant means for revenue for the facility that the presence of odeum and conference rooms provide. This concept is discussed further in the team's conclusion section.

Table 13, the Cost Estimate Summary organized by CSI Masterformat for the Alternative Design, is shown below.

Table 13: Gateway Mixed-Use Alternative Facility Cost Estimate Summary

GATEWAY MIXED-USE FACILITY COST ESTIMATE SUMMARY			
Alternative Design			
DIVISION			
02 SITEWORK		$	82,730.81
03 CONCRETE		$	1,542,819.49
04 MASONRY		$	1,584,941.15
05 METALS		$	2,500,811.43
06 MILLWORK		$	269,379.02
07 THERMAL & MOISTURE		$	381,728.14
08 DOORS AND WINDOWS		$	255,784.98
09 FINISHES		$	1,659,399.22
10 SPECIALTIES		$	97,380.96
11 EQUIPMENT		$	3,233,494.37
12 FURNISHINGS		$	-
13 SPECIAL CONSTRUCTION		$	-
14 CONVEYING SYSTEMS		$	292,507.34
15-16 MEP		$	9,775,881.54
	TOTAL	$	21,676,858.47

Table 14 shows a summary of the facility cost estimates performed by the project team. Spreadsheets for detailed cost estimates of the proposed facility and the alternative design estimate can be found in Appendix 10.8.1 and 10.8.2 respectively.

Table 14: Cost Estimate Summary Table

Cost Estimate Summary Table	
RS MEANS SQ FT ESTIMATE	$ 16,945,000.14
ORIGINAL ESTIMATE	$ 18,707,083.01
ALTERNATIVE DESIGN ESTIMATE	$ 21,676,858.47

7.2 LEED Certification

As previously mentioned, one aspect in the design of the facility will be achieving some sort of LEED certification level. This initiative was present throughout the structural design and the cost estimate stages of the project. The group decided to achieve "Silver" LEED certification, between 50 and 59 LEED certification points, on the proposed facility. It should be noted that LEED has recently upgraded to LEED v3, a policy that is more rigorous than the previous LEED 2.2. The MQP proposal solely evaluated the building with the latest LEED v3 certification standards. Recently, with the advent of more LEED Accredited buildings constructed, the cost of green building has become comparable to non green construction. (Langdon, *The Cost of Green Revisited*, 2007)

Before the design of a LEED Accredited facility, the owner and architect openly discuss the environmental goals of the project at hand (MacEachern, 2009). The two parties collaborate and discuss what LEED certification level the owner wishes to achieve and then proceed to discuss which LEED points the architect will incorporate into the facility. The project team was not informed of any LEED credits that were incorporated into the preliminary design of the building, only that the building was to achieve a level of LEED certification. Additionally, the drawings distributed to the project team did not include any LEED features. These circumstances allowed the project team the freedom to identify which LEED credits would be included in the design and construction of the facility.

Because LEED is a point-based certification system, the group identified LEED points that were easily achieved, yet were somewhat unrelated to the construction of the building itself. This included but was not limited to parking spaces for eco-friendly vehicles, alternative transportation to the facility and the participation of a LEED Accredited Professional. To achieve these points, “a principal participant of the project team must be a LEED AP” (www.usgbc.com). Additionally, points were assigned for recycling and reusing construction materials during the erection of the building. Cost allowances for increased costs were considered in the cost estimates. These points provided the very beginning of the team’s LEED certification point total and were not factored into the design decisions for the facility

17			Sustainable Sites		Possible Points: 26
Y	N	?			
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
1			Credit 2	Development Density and Community Connectivity	5
1			Credit 3	Brownfield Redevelopment	1
6			Credit 4.1	Alternative Transportation—Public Transportation Access	6
			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
3			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicle	3
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
			Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
			Credit 6.2	Stormwater Design—Quality Control	1
			Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
			Credit 8	Light Pollution Reduction	1

Figure 40: Gateway Mixed Use Facility LEED Accreditation Checklist Example

The team then began to go through the list of green building components in LEED v3 examining which credits would be practical for the facility. The team debated which credits would not only be achievable, but also make an environmental impact. Figure 40 highlights the "Sustainable Sites" section of the LEED Accreditation Checklist. The project earned points based on "Site Selection", which gives points based on the location of the building, and "Development Density and Community Connectivity", which awards credits based on how the building blends into the community. Additionally, because the Gateway campus is being built on previously contaminated land, the facility gains points for "Brownfield Redevelopment". As previously mentioned, the project has potential to earn points in the "Alternative Transportation" section with Worcester's public transportation system, WPI's fuel efficient Zipcars and the previously constructed parking structure on the Gateway campus. The structure will also employ an eco-friendly stormwater runoff quantity control system to mitigate runoff and a white membrane roof to reduce heat island effect. Last, although not part of the group's building design, the facility will gain points from the quadrangle area located on the parking garage side of the facility.

The project team conducted this assessment process for each of the six remaining certification sections. Some of the major credits that earned points include “Optimize Energy Performance”, “Construction Waste Management”, “Regional Materials” and “Low-Emitting Materials – Paints and Coatings”. The team anticipated that the facility could optimize energy performance by 26%. Additionally during construction, the team projected that the construction manager could recycle or salvage over 75% of all construction waste. These goals have already been achieved by a facility within WPI’s campus in East Hall, the LEED Gold certified dormitory. Also, the group assumed that the construction manger and subcontractors would use construction materials such as plywood and steel from regional suppliers. A small cost increase was considered to account for the lack of prospective bidders. Last, the team suggested that low-emitting paints be used where applicable in the facility.

It should be noted that all LEED materials were reflected accordingly in Table 12 and Table 13. These materials included items such as paints, wood, steel and plumbing fixtures. A full LEED New Construction Project Checklist that displays the facility’s LEED points appears in Appendix 10.10.

7.2.1 Impact on Construction Schedule and Cost Estimate

The project team considered the potential for the LEED provisions to impact the project’s schedule and cost. Overall, the construction schedule was not affected enough to cause significant delays to the project. The majority of LEED suggested construction materials such as efficient water fixtures are similar to their “non-green” counterparts in terms of installation but may require a longer procurement period. One issue that may arise within in the project is the possibility of extended lead times of fabricated items such the elevator or structural steel due to the purchase from regional suppliers.

In the cost estimate, LEED certified materials made a notable impact on the overall project cost. If a Contractor is limited to only local suppliers, the construction cost will tend to rise due to lack of competition. The team took this issue into consideration by looking for "green" cost estimate values in *RS Means Construction Cost Data Manual 2009*. If the project team did not find a value for a "green" cost estimate, the original cost estimate for the item was left in place to stay congruent with the RS Means values.

8. Conclusions

The project investigated preliminary design layouts as well as structural frame and construction plan for Lot 3commercial building of the Gateway Park expansion at Worcester Polytechnic Institute. A structural steel design, including an additional floor featuring an open-style conference center, was selected following studies of structural steel and reinforced concrete. Elements of the foundation system were also designed. A phased construction plan, project schedule and cost estimate were prepared and submitted as project deliverables. The final cost estimate for the team's recommendation was $21.6 million with a construction schedule spanning November 15, 2009 to March 25, 2011. Additional aspects of the project include LEED, floor layouts and building information modeling (BIM).

As the project team reached the end of their required work, the team began to develop opinions and recommendations about the final design of the Gateway structure. The group discussed building aspects including structural factors, cost considerations and overall building layouts to devise what the team believed to be the most appropriate proposal for the facility. The team decided that a structural steel design with an additional floor would be the most useful and economical scheme for the Gateway campus.

The structural design process was one that was extensive and technical. Designs were prepared in accordance with established building codes and design specifications. Two initial designs were considered: reinforced concrete and steel. The tenants requested tenant's floor layouts significantly influenced the project team's designs. Based upon these needs, the floor and structural bay layouts were not flexible. As a result, the reinforced concrete design was deemed to be an inefficient solution for the desired spans and required loads. An in-depth steel analysis was then carried out to provide an accurate structural design.

Cost estimates are essential inputs to a building's overall development. They must be developed along with a facility's preliminary design concepts and constantly reevaluated throughout the design and construction processes. The initial cost estimate is vital because it puts a project's overall feasibility into perspective. It will also allow an owner to gain an understanding of how much outside investment will be required to follow through with a prospective construction project. The project team retained valuable knowledge pertaining to the costs of different elements used in the construction process.

The cost estimate yielded a construction cost of $18.7 million for the four-story facility. This amount gives a cost per square foot of $212.70 which is higher than the preliminary cost per square foot estimate of $192.67 but still within reason for the building's usage and size. The RS Means estimate values used by the project team did not reflect multiple use facilities which may have been the difference in the two estimates. The five-story facility was estimated at $21.6 million. This addition could prove to be an asset to the facility as it has the ability to provide a source of revenue for the Owner. However, it will be a worthwhile investment for the Owner to extend the design of the facility and conduct a cost estimate based on the subsequent design. Also, the Owner should be advised to check its personal assets to examine the monetary feasibility of adding the fifth story. The construction industry in the recent past has encountered difficult financial times, suggesting that adding an odeum or conference center may be more reasonable to include in a future Gateway facility. Included within the cost estimates of both facilities was the use of green products and construction procedures. The project team designed and estimated the facility to achieve the level of Silver LEED v3 New Construction accreditation.

Like cost estimates, preliminary construction schedules must be produced and continually reevaluated throughout the building process. A construction schedule allows parties invested in the project to visualize the sequence of construction activities. Additional values of a construction schedule include accurately setting a completion date and identifying possible conflicts between specific activities and seasonal weather. The team's project was fortunate enough to have limited restraints on construction activities. The group was able to use other construction schedules to estimate activity durations and sequences. In the team's assessment, it was determined that the four-story design would have a construction duration from November 15, 2009 to February 18, 2011. In contrast, the team's assessment of the five-story facility generated a duration from November 15, 2009 to March 25, 2011. The team's project schedules were consistent with the timeframes outlined by the information distributed to the project team.

WPI has been developing the minds of aspiring young professionals in the field of engineering for years. It was a unique opportunity for the project team to utilize the acquired education from WPI to make useful recommendations for future Gateway Park building development. This has been a great summation project for our educational experiences because it forced the project team to combine the knowledge acquired from multiple undergraduate courses and apply it to practical situations. The skills developed in this project alone will help each member of the project team in their professional endeavors.

As a whole, the project team applied the education provided by WPI to a real-life situation. The tasks at hand required the ability to apply an understanding of general concepts to solve specific, unforeseen situations. As was stated at the outset of the project, the overall objective was to provide a conceptual structural design with an construction cost estimate and timeline that reflected the level of design available to the project team. The project team identified key tasks that allowed for the fulfillment of these objectives. The tasks include the development process for the progression of structural design and construction management for Lot 3. However, as with any large-scale project, the team had to adapt to unanticipated aspects of the design process such as implications involving the elevator design, construction activity durations, and foundation design. Overall, the project team was able to meet the objectives along with these complications by utilizing related knowledge and additional research.

It would be a benefit for WPI to consider the proposed 5^{th} floor design as it is not only well-suited for the campus, but the community as well. The proposed odeum, with a floor area of 9,900 square feet, will provide useful space for campus activities, conventions, large conferences, city meetings, etc. In terms of a cost estimate, the alternative 5^{th} floor design would only cost an extra $3 million compared to the original four-story design. This would result with an overall project cost of $21.6 million. Considering the additional cost, the project team feels the alternative design would be a profitable asset to the Gateway Park Campus. The additional space could facilitate generation of future revenue charging other organizations to hold the events previously mentioned. The building is in an ideal location as it is right off of Route 290 and downtown Worcester making it easily accessible to potential occupants. If this odeum did not create enough revenue, non-load bearing partitions could be used to divide the open space for additional lab or office space as the floor system was designed to hold a live load of 125 psf.

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10. Appendices

The following sub-chapters contain information that was essential in completing the MQP but not vital to conveying the methodology, results, or conclusions.

10.1 Project Proposal

Project Numbers: LDA - 1001

GFS - 1003

DESIGN OF WPI MIXED-USE FACILITY FOR GATEWAY PARK

A Major Qualifying Project Proposal

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Civil Engineering

by

Paul F. Galligan

Rens F. Hayes IV

Thomas Zajac, Jr.

Date: October 15, 2009

Approved:

Prof. L. D. Albano

Prof. G. S. Salazar

Introduction

Worcester Polytechnic Institute, with its lasting commitment to redefining education and research, brought Gateway Park to the community in 2005. Gateway Park provides a foundation for scientists, scholars, students, and entrepreneurs to research and prosper. Life sciences, biotechnology, biochemical engineering companies and research programs will thrive in this 55-acre mixed use destination. It is designed to "foster innovation and create a smooth product pipeline from the lab to the marketplace." (Gateway Park, 2008)

Lot 3, in particular, will accommodate a four story, 20,000 square foot facility. The context of this facility currently includes multiple life sciences companies, a wet laboratory training facility, leasable office space, and a local high school. The proposed tenants include Massachusetts Biomedical Initiatives, Blue Sky Biotech, Massachusetts Academy of Math and Sciences, and Highland Executive Suites. This facility will become a versatile and integral part of Gateway Park. The integration of business and education in Lot 3 is a representation of the Gateway Park vision.

The project team's overall objective is to provide the project sponsor with a conceptual design that is structurally sound, cost effective and maximizes the use of multi-use space. The project team has identified key tasks that will allow for the fulfillment of these objectives. The tasks include the development process for the progression of structural design and construction management for Lot 3. The proposed floor layouts and needs of the tenants will be accounted for in the preliminary design. In the structural facet of the engineering design, structure frame and foundation design will be investigated. In the construction management aspect, the project team will propose a project construction timeline, plan and cost estimate. Various alternatives to the facility have been considered, but a proposed 20,000 square foot odeum with no interior columns on an additional floor will be investigated. The entire proposal will be completed with the LEED certification requirements in mind. Construction options and recommendations are to be made based on the project team's investigation.

A substantial amount of background research has been conducted to prepare for the preliminary design process. The history and vision of Gateway Park was investigated and implemented into the project team's objectives. Additionally, geotechnical reports, zoning implications and building requirements were explored to assure the design will be completed within the proper constraints. LEED certification requirements and wet laboratory facilities were researched to get a complete understanding of the challenges ahead. The methodology portrays the project team's approach to each aspect of the engineering design. As a capstone design experience, the project team looks to incorporate previous coursework and field experience to solve the real world constraints of the construction process for Lot 3.

Background

Gateway Park

One of the idealistic staples of Worcester Polytechnic Institute is its commitment to research and providing opportunities for individuals to freely explore their respective fields of study. Fulfilling this goal is Gateway Park, a joint venture between Worcester Polytechnic Institute and the Worcester Business Development Corporation. This 12-acre plot will soon provide 500,000 square feet of lab space, loft condominiums and several thousand square feet of retail space right in the heart of Worcester (Hurd, 2009). In the near future, Gateway Park will become a pivotal part of the 55-acre Gateway Redevelopment District that intends to revitalize its neighborhood by redeveloping the surrounding area and creating up to two thousand high wage occupations.

History of Gateway District

The Gateway District traces its roots to the manufacturing district of Worcester, Massachusetts. One of the premier companies to occupy the plot was the Washburn and Moen Manufacturing Company, a leading producer of steel wire. Although Washburn and Moen was an integral part of Gateway, it left the surrounding area with considerable soil contamination. This pollution classified Gateway as a “brownfield” site, a plot of land that is constructible but needs to be purged of its contaminants. (Welcome to Gateway Park, 2008)

March 2005 marked the advent of the Gateway Park redevelopment project. A $2.5 million grant from the United States Economic Development Administration allowed Worcester Polytechnic Institute and the Worcester Business and Development Corporation to begin bringing Gateway Park to life by ridding the brownfield sites and finding prospective developers.

Current Status of Gateway Park

In April 2007, WPI took its first step in creating a haven for life science study by completing the WPI Life Sciences and Bioengineering Center at Gateway Park. This 4-story facility is roughly 125,000 square feet of laboratory, conference and office space. It currently houses four WPI academic departments, several diverse research groups and modern conference rooms and offices. In addition, a multi-story parking garage that services the Gateway Park area was completed in June 2007 (www.gatewayparkworcester.com). Since the erection of these buildings, there has not been much progress made in the sense of new construction. However, WPI has made significant strides in marketing the ideology and goals of the Gateway project. (Hurd, D'Anne, 2009)

Despite its singular research building, Gateway Park has been making a considerable impact on the biomedical research world. In September 2009, several researchers at the Life Sciences and Biotechnology Center received awards totaling over $1.3 million from the National Institutes of Health and the National Science Foundation. The awards were given for a variety of research topics from engineering blood vessels and mechanical properties of heart valves to using stem-cells to restore function to damaged heart tissue. ("WPI Receives $1.3 million for Ongoing Life Science Research", Press Release, September 24, 2009) Additionally, its accolades include the 2007 Phoenix Award, a national honor that recognizes developments that reuse "brownfield" sites for new, productive uses.

Gateway has been contacted by various companies interested in leasing space in future buildings that will occupy the Gateway property. As of September 2009, Worcester Polytechnic Institute has approximately 60,000 square feet of lab and office space claimed in its next proposed building, an 80,000 square foot mixed use laboratory and office center. (www.gatewayparkworcester.com)

The Future of Gateway Park

The future vision of Gateway is bold and bright. As mentioned before, the entire Gateway business venture will incorporate 500,000 square feet of laboratories as well as space for commercial and retail lease. In total, the Gateway Redevelopment District is a locality that has been selected to be rejuvenated from a former manufacturing region to a new, contributing part of Worcester.

The next phase of Gateway Park consists of a variety of buildings with individual uses that will contribute to the diversity of the Gateway District. Building 3 (see Figure 1 below) will be a mixed-use graduate housing development with retail spaces in the bottom floor. Scheduled to break ground in 2011, this structure will be closely related to Founders Hall, a Worcester Polytechnic Institute undergraduate dormitory that supports living space on upper floors and a restaurant and convenience store on the ground floor. Building 4, a condominium complex with readily available parking will provide living quarters within the boundaries of Gateway, blending in with the surrounding neighborhood. In addition to the condos in Building 4, Building 5 will consist of affordable market-rate condominiums and commercial and retail space.

Figure 1: Proposed Gateway Park Complex

From our interview with D'Anne Hurd, the Vice President of Business Development at Gateway, we learned about three buildings that will be the life science "backbone" of Gateway Park. Each of these buildings, (Buildings 6, 7 & 8) will be leased out for commercial use. They will mainly consist of leased "wet" laboratories and offices that will house life science companies focused on life science research. These facilities, 100,000 square feet, 80,000 square feet and 140,000 square feet, respectively, have attracted the likes of many international corporations looking to expand to a region with a more attractive cost of living and research.

Figure 2: Artists Rendition of Gateway Park

Building 7: "Lot 3" Prescott Street

Proposed to break ground in November 2009, Building 7 is an 80,000 square foot edifice located at the intersection of Prescott Street and Washburn Way. The exact address of this building is yet to be determined, but this project will reference it as the "Lot 3" building. As mentioned previously, this facility will consist mainly of "wet" laboratories. One of the proposed tenants is Massachusetts Biomedical Initiatives, a non-profit biomedical corporation that has claimed 10,000 square feet of laboratories. Additionally, Blue Sky Biotech has expressed interest in expanding, and it has claimed 10,000 square feet to add offices and laboratories next to its headquarters in the Life Sciences and Bioengineering Center. However, life science research companies are not the only tenants in the facility. The Massachusetts Academy of Math and Sciences, a local high school for exceptional students, has signed a lease to become part of the ground floor. Also, Highland Executive Suites, an upscale office space leasing company has requested 10,000 square feet to fit out. (Hurd, 2009)

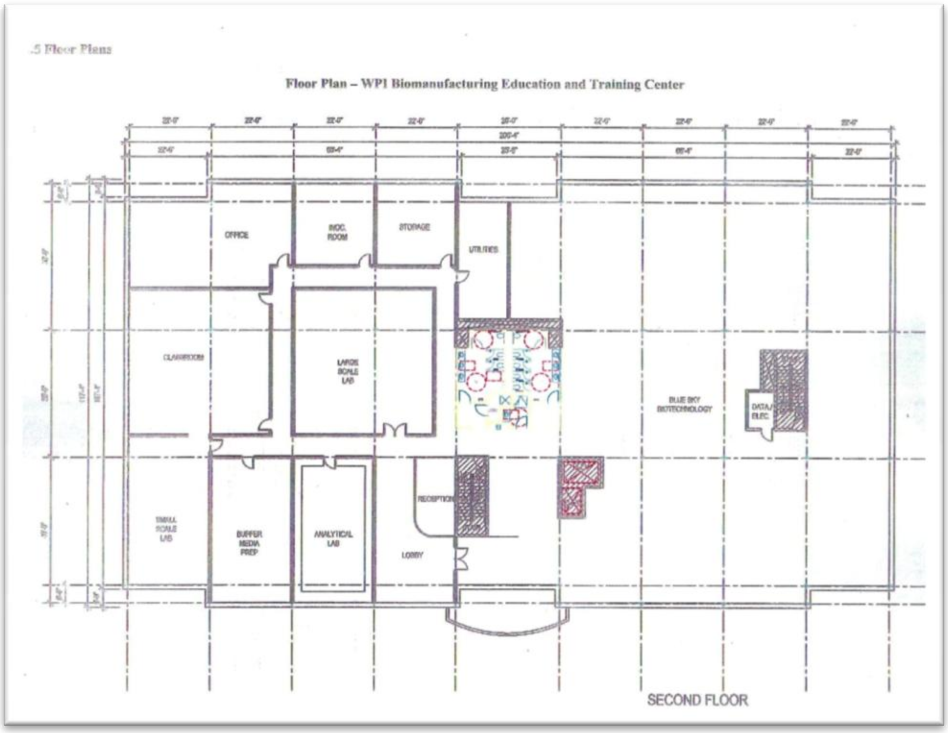

Figure 3: Floor Plan - WPI Biomanufacturing Education and Training Center

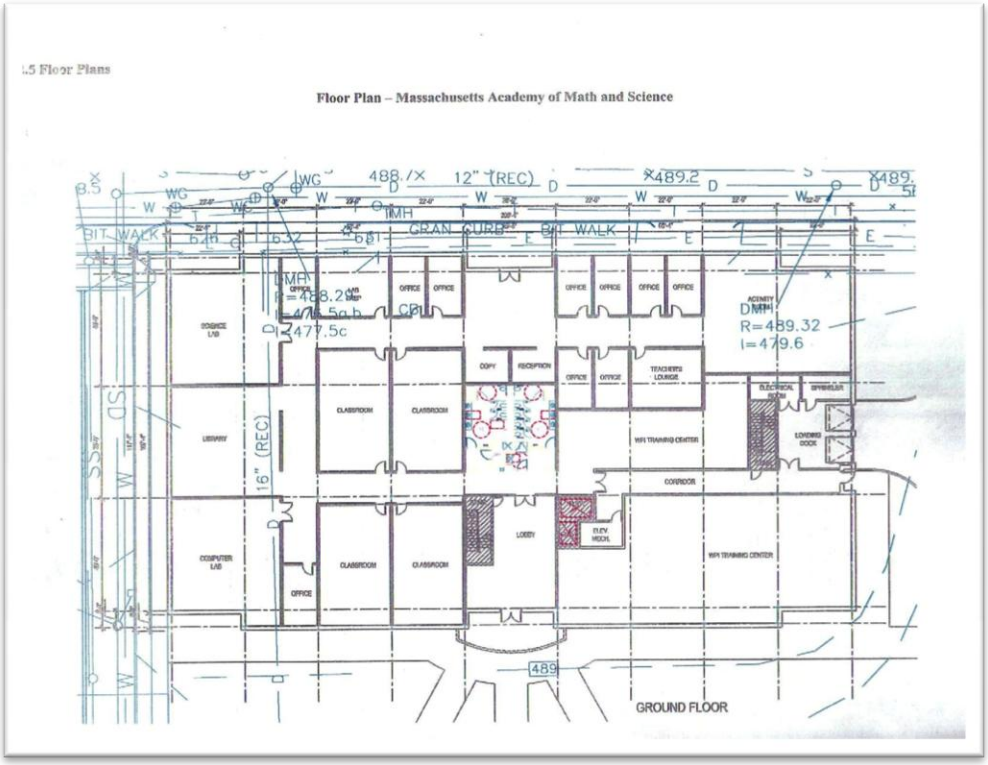

Figure 4: Floor Plan - Massachusetts Academy of Math and Science

Overall, the "Lot 3" building will become a versatile and integral part of Gateway Park. It has the ability to be used as an educational center as well as a means of profit; an ideal situation for Gateway Park as it moves forward in development.

Gateway Park: Soils and Geotechnical Report

In October 2005, a preliminary geotechnical report was done on the soils in Gateway Park by Maguire Group Inc., an architectural and engineering firm located in Foxborough, MA. It primarily focused on the soils around the proposed parking garage and the adjacent facilities and plaza. The report introduces the site history of Gateway as well as the regional topsoil and subsurface history of the adjoining area.

The report also outlines the testing programs and procedures done by the respective boring and testing companies. Overall, there were twenty five bore holes drilled in the Gateway area. These were strategically placed throughout the proposed Gateway layout to present the best possible estimation for the existing soil conditions. The borings were performed by New Hampshire Borings, Inc. and cylinders were forwarded to the firm of Paul B. Aldinger and Associates for soil testing. Groundwater location wells were excavated to locate the groundwater table below the Gateway Park locale. (Maguire Group, 2005)

Soil data was collected and grouped by proximity to a prospective structure that was projected to be built in 2005. These five groups include the plaza, building number 8, the present parking facility, the at-grade parking lot and the access road that will weave through the Gateway campus. These groups make up what is identified as the “Lower Site” of Gateway Park.

In reading the geotechnical report, there is no information that directly pertains to the “Lot 3” building. However, there are three boring logs, designated as MGI-08, MGI-11 and MGI-14, very close to the proposed building that will provide the group with enough geological information with which to design foundations. MGI-8 is located between “Lot 3” and proposed Building number 2 near Prescott Street. MGI-11 is located within the plaza at the midpoint of the eastern exterior wall of “Lot 3”. Lastly, MGI-14 is located off of the northeastern corner of the facility, closest to the existing Life Science and Biotechnology Center. (Maguire Group, 2005)

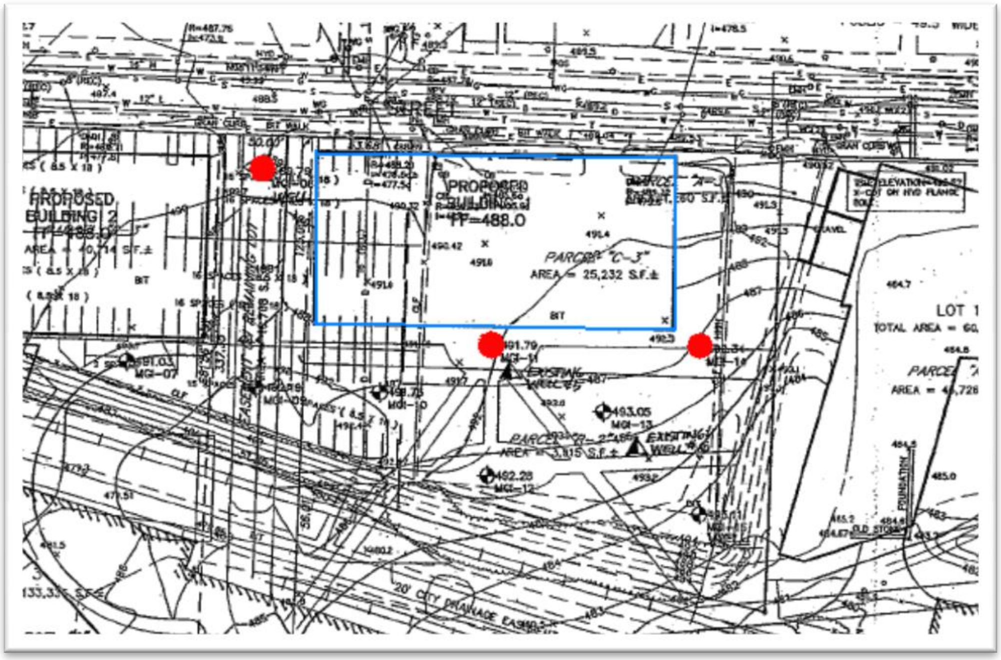

Figure 5: Location of Gateway Park Soil Borings

In looking at the boring logs done in 2005, the soil conditions seem to be consistent throughout the project site. The profiles are principally medium to very dense sand with a little bit of silt. Small amounts of gravel appear in MGI-14, the closest boring log to the Life Sciences Center. Uniform conditions like those found in the preliminary geotechnical report tend to provide a stable foundation base and facilitate the design of concrete footings

Zoning Ordinance of the City of Worcester

Land use and zoning laws regulate the use and development of real estate. Zoning is the most common form of land-use regulations. Municipalities use zoning regulations and restrictions to control and direct the development of property within their jurisdiction. In addition, easements and eminent domain are two legal issues related to land use. An easement allows the holder to use property that he or she does not actually own or possess for purposes such as a road or utility access. The government's power to take private land (while providing compensation) for public use is known as eminent domain. (Land Use & Zoning, 2009)

Various geographic areas, or zones, are restricted to certain uses and development such as residential and commercial. These zones are then subdivided by additional use restrictions. These subdivisions may include industrial, light-industrial, commercial, light-commercial, agricultural, single-family residential, multi-unit residential, schools, and other purposes. Zoning laws may affect issues such as parking, setbacks, floor area ratios, lot size, height restrictions, etc. Therefore, entrepreneurs and business owners need to be aware of zoning regulations when looking to set up, expand, or relocate business establishments. (Zoning Ordinances Law & Legal, 2008)

Municipalities use zoning as a primary technique to manage the future development of community, protect neighborhoods, concentrate business (retail and industrial), and even channel traffic. As a result, homeowners in a residential zone do not have to worry about a gas station going up next door, however, a home-based business may not be in accordance with residential zoning restrictions if it requires signs or frequent traffic from customers. Similarly, a factory in an industrial zone does not have to worry about noise complaints from residential neighbors. This prevents neighbors, both business oriented and residential, from having a disagreement about regulations. Each Municipality has its own visions and goals portrayed by specific Zoning Ordinances. Lot 3, located on Prescott Street, is restricted by the specifications set forth by the Zoning Ordinance of the City of Worcester.

The Zoning Ordinance of the City of Worcester (ZOCW) states its objective of promoting the health, safety and general welfare of the public while complying with Worcester's plans for progress and growth. To satisfy this objective, the ZOCW is devised to encourage the appropriate use of land, which is defined by six characteristics:

- Creates and maintains an environment in which people can fulfill the social, economic and other needs of present and future generations.
- Facilitates transportation, water supply, drainage, sewerage, schools, parks, open space, lights and other public requirements.
- Encourages economic development and housing suitable for the present and future needs.
- Protects against: overcrowding of land; air and water pollution; use of land incompatible with nearby uses; undue intensity of noise; danger and congestion in transportation; and loss of life, health, or property from fire, floor panic or other dangers.
- Protects natural environment including its scenic and aesthetic qualities.
- Promotes the preservation of historical/architectural significant land uses.

The administrative authority of the ZOCW is the Director of Code Enforcement, whom will withhold a building permit for a structure in violation of the Ordinance. An investigation or inspection will be made of the pertaining property if the Director of Code Enforcement has any reason to believe the ZOCW has been compromised. Any person or organization violating the Ordinance may be fined no more than three hundred dollars for each offense, but a violation is considered to be a new offense each day it is not corrected. There is, however, the right for any person to appeal a violation and apply for a variance or special permit. The Special Permit Granting Authority (SPGA) is either the Zoning Board of Appeals (ZBA) or the Planning Board depending on the context of the permit request. Special permits are usually granted given the benefits outweigh the adverse effects to the city or neighborhood. It is also important to note that permits are acquired before the start of construction. (Zoning Ordinance of the City of Worcester, 2008)

For the purpose of the ZOCW, the city was divided into a number of districts: Residence, Business, Industrial, Manufacturing, Institutional, Airport, and Overlay Districts as well as Open Space Zones. "Lot 3" of Gateway Park is located in the Business District, specifically BG-6.0: Business, General. The school, research laboratories, and offices planned to be located at Lot 3 are all in accordance with the specifications of this zoning district. A more complete description of permitted uses by zoning districts in terms of residential, business, manufacturing, and general uses can be found in Appendix A. This table from the 2008 ZOCW verifies all intended uses on Lot 3 are in accordance.

Each zoning district also has restrictions on the dimensions of the building, lot, and where the building sits on the lot. This helps control the aesthetics of a particular neighborhood. One of the primary specifications noted for BG-6.0 is the maximum floor area ratio (FAR). There can be no more than 6 square feet of building per 1 square foot of land. A required rear yard setback of at least 10 linear feet is also noted. An interesting observation is the ZOCW does not specify a height restriction for zone BG-6.0. The City Planning Board, however, takes the surrounding area into consideration. In other words, a skyscraper would seem out of place if it was neighboring only four story buildings. Therefore, the height restriction for units within the BG-6.0 zoning district may be no more than six times the floor area. An additional floor space premium of 600 square feet per parking space added is allowed where off-street parking is provided on-site or within 1,000 feet of the building. (ZOCW, 2008)

Lot 3 also lies within the Mixed Use Overlay Zone. The intent of each mixed use development is to contain a variety of land uses. It is specifically defined as a development "characterized by two or more significant revenue producing uses, such as retail, office, residential, hotel/ motel, entertainment/cultural/recreational which are mutually supporting, exhibit physical and functional integration and are developed in conformance with a coherent plan." (ZOCW, 2008) There are some additional limitations to Lot 3 because it lies within the mixed use overlay zone. One single development may not constitute more than 75% of the gross floor area. Recreational or open space must constitute at least 5% of the gross floor area. This open space is characterized as an area that is free and accessible to the public for activities and/or amenities. Lastly, it is important to abide by the most restrictive limitations, whether it is a BG-6.0 or mixed use overlay zone detail. (ZOCW, 2008)

Leadership in Energy and Environmental Design

To fulfill its commitment to sustainability, Worcester Polytechnic Institute has pledged to design and construct buildings with Leadership in Energy and Environmental Design certification in mind. Since its commitment to sustainability, the university has constructed three buildings that have achieved some sort of LEED accreditation. WPI's first LEED certified building was the undergraduate admissions facility, the Bartlett Center. This building, which stands adjacent to WPI's quadrangle, was completed and registered as a LEED certified facility in 2006. Following the Bartlett Center was the WPI Life Sciences and Bioengineering Center. Completed and registered in 2007, this was the Institute's second LEED certified building and first in Gateway Park. The latest addition to Worcester Polytechnic Institute's LEED certified structures is East Hall, a state-of-the-art undergraduate dormitory that holds a "Gold" certification. East Hall serves as Worcester Polytechnic Institute's proudest accomplishment in sustainable design, holding one of the only green roofs in the Worcester area. (WPI Sustainability, 2008)

LEED Certification

Leadership in Energy and Environmental Design is an initiative started by the United States Green Building Council (USGBC) that strives to rate buildings and communities that have committed to design and build with energy efficiency, water conservation and emission reduction in mind. It accomplishes this goal by recommending products that are environmentally friendly or locally obtained. Additionally, it establishes protocols and procedures for owners to maintain during construction and occupancy. Within the last year, the USGBC upgraded LEED to "v3", an updated and more extensive certification program. (USGBC, 2009)

LEED is internationally recognized as one of the premier sustainability evaluation systems available for developers and property owners. It uses an objective-based point system to designate different levels of sustainability: Certified, Silver, Gold and Platinum. Each related point is grouped into a category. When the building is complete and ready to be examined for certification, a team of LEED Accredited Professionals will determine the point total based on construction procedures, current equipment and future building protocol. The sum of these point totals equates to the facility's sustainability level. (USGBC, 2009)

One of the categories that LEED focuses on is "Sustainable Sites". This rating category encourages owners to build upon previously developed land, create regionally appropriate landscaping, control stormwater runoff and minimize construction related pollution (www.usgbc.org). These initiatives encourage the healthy use of the land that the building is constructed on. Another category, "Water Efficiency," focuses on wiser use of potable water in the building and landscaping that is environmentally friendly in regards to runoff dispersion. Items that can be used towards LEED accreditation points include efficient water fixtures and appliances as well as designated runoff wetland areas and permeable pavement.

The "Energy and Atmosphere" division is one of the broader point categories. This category encompasses building emissions and electricity, two very important aspects of environmental concern. It promotes the use of lighting systems and strategies that ensure that unused lights are turned off. Additionally, it encourages the use of clean, renewable sources of energy as a source of power that produces minimal emissions. Another category, "Materials & Resources" plays a large part in LEED accreditation. LEED encourages the use of locally grown or fabricated construction materials, such as lumber, drywall or structural framing, when selecting components that will be part of the facility. "Materials and Resources" also focuses on the reduction of waste and the use of recycled materials throughout the construction process.

LEED 2009 FOR NEW CONSTRUCTION AND MAJOR RENOVATIONS PROJECT CHECKLIST

Sustainable Sites		**26 Possible Points**
☑ Prerequisite 1	Construction Activity Pollution Prevention	Required
☐ Credit 1	Site Selection	1
☐ Credit 2	Development Density and Community Connectivity	5
☐ Credit 3	Brownfield Redevelopment	1
☐ Credit 4.1	Alternative Transportation—Public Transportation Access	6
☐ Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
☐ Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
☐ Credit 4.4	Alternative Transportation—Parking Capacity	2
☐ Credit 5.1	Site Development—Protect or Restore Habitat	1
☐ Credit 5.2	Site Development—Maximize Open Space	1
☐ Credit 6.1	Stormwater Design—Quantity Control	1
☐ Credit 6.2	Stormwater Design—Quality Control	1
☐ Credit 7.1	Heat Island Effect—Nonroof	1
☐ Credit 7.2	Heat Island Effect—Roof	1
☐ Credit 8	Light Pollution Reduction	1
Water Efficiency		**10 Possible Points**
☑ Prerequisite 1	Water Use Reduction	Required
☐ Credit 1	Water Efficient Landscaping	2-4
☐ Credit 2	Innovative Wastewater Technologies	2
☐ Credit 3	Water Use Reduction	2-4

Figure 6: LEED Checklist 2009

The previous four categories are the major divisions that incorporate most of the building's sustainable features. LEED also includes divisions such as "Locations and Linkages" and "Awareness & Education" that focus on the transportation of building tenants and the education of the tenants, respectively. It should be noted that these divisions do not necessarily pertain to the construction or components of the building yet still provide valuable accreditation points. (USGBC, 2009)

As a result Worcester Polytechnic Institute's sustainability pledge, Leadership in Energy and Environmental Design becomes a significant part of any development project within WPI's realm. Additionally, sustainability is one of the most attractive revenue tools for companies and developers alike. The ability to have a sustainable initiative sends positive messages about the identity of a corporation, big or small. (Shireman, 2005)

Similar Facilities

This section of the background will discuss similar facilities that will be of use to the project team in comparing floor layouts, wet lab space, construction timelines, and cost estimating. As previously mentioned, the Gateway Park Lot 3 building will be a mixed-use facility consisting of commercial laboratory, office and educational space. In the alternative design, open-area conference or meeting space will be investigated and proposed for the fifth floor. The project team has identified the WPI Life Sciences and Biotechnology Center and the Charles River Laboratories Building 21 as two buildings that have similar, specific components to that of the proposed building.

The WPI Life Sciences and Biotechnology Center was the first Gateway Park building and was completed in April 2007. This state of the art facility houses four WPI academic departments, several diverse research groups, and modern conference rooms and offices. Examining laboratory layouts in this building will help the project team finalize similar designs for the proposed building. Also, adjacencies between lab, educational and office space will be investigated to determine effectiveness and overall feasibility. Once the final design for the proposed building's layout is completed, the project group will use the cost per square foot for the current building's lab, office and educational space in order to develop a cost estimate for the proposed building. For example, the cost per square foot for the proposed lab space will include HVAC and MEP system's cost per square foot for similar wet lab space. Having a detailed, breakdown of each system will allow for a comparison when comparing the costs to other buildings.

Charles River Laboratories (CRL) is an emerging biotechnology and pharmaceutical drug development corporation that is headquartered in Wilmington, Massachusetts. One of the group members worked on a project last summer involving the design of a 100,000 ft. facility mainly comprised of laboratory and office support space. This facility will use estimates from previous CRL built facilities around the world. By comparing cost estimates with the WPI Life Sciences and Biotechnology Center, the project team will be able to accurately gain a total cost per square foot for the proposed building.

Methodology

The following section will provide a detailed description of how the project team will complete a proposed design, construction plan and cost estimate for the WPI Gateway Park "Lot 3" building. The scope of work is broken down into categories based upon anticipated time of completion and type of task. These tasks include all architectural, engineering and construction works for the proposed building.

Architectural Design & Layout

Preliminary layouts by the contracted design team were provided to the project team. The designs feature four to five floors of commercial laboratory space based on a 20,000 sq ft footprint, with a majority of the floor area dedicated to the previously discussed "wet lab" space. The designs outline the building and designate space to be given to potential tenants who have already signed on with the project or will do so in the near future. Much of the floor space, especially the wet lab space, has been outlined but not properly defined. There are no current layouts showing HVAC, MEP systems, equipment, countertop space or any other detailed parts of the labs. Based upon information gathered from the owner about the potential tenants and similar facilities, the project team will design the space layout for each floor of the building. This special layout will use column placement to dictate where walls, offices, and other interior components will lie. This is an important part of the project scope to finalize because the arrangement of lab space will affect the loading on the structural bays discussed below.

For the initial design of the building layout, the project team will heavily rely on the proposed layouts that were received from D'Anne Hurd. Feedback from the proposed tenants was provided to the owner and conveyed to the project team in previous meetings. In addition, detailed project documents and proposals outlined the desired the services and capabilities of the proposed tenants that the leased space would need to provide. Second, the project team has identified typical features of wet lab space and will use the information to generate its own layout. Finally, similar facilities will be researched to determine if the layout generated by the project team follows the same standards set forth from the current industry. For the smaller educational space, a comparable process will be followed that will take into account the program's needs, design a layout that suits their needs, and compare the proposed design with similar projects. Through this process, the project team is confident that it can generate an effective design that meets the needs of the proposed tenants while taking into consideration the approach of the engineering design.

To illustrate the preliminary architectural design, the project team will use the computer program REVIT. REVIT is a three-dimensional, object-based architectural layout program that not only provides layouts, but provides square footages that facilitate the calculation of preliminary cost estimates. The program will also be able to provide 11"x17" drawings that will show exterior and interior elevations and building sections.

Structural Engineering Design

One of fundamental deliverables of our project is the structural design of the building. The structural bays will be coordinated with the layout of the building, or in this case the laboratory space and school. Adjustments can be made to the bays if specific layouts are necessary. The frame is made up of a grid with repeating standard structural bays. Special areas, such as elevators, are handled separately. Included in the structural system are bay sizes, shape and size of structural members, loads, floor compositions and curtain walls. The gravity load design will be completed for two frames: one of structural steel and one of reinforced concrete. One of the two frames will be chosen for further design based on criteria that include cost estimates of material and constructability. The chosen system will then be designed for lateral loading with necessary adjustments being made to framing members. Next, the project team will design standard connections or reinforcement details for the structural frame. Once the structural frame is selected and finalized, foundation design will begin to evaluate the necessary footing size to adequately transfer the load from the structural frame to the ground. Engineering calculations will be provided by the project team as well supported through the use of spreadsheets and simulation programs such as RISA or STAAD.

Construction Plan & Schedule

Once all the tasks for the conceptual designs have been identified, a detailed construction plan will be prepared. The construction plan will incorporate all engineering and construction tasks that are to be completed for the project. Tasks will be broken down into CSI Masterformat to provide a more detailed perspective into the project's completion. Through the construction schedule, a detailed critical path can be determined, that is, which activities govern the pace of the project. The critical path is an accurate way to estimate a project's expected time of completion. Additionally, construction phases will be used to document progress through the schedule. The project scheduling computer program Primavera will be used to set up the construction schedule for this project.

The construction project schedule for systems that are not within the project scope, such as MEP systems, will be loosely based upon other construction schedules that the group obtains. Ideally, the team will assemble the schedules from typical high school, laboratory facility and office building. Each schedule will be examined and condensed to match the preliminary construction timeframe. Then, the schedules will be cross referenced to our list of major construction activities and new activities will be added if necessary. Lastly, the revised schedules will be united to produce a master schedule that will be part of our final submittal package.

Cost Estimate

A cost estimate incorporating all aspects of the project will be completed as a project deliverable. The project group will generate a design that meets the needs of WPI while keeping the cost as close to its expected value as possible. A preliminary cost estimate will be calculated using facility square footages and RS Means construction cost per square foot values. Later, as the project develops, a cost estimate will be provided based on the calculated materials and equipment needed within the facility. Variables that will influence the price will be the cost of equipment, labor, construction, and materials. The materials and services required will be evaluated at each step of the design process to construct a running cost estimate. The cost estimate will be organized in a spreadsheet broken down into separate categories of building construction based on the CSI Masterformat.

Unless otherwise noted, cost estimates will be based on current market prices or assumed construction costs provided by RS Means. The group will develop a cost for the project including the construction of the building, the interior furnishings, special equipment and site work. The base construction and special equipment costs, including HVAC and MEP systems, will be derived from typical square footage cost of similar buildings. Additionally, costs of other aspects of the project that are not within the design scope will be determined on case by case basis. The summation of all obtained costs will become the group's estimated total cost and submitted as the project deliverable.

Site & Utility Planning

The site and utility designs are a very important part of any project as they can cause major delays if planned poorly or not taken into consideration beforehand. The site design governs all traffic and parking regulations and must meet all zoning ordinances. Situated in a downtown area, parking is challenging and will be alleviated on-site through the newly built parking garage and future planned parking areas. The utility design will consider existing utilities on site and those that can be accessed from the nearby WPI Life Sciences and Bioengineering Center. Coordination of water, gas, electrical, sewer, and telecommunication locations will be performed on this pad-ready site. The group will rely on utility sketches and drawings to plot approximate tapping points.

As the construction schedule becomes finalized and construction phases begin to become more apparent, the project team will create an overall construction site plans. These plans will designate laydown areas and direct construction traffic in relation to the various construction phases. The project team will generate coordination drawings and narratives to illustrate the proposed plan.

LEED Certification

As previously mentioned, one aspect in the design of the facility will be assigning the building some sort of LEED certification level. This process will be present throughout the structural design and the cost estimate stages of the project. The group has decided to achieve "Silver" LEED certification on the proposed facility. This will reach LEED certification without creating a significant financial burden on the university to provide excessive environmental alternatives. It should be noted that LEED has recently upgraded to LEED v3, a policy that is more rigorous than the previous LEED 2.2. The major qualifying project will solely evaluate the building with the latest LEED verification standards.

Because LEED is a point-based certification system, the group will first identify LEED points that can be easily maintained and are somewhat unrelated to the scope of the project. This includes but is not limited to parking spaces for eco-friendly vehicles, alternative transportation to the facility and the inhabitance of a LEED Accredited Professional. Additionally, points can be assigned by recycling and reusing construction materials during the erection of the building. These points will provide the very beginning of our LEED certification point total and will most likely not be factored into the design of the facility.

Next, the project team will examine the other LEED certified facilities that are located on Worcester Polytechnic Institutes campus to indentify the common LEED points and requirements that the buildings shared. It is assumed that the university will use similar technologies in new buildings if they were habitually used in previous certified facilities. This information can be easily obtained by examining the LEED checklists that were submitted and approved for each structure. If these are not available, the group will tour each building and take note of similar and applicable “green” strategies employed. The project group is also aware that there are certain LEED accreditation requirements that must be met in order to become LEED certified. These requirements will take first priority as the design of the facility progresses.

Throughout the weeks of the completion of the project, the team will be responsible for identifying opportunities for the facility to earn LEED points by recognizing when and if equipment can be upgraded to a more efficient or eco-friendly model. When this occurs, the cost of the unit must be factored into the total cost estimate to maintain the integrity of the effect of the LEED upgrades. One particular facet of the project that will most likely be affected by this process will be the selection of HVAC units for the facility.

Over the course of the term, the project team will become well-versed in the design aspects of a LEED certified facility. Early preparation by examining LEED suggested alternatives will help the team as it moves forward through the weeks and incorporate said alternatives into the design and cost estimate.

Alternate Approach: 5th Floor Conference Center/Odeum

The initial proposal for Gateway Park "Lot 3" building is four 20,000 sq ft floors mainly consisting of laboratory or educational space. It was expressed to the project team that alternate designs involving a fifth floor could be considered if there was a need. Wet labs are designed, built and fitted to a certain specification. Equipment, HVAC and MEP systems, and other characteristics of a lab are built for its intended purpose. To change or alter the space in order to use it for another purpose would be expensive and time consuming. The most obvious use of an additional floor would be wet lab space similar to the underlying floors; though, building additional lab space could be a risk to the owner if the space cannot be filled. Another option is to shell out the top floor, that is, not to include any interior walls and develop the space at a later date. However, empty space is not a revenue producer.

While much of the first four floors of the proposed building already has detailed preliminary design, the project team will propose a fifth floor that features an open-style conference center or odeum along with small meeting rooms and additional office space. No such similar flexible or open space was found in the initial designs of the building. This space could serve as a general assembly area that would have the capabilities to house events from small lectures to large conferences and conventions. The meeting space would have the capabilities to hold student groups, local community groups, small business meetings, lectures, etc. With its modern feel and newest technology, this space certainly would attract numerous types of users and garner consistent revenue. The floor will consist of limited interior columns to not only maximize open space, but also ensure that it could more easily be transformed into additional laboratory space. Flexible and open space would highly complement the laboratory space currently planned and give the building an additional feature that would make it more attractive to prospective tenants.

With the addition of the "odeum" alternative, the overall cost estimate would have to be adjusted. The estimate would have to reflect additional steel or concrete, wall space and MEP equipment that would make up the supplementary floor space. The structural changes would reflect dead and live loads that must be considered with the open-area floor. Although the floor will be originally planned for the open-area "odeum," the frame of the building must be designed to support the worst-case scenario of its use. The cost estimates and construction schedule will reflect these changes.

Project Schedule

The research and conceptual design for the Gateway Park "Lot 3" Building will begin in the last week of August 2009 and end the third week of December 2009. The project team will divide the work into weekly segments that follow the WPI academic schedule. It should be noted that the Fall Semester 2009 consists of A Term, B Term and one week of fall break. The following table depicts the schedule of the tasks and deliverables that will be completed on a week to week basis:

Table 1: Project Timeline

Week	Dates	Weekly Tasks & Deliverables
1	08/30 – 09/05	First meeting with advisors; Schedule meeting with owner; Begin research
2	09/06 – 09/12	Initial meeting with owner; Preliminary Proposal due
3	09/13 – 09/20	Finalize project scope; Begin Project Schedule
4	09/20 – 09/26	Begin Introduction, Background, Methodology, & Capstone Design
5	09/27 – 10/3	Submittal #1: Initial Draft of Proposal
6	10/04 – 10/10	Revisions of Proposal; Review tutorials for Revit, Primavera, STAAD
7	10/11 – 10/17	Submittal #2: Final Proposal
8	10/18 – 10/24	*Fall Break:* Begin Project Scheduling & Construction Plan (Primavera) Design of Loading Combinations and Roof

9	10/25 – 10/31	Building Area Layout & Fit-out (Revit) Cost Estimating: Shell, Sitework, Interiors Design of Beams, Girders for both steel and reinforced concrete frames
10	11/01 – 11/07	Cost Estimating: Equipment, Utilities Design of Columns, Connections for both steel and reinforced concrete frames
11	11/08 – 11/14	Cost Estimating: Substructure, Foundation Design Submittal #3: Structural Frames, Scheduling & Construction Plan
12	11/15 – 11/21	Create conceptual design (Revit) Continue Cost Estimating Design of Foundations
13	11/22 – 11/28	Finalize Cost Estimate, Project Schedule Submittal #4: Foundation Design, Itemized Total Cost
14	11/29 – 12/05	Submittal #5: Initial Draft Final Report
15	12/06 – 12/12	Revisions of Final Report
16	12/13 – 12/17	Submittal #6: Final Report

Capstone Design Criteria

The construction of such a diverse building will introduce many difficulties for us as we complete our Major Qualifying Project. Some of the challenges that we have identified follow the standards set forth in the ABET General Criterion Curriculum. The standards state that students "must be prepared for engineering practice," and recognize "realistic restraints" that are involved with a real-world project (Criteria for Accrediting Engineering Programs/ABET). This section of the report will address specific restraints that apply to the project, including issues involving economics, constructability, the environment & sustainability,

Economic

From an economic standpoint, a general cost analysis needs to be done for the project including cost implications of alternative approaches in design or construction. A generalized cost per square footage can then be calculated by referencing similar designs from previously constructed buildings of similar size, shape and purpose. The overall goal for this facility from the economic standpoint will be to provide a constant and healthy stream of revenue to both Worcester Polytechnic Institute and the Worcester Business Development Commission. This influx of money can be maximized by designing a building that attracts tenants and satisfies their specifications while being built at minimal cost. A simple, cost estimate will be done to compare the revenue on a long-term basis.

Constructability

Constructability should not be a major issue as there is ample laydown space and curb access during the construction phase. Efforts to standardize sizes and materials would enhance the effort to maximize repeatability, especially when choosing member sizes in both the structural steel and reinforced concrete alternatives. One of the most important ways to attack the issue of constructability is the generation of an effective and logical construction plan. The construction plan should encompass the order in which materials should be delivered to the site and the order in which they should be added to the facility. Seemingly trivial, the procurement of equipment and materials can help or burden the project's schedule.

Another issue of constructability that will be a difficult obstacle will be accommodating the mixed use aspect of the facility. The group will need to combat complications such separating the school from the remainder of the building while isolating each wet laboratory workspace to be its own cell within the building.

Environmental & Sustainability

As WPI has committed to future buildings to be environmentally friendly, environmental and sustainability issues will certainly be a major focus for the project. Difficulties could include issues surrounding storm water management, LEED certification, EPA "brownfield" site conditions and maximizing flexible space. The project team will try to incorporate as many environmentally friendly systems as possible but also must keep in mind the restrictions of these aforementioned systems and their effect on the total cost of construction.

Health & Safety

Both the design and construction phases would need to take into account all local, state and federal building, health and safety codes. The project team and contracted construction team will consult and abide by the Occupational Safety and Health Administration. This standard is customary for construction projects throughout the United States.

Social, Ethical & Political

Social, ethical and political problems are closely associated and can delay or stop projects altogether if the proposed development falls out of favor. No doubt a project of this magnitude would have a great impact on the local community, especially the surrounding old mill district. Depending on the kind of tests that are being conducted (stem cell research, animal testing, etc.), ethical issues could arise within the community if the public thinks that the development does more harm than good. However, the proposed building could ensure it's a positive one by enhancing education and the interest of the Massachusetts Academy students in the field of mathematics and sciences, and acting as a catalyst for community growth in the area around Gateway Park. The Gateway Park expansion would provide thousands of jobs in both the short-term and long-term and invigorate continued growth and opportunity to Worcester. By continuing WPI's pledge for sustainability and environmental friendly buildings through the "Silver" LEED certification, the community would be less inclined to worry about long-term ramification to the environment. Overall, the Lot 3 building will contribute far more positive than negative effects on the city of Worcester and its local community; therefore, most social, ethical and political issues will be at a minimum.

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10.2 Permitted Uses by Zoning Districts Table 4.1 (ZOCW, 2008)

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
GENERAL USE

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
1. Agriculture, horticulture, viticulture, flora culture on parcels less than five (5) acres	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
2. Cemetery, crematory, memorial park	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N
3. Clinic	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	N	Y	N
4. Club, lodge, other private grounds (non-profit and private)	SP	SP	SP	SP	SP	SP	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	N	N	N
5. Day Care Center	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
6. Heliport	N	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	Y
7. Library/Museum (non-profit)	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	Y	Y	N
8. Library/Museum (profit)	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	N	N	N
9. Licensed hospital, Sanitarium	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	Y	Y	N
10. Non-accessory residential parking	SP	SP	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N
11. Non-residential parking facility (non-accessory)	N	N	N	N	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
12. Nursing or convalescent home/institution/facility	N	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	Y	N
13. Open lot storage of more than one (1) unregistered automobile in excess of (7) seven days	N	N	N	N	N	N	SP	SP	SP	SP	N	SP	SP	SP	SP	SP	SP	N	N	N	N
14. Personal Wireless Service Facilities Interior-Mounted and Side-Mounted	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
15. Personal Wireless Service Facilities Roof-Mounted, Ground-Mounted, and Structure-Mounted	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
Y – Yes; N – No; SP – Special Permit																					

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
GENERAL USE - Continued

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
16. Place of worship	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
17. Radio/TV Transmission Tower	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	N	N	N	N
18. Recreational/service facility (non-profit)	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	Y	Y	N
19. Religious or educational use (EXEMPT)(See Art. XVII; M.G.L.c.40A, s.3)	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
20. Schools (K-12, college, University, technical institute) non-profit	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
21. Schools (vocational, professional, other) profit	N	N	N	N	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	SP
22. Shooting Ranges – Indoor/Outdoor (see note 11)	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	N	SP	N	N	N	N
23. Teen/Youth Center	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	N
24. Transformer, pumping station, sub-station, telephone exchange	SP	SP	SP	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
25. Wind Energy Conversion Facilities	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
Y – Yes; N – No SP – Special Permit																					

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
BUSINESS USES

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
1. Adult entertainment establishments	N	N	N	N	N	N	N	N	N	N	SP	N	N	N	N	N	N	N	N	N	N
2. Animal hospital, clinic, pet shop	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
3. Bank, credit union	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	SP
4. Bank, credit union with drive thru	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP
5. Bus station or terminal, RR passenger station	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y
6. Food service (drive-thru)	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	N
7. Food service (excludes consumption/sale of alcoholic beverages)	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	SP	SP	Y
8. Food service (includes consumption/sale of alcoholic beverages) and/or providing dancing or entertainment	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	SP	SP	Y
9. Funeral undertaking establishment	N	N	SP	SP	Y	Y	Y	Y	Y	Y	Y	N	N	N	N	N	N	N	N	N	N
10. In-door recreation, health club-profit	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
11. Indoor rental & service of equipment for home and recreational uses	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
12. Kennel	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	N
13. Marina	N	N	N	N	N	N	SP	N	N	N	N	N	N	N	N	N	N	N	N	N	N
14. Motel, hotel, inn	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	Y	Y

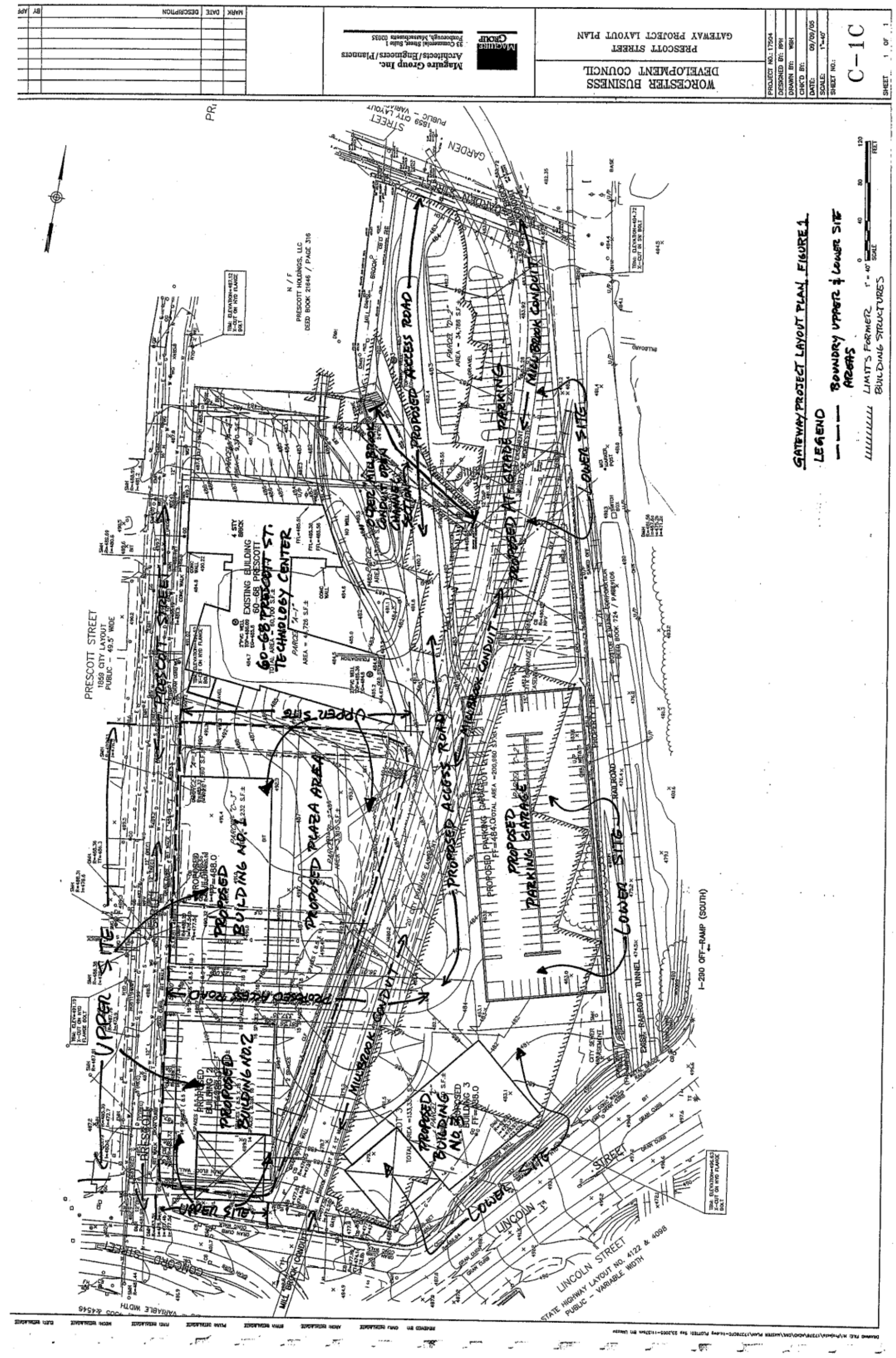
Y – Yes; N – No;
SP – Special Permit

PERMITTED USES BY ZONING DISTRICTS – Table 4.1
BUSINESS USES - Continued

	RS 10	RS 7	RL 7	RG 5	BO 1	BO 2	BL 1	BG 2	BG 3	BG 4	BG 6	ML 0.5	ML 1	ML 2	MG 0.5	MG 1	MG 2	IP 0.33	IN S	IN H	A 1
15. Motor vehicle/trailer/boat sales, rental	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y
16. Motor vehicle service, repair, garage, display	N	N	N	N	N	N	SP	Y	Y	Y	SP	Y	Y	Y	Y	Y	Y	N	N	N	Y
17. Automobile Refueling Station	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	SP
18. Office, general (travel agency, auto driving school)	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	Y
19. Office, professional	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y	N
20. Outdoor recreation (for Profit)	N	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	N
21. Package store (alcoholic beverage sale not to be consumed on premise)	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	N	N
22. Radio/TV studio	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N
23. Research lab. w/o manufacturing abilities	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y
24. Retail Food Sales	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	SP	SP	Y
25. Retail greater than 50% display space outdoors	N	N	N	N	N	N	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	SP	N	N	N	N
26. Retail sales, including retail with incidental fabrication assembly	N	N	N	N	N	N	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	SP	SP	Y
27. Service shop, personal services	N	N	SP	SP	SP	SP	Y	Y	Y	Y	Y	SP	SP	SP	SP	SP	SP	N	SP	SP	Y
28. Theatre, motion picture theatre, concert hall	N	N	N	N	N	N	SP	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	Y	N	N
29. Wholesale business or storage conducted entirely within an enclosed structure (with noise, dust, fumes, gases and odors confined to the premises)	N	N	N	N	N	N	N	N	Y	Y	Y	Y	Y	Y	Y	Y	Y	Y	N	N	Y

Y – Yes; N – No;
SP – Special Permit

10.3 Geotechnical Report Sketches



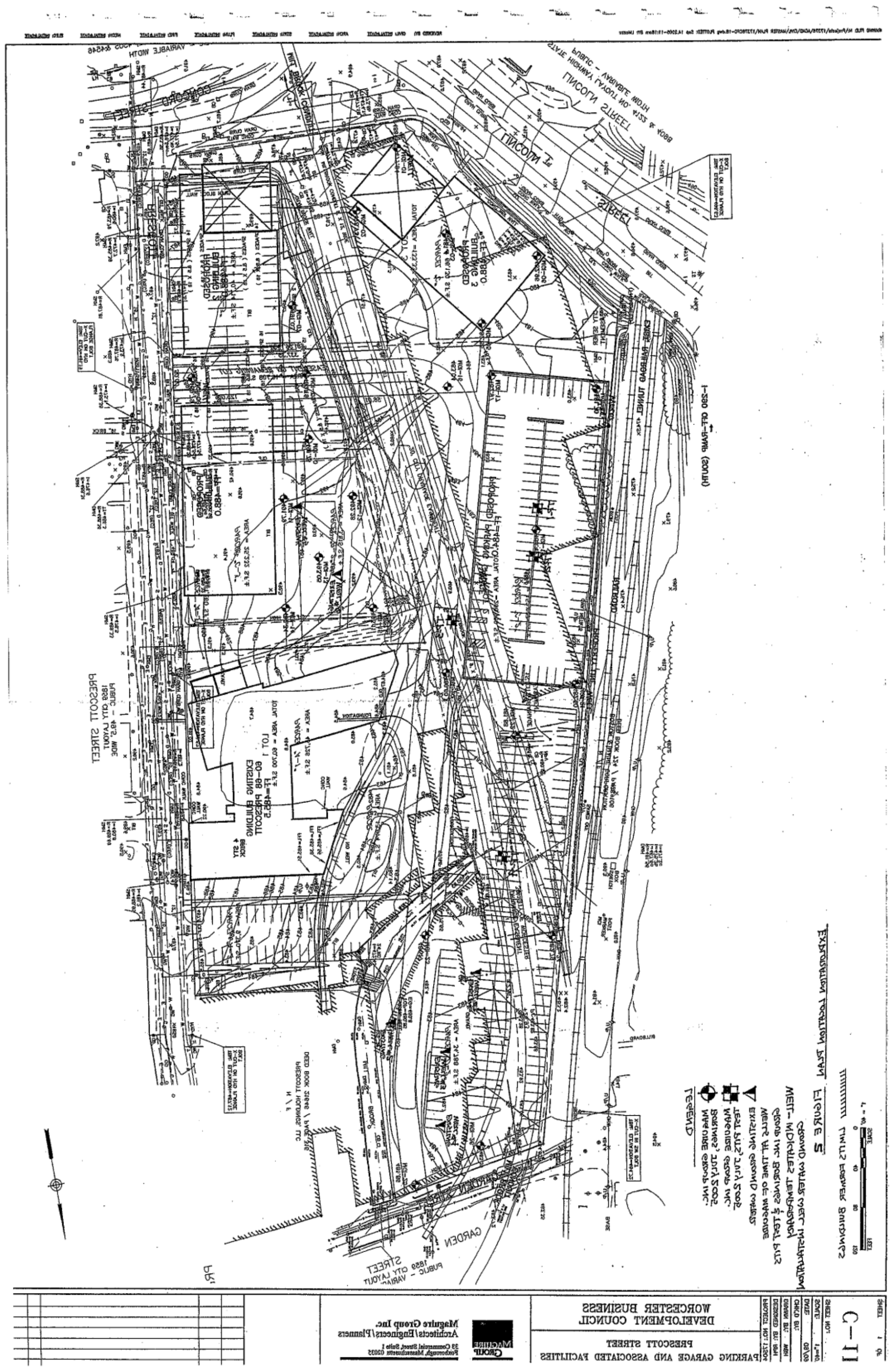
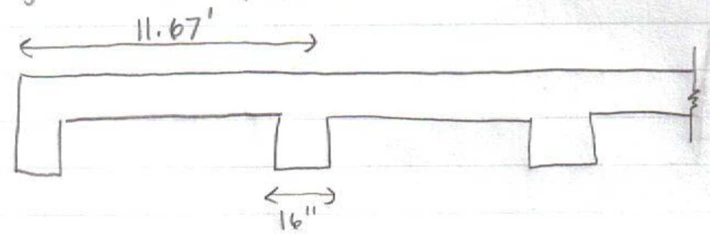


FIGURE 2
EXPLORATION LOCATION PLAN
LEGEND
PRESCOTT STREET
LINCOLN STREET
GARDEN STREET
WORCESTER BUSINESS
DEVELOPMENT COUNCIL
PRESCOTT STREET
PARKING GARAGE AND ASSOCIATED FACILITIES
Maguire Group Inc.
Architects/Engineers/Planners
C-11

10.4 Reinforced Concrete Design Appendices

10.4.1 One-way Slab, T-beam Girder Design



① Estimate floor thickness

End Bay: $\min h = \frac{\ell}{24} = \frac{11.67}{24} = 0.49' = 5.84''$ ←

Interior Bay: $\min h = \frac{\ell}{28} = \frac{11.67}{28} = 0.42' =$

Try 6" slab

② Compute the trial unfactored loads

slab: $w_D = \frac{6''}{12''/ft} \times 145\ lb/ft^3 = 72.5\ lb/ft^2$

Other dead loads:

MEP = 5 psf

Ceiling = 2 psf

floor cover = 0.5 psf

Total DL = 80 psf

LL = 125 psf for (

③ Load Combinations

$U = 1.4D = 1.4(80psf) = 112\ psf$

$U = 1.2D + 1.6L = 1.2(80) + 1.6(125) = 296\ ps$

④ Select Strength Reduction Factor

→ Tension controlled $\phi = 0.9$

ℓ_n clear span $= 11.67' - \frac{15}{12} = 10.59$

5) Check whether slab thickness is adequate for the moment

$$\omega = \frac{\rho f_y}{f'_c} = \frac{(0.1)(60000)}{4000} = 0.15$$

$$\phi k_n = \phi\left[f'_c\,\omega(1-.59\omega)\right] = 0.9\left[(4000)(0.15)(1-0.59(0.15))\right] = 492.2$$

First Interior Support → $M_u = \frac{w_u \ell_n^2}{10} = \frac{(296)(10.59)^2}{10} = 3.32^{k/1}$

Second Interior Support → $M_u = \frac{w_u \ell_n^2}{11} = 3.02^{k/1}$

$$bd^2 = \frac{M_u \times 1200}{\phi k_n} \Rightarrow 16d^2 = \frac{(3.32^{k/1})(12000)}{492.2} = 80.94$$

$$d = 2.25''$$

$$d = 6.00 - \left(.75 + \frac{.5}{2}\right) = 5 \geq 2.25''$$

↳ assuming 3/4 clear cover & No. 4 bars

6) Check whether thickness is adequate for shear

Typical interior support

$$V_u = \frac{1.15 W_u \ell_n}{2} = \frac{1.15(293)(10.59)}{2} = 1784.2 \text{ lb/ft of width}$$

$$= .75(2\sqrt{f'_c}\,b_w d)$$

$$\phi V_c = 0.75(2\sqrt{4000} \times 16 \times 5) = 7589.5 \text{ lb/ft} > 1784.2 \text{ lb/ft}$$

→ OK, no stirrups needed

use $h = 6''$, $d = 5''$, $w_u = 293$ psf

7) Reinforcement for One-Way Slab

→ see spreadsheet

→ T 8.4.1 (ACI Moment Coefficients)

1) Recheck dead load

$$(1 \times 1 \times \frac{28}{12})\ ft^3/ft \times 0.145\ kip/ft^3 = 0.338\ k/ft$$

$$W_u = 1.2(1.694 + 0.338) + 1.6(2.75) = 6.8388\ k/ft$$

$$M_u = \frac{W_u L^2}{8} = \frac{6.8388\ k/ft\ (22')^2}{8} = 413.7\ ^{\prime k}$$

5) Compute Area of reinforcement (A_s)

$$d_r = (d - \frac{a}{2}) = 0.875d = 0.875(26) = 22.75''$$

$$A_s = \frac{M_u}{\phi F_y d_r} = \frac{413.7^{\prime k}(12)}{0.9(60)(22.75)} = 4.04\ in^2$$

6) Minimum Reinforcement ($A_{s\,min}$)

$$A_{s\,min} = \frac{3\sqrt{f'c}}{f_y}(bd) = \frac{3\sqrt{4000}}{60{,}000}(16)(26) = 1.32\ in^2$$

7) Select Steel Rebar

$$A_{s\,REQ'D} = 4.04\ in^2$$

Bar Size	# Bars	$A_s (in^2)$
#11	3	4.68
#10	4	5.08
#8	6	4.74 ← choose 6 #8 Bars
#7	8	4.80

8) Compute ϵ_t and check tension controlled

$$a = \frac{A_s F_y}{.85 f'c\, b} = \frac{(4.04\ in^2)(60{,}000\ psi)}{.85(4000)(16'')} = 4.46'' \qquad c = \frac{a}{\beta} = \frac{4.46}{.85} = 5.24''$$

$$\epsilon_t = .003\left(\frac{d_t - c}{c}\right) = .003\left(\frac{26 - 5.24}{5.24}\right) = 0.012 > .005$$

→ section is tension controlled

→ $F_s = f_y$

→ $\phi = 0.9$

Design of a continuous T-beam

① Compute the trial factored loads on beam

- Positive Moment at Midpoint

$$A_T = \frac{192 \times 312}{144} = 416\ ft^2$$

$$L = L_0\left(.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right) = 125\left(.25 + \frac{15}{\sqrt{2(416)}}\right) = 96.3\ psf$$

- Positive Moment at center

$$A_T = \frac{192 \times 320}{144} = 427\ ft^2$$

$$L = 125\left(.25 + \frac{15}{\sqrt{2(427)}}\right) = 95.4\ psf$$

- Negative Moment

$$A_T = \frac{192 \times 632}{144} = 843\ ft^2$$

$$L = 125\left(.25 + \frac{15}{\sqrt{2(843)}}\right) = 76.9\ psf \leftarrow$$

② Select Strength Reduction Factors

$\phi = 0.9$ flexure tension controlled

$\phi = 0.75$ shear

→ Dead Load

Slab	72.5 psf
MEP, ceiling, cover	7.5 psf
	80 psf

→ Live Load (Reduced) = 76.9 psf

$w_u = 1.2(80) + 1.6(76.9) = 219.04\ psf$

→ Factored Load/ft = 219.04 psf × 11.67'' = 2556.2

= 2.56 k/ft

Assume weight of stem to be 0.4 k/ft

→ Trial Load/ft = 2.56 + 0.4 k/ft = 2.96 k/ft

③ Choose actual size of the beam stem

a) min depth based on deflection

$$\min h = \frac{\ell}{18.5} = \frac{22(12)}{18.5} = 14.27''$$

b) min depth based on neg moment at exterior face of int. support

$$\text{moment} = \frac{w_u \ell_n^2}{10} = \frac{(2.96)(20.5)^2}{10} = 124.4'^k$$

(T3.6.1)

$$R_n = \rho f_y \left(1 - \tfrac{1}{2}\rho m\right) \qquad m = \frac{f_y}{.85 f'_c} = 17.65$$

$$= 0.02(60)\left(1 - \tfrac{1}{2}(0.02)(17.65)\right)$$

$$= 0.9882 \text{ ksi}$$

$$bd^2 = \frac{M_u}{\phi R_n}(12{,}000) = \frac{124.4'^k}{(0.9)(988.2\text{ psi})}(12000) = 1678.5 \text{ in}^3$$

possible beam sizes $\left(b \approx \frac{2}{3} d\right)$

b	d	h (d + 2.5)
10"	12.96"	15.46"
8"	14.48"	16.98" ←
6"	16.72	19.23"

Try an 8" wide by 17" deep extending 11" below slab stem (slab 6") with d = 14.5"

c) check shear capacity of T-beam

$$V_u = \phi(V_c + V_s)$$

max shear from beam loads at interior end of B_3:

$$V_u = 1.15 \frac{w_u \ell_n}{2} = 1.15(2.96)(10.25) = 34.89^k$$

$$V_c = 2\sqrt{f'_c}\, b_w d = 2\sqrt{4000}(8)(14.5) = 14.67^k$$

$$V_s = 8\sqrt{f'_c}\, b_w d = 8\sqrt{4000}(8)(14.5) = 58.69^k$$

absolute max $\phi V_n = 0.75(V_c + V_s) = 0.75(14.67 + 58.69) = 55.02^k > V_u = 34.89^k$

∴ OK

use b = 8"
d = 14.5"
h = 17"

④ Compute dead load of the stem and recompute Load/ft

wt/ft of stem below slab $= \frac{8(11)}{144} \times (.145) = 0.089$

→ Total Dead load B3 – B4 – B3

$w_D = 0.080 \times 11.67 \times 0.089 = 0.083\ ^k/ft$

→ Live Load B3 – B4 – B3

$w_L = 0.0963 \times 11.67 = 1.12\ ^k/ft$ (Beam B_3)

$w_L = 0.0769 \times 11.67 = 0.90\ k/ft$ (Neg @ B)

$w_L = 0.0954 \times 11.67 = 1.11\ k/ft$ (Pos for B4)

→ Summary of Factored Loads B3-B4-B3

$w_u = 1.2(0.083) + 1.6(1.12) = 1.89\ k/ft$ (Beam B_3)

$w_u = 1.2(0.083) + 1.6(0.90) = 1.54\ k/ft$ (Neg @ B)

$w_u = 1.2(0.083) + 1.6(1.11) = 1.88\ k/ft$ (Pos for B4)

ACI 8.10.2) ⑤ Calculate flange width for positive moment regions (interior)

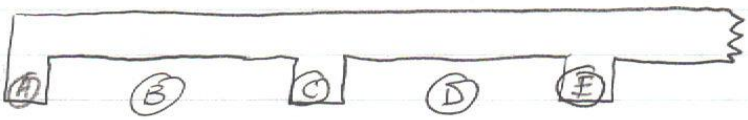
a) $b_E = \frac{L}{4} = \frac{11.67}{4} = 2.98' = 35.81''$ ←

b) $b_E = b_w + 16t = 8'' + 16(6'') = 104''$

c) b_E = center - center spacing of beams = 140''

(6) Compute the beam moments

Calc of moments for beam B3-B4-B3



1. l_n (ft)	20	20	20.34'		20.67'	20.34'	
2. w_u (k/ft)	1.89	1.89	1.54		1.88	1.54	
3. $w_u l_n^2$	756	756	637.10		803.23	637.10	
4. C_m	1/24	1/14	1/10	1/11	1/16	1/11	1/10
5. $C_m w_u l_n^2$ (ft·kips)	-31.5	54	-63.7		50.2	-63.7	

(7) Design of flexural reinforcement

a) A_s @ max neg moment (first interior support)

Assume: $J = 0.875$, $\phi = 0.9$

$$A_s = \frac{M_u}{\phi F_y J d} \times 12000 = \frac{63.7 \times 12000}{(0.9)(60{,}000)(.875)(14.5)}$$

$$A_s = 1.1157 \text{ in}^2$$

$$a = \frac{A_s f_y}{.85 f'_c b_w} = \frac{1.1157(60000)}{.85(4000)(8)} = 2.46 \text{ in}$$

$$A_s = \frac{M_u (12{,}000)}{(.9)(60000)(14.5 - \frac{2.46}{2})} = 0.016746 M_u$$

min reinforcement

$$A_{s\,min} = \frac{3\sqrt{4000}}{60000}(8)(14.5) = 0.367 \text{ in}^2$$

and

$$A_{s\,min} \geq \frac{(200)(8)(14.5)}{60000} \geq 0.387 \text{ in}^2 \leftarrow$$

→ see attached spreadsheet for calculations of the area of steel and selected bars

(8) check distribution of reinforcement

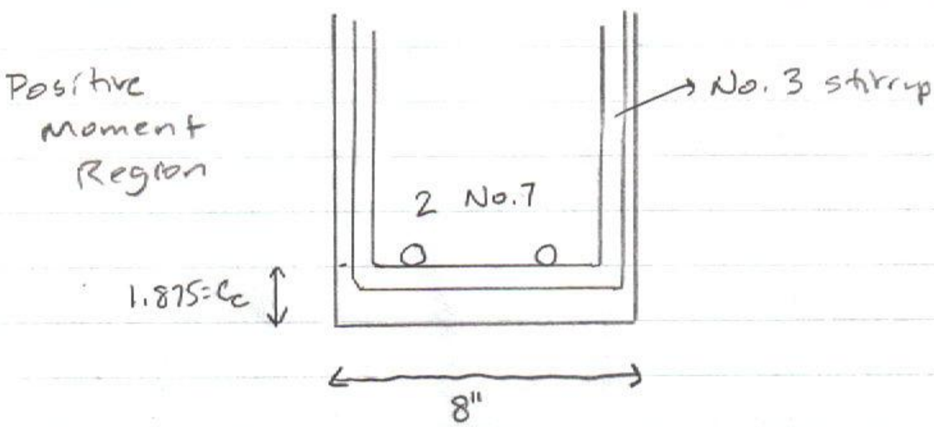
$c_c = 1.5''$ cover + $0.375''$ stirrup No. 3 $= 1.875''$

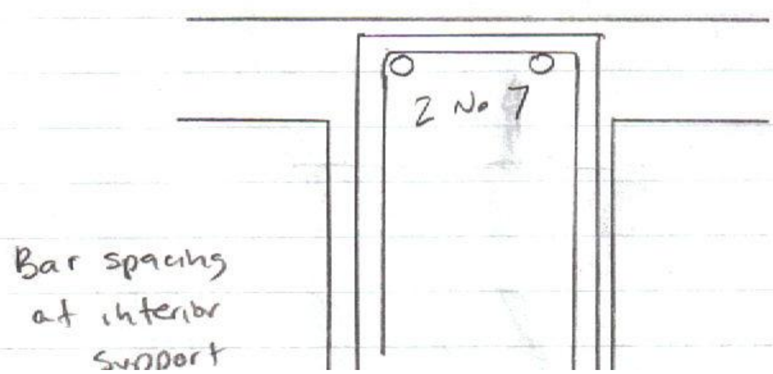
max bar spacing

$s = \frac{540}{F_s} - 2.5c_c \le 12\frac{36}{F_y}$ $\quad F_s = 0.6F_y = 3($

$= \frac{540}{36} - 2.5(1.875) = 10.3 \le 12''$

$b_w = 8''$ OK





Slab Design

Line Number	2S1			2S2			2S3		
	Support	Middle	Support	Support	Middle	Support	Support	Middle	Support
1. ACI Moment Coefficient	- 1/24	1/14	- 1/10	- 1/11	1/16	- 1/11	- 1/11	1/16	- 1/11
2. Mu	-1.37	2.35	-3.29	-2.99	2.05	-2.99	-2.99	2.05	-2.99
3. Required Rn	45.64	78.24	109.53	99.57	68.46	99.57	99.57	68.46	99.57
4. Required p	0.0009	0.0015	0.0021	0.0019	0.0013	0.0019	0.0019	0.0013	0.0019
5. Required As	0.07	0.12	0.17	0.15	0.11	0.15	0.15	0.11	0.15
6. Provided As (ACI-10.5.4 min =0.12), and stirrup	#4@16st (0.15)	#4@16st (0.15)	#4@12st (0.20)	#4@16st (0.15)	#4@16st (0.15)	#4@16st (0.15)	#4@16st (0.15)	#4@16st (0.15)	#4@16st (0.15)

Beam Design

7)

	A	B	C	D	E
ln (ft)	20	20	20.34	20.67	20.34
Wu (k/ft)	1.89	1.89	1.54	1.88	1.54
Wu*ln^2	756	756	637.12	803.23	637.12
Cm	- 1/24	1/14	- 1/10	1/16	- 1/10
Mu (Cm*Wu*ln^2)	-31.50	54.00	-63.71	50.20	-63.71
As required	0.55	0.95	1.12	0.88	1.12
As > As min?	No	No	No	No	No
Bars Selected	2 No. 7	2 No. 7	2 No. 7	2 No. 7	2 No. 7
As provided	1.20	1.20	1.20	1.20	1.20
bw OK?	Yes	Yes	Yes	Yes	Yes

9)

	A	B	C	C	D	E
ln (ft)		20			20.67	
Wu (k/ft)		1.89			1.88	
Wlu (k/ft)		1.12			1.11	
Wuln/2		18.90			19.43	
Cv	1	0.15	1.15	1	0.15	1
Vu	18.9	2.835	21.735	19.4298	2.91447	19.4298
Vn	25.2	3.78	28.98	25.9064	3.88596	25.9064

Girder Design

1) Estimate Dead Load of Beam

- 22 ft. span

Dead Load = 77 psf (22') = 1.694 k/ft

Live Load = 125 psf (22') = 2.75 k/ft

Total = 4.444 k/ft

weight of beam 10% - 20% of loads carried = 0.4 - 0.9 k/ft

→ estimate beam weight at 0.5 k/ft

2) Compute Factored Moment (M_u)

$w_u = 1.2\,D + 1.6\,L = 1.2\,(1.694\text{ k/ft} + 0.5) + 1.6\,(2.75\text{ k/ft} + 0$

$w_u = 7.8328\text{ k/ft}$

$$M_u = \frac{w_u L^2}{8} = \frac{(7.8328\text{ k/ft})(22')^2}{8} \doteq 473.9\ '^k$$

3) Compute b and d

assume $\theta = 0.9$, $\rho = 0.01$, $f_y = 60\text{ ksi}$, $f'_c = 4\text{ ksi}$

$$m = \frac{f_y}{0.85 f'_c} = \frac{60}{0.85(4)} = 17.65$$

$$R_n = \rho f_y\left(1 - \tfrac{1}{2}\rho m\right) = 0.01(60{,}000)\left[1 - \tfrac{1}{2}(0.01)(17.65)\right] = 547.1\text{ psi}$$

$$M_{N\,REQ'D} = \frac{M_u}{\theta} = \frac{473.9\ '^k}{0.9} = 526.6\ '^k$$

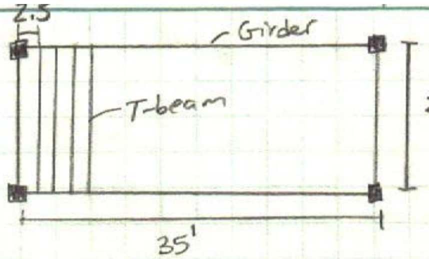
$$bd^2_{REQ'D} = \frac{M_{N\,REQ'D}}{R_N} = \frac{526.6\ '^k(12000)}{547.1\text{ psi}} = 11{,}550\text{ in}^3$$

- d/b around 1.5 - 2
- assume 1 layer reinforcement

b	d	h
16"	26"	26 + 2 = 28"
14"	28"	28 + 2 = 30"

→ Try cross section b = 16" d = 26" h = 28"

10.4.2 Joist Construction Design



Slab design

ACI 318-9.5 slab thickness ≥ 3.5 in

Trial Unfactored Loads:

DL: Slab $\left(\frac{3.5}{12} \times 145\right) = 42.3$ LL = 125 psf

MEP, ceiling, fl. cover = 7.5

49.8 psf

Load Combinations:

$w_u = 1.2D + 1.6L = 1.2\left(\frac{3.5(0.145)}{12}\right) + 1.2(0.075) + 1.6(.125) = 0.34 \text{ ksf}$

$M_u = \frac{1}{2} w_u \left(\frac{30}{12}\right)^2 = 1.0648 \text{ ft}\cdot k/ft$

$\phi M_N = \phi f_r \left(\frac{1}{6} b h^2\right)$ $\phi M_n = M_u$

$f_r = 5\sqrt{f'c} = 316.23$

$b = 12$

$$h = \sqrt{\frac{(1.0648)(12{,}000)}{\frac{1}{6}(0.55)(316.2277)(12)}} = 4.494 \rightarrow \underline{4.5''}$$

Shrinkage + Temp Control ACI 7.12

$A_s = 0.0018(12)(4.5) = 0.972 \text{ in}^2/\text{ft}$

T 10.11.1 → 4x12 - W3.5 x W2 (A_s = 0.105 > 0.972)

Joist Design

ACI 9.5a $\min h = \frac{L}{21} = \frac{35(12)}{21} = 20''$ → Assume joists 15.5" deep below bottom of slab, 6" width

$w_D = [(4.5 + 15.5)6 + 30(4.5)]\frac{0.145}{144} = 0.26 \text{ k/ft}$

$w_u = 1.2(.26) + 1.2(0.075)\left(\frac{35}{12}\right) + 1.6(.125)\left(\frac{35}{12}\right) = 1.1578 \text{ k/ft}$

(neg) $M_u = \frac{(1.1578)(33.5)^2}{} = 118.13 \text{ ft}\cdot k$

ACI 7.7.1c $\left(\frac{\text{min}}{\text{cover}} = 3/4''\right)$ Assume #5 bar

$d = 15.5 - 0.75 - 0.31 = 14.44''$

$\text{req'd } R_n = \frac{M_u}{\phi b d^2} = \frac{118.13(12{,}000)}{(0.9)(6)(14.44)^2} = 1101 \text{ psf}$

$\text{req'd } \rho = 0.02$ (max)

$\text{req'd } A_s = 0.02(6)(15.44) = 1.85 \text{ in}^2$

$A_{s\,min} = \frac{3\sqrt{4000}}{60000} 2(6)(15.44) = 0.59 \text{ in}^2$

$V_u = (1.1578)(12.25 - 1.16) = 12.57^k$

$\phi V_c = \phi(1.10)(2\sqrt{f'_c})\, b_w d = 0.75(1.1)(2\sqrt{4000})(5)(15.44)/1000$

$= 8.06 < 12.57^k$

Taper beam to meet shear requirement

2½ for 30'' forms — $b_w = 6 + \left(\frac{3.0 - 1.16}{3.0}\right) 6 = 9.68''$

$\phi V_c = 8.06\left(\frac{9.68}{6}\right) = 13.00\,k > 12.57^k$ ✓

3 ft

Fig 10.11.1

(pos) $M_u = \frac{1}{16}(1.1338)(33.5)^2 = 79.82 \text{ ft}\cdot k$

→ assume depth of rect. stress distribution falls within flange → $a \approx 1''$

$\text{req'd } A_s = \frac{M_u}{\phi f_y (\text{arm})} = \frac{79.82(12)}{0.9(60)(15.44 - .5)} = 1.19 \text{ in}^2$

$a > \frac{t}{2} = 2.25$ ∴ effective section of compression zone is rectangular

see spreadsheet
for shear @ support and midspan

use 1 #8 bottom bar
1 #6 truss bar
1 #8 top bar

inflection point @ 0.354 L_n from centerline

ACI 12.11.3 must be checked

1 #8 bar extents beyond inflection

$$c = 0.85 f'_c b_E a = 0.85(4)(36) a = 122.4a$$

$$T = .79(60) = 47.4$$

$$a = 2.58''$$

$$M_n = 12\left[15.44 - 0.5(2.58)\right] 1/12 = 14.15 \text{ ft}\cdot\text{k}$$

$$V_u = 1.1388(0.354)(33.5) = 13.45 \text{ k}$$

$$L_a = 12 d_b = 12(.79) = 9.48''$$

$$d = 15.44''$$

embeddment length

$$\frac{M_n}{V_u} + L_a = \frac{14.15(12)}{13.45} + 15.44 = 28.06''$$

T 6.6.2

$$L_d(\#8) = 71.2''$$

Girder Design:

$DL = 77.68(22') = 1.709$ k/ft $LL = 125(22') = 2.75$ k/ft

$$W_u = 1.2D + 1.6L = 1.2(1.709) + 1.6(2.75) = 6.45 \text{ k/ft}$$

$$M_u = \frac{W_u L^2}{8} = \frac{6.45(22)^2}{8} = 390'^{k}$$ $R_N = 547.1 \text{ psi} \rightarrow \rho = 0.01$

$$bd^2 \text{ req'd} = \frac{M_N \text{ req'd}}{R_N} = \frac{390}{.9(547.1)} = 0.79 \times 12000 = 9504 \text{ in}^3$$

b	d	h	$A_s=$
12"	28"	30"	
14"	26"	28"	
16	24"	26" ← trial size	

$M_N = A_s f_y (d - \frac{a}{2}) =$

Compute ϕM_n

$$M_n = A_s f_y \left(d - \frac{a}{2}\right) = \frac{(4.04)(60{,}000)\left(26 - \frac{4.46}{2}\right)}{12000} = 480.15^{1k}$$

$$\phi M_n = 0.9(278.15^{1k}) = 432.14^{1k}$$

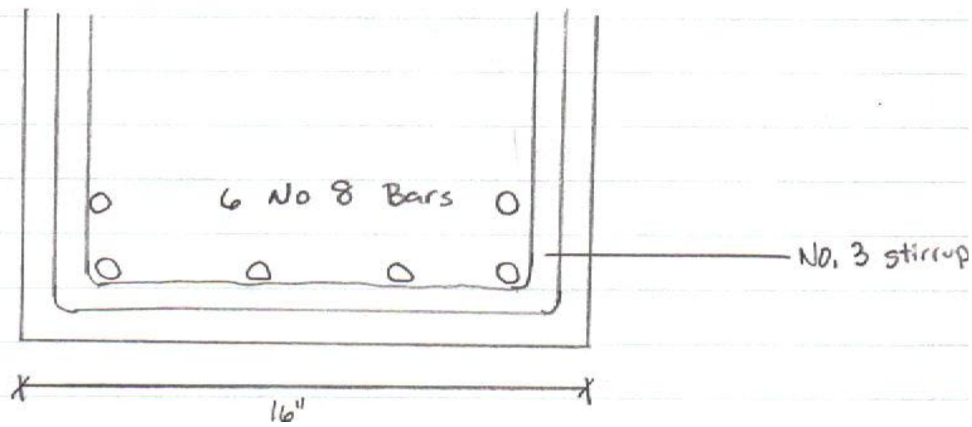
$$\phi M_N \geq M_U$$

$$432.14^{1k} \geq 413.7^{1k}$$

→ design is adequate

→ use $b = 16''$, $d = 26''$, $h = 28''$

→ $f'c = 4000$ psi, $f_y = 60000$ psi



10.5 Structural Steel Design Appendices

10.5.1 Sample Steel Beam and Girder Design

Composite Beam 1						
35' x 22' Lab Bay						
3 Infill Beams spanning 35'						
Dimensions						
Beam Length	35	ft				
Tributary Width	5.5	ft				
Slab Thickness	4.5	in				
Service Loads						
DEAD LOADS	PLF		LIVE LOADS	PLF		
Concrete Slab (4.5", 145 PCF)	330		Light Manu.	687.5		
Floor Decking & Insulation	55					
MEP	27.5					
Suspended Ceilings	11					
Total	423.5			687.5		
Loading Cominations						
Factored	PLF		Unfactored	PLF		
Wu = 1.4D	592.9		Wu = D + L	1111		
Wu = 1.2D + 1.6L	1608.2	*Governs*				
Critical Moment Mu						
	ft-kips			ft-kips		
Mu = (Wu*L^2)/8	246.2556		Mu = (Wu*L^2)/8	170.1219		
Construction Loads						
DEAD LOADS	PLF		LIVE LOADS	PLF		
Beam Weight (Assume)	36		Concrete Slab	330		
			Const. LL	110		
Total	36			440		
Loading Combinations (Const)						
Factored	PLF		Unfactored	PLF		
Wu = 1.2D + 1.6L	747.2	PLF	Wu = DL + LL	476		
Critical Moment Mu (Const.)	ft-kips			ft-kips		
Mu = (Wu*L^2)/8	114.415		Mu = (Wu*L^2)/8	72.8875		
Required Capacity during Const.	in^3					
Zx = Mu/(.9*fy)	30.51067					
W18x35	66.5	OK				Table 3-2 AISC

Plastic Capacity W18x35						
FLB = $b_f/(2t_f)$	7.06	< 9.2	OK			Table 1-1 AISC
WLB = h/t_w	53.5	< 90.5	OK			Table 1-1 AISC
LTB			OK			
Check Deflection (Unshored Const.)						
C_1	161					AISC
Δmax	1.5	in.				
REQ'D Ix = $(M*L^2)/(C_1*\Delta)$	369.7192	in^4				
W18x35	510	OK				Table 1-1 AISC
Adjust Loading Combination						
Factored			Unfactored			
Wu = 1.2D + 1.6L	1650.2		Wu = D + L	1146		
Mu = $(Wu*L^2)/8$	252.6869		Mu = $(Wu*L^2)/8$	175.4813		
W18 x 35						
ΣQn	515	kips				
F'c	3	ksi				
b_e = trib. width	66	in	*Governs*			
b_e = .25L	105	in				
a = $\Sigma Qn/(.85*f'c*b_e)$	3.060012					
Determine REQ'D I_{lb}						
Y2 = ts - a/2	2.969994					
Y1 = PNA @ TFL	0					
Δ limit = L/360	1.166667	in				
REQ'D I_{lb} = $(M*L^2)/(C_1*\Delta)$	1144.443	in^4				
W18x35	Y2 = 3					
I_{lb}	1230		> 1144 in^4 OK			Table 3-20 AISC
ΦMp	457		> 252 ft-kips OK			Table 3-19 AISC
Partial Composite Investigation						
W18x35						
Y1 = PNA @ 3	0.213					
ΣQn	387	kips				
a = $\Sigma Qn/(.85*f'c*b_e)$	2.299465					
Y2 = ts - a/2	3.350267					
	Y2 = 3	Y2 = 3.5	Req'd			
I_{lb}	1130	1180	> 1144 in^4 OK			Table 3-20

						AISC
ϕMp	428	442	> 252 ft-kips OK			Table 3-19 AISC
	Y2 = 3.35					
I_{lb}	1165		> 1144 in^4 OK			
ϕMp	437.8		> 252 ft-kips OK			
Partial Composite Shear Capacity						
Stud Diameter	0.75	in				
Asc	0.441786	in2				
Fu	65	ksi				
Qn = Asc * Fu	28.71612	ksi				
Weight of Conc	145	PCF				
F'c	3	ksi				
Ec = W^1.5 * sqrt(f'c)	3024.215	ksi				
Qn = .5*Asc*sqrt(f'c*Ec)	21.04018	k	< 28.7 k OK			
Number of Studs						
N = ΣQn/Qn	18.39338					
Use	38	Studs				
Spacing						
Min = 6*ds	4.5	in				
Max = 8*ts	36	in				
Actual = L/(N+1)	10.76923	in	38 Studs OK			
Shear Capacity of Web						
Vu = Wu*L/2	28.8785	kips				
depth beam =	17.7	in				
web thickness =	0.3	in				
ϕVn = 0.6*Fy*Aw	159.3	kips	> 28.9 kips OK			

10.5.2 Sample Steel Column and Base Plate Design

BASE CORNER COLUMN 3					
35' x 28' Lab Bay					
Service Loads					
Tributary Area	300	SF			
Floor Loads					
DEAD LOADS	LBS		LIVE LOADS	LBS	
Concrete Slab (4.5", 145 PCF)	18000		Light Manu.	37500	
Floor Decking & Insulation	3000				
MEP	1500				
Suspended Ceilings	600				
W21x44 Girder (x.5*28')	616				
W18X40 Beam (x1/2x35')	700				
W18x40 Beam (.75*35')	1050				
W12x14 Beam (x1/2x5')	35				
Ext Brick (5lbs*180 bricks)	900				
Total	26401			37500	
Factored	LBS				
Pu = 1.4D	36961.4				
Pu = (1.2D + 1.6L)	91681.2	*Governs*			
Roof Load					
Tributary Area	831.25	SF			
DEAD LOADS	LBS		SNOW LOAD	LBS	
Girder Joist 2 (x.5x105PLFx35')	616		Snow	41562.5	
Odeum Joist 1 (x3x44'x48PLF)	6336				
Odeum Joist 2 (x1x33'x29PLF)	957				
W12x14 Beam (x1/2x5')	35				
W21x44 Girder (x14')	616				
W18x35 Beams (x.75x35')	918.75				
Concrete Slab (4.5", 145 PCF)	18000				
Floor Decking & Insulation	8312.5				
MEP	4156.25		LIVE LOADS		
Suspended Ceilings	1662.5		Roof LL	16625	
Total	41610				

Factored	LBS		Brace Weight		
Pu = 1.4D	58254		1.2D =	1.31568	k
Pu = 1.2D + 1.6S	116432	*Governs*	Wind Load	33.7	k
Pu = 1.2D + 1.6Lr	76532		Wind load	10.7	k
RESULTING Pu					
Pu = 4*Floor + Roof	518.1725	kips			
KL =	12	ft			
Beam	ϕPn	Wt (plf)			*Table 4-4 AISC*
HSS9x9x1/2	564	55.5			
HSS10x10x3/8	497	47.8			
TOP CORNER COLUMN 3					
RESULTING Pu					
Pu = 2*Floor + Roof	311.8101	kips			
KL =	12	ft			
Beam	ϕPn	Wt (plf)			*Table 4-4 AISC*
HSS8x8x5/16	314	31.8			
HSS7x7x3/8	306	32.5			
BASE PLATE					
DIMENSIONS					
Pu =	518.1725	kips			
HSS9x9x1/2	81	in2			
d=bf =	9				
X = sqrt(A2/A1)	2				
ϕ =	0.6				
f'c	3	kdi			
A1 = Pu/(ϕ*.85*f'c*X)	169.3374				
Use A1 =	196	in2			
N=	14	in2			
B=	14	in2			
ϕPp = ϕ.85*f'c*A1*X	599.76	kips OK			

PLATE THICKNESS					
m= (N-.95*d)/2	2.725				
n = (B - .8bf)/2	3.4	governs = l			
n' = sqrt(d*bf)/4	2.25				
t = l*sqrt((2*Pu)/(.9Fy*B*N))	1.373506	in			
t =	1.375	in			

10.5.3 Sample Steel Connection Design

Connection INT Beam 1 W18x35 to INT Girder 1 W 21x50			
Bolt to Beam, Shop Weld to Girder			
SINGLE SHEAR PLATE CONNECTION			
W18x35			
L=	35	ft	
h/tw	53.5	< 53.9	PLASTIC
Fy =	50	ksi	
tw=	0.3	in	
d=	17.7		
ϕ	1		
Service Loads			
Wu = Beam 1 (Int)	1650.2	PLF	
Vu = WuL/2	28.8785	kips	
ϕVn= ϕ*.6*Fy*d*tw	159.3	kips	≥ 28.9 kips OK
Det # of Bolts			
A325-X Fv =	60	ksi	
A325-N Fv =	48	ksi	
db =	0.75	in	
Ab =	0.441786	in2	
ϕ =	0.75		
ϕRn(N) = ϕ*Fv*Ab	15.90431	k per bolt	
ϕRn(X) = ϕ*Fv*Ab	19.88039	k per bolt	
# Bolts = Vu/ϕRn	1.815765		
# Bolts	3	OK	

A36 SHEAR PLATE			
Height	9	in	
Width	4.5	in	
9"x4.5"x t"			
Fy =	36	ksi	
Fu =	58	ksi	
Dist btwn edge and bolt o.c.	1.5	in	
Dist btwn bolts o.c.	3	in	
n bolts @ 3" spacing	2		
3/4" bolt holes = 7/8"	0.875	in	
Bolt Bearing			
Lc1 = btwn bolts	2.125	in	
Lc2 = edge & bolt	1.0625	in	
ϕ	0.75		
ϕRn = ϕ*2.4*db*t*Fu =	78.3	*t	Governs bottom bolts
ϕRn = ϕ*1.2*Lc1*t*Fu =	110.925	*t	
ϕRn = ϕ*1.2*Lc2*t*Fu =	55.4625	*t	Governs top bolt
BearCap = ΣϕRn	212.0625	*t	≤ 28.9 kips
			-
t ≥	0.136179	in.	
Shear Rupture			
ϕ =	0.75		
Anv = H- #bolts*db	6.375	*t	
ϕRn = ϕ*.6*Fu*Anv	166.3875	*t	≤ 28.9 kips
			-
t ≥	0.173562	in.	
Shear Yielding			
ϕ =	1		
Ag	9	*t	
ϕRn = ϕ*.6*Fy*Ag	194.4	*t	≤ 28.9 kips
t ≥	0.148552	in.	
Block Shear Rupture			
Tension Rupture	46.2	kips*t	Table 9-3a

Shear Yield	72.9	kips*t	Table 9-3b
Shear Rupture	83.2	kips*t	Table 9-3c
ϕRn =ϕ(SR+ TR)	97.05		
ϕRn = ϕ(SY + TR)	89.325	*Governs*	≤ 58.1 kips
t ≥	0.323297	in.	GOVERNS
USE t =	0.375	in.	
W18x35 BEAM			
Fy =	50	ksi	
Fu =	65	ksi	
Dist btwn edge and bolt o.c.	1.5	in	
Dist btwn bolts o.c.	3	in	
n bolts @ 3" spacing	2		
3/4" bolt holes = 7/8"	0.875	in	
Bolt Bearing			
Lc1 = btwn bolts	2.125	in	
Lc2 = edge & bolt	1.0625	in	
ϕ	0.75		
ϕRn = ϕ*2.4*db*t*Fu =	87.75	*t	Governs btwn bolts
ϕRn = ϕ*1.2*Lc1*t*Fu =	124.3125	*t	
ϕRn = ϕ*1.2*Lc2*t*Fu =	62.15625	*t	Governs top bolt
BearCap = ΣϕRn	237.6563	*t	≤ 58.1 kips
			-
t ≥	0.003156	in.	≤ 0.3 in. OK
Shear Rupture			
ϕ =	0.75		
Anv = L - 3*db	6.375	*t	
ϕRn = ϕ*.6*Fu*Anv	186.4688	*t	≤ 58.1 kips
			-
t ≥	0.004022	in.	≤ 0.3 in. OK
Shear Yielding			
ϕ =	1		
Ag	9	*t	
ϕRn = ϕ*.6*Fy*Ag	270	*t	≤ 58.1 kips

t ≥	0.002778	in.	≤ 0.3 in. OK
Block Shear Rupture			
Tension Rupture	51.8	kips*t	Table 9-3a
Shear Yield	101	kips*t	Table 9-3b
Shear Rupture	93.2	kips*t	Table 9-3c
ϕRn =ϕ(SR+ TR)	108.75	kips*t	≤ 58.1 kips
ϕRn = ϕ(SY + TR)	114.6	*kips*t*	
t ≥	0.265549	in.	≤ 0.3 in. OK
WELDED CONNECTION			
W24x55 Girder			
web thickness	0.395	in.	
Fy =	50	ksi	
Fu =	65	ksi	
9"x4.5"x0.25" Plate			
thickness	0.25	in	
Fy =	36	ksi	
Fu =	58	ksi	
Det Weld Length			
amax	0.25	in.	*Table J2.4 AISC*
te = .707*a	0.17675		
E70 Electrode Fexx =	70	ksi	
ϕ	0.75		
ϕRn = ϕ*.6*Fexx*te	5.567625	kips/in	
Check Shear Yield Base Metal			
ϕRn = ϕ*.6*Fy*tw	11.85	kips/in	> 5.6 kips/in
Check Shear Fracture Base Metal			
ϕRn = ϕ*.6*Fu*tw	11.55	kips/in	> 5.6 kips/in
Lw = Vu/ϕRn	5.186862	in.	Complete Weld Sufficient

10.6 Foundation Design Appendices

10.6.1 Sample Spread Footing Design

Base plate width c (in)	23		allowable bearing pressure	6500
base plate depth d (in)	23		f'c (psi)	4000
uf dead load (k)	492.1		fy (psi)	60,000
uf live load (k)	616.8			
uf total load	1108.9			
min depth of embedment (D)	48			
W	600			
required width (B)	13.71	14	168	
factored total load	1737.5			
required thickness (T)	42	3.5		
effective depth (d)	38			
Vuc	425510.2			
b0	46			
phiVnc	442212.908	**OK**		
cantilever distance (l) (in)	72.5			
Muc (in-lb)	27180757.07			
As (in^2)	13.50			
Asmin	11.49	**OK**		
As provided	13.50	**Use 6 # 14 bars both ways**		
Clear span	14.27			
Ld provided	69.5			
Ld required	48.18	**OK**		

10.6.2 Sample Continuous Footing Design

Typical Interior Spread Footing

Base plate width c (in)	23		allowable bearing pressure	6,383
base plate depth d (in)	23		f'c (psi)	4000
uf dead load (k)	492.1		fy (psi)	60,000
uf live load (k)	616.8			
uf total load	1108.9			
min depth of embedment (D)	48			
W	600			
required width (B)	13.85	14	OK	
factored total load	1737.5			
required thickness (T)	54	4.5		
effective depth (d)	50			
Vuc	425510			
b0	46			
phiVnc	581859	OK		
cantilever distance (l) (in)	72.5			
Muc (in-lb)	27180757			
As (in^2)	10.18	OK		
Asmin	15.12	OK		
As provided	15.75	**Use 7 # 14 bars both ways**		
Clear span	14.27			
Ld provided	69.5			
Ld required	48.18	OK		

Bearing Capacity – Interior Spread Footing

BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date	December 14, 2009	
Identification	**Typical Interior Spread Footing**	

Input

Units of Measurement		
	E	SI or E
Foundation Information		
Shape	SQ	SQ, CI, CO, or RE
B =	14	ft
L =		ft
D =	4.5	ft
Soil Information		
c =	0	lb/ft^2
phi =	32	deg
gamma =	62.4	lb/ft^3
Dw =	18	ft
Factor of Safety		
F =	3	

Results

	Terzaghi		Vesic	
Bearing Capacity				
q ult =	17,458	lb/ft^2	19,149	lb/ft^2
q a =	5,819	lb/ft^2	6,383	lb/ft^2
Allowable Column Load				
P =	1,141	k	1,251	k

Typical Exterior Spread Footing

base plate width c (in)	17		allowable bearing pressure	5,140
base plate depth c (in)	17		f'c (psi)	4000
uf dead load (k)	271.2		fy (psi)	60,000
uf live load (k)	319.5			
uf total load	590.7			
min depth of embedment (D)	48			
W	600			
required width (B)	11.41	11.5	**OK**	
factored total load	922.8			
required thickness (T)	42	3.5		
effective depth (d)	38			
Vuc	223730			
b0	34			
phiVnc	326853	**OK**		
cantilever distance (l) (in)	60.5			
Muc (in-lb)	12238364			
As (in^2)	6.03	**OK**		
Asmin	9.44	**OK**		
As provided	10.00	**Use 10 # 9 bars both ways**		
Clear span	11.55			
Ld provided	57.5			
Ld required	28.46	**OK**		

Bearing Capacity – Exterior Spread Footing

BEARING CAPACITY OF SHALLOW FOUNDATIONS
Terzaghi and Vesic Methods

Date	December 14, 2009
Identification	**Typical Exterior Spread Footing**

Input

Units of Measurement

	E	SI or E

Foundation Information

Shape	SQ	SQ, CI, CO, or RE
B =	11.5	ft
L =		ft
D =	3.5	ft

Soil Information

c =	0	lb/ft^2
phi =	32	deg
gamma =	62.4	lb/ft^3
Dw =	18	ft

Factor of Safety

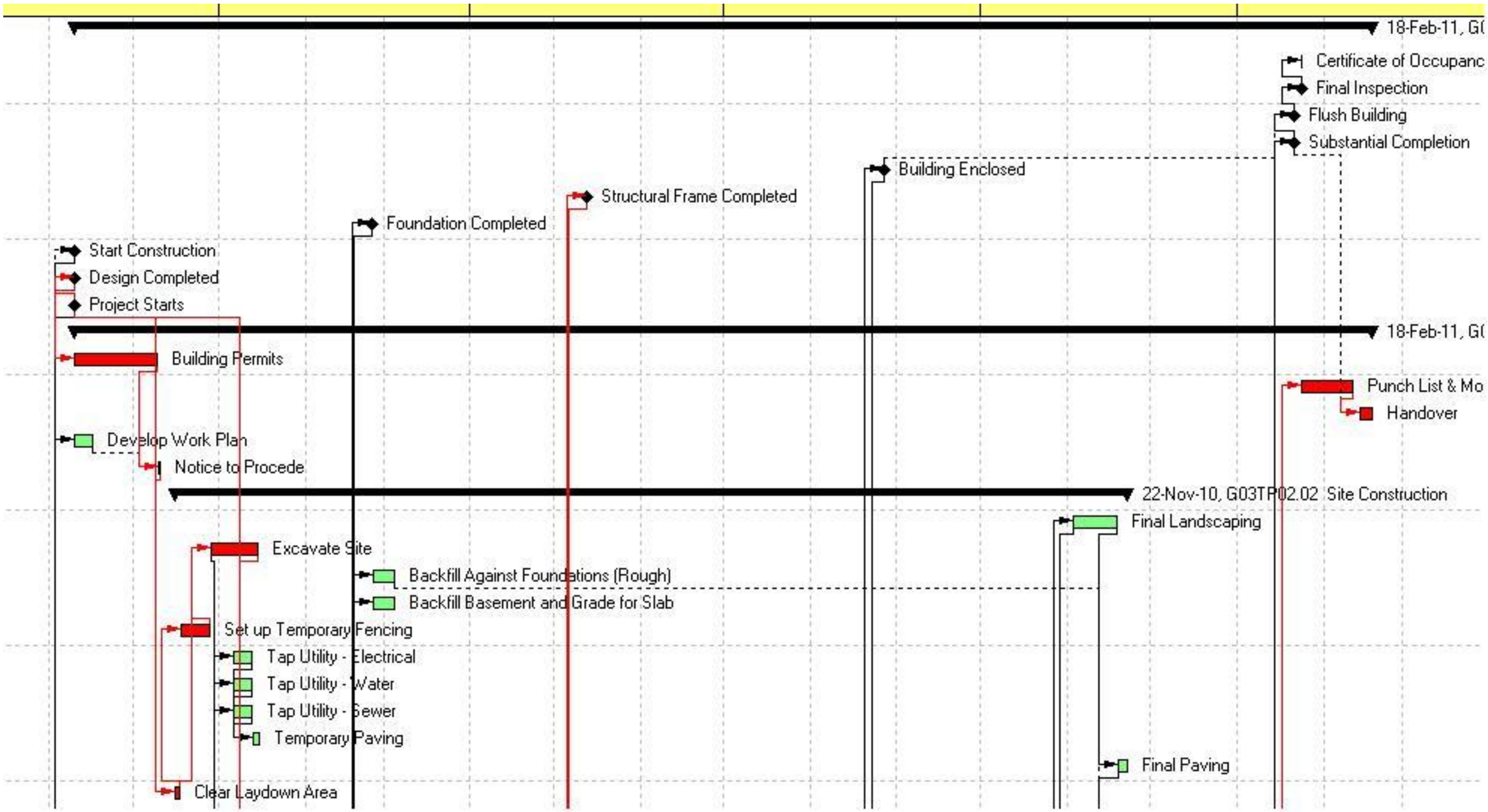
F =	3

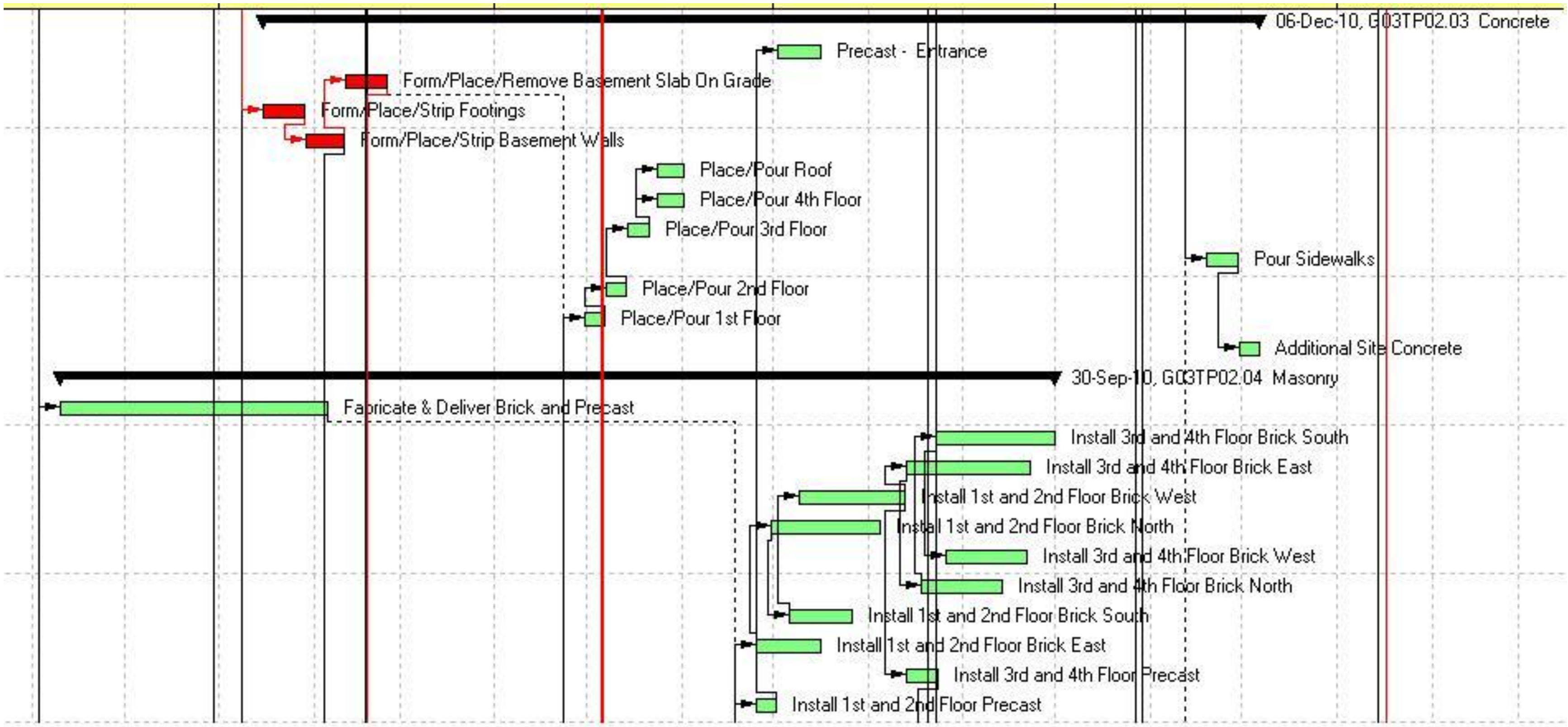
Results

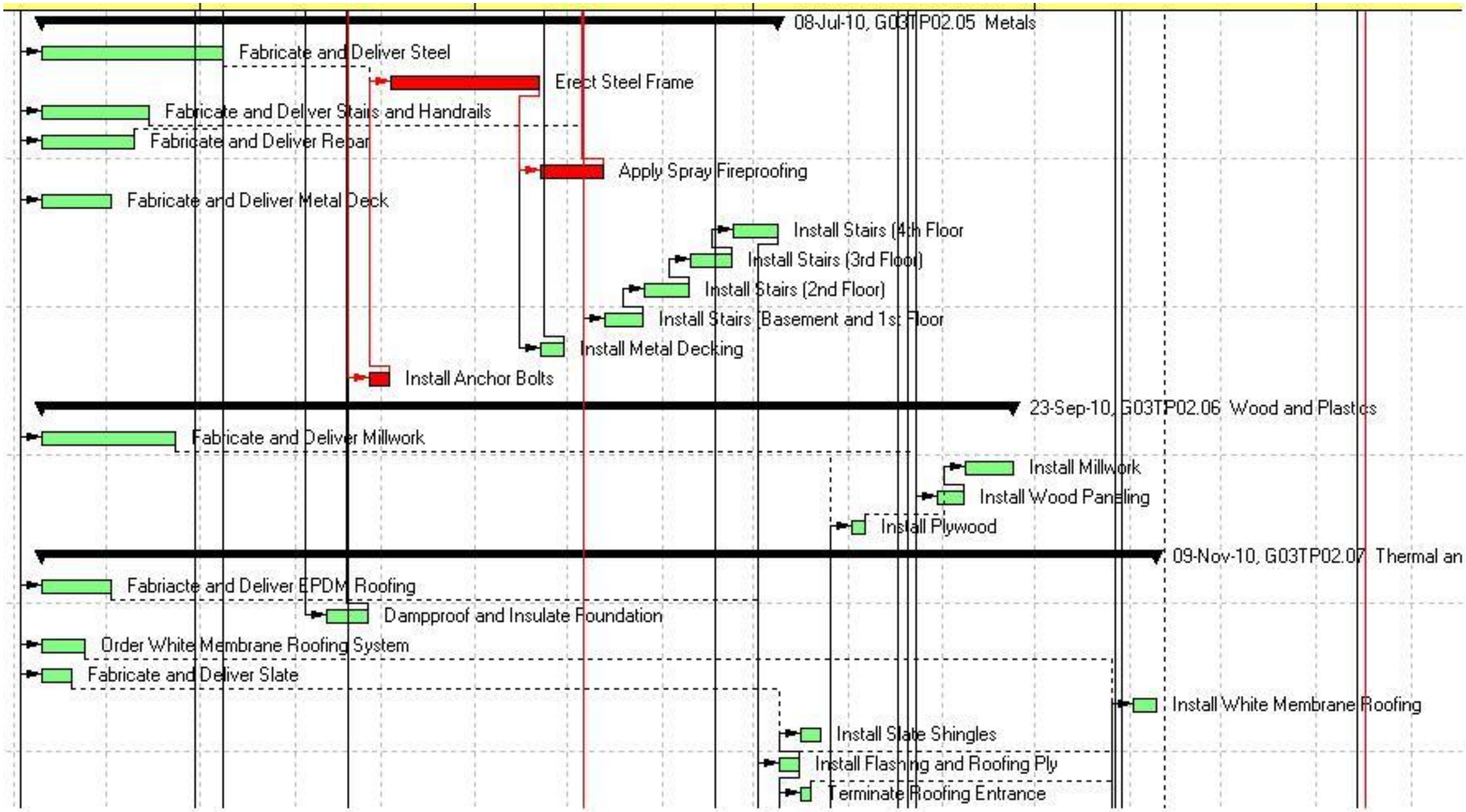
	Terzaghi		Vesic	
Bearing Capacity				
q ult =	14,279	lb/ft^2	15,421	lb/ft^2
q a =	4,760	lb/ft^2	5,140	lb/ft^2
Allowable Column Load				
P =	629	k	680	k

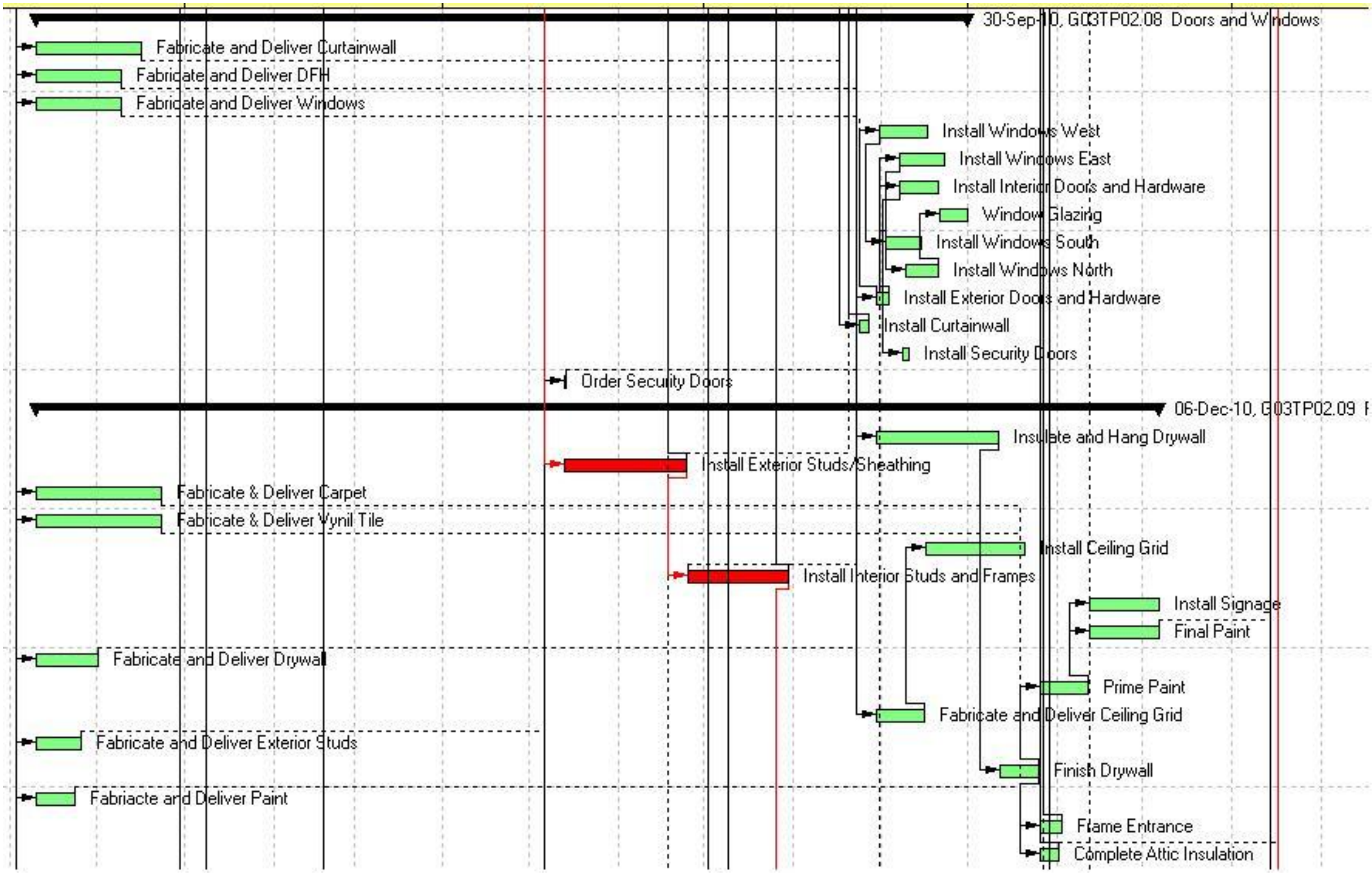
10.7 Construction Schedule

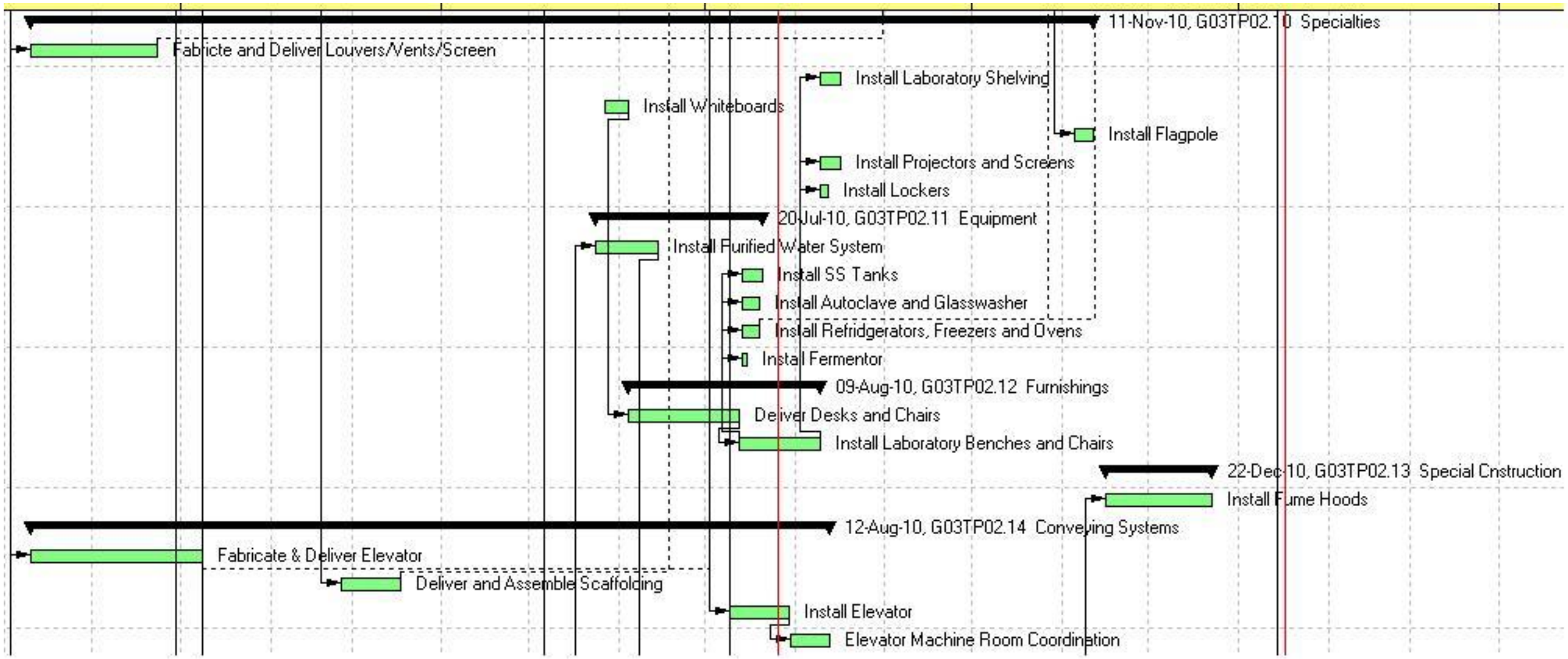
10.7.1 Original Schedule

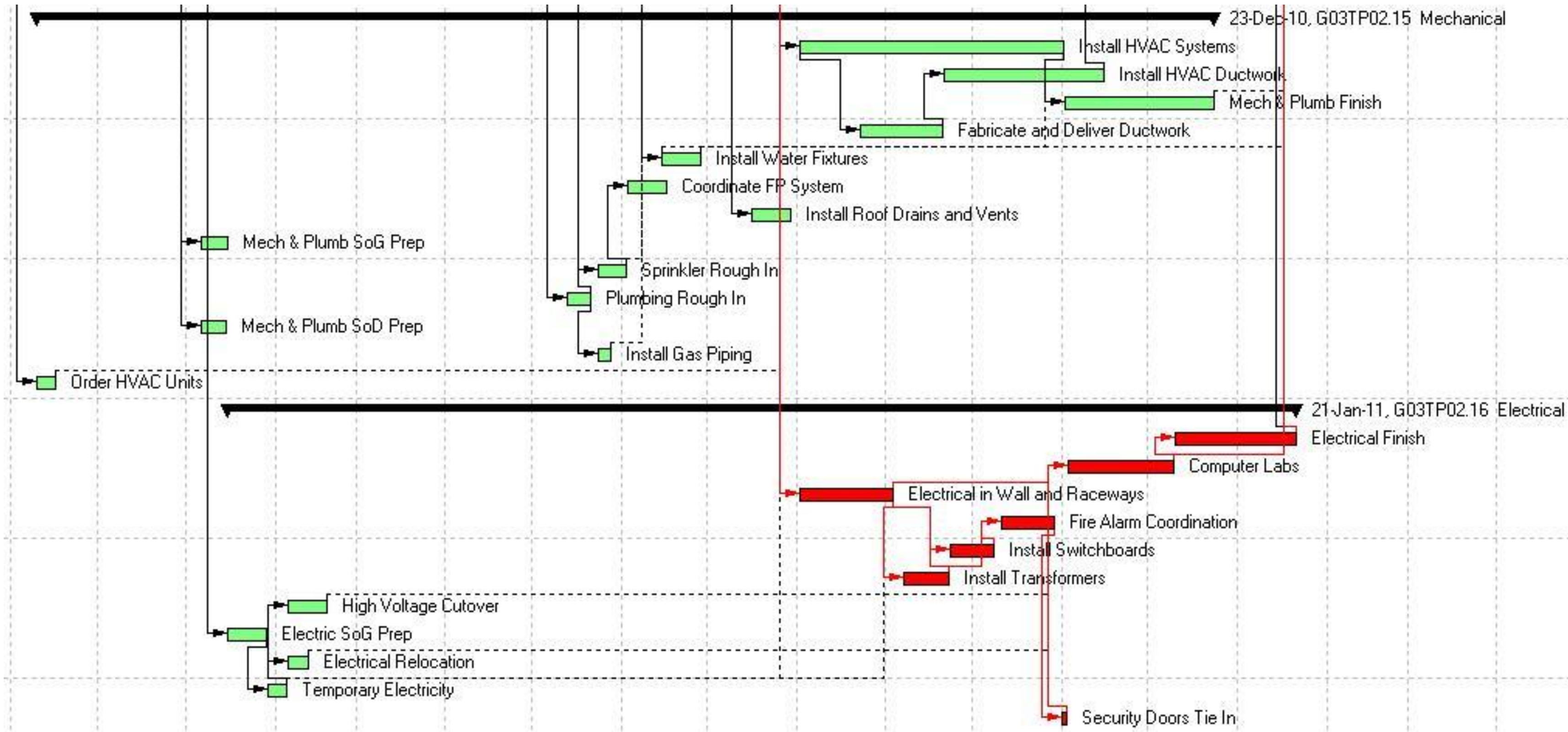



06-Dec-10, G03TP02.03 Concrete
Precast - Entrance
Form/Place/Remove Basement Slab On Grade
Form/Place/Strip Footings
Form/Place/Strip Basement Walls
Place/Pour Roof
Place/Pour 4th Floor
Place/Pour 3rd Floor
Pour Sidewalks
Place/Pour 2nd Floor
Place/Pour 1st Floor
Additional Site Concrete
30-Sep-10, G03TP02.04 Masonry
Fabricate & Deliver Brick and Precast
Install 3rd and 4th Floor Brick South
Install 3rd and 4th Floor Brick East
Install 1st and 2nd Floor Brick West
Install 1st and 2nd Floor Brick North
Install 3rd and 4th Floor Brick West
Install 3rd and 4th Floor Brick North
Install 1st and 2nd Floor Brick South
Install 1st and 2nd Floor Brick East
Install 3rd and 4th Floor Precast
Install 1st and 2nd Floor Precast

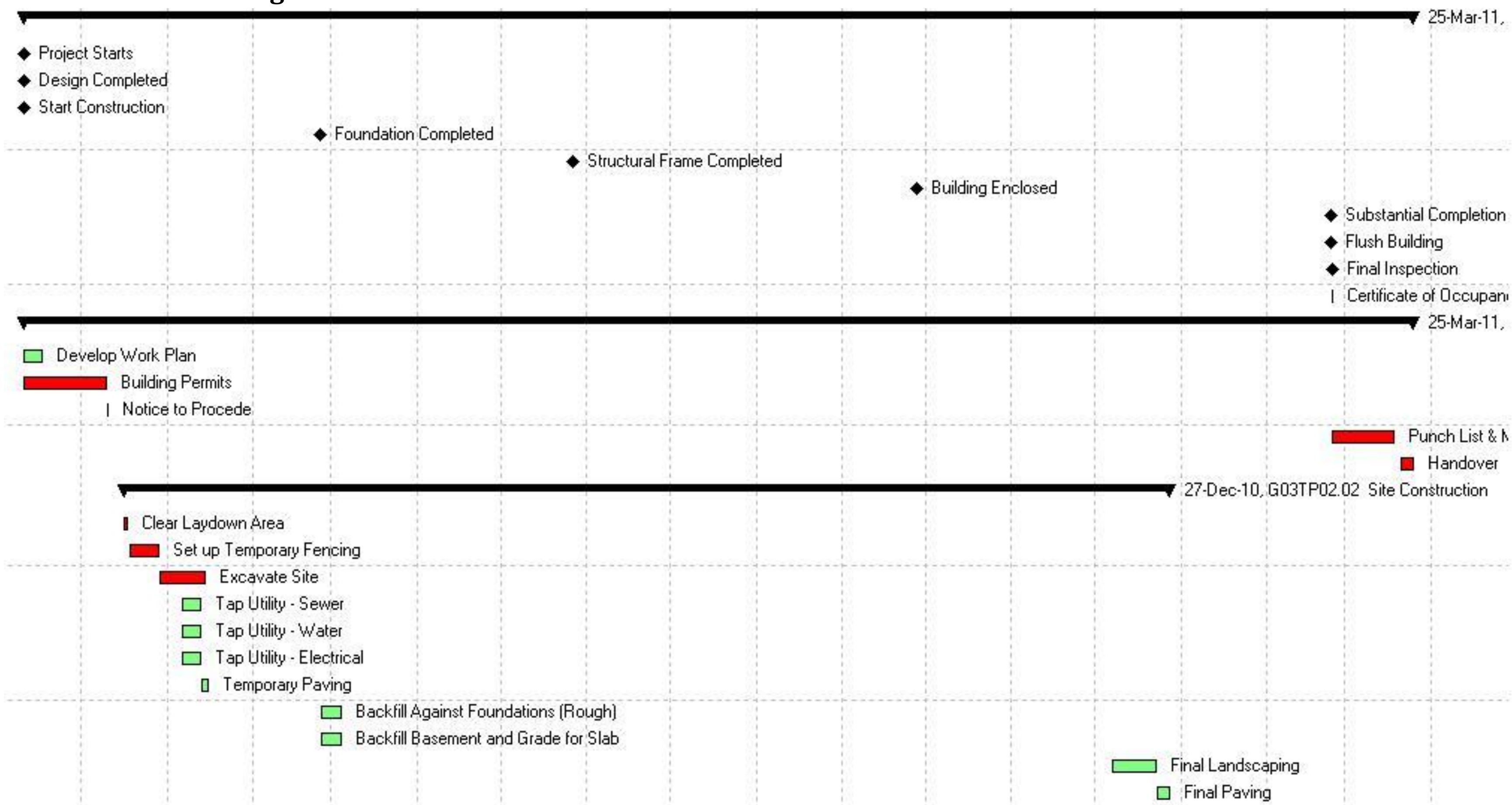

08-Jul-10, G03TP02.05 Metals
Fabricate and Deliver Steel
Erect Steel Frame
Fabricate and Deliver Stairs and Handrails
Fabricate and Deliver Rebar
Apply Spray Fireproofing
Fabricate and Deliver Metal Deck
Install Stairs (4th Floor
Install Stairs (3rd Floor)
Install Stairs (2nd Floor)
Install Stairs (Basement and 1st Floor
Install Metal Decking
Install Anchor Bolts
23-Sep-10, G03TP02.06 Wood and Plastics
Fabricate and Deliver Millwork
Install Millwork
Install Wood Paneling
Install Plywood
09-Nov-10, G03TP02.07 Thermal an
Fabriacte and Deliver EPDM Roofing
Dampproof and Insulate Foundation
Order White Membrane Roofing System
Fabricate and Deliver Slate
Install White Membrane Roofing
Install Slate Shingles
Install Flashing and Roofing Ply
Terminate Roofing Entrance

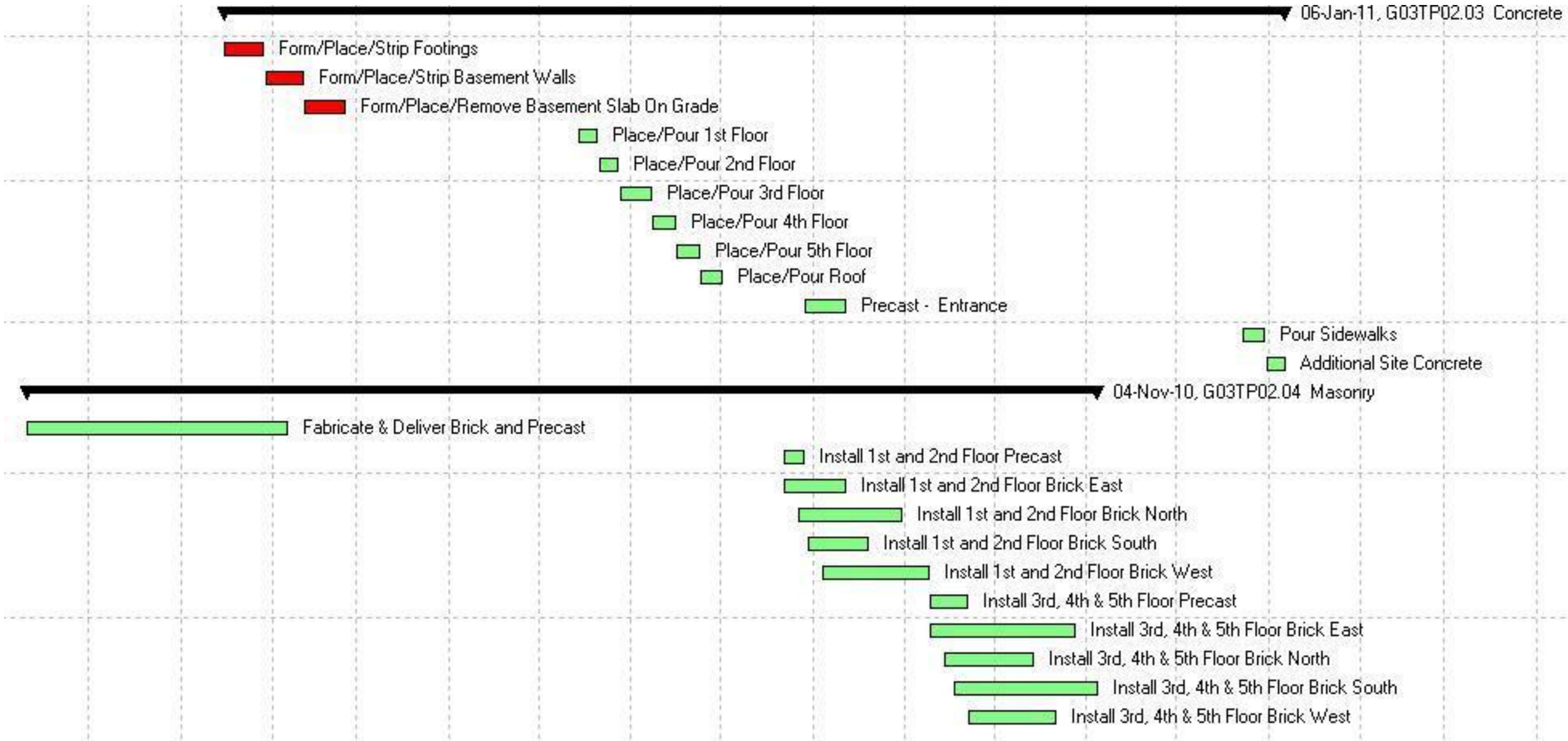

30-Sep-10, G03TP02.08 Doors and Windows
Fabricate and Deliver Curtainwall
Fabricate and Deliver DFH
Fabricate and Deliver Windows
Install Windows West
Install Windows East
Install Interior Doors and Hardware
Window Glazing
Install Windows South
Install Windows North
Install Exterior Doors and Hardware
Install Curtainwall
Install Security Doors
Order Security Doors
06-Dec-10, G03TP02.09
Insulate and Hang Drywall
Install Exterior Studs/Sheathing
Fabricate & Deliver Carpet
Fabricate & Deliver Vynil Tile
Install Ceiling Grid
Install Interior Studs and Frames
Install Signage
Final Paint
Fabricate and Deliver Drywall
Prime Paint
Fabricate and Deliver Ceiling Grid
Fabricate and Deliver Exterior Studs
Finish Drywall
Fabriacte and Deliver Paint
Frame Entrance
Complete Attic Insulation

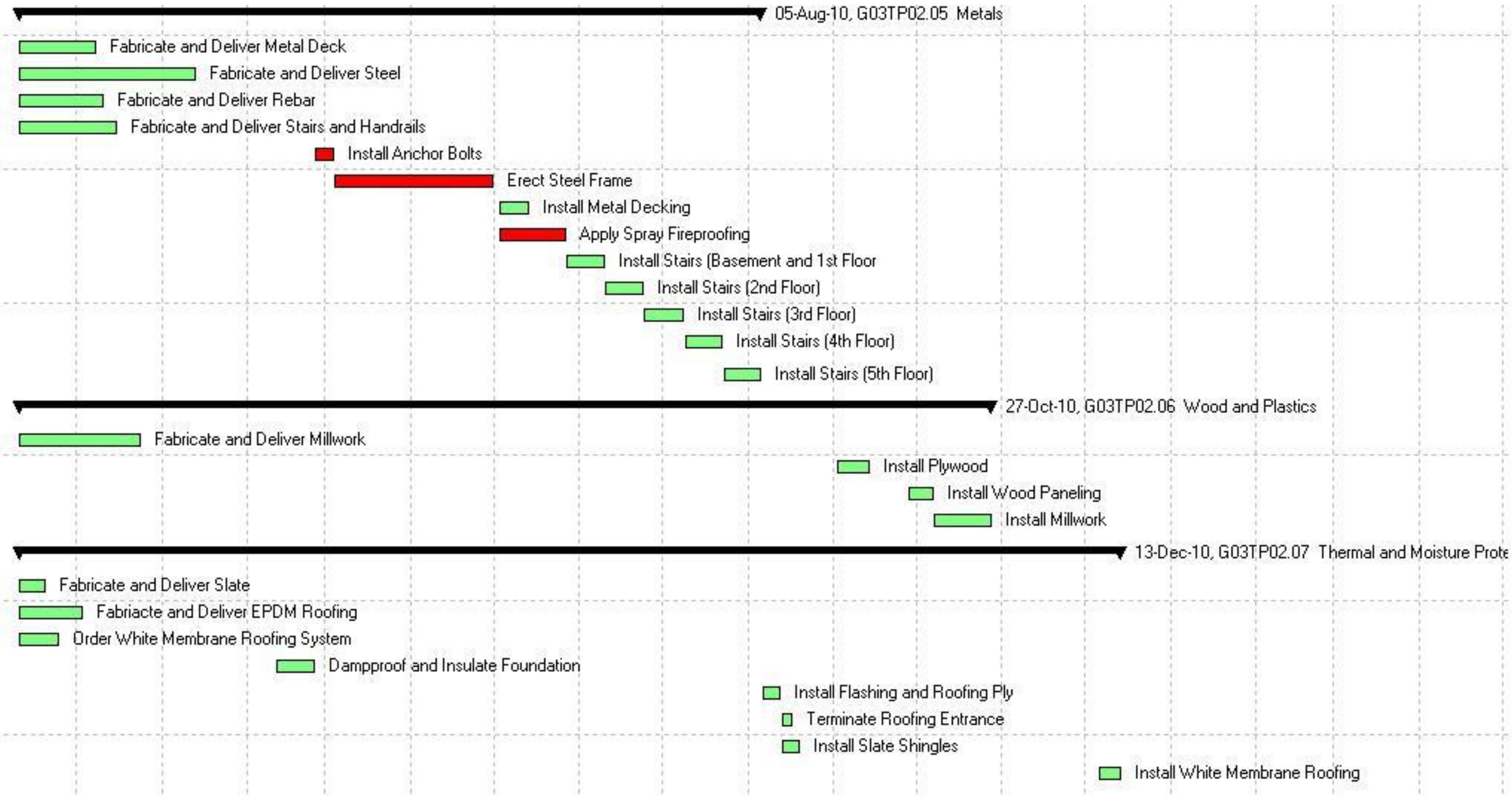

11-Nov-10, G03TP02.10 Specialties
Fabricte and Deliver Louvers/Vents/Screen
Install Laboratory Shelving
Install Whiteboards
Install Flagpole
Install Projectors and Screens
Install Lockers
20-Jul-10, G03TP02.11 Equipment
Install Purified Water System
Install SS Tanks
Install Autoclave and Glasswasher
Install Refridgerators, Freezers and Ovens
Install Fermentor
09-Aug-10, G03TP02.12 Furnishings
Deliver Desks and Chairs
Install Laboratory Benches and Chairs
22-Dec-10, G03TP02.13 Special Cnstruction
Install Fume Hoods
12-Aug-10, G03TP02.14 Conveying Systems
Fabricate & Deliver Elevator
Deliver and Assemble Scaffolding
Install Elevator
Elevator Machine Room Coordination

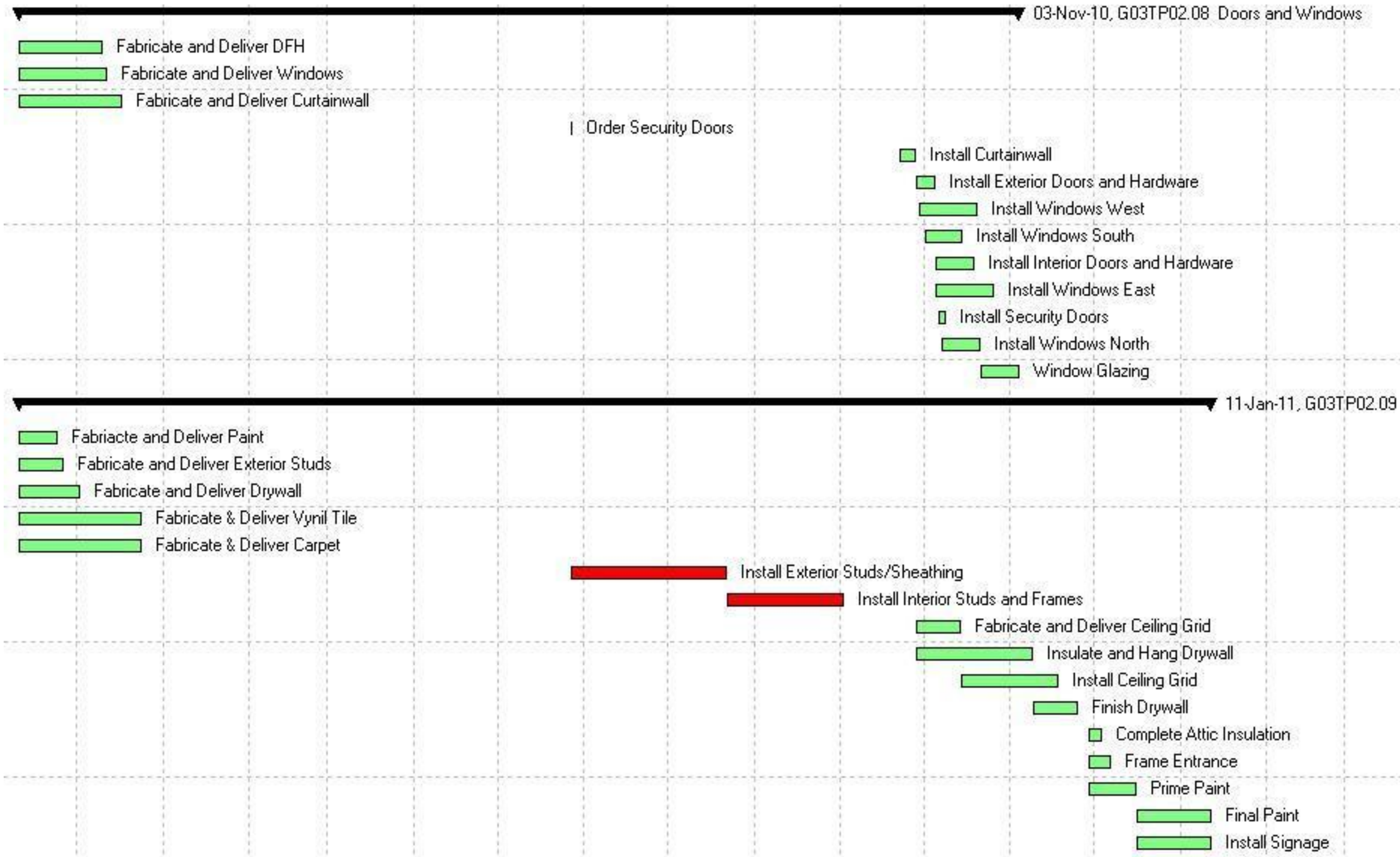

23-Dec-10, G03TP02.15 Mechanical
Install HVAC Systems
Install HVAC Ductwork
Mech & Plumb Finish
Fabricate and Deliver Ductwork
Install Water Fixtures
Coordinate FP System
Install Roof Drains and Vents
Mech & Plumb SoG Prep
Sprinkler Rough In
Plumbing Rough In
Mech & Plumb SoD Prep
Install Gas Piping
Order HVAC Units
21-Jan-11, G03TP02.16 Electrical
Electrical Finish
Computer Labs
Electrical in Wall and Raceways
Fire Alarm Coordination
Install Switchboards
Install Transformers
High Voltage Cutover
Electric SoG Prep
Electrical Relocation
Temporary Electricity
Security Doors Tie In

10.7.2 Alternate Design Schedule

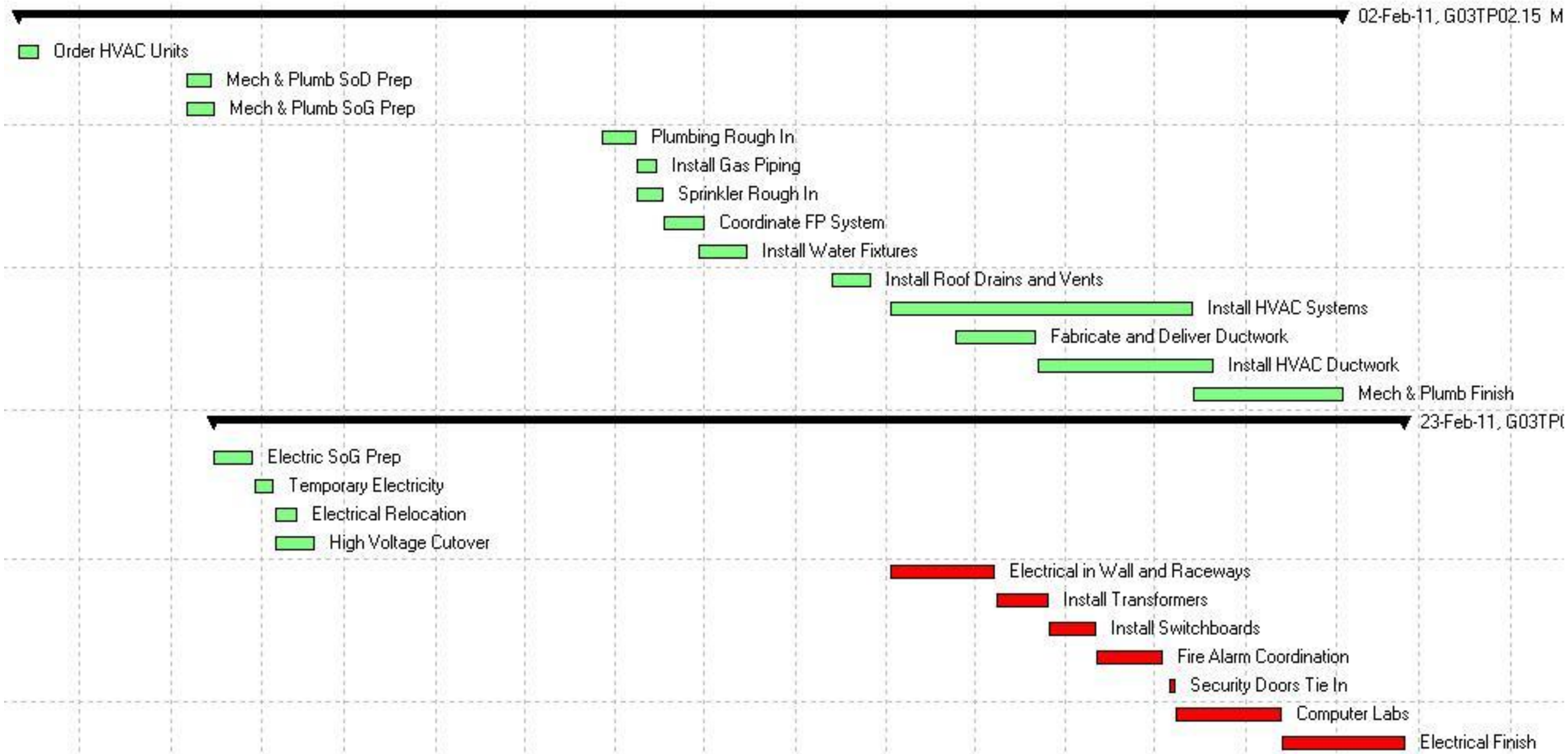



06-Jan-11, G03TP02.03 Concrete
Form/Place/Strip Footings
Form/Place/Strip Basement Walls
Form/Place/Remove Basement Slab On Grade
Place/Pour 1st Floor
Place/Pour 2nd Floor
Place/Pour 3rd Floor
Place/Pour 4th Floor
Place/Pour 5th Floor
Place/Pour Roof
Precast - Entrance
Pour Sidewalks
Additional Site Concrete
04-Nov-10, G03TP02.04 Masonry
Fabricate & Deliver Brick and Precast
Install 1st and 2nd Floor Precast
Install 1st and 2nd Floor Brick East
Install 1st and 2nd Floor Brick North
Install 1st and 2nd Floor Brick South
Install 1st and 2nd Floor Brick West
Install 3rd, 4th & 5th Floor Precast
Install 3rd, 4th & 5th Floor Brick East
Install 3rd, 4th & 5th Floor Brick North
Install 3rd, 4th & 5th Floor Brick South
Install 3rd, 4th & 5th Floor Brick West


05-Aug-10, G03TP02.05 Metals
Fabricate and Deliver Metal Deck
Fabricate and Deliver Steel
Fabricate and Deliver Rebar
Fabricate and Deliver Stairs and Handrails
Install Anchor Bolts
Erect Steel Frame
Install Metal Decking
Apply Spray Fireproofing
Install Stairs (Basement and 1st Floor
Install Stairs (2nd Floor)
Install Stairs (3rd Floor)
Install Stairs (4th Floor)
Install Stairs (5th Floor)
27-Oct-10, G03TP02.06 Wood and Plastics
Fabricate and Deliver Millwork
Install Plywood
Install Wood Paneling
Install Millwork
13-Dec-10, G03TP02.07 Thermal and Moisture Prote
Fabricate and Deliver Slate
Fabriacte and Deliver EPDM Roofing
Order White Membrane Roofing System
Dampproof and Insulate Foundation
Install Flashing and Roofing Ply
Terminate Roofing Entrance
Install Slate Shingles
Install White Membrane Roofing


03-Nov-10, G03TP02.08 Doors and Windows
Fabricate and Deliver DFH
Fabricate and Deliver Windows
Fabricate and Deliver Curtainwall
Order Security Doors
Install Curtainwall
Install Exterior Doors and Hardware
Install Windows West
Install Windows South
Install Interior Doors and Hardware
Install Windows East
Install Security Doors
Install Windows North
Window Glazing
11-Jan-11, G03TP02.09
Fabriacte and Deliver Paint
Fabricate and Deliver Exterior Studs
Fabricate and Deliver Drywall
Fabricate & Deliver Vynil Tile
Fabricate & Deliver Carpet
Install Exterior Studs/Sheathing
Install Interior Studs and Frames
Fabricate and Deliver Ceiling Grid
Insulate and Hang Drywall
Install Ceiling Grid
Finish Drywall
Complete Attic Insulation
Frame Entrance
Prime Paint
Final Paint
Install Signage

15-Dec-10, G03TP02.10 Specialties
Fabricte and Deliver Louvers/Vents/Screen
Install Whiteboards
Install Lockers
Install Laboratory Shelving
Install Projectors and Screens
Install Flagpole
28-Jun-10, G03TP02.11 Equipment
Install Fermentor
Install Refridgerators, Freezers and Ovens
Install Autoclave and Glasswasher
Install SS Tanks
Install Purified Water System
07-Apr-10, G03TP02.12 Furnishings
Deliver Desks and Chairs
Install Laboratory Benches and Chairs
25-Jan-11, G03TP02.13
Install Fume Hoods
15-Sep-10, G03TP02.14 Conveying Systems
Fabricate & Deliver Elevator
Deliver and Assemble Scaffolding
Install Elevator
Elevator Machine Room Coordination
02-Feb-11, G03TP02.


02-Feb-11, G03TP02.15 M
Order HVAC Units
Mech & Plumb SoD Prep
Mech & Plumb SoG Prep
Plumbing Rough In
Install Gas Piping
Sprinkler Rough In
Coordinate FP System
Install Water Fixtures
Install Roof Drains and Vents
Install HVAC Systems
Fabricate and Deliver Ductwork
Install HVAC Ductwork
Mech & Plumb Finish
23-Feb-11, G03TP(
Electric SoG Prep
Temporary Electricity
Electrical Relocation
High Voltage Cutover
Electrical in Wall and Raceways
Install Transformers
Install Switchboards
Fire Alarm Coordination
Security Doors Tie In
Computer Labs
Electrical Finish

10.8 Cost Estimates

10.8.1 Cost Estimate (Original Design)

GATEWAY MIXED-USE FACILITY COST ESTIMATE SUMMARY

DIVISION		
02 SITEWORK	$	82,730.81
03 CONCRETE	$	1,510,834.89
04 MASONRY	$	1,358,276.88
05 METALS	$	2,193,501.68
06 MILLWORK	$	240,446.29
07 THERMAL & MOISTURE	$	363,037.23
08 DOORS AND WINDOWS	$	219,276.75
09 FINISHES	$	1,374,222.21
10 SPECIALTIES	$	84,789.44
11 EQUIPMENT	$	3,166,736.47
12 FURNISHINGS	$	-
13 SPECIAL CONSTRUCTION	$	-
14 CONVEYING SYSTEMS	$	292,507.34
15-16 MEP	$	7,820,723.02
TOTAL	$	18,707,083.01

02 - SITEWORK

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION		TOTAL
Temporary Fencing	780	LF	4.68	1.0641779	1.07	$	4,156.60
Earthwork	1396	BCY	5.6	1.03159	1.07	$	8,629.08
Curbing	400	LF	19.95	1.03159	1.07	$	8,808.33
Sidewalks	400	LF	22.35	1.03159	1.07	$	9,867.98
Utility (Water)	50	LF	56.5	1.03159	1.07	$	3,118.24
Utility (Sewer)	50	LF	34.95	1.03159	1.07	$	1,928.89
Site Restoration	25	MSF	1675	1.03159	1.07	$	46,221.68
						$	82,730.81

03 - CONCRETE

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Footing Concrete	1071	CY	305	1.03159	1.07	360,649.50
CMU	7440	SF	7.75	1.03159	1.07	63,645.18
Cast in Place Sills	588	LF	25.55	1.03159	1.07	16,582.85
Slab on Grade	21987	SF	7.29	1.03159	1.07	176,923.05
Slab on Deck	86429	SF	8.19	1.03159	1.07	781,329.62
Stairs	8	FLIGHT	12650	1.03159	1.07	111,704.69
						1,510,834.89

04 - MASONRY

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Exterior Brick	50870	SF	23.9	1.03159	1.07	$ 1,341,993.89
Temporary Heat	880	CSF FL	16.25	1.0641779	1.07	$ 16,282.99
						$ 1,358,276.88

05 - METALS

ITEM	COST
Typical HSS Columns	$ 53,945.00
W Shape Beams (Floor)	$ 1,594,188.00
W Shape Beams (Roof)	$ 205,290.50
W Shape Columns	$ 45,018.73
Joist Girders	$ 28,665.00
Connections & Anchor Bolts	$ 192,710.72
Footing Reinforcement	$ 73,683.73
TOTAL METALS COST	$ 2,193,501.68

06 - WOOD AND PLASTICS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Plywood	76166	SF	2.86	1.03159	1.07	$ 240,446.29
						$ 240,446.29

07 - THERMAL & MOISTURE PROTECTION

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Dampproofing and Insulation (Foundation)	2588	SF	4.65	1.03159	1.07	$ 13,283.37
White Membrane Roof	87000	SF	2.05	1.03159	1.07	$ 196,862.96
Flashing	21987	SF	4.3	1.03159	1.07	$ 104,357.90
Exterior Sheathing	28799	SF	1.48	1.0641779	1.07	$ 48,533.00
						$ 363,037.23

08 - DOORS & WINDOWS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Wood Doors 1	107	EA	565	1.03159	1.07	$ 66,730.31
Wood Doors 2	18	EA	613	1.03159	1.07	$ 12,179.34
Glass Entrance Door	10	EA	430	1.03159	1.07	$ 4,746.35
Overhead Doors	2	EA	4275	1.03159	1.07	$ 9,437.50
Specialty Doors	1	EA	4875	1.03159	1.07	$ 5,381.03
Entrances	2	EA	6100	1.03159	1.07	$ 13,466.38
Windows 1	187	EA	492	1.03159	1.07	$ 101,554.13
Windows 2	9	EA	582	1.03159	1.07	$ 5,781.71
						$ 219,276.75

09 - FINISHES

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Drywall Partitions 1	76166	SF	3.8	1.03159	1.07	$ 319,474.09
Drywall Partitions 2	50870	SF	2.35	1.03159	1.07	$ 131,953.37
Tile	54968	SF	4.14	1.03159	1.07	$ 251,189.32
Ceilings	87949	SF	4.3	1.03159	1.07	$ 417,436.35
Carpet	32981	SF	4.17	1.03159	1.07	$ 151,806.64
Paint	127036	SF	0.73	1.03159	1.07	$ 102,362.43
						$ 1,374,222.21

10 - SPECIALTIES

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Visual Display Boards	4200	SF	12.9	1.01359	1.07	$ 58,760.45
Flagpole	1	EA	4000	1.01359	1.07	$ 4,338.17
Lockers	100	EA	200	1.01359	1.07	$ 21,690.83

$ 84,789.44

11 - EQUIPMENT

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
LABORATORY EQUIPMENT	54968	SF	46.60	1.03159	1.07	$ 2,827,396.74
OFFICE EQUIPMENT						
Desks	17	EA	500.00	1.03159	1.07	$ 9,382.31
Chairs	30	EA	272.00	1.03159	1.07	$ 9,007.02
Copy/Fax	2	EA	5,000.00	1	1.07	$ 10,700.00
Drawing Table	2	EA	1,000.00	1.03159	1.07	$ 2,207.60
Filing Cabinets	15	EA	290.00	1.03159	1.07	$ 4,801.54
SCHOOL EQUIPMENT						
Chairs	20	EA	150.00	1.03159	1.07	$ 3,311.40
Desk/Chair	100	EA	80.00	1.03159	1.07	$ 8,830.41
Projection Screens	9	EA	26,670.00	1.03159	1.07	$ 264,945.43
Book Shelving	119	LF	165.50	1.03159	1.07	$ 21,738.81
Discussion Tables	4	EA	1,000.00	1.03159	1.07	$ 4,415.21
						$ 3,166,736.47

14 - CONVEYING SYSTEMS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Elevators	2	EA	132,500.00	1.03159	1.07	$ 292,507.34
						$ 292,507.34

15-16 - MEP

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Mechanical & Electrical	87949	SF	63.9	1.0977953	1.07	$ 6,601,413.12
Plumbing	87949	SF	12.56	1.0315963	1.07	$ 1,219,309.90
						$ 7,820,723.02

Structural Steel Takeoff

Section	TYPICAL COLUMNS	SECTION	SHAPE	DIMENSION (in)	THICKNESS (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (kips)	TAKE OFF		
										UNIT	PRICE	TOTAL
Typical	Column 1 Interior	Base	HSS	16	1/2	103	24.083	2	4.96	EA	2500	$ 5,000.00
		Top	HSS	10	1/2	62.5	35.917	2	4.49	EA	1925	$ 3,850.00
	Column 1 Side	Base	HSS	12	3/8	58	24.083	2	2.79	EA	2200	$ 4,400.00
		Top	HSS	8	3/8	37.6	35.917	2	2.70	EA	1075	$ 2,150.00
	Column 1 Outside Corner	Base	HSS	7	5/16	27.5	24.083	2	1.32	EA	750	$ 1,500.00
		Top	HSS	5	5/16	19	35.917	2	1.36	EA	400	$ 800.00
	Column 1 Inside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	6	5/16	23.3	35.917	2	1.67	EA	560	$ 1,120.00
	Column 2 Interior	Base	HSS	14	5/8	110	24.083	4	10.60	EA	2350	$ 9,400.00
		Top	HSS	9	5/8	67.6	35.917	4	9.71	EA	1500	$ 6,000.00
	Column 2 Side	Base	HSS	9	1/2	55.5	24.083	4	5.35	EA	1500	$ 6,000.00
		Top	HSS	7	3/8	32.5	35.917	4	4.67	EA	750	$ 3,000.00
	Column 2 Corner	Base	HSS	7	5/16	27.5	24.083	4	2.65	EA	750	$ 3,000.00
		Top	HSS	5.5	5/16	21.2	35.917	4	3.05	EA	450	$ 1,800.00
	Column 3 Corner	Base1	HSS	9	3/8	42.7	24.083	1	1.03	EA	1200	$ 1,200.00
		L Base	HSS	8	1/2	48.7	24.083	1	1.17	EA	1075	$ 1,075.00
		Top	HSS	7	5/16	27.5	35.917	2	1.98	EA	750	$ 1,500.00
										TOTAL COST		$ 53,945.00

Odeum	TYPICAL COLUMNS	SECTION	SHAPE	DIMENSION (in)	THICKNESS (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (kips)	TAKEOFF		
										UNIT	PRICE	TOTAL
	Column 1 Interior	Base	HSS	14	1/2	89.6	24.083	2	4.32	EA	2350	$ 4,700.00
		Top	HSS	8	1/2	48.7	23.917	2	2.33	EA	1075	$ 2,150.00
	Column 1 Side	Base	HSS	12	1/2	75.9	24.083	2	3.66	EA	2200	$ 4,400.00
		Top	HSS	12	3/8	58	38.917	2	4.51	EA	2200	$ 4,400.00
	Column 1 Outside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	7	3/8	32.5	38.917	2	2.53	EA	750	$ 1,500.00
	Column 1 Inside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	6	3/8	27.4	38.917	2	2.13	EA	560	$ 1,120.00
	Column 2 Interior	Base	HSS	12	5/8	93.1	24.083	4	8.97	EA	2200	$ 8,800.00
		Top	HSS	9	1/2	55.5	23.917	4	5.31	EA	1500	$ 6,000.00
	Column 2 Side	Base	HSS	12	3/8	58	24.083	4	5.59	EA	2200	$ 8,800.00
		Top	HSS	7	5/16	27.5	38.917	4	4.28	EA	750	$ 3,000.00
	Column 2 Corner	Base	HSS	6	3/8	27.4	24.083	4	2.64	EA	560	$ 2,240.00
		Top	HSS	5	5/16	19	38.917	4	2.96	EA	400	$ 1,600.00
	Column 3 Corner	Base	HSS	10	3/8	47.8	24.083	1	1.15	EA	1925	$ 1,925.00
		Top	HSS	7	3/8	32.5	38.917	1	1.26	EA	750	$ 750.00
		L Base	HSS	9	1/2	55.5	24.083	1	1.34	EA	1500	$ 1,500.00
		L Top	HSS	8	5/16	31.8	38.917	1	1.24	EA	1075	$ 1,075.00
										TOTAL COST		$ 58,260.00

TYPICAL BEAMS & COLUMNS	SHAPE	DEPTH (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (k)	TAKE OFF		
							UNIT	PRICE	TOTAL
Floor									
Beam 1 Interior	W	18	35	35	46	56.35	LF	72.0	$ 463,680.00
Girder 1 Interior	W	21	50	22	4	4.4	LF	98.5	$ 34,672.00
Beam 1 Exterior	W	16	26	35	6	5.46	LF	53.0	$ 44,520.00
Girder 1 Exterior	W	16	31	22	4	2.728	LF	63.5	$ 22,352.00
Beam 2 Interior	W	21	44	40	44	77.44	LF	87.5	$ 616,000.00
Girder 2 Interior	W	24	55	22	12	14.52	LF	107.0	$ 112,992.00
Girder 2 Exterior	W	18	35	22	12	9.24	LF	72.0	$ 76,032.00
Beam 2 Small	W	12	14	5	8	0.56	LF	32.0	$ 5,120.00
Beam 3 Interior	W	18	40	35	15	21	LF	81.0	$ 170,100.00
Girder 3 Interior	W	24	68	28	2	3.808	LF	130.0	$ 29,120.00
Girder 3 Exterior	W	21	44	28	2	2.464	LF	87.5	$ 19,600.00
							TOTAL COST		$ 1,594,188.00

							UNIT	PRICE	TOTAL
Typical Roof									
RBeam 1 Interior	W	16	31	35	23	24.955	LF	63.5	$ 51,117.50
RGirder 1 Interior	W	18	35	22	2	1.54	LF	72.0	$ 3,168.00
RBeam 1 Exterior	W	16	26	35	3	2.73	LF	53.0	$ 5,565.00
RGirder 1 Exterior	W	18	35	22	2	1.54	LF	72.0	$ 3,168.00
RBeam 2 Interior	W	18	46	40	22	40.48	LF	92.0	$ 80,960.00
RGirder 2 Interior	W	21	44	22	6	5.808	LF	87.5	$ 11,550.00
RGirder 2 Exterior	W	16	31	22	6	4.092	LF	63.5	$ 8,382.00
RBeam 2 Small	W	12	14	5	4	0.28	LF	32.0	$ 640.00
RBeam 3 Interior	W	18	35	35	12	14.7	LF	72.0	$ 30,240.00
RGirder 3 Interior	W	21	53	28	2	2.968	LF	100.0	$ 5,600.00
RGirder 3 Exterior	W	21	44	28	2	2.464	LF	87.5	$ 4,900.00
							TOTAL COST		$ 205,290.50
Odeum Roof									
Ext RBeam	W	12	14	22	8	2.464	LF	32.0	$ 5,632.00
RBeam 2 Small	W	12	14	5	4	0.28	LF	32.0	$ 640.00
							TOTAL COST		$ 6,272.00
Columns									
Col 3 (Int2) Base	W	14	132	24.083	2	6.357912	LF	236.0	$ 11,367.18
Col 3 (Int2) Top	W	12	87	38.917	2	6.771558	LF	167.0	$ 12,998.28
Col 3 (Int3) Base	W	12	120	24.083	2	5.77992	LF	220.0	$ 10,596.52
Col 3 (Int3) Top	W	12	72	35.917	2	5.172048	LF	140.0	$ 10,056.76
							TOTAL COST		$ 45,018.73

JOIST GIRDERS	G	N	F	PLF	LENGTH	# MEMBERS	TOTAL WEIGHT (k)	UNIT	PRICE	TOTAL
								TAKE OFF		
								UNIT	PRICE	TOTAL
Joist Girder 1	36	7	48	105	35	3	11.025	TON	2600	$ 14,332.50
Joist Girder 2	36	7	48	105	35	3	11.025	TON	2600	$ 14,332.50
								TOTAL COST		$ 28,665.00

Long Span Joist - LH Series	DEPTH	PLF	LENGTH	# MEMBERS	TOTAL WEIGHT (k)	UNIT	PRICE	TOTAL
Odeum Joist 1	48	42	88	20	73.92	LF	56	$ 98,560.00
Odeum Joist 2	36	30	66	2	3.96	LF	42	$ 5,544.00
						TOTAL COST		$ 104,104.00

10.8.2 Cost Estimate (Alternate Design)

GATEWAY MIXED-USE FACILITY COST ESTIMATE SUMMARY

Alternative Design

DIVISION

02 SITEWORK	$	82,730.81
03 CONCRETE	$	1,542,819.49
04 MASONRY	$	1,584,941.15
05 METALS	$	2,500,811.43
06 MILLWORK	$	269,379.02
07 THERMAL & MOISTURE	$	381,728.14
08 DOORS AND WINDOWS	$	255,784.98
09 FINISHES	$	1,659,399.22
10 SPECIALTIES	$	97,380.96
11 EQUIPMENT	$	3,233,494.37
12 FURNISHINGS	$	-
13 SPECIAL CONSTRUCTION	$	-
14 CONVEYING SYSTEMS	$	292,507.34
15-16 MEP	$	9,775,881.54
TOTAL	$	21,676,858.47

02 - SITEWORK

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Temporary Fencing	780	LF	4.68	1.0641779	1.07	$ 4,156.60
Earthwork	1396	BCY	5.6	1.03159	1.07	$ 8,629.08
Curbing	400	LF	19.95	1.03159	1.07	$ 8,808.33
Sidewalks	400	LF	22.35	1.03159	1.07	$ 9,867.98
Utility (Water)	50	LF	56.5	1.03159	1.07	$ 3,118.24
Utility (Sewer)	50	LF	34.95	1.03159	1.07	$ 1,928.89
Site Restoration	25	MSF	1675	1.03159	1.07	$ 46,221.68
						$ 82,730.81

03 - CONCRETE

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Footing Concrete	1071.00	CY	305	1.03159	1.07	$ 360,562.21
CMU	7440	SF	7.75	1.03159	1.07	$ 63,645.18
Cast in Place Sills	735	LF	25.55	1.03159	1.07	$ 20,728.56
Slab on Grade	21987	SF	7.29	1.03159	1.07	$ 176,923.05
Slab on Deck	86429	SF	8.19	1.03159	1.07	$ 781,329.62
Stairs	10	FLIGHT	12650	1.03159	1.07	$ 139,630.86
						$ 1,542,819.49

04 - MASONRY

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Exterior Brick	59462	SF	23.9	1.03159	1.07	$ 1,568,658.17
Temporary Heat	880	CSF FL	16.25	1.0641779	1.07	$ 16,282.99
						$ 1,584,941.15

05 - METALS

ITEM	COST
HSS Columns	$ 58,260.00
W Shape Beams (Floor)	$ 1,992,735.00
W Shape Beams (Odeum)	$ 6,272.00
W Shape Columns	$ 45,108.73
Long Span Joists (Odeum)	$ 104,104.00
Anchor Bolts & Connections	$ 220,647.97
Footing Reinforcement	$ 73,683.73
TOTAL COST	$ 2,500,811.43

06 - WOOD & PLASTICS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Plywood	85331	SF	2.86	1.03159	1.07	$ 269,379.02
						$ 269,379.02

07 THERMAL & MOISTURE PROTECTION

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Dampproofing and Insulation (Foundation)	2588	SF	4.65	1.03159	1.07	$ 13,283.37
White Membrane Roof	87000	SF	2.05	1.03159	1.07	$ 196,862.96
Flashing	21987	SF	4.3	1.03159	1.07	$ 104,357.90
Exterior Sheathing	39890	SF	1.48	1.0641779	1.07	$ 67,223.91
						$ 381,728.14

08 - DOORS & WINDOWS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Wood Doors 1	120	EA	565	1.03159	1.07	$ 74,837.73
Wood Doors 2	18	EA	613	1.03159	1.07	$ 12,179.34
Glass Entrance Door	12	EA	430	1.03159	1.07	$ 5,695.61
Overhead Doors	2	EA	4275	1.03159	1.07	$ 9,437.50
Specialty Doors	1	EA	4875	1.03159	1.07	$ 5,381.03
Entrances	2	EA	6100	1.03159	1.07	$ 13,466.38
Windows 1	234	EA	492	1.03159	1.07	$ 127,078.44
Windows 2	12	EA	582	1.03159	1.07	$ 7,708.95
						$ 255,784.98

09 - FINISHES

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Drywall Partitions 1	87257	SF	3.8	1.03159	1.07	$ 365,994.68
Drywall Partitions 2	60035	SF	2.35	1.03159	1.07	$ 155,726.77
Tile	67714	SF	4.14	1.03159	1.07	$ 309,435.20
Ceilings	109936	SF	4.3	1.03159	1.07	$ 521,794.25
Carpet	40793	SF	4.17	1.03159	1.07	$ 187,764.12
Paint	147292	SF	0.73	1.03159	1.07	$ 118,684.20
						$ 1,659,399.22

10 - SPECIALTIES

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Visual Display Boards	5100	SF	12.9	1.01359	1.07	$ 71,351.97
Flagpole	1	EA	4000	1.01359	1.07	$ 4,338.17
Lockers	100	EA	200	1.01359	1.07	$ 21,690.83
						$ 97,380.96

11 - EQUIPMENT

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
LABORATORY EQUIPMENT	54968	SF	46.60	1.03159	1.07	$ 2,827,396.74
OFFICE EQUIPMENT						
Desks	17	EA	500.00	1.03159	1.07	$ 9,382.31
Chairs	120	EA	272.00	1.03159	1.07	$ 36,028.07
Copy/Fax	2	EA	5,000.00	1	1.07	$ 10,700.00
Drawing Table	2	EA	1,000.00	1.03159	1.07	$ 2,207.60
Filing Cabinets	15	EA	290.00	1.03159	1.07	$ 4,801.54
SCHOOL EQUIPMENT						
Chairs	220	EA	150.00	1.03159	1.07	$ 36,425.44
Desk/Chair	100	EA	80.00	1.03159	1.07	$ 8,830.41
Projection Screens	9	EA	26,670.00	1.03159	1.07	$ 264,945.43
Book Shelvings	119	LF	165.50	1.03159	1.07	$ 21,738.81
Discussion Tables	10	EA	1,000.00	1.03159	1.07	$ 11,038.01
						$ 3,233,494.37

14 - CONVEYING SYSTEMS

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Elevators	2	EA	132,500.00	1.03159	1.07	$ 292,507.34
						$ 292,507.34

15-16 - MEP

ITEM	QUANTITY	UNITS	MEANS MULTIPLIER	INFLATION	LOCATION	TOTAL
Mechanical & Electrical	109936	SF	63.9	1.0977953	1.07	$ 8,251,747.64
Plumbing	109936	SF	12.56	1.0315963	1.07	$ 1,524,133.90
						$ 9,775,881.54

STRUCTURAL STEEL TAKEOFF (ALTERNATE DESIGN)

Section	TYPICAL COLUMNS	SECTION	SHAPE	DIMENSION (in)	THICKNESS (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (k)	TAKE OFF UNIT	TAKE OFF PRICE	TAKE OFF TOTAL
Typical	Column 1 Interior	Base	HSS	16	1/2	103	24.083	2	4.96	EA	2500	$ 5,000.00
		Top	HSS	10	1/2	62.5	35.917	2	4.49	EA	1925	$ 3,850.00
	Column 1 Side	Base	HSS	12	3/8	58	24.083	2	2.79	EA	2200	$ 4,400.00
		Top	HSS	8	3/8	37.6	35.917	2	2.70	EA	1075	$ 2,150.00
	Column 1 Outside Corner	Base	HSS	7	5/16	27.5	24.083	2	1.32	EA	750	$ 1,500.00
		Top	HSS	5	5/16	19	35.917	2	1.36	EA	400	$ 800.00
	Column 1 Inside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	6	5/16	23.3	35.917	2	1.67	EA	560	$ 1,120.00
	Column 2 Interior	Base	HSS	14	5/8	110	24.083	4	10.60	EA	2350	$ 9,400.00
		Top	HSS	9	5/8	67.6	35.917	4	9.71	EA	1500	$ 6,000.00
	Column 2 Side	Base	HSS	9	1/2	55.5	24.083	4	5.35	EA	1500	$ 6,000.00
		Top	HSS	7	3/8	32.5	35.917	4	4.67	EA	750	$ 3,000.00
	Column 2 Corner	Base	HSS	7	5/16	27.5	24.083	4	2.65	EA	750	$ 3,000.00
		Top	HSS	5.5	5/16	21.2	35.917	4	3.05	EA	450	$ 1,800.00
	Column 3 Corner	Base1	HSS	9	3/8	42.7	24.083	1	1.03	EA	1200	$ 1,200.00
		L Base	HSS	8	1/2	48.7	24.083	1	1.17	EA	1075	$ 1,075.00
		Top	HSS	7	5/16	27.5	35.917	2	1.98	EA	750	$ 1,500.00
										TOTAL COST		$ 53,945.00

Odeum	TYPICAL COLUMNS	SECTION	SHAPE	DIMENSION (in)	THICKNESS (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (k)			
	Column 1 Interior	Base	HSS	14	1/2	89.6	24.083	2	4.32	EA	2350	$ 4,700.00
		Top	HSS	8	1/2	48.7	23.917	2	2.33	EA	1075	$ 2,150.00
	Column 1 Side	Base	HSS	12	1/2	75.9	24.083	2	3.66	EA	2200	$ 4,400.00
		Top	HSS	12	3/8	58	38.917	2	4.51	EA	2200	$ 4,400.00
	Column 1 Outside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	7	3/8	32.5	38.917	2	2.53	EA	750	$ 1,500.00
	Column 1 Inside Corner	Base	HSS	8	3/8	37.6	24.083	2	1.81	EA	1075	$ 2,150.00
		Top	HSS	6	3/8	27.4	38.917	2	2.13	EA	560	$ 1,120.00
	Column 2 Interior	Base	HSS	12	5/8	93.1	24.083	4	8.97	EA	2200	$ 8,800.00
		Top	HSS	9	1/2	55.5	23.917	4	5.31	EA	1500	$ 6,000.00
	Column 2 Side	Base	HSS	12	3/8	58	24.083	4	5.59	EA	2200	$ 8,800.00
		Top	HSS	7	5/16	27.5	38.917	4	4.28	EA	750	$ 3,000.00
	Column 2 Corner	Base	HSS	6	3/8	27.4	24.083	4	2.64	EA	560	$ 2,240.00
		Top	HSS	5	5/16	19	38.917	4	2.96	EA	400	$ 1,600.00
	Column 3 Corner	Base	HSS	10	3/8	47.8	24.083	1	1.15	EA	1925	$ 1,925.00
		Top	HSS	7	3/8	32.5	38.917	1	1.26	EA	750	$ 750.00
		L Base	HSS	9	1/2	55.5	24.083	1	1.34	EA	1500	$ 1,500.00
		L Top	HSS	8	5/16	31.8	38.917	1	1.24	EA	1075	$ 1,075.00
										TOTAL COST		$ 58,260.00

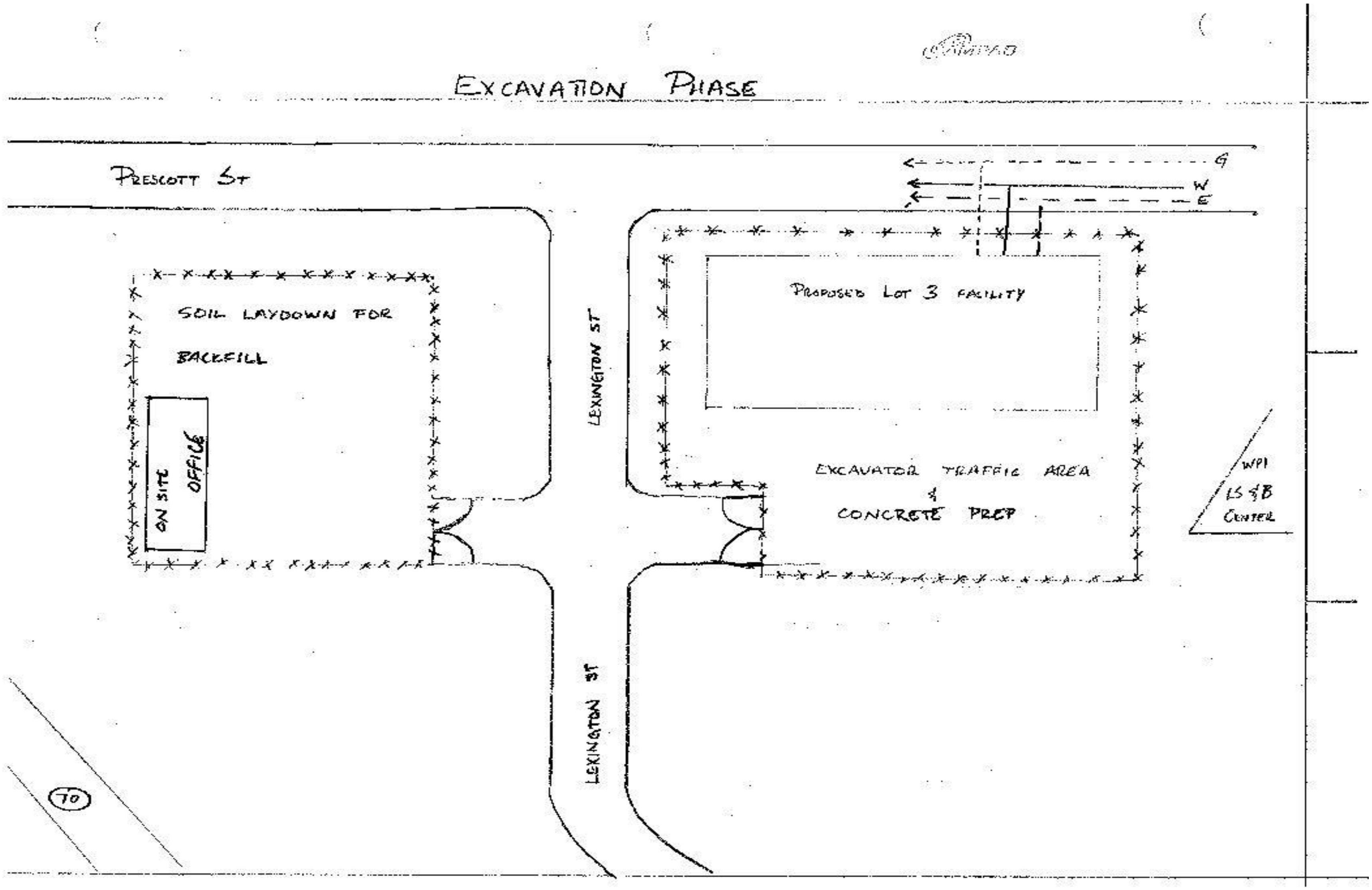
TYPICAL BEAMS & COLUMNS	SHAPE	DEPTH (in)	PLF	LENGTH (ft)	# MEMBERS	TOTAL WEIGHT (kips)	TAKE OFF		
							UNIT	PRICE	TOTAL
Floor									
Beam 1 Interior	W	18	35	35	46	56.35	LF	72.0	$ 579,600.00
Girder 1 Interior	W	21	50	22	4	4.4	LF	98.5	$ 43,340.00
Beam 1 Exterior	W	16	26	35	6	5.46	LF	53.0	$ 55,650.00
Girder 1 Exterior	W	16	31	22	4	2.728	LF	63.5	$ 27,940.00
Beam 2 Interior	W	21	44	40	44	77.44	LF	87.5	$ 770,000.00
Girder 2 Interior	W	24	55	22	12	14.52	LF	107.0	$ 141,240.00
Girder 2 Exterior	W	18	35	22	12	9.24	LF	72.0	$ 95,040.00
Beam 2 Small	W	12	14	5	8	0.56	LF	32.0	$ 6,400.00
Beam 3 Interior	W	18	40	35	15	21	LF	81.0	$ 212,625.00
Girder 3 Interior	W	24	68	28	2	3.808	LF	130.0	$ 36,400.00
Girder 3 Exterior	W	21	44	28	2	2.464	LF	87.5	$ 24,500.00
							TOTAL COST		$ 1,992,735.00

Typical Roof										
RBeam 1 Interior	W	16	31	35	23	24.955	LF	63.5	$	51,117.50
RGirder 1 Interior	W	18	35	22	2	1.54	LF	72.0	$	3,168.00
RBeam 1 Exterior	W	16	26	35	3	2.73	LF	53.0	$	5,565.00
RGirder 1 Exterior	W	18	35	22	2	1.54	LF	72.0	$	3,168.00
RBeam 2 Interior	W	18	46	40	22	40.48	LF	92.0	$	80,960.00
RGirder 2 Interior	W	21	44	22	6	5.808	LF	87.5	$	11,550.00
RGirder 2 Exterior	W	16	31	22	6	4.092	LF	63.5	$	8,382.00
RBeam 2 Small	W	12	14	5	4	0.28	LF	32.0	$	640.00
RBeam 3 Interior	W	18	35	35	12	14.7	LF	72.0	$	30,240.00
RGirder 3 Interior	W	21	53	28	2	2.968	LF	100.0	$	5,600.00
RGirder 3 Exterior	W	21	44	28	2	2.464	LF	87.5	$	4,900.00
							TOTAL COST		$	205,290.50
Odeum Roof										
Ext RBeam	W	12	14	22	8	2.464	LF	32.0	$	5,632.00
RBeam 2 Small	W	12	14	5	4	0.28	LF	32.0	$	640.00
							TOTAL COST		$	6,272.00
Columns										
Col 3 (Int2) Base	W	14	132	24.083	2	6.357912	LF	236.0	$	11,367.18
Col 3 (Int2) Top	W	12	87	38.917	2	6.771558	LF	167.0	$	12,998.28
Col 3 (Int3) Base	W	12	120	24.083	2	5.77992	LF	220.0	$	10,596.52
Col 3 (Int3) Top	W	12	72	35.917	2	5.172048	LF	140.0	$	10,056.76
TOTAL					8	24.081438	**TOTAL COST**		$	45,018.73

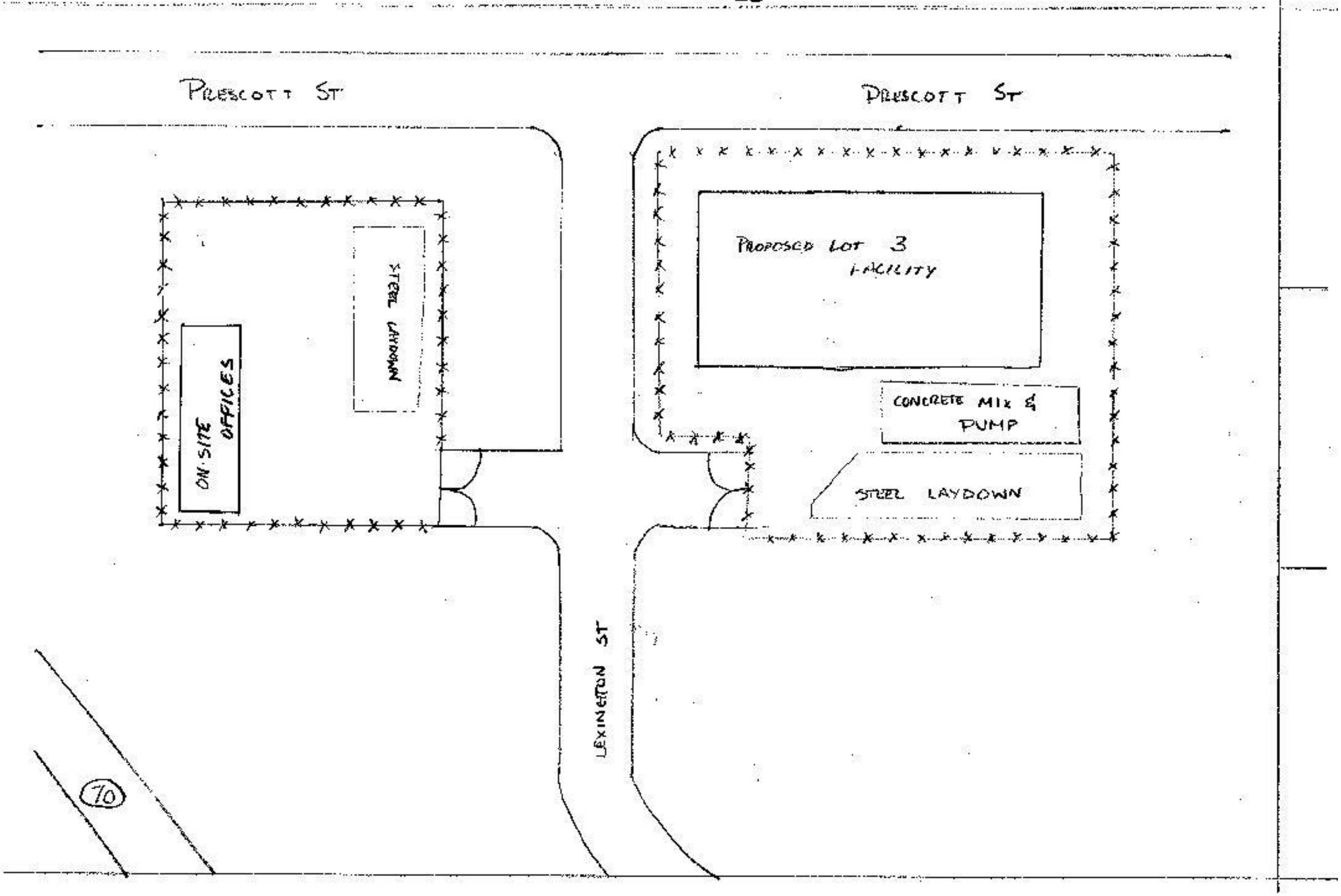
JOIST GIRDERS	G	N	F	PLF	LENGTH	# MEMBERS	TOTAL WEIGHT (kips)	UNIT	PRICE	TOTAL
								TAKE OFF		
Joist Girder 1	36	7	48	105	35	3	11.025	TON	2600	$ 14,332.50
Joist Girder 2	36	7	48	105	35	3	11.025	TON	2600	$ 14,332.50
								TOTAL COST		$ 28,665.00

Long Span Joist - LH Series	DEPTH	PLF	LENGTH	# MEMBERS	TOTAL WEIGHT (kips)	UNIT	PRICE	TOTAL
Odeum Joist 1	48	42	88	20	73.92	LF	56	$ 98,560.00
Odeum Joist 2	36	30	66	2	3.96	LF	42	$ 5,544.00
						TOTAL COST		$ 104,104.00

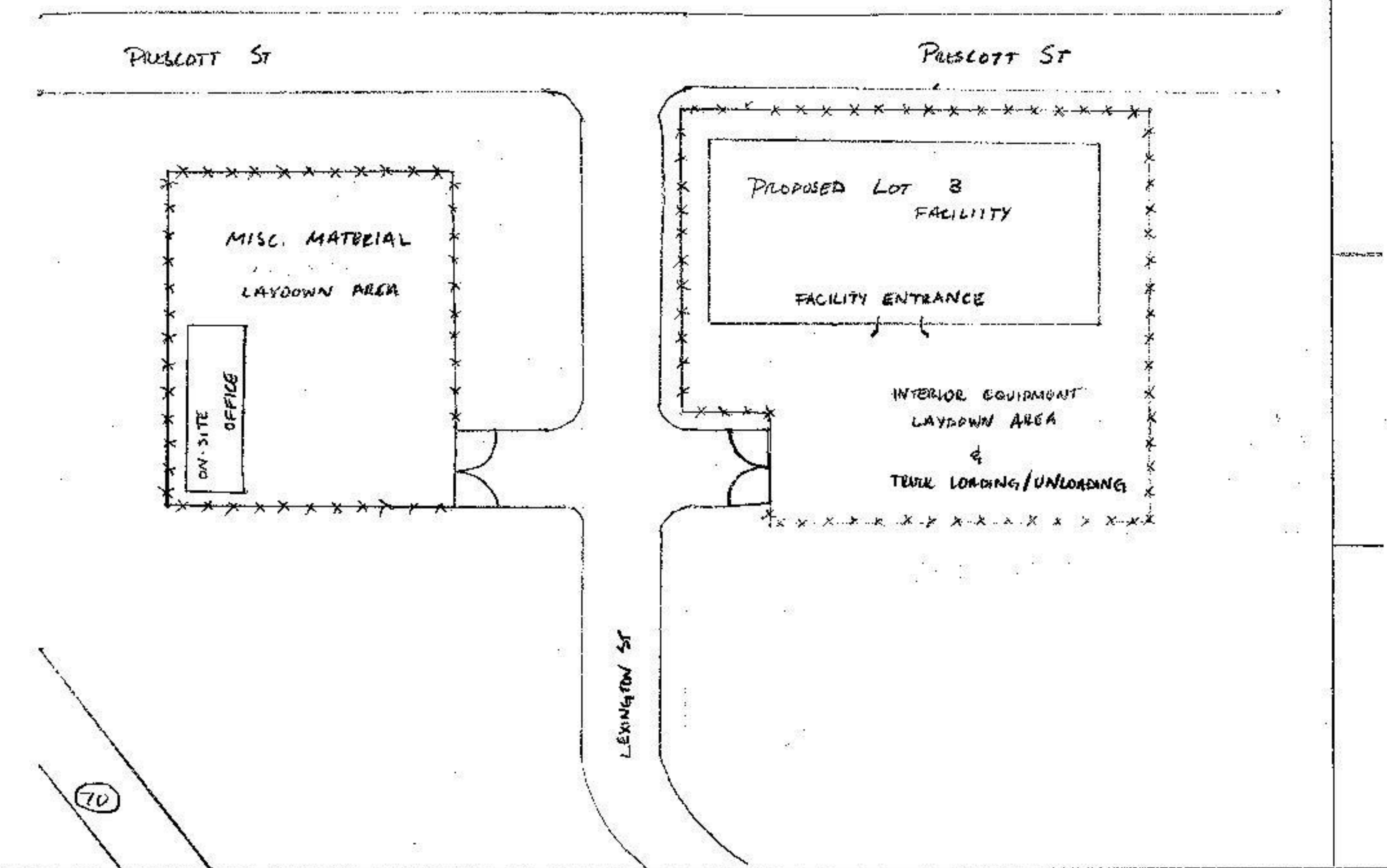
10.9 Construction Plan Sketches

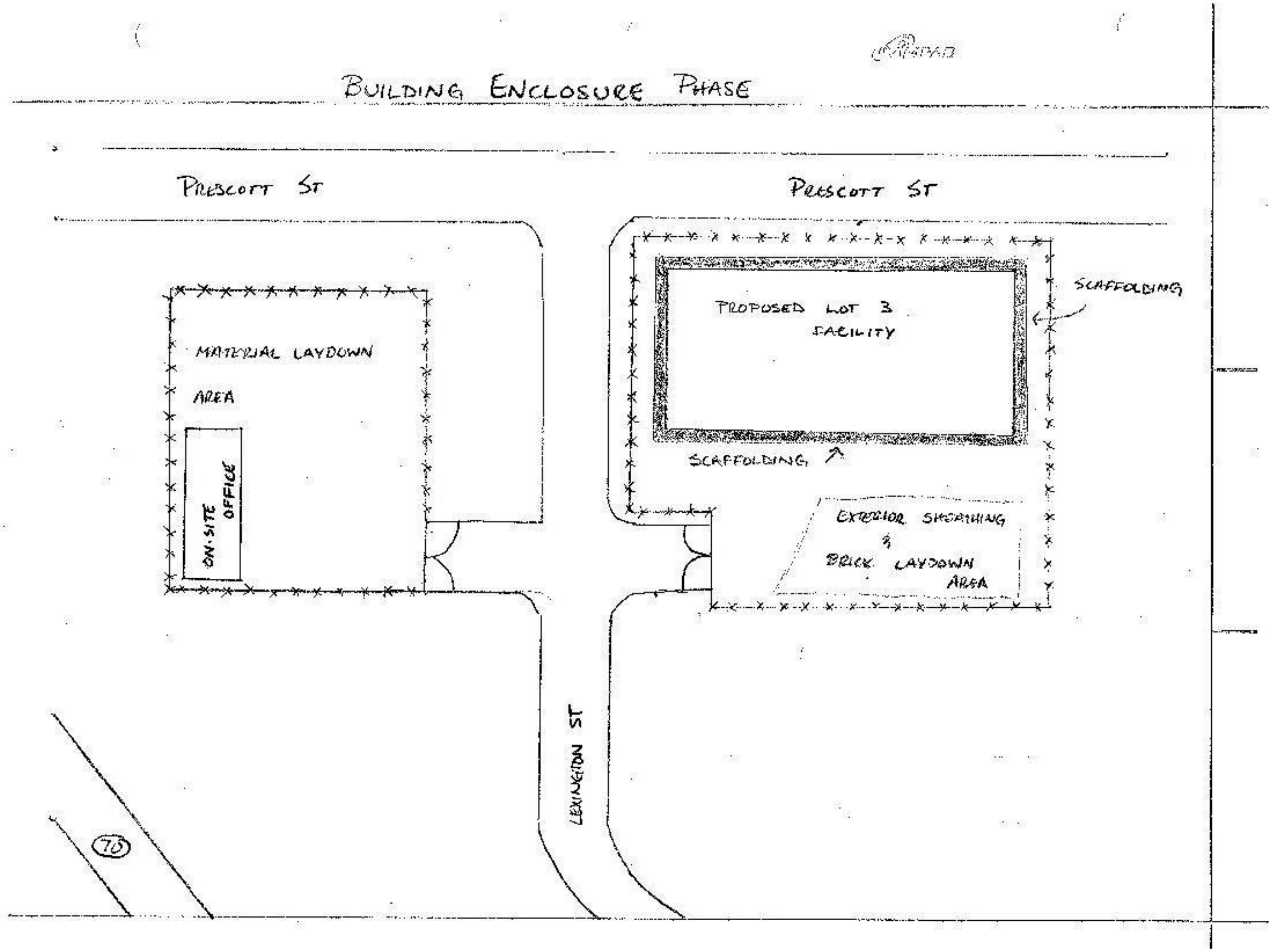


STRUCTURAL PHASE



INTERIOR FIT-OUT PHASE





BUILDING ENCLOSURE PHASE
PRESCOTT ST
PRESCOTT ST
MATERIAL LAYDOWN AREA
ON-SITE OFFICE
PROPOSED LOT 3 FACILITY
SCAFFOLDING
SCAFFOLDING
EXTERIOR SHEATHING & BRICK LAYDOWN AREA
LEXINGTON ST
70

10.10 LEED Certification Checklist

Y	N	?			Points
			LEED 2009 for New Construction and Major Renovation		
			Project Checklist		
			Gateway Mixed Use Facility		
			17-Dec-09		
17	0	0	Sustainable Sites	Possible Points:	26
Y	N	?			
Y			Prereq 1	Construction Activity Pollution Prevention	
1			Credit 1	Site Selection	1
1			Credit 2	Development Density and Community Connectivity	5
1			Credit 3	Brownfield Redevelopment	1
6			Credit 4.1	Alternative Transportation—Public Transportation Access	6
			Credit 4.2	Alternative Transportation—Bicycle Storage and Changing Rooms	1
3			Credit 4.3	Alternative Transportation—Low-Emitting and Fuel-Efficient Vehicles	3
2			Credit 4.4	Alternative Transportation—Parking Capacity	2
			Credit 5.1	Site Development—Protect or Restore Habitat	1
1			Credit 5.2	Site Development—Maximize Open Space	1
1			Credit 6.1	Stormwater Design—Quantity Control	1
			Credit 6.2	Stormwater Design—Quality Control	1
			Credit 7.1	Heat Island Effect—Non-roof	1
1			Credit 7.2	Heat Island Effect—Roof	1
			Credit 8	Light Pollution Reduction	1
4	0	0	Water Efficiency	Possible Points:	10
Y			Prereq 1	Water Use Reduction—20% Reduction	
2			Credit 1	Water Efficient Landscaping	2 to 4
				Reduce by 50%	2
				No Potable Water Use or Irrigation	4
			Credit 2	Innovative Wastewater Technologies	2
2			Credit 3	Water Use Reduction	2 to 4
				Reduce by 30%	2
				Reduce by 35%	3
				Reduce by 40%	4

10	0	0	Energy and Atmosphere		Possible Points:	35
Y			Prereq 1	Fundamental Commissioning of Building Energy Systems		
Y			Prereq 2	Minimum Energy Performance		
Y			Prereq 3	Fundamental Refrigerant Management		
8			Credit 1	Optimize Energy Performance		1 to 19
					Improve by 12% for New Buildings or 8% for Existing Building Renovations	1
					Improve by 14% for New Buildings or 10% for Existing Building Renovations	2
					Improve by 16% for New Buildings or 12% for Existing Building Renovations	3
					Improve by 18% for New Buildings or 14% for Existing Building Renovations	4
					Improve by 20% for New Buildings or 16% for Existing Building Renovations	5
					Improve by 22% for New Buildings or 18% for Existing Building Renovations	6
					Improve by 24% for New Buildings or 20% for Existing Building Renovations	7
				X	Improve by 26% for New Buildings or 22% for Existing Building Renovations	8
					Improve by 28% for New Buildings or 24% for Existing Building Renovations	9
					Improve by 30% for New Buildings or 26% for Existing Building Renovations	10
					Improve by 32% for New Buildings or 28% for Existing Building Renovations	11
					Improve by 34% for New Buildings or 30% for Existing Building Renovations	12
					Improve by 36% for New Buildings or 32% for Existing Building Renovations	13
					Improve by 38% for New Buildings or 34% for Existing Building Renovations	14
					Improve by 40% for New Buildings or 36% for Existing Building Renovations	15
					Improve by 42% for New Buildings or 38% for Existing Building Renovations	16
					Improve by 44% for New Buildings or 40% for Existing Building Renovations	17
					Improve by 46% for New Buildings or 42% for Existing Building Renovations	18
					Improve by 48%+ for New Buildings or 44%+ for Existing Building Renovatio	19
			Credit 2	On-Site Renewable Energy		1 to 7
					1% Renewable Energy	1
					3% Renewable Energy	2
					5% Renewable Energy	3
					7% Renewable Energy	4
					9% Renewable Energy	5
					11% Renewable Energy	6
					13% Renewable Energy	7
			Credit 3	Enhanced Commissioning		2
2			Credit 4	Enhanced Refrigerant Management		2
			Credit 5	Measurement and Verification		3
			Credit 6	Green Power		2

9	0	0	Materials and Resources		Possible Points: 14
Y			Prereq 1	Storage and Collection of Recyclables	
			Credit 1.1	Building Reuse—Maintain Existing Walls, Floors, and Roof	1 to 3
				Reuse 55%	1
				Reuse 75%	2
				Reuse 95%	3
			Credit 1.2	Building Reuse—Maintain 50% of Interior Non-Structural Elements	1
2			Credit 2	Construction Waste Management	1 to 2
				50% Recycled or Salvaged	1
				75% Recycled or Salvaged	2
2			Credit 3	Materials Reuse	1 to 2
				Reuse 5%	1
				Reuse 10%	2
2			Credit 4	Recycled Content	1 to 2
				10% of Content	1
				20% of Content	2
2			Credit 5	Regional Materials	1 to 2
				10% of Materials	1
				20% of Materials	2
			Credit 6	Rapidly Renewable Materials	1
1			Credit 7	Certified Wood	1

10	0	0	Indoor Environmental Quality		Possible Points: 15
Y			Prereq 1	Minimum Indoor Air Quality Performance	
Y			Prereq 2	Environmental Tobacco Smoke (ETS) Control	
			Credit 1	Outdoor Air Delivery Monitoring	1
1			Credit 2	Increased Ventilation	1
1			Credit 3.1	Construction IAQ Management Plan—During Construction	1
			Credit 3.2	Construction IAQ Management Plan—Before Occupancy	1
1			Credit 4.1	Low-Emitting Materials—Adhesives and Sealants	1
1			Credit 4.2	Low-Emitting Materials—Paints and Coatings	1
1			Credit 4.3	Low-Emitting Materials—Flooring Systems	1
			Credit 4.4	Low-Emitting Materials—Composite Wood and Agrifiber Products	1
1			Credit 5	Indoor Chemical and Pollutant Source Control	1
1			Credit 6.1	Controllability of Systems—Lighting	1
1			Credit 6.2	Controllability of Systems—Thermal Comfort	1
1			Credit 7.1	Thermal Comfort—Design	1
			Credit 7.2	Thermal Comfort—Verification	1
1			Credit 8.1	Daylight and Views—Daylight	1
			Credit 8.2	Daylight and Views—Views	1

1	0	0	**Innovation and Design Process**	Possible Points:	6
			Credit 1.1	Innovation in Design: Specific Title	1
			Credit 1.2	Innovation in Design: Specific Title	1
			Credit 1.3	Innovation in Design: Specific Title	1
			Credit 1.4	Innovation in Design: Specific Title	1
			Credit 1.5	Innovation in Design: Specific Title	1
1			Credit 2	LEED Accredited Professional	1
0	0	0	**Regional Priority Credits**	Possible Points:	4
			Credit 1.1	Regional Priority: Specific Credit	1
			Credit 1.2	Regional Priority: Specific Credit	1
			Credit 1.3	Regional Priority: Specific Credit	1
			Credit 1.4	Regional Priority: Specific Credit	1
51	0	0	**Total**	Possible Points:	110

Certified 40 to 49 points Silver 50 to 59 points Gold 60 to 79 points Platinum 80 to 110