Project Number: LDA 0803

DESIGN OF WPI GRADUATE STUDENT HOUSING FOR GATEWAY PARK

A Major Qualifying Project

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

in Civil Engineering

by

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Abstract

This project investigated, designed, and analyzed a proposed graduate residence hall as part of the Gateway Park expansion at Worcester Polytechnic Institute. After a brief comparison of concrete and steel superstructures, a final design was completed. This information was used to develop a foundation system to distribute loading. A cost analysis and schedule were also developed. The project was the broken down into additional areas of interest with further studies in underground parking, site development, and LEED implications.

Capstone Design Statement

In accordance with the ABET General Criterion for capstone design, this Major Qualifying Project has incorporated seven realistic constraints based on a culmination of knowledge gained from previous coursework and exploration of new studies as appropriate. The specific constraints are economic, environmental, sustainability, constructability, health and safety, social, and political. Each constraint is briefly discussed below.

Economic

Group members developed their previous understanding of construction economics by exploring the cost analysis of the designed features of the graduate housing facility. Additionally, cost implications of alternative measures were explored when possible. Cost comparisons of the facility were made with buildings of similar size and purpose to provide an understanding of scale and what appropriate values might be in a real-life design scenario.

Environmental

One of the growing concerns in the modern era, a storm water management system was explored, key to protecting the area from the effects of excess runoff. This plan is usually required by local and state environmental commissions.

Sustainability

As cited in the report, mixed-use facilities are believed to be more sustainable structures because there is more flexibility for later use of the space if there is a deviation from the original purpose. Additionally, this project reclaims a former brown field to use with the financial assistance of the United Stated Environmental Protection Agency. Previously unusable land was brought back to being a functional downtown property. In one instance, the LEED initiatives addressing reuse of water and creative uses of storm water were discussed as well as the adoption of how green building concepts could potentially benefit the building and the environment.

Constructability

In all possible instances the designers chose construction materials that were of a standard size or developed a plan that allowed for maximum repeatability. An example of this is the depth of the foundations, where nearly all spread footings are even at four feet below the finished grade, which enables uniform excavation across the site. Additionally, standard member sizes were defined for the proposed construction alternatives in structural steel and reinforced concrete construction.

Health and Safety

Health and Safety considerations were met through the application of appropriate building code provisions. Structural design and emergency egress were two areas which were governed by the International Building Code of 2006.

Social

Residential and commercial services as well as design layouts were developed from explorations of other national institutions and applied to the project. The premise of the selected type of facility the project was based upon what would make a WPI resident's life easier while living away from the main campus. Its location, interior design, and preservation of green space all encourage more human interaction. The proximity to other businesses as well as labs and classes encourage city residents and employees to engage more in the community on a street to street level. Additionally, the building serves both the public as well as rent-paying private graduate student residents of WPI.

Political

An understanding of the political effects of the project was realized by two aspects. One was through communications with one of the initial contacts of the project who noted that this project's inception could potentially be used by the University to showcase to the Worcester community that WPI's intentions are to keep and develop the land with the economic viability of WPI and the City in mind. Additionally, the requirements of the Zoning Ordinances of the City of Worcester were significant in developing both initial and final designs and layouts. Review of the Zoning Ordinances raised our awareness for the need to gain approval by a citizen-run City Planning Board as well as to obtain the proper permits from the City. Another political implication relates to the sustainability as the site would not be available if not for the help of local, state, and government officials and agencies.

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- Professor L. Albano

Authorship

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

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1 Introduction

In the fall of 1927, Sanford Riley Hall opened as the first residence hall on the Worcester Polytechnic Institute Campus (Tymeson, 1965). It housed a hundred and fifteen students and included amenities such as a dining facility and laundry service. The hall finally allowed WPI students to have a place to sleep, eat, and live that was within a short walk from their classes and research.

The WPI campus has grown significantly since 1927, both in space and population, but the need for student housing near academic areas still remains. The university currently only guarantees housing to first-year students, with many upperclassmen and all graduate students looking for off-campus apartments. One specific area of concern is WPI's newly opened Life Sciences Research Laboratory at Gateway Park, which is located east of the main campus near Interstate 290 on Prescott Street. Here, WPI graduate students work alongside faculty in cutting-edge laboratories. Yet, these students require nearby housing or face commuting from elsewhere since the main campus does not specifically offer living space for graduates. Therefore, as part of the Gateway Park Development Plan, the University has allotted space for graduate student housing near WPI's new research facility.

It was the task of the project team to develop a preliminary design for a mixed-use facility that would include retail space along with apartment-style residences for graduate students in the Gateway Park District. Engineering design included aspects such as conceptual building layout, structure frame design, and building foundation design. A cost estimate for the facility's construction was also created to give a preliminary dollar value to the project. Additionally, a preliminary construction plan and schedule based on major milestones was furnished to predict the duration of the project. Site and utility planning was also studied along with an alternative underground parking option for the facility. Lastly, LEED certification requirements were investigated with construction options and recommendations for the building outlined by the team.

However, before various design steps could begin, research was conducted on the Gateway Park District and the site of the proposed graduate housing. Background information was also compiled on residential halls at WPI and at other schools in order to compare current facilities at the University and gain awareness of trends for recent building projects at colleges. Zoning restrictions and building standards to be used for design were also researched as part of the background study. A methodology was then given of how the team approached and tackled the design of the building and its related components. Finally, the results of design calculations and study were compiled along with recommendations and conclusions by the team in order to give a finished picture of the facility.

Overall, as a capstone design experience, the project allowed the team to incorporate knowledge obtained from previous course work and industry standards but also to tackle real world constraints that are placed on projects such as economic; environmental; sustainability; manufacturability; ethical; health and safety; social; and political issues. Therefore, the mission of the project was twofold. First, capstone design criteria set for the project were met by synthesizing research and analysis with standard and realistic constraints in order to obtain a best fit solution for the site. Second, the project was aimed at creating a baseline concept for development of the site. It is the hope of the project team that this baseline can be used by the WPI administration as a promotional and planning tool when the graduate housing is actually designed for the next phase of the Gateway Park Development Plan.

2 Background

It is imperative upon any engineer that he or she understands both the technical and non-technical issues associated with project design. In many cases, implications and design parameters to technical issues arise from non-technical parameters that may not be initially known by the engineers of the project. These non-technical areas encompass such concerns as zoning, past history of the site, and a study of client needs. Without a study of such areas, the technical design could prove inadequate due to a lack of consideration of an unknown issue. In practice, this can often lead to rework, delay of construction, and increased costs. Therefore, the background study served to investigate the underlying issues that surround the history and non-technical understanding of a number of areas to provide insight into what the design of a proposed graduate residence hall would entail.

2.1 Gateway Park

On September 17, 2007, Worcester Polytechnic Institute (WPI) and the Worcester Business Development Corporation (WBDC) officially opened the new WPI Life Sciences and Bioengineering Center at Gateway Park. WPI President Dennis D. Berkey spoke of the new facility as playing “a vital role in Worcester’s economic development and in WPI’s ability to make a difference in the world” (WPI, September 17, 2007). However, this new research facility is only the first step in the larger redevelopment of the Gateway Park District. The Gateway Park Development Plan incorporates space for cutting edge research, commercial facilities for life science companies, and residential units for the employees and scientists who will work there. Its goal is to create a vibrant research community while also revitalizing the area as part of a new downtown Worcester.

2.1.1 History of Gateway Park

During the Industrial Revolution and throughout the 20th century, Worcester was and has been known as a manufacturing center, with many products and goods originating from this city in Central Massachusetts. The area of Gateway Park was once full of manufacturing facilities with the most historic being the Northworks of the Washburn and Moen Manufacturing Company, a leader in the production of piano and steel wire (Tymeson 1965). Even though the structure still stands today, much of the manufacturing has left the area with many of the old buildings gone. However, while many buildings are gone, the chemical contamination caused by the manufacturing processes once located here remains in the underlying soil. Therefore, much of the area has been designated as a brownfield. The development of Gateway Park hopes to bring new life into the area.

2.1.2 Current Facility at Gateway Park

Gateway Park is a developing, twelve-acre mixed-use destination for life sciences and biotech companies as a partnership between Worcester Polytechnic Institute and the Worcester Business Development Corporation. The WBDC is a non-profit business organization who serves as a leading innovator in economic development throughout Worcester, resulting in job creation and tax based expansion (About WBDC, 2005). The current development plan includes five life sciences buildings with 500,000 square feet (sf) of lab space, 241,000 sf of condominiums, several retail establishments, a parking garage, and possibly graduate housing. These buildings are expected to have an affordable rent of $20-30 per square foot to compete with higher priced bioengineering space currently in Cambridge, Massachusetts and promote the industry in Worcester (Gateway Park Facts and Figures, 2007). The park will also include a parking garage for 680 cars and approximately 980 additional parking spaces spread throughout the area. Furthermore, Gateway Park is a small part of the larger

55-acre Gateway Redevelopment District that will encompass businesses, restaurants, offices, and a Marriott Hotel.

The first building constructed at Gateway was the WPI Life Sciences and Bioengineering Center. A forty million dollar project that WPI will use for graduate education and research in the life sciences, the structure is a combination of a renovated industrial building that is connected to a new state-of-the-art lab facility with a green courtyard in the middle. The new building is a four-story lab facility that will be used for research in wet life sciences, regenerative medicine, molecular nanotechnology, biosensors, plant systems, tissue engineering, and un-tethered healthcare (WPI Life Sciences and Bioengineering Center, 2007). The lab rooms are flexible as they can be adapted to fit the biotech industry's changing research needs. The renovated industrial building will be used for faculty offices, meeting rooms, and other amenities. The offices will house administrative and academic departments such as the WPI Corporate and Professional Education Department and the WPI Bioengineering Institute. The WPI Bioengineering Institute is a research center for biology, biotechnology, biomedical engineering, chemistry, biochemistry, and chemical engineering. This building will also have space for some businesses and commercial tenants along with Massachusetts Biomedical Initiatives, an organization that promotes the startup of biomedical companies.

The main goal of Gateway Park is to develop leading–edge research programs and foster the growth of life science, biotechnology, and bio/chemical engineering. It will develop central Massachusetts as a center for the growing life science industry. The park will serve as a destination for many large and small companies and establish a transfer of technology and knowledge between the commercial sector and WPI. Life science companies and university researchers will always have a need for each other. Life science companies need the discoveries made in research labs while the university needs the monetary investments, employment opportunities and commercial perspective that will benefit students. Therefore, Gateway Park strives to strengthen the connection between industry and academia by creating a common meeting space and research district.

Figure 1: Side View of the Main and First Constructed Building at 60-68 Prescott Street

One of Gateway Park's advantages is that it is in close proximity to other researchers and companies. Prior to Gateway Park there was a shortage of affordable laboratory space in the area. In 2005 Worcester had only nine percent of its 328,000 sf of lab space vacant, leaving no space for a company to grow (Space Race, 2006). Cambridge has always been a center for life sciences with seven million square feet of lab space and access to Harvard and the Massachusetts Institute of Technology. (Space Race, 2006) Therefore, any increase in lab space in Central Massachusetts will not only offer companies a new option but help to break the monopoly that Cambridge has on the life sciences research industry in Massachusetts. Another reason why companies are now considering Worcester as their location is because of the lease rates for laboratory space. In 2006 the cost per square foot of lab space in Cambridge and Boston ranged from $45-75 while it was about $25 in the suburbs and Worcester (Space Race, 2006).

2.1.3 Further Master Plan for Gateway Park

As stated previously, the ultimate goal of Gateway Park is to reinvigorate the area of Prescott and Grove Streets in Worcester by creating a new district for the life sciences research industry near downtown Worcester. The WPI Life Sciences and Bioengineering Center and parking garage are only the first phase of a larger redevelopment plan. The Gateway Park redevelopment plan encompasses 55 acres of current, remodeled, and new structures that stretch from Lincoln square in the south to the old Northworks building in the north (Hurd, September 2007). Figure 2 is the architect Carole Schlessinger's rendition of the finished layout of Gateway Park. The redevelopment will include three other phases: the remodeling of the old Worcester Vocational School building into luxury condominiums; the construction of three commercial facilities to house a total of 320,000 square feet of space for life science companies; and the construction of roughly 87,000 square feet of space for retail and graduate housing. It is this last phase of retail space and graduate housing that the project team will strive to research and develop to form a baseline for the University.

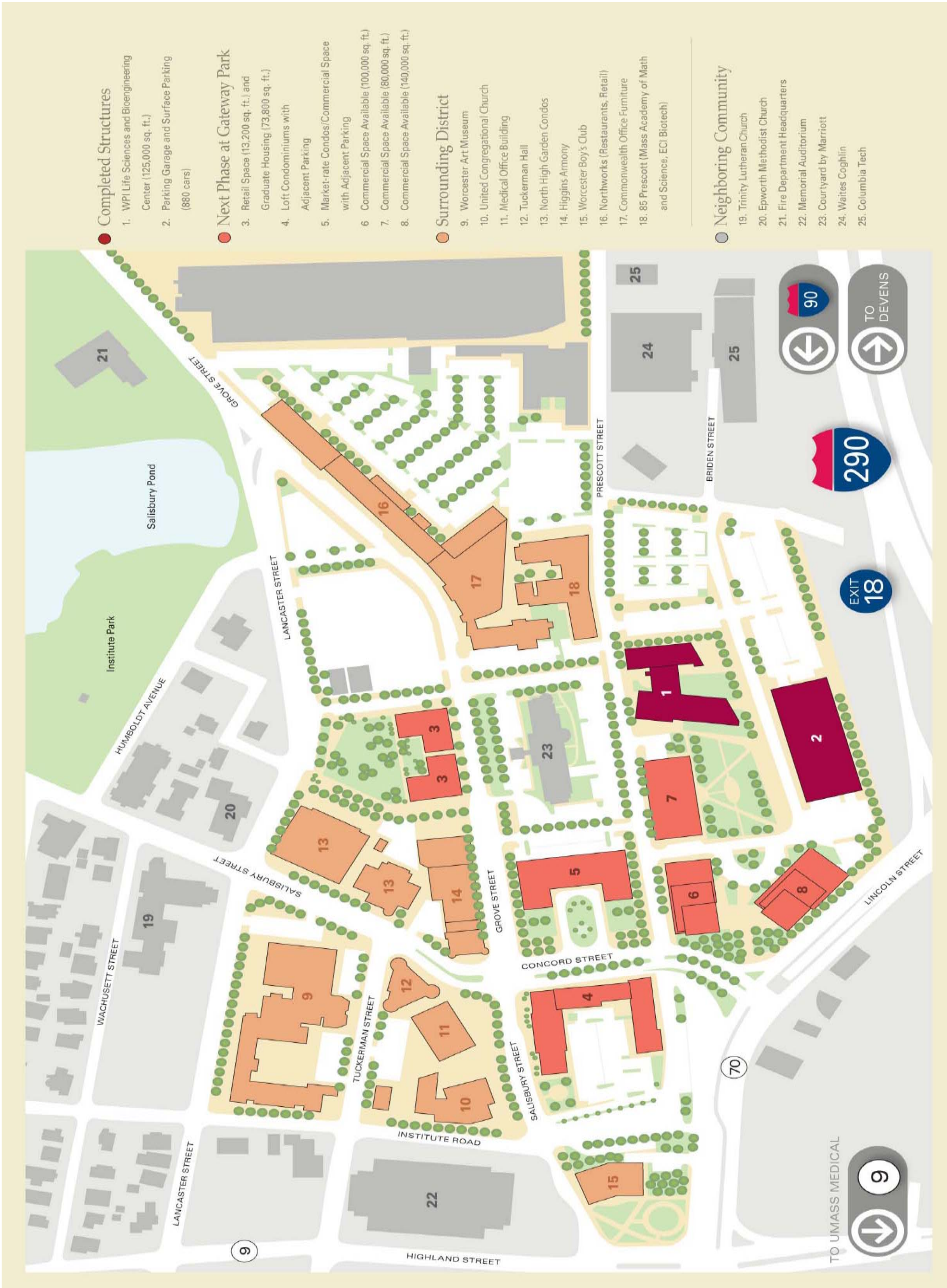

Figure 2: Architect's Rendering of Anticipated Final Layout of Gateway Park
(Courtesy of CSS, Crosby Schlessinger Smallridge Architecture)

2.1.4 Graduate Housing at Gateway Park

The Gateway Redevelopment Plan calls for graduate housing for WPI to be placed on an empty lot located west of the current Life Sciences and Bioengineering Center, which is designated in Figure 2 on the previous page as area three.. Therefore, one of the first tasks of the project team was to research the history of the site along with the services and amenities expected to be provided in the new building.

2.2 Campus Residential Halls Around Worcester

Worcester, known as the “Heart of the Commonwealth” among local residents and businesses, is also host to ten universities and colleges, nine of which offer housing. Housing availability and options were investigated both on campus and throughout the city’s collegiate community. This investigation was conducted in order to study any trends and alternatives in the types of amenities, layouts, and spaces found in new residential halls at other campuses.

2.2.1 Current Student Housing on the WPI Campus

As WPI continues its growth and expansion, the need for additional student housing is becoming more and more urgent. Currently, WPI offers twelve residence halls on or near campus that range from traditional dormitory room halls, to apartment-style residences, to WPI-owned off-campus apartments. The Institute guarantees housing to first-year students; therefore, five of the six largest halls, with a total capacity of 751 students, are reserved for incoming freshman. The remaining residences encompass three apartment-style housing complexes for upperclassmen and four WPI-owned houses in the immediate area of campus (WPI Office of Residential Services, October 2007). In total these seven complexes can house 475 students, yet only 449 of that number are specifically reserved for upperclassmen. The four main residence halls for upperclassmen out of these seven complexes include Founders Hall, Fuller Apartments, Ellsworth Apartments, 26 Hackfield House, and 25 Trowbridge House.

First, the Fuller and Ellsworth Apartments are located along Institute Road between Schussler and Einhorn Roads and were completed in 1973 (Worcester Polytechnic Institute, April 2006). Fuller and Ellsworth offer two, three, five, and seven person studio and townhouse style units with a total capacity of 102 and 87 students respectively. Units include kitchens, bathrooms, and bedrooms with two to three beds each. The apartments offer telephone, cable, and Internet access but are not handicap accessible. Coin-operated laundry machines are located in the basement of Ellsworth.

Next, 26 Hackfield House and 25 Trowbridge House are both homes owned by WPI in the immediate area on Hackfield Street and Trowbridge Street respectively. Combined, they accommodate twenty eight students with rooms that include singles, doubles, and triples. Residents have a common kitchen; coin-operated laundry machines; and services such as cable, phone, and Internet (WPI Office of Residential Services, October 2007). However, these homes are also not handicap accessible.

Finally, Founders Hall is the most recent WPI residential hall located on Boynton Street. Completed in 1985 for a total cost of seven million dollars, the four-story building offers upperclassmen apartment units that house four to six people (Worcester Polytechnic Institute, April 2006). Units include a common area along with single and double bedrooms. These apartments do not have kitchens but a newly renovated campus restaurant and convenience store can be found on the ground floor. The hall is handicap accessible with elevators, has coin-operated laundry machines on the basement level, and offers conference rooms and study lounges. (WPI Office of Residential Services, July 2007). The hall also houses the WPI Campus Police Headquarters.

Overall, due to the age of current residential halls and the increasing number of undergraduate students on campus, the need for upperclassmen housing is a major concern for WPI. This is being alleviated somewhat by the construction of a new residence hall adjacent to the Founders Hall complex. However, the need for graduate student housing at Gateway Park is still a concern that has yet to be solved by WPI.

2.2.2 New Residential Hall at WPI

The University is striving to solve the problem of student housing with new facilities. In April of 2007, WPI broke ground and announced the construction of a new upperclassmen residential hall, located between Boynton and Dean Streets and adjacent to Founders Hall. Ultimately, this residential hall offers the project team with an example of the type of structure that WPI is looking at for upperclassman students which can correlate to graduate students. Therefore, this project can be used as a potential design example for the housing at Gateway Park.

The four-story building, which will open in the Fall of 2008, will offer apartment-style units with a total building capacity of 232 students (Worcester Polytechnic Institute, April 2007). Apartment units will house four people with single or double bedrooms. A full-kitchen, living space, and compartmentalized bathroom will also be included in each unit. The building will offer amenities such as air conditioning, health and fitness space, conference rooms for project groups, and wireless Internet. A 189-space parking garage is also included as part of the complex. Vice President of Student Affairs and Campus Life Janet Richardson states that the “building is designed specifically with the students’ needs and expectations in mind, including their desire for privacy, independence, safety, and security…With its technology suites and wireless access, the facility is also well suited for meeting their academic requirements and responsibilities, particularly those related to their required project work" (Worcester Polytechnic Institute, April 2007). The building will also house the new offices for the Director of Residence Life.

One of the important features of the new residential building is that it will strive to obtain a silver rating through the Leadership in Energy and Environmental Design (LEED) Green Building Rating System. For example, demolition and construction waste for the site has been reused and recycled as much as possible; natural lighting will be maximized throughout the structure to reduce energy consumption; and energy efficient equipment such as boilers will be used in the outfit of the building.

Overall, the university hopes the new residence hall will bring upperclassmen students back on-campus with more campus housing and also create a new vibrant campus community on Boynton Street. Additionally, the style and design of the new WPI facility matches those designed and constructed for other Worcester-area universities.

2.2.3 Recent Housing Projects at Other Worcester Colleges

As the needs and the desires of college upperclassmen have changed over recent years, so have the spaces where they live and study. Other Worcester-area colleges, such as The College of the Holy Cross, Clark University, and Worcester State College, have begun to accommodate their upperclassmen students with more, up to date, apartment-style housing facilities.

The College of the Holy Cross completed its newest residential hall in 2003. The Apartment Building is a five story, 85,000 square foot facility that accommodates 244 seniors in 61 apartment units (College of the Holy Cross, 2007). Living units house four students in two double bedrooms. A compartmentalized bathroom is included along with a living room and kitchen. The kitchen offers amenities such as a garbage disposal and dishwasher. Laundry is located on the ground floor, and a study area can be found on each floor. Last, the facility offers a function room on the ground level that can be used by faculty, staff, and students.

Clark University has also expanded its apartment-style housing for upperclassmen with the completion of Blackstone Hall for the 2007-2008 academic year. The facility accommodates 208 people with apartment capacity ranging from four to six students (Clark University, 2008). The exterior design of the building has a modern style and includes green space as part of the lot. Four person units contain single bedrooms, while six person units include both single and double bedrooms. Like apartments in other college facilities, units have compartmentalized bathrooms, living spaces, and kitchens. Amenities in each unit include air conditioning, wireless Internet, and dishwashers; the facility also boasts study and lounge spaces for residents. These apartments are available to junior and senior students with a limited number available to graduate students.

Last, Worcester State College constructed a major addition to their residence hall space with the completion of Wasylean Hall in August of 2004. As with other college facilities mentioned, the six-story building offers suite-style units and is able to house 348 students. Suites fit two, four, or six people and include kitchens and common living rooms. Handicap accessible, the building has recreational and study space throughout the floors (Worcester State College, 2007). On the ground level, a coffee shop and mailroom are available for residents. The Office of Residence Life and Campus Police are also located on the ground floor. Designed by ADD Inc of Boston and built by Suffolk Construction, Wasylean Hall was chosen in June of 2005 for a 2005 honor award for design excellence from the Central Massachusetts Chapter of the American Institute of Architects (Worcester State College, 2007).

2.3 Nationwide Colleges

WPI is in competition with other American universities for students wanting to further their education in engineering, science, and management. To evaluate how WPI compares to some other universities, a selection of seven institutions with graduate programs in the same areas of WPI's were investigated. A summary chart, Table 1, was made to compare the prevalence of different living options available on all of the campuses. Overall, there were six on-campus options identified in addition to finding one's own apartment off-campus.

Table 1: Summary Chart of Availability of Graduate Housing Types at Some National Institutions

School	Off Campus	Dorm Style	Apt. Style	Houses	Family	RA Option	Greek
Rensselaer	X		X	X			
Clarkson	X			X			
Columbia	X	X					
U. Massachusetts	X	X			X		
Ohio State University	X	X	X				
Northwestern	X		X		X		
MIT	X	X	X		X	X	X
Boston College	X		X		X		
WPI	X						

The selection of these schools was determined by several factors, including similarity in student population to WPI, the similarity of degree programs, and other urban universities. Additionally, several schools were chosen to explore geographical differences, an overlap of some academic areas, options available at considerably larger universities, and to look at both public and private institutions. This broad view of options was considered in order to create a more thorough search of schools that were outside of WPI's traditional competitors with the hopes that diverse ideas for additional living arrangements or services could be investigated for possible inclusion. In comparison to other institutions mentioned in Table 1, the WPI graduate body of 1000 students is generally smaller but not the smallest. RPI is comparable in size while Clarkson has only a third of the students in their graduate programs. UMass, Northwestern, MIT, and Boston College range in size from 4600 students to 6200. Northwestern and MIT both have similarly sized or larger programs in graduate versus undergraduate education. Ohio State and Columbia were both in excess of 13,300 students, though these numbers are representative of professional and medical schools in addition to general math science and engineering graduate programs.

WPI's lack of graduate housing is stark in comparison to several universities, especially technical education rival Massachusetts Institute of Technology (MIT). However, like all of the institutions surveyed, WPI does offer some assistance in finding and obtaining an off-campus apartment.

The type of facilities offered at each of the schools differs as greatly as their individual profile. Both public and private institutions are represented within a geography that covers New England, the Northeast, and parts of the Mid-West. Some universities are more prestigious than others, and size is also a varying factor. A wide selection of schools was made to try to capture a wide range of living styles that could potentially be adapted to WPI's campus.

Apartments are the most popular on-campus offering, found at five of the other eight campuses. Some universities offer several sizes and set ups of furnished apartments. Different arrangements include studio, twin studio, one bedroom, two bedrooms, and three bedrooms. A kitchen or kitchenette is always available to provide for an independent living style. All apartments contain a private bathroom and a common area. The column heading "Family" in Table 1 refers to the ability of a graduate student to live on campus in an apartment with a spouse or family, including children. This is a very limited option everywhere it is offered, but the WPI Administration has expressed an interest in having family housing at the Gateway Complex (Vice President D'Anne Hurd, September 12, 2007).

Dormitory style housing is the second most offered living arrangement for graduate students. This set up varies from campus to campus, and even among residence halls on the same campus. One arrangement is a series of single, private bedrooms in a hallway with a large shared bathroom and a common area for study and socializing. There are traditionally three different methods to solve cooking and eating needs. The first is to completely rely on a dining hall in the building or nearby. A second option is a shared kitchen space on each floor with residents responsible for their own cooking supplies. The last option is a combination of the two previous options; the dining hall is open during the week while the residence hall kitchen is utilized on the weekend.

Several options were relatively unique to a particular campus. One such option was living in a family-style house, while another campus advertised the ability to be a resident advisor. A third unique option available at MIT is living in Greek housing, even though the resident may not be an initiated member of the particular fraternity or sorority. RPI is one campus where undergraduates and graduate students may share a dining hall and building but are separated by floor. Larger residences were able to have themes, like Columbia University's International House, home to seven hundred students from over one hundred countries.

Yale University, a national institution not represented in Table 1, provides dormitory rooms of varying sizes to their graduate students in on-campus housing. Single rooms may be as small as 90sf, or as large as 250sf. The size of these rooms also depends on location within the building, which residence hall it is located in, and the type of housing, for example, if the residence is styled like a dormitory room or a studio. With an understanding of the differences in undergraduate housing options at WPI, it can be assumed that a similar variance in room sizes is common to all campuses for graduate housing.

Furnishing of an apartment is also a variable in graduate housing, even within the same housing structure. For example, only 80 percent of Columbia apartments are furnished, but all contain a refrigerator and stove (Columbia University Facilities, 2007). Additionally, the apartments are furnished generally by the number of residents; two-person apartments are more likely to be unfurnished than four-person apartments. The ability for a graduate student to have their own private bathroom is possible at some schools, including RPI.

On each university's graduate housing website, the location of the housing to the campus was touted. Yale notes proximity to the campus center and campus shuttles as reasons to live on campus. With Gateway Park housing WPI's graduate programs in Biomedical Engineering, Biology, and other life sciences, a location nearby to classes could prove to be advantageous. WPI does own some property off of the main parcel on 75 Grove St that has the potential to be developed for residential use. University of California – Irvine houses 50 percent of its graduate students, citing difficulty to find housing in a metropolitan community, easing the transition to a scholarly environment, especially for those traveling from a long distance, and the stressful and time consuming process of settling into a new place as reasons for living on campus. Noting that they are in contrast to most research institutions, UC-I guarantees housing for all newly admitted Ph.D. students.

Some MIT students (Bio99, 2000) offered insight as to their decision making process for living on or off campus. Difficulty resulted for many students because living with a significant other disqualified them from on-campus housing, while others were denied housing because of a poor spot in the housing lottery system. Independence of a “bureaucratic” housing committee was another reason many of these students chose to live off campus. Additionally, some students may want to escape campus and get away from the academic atmosphere.

2.3.1 Services offered in Graduate Housing Centers

Just as the types and availability of graduate housing facilities at each school varies greatly, the types of services available also showcases a wide array of options. Six schools, including two on the initial list for facility comparison, were investigated to explore what services are offered to graduate students who choose to live on campus. The six schools included RPI and Columbia from the first list, as well as Nova Southeastern University, Virginia Polytechnic Institute and State University (Virginia Tech), Pennsylvania State University (Penn State), and the University of Miami.

Laundry was the most prevalent service available, present in every facility. In some cases, like at RPI, a cash laundry room was present on each individual floor of a building. For institutions with more of an apartment-style living, a larger common laundry facility existed within a building for everyone’s use. Another common feature was the presence of mail facilities on-site. These were present at Virginia Tech, Penn State, and Columbia.

Access to food and cooking facilities was another service offered in graduate housing facilities. At RPI, kitchens were available for those who did not have a kitchenette in their room.

Virginia Tech's graduate facilities were located within a close proximity of several dining options, from restaurants to cafes to dining halls. Students at Virginia Tech were required to be on meal plans, though kitchen facilities are available for use. Alternatively, Nova did not require but rather suggested that graduate students have a declining balance for a meal card so that they would be able to eat while on the academic and student life centers of campus. Miami's apartment complex includes a convenience store for access to food outside of what one might make in their own kitchen. Columbia was unique in that their International House had a pub in it.

Since the purpose of the graduate students being at their respective institutions is to pursue learning at a higher level, an academic atmosphere was built into the housing. Study lounges can be found at Virginia Tech and Columbia. Additionally, Columbia also housed computer laboratories in graduate residences, as well as Miami.

Social programming and involvement with other graduate students was an interesting offering available to graduate students, somewhat reflecting the atmosphere that is fostered in freshmen residence halls. The hope is to build communities in the residences, not just people living together. This philosophy and programming is present at Virginia Tech, Penn State, and Columbia, to name a few. In addition to social programming, Columbia also encourages its residents to become involved in the neighborhood community through, among other opportunities, tutoring programs. There is also mention of a language exchange in the International House.

Parking and transportation is generally an issue for graduate students as not all graduate housing facilities are right next to the academic section of campus. To remedy this, Miami placed a stop for the shuttle bus system within the graduate housing complex to bring people to campus as well as parking facilities on-site for those who have cars.

Several universities are proud of some amenities that while possibly available on other campuses are mentioned specifically at these institutions. Penn State offers a playground for its family living option and was the only institution to mention a trash and recycling option. Columbia's International House contained a gym, fitness center, and music practice rooms within the facility.

2.4 Site at 75 Grove Street

The Gateway Park District is located off of Exit 18 from Interstate 290 West in Worcester, Massachusetts. The site of the proposed graduate housing is found at 75 Grove Street, abutting both Faraday and Lancaster Streets, as seen in Figure 1. Currently, the 72,488 square foot lot is being used minimally for excess parking by nearby establishments. To the north of the site and across Faraday Street there is a large parking lot used for nearby businesses along with an electric substation used by National Grid. The substation includes electrical transformers and a brick building. A pre-existing Marriott Courtyard Hotel is located to the east of the site, across Grove Street. To the south, the lot is bordered by The Worcester Armory and the Massachusetts Veterans Shelter, alongside the North High Garden Condominiums. Finally, the west side of the lot is bordered by Lancaster Street with residential houses across the street.

Figure 3: Site Aerial Photo as pictured in Google Maps on October 8, 2007. The red dots were added to clarify the location of 75 Grove Street.

2.4.1 History of Site

The site at 75 Grove Street was previously owned by the Logan, Swift, and Brigham Envelope Company. A first building was constructed in 1889 extending from Grove Street along Faraday Street. In 1897 the company built an additional building on the Lancaster Street side. Ten years later, the company merged with nine other envelope companies and an addition was added to the building on the south side of the existing structure. In the 1970's the company was sold to Parker Affiliates and was renovated into office space. The building was ultimately torn down in 1999 (Szela et al., 2000).

The previous owners of 75 Grove Street used the property for manufacturing so the EPA designated it as a brownfield. A brownfield is a property that may be contaminated by a potential presence of pollutants, chemicals or hazardous substances (US Environmental Protection Agency, 2007). Many of the chemicals found on the 75 Grove Street site were typical in the metal industry. Some chemicals found were polycyclic aromatic hydrocarbons that are present in coal and tar, arsenic, which is a chemical used in metal working, and thallium, which is a pollutant metal delivered from lead and zinc (Szela et al., 2000). The envelope industry located on this site was not in the category that typically released these chemicals. These chemicals most likely were the remains of manufacturing that occurred in the surrounding sites. These chemicals would prove hazardous to tenants in any future structure, and therefore a cleanup process was necessary before any new construction could begin on the site. The cleanup effort was funded by a $200,000 sub-grant from the city of Worcester. Cleanup of the site was completed in March 2006 and included the removal of contaminated soil as well as groundwater monitoring. (U.S. Environmental Protection Agency ARC Grant Announcements, 2007)

2.4.2 Soils and Geology

Contaminated soils and groundwater monitoring results define the physical landscape of the earth, a study classified as geology. Understanding the soils and geology as well as soil mechanics specifically is especially important for an engineer (Coduto, 2001).

Any building is dependent upon its foundation system for support and ultimate transfer or both gravity and lateral loading from the structure. A strong foundation system is dependent on its surround – the earth. Natural earth materials of rocks and soil, as well as the presence of groundwater, play a role in the foundation design. To better understand the underground conditions of a site, a soil analysis is conducted. In July 2005, the Maguire Group was hired to develop a soil analysis report for several parcels on the main Gateway Park project site. This report ultimately included commentary and results on the local geology, subsurface soil exploration, a soil profile, soil characteristics, and geotechnical needs for the site.

To obtain the information, the Maguire Group (2005) and Cullinan Engineering consultants developed a test system combination that included boring excavations and groundwater observation wells. A boring is a technique practiced by drilling deep into the earth to collect a sample of the soil for analytical testing while a groundwater observation well is used to monitor the level of groundwater, or water beneath the earth's surface, continuously in addition to the water pressure and water quality (Wyoming Department of Environmental Quality, 2008). The purpose of these techniques is to gain information for developing a foundation plan so that a building's load may be dispersed over a wider area than the columns can provide.

The specific program that was conducted included twenty five boring excavations, twenty of which were considered shallow, up to a depth of sixteen feet, and five which were deep, measuring up to sixty one feet below the earth's surface, ultimately finding bedrock. All testing on the site followed American Society of Testing Materials (ASTM) standards, as tests included hollow stem auger explorations. A hollow stem auger is a helical shaft used for drilling into soil (West Coast Foundations, 2003).

While no aerial view of the layout of the excavation and well placements was available, field sketches included in the report allowed for a diagram to be constructed by piecing together testing location designations, as seen in Figure 4. The orange circles designate the location of a boring excavation designated by the Maguire Group's report.

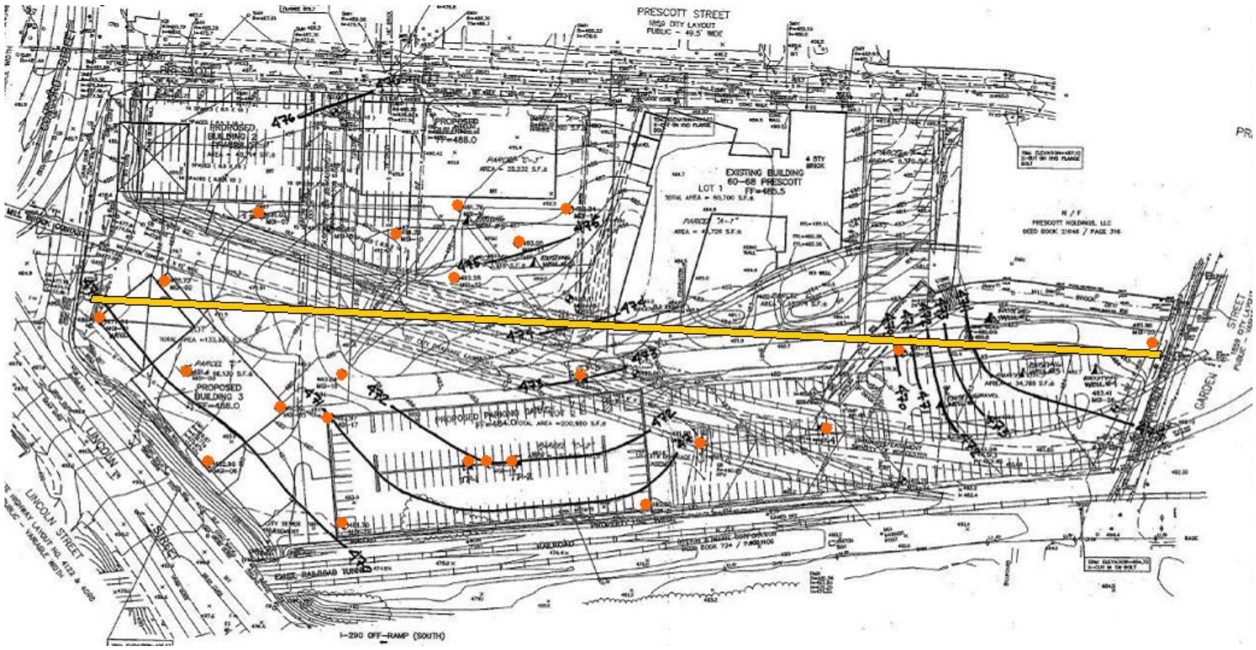

Figure 4: Assumed Boring Locations of Gateway Park Complex

To gain an understanding of the groundwater table and the type of soil that would be present on the 75 Grove Street site, a soil profile was developed as seen in Figure 5. The yellow line across Figure 4 is the line where the soil profile is estimated to be throughout the whole site. This differs from most soil profiles in a geotechnical report as those profiles typically only explore one excavation site at a time. The purpose of a soil profile is to explore the loading capabilities of the subsurface environment or the soil's ability to distribute the structure's loading without disruption.

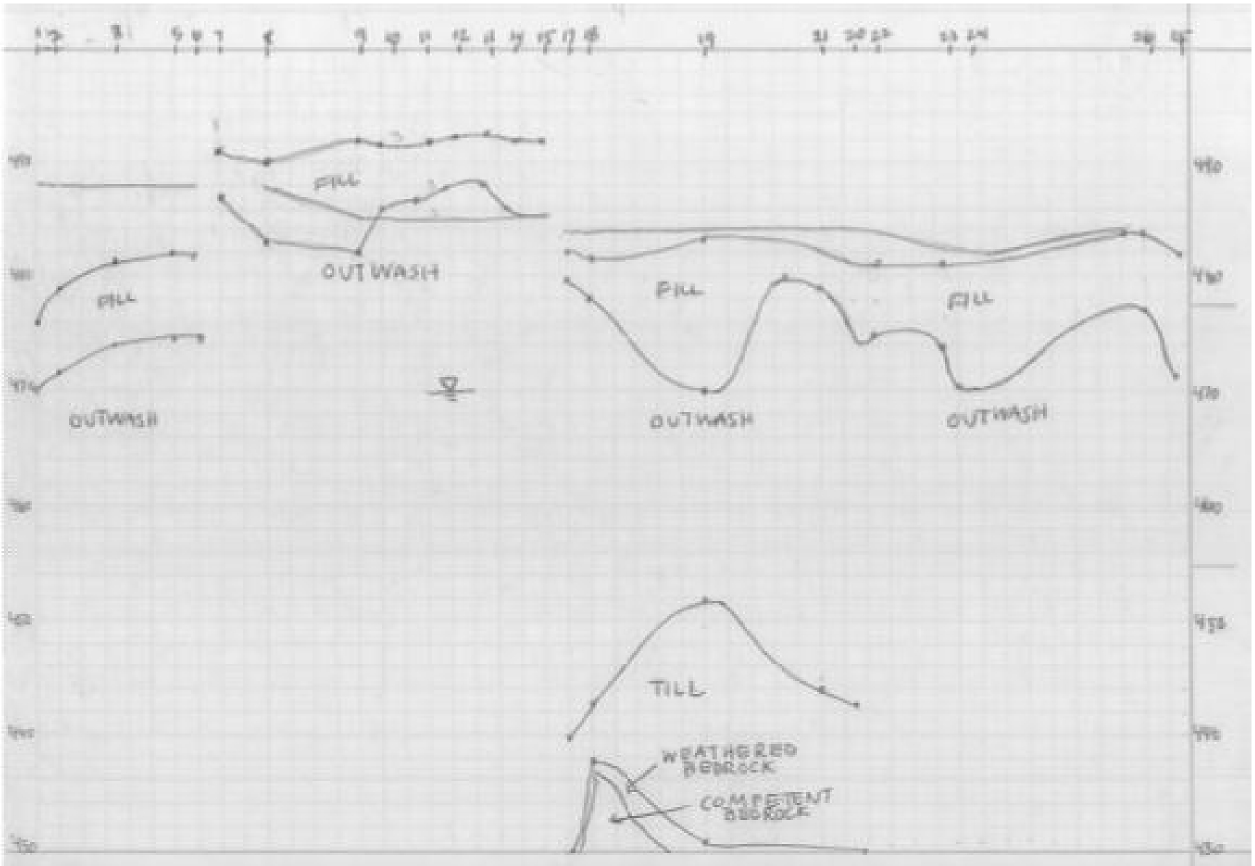

Figure 5: Soil Profile Developed from Maguire Field Reports

It is interesting to note that the groundwater level on all field sketches and the site soil profile was consistent in its elevation above sea level at 470 feet. The depth from the surface varied with the surveyed elevation. This finding is helpful because a uniform groundwater depth would be easier to apply when designing foundations for a relatively flat site, since finding all of the different values could be tedious.

Within the soil profile is displayed a rudimentary description of Gateway Park's geology. Sketches from the report provide a more detailed portrayal of the geology and soil characteristics. Table 2 provides an analysis of how the soil can be described throughout the site.

Table 2: Results of Subsurface Soil Exploration from the Maguire Report

	Color	Density	Sand Type	Average Strata Thickness (Feet)	Strata Thickness Range (Feet)	USCS Group Symbol Range
Surficial Fill Upper Level	Brown	Medium to Very	Fine to Coarse	6	3 to 10	SP, SM, SW
Surifcial Fill Lower Level	Brown	Medium to Very	Fine to Medium	8	3 to 15	SP, SM
Glacial Outwash	Brown	Medium to Very	Fine to Coarse	32	19 to 39	SW, SP, SM, GP, GW
Glacial Till	Gray, Brown	Dense to Very	Fine to Medium	15	6 to 22	SP, SM, SW
Weathered Bedrock	- -	- -	- -	3	1 to 5	- -
Competent Bedrock	- -	- -	- -	16	15 to 17	- -

The last column in Table 2 refers to the Unified Soil Classification System, or USCS, Group Symbol Range. This system was based upon a World War II system developed for the purpose of designing airfields. In 2008, this system has seen numerous adaptations from US Government agencies and was most recently standardized by the American Society for Testing and Materials (ASTM) as ASTM D 2487-93. The USCS is applicable for all geotechnical work on an international basis for purposes other than road and highway design (Chen, 2003). It is important not to confuse applications of the USCS and its AASHTO counterpart as they do not have the same purposes. The US Army Engineer Waterways Experimentation Station distributed a description of soils in a wetlands soils report that was based upon the USCS standards (Johnson and Leach, 1994). An excerpt of their table can be seen in Figure 6.

A system based on the combination of two specific letters allows an engineer to first determine what kind of soil a sample is and second to describe characteristics relating to its grain size and plasticity. There are several other distinguishing factors for soil classification, including color and odor as the main areas. Some types of soil cannot be simply classified. In this instance, a soil is given a dual classification where gradation determines the first symbol and plasticity characteristics represent the second groups of letters (Chen, 2003).

UNIFIED SOIL CLASSIFICATION SYSTEM

MAJOR DIVISIONS			GROUP SYMBOLS	DESCRIPTIONS
COARSE GRAINED SOILS More Than Half Retained on 200 Sieve	GRAVELS More Than Half Coarse Fraction Retained on No. 4 Sieve	Clean Gravels (Little or no Fines)	GW	Well Graded Gravels, Gravel - Sand Mixtures, Little or no Fines
			GP	Poorly Graded Gravels, Gravel - Sand Mixtures, Little or no Fines
		Gravels With Fines (Appreciable Fines)	GM	Silty Gravels, Gravel-Sand-Silt Mixtures
			GC	Clayey Gravels, Gravel-Sand-Clay Mixtures
	SANDS More Than Half Coarse Fraction Passes a No. 4 Sieve	Clean Sands (Little or no Fines)	SW	Well Graded Sands, Gravelly Sands, Little or no Fines
			SP	Poorly Graded Sands, Gravelly Sands, Little or no Fines
		Sands With Fines (Appreciable Fines)	SM	Silty Sands, Sand - Silt Mixtures
			SC	Clayey Sands, Sand - Clay Mixtures
FINE GRAINED SOILS More Than Half Passes 200 Sieve	SILTS and CLAYS Liquid Limit Less Than 50		ML	Inorganic Silts & Very Fine Sands, Silty or Clayey Fine Sands, Clayey Silts
			CL	Inorganic Clays of Low to Medium Plasticity, Lean Clays
			OL	Organic Silts & Organic Silty Clays of Low Plasticity
	SILTS and CLAYS Liquid Limit Greater Than 50		MH	Inorganic Silts, Fine Sand or Silty Soils, Elastic Silts
			CH	Inorganic Clays of High Plasticity, Fat Clays
			OH	Organic Clays of Medium to High Plasticity, Organic Silts
Highly Organic Soils			PT	Peat and Other Highly Organic Soils

Figure 6: USCS Soil Classification System (Used from the San Diego State University Department of Geological Sciences Website)

The purpose of this table is to gain an understanding of the characteristics and behaviors of soils that may be present on a site. Certain kinds of soil are inadequate for structural purposes and it is important to know if those kinds of soils are present. Coduto (2001) notes that there is also a significant difference in design of foundations that will sit on bedrock versus foundations that will sit or bear on a great depth of soil. Additionally, some types of soil, like peat, are not suitable to properly sustain loading from a structural foundation (Coduto, 2001).

This report from the Maguire Group (2005) is important to this project's development of the 75 Grove Street site because there are not sufficient time, funding, or other resources to make the same discoveries on the site within the scope of this project. However, it is necessary for design, especially foundation design, to have an understanding of site conditions. It is appropriate for the Gateway Park report to be used hypothetically for this site because of the proximity of the two to each other, the only distance between being Grove Street passing through. When WPI elects to develop the land, they would be ethically bound to have a study conducted on the subsurface conditions.

2.4.3 Plan for Site as Part of the Gateway District

75 Grove Street was selected as the location for this Major Qualifying Project over any of the other planned Gateway Park development sites because its design and development could be of direct use to WPI. During a September 12, 2007 interview, the University's Vice President of Business Development and General Counsel D'Anne Hurd made note that the development schedule of Gateway Park calls for a more immediate focus on commercial and laboratory space. However, university-owned housing is still a major component that will be addressed. Because of this time frame, the group was able to design creatively and with minimal restrictions. Also, the timeline of WPI's development plans at Gateway allows the concept produced by the team to have a greater influence on the actual design process initiated by the University. Finally, the

conceptual design of this site will give the University a preliminary concept for the lot to showcase to the City and the Worcester Business Development Corporation.

There are many factors that went into site development considerations. These areas include parking, use of open space, drainage and utilities. There was a challenge in meeting the first two objectives combined on one lot. Alternative parking methods and locations were sought out to meet the needs of the building. Vice President Hurd and other members of the WPI administration intend that open space be integrated into the design. Utilities and drainage needed to be coordinated with what exists in areas both within and around the lot. While this project did not involve contacting the providers of gas, electric, water, and sewer along with other City departments, it did ensure that the proper considerations were taken into account in the design.

2.5 Zoning and Implications

A glossary on the US International Information Programs website describes zoning as "The public regulation of land and building use to control the character of a place" (US Department of State, 2008). "Zoning's original purpose was to protect home-owners in residential areas from devaluation by industrial and apartment uses that had been made footloose by trucks and buses around 1910-20" (Fischel, 2004). Perhaps in a more modern setting, zoning is utilized as a land-use policy (Deng, 2003). Through legal and policy manipulations throughout the history of the use of zoning ordinances, zoning today has modernized and now allows for "sensible mixes of land usage" (Schilling and Linton, 2005). Schilling and Linton also point out that zoning in the twenty-first century actually encourages a healthier lifestyle.

Six points highlight the purpose of the Zoning Ordinance of the City of Worcester (ZOCW). Among the main purposes served by the ZOCW are preserving the health, safety, and general welfare of the public as well as to comply with the City's plans for progress and growth.

Prevention of over concentration of population and land use, promotion of natural environmental development and historical preservation, and encouragement of economic development and housing for persons of all income level are also cited as goals of the ZOCW (Zoning Ordinance of the City of Worcester, 2008).

It is important that a structure complies with all Zoning Ordinance requirements for a variety of reasons. Should a project not follow all ordinances as writ, the possibility exists that the development cost, project cost, and project schedule could be negatively affected. For example, construction or other progress could be halted. The owner benefits from compliance with the ZOCW because a project can be completed within budget and time frame constraints. Additionally, legal challenges on procedural or technical grounds may be avoided, meaning that it is especially important to be very detailed in the specifics of the project, as that is where legal disputes can occur (The Ohio State University Fact Sheet, 2007). For example, in Philadelphia, not following set requirements can lead to a zoning hearing being dismissed (Instructions for Appeal to the Zoning Board of Adjustment, 2007). Geographically, some cities are more lenient with zoning than others, for example, the Chicago Tribune (Mihalopoulos, et al., 2008) notes that cities like Boston, New York, and San Francisco are much stricter with their zoning and city planning ordinance than is a city like Chicago. Additionally, the owner earns the respect of the others in the vicinity of the project, policy makers, and others who are involved in decision making for the city's future. In an interview with Jonathan Fine, the president of an activist group Preservation Chicago, his opinion on the subject is that "the problem we have is that the zoning code is being perverted for a handful of developers, a handful of their lawyers and a handful of politicians" (Mihalopoulos, et al., 2008). Developers in this case can be construed with a negative connotation by some groups as trying to change the landscape of a neighborhood in a deconstructive manner. Zoning can be at the hands of politics in a city, as the final voting on changes to the map are voted upon by the Worcester City Council, but in places like Chicago, the expert opinions of the city planning boards are not always heeded (Mihalopoulos et al., 2008).

Zoning requirements do not significantly alter the ability to obtain the proper permits necessary for a new construction project. The only caveat to this is if the project in question goes outside of what is prescribed in the ordinances. A fine of not more than $300 per instance would be assessed for any violations as found by the Director of Code Enforcement. The ability to petition the Zoning Board of Appeals (ZBA) is available for the purpose of obtaining special permits or variances, often provided that most requirements are met and a hardship can be established. The City Planning Board would also be involved in this process. The purpose of the City Planning Board is to draw the lines on the City's Official Zoning Map, enforcing subdivision control laws, enforce those Massachusetts General Laws which apply to land use, and acts as a participating member in reviewing documents and plans for the Massachusetts Environmental Protection Act (City of Worcester Boards & Commissions, 2008).

The ZOCW institutes dimension controls to limit certain neighborhoods' aesthetics to a particular specified use. For the zone which the proposed residence hall is in, BG-6.0, residential and non residential structure follow the same requirements. A BG-6.0 zone means that it is a "General Business" zone that may allow dormitories, single- and multi-family dwellings, clinics, day care centers, libraries, religious centers, schools and universities, banks, food service establishments, health center and work-out facilities, general and professional offices, research laboratory, wholesale business or storage, and some light manufacturing.

Though the zoning does not specify height requirements based on elevation, the City Planning Board would take into consideration the surrounding area, so that typically if most buildings are no more than five stories, then a ten floor building would not be considered as it would be out of place. Within the BG-6.0 zone, the height restriction is imposed through a floor area ratio (FAR). This means that a building's height may be no more than six times the area of the floor. Another restriction is the rear yard setback minimum of ten feet, a maximum frontage of two hundred feet but not less than forty feet per dwelling unit, and a five thousand square foot lot minimum. Some of the dimension restrictions are not as strict as others given that certain documented provisions are followed. For example, a square footage allowance is granted for a given number of off-street parking spaces that are made available on site.

In a Student Town Hall Meeting, WPI President Dr. Dennis Berkey characterized parking as an issue that, loosely quoted, he believes "is the bane of all university presidents' existence" (Dr. Dennis D Berkey, 2007). Parking is explicitly covered in the ZOCW. The number of parking spaces is dependent upon the number of dwelling units and seats in a restaurant among other guidelines. Additionally, the size of parking spaces is regulated and based on whether a space will be intended for a conventional or compact-sized vehicle (ZOCW, 2008). Handicapped accessible spaces are required and based upon the total number of parking spaces allocated for a development. An additional requirement for parking that might be unexpected is that of landscaping. The implementation of landscaping architecture is required in ZOCW, including traffic islands, trees, and shrubs, to provide a better aesthetic than a large asphalt area. Additionally, the landscaping can help with storm water management, explored later in Section 10.2.

In instances where the project design is well within zoning requirements, it will be important to take aspects of the local neighborhood into account. For example, a large glass structure may not fit in the same environment with a historic, brick-faced-building neighborhood.

Because zoning regulations are so strict, it is sometimes necessary to fill out extensive paperwork, especially if a variance or special permission is needed. The ZOCW does not allow for any alteration or erection without proper permits. However, this project will explore only options that are in accordance to the ZOCW that will not needing special permit processes.

The Zoning Ordinance pays particular attention to site development on a project. A number of factors are noted that approval must be garnered from the Planning Board for designs relating to a number of specific areas, cited as “access, drainage, including detention and retention ponds, capacity, circulation, safety to pedestrians and vehicles using the facility and the abutting streets, finished grades, lighting, berms, curbing, fencing, walkways and landscaping” (ZOCW, 2008). The ZOCW (2008) mandates a site plan review to ensure that environmental concerns, largely those imposed on national and state level, are met. Worcester also has a citizen’s board called the Conservation Commission whose duty it is to ensure that development in the city meets both the state and local standards set by the Massachusetts Wetlands Protection Act and the City of Worcester Wetlands Protection Ordinance. Further duties of this committee include acting as “a participating agency in the review process of the Massachusetts Environmental Protection Act” (City of Worcester Boards & Commissions, 2008). Construction methods and means are also considered important. This is particularly true in the case of filling and excavation. Proof of planning for erosion control is expected to be used and submitted upon any activity during construction that could potentially cause damage to the natural environment. Additionally, there is an emphasis placed on not creating a disturbance to flood plains. The purpose of this provision is to maintain and not disrupt the current state of wetlands as part of management practices and preserve the area (ZOCW, 2008).

Areas of the zoning ordinance can have affects on the planned usage of the building. Since it is slated to contain retail and commercial businesses as well as residences, there are unique circumstances that could apply. One might assume that a large, flashing sign is not needed to denote a university residence hall. On the contrary, businesses on the ground floor would require signage to draw attention to their presence. However, the business' signs are restricted in their size and appearance to better fit within the existing neighborhood. While considering signs, the sizing and placement is also important in publicizing the project on-site and during construction.

The ZOCW requires that the Planning Board review all development and projects that have an impact upon the natural and built environments of the City and upon the nature and provision of public services" (ZOCW, 2008). This committee also has jurisdiction over the ability to grant special permits if needed, as well as modify or not accept the plans as presented. Though the process is extensive and requires the submission of many documents as well as a presentation in a public forum, it is not a process which can be neglected, especially for larger projects over 10,000 square feet in area (ZOCW, 2008). However, an appeals process is in place to continue development rather than not consider any part of the project.

Permits are necessary to have before construction can occur. Before permit investigation can begin, developers in Worcester are required to file an application with the city to be delivered to the Management Services Section of the Worcester Public Works Department. Along with this application, all drawings, sketches, explanations, notification of the city water and sewer departments must be submitted. In total, the documents must describe or show "the location of the work to be done in relation to the outstanding features of the road" as well as "the character and extent of the work" (City of Worcester, MA Department of Public Works Management Services, 2004).

While zoning has proved to be helpful in shaping growth of communities, the ordinances are in dire need of being updated to facilitate sustainable development, often characterized interchangeably with mixed-use developments. Though zoning is the responsibility of a municipality, the change in this direction is the responsibility of a number of parties, from local government to the private sector.

2.5.1 Mixed-Use Facilities

As Lassen (2007) notes, mixed-use facilities represent "recent trends in urban revitalization" that set out to serve the purpose of being a "live-work-play destination". Some of these recent trends include zoning changes that allow for mixed-use areas that promote the immersion of residential and business areas. This works towards a more sustainable culture as well as healthier living, for example, as it promotes walking versus driving.

The retail space will be designed to provide a strong, structural base for the building with the ability to meet the needs of all companies who buy the available area. Flexibility is a main tenet that is important to consider when developing a mixed-use facility. By allowing a space to be designed as a tenant fit-out means that not only the first tenant but later tenants as well, have the ability to change the space to meet their particular needs.

Heath et al. (2006) have found sufficient evidence in their study of urban environments and physical activity that "Community-scale urban design/land-use policies and practices" and "street-scale urban design/land-use policies and practices" aid in increasing the physical activity of those who are impacted in the selected area. The relationship of the physical built area potentially encourages residents to participate in greater physical activity by providing an inviting area of green space as well as the ability to walk to school, work, or shopping. Along with this result, increased levels of activity are linked directly to the ability to combat the fight against obesity in America (Heath, et al., 2006). The authors of this study concluded that mixed-use development in urban planning can prove to be an asset in developing better health practices, especially in doing physical activity.

Pivo and McNamara (2005) cite that it is scientifically proven that mixed-use development is a “financially prudent” form of responsible property investment. Within their research, Pivo and McNamara (2005) were able to determine that among other types of property investment, mixed-usage offers “the potential for increased performance in reduced risk” relating to the ability to produce positive returns on investment thus leading to shorter payback periods. Economically, the ability to return your investment in the property is likely because there will always be a need for places to live and stores for expendable income to be spent. Other positive investment opportunities noted by the authors that this project can be defined by include flexible building systems, for the ability to transform the first floor based on tenant needs and urban revitalization, where several hundred students are finding housing in the outskirts of downtown within walking distance of the city common and within a mere hundred feet of one of the city’s largest biggest business development.

While there are several benefits that impact both individuals and communities with urban and mixed-use development, Rosenthall, et al. (2007) notes that there are some hazards involved with the rapid urbanization across the globe. One primary concern is the global climate. At the time of the report in 2007, 3 percent of the earth’s livable surface was urban, with 50 percent of the world’s population in that same space. As a result, the ecological footprint of the urban centers, that is, for example, based upon the amount of energy used or pollutants produced by a selected population, is much larger in urban centers than the world wide average.

An additional problem that hampers mixed-use development may be an aversion to change from homogenous settings by the local government (Majoor, 2006). In contrast, Worcester government has allowed zoning changes on a regular basis to encourage creative business design, including re-zoning of certain areas that could provide an economic and social stimulus to the city.

2.6 International Building Code (IBC)

The International Building Code 2006 Edition sets out general requirements for structural design including strength, serviceability, analysis, and occupancy categories. Strength is important so a collapse and human harm can be prevented, as is serviceability so that members are stiff enough to limit deflections. Failure can be predicted by large deflections and cracks in the structural material. This failure can be delayed or prevented by limiting the deflection. Completing an analysis ensures that the final design will be structurally sound in that all loads will be transferred successfully from the original point to elements which are load resisting, and ultimately distributed into the substructure and the ground the structure sits upon. (IBC, 2006) Occupancy category assures the appropriateness of the design.

One set of equations used for load and resistance factor design (LRFD) is calculated in combination with design of both the steel and reinforced concrete structures. The IBC code sets these equations forth in Section 1605.2.1. Among the seven basic load combinations, it is important to select the one that predicts the most critical design effects. The combinations include several factors, including dead, live, snow, rain, and wind loads as well as the combination of vertical and horizontal earthquake loads, loads due to fluids with well defined pressures and maximum heights,

The dead loads in a building are established from weight of the permanent fixtures in a structure. These elements include but are not limited to the frame, flooring, mechanical systems, walls, stairs, and roofs. In all instances possible, the actual weights of the systems will be used. If this is not possible, a comparison will be made with a building that is similar in size and purpose to the proposed graduate housing facility.

Live Loads are subject to minimum considerations found in Table 1607.1 of the IBC. Table 3 provides a selection from IBC Table 1607.1 with applicable uses and their required minimum live load considerations for what would be important in a graduate student residence with retail and restaurants on the first floor. The values listed are what will govern the calculations for loading unless actual numbers provide that a larger figure must be used. Live loads are a challenging determinant because the magnitude can change and the lifestyle and temporary loads, for example, furniture layouts, can move throughout.

Table 3: Applicable excerpts from IBC 2006 for live load minimum considerations

	OCCUPANCY OR USE	UNIFORM (psf)	CONCENTRATED (lbs)
4	Assembly areas and theaters		
	Lobbies	100	-
13	Corridors, except as otherwise indicated	100	-
14	Elevator machine room grating	-	300
28	Residential		
	Hotels and multi-family dwellings		
	Private rooms and corridors	40	-
	Public rooms and corridors	100	-
30	Roofs		
	All roofs subject to a maintenance worker	-	300
	Ordinary flat, pitchedm, and curved roofs	20	-
36	Stairs and exits		
	All other (non one or two family dwellings)	100	min 300
38	Stores		
	Retail - First floor	100	1000

Some live load factors are specific to the New England region and must be accounted for. One such type of loading is snow loading. A gravity loading factor, the snow loading is determined by values listed in the IBC. Snow loads affect mainly the roof design, but as a result all columns, beams, and girders are susceptible to the additional loading.

Another regional factor is wind loading. Blizzards and remnants of tropical storms and hurricanes, as well as rare tornadoes, play a factor in the winds in Worcester. Unlike snow loads, wind loads are measured and applied to structural design laterally. Wind loading can be determined by standard values in the IBC.

Occupancy Category is based upon Table 1604.5 and was determined for this structure to be a Type II. This is because it is a college facility for fewer than five hundred occupants. The type of occupancy structure is based upon the number of occupants and the importance of the structure's use in case of an emergency. For example, a hospital would be designed to survive earthquake loading more conservatively than a single family home.

The IBC 2006 edition sets forth minimum requirements for structural design. However, according to the City of Worcester Department of Code Enforcement, the Massachusetts State Building Code is adopted and must be adhered to when building in the city. In some instances, the state code is more stringent than the IBC. When this situation arises the State Code takes precedence over the IBC. In one instance, a small but nonetheless difference is seen in the snow loading factor for Worcester. The IBC's Figure 1608.2 shows Central Massachusetts, including Worcester, as being under 50 psf of design snow loading, while the Massachusetts State Code design minimum is at 35 psf.

2.7 Foundation Design Concepts

An anonymous author-artist created a poster that hangs in WPI's Kaven Hall noting that some of the civil engineer's best work is not even seen by those who rely on it every day. Foundation design is one area to which the statement applies rather well. It is this geotechnical based design that determines whether or not the structure above it will remain standing properly. There are a number of factors which define foundation design, including type, geometry, bearing pressure capacity, settlement, and loading.

2.7.1 Types of Foundations

Though a foundation may serve the same purpose no matter what its geometry, there are two main categories and a number of smaller types of foundations that exist. The two main categories in which foundations are broken into include shallow foundations and deep foundations.

Shallow foundations are used in situations where the placement of the foundation is close to the surface. Within the group of shallow foundations are both mat and spread footings. Mat foundations, made out of reinforced concrete, cover the entire footprint of the building. The benefits of mat foundations are that they provide sufficient load capacity for extremely high loads, poor soil conditions, or erratic soil conditions that are likely to experience differential settling. Additionally, if a foundation is going to lie within a groundwater table, constantly exposing it to water, it is far easier to protect a larger foundation from water damage than it is smaller and numerous foundations (Coduto, 2001). Spread footings are the most common type of foundation built. These subsoil structures are able to distribute the loading from a column or group of columns by spreading the load over a much larger area than the column. The best kind of situations for spread footings to be applied include up to medium sized structures to be built upon moderate to good soil conditions. A number of different types of spread footing geometries exist. A square spread footing has equal side lengths and is usually centrally loaded. There are also rectangular footings that are useful for eccentric loading and spacing problems near property lines, circular spread footings, which are useful for structures like a flag pole or transmission lines, continuous footings, used to support load bearing walls, combined footings to support more than one column at a time, and ring spread footings, which behave like continuous footings generally used for storage tanks (Coduto, 2001).

Deep foundations help to anchor the building in a different manner and different soil characteristics than shallow foundations. The main reasons for required deep foundations include that the upper soils are tremendously weak or the loads are equally as large. Though it might seem prudent to use larger spread footings, any foundation design that exceeds one-third of the structure's foot print is likely to be economically disadvantageous (Coduto, 2001). Different types of deep foundations include piles, drilled shafts, caissons, auger-cast piles, pressure injected footings, anchors, and mandrel-driven thin shells filled with concrete. Installation methods for these foundations vary, consisting of driving, or forcing, prefabricated members into the ground, drilling a shaft and filling it with concrete and the reinforcing steel, or pumping grout through an auger while it is retracted from the hole, to name just a few.

Deep foundations are susceptible to normal, moment, shear, and torsion forces just the same as shallow foundations are. The greatest difference between the two is that deep foundations extend typically from 50 to 150 feet below the surface. Additionally, the bottom shape of the foundations can differ while shallow foundations are the same size throughout.

2.7.2 Governing Design Factors

The two most important factors in the design of foundation are bearing pressure and settlement. Both of these are failures can occur by not taking the proper information and soil data into consideration. The presence of weak soil, or a load larger than the soil is able to uphold, forces a foundation to create an upheaval of soil and toppling of the foundation. This condition is described as “the most dangerous” (Tao, 2008) type of failure. Settlement refers to the downward movement of the loading a structure acts on the ground (Coduto, 2001). A structure can settle uniformly, meaning the whole structure settles at the same rate to the same depth. One famous example of this is the Palace of Fine Arts in Mexico city, which has settled a total of 3 meters, almost 10 feet, since construction commenced in 1904 (Tao, 2008). A second type is differential settling, where only a portion of the structure settles. In some cases, there is distortion that results because the settlement is much greater in some parts of the soil than others. Italy’s Leaning Tower of Pisa is among the most famous example of differential settling, though without distortion. All structures and foundations will settle, so it is important for a geotechnical engineer to limit the amount of settlement that will occur.

Important factors of the geometry, construction, and depth of the foundation play a critical role in its design. The width, length, and thickness are primarily what will govern the exact geometry after a type is selected. The depth below the surface has two impacts. The first relates to the depth of the footing from the surface, which is measured from the foundation base to the surface. The thickness is less than of even equal to this value. Another factor relating to depth is the depth of the groundwater beneath the surface. The deeper the water table, the more beneficial it is towards a simpler design, particularly for shallow foundations.

Shear failure for spread footings occurs by the applied normal, moment, and shear forces by two-way shear. One-way shear is affected only by the subjection of vertical loads. Both of these failures assume that there is a critical area well within the edges of the foundation foot print where the rupture will occur. To offset these possibilities, thickness and effective depth as well as the size of the reinforcement become important considerations.

2.7.3 Loading

The way that loading is considered for foundation design is different than that of typical structural design. Where the IBC calls for the use of LRFD, foundation design simply uses the service load. The service load refers to no additional multipliers to adjust the value of the forces. The reason for this is because some loads are acting in opposite directions; in particular, the soil is pushing back up on the foundation which is pushing down (Coduto 2001). Foundation design differs from other structural areas because it does not consider the factored normal load. Instead, Coduto (2001) states that even if the factored load was used for superstructure design, footing width must be determined with un-factored, or service, loading. This consideration makes a considerable impact in the design of the foundations. For example, consider that a structure has a dead load of 95 kips, a live load of 50 kips, a roof live load of 8 kips, and a snow live load of 20 kips, resulting in a total service load of 173 kips. By applying Coduto's (2001) Equation 2.7, referencing the LRFD code developed by the American Concrete Institute, where the dead load multiplier is 1.4 and the sum of the live loads is multiplied by 1.7, the resulting factored load is 265. 6 kips. The difference between the two is nearly 35 percent.

3 Methodology

As with most design projects, the methodology of the design team progressed in stages from general research to conceptual and engineering design. Beginning with general research of the site and project, many of the design areas that would be required for actual building design such as architectural layout, structural design, foundations, and project management were outlined and established. Areas of additional study pertinent to the facility's design were also pursued by the group and included LEED certification options, the site and utility design, and an alternative parking option. Overall, the goal of the team was to provide design options and baselines for the project client WPI so that the data can be used for further study.

3.1 Background Research

In order to design a facility, designers must understand the context and background of the subject which encompasses the project's design. As the first step in the design, a background study of the both the client, WPI, and the Gateway Redevelopment Project was conducted.

First, an interview with WPI Vice President and General Counsel D'Anne Hurd was scheduled in order to obtain background information of the Gateway Project and of the need for a graduate housing complex. Design criteria, such as the need for open green space, were discussed along with possible contacts for aid in research and design.

Second, the research was conducted on the envisioned Gateway Park district along with the specific site at 75 Grove Street. Site plans were furnished along with soil profile from various sources to aid in developing the site.

Finally, a study of WPI's current housing options for students was conducted to assess the current status of the University's student housing. Research on student housing at other collegiate institutions both in Worcester and across the nation was conducted to learn any possible recent trends in the type of housing being built by colleges and universities.

3.2 Architectural Design

With research on what is envisioned by the client for the future graduate housing facility, the next phase of the project focused on the architectural design and layout of the building. Applicable code requirements, architectural standards, and Worcester zoning specifications were all compiled to develop the site placement and layout of the building. Such factors as natural light and availability of green space were also taken into consideration during design.

Floor plans for both the retail and residential spaces were then developed using these specifications and AutoCAD software.

3.3 Structural Design

The structural design of the building evolved directly from the architectural layout finalized by the design team. Structural framing options considering both concrete and steel materials were compared on a cost and constructability basis. Once a framing method was determined, structural components such as beams and girders were designed based on the Load Resistance Factor Design Method. The use of Excel spreadsheet software was used to aid in the multiple calculations. Options for the lateral load resisting system were also compared on a cost basis. The elevator shaft and stairwell frames were then designed to be incorporated into the structural frame. Finally, mention of the connection considerations was given in order to touch upon all aspects of the structural frame design.

3.4 Foundation Design

In designing the foundation system, initial assumptions were made on the type of foundation that would be used based on the layout and concept. Next, the soil profile was studied in depth to obtain necessary design values for the capacity of the soil. Engineering calculations were then conducted for the design of typical concrete spread footings. The Vesic and Terzaghi methods were used for calculating allowable bearing stress for the footing while the Classical and Schmertmann methods were used to determine allowable footing deflections. Excel spreadsheets were used to facilitate calculation, and column loads and end reactions were furnished from the structural design.

In addition, the connection of footings to base plates, along with the required amount of steel reinforcement in the footing was studied for the foundation. Overall implications of the design were then summarized in concluding remarks.

3.5 Project Management

3.5.1 Cost estimate

A cost estimate was developed for the building at 75 Grove Street. The cost estimate was completed over various stages of the design process. As the design of the building progressed more costs could be defined. The cost of construction was based on RS Means cost values. These prices were adjusted to resemble the local prices in Worcester Massachusetts. The cost values were determined by square foot costs, unit costs, and also by assembly and system estimates.

As each part of the project was designed a cost for that division of construction could be developed. The first element to be designed was the floor layout followed by the steel design. The cost of steel was determined once the steel design was completed. Because the design for this section was very detailed the cost estimate could be performed using unit costs. When the steel design was completed the layout of the building and the loads on the foundations could be finalized.

For the next part of the cost estimate to be performed many assumptions were made. A floor layout and building size allowed for all of the interior cost estimates to be performed. There were no plans to define exactly what the interior looked like so everything was assumed based on the study of similar buildings and the needs of WPI students. Furnishings were also estimated based on the layout of each dorm room. Services were priced based on square foot costs for each type of system. When everything on the interior and shell of the building was defined the foundation was designed.

The foundation was designed to support weight of the building and everything in it so it had to be done last. Each type of column footing was priced based on the unit cost of every element required to construct the footing. Once every part of the building had a construction price the work surrounding the building needed to be estimated. The sitework was the last division of the building to get a price because it was the last part of the project to be designed. Prices were determined by unit costs.

3.5.2 Project Schedule

The schedule for the construction of the new building at 75 Grove Street was based off of the construction of a new residence hall at WPI. The first step in developing a schedule was to define all of the relevant projects that need to occur for the building to be constructed. Once all of the activities were defined they were assigned a duration based on the size of similar construction projects. Every one of the activities had to be linked together based on what order they could be performed in. To save time some activities were required to start once a certain percentage of the previous task was completed. After all the project activates were linked together and had durations their start and finish dates could be calculated. This demonstrated where the float was in the schedule and showed the critical path to finishing construction on time.

3.6 LEED Based Design

The LEED research on this project covered the benefit of water efficiency. A water cost savings for the building was determined if the design called for more efficient plumbing fixtures. The first step was to determine what the total water consumption of the building would be per year with standard fixtures compared to with efficient fixtures. A total cost difference in the two types of fixtures for the whole building was also calculated. The initial cost of fixtures and the cost of water spent per year were both graphed over a span of ten years. The efficient water fixtures cost more initially but were paid off after eight years of use.

3.7 Site and Utility Design

This area of study involved a significant amount of design in order to develop the site plan for 75 Grove Street with consideration of areas ranging from surfacing parking to the integration of utilities. First, the surface parking layout was developed using the 2007 Worcester Zoning Ordinance. Drainage slopes and storm drain were then designed for the parking area in order to prevent the pooling of water. Utility design considered the layout for telecommunication lines, electrical lines, gas mains, and water mains running from Grove Street to the exterior wall of the facility. Finally, implications concerning all of these areas were summarized and addressed in reference to the entire project.

3.8 Alternative Parking Option

As a further area of study, the concept of an alternative parking structure for the building at 75 Grove Street was studied in an effort to provide adequate and secure parking for residents and commercial tenants. However, design also focused on providing a parking structure while not removing the green space asked for by the client. Therefore, two below grade structures were considered for the design of the parking facility. A preliminary cost analysis was completed for each structure and a comparison between the two used to determine a final design. Additional implications such as constructability, energy, and functionality were considered throughout the design.

4 Layout

Before any engineering calculations and design can be conducted for the site at 75 Grove Street, the architectural layout and plan of the proposed structure must be produced by designers. The layout must strive to meet the vision and expectations of the client along with the needs for the intended occupants through. However, in addition to facilitating the architectural program, the layout must also be architecturally pleasing and integrate well with the structural components of the building. Therefore, the design team's first major area of design involved the conceptual layout and plan for the facility at 75 Grove Street.

4.1 Architectural Program

The first step in the design of the mixed-use facility at 75 Grove Street was to develop an architectural program for the site and each of the floors. The client, WPI envisioned a roughly 80,000 square foot building with roughly 70,000 square feet of residential space and 13,000 square feet of retail space (Vice President Hurd, September 12, 2007). The program for the building called for these areas to be separated in the building and function independently. This separation allows the retail floor to be open to the public and have more activity. Meanwhile, the residential floors are secure from outsiders and have quieter, more private spaces. Finally, the program for the building must meet residential space requirements with 200 square feet of living space for each person in residence (IBC 2006). Finally, WPI also expressed the concern that open green space be included in the design and program of the site.

Services that will be offered within the new structure extend beyond the basic residential-only setup. Considering that the housing is in close proximity to a business district, the proposed building will cater to both commercial and residential needs. Small retail businesses will be housed on the ground floor while upper levels are reserved solely for housing purposes.

Several types of retails businesses that are anticipated to operate on the structure's ground floor are intended to appeal to graduate student residents, employees of Gateway Park, and others in the area. This new residence hall goes along with a thriving revival of a design concept, as "the idea of live-work-play destinations…underscores the longing for a return to small-town convenience and sociability" (Lassen, 2007). One store will be a 3,536 square foot coffee shop that would likely either be a well known national brand like Dunkin Donuts, Starbucks, or a similar establishment. Because of the generous space allowance, it is anticipated that the layout and furniture would create an atmosphere available for both socializing and studying. A casual dining restaurant, similar to a Panera "bakery-café" (panera.com), is also projected. The space measures 4,393 square feet, a large size that aims to serve similar purposes to those that were set out for the coffee shop. This section of the building provides the ability to eat a sit down meal with friends and associates, or to grab a so-called 'quick bite' to eat during or after work. A portion of this space is assumed to be used for a kitchen area and a dishwashing facility. Because the residences will have their own kitchens, there is no need for a formal meal plan based dining hall.

As this building is nearly three quarters of a mile from the main WPI campus, facilities there would not likely be very convenient for use of students living in the new building. With this consideration in mind, a workout facility and at least one ATM for a national bank will also be included on the lower level. The ATM will be located in a small convenience store, only 760 square feet in area, with everyday living basics and snacks. A gym facility could potentially be run by the Athletic and Physical Education Department or the space contracted out to a private proprietor. The gym would contain the typical cardio and nautilus machines as well as free weights, with mirrors lining the perimeter of the 4,508 square foot facility. It is imagined that the gym, which could potentially offer memberships to Gateway and other area employees as well, will include small locker rooms with showers and lockers for those who do not live on the floors above.

Because the immediate area does not have a laundry facility, the graduate residence will have space on the ground floor for those who live in the building. For security reasons it is not intended to be open to the public. There are 122 residents planned to live in the building and the capacity of the room does not need to be expanded beyond that.

To meet Americans with Disabilities Act (ADA) guidelines, the building will be handicapped accessible, with elevators located in the middle of the building to minimize distances walked for those who have difficulty. Elevators are necessary because of the multiple story structure, in addition to being useful and convenient for able bodied residents.

The residential set up of the building was determined by investigating the upperclassmen and graduate options already in existence on WPI's campus as well as graduate resident halls at other major US institutions. There were a number of considerations taken into account in terms of the type of living accommodations that would be available. The wide spectrum included singles or doubles in a dormitory style building, a two-person suite including a common room that shared cooking with another suite, and apartment-styles residences.

In the end, apartments of varying sleeping capacities with the ability to cook were the chosen living space. This resulted because in comparing the living styles of freshmen and upperclassmen residence halls, it was concluded that there was a greater sense of freedom available moving from one to the other as WPI students progressed through on campus housing.

Additionally, through learning more about options available at other institutions, the options of family living for those who were married or with children appeared to be at a premium, and thus likely coveted.

Overall, one hundred twenty five residents would be housed in the proposed Gateway Graduate Residence Hall. The variety of services that are proposed parallels those available on the main campus in an environment that is catering to a more mature sector of the population of college graduates and professionals. It can potentially draw in and integrate new business into the city while exposing more students to what is already available in the downtown area. Another benefit of the proximity to other businesses, residences, and downtown is the prevalence of and ability to use public transportation to reduce problems like emissions and parking. Additionally, walking could reduce the same problems.

4.2 Buildable Area

To begin, the site plan needed to be obtained and studied by the group. The layout of the site can be seen in Figure 7 on the following page. The site is bordered by buildings to the south and streets to the north, east, and west. Zoning requirements call for a 15-foot setback along all streets. Additionally, the site contains an easement that runs east to west on the south end of the lot. Depending on the function and owner of this easement, construction would either be prohibited over it or require special permitting and approval. Therefore, the intention of avoiding construction over the easement, the buildable area of the lot was established on the north side of the site. Considering the 15-foot set back from the curb and a conservative 10-foot setback from the easement, the buildable area consists of about 46,934 square feet and is shown in Figure 7.

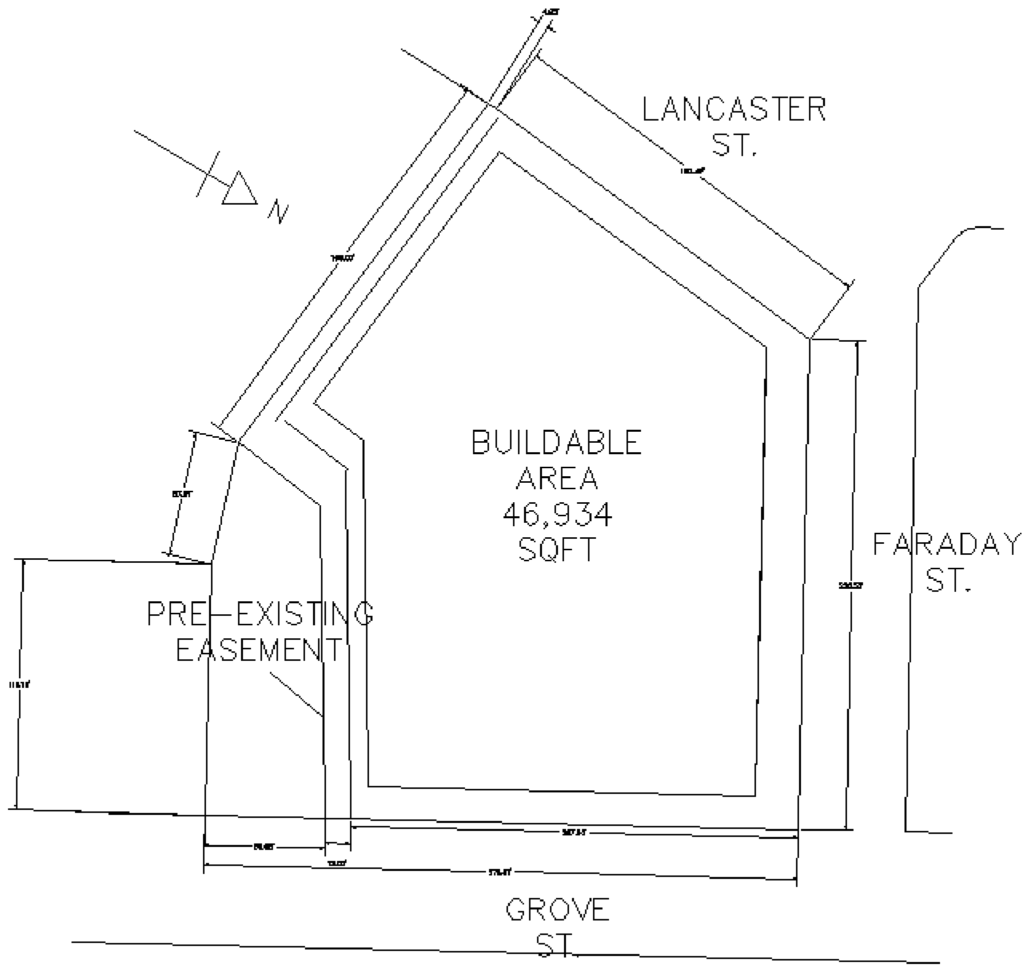

Figure 7: Buildable Area for the Site

Based on this definition, the footprint of the building was located on the site. First, the team recognized that businesses would want curbside space on Grove and Faraday Streets to allow for street side windows, advertising, and visibility. Additionally, the 15-foot setback could accommodate possible curbside parking space. Second, the group decided that the building should remain away from the easement in order to make the permitting process easier. This decision offered two advantages. One, a few surface parking spaces were placed in the south east corner of the lot. Next, the placement of the building on Grove and Faraday streets created opportunity for semi-private, communal, green space bordering the south and west edges of the lot. This community space is private enough to be enjoyed by tenants away from the street curbs, yet is open enough to link the area with Gateway Park to the east and Institute Park to the west. Therefore, based on this placement, the building footprint evolved into a reversed L shape or the image of the Greek letter gamma from an aerial view. This design would allow businesses to advertise along Grove and Faraday streets and have easy curbside access, but the layout of the building also allows retail and apartment spaces on the south and west sides of the building to receive more natural afternoon sunlight.

With the building positioned on the site, attention was focused on the overall dimension and spatial layout of the building's footprint which can be seen along with its position in Figure 8. First, the dimensions of the footprint were estimated as 60 feet by 220 feet for the North leg of the building and 60 feet by 180 feet for its East leg. The 180-foot and 220-foot lengths were used to maximize the building's frontage along Faraday and Grove Streets with in the buildable area. The 60-foot dimension of the two legs allowed for the required amount of square footage expected by the client on the ground floor to be obtained in the structure while still falling within the buildable area. Retail space on the bottom floor has roughly 13,000 square feet of rentable space while the 3 floors above have over 60,000 square feet of livable space. Based on these overall dimensions, 20 foot by 20 foot structural bays were assumed for design. The West end also included a diagonal slice so that the building runs roughly parallel to Lancaster Street.

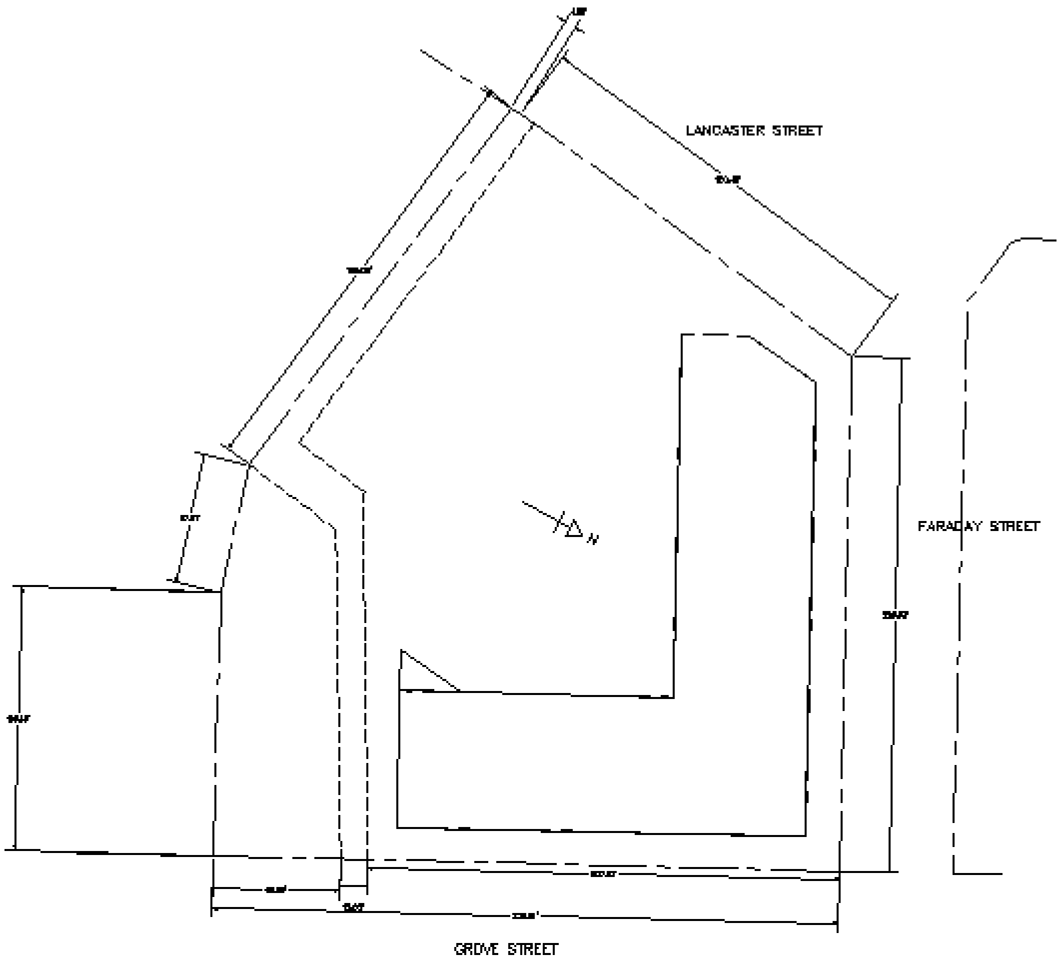

Figure 8: Building Footprint and Site Plan

Ultimately, the square footage value for retail space meets the expectations of the client but the residential space falls below the target value of 70,000 square feet. The loss of livable space was due to the restrictions of the street locations, the requirement to include green space, and the decision to not build over the easement. Additionally, the group wanted to ensure that each apartment received a large amount of window space and natural lighting along with separation from any retail space on the first floor. One possible option would be to add a fifth story to the structure, but the group felt that the resulting building height would not blend in with the surrounding facilities. Additionally, the additional story would add cost to the budget and time to the schedule. Therefore, it was determined that the proposed four-story design, even with the reduced livable area, was an acceptable option for the site.

4.3 Layout and Egress Requirements

The layout of the building was designed using the standards from the 2006 IBC along with architectural standards from the text Architectural Graphical Standards 10th Edition by The American Institute of Architects (2000). These references were used to determine such values as the minimum square footage per apartment; the minimum and appropriate wall thickness based on material and required fire rating; and stairwell location and design. Handicap accessibility standards were also considered in the development of public and private apartment spaces. These requirements and standards are summarized in Appendix 13.1.

The architectural standards governed the spacing of rooms, doorways, and furnishing in order that wheelchair access could be made available in each unit (American Institute of Architects, 2000). For example, the size of the bathroom in each unit was designed large enough for a wheelchair to enter and turnaround in the space. Also in respect to the bathroom, the toilet, sink, and shower spaces were separated so that roommates could use the different amenities at the same time.

Meanwhile, the building code was the main resource used to meet safety requirements and design assumptions were made based on these requirements. First, it was assumed that the building would be provided with an automatic sprinkler system. This assumption allowed for stairwells to egress through the first floor public spaces and also increased the minimum egress paths from individual apartment doors to an exit. However, the disadvantage is that, with kitchens in each apartment, there is a potential for false alarms of the system, which could lead to unnecessary and costly water damage. Second, in an effort to be conservative and also meet maximum egress path lengths, the building has three main stairwells, with two exiting directly to the exterior of the building. Finally, it should be noted that, with a total height of 46 feet, the elevation of the building does not classify it as a high rise structure and therefore does not need to meet any special requirements related to this classification.

4.4 Design Development

Next, with requirements for the building outlined, the layout of the building's interior floors and spaces was established. Architectural drawings for each of the floors is shown in Figures 9 through 12. The first floor of the structure is devoted to retail space. Figure 9 shows the ground floor with spaces allocated for a potential restaurant; coffee shop; convenience store or bank; and athletic gym. There was also space for a mailroom and vending machines. The entranceway and atrium was located in the East leg of the building. Elevator, equipment, and trash space were also placed at the interior of the structure so that window space may be maximized. Finally, stairwells have been placed at the west and south ends of the building with the south stairwell would only have access to the outdoors and would be reserved as an emergency stairway only. A third stairwell is located towards the center of the building but does not begin until the second floor. Access between the ground floor and the second floor is through the use of grand staircases in the atrium.

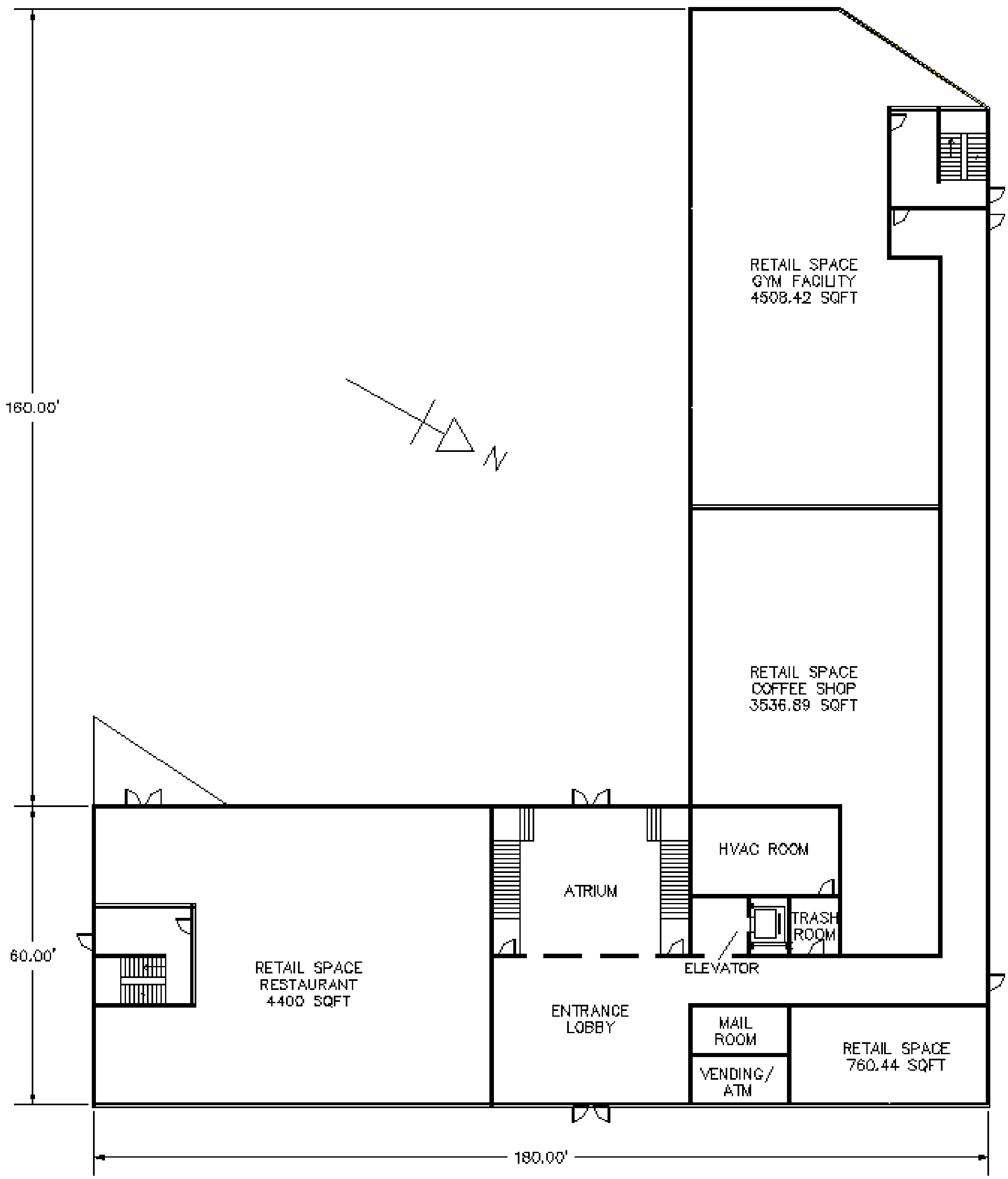

Figure 9: Ground Floor Layout

The second floor layout of the building shown in Figure 10 is composed of graduate student apartments and common spaces. Six four-person apartments face south and west and look out onto the communal green space. Six two-person apartments and two single person apartments face Faraday and Grove Street on the north and east sides of the building. The planned total occupancy of the floor is 38 people. Additionally, the floor layout includes two common areas. The first is located near the central entranceway, across from the atrium. It is envisioned that a glass wall would divide this common area from the atrium space but still allow occupants to view the green space outside and receive maximum natural lighting. The second common area is located on the west end of the building. Again, it is envisioned that this space would have a glass curtain wall in order to allow occupants the view of Lancaster and Faraday Street and receive a maximum amount of light. Finally, space is reserved for a laundry room near the main entrance to the floor and the center stairwell to the upper floors.

The third and fourth floors follow the same spatial design as that of floor two. However, the space allocated to the atrium in the second floor has been replaced by a seventh four-person apartment which increases the floor occupancy to 42 people. The layout for these floors is shown in Figure 11. Finally, Figure 12 illustrates the roof layout which designates space for the elevator equipment and roof access through the center and northwest stairwell.

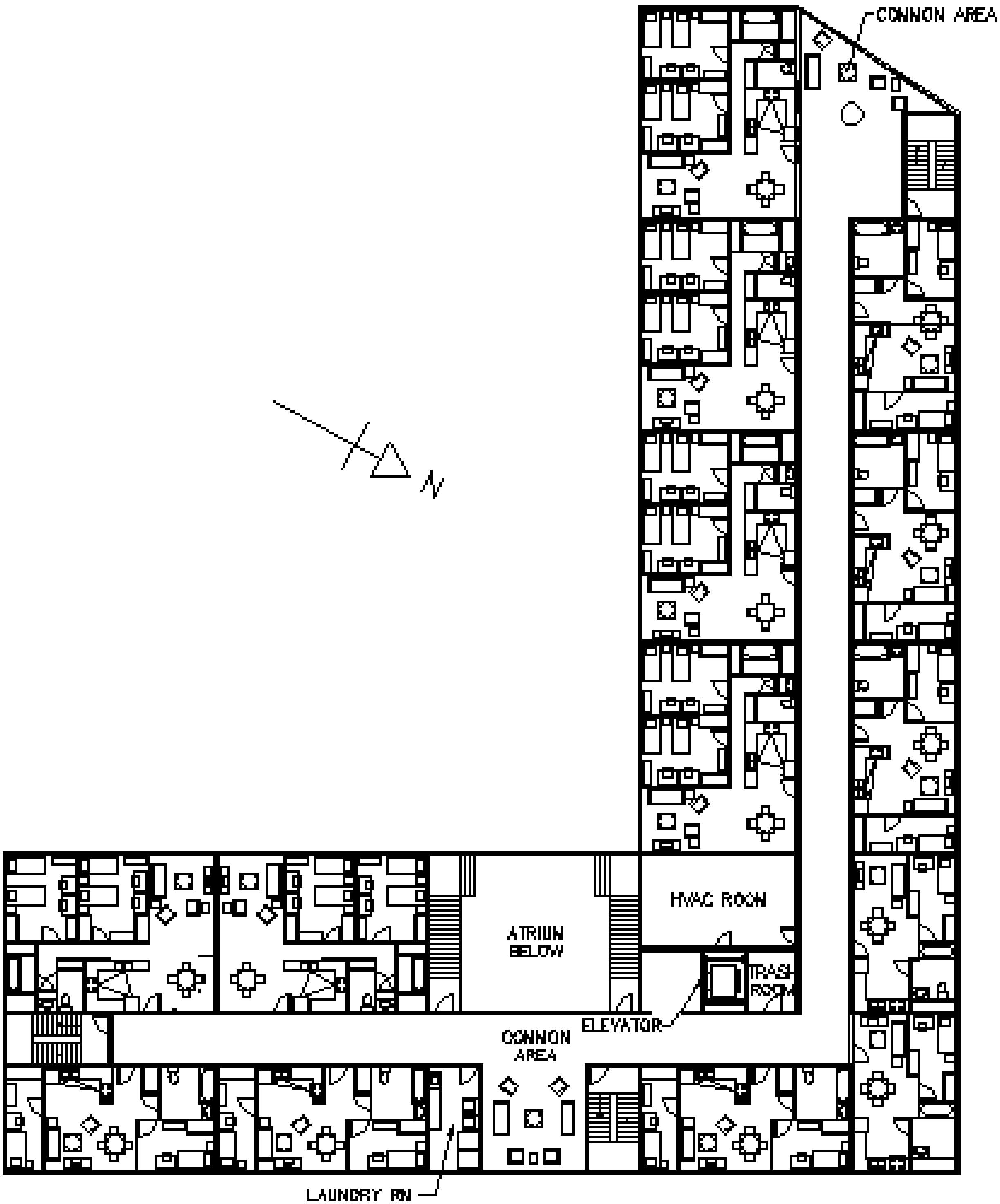

Figure 10: Floor Layout for Second Floor

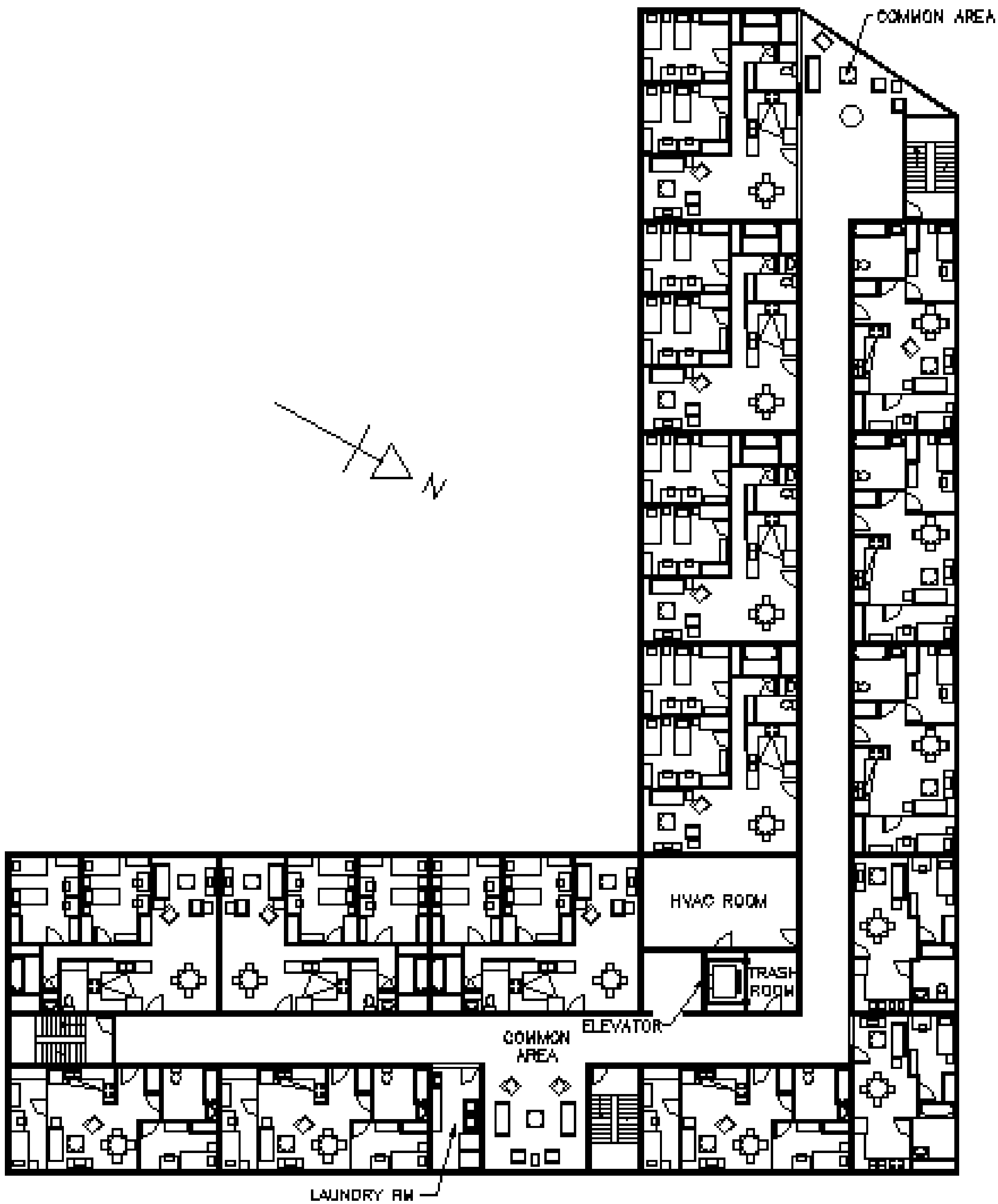

Figure 11: Third and Fourth Floor Layout

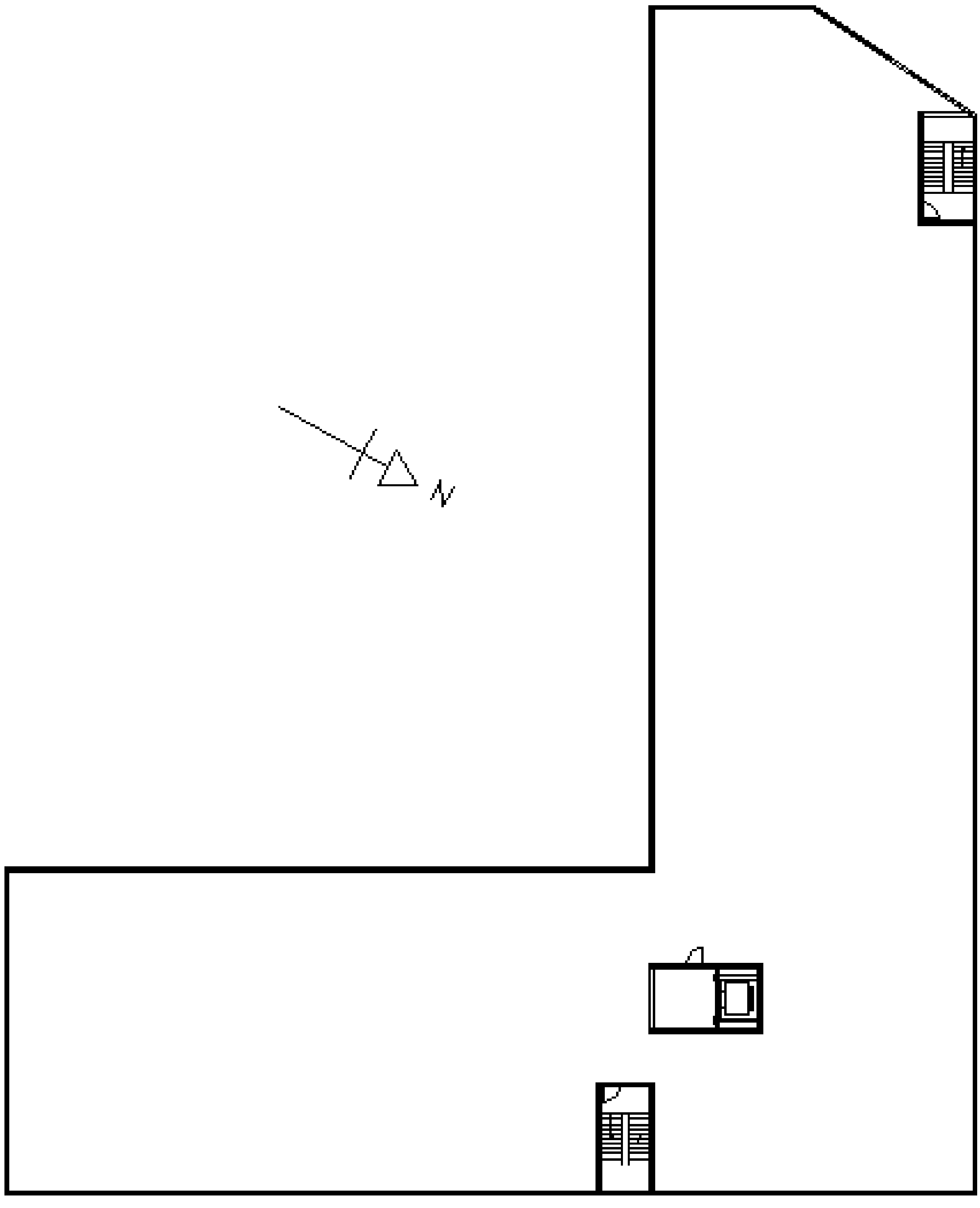

Figure 12: Roof Layout

5 Structural Design

After an architectural concept was established for 75 Grove Street, the structural layout and design of the building was engineered and developed. First, both reinforced concrete and steel structural components such as beams, girders, and columns were compared for the design of a sample section of the structure, with steel being the material chosen based on a comparison of cost and ease of construction. Based on this decision, the structural frame for the entire buildings was designed for gravity loading. Framing options to resist lateral loading were then investigated and compared based on cost and ease of integration into the layout. Structural frame designs were also completed for the building's elevator shaft and stairways. Finally, consideration of structural member connections was discussed.

5.1 Comparison of Structural Systems

With today's engineering technology, the use of building materials such as steel and reinforced concrete are almost interchangeable in terms of building construction. In most cases, the differing characteristic between the two is cost of construction and speed of construction. Therefore, a comparison between a typical section of the building designed in steel and then concrete was conducted and based on construction cost.

First, the cost of the sample building section was determined using engineering calculations and cost estimates from the 2006 RS Means Construction Data and 2007 RS Means Square Foot Costs. The typical structural section encompassed a floor area 20 feet by 60 feet and included all four stories for both steel and concrete. The sample section was larger than the 20-foot by 20-foot bays used in the architectural layout due to the potential for larger bay sizes with reinforced concrete.

For the steel option, standard W shape sections from the AISC Steel Construction Manual were used while typical 150 pounds per cubic foot concrete and reinforcing steel were used for the concrete option. Ultimately, four options were investigated: steel W sections; standard pre-cast beams and columns; cast-in-place beams, columns, and one-way slabs; and cast-in-place flat plate construction. Table 2 displays the costs per standard bay for the various construction methods.

Table 4: Cost Comparison Between Construction Material and Methods

Construction Method	Cost per Section	Cost per Floor ($/sf)	Reference Section
Structural Steel Framing	$93,591.75	$77.99	5.3
Pre-cast Reinforced Concrete	$112,460.00	$93.72	5.2
Cast In Place Concrete (Beams, Columns, & 1 Way Slab)	$161,672.00	$134.72	5.2.1
Flat Plate Concrete	$60,000.00	$50.00	5.2.2

Based on these cost estimates, it would appear that the flat plate concrete construction would be the clear choice for the structural design. However, researching the different construction techniques, it was determined that the steel framing would be the better choice of building material due to its predominance in the region. There was also the concern of the time required with the erection of concrete formwork. Sufficient time is also required for the curing of the concrete and fast setting concrete could bring in more costs. Finally, concrete also had the disadvantage that it would require protection from cold during the winter. Therefore, the structural steel framing was selected as the method of construction since it was not the most expensive, can be erected fairly quickly even in cold weather, and is well established in the area.

5.2 Reinforced Concrete

Hand design calculations for different structural frame designs in reinforced concrete were prepared during design. The first design was a one-way slab with T-beams and girders. The second design was cast-in-place flat plate construction. Both methods considered the design of columns and used a 20' by 20' bay size. This was the standard bay size chosen to optimize the building layout. In all designs a dead load of 6.5 pounds per square foot was used for mechanical equipment, floor coverings, and ceilings. A live load of 40 pounds per square foot was also accounted for residential areas. These loads were calculated based on the provisions of the International Building Code.

5.2.1 Slab, Beam, and Girder Design

The design of the one-way slab resulted in a floor that was four and three quarters of an inch thick. This is a thin floor but when combined with the thickness of the reinforced concrete T-beam and girders the overall depth of construction became very large. The stem on the T-beam was calculated to be eight inches wide by fifteen inches deep. The supporting girders were calculated to be twelve inches wide by eighteen inches deep. When the dead loads of these systems were calculated, they needed a column that was twelve inches by twelve inches to support their weight. The total depth of the combined floor slab and girder system was almost two feet. Figure 13 shows the T-beam spacing and bay size layout for a section of the building.

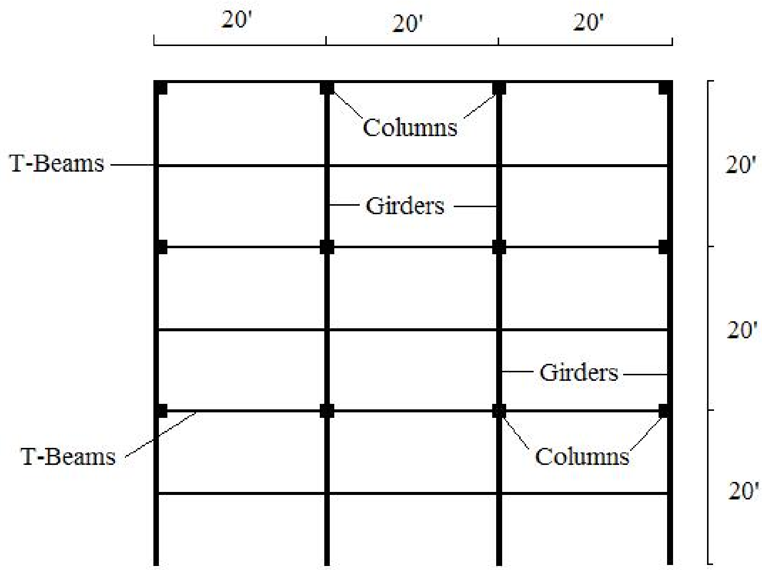

Figure 13: T-beam, Girder, and Column Layout

The first step in designing the one-way slab was to estimate the floor thickness. Based on the clear span between columns the minimum thickness of the slab was estimated to be 4.75 inches. After this step the trial service loads were computed using the 6.5 pound per square foot dead load, the 40 pound per square foot live load, and the weight of the 4.75 inch thick concrete slab. The next two steps were to select the load and strength reduction factor. The flexural reinforcement was designed to meet the requirements for shrinkage, temperature reinforcement, and crack control. A #3 bar spaced at twelve inches was adequate to meet all of the requirements.

The T-beam was designed based on the trial factored loads acting on the beam. A strength reduction factor was selected to determine the trial load per foot of the beam. The next step was choosing the actual size of the beam stem. A beam with a depth of 15 inches and width of 8 inches was selected based on the required shear capacity. The flexural steel reinforcement was designed once the new dead load was calculated and the moments and flange width were determined. Two #4 bars were used in the top and bottom of the T-beam to meet requirements so no steel was required in the slab. The bars on the top of the beam are using compression steel. After defining the steel for shear reinforcement the last step was to calculate the bar cutoffs and lap splicing. A typical T-beam is shown in Figure 14.

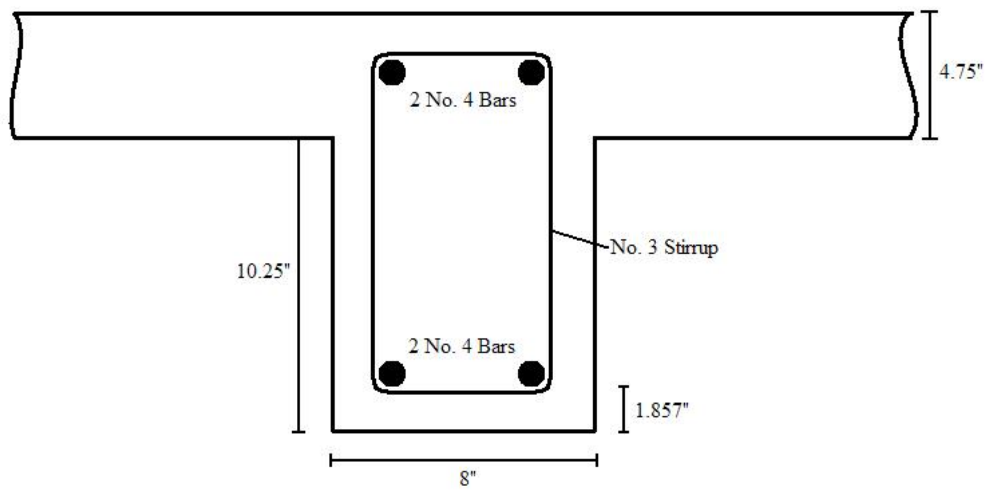

Figure 14: Typical T-Beam

The girder was designed to support the loads of the one-way slab and T-beam. First the dead load of the beam was estimated and the factored moment was calculated. Next the size of the girder was determined to have a width of 12 inches and a depth of 18 inches. Once this was determined the dead load could be re calculated and the moment revised. Following this the area of reinforcing steel was calculated and the bars were selected. Finally the moments were checked to make sure the beam could support the loads. A typical reinforced concrete girder section is shown in Figure 15.

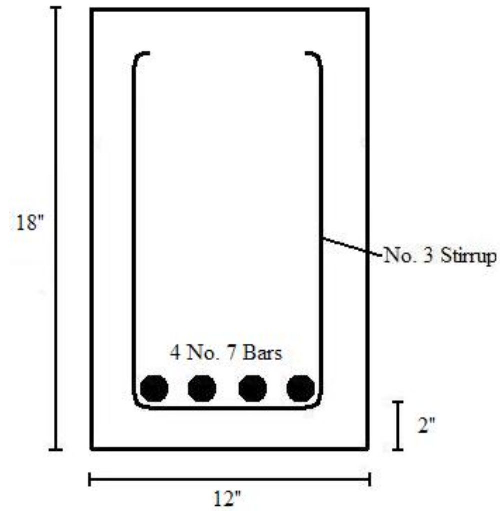

Figure 15: Typical Girder

The last part of the concrete design was the columns. The columns were designed to support all loads placed on the structure. The design was completed for an interior column on the first floor of the building because it has the largest tributary area and supports the greatest load. The first step was to select a trial size and trial reinforcements based on what moments were acting on the column. After steel was selected the columns were finished by designing lap splices and selecting column ties. A standard column is shown in Figure 16. All of the calculations for slabs, beams, columns and girders designs can be seen in Appendix 13.2.

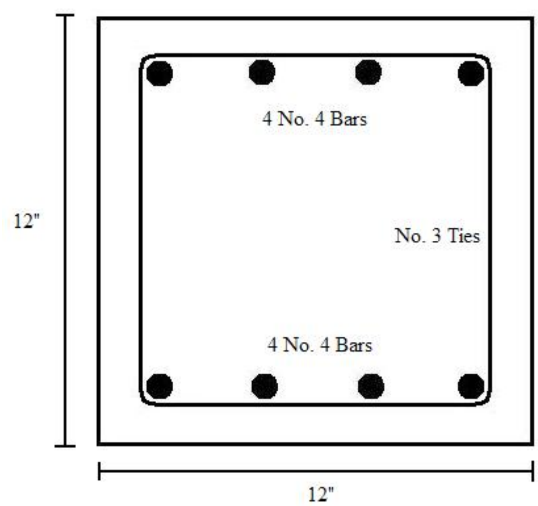

Figure 16: Typical Column

5.2.2 Cast-in-Place Flat Plate Construction

The use of cast-in-place flat plate construction was also evaluated. This resulted in a floor thickness of seven and a half inches, and columns that were twelve inches by twelve inches at the exterior corners and twelve inches by twenty inches in all other cases. The flat plate design would also use much less reinforcement than the beam and girder design.

The design of the flat plate system was an eleven step process. The first step in calculations was to determine the load combinations. A dead load of 6.5 pounds per square foot, a live load of 40 pounds per square foot, and the weight of the slab were used in all calculations. The second step was to select the thickness of the slab based on the deflections. A minimum thickness of seven inches was determined. This thickness had to be checked for shear around the columns. The thickness was increased to 7.5 inches to resist the shear at the exterior columns.

The next few steps were to divide the slab into moment strips along the column lines and calculate the moments. The moments were calculated creating charts for each slab strip in the east to west direction and north to south direction, which can be found in Appendix 13.2.5. The moments that were calculated had to be distributed to all of the moment strips and column strips so that the reinforcement could be designed. The reinforcement for all strips spanning east to west and north to south was determined based on the minimum area of steel required due to the moments. Once the steel reinforcing for flexure was established, the shear at the exterior columns had to be checked for shear and moment transfer. Calculations indicated that the reinforcement and 7.5-inch slab thickness selected were adequate to support the loads. All of the calculations and examples for the flat plate construction can be seen in Appendix 13.2.5.

5.2.3 Comparison

The better choice of the two reinforced concrete systems would be the flat plate construction. The slab, beam, and girder design could support more load but the flat plate design was more affordable. The cast in place beam and one way slab system had a cost of $13.55 per square foot and the cast in place flat plate system had a price of $11.57 per square foot. The flat plate design resulted in a thinner floor slabs and still adequately supported the necessary loads. By decreasing the thickness of the floor slabs this design would reduce costs in other areas of construction. The total height of the building will be reduced by a few feet, which would reduce the amount of brick used on the outside of the building and the length of the risers for the utilities running through the building. The flat plate design is one smooth continuous slab with no beams that are thicker than the depth of the slab. This would make installing utilities much easier because they would be placed within the floor slab and have no obstructing beams. If a reinforced concrete design was chosen, then the cast-in-place flat plate construction would work best.

5.3 Steel and Structural Components

The design of the structural steel frame involved the technical design of the gravity and lateral load resisting systems along with their integration into the architectural layout. First, options for infill beams and girders in typical structural bays along with supporting columns were designed for gravity loads as part of the gravity system. Second, beams, girders, and columns were designed for atypical areas of the building such as girders spanning over the entranceway and atrium. Once a gravity system was determined, focus then shifted to the lateral load resisting system with the investigation of both braced and un-braced frames. Finally, the fit up and connection considerations were investigated for structural members.

5.3.1 Concrete Slab and Steel Decking Design

The first step in the design of the structural components was the design of the concrete floor and roof slab. This system was composed of a continuous concrete slab supported over steel infill beams with corrugated steel decking used as formwork and reinforcement. A cross-section of the slab can be seen in Figure 17. The design was dependant on code requirements and the span of the slab used in calculations. First, the IBC was researched to determine the fire safety requirements for the floor slab. Table 601 of the IBC specified that floors for type I construction must have a 2-hour fire rating (IBC, 2006), while Table 720.1 stated that in order to meet this rating, a concrete slab with 1 ½ " deep steel decking must be 3" thick. Therefore, the slab was assumed to be 4.5" thick to meet this requirement and also provide enough cover for shear studs. Using the Steel Deck Institute's (SDI) 2006 Manual of Construction with Steel Deck, a 1 ½" deep steel deck was selected for the design of the slab as a typical sized corrugated decking for floor systems (Steel Deck Institute, 2006). The next step in the design was to determine the design span of the slab and use calculations to see if its thickness and reinforcement were adequate. Looking at the possible design schemes for infill beam, the largest tributary span was 5 ft. Therefore, this value was used and the slab was designed as a simply supported beam by considering a 1-foot wide section between two beams. Through these calculations, which can be found in Appendix 13, the slab was determined to have adequate moment capacity to support loads, and the steel decking was verified as adequate reinforcement for the concrete. A cross-section of the slab is shown in Figure 17.

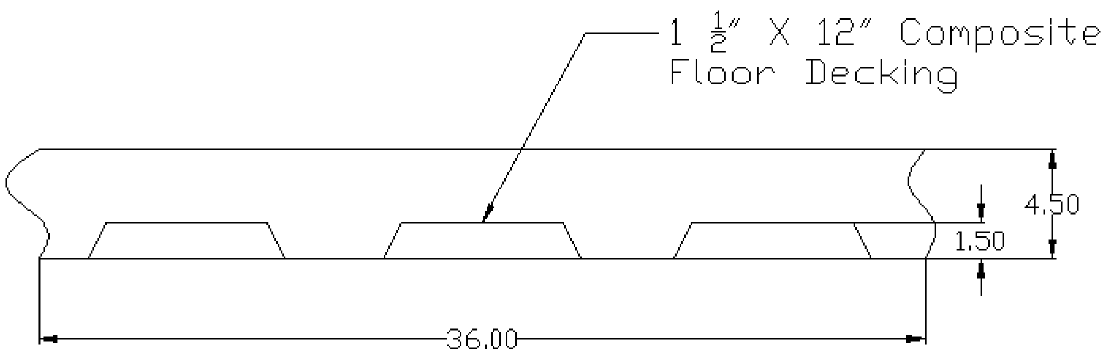

Figure 17: Concrete Floor Slab Design

5.3.2 Composite Infill Beams and Girders

Once the thickness of the concrete slab was determined, the design of typical infill beams and girders could proceed with a focus on varying options for a structural bay. Figures 18 through 22 illustrate the five infill bays schemes that were investigated. Hand calculations along with Excel spreadsheets were used in the design of these options and can be found in Appendix 13.5.1. Each beam and girder was designed as a composite beam with part of the concrete slab acting in conjunction with the beam’s top flange through the use of shear connectors or studs. Composite design allows for larger moment capacity and reduced beam size. Preliminary cost data for steel and shear studs using estimates from the 2007 RS Means Construction Cost Data were then used to decide which scheme should be chosen for the design of the building. These cost estimates were based on dollars per ton of steel and dollars per shear stud with adjustment factors added for labor, equipment, overhead, and geographic region of the country.

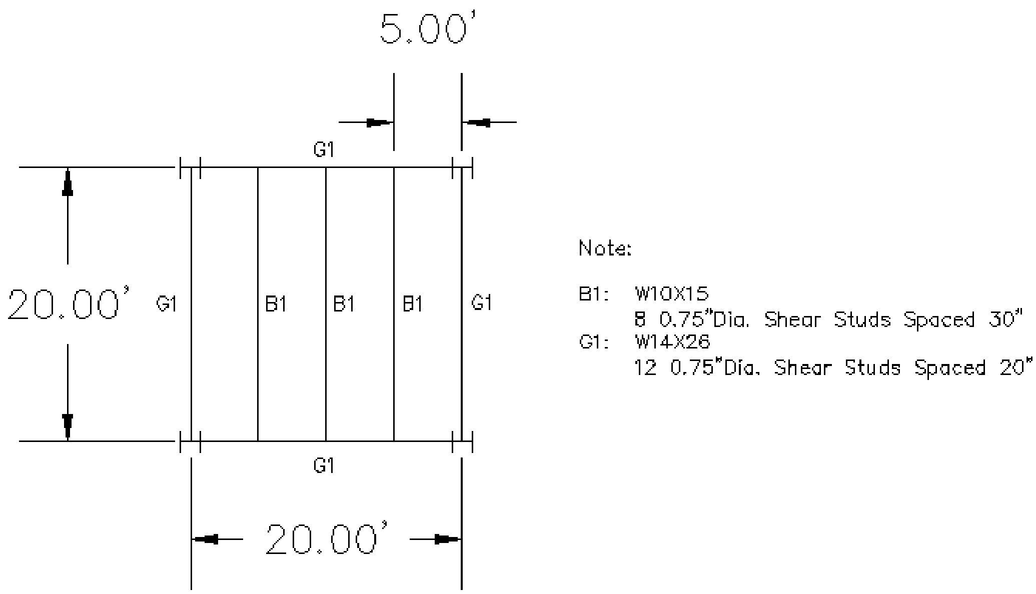

Figure 18: Structural Bay Scheme 1

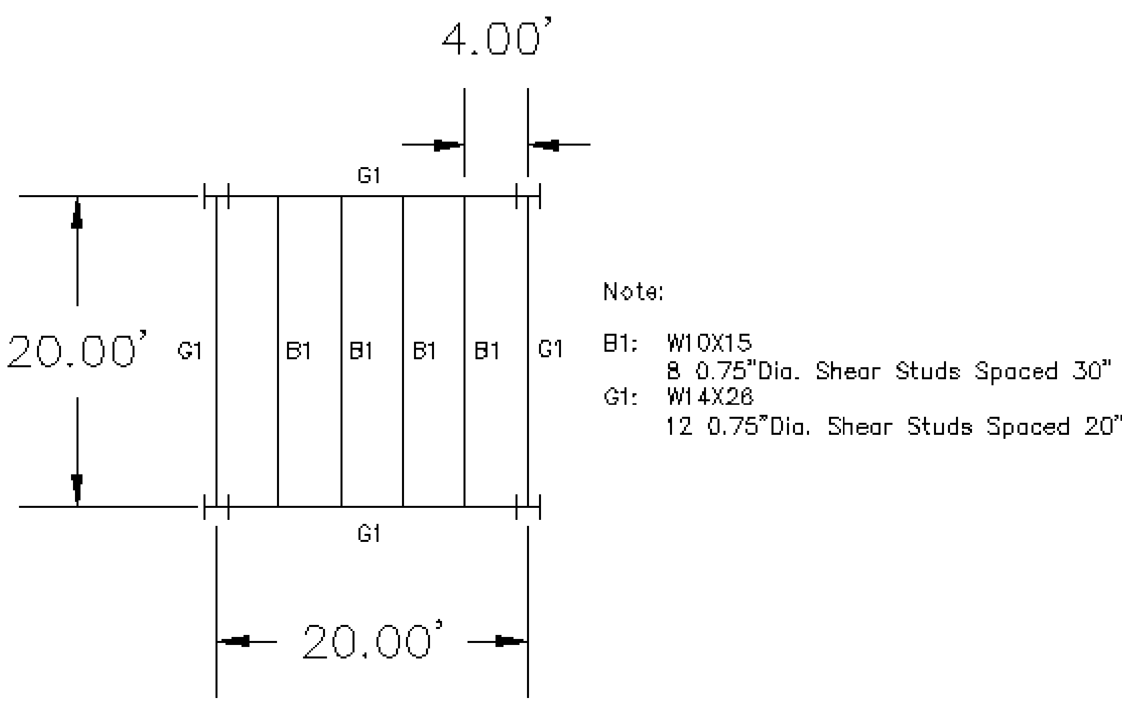

Figure 19: Structural Bay Scheme 2

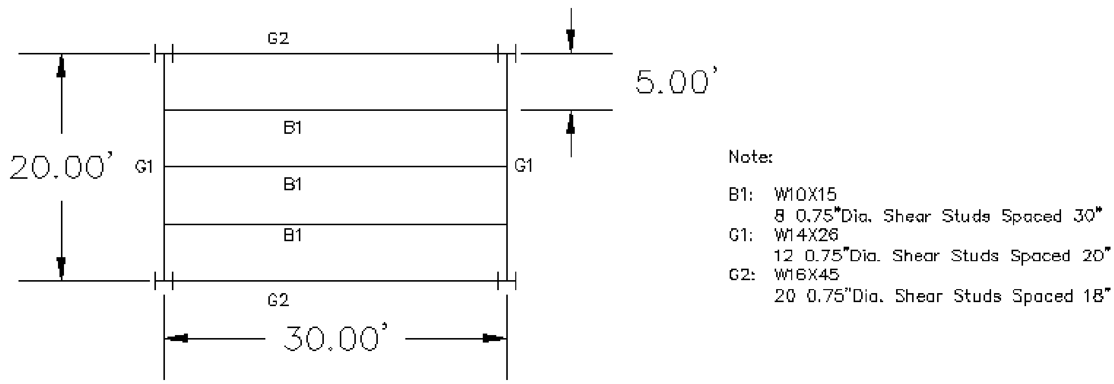

Figure 20: Structural Bay Scheme 3

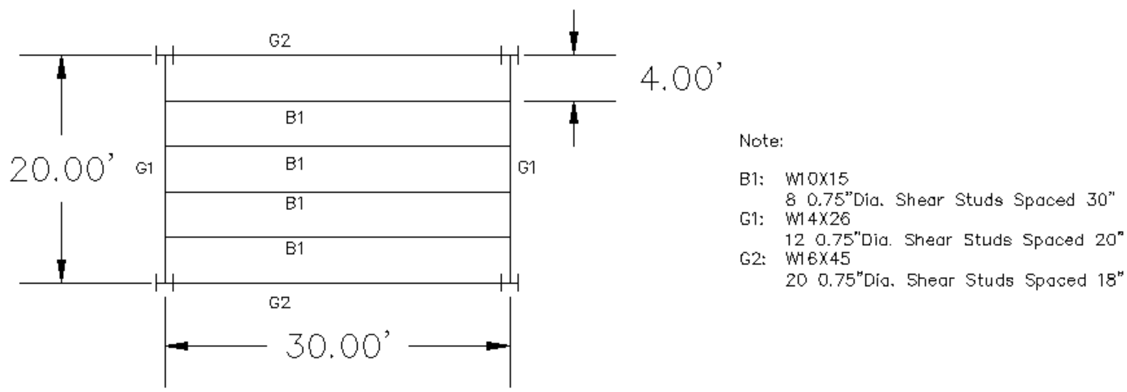

Figure 21: Structural Bay Scheme 4

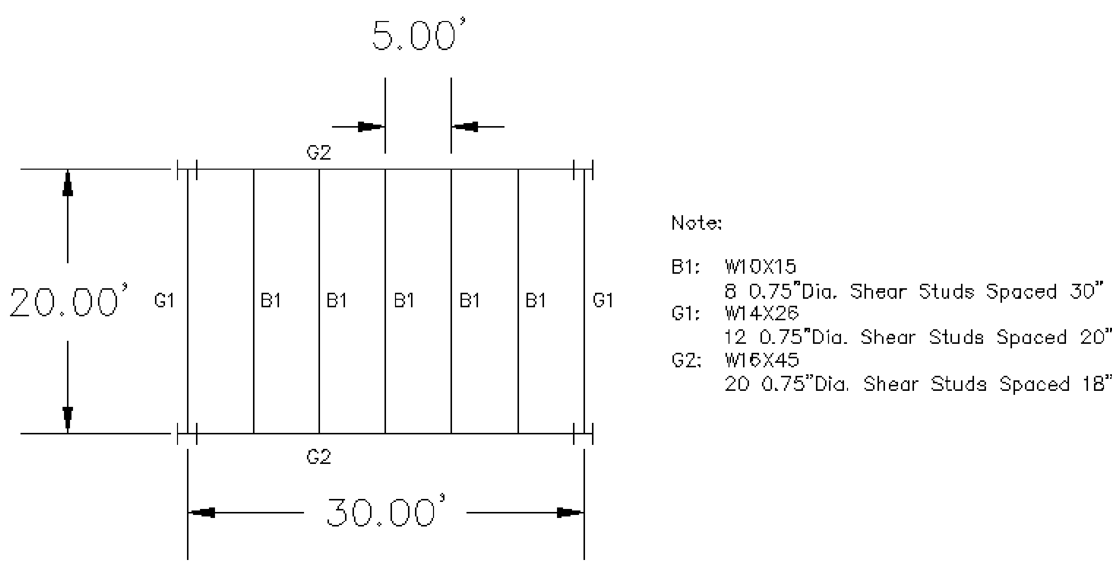

Figure 22: Structural Bay Scheme 5

Table 5 below illustrates the results of this cost investigation using the RS Means data. The steel was priced at $3050 per ton of material while a shear stud was priced at $2.10 per stud. Looking at the first section of the table, bay Scheme 1 proved to have the lowest design cost while considering each bay individually. However, a 60-foot by 20-foot section of the building would require three repetitions of Scheme 1 while Scheme 5 would require only two repetitions and two fewer columns. Therefore, the cost of a 60-foot by 20-foot section was calculated for Schemes 1 and 5 to see which would offer the most savings in terms of construction. First, the second section of Table 5 compares the bay prices based on only beam and girder sizes. Again, bay Scheme 1 had the lower cost by $3,149.90. Table 6 takes the comparison one step further and calculates a 20-foot X 60-foot section over four stories and accounts for the change in column number. While many would predict Scheme 5 to be cheaper due to its reduction in columns, bay Scheme 1 is still cheaper by a difference of $9,187.96. Therefore, bay Scheme 1 was selected because it was the cheaper option and could be fit into the building layout.

Looking at the square foot costs of Table 5, bay one is $11.74 per square foot in terms of material. This value coincides with the listed cost benchmark for $11.75 per square foot for a 20--foot by 25-foot structural bay with W21 composite beams, a steel deck, and 5.5 inch concrete slab in the 2006 RS Means Assembly Costs Data. However, the larger 20-foot by 30-foot bay scheme would still be advantageous because it would allow more flexibility in designing spaces with fewer columns. This advantage is especially important to areas such as the restaurant and other retail space, where more open space is a selling point for potential tenants. Therefore, the roughly $9,000 addition in cost per section could be worth twice as much in profits through either the sale or lease of retail space as the administration so chooses. Therefore, the larger bay Scheme 5 could be reserved as an alternate option for more open space.

Table 5: Steel Bay Scheme Comparison

Bay	cost/ton	ton	cost of steel	cost/stud	# of studs	cost of studs	Total Cost	Cost/sqft
1	$3,050	1.49	$4,544.50	$2.10	72	$151.20	$4,695.70	11.73925
2	$3,050	1.64	$5,002.00	$2.10	72	$151.20	$5,153.20	12.883
3	$3,050	3.04	$9,272.00	$2.10	100	$210.00	$9,482.00	23.705
4	$3,050	3.19	$9,729.50	$2.10	104	$218.40	$9,947.90	24.86975
5	$3,050	2.62	$7,991.00	$2.10	104	$218.40	$8,209.40	20.5235
	cost/ton	ton	cost of steel	cost/stud	#of studs	cost of studs	Total Cost (60'X20' Section)	Cost/sqft
1	$3,050	3.95	$12,048	$2.10	192	$403.20	$12,450.70	10.37558
5	$3,050	4.98	$15,189	$2.10	196	$411.60	$15,600.60	13.0005

Table 6: Steel Bay Scheme Comparison (Including Columns)

Structural Bay with Consideration of Column Reduction

Scheme	Item	Quantity	Cost/Item	Total Cost	Location Factor	Cost
1						
	20X20 Bay (20'X60' Section)	4	$12,450.70	$49,802.80	1.084	$ 53,986.24
	Interior Column 3-4 Floors W10X26	4	$ 436.15	$ 1,744.60	1.084	$ 1,891.15
	Interior Column 1-2 Floor W10X33	4	$ 654.23	$ 2,616.92	1.084	$ 2,836.74
	Exterior Column 3rd Floor W10X26	8	$ 436.15	$ 3,489.20	1.084	$ 3,782.29
	Exterior Column 1st Floor W10X33	8	$ 654.23	$ 5,233.84	1.084	$ 5,673.48
	Corner Column 3rd Floor W10X26	4	$ 436.15	$ 1,744.60	1.084	$ 1,891.15
	Corner Column 1st Floor W10X33	4	$ 654.23	$ 2,616.92	1.084	$ 2,836.74
	4.5" Concrete Slab	4	$ 2,106.00	$ 8,424.00	1.084	$ 9,131.62
	Steel Decking	4	$ 2,736.00	$10,944.00	1.084	$ 11,863.30
	Total	**-**	**-**	**$86,616.88**	**-**	**$ 93,892.70**
5						
	20X30 Bay (20'X60' Section)	4	$15,600.60	$62,402.40	1.084	$ 67,644.20
	Interior Column 3rd Floor	2	$ 436.15	$ 872.30	1.084	$ 945.57

W10X26					
Interior Column 1st Floor W10X39	2	$ 773.18	$ 1,546.36	1.084	$ 1,676.25
Exterior Column 3rd Floor W10X26	6	$ 436.15	$ 2,616.90	1.084	$ 2,836.72
Exterior Column 1st Floor W10X33	6	$ 654.23	$ 3,925.38	1.084	$ 4,255.11
Corner Column 3rd Floor W10X26	4	$ 436.15	$ 1,744.60	1.084	$ 1,891.15
Corner Column 1st Floor W10X33	4	$ 654.23	$ 2,616.92	1.084	$ 2,836.74
4.5" Concrete Slab	4	$ 2,106.00	$ 8,424.00	1.084	$ 9,131.62
Steel Decking	4	$ 2,736.00	$10,944.00	1.084	$ 11,863.30
Total	**-**	**-**	**$95,092.86**	**-**	**$103,080.66**

5.3.3 Column Design

With the infill beams and girders designed for typical structural bays, typical interior, exterior, and columns were designed based on gravity loads. The columns were designed in two-story stacks with one continuous column extending from the ground to third floor and another column extending from the third to fourth floor. This will ease and speed up the erection process and reduce connections between columns. The columns were designed only for axial gravity loads since most of the lateral loads and deflections will be resisted by the lateral load resisting frame. However, some of these columns will later make up the resisting frame and there size must be adjusted.

Axial loads on the column were calculated using the tributary areas associated with each type of column. Through hand calculations and Excel spreadsheets which can be found in Appendix 13.5.2, it a W10X26 section was selected to meet design criteria for exterior and interior column stacks beginning on the third floor along with all corner columns. For exterior and interior column stacks beginning on the ground floor, a W10X33 section was selected based on the calculations. One issue with these column sizes was a constructability concern for connecting the W14X26 girders to the W10X26 columns. However, the girder's flange width of 5.03 inches is less than 8.25 inches and 5.77 inches which are the web depth and flange width respectively of the W10X26 column. Figures 23 and 24 illustrate typical sections of the building frame with the columns and column sizes labeled.

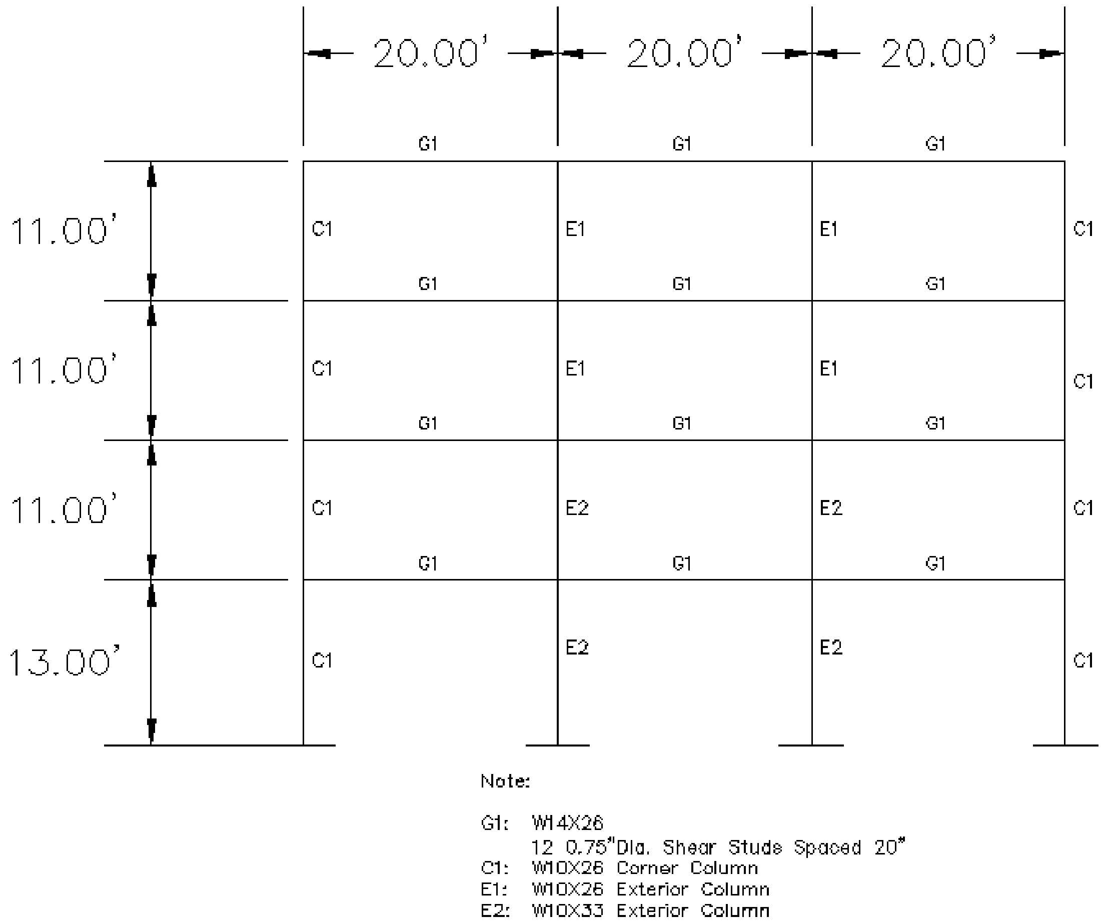

Figure 23: Typical Elevation 1

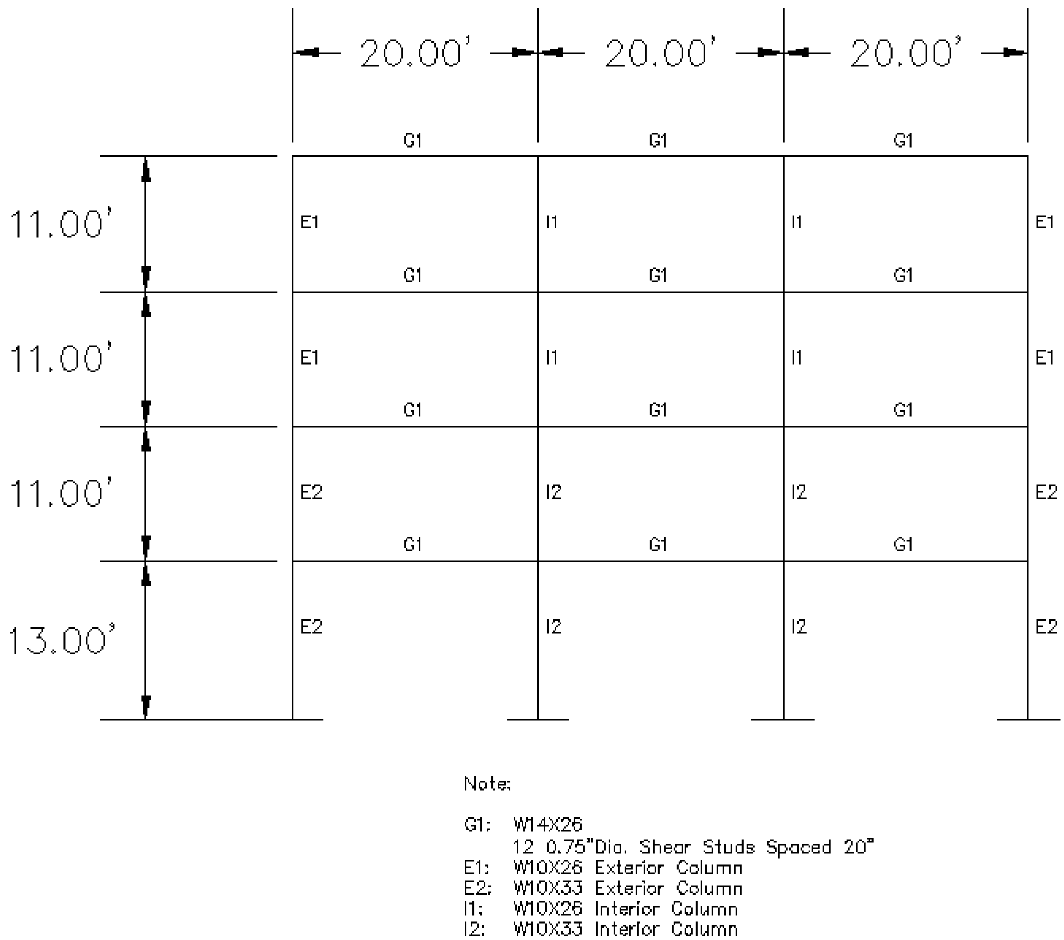

Figure 24: Typical Elevation 2

5.3.4 Atypical Areas of the Gravity System

Next, with typical bays and columns designed for the structural frame, the atypical areas of the structural frame were addressed. Three areas required special calculations for the design of beams, girders, and columns: the 20’X40’ bays in the center of the building, the bays located on the second floor over the atrium, and the common area at the northwest end of the building. The design of elevator and stairwell spaces are discussed separately in Sections 5.3.6 and 5.3.7.

First, the atrium on the ground floor of the building spans 40 feet. If typical structural bays were used for this area, columns would be located in the middle of this public space. Therefore, Figure 25 illustrates a bay scheme for the second floor layout over the atrium where bays are increased to 20 feet by 40 feet in order to allow for the removal of columns. There is also a 10-foot by 40-foot bay to account for the hallway on the second floor. From the design calculations and Excel spreadsheets, the typical W14X26 girder was increased to W21X57 and W30X99 steel members as shown in Figure 25 in order to resist loads and deflection limits. This design also increased the size of the columns since a W30X99 girder cannot be fit up to a W10X26 column stack. Therefore, the columns were upgraded to a W18X86 steel member in places with connections to these girders.

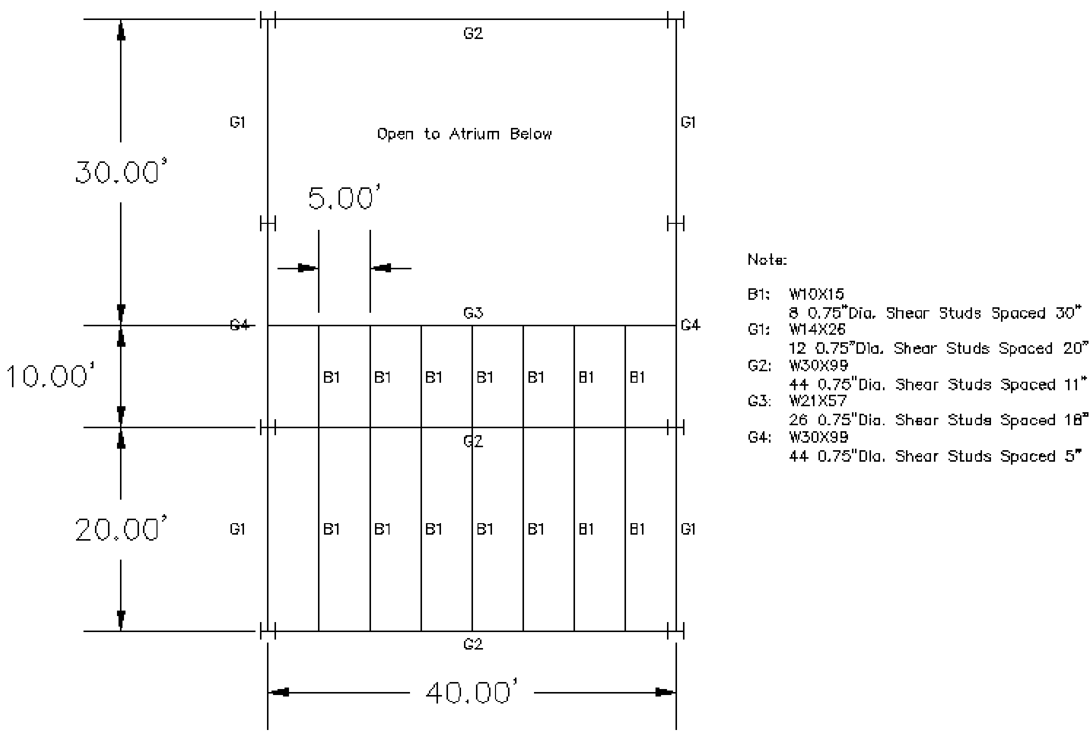

Figure 25: Design of Second Floor Over Atrium Space

Since the atrium space is only located on the first level, it would initially be assumed that the upper floors have typical structural bays, with column loads being supported by transfer girders that span over the atrium. However, these concentrated columns loads can cause large bending moments and deflections in the spanning girders. In order for the loads and deflections on the W30X99 girders marked as G2 in Figure 25 to be reduced, the columns were not only removed from the atrium space on the ground floor but at all stories above the atrium. In other words, the atypical 20-foot by 40-foot bay over the atrium, which is shown again in Figure 26, was applied on all four floors over the atrium and entranceway. If not, the girders would have increased to a significantly larger W33X141 sized girder. Therefore, no columns in the drawings are discontinuous and the 40-foot long girders are not transferring concentrated column loads. Again, column sizes must be increased to W18X86 in order for proper fit up of the girders to the columns.

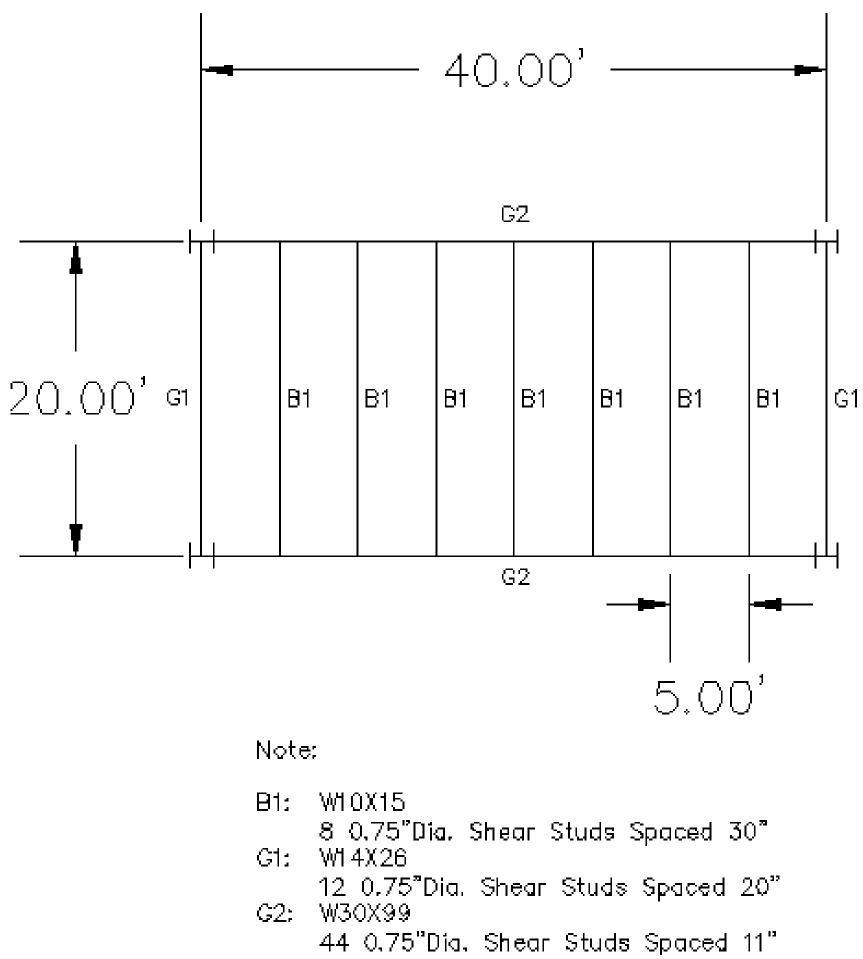

Figure 26: Atypical Bay for 3rd and 4th Floors and the Roof

The third atypical area involved the design of the common area on the northwest end of the building. Shown in Figure 27, the layout has a diagonal cut that roughly parallels Lancaster Street. The area was designed for gravity loading with typical beam, girder, and column sizes used in design. Even though the tributary area is smaller and the structural members could possibly be reduced, from a production and fabrication standpoint it is more effective to use the standard sizes of the project.

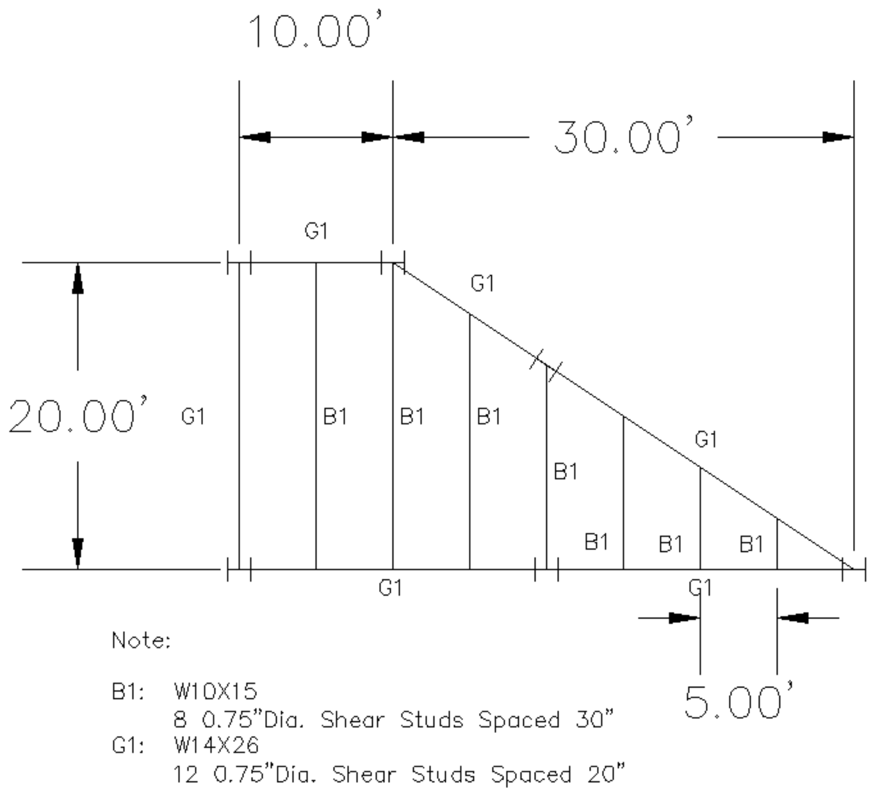

Figure 27: Northwest Common Area

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5.3.5 Lateral Load Resisting System

Once the gravity system was designed for the building, the process of designing the lateral load resisting system was begun. Wind and Earthquake loads were calculated using sections of the IBC 2006, ASCE 7 and examples from Design of Wood Structures by Breyer (2003).

First, wind loads were calculated by using wind pressure values from the ASCE 7 Minimum Design Loads for Buildings and Other Structures. These wind pressures were multiplied by the tributary wall area of each story to get the wind load in kips at each floor. Next, earthquake loads were determined by using seismic factors from the IBC and design procedures from the Breyer text, illustrating the process that was developed based upon IBC and ASCE 7 processes, in which seismic factors and the weight of the building are used to calculate the base shear force of the building during an earthquake and the distribution of that shear to each floor. Ultimately, the earthquake loading proved to be greater in value than the wind-loading, and it was for the initial design of lateral resisting frame members. This design was completed through calculations and the use of a computer program entitled RISA-2D. During an earthquake, deflection of the building frame is not the major concern of occupants but it is a concern during normal occupancy conditions. Therefore, once initial member sizes were determined, the frame was redesigned using RISA-2D in order to limit lateral deflections. To simulate normal lateral loading, a convention of two-thirds of the wind design load was used along with a total lateral deflection limit of H/500, or 1.1 inches, for our building.

For design, there are two types of frames that can be used for the lateral load resisting system: a braced frame and a rigid or un-braced frame. A braced frame consists of axially-loaded, pin-connected members while an un-braced frame consists of framing members with fixed end connections which are designed to resist bending moments. The decision on which frame would be chosen for the building was based on two major criteria: the cost savings provided by the frames along with its ability to be integrated effectively into the architectural layout. The lateral resisting system, when placed within the structural layout, must resist lateral loading from all directions, and be placed symmetrical about the centroid of the building in order to reduce instabilities and eccentric moments which would cause the building to twist. This is all in addition to the requirement that frames must not intersect building spaces and must not interrupt the functions of the building. Meeting these two criteria proved to be a challenge for the design team. First, the footprint of the building caused the team to design lateral systems for both legs of the building. Second, since the interior layout of the retail and residential spaces vary; it was difficult to place a frame without some disruption to the layout. For the graduate housing project, ultimately five braced frame options were designed along with one un-braced frame option.

Figures 28 through 32 illustrate the elevation view of the five schemes designed for the project. Scheme 1 was a braced frame design with a frame one bay wide and a single diagonal brace at each story. This scheme was considered since it was a basic braced frame that could allow for space below it for potential openings depending on its placement in the building. Scheme 2 was another braced frame 20 feet wide with K diagonals at each floor and was considered because it would potentially allow for space below it and reduced member sizes. Scheme 3 was composed of two braced frame connected by a middle bay width of rigid links for a total length of 60 feet. Since the hallway travels through the center of the building, this frame was considered in hopes that it would reduce required member sizes while also avoiding interference with the hallway. Scheme 4 involves a combination of Schemes 1 and 2 with a single diagonal on the ground floor and K girders on the residential floor. It was the hope of the design team that this design would provide the least interference with the building layout depending on the placement of the frame. Finally, the last scheme involved an un-braced frame which had the advantage of no diagonals to interfere with hallways, doors, and windows.

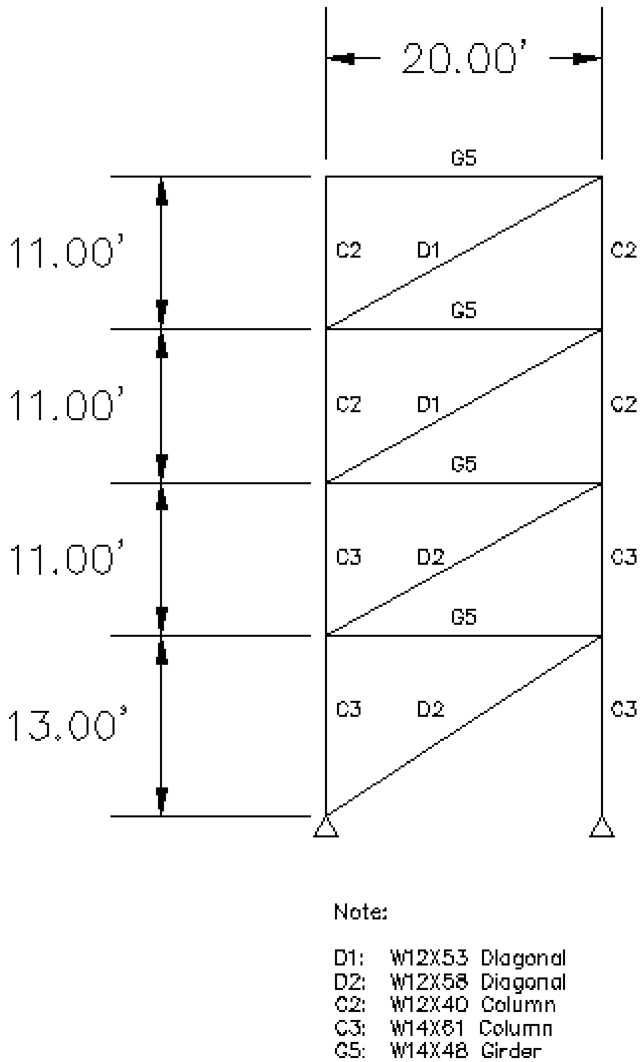
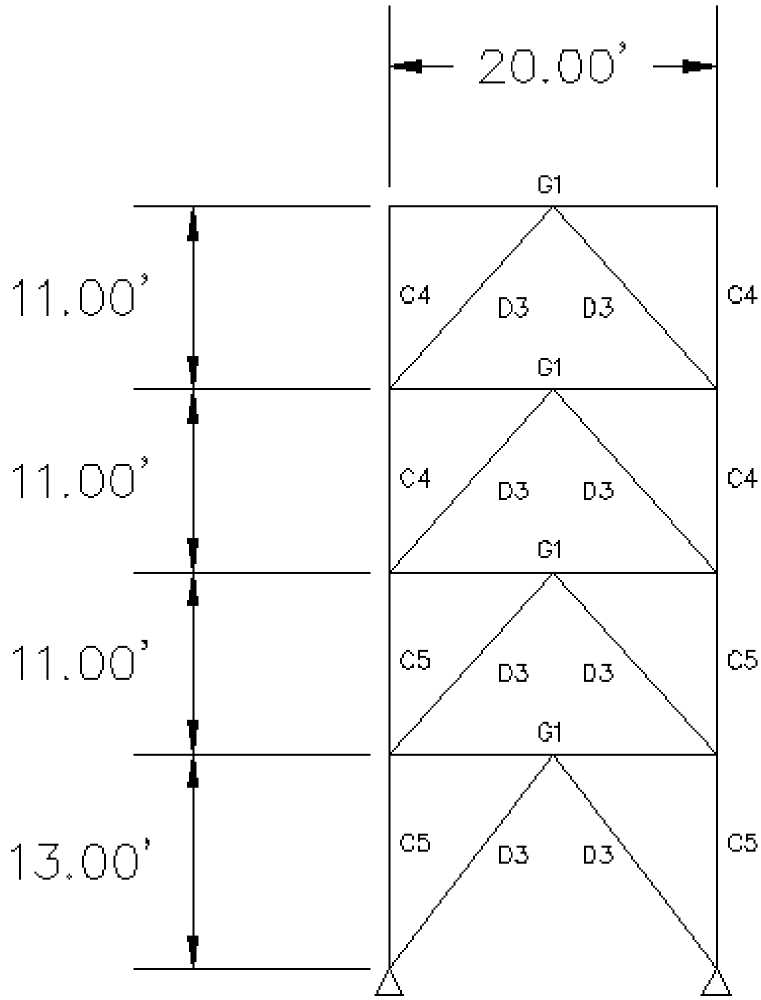


Figure 28: Braced Frame Scheme 1



Note:

G1: W14X26
C4: W10X26 Column
C5: W10X49 Column
D3: W10X33 Column

Figure 29: Braced Frame Scheme 2

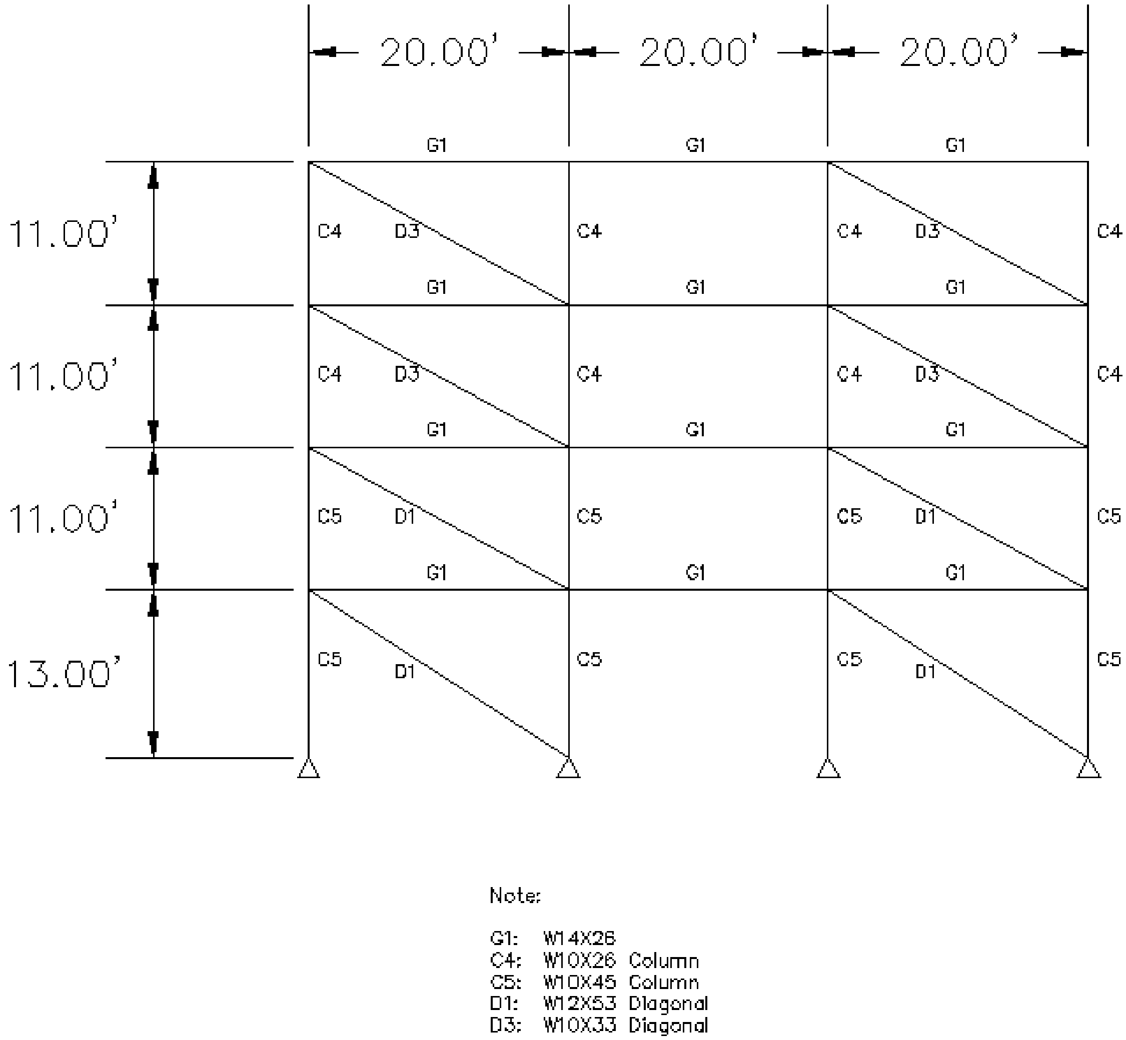


Figure 30: Braced Frame Scheme 3

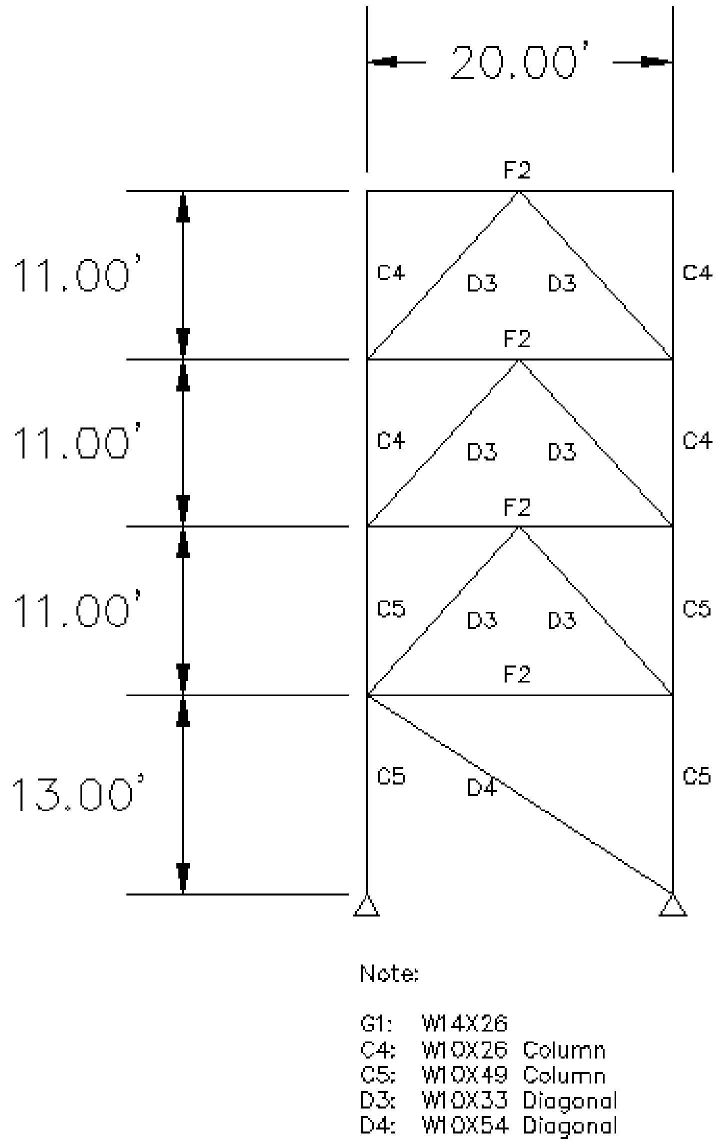


Figure 31: Braced Frame Scheme 4

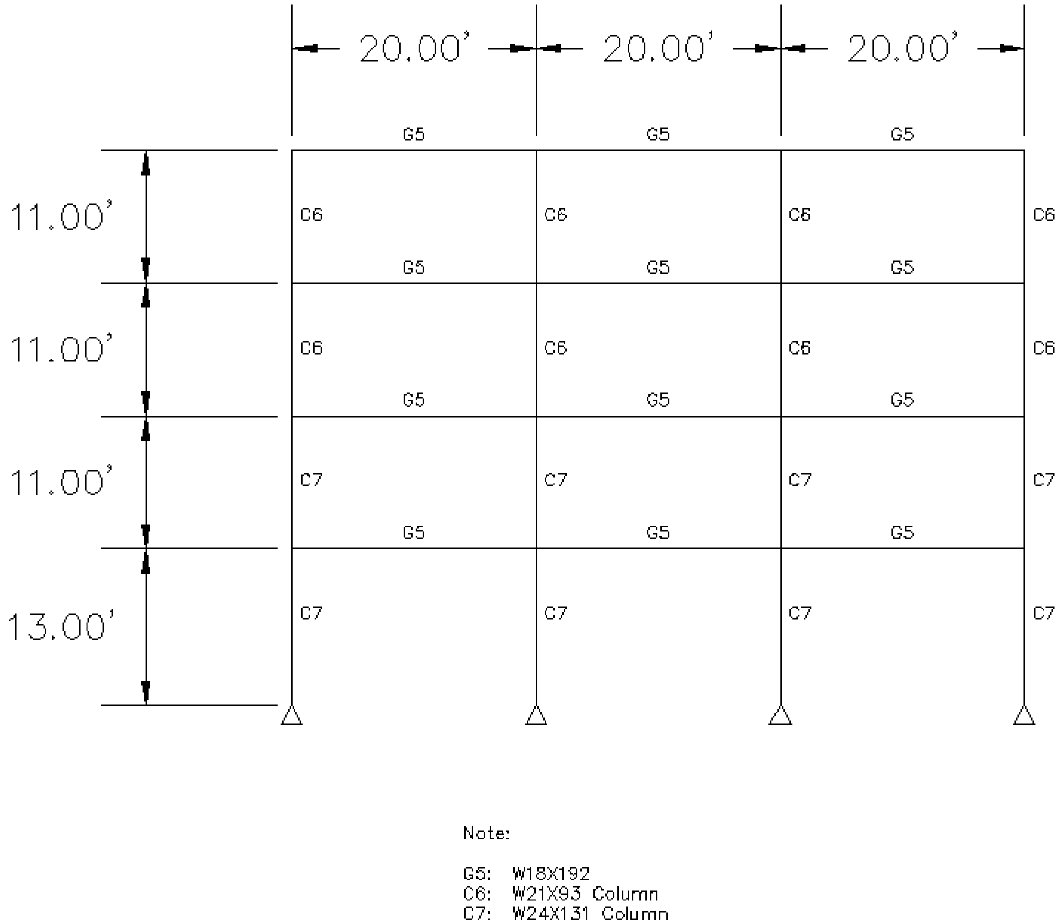


Figure 32: Un-Braced Frame Scheme 5

Again, the decision of which frame was best suited for the project was based on cost savings and ease of integration into the architectural and structural layouts. Once each frame was designed for lateral loads, a preliminary cost analysis was conducted. Table 7 displays a cost comparison between the five frame options from Figures 28-32. From this comparison, Schemes 1, 2, and 4 had the lowest cost. This was due to the diagonals of the braced frames and the presence of only axial loads in the frame members. Since the un-braced frame in Scheme 5 had to also resist bending moment, the required member sizes were much larger, which increased cost. Additionally, even though Scheme 3 was technically two frames, it would still have required the same number of frames in the building and was therefore not cost effective.

Table 7: Steel Frame Cost Comparison

Scheme	Cost
1	$ 20,178.84
2	$ 16,375.49
3	$ 38,217.22
4	$ 16,548.98
5	$ 112,241.91

However, the frame must be also to be integrated into the architectural and structural layouts of the building. To create a symmetric resistance to lateral loading, eight frames were placed in the building at locations shown in Figure 33. Looking at the three braced frame options, it was determined that the braced frame in Scheme 1 could be placed in the building with the least impact to the architectural design. Scheme 2 and Scheme 4 would ultimately bisect the hallways in the center of the building and therefore could not be used. However, Scheme 1 also created design impacts which included diagonals on exterior wall sections which created less space for windows in some rooms and some encroachment of diagonals into corridor space. However, designers felt that these impacts can be covered and hidden with architectural accents. Overall, this section of the building design proved to the group that cost is not always the defining factor in the design process.

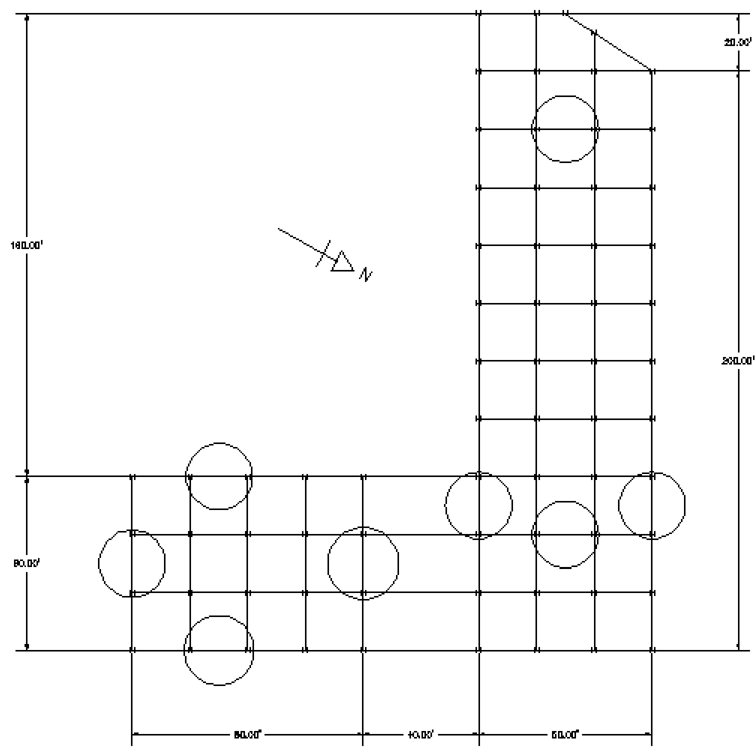


Figure 33: Location of Braced Frames, Schemes 1 or 6

In an attempt to improve on the design of the braced frame, a sixth frame, which was a variation of Scheme 1, was studied by the team. Shown in Figure 34, the frame is a smaller 10-foot wide frame. Gravity columns and girders are included on the right side of the frame in order for a comparison to be made later with the 20-foot wide frames of Schemes 1 and 2. Diagonals similar to those of Scheme 1 were placed in the left bay of the frame, which allowed the other bay to have free space for windows and corridors. The framing members were then designed in order to meet loading and deflection requirements with final sizes shown in Figure 34. Based on these sizes, a cost estimate, shown in Table 8, was then prepared so that this frame could be compared with Schemes 1 and 2. Ultimately, this new steel frame had an estimated cost of $24, 247.42, which is only slightly higher than Scheme 1 and offers more architectural advantages. However, this new steel frame would cause additional cost with the need for a third concrete footing. Therefore, the architect and client would need to determine if the encroachment of

Scheme 1 could be adequately accounted for or if this new sixth scheme was worth the added cost.

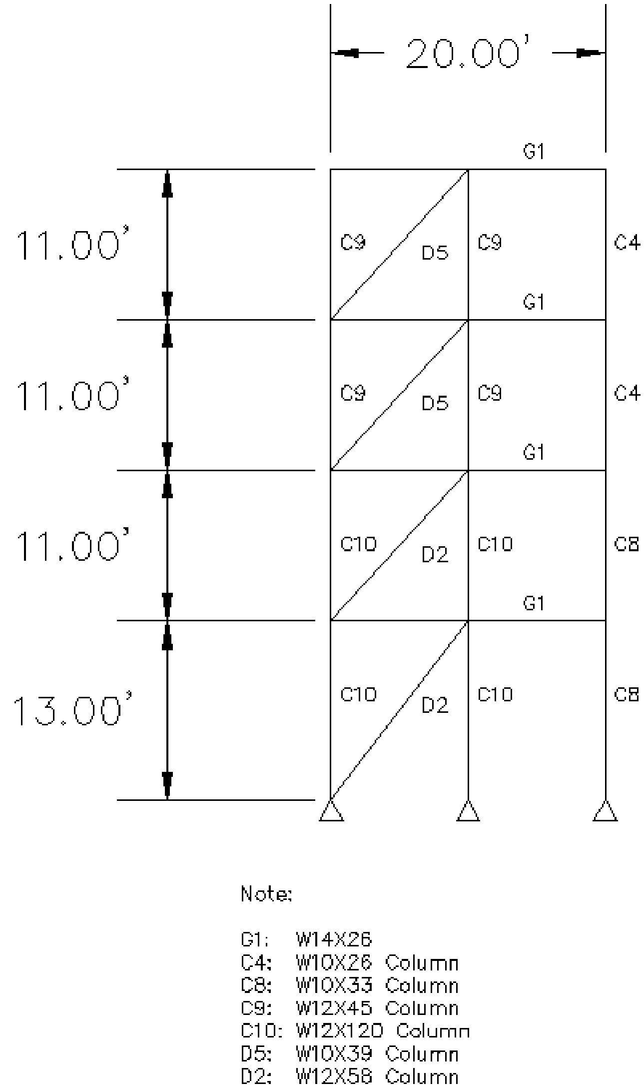


Figure 34: Braced Frame Scheme 6

Table 8: Steel Cost Revisited

Steel Frame Cost Comparison		
Scheme		Cost
1	$	20,178.84
2	$	16,375.49
6	$	24,247.42

5.3.6 Stair Design

While not a part of the major structural system, the design of the stairways was necessary to create a safe and functional egress system for the building. Ultimately three main stairways are located in the building: one at the west end of the building; one at the south end of the building; and in the center of the building off of the atrium. This center staircase also includes a grand staircase for the flight between the first and second floors. Each of these locations can be seen in Figures 9 through 12 or the layout plans of the building.

Table 9 illustrates specifications taken from the 2006 IBC for the design of the typical staircases. In addition, a 100 psf live load was used for the design of beams, girders, and columns.

Table 9: Stair Specifications

Stairs Specification		
No.	Description	Source
1	To be considered part of a means of egress, must have a width of 48 inches minimum between handrails and must incorporate and area of refuge	IBC 2006 Section 1007.3
2	The clear width of 48 inches between handrails is not required at exit stairway as in buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 or 903.3.1.2	IBC 2006 Section 1007.3
3	Width shall not be less than 44 inches	IBC 2006 Section 1009.1
4	Stair treads and risers shall be of uniform size and shape.	IBC 2006 Section 1009.3.2
5	The width of landings shall be not less than width of stair. Every landing shall have a length in direction of travel not less than stair width	IBC 2006 Section 1009.4
6	One stairway will lead to the roof	IBC 2006 Section 1009.11
7	Exit stairways shall be fire resistant and comply with section 706 for exterior walls	IBC 2006 Section 1020.1 - 1020.1.4

First, the design of a typical two flight staircase, which is shown in Figures 35 and 36 below, was designed by the project group. For design, it was assumed that stairs were composed C10 steel channel stringers, steel angle supports, gypsum board, and a 2 inch concrete topping. From these dead loads along with the 100psf live load, it was determined that W10X15 and

W14X26 sections could be used for beams and girders respectively. While smaller sections could have potentially been used, the same sizes as those used for the gravity system were chosen in order to facilitate constructability when material arrive on the jobsite.

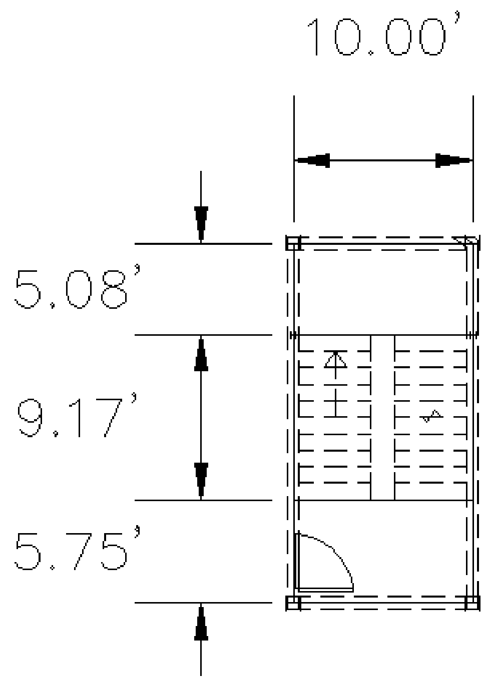


Figure 35: Typical Plan of Two Flight Staircase

For column design, tributary areas for some columns were decreased since two additional columns were added to provide a column at each corner of the stairway. While stairway girders could have been connected to girders of the gravity system, it was decided to add two columns so that the staircase could support itself in the event of an emergency. After engineering calculations were conducted, it was decided to use similar columns to the gravity system in order to ease constructability on the jobsite.

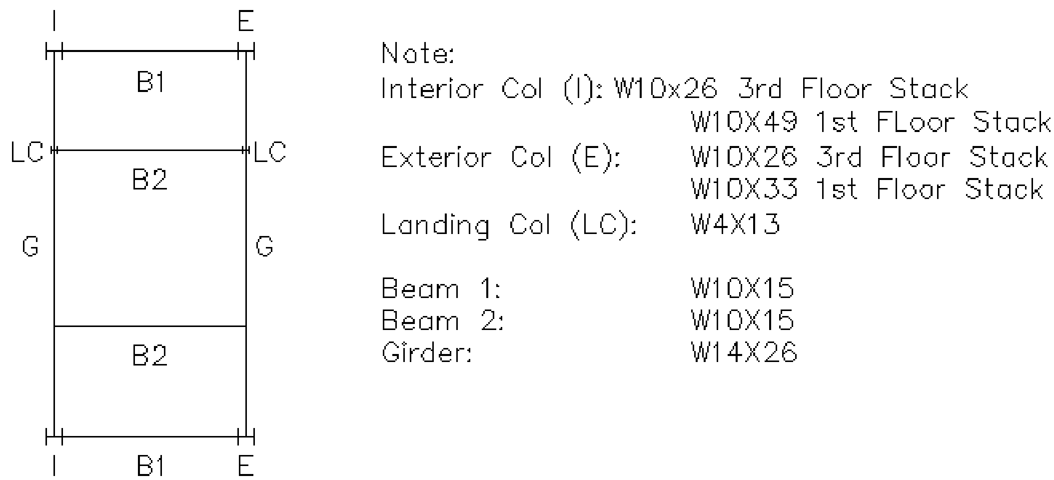


Figure 36: Member Sizes for Typical 2 Flight Staircase

One of the main concerns with the design of the staircase was how to support the intermediate landings. While landings at story heights were simply connected to the girders, intermediate landings could only be connected on one side to 2 end columns. Therefore, structural members needed to be designed to support the other end of the landing. Additional columns running the entire height of the building would require much more steel along with additional concrete footings. Therefore, support columns were placed between the landing and the overhanging girder, which essentially hung the landing for the girders above as seen in Figure 37. This method was chosen in order to put these columns in tension rather then make them compression members susceptible to buckling. Ultimately, a W4X13 section was chosen for design.

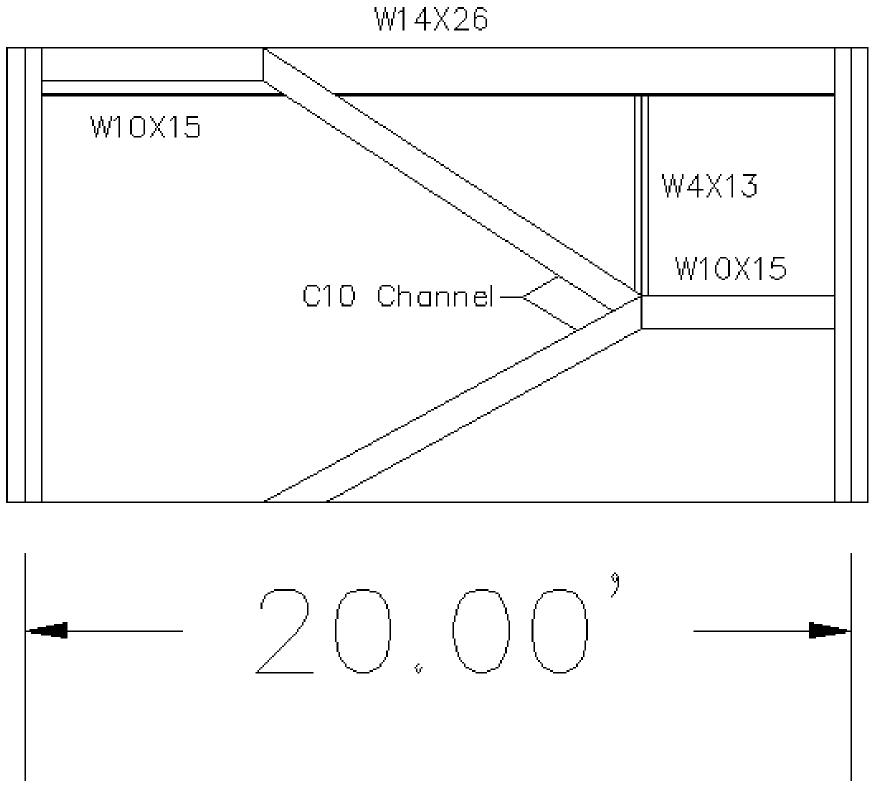


Figure 37: Typical 2 Flight Stairway Elevation

With the typical two flight staircases designed, design of the grand staircase in the atrium could be investigated. Figure 38 illustrates two views of the staircase along with final column sizes. Beam sizes for the upper and lower landings remained the same for the previous stair design. Since the columns only support one flight of stairs, the cross section of the column was reduced to a W6X25. As with the previous stair design, the atrium staircase was designed as its own functional unit. However, the upper end of the staircase could be framed with the floor girder in order for the two columns to be removed.

Ultimately, the staircases provide ample means of access to the upper floors since one can easily be reach from any area of the building. The only concern is that the south staircase is intended as only an emergency stairway since it evacuates at ground level either outside or in the middle of the restaurant. Therefore, signage is required for this stairwell.

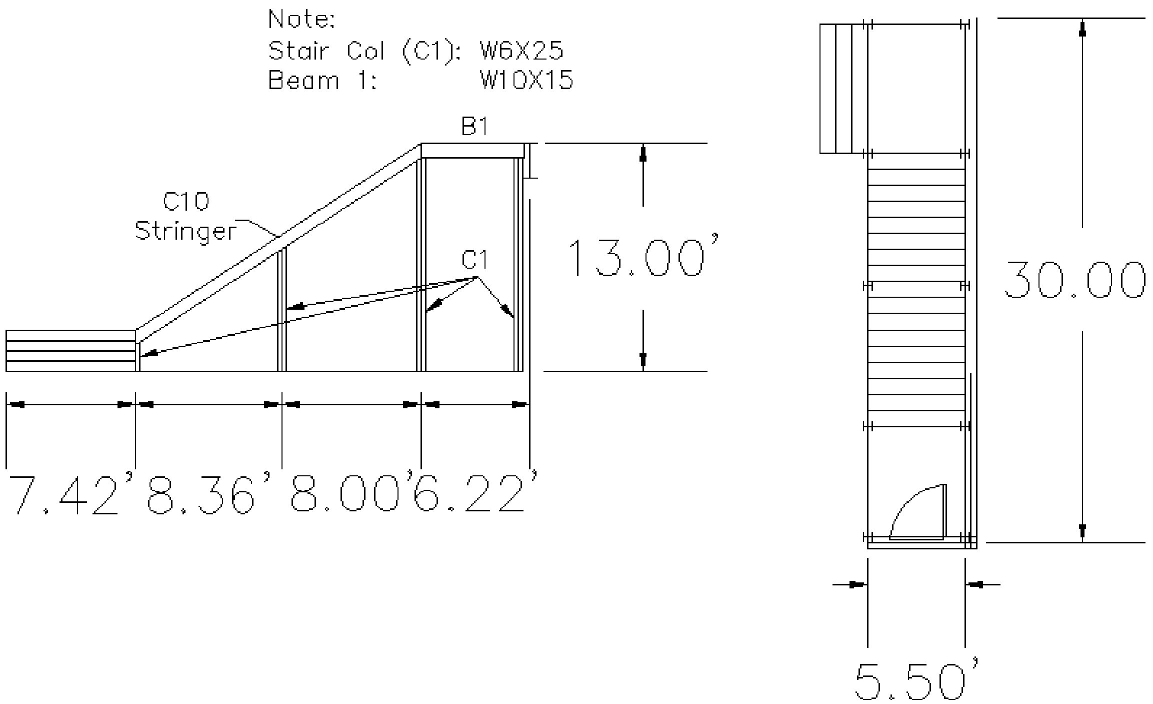


Figure 38: Plan and Section for Grand Staircase

5.3.7 Elevator Design

The elevator system is not only a means of convenience for tenants in a residential or commercial facility, but serves as access for handicapped tenants and as a potential lifeline for first responders to quickly get to and remove tenants quickly in a medical emergency. Therefore, an elevator is an essential part of any structure over four stories. Table 10 illustrates various specifications and requirements concerning elevator design. For this project, while the actual conveying system and elevator car were not designed by the team, the elevator structural frame was designed as part of the overall structural package.

Table 10: Elevator Specifications

Elevators		
Item No.	Description	Source
1	1 per 75 units (44 units in our facility) (120 people). Our design includes 1 (2000 lb) elevator. Inside Car dimensions 68 inches by 51 inches. Shaft dimensions 83 inches by 88 inches.	Architects Studio Companion p181/ Architectural Graphic standards p668

2	Minimum Width of an elevator lobby serving a single bank of elevators if 8ft	Architects Studio Companion p181
3	Elevator shafts are noisy and should not be located next to occupied space, especially in hotels and residential buildings.	Architects Studio Companion p181
4	A building drift limit of height H divided by 500	Serviceability Design Considerations for Steel Buildings p29: ASCE Design Guide 3 - Chapter 7
5	Girder deflection limit = span length over 1666	Serviceability Design Considerations for Steel Buildings p29: ASCE Design Guide 3 - Chapter 7
6	For elevators servicing 4 or more stories above grade plane, one elevator shall be provided for fire department emergency access to all floors. Must accommodate a 24in by 84in stretcher in the horizontal position.	IBC 2006 Section 3002.4
7	Elevators shall not be in a common shaft enclosure with a stairway.	IBC 2006 Section 3002.7
8	Glass in elevator enclosures shall comply with Section 2409.1	IBC 2006 Section 3002.8
9	Where only one elevator is installed, the elevator shall automatically transfer to standby power within 60 seconds after failure of normal power.	IBC 2006 Section 3003.1.2
10	Hoistways more than 3 stories high require vents for smoke and gas in the event of a fire located at the top of the hoistway.	IBC 2006 Section 3004
11	Elevator Machine rooms shall be provided with ventilation and fire barriers	IBC 2006 Section 3006
12	Elevators must meet seismic design requirements in Sections 13.2.1 and 13.2.2	ASCE 7-05 Chapter 13
13	Structural systems and members thereof shall be designed to have adequate stiffness to limit deflections and lateral drift. See Section 12.12.1 of ASCE 7 for drift limits applicable to earthquake loading.	IBC 2006 Section 1604.3
14	Elevator Machine Room grating (on area of 4 in^2) = 300lb concentrated load.	IBC Table 1607.1
15	Elevator loads shall be increased by 100 percent for impact and the structural supports shall be designed within the limits of deflection prescribed by ASME A17.1	IBC 2006 Section 1607.8.1
16	Openings through a floor/ceiling assembly shall be protected by a shaft enclosure complying with this Section.	IBC 2006 Section 707.2

17	Enclosures shall have a fire-resistance rating of not less than 2 hours where connecting four stories of more.	IBC 2006 Section 707.4
18	Elevator enclosures shall be constructed in accordance with Section 707 and Chapter 30.	IBC 2006 Section 707.14
19	An enclosed elevator lobby shall be provided at each floor where an elevator shaft enclosure connects more than three stories. The lobby shall separate the elevator shaft enclosure doors from each floor by fire partitions equal to the fire resistance rating of the corridor and the required opening protection. Elevator lobbies shall have at least one means of egress complying with Chapter 10 and other provisions within this code.	IBC 2006 Section 707.14.1
20	Enclosed elevator lobbies are not required at street level if level has automatic sprinkler system. Elevators not in a shaft do not require a lobby.	IBC 2006 Section 707.14.1
21	To be considered part of a means of egress, an elevator must comply with emergency operation and safety requirements of Section 2.27 of ASME A17.1	IBC 2006 Section 1007.4

Based on the specifications listed above, the elevator lobby and elevator shaft were designed for the graduate housing facility. First, the elevator lobby, shown in Figure 39, was designed as a 12-foot by 12-foot space in front of the elevator shaft at each level. A 5-foot entranceway was provided for access to the floor. Since the building was assumed to have an automatic sprinkler system, each elevator lobby was not required to be enclosed.

Meanwhile, the elevator shaft was designed as an 8-foot by 8-foot independent steel frame. The elevator frame is designed independently so that it can better resist loading effects to make sure the elevator performs well during service. Since diagonal bracing would block the elevator door, the steel frame, shown in Figure 40 was designed to have rigid connections. Through the use of Microsoft Excel spreadsheets, the rigid frame girders and columns were designed to resist moments induced by earthquake loads along with deflection limits specified by ASCE 7 (2000). As stated in the table above, the lateral sway deflection must be less than the total building height divided by 500, while girder deflections must be less than span length divided by 1666. Figure 40 below shows that the final design of the frame consisted of W12X53 girder sections, W12X53 column sections for the third and fourth floors, and W14x109 column sections for the first and second floors.

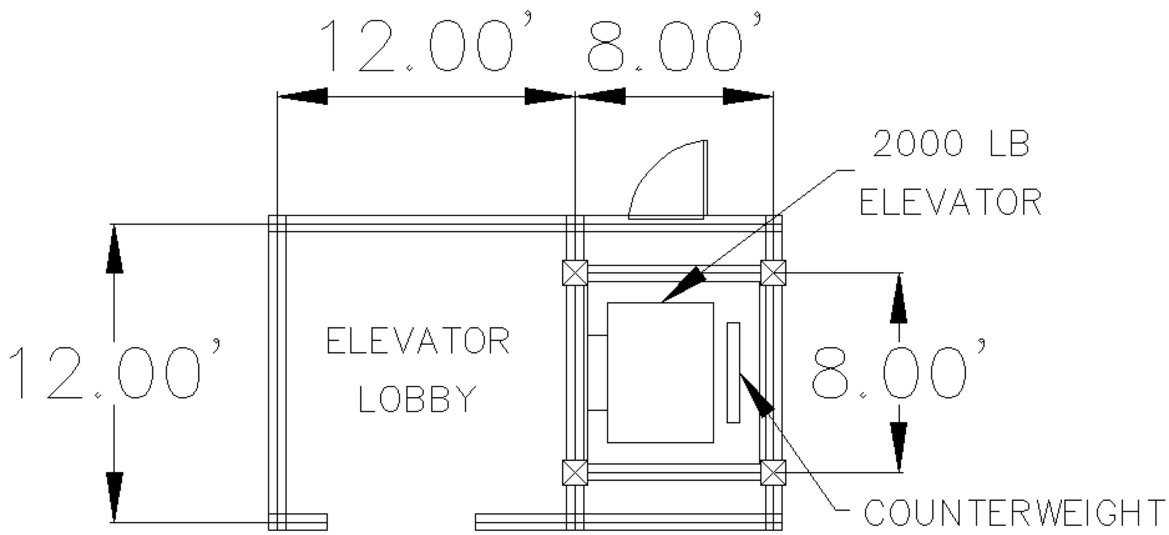


Figure 39: Elevator Layout

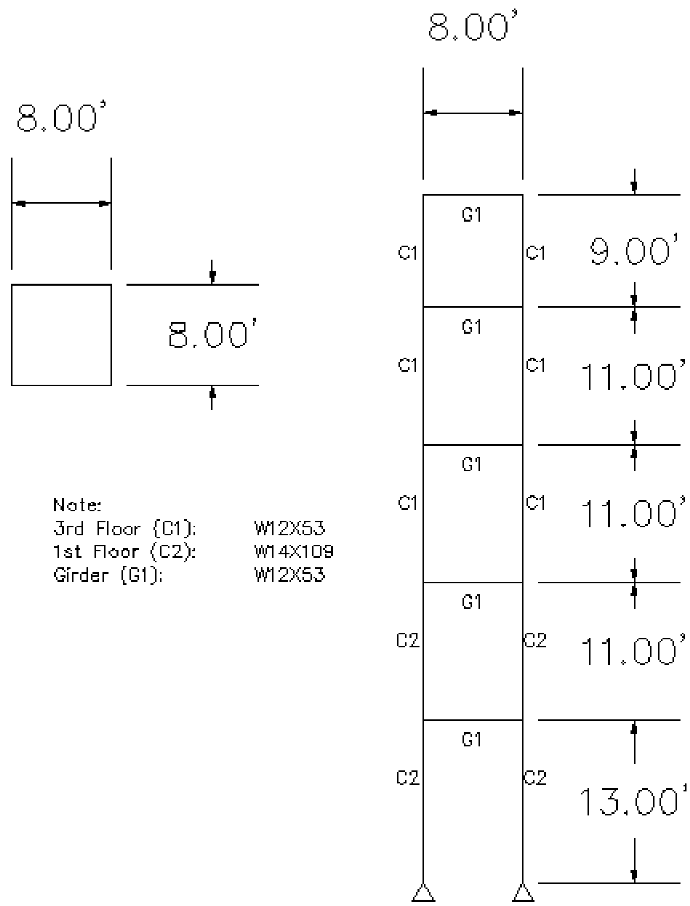


Figure 40: Elevator Rigid Frame

5.3.8 Steel Column Base Plates

At the connection points between the steel support columns and the concrete footings, steel base plates are required to safely transmit the buildings loads to the footing and prevent the W column section from crushing and damaging the concrete footing. A36 steel plate was used as the design material of the plates with calculations and Excel spreadsheets, which can be found in Appendix 13.5.3, used to determine required dimensions. Design procedures were obtained from examples presented in Structural Steel Design by McCormac, Jack. The design calculations strived to optimize the best length and width of the plate so that the squarest plate possible was used in the field. The required thickness to prevent bending of the plate was also determined with the calculations. One assumption used in the design was that the area of the concrete footing was assumed as significantly larger than the area of the plate.

Table 11 illustrates the results of the first base plate analysis with required sizes for all the various types of column sizes involved with the building.

Table 11: Minimum Column Base Plate Dimensions

Assuming the Area of the Footing is far larger than the Area of the Plate					
Location	Column Size	Plate Length	Plate Width	Plate Thickness	All in inches
Interior	W10X33	10	8	0.875	
Exterior	W10X26	10	6	0.75	
Corner	W10X26	10	6	0.5	
Braced Frame	W14X61	16	14	1.25	
Interior Stair Columns	W10X49	12	12	1.125	
Exterior Stair Columns	W10X33	12	8	0.875	
Atypical Interior Column	W14X48	14	8	0.875	
Atypical exterior Column	W14X48	14	8	0.5	

However, from a fabrication and constructability standpoint, it is impractical and not cost efficient to use 6 separate types of base plates for the project. Therefore, from a structures standpoint, it was decided that a 12” X 12” X 1 3/8” base plate would be used for gravity columns and the columns of interior stairs. Meanwhile, a 14” X 8” by 1 1/4” plate would be used for all columns located in the braced frame and all atypical columns. However, the plates must also be optimized from the perspective of the concrete footing design. Based on this design, the final base sizes were determined and summarized in Table 12. Please refer to the foundations section for further description on these final optimization sizes for the base plates.

Table 12: Revised Base Plate Sizes

Finalized Sizes for Column Based Plates (based on structural and footing design)				
Location	Plate Length	Plate Width	Plate Thickness	All in inches
Gravity and stairs	12	12	1.125	
Braced Frame and Atypical	16	16	1.25	

5.3.9 Connection Considerations

During the engineering design and construction of steel building frames, structural member connections are usually designed by the manufacturer of steel sections rather than the engineer. However, the engineer of record is responsible to check the accuracy of these connection details. In order to formulate a general idea of connection sizes for the steel frame, the most typical bolted connection in the frame was designed for the joining of a W10X15 infill beam to a W14X26 girder.

Using an Excel spreadsheet to facilitate design calculations, it was determined that a 3 ½" X 3 ½" X 1/8" Steel Angle, shown in Figure 41, with a depth of 5 ½" would be adequate for this typical connection. The 1/8-inch thickness requirement appeared thin but was probably do to a low shear value of 7.4l kips at the connection point. Ultimately, this angle size calculated by the engineer would be compared with the sizes proposed by the manufacturer to ensure that minimum values have been met. Additionally, due to the many different types of connections in the buildings, the manufacturer may specify only a few connection types in order to lower the cost of fabrication and increase constructability. Therefore, this minimum thickness value will probably realistically be ¼-inch thick or higher.

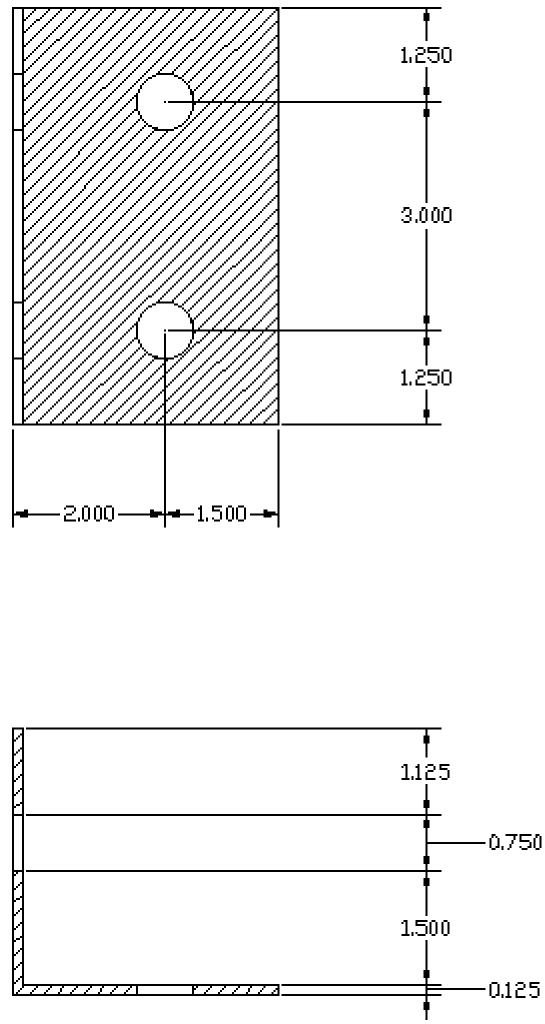


Figure 41: Typical Connection Detail

6 Foundations

A structure may be soundly designed and have considered all possibilities throughout the process, but if its substructure is incapable of distributing the applied loads to the supporting soil, the building may not be a building for long. Foundation design takes more into consideration than merely the loading from the columns. It is these considerations along with implications for failure, relationship to soil properties, and possible geometric alternatives that govern design of the underground system which anchors the building.

6.1 Selection of Foundation

The soil exploration studies discussed in the Background and interpretation of the data are vital to a successful foundation design. Analysis of the soil layers and the column loading from the structure that they would bear was done to begin the first steps of this process with the assistance of the geotechnical report. Several factors were compared to establish that shallow foundations, rather than deep foundations, were the most practical to use. One such factor is the loading. The facility in question has a significant loading as a result of the magnitude of the building in stories and size but is not so large that it requires a special design. Another factor considers the depth of bedrock beneath the soil layers and the surface. The distribution of loads through foundations affects soil differently than it does rock, just as the rock and soil react differently to the foundation. The development of the soil profile was helpful in determining that the groundwater table was 18 feet below the surface. This depth was consistent across the whole Gateway Park complex and was a beneficial value in the decision making process because a high water table could potentially have been another variable to design around.

There were several advantages accompanying the selection of a shallow foundation system that did not play a role in the decision making process. Coduto (2001) notes that these reasons and benefits are primarily inclusive of economics and constructability. Shallow foundations do not require expensive drilling with complicated equipment but rather just excavation. One benefit of the site consisting of gravels and sands as opposed to primarily 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.

A simple, single, square, concentric loaded spread footing was selected to support the column loading for the graduate student residence hall. Figure 42 is a graphical explanation of the substructure element.

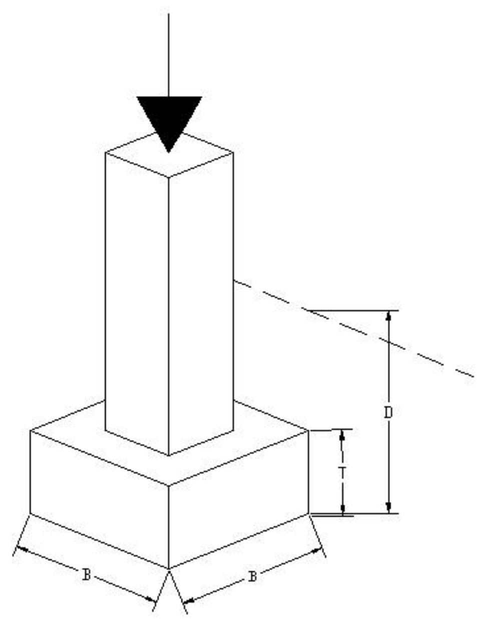


Figure 42: Square Spread Footing Dimensions

The value B represents the length and width of the foundation base, T is the footing thickness or height, and D is the depth from the ground surface, which is denoted by the dotted line. These dimensions, along with other factors like groundwater depth, normal loading (expressed in Figure 42 by the downward arrow), and bearing pressure, contribute at the same time to the load the foundation can distribute and what size it needs to be to distribute a certain load. Other types of shallow foundations considered were rectangular spread footings and continuous spread footings. These options have more complex design considerations and are useful in situations like eccentric, or non-centered, loading that would be applicable if the foundation were very close to a property line or other space inhibiting factor. Because the columns will bear the weight of the exterior walls, a continuous wall footing is not necessary.

6.2 Technical Design

Like the structural steel design, foundation systems are also susceptible to shear failure. Additionally, foundations face two additional structural challenges the superstructure does not directly face: bearing pressure and settlement. Though the building itself would react along with the foundation, it is best to design with safety and longevity in mind.

6.2.1 Governing Formulas of Bearing Pressure

Throughout the twentieth century, geotechnical engineers developed methods to determine the bearing pressure capacity of soils. Two formulas have earned wide acceptance in the field, those being the Terzaghi and Vesić Bearing Capacity Formulas (Coduto, 2001).

General guiding factors for Terzaghi include, among others, that the depth is less than or equal to the width of the foundation; that the foundation is rigid compared to the soil; and that the concentrated load is applied vertically and is compressive. Another factor includes the assumption of a flat, level ground surface, a condition which is present on the 75 Grove Street site. Should the foundation be placed on or near to a large slope, there are additional factors which impact foundation design and are accounted for through use of the Vesic formula.

The Vesić Bearing Capacity Formula is considered a more accurate alternative to the Terzaghi model and is applicable to a much wider variety of spread foundations, especially in terms of the type of loading and geometry. This accuracy comes with a more developed equation, including fifteen individual factors relating to footing geometry, depth, load inclination, base inclination, and ground inclination – all added to further develop Terzaghi's basic formula. 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. The Terzaghi formula for the ultimate bearing capacity, q_{ult}, is defined in Equation 1 (Coduto, 2001).

Equation 1: Terzaghi's Bearing Capacity Formula

$$q_{ult} = 1.3c'N_c + \sigma'_{zD}N_q + 0.4\gamma'BN_\gamma$$

The N_i values designate Terzaghi's three bearing capacity factors, c' is the soil's effective cohesion, σ'_{zD} is the vertical effective stress at the specified depth, and γ' is the effective unit weight of soil. The coefficients 1.3 and 0.4 are constants and B was previously defined in Figure 42 as the width of the footing.

Coduto (2001) developed a series of spreadsheets to assist in calculating the allowable maximum bearing pressure and developing a foundation design, as seen in Figure 42. These spreadsheets allow the user to save time and ensure that with the assumption the intended values are entered correctly, the work will be correct and the risk of human error will be minimal. In designing the foundation, there was a small challenge to start. It is necessary to have an allowable bearing pressure, q_a, to determine the initial width of the square spread footing, *B*, and vice versa. To define the exact dimensions and capacities of a footing and the reaction from the bearing pressure, a great amount of "guess and check" work is required. For example, the weight of the foundation is a factor of developing the allowable bearing capacity, but would require knowing the width to determine it. As a result the procedure would have been repeated until an acceptable value was reached. To have completed this by hand seemed like an impossible task, but the allowable bearing stress Excel spreadsheet was a useful tool in bypassing this problem. Knowing variables like the distance from the surface to groundwater level, Dw, and the distance from the bottom of the foundation to the ground surface, D, a guess and check philosophy could be used. In this step, all of the known values were inputted and the *B* value was varied until the calculated load, *P*, was as close to but not less than the actual load as possible.

	A	B	C	D	E	F	G	H	I	J
1	**BEARING CAPACITY OF SHALLOW FOUNDATIONS**									
2	**Terzaghi and Vesic Methods**									
3										
4	Date		March 21, 2008							
5	Identification		Example 6.4							
6										
7	**Input**					**Results**				
8		Units of Measurement						Terzaghi		Vesic
9			E	SI or E			Bearing Capacity			
10							q ult =	12,718 lb/ft^2		15,223 lb/ft^2
11		Foundation Information					q a =	4,239 lb/ft^2		5,074 lb/ft^2
12		Shape	SQ	SQ, CI, CO, or RE						
13		B =	8	ft			Allowable Column Load			
14		L =		ft			P =	271 k		325 k
15		D =	4	ft						
16										
17		Soil Information								
18		c =	0	lb/ft^2						
19		phi =	32	deg						
20		gamma =	62.4	lb/ft^3						
21		Dw =	18	ft						
22										
23		Factor of Safety								
24		F =	3							
25										
26	Copyright 2000 by Donald P. Coduto									

Figure 43: Coduto's Bearing Capacity of Shallow Foundations using the Terzaghi and Vesic Methods

The geotechnical report provided sufficient data to complete the Soil Information section. Determining the embedment depth was assumed through use of a table provided by Coduto (2001) relating the minimum depth required for square footings based on the loading that would be experienced. Most loads for this facility required a depth of only 18 or 24 inches below the surface. In this instance, a value of four feet was applied throughout the site because it was the depth at which frost in the Worcester area became an important factor; the freeze thaw cycle of winter and summer weather causes soil to expand and contract, sometimes becoming more saturated with water. This presence of a weakened surface soil could in some extreme cases be detrimental to buildings, especially through settlement.

6.2.2 Governing Formulas of Settlement

As noted previously, settlement was the most critical factor of foundation design. Once the bearing pressure and all required dimensions were determined, foundation settlement was explored for the project. In addition to the bearing pressure spreadsheet, Coduto (2000) developed two more spreadsheets comparing both settlement and bearing pressure values. These spreadsheets considered settlement analysis for tow widely used methods, the Classical Method and the Schmertmann Method. A difficulty arose with use of the two spreadsheets, though it involved a simple resolution. Inputting values in English Units would not produce a numerical result, so the engineered spreadsheets for the foundation system provided a simple conversion factor so the equivalent value could be entered in SI, or International System of, units. Similarly, a reverse conversion was done to convert the results from the spreadsheets into English units consistent with the rest of the foundation design.

Figure 44 is an example of the Classical Method for settlement spreadsheet for a typical interior foundation design. The spreadsheet considers the geometric shape and factors, expected design loading, depth of the groundwater table, and a rigidity factor that Coduto (Coduto, 2001) noted in his text; for spread footings the rigidity factor is 0.85. Other considerations of the spreadsheet consider behavior of the soil, especially with relation to consolidation, and soil properties like unit weight which can have considerable impact on a structure’s settlement. A clay soil would be more susceptible than gravelly soil and this is represented by the unit weight properties.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS

Classical Method

Date	March 21, 2008				
Identification	Typical Interior				
Input				**Results**	
Units	SI	E or SI			
Shape	SQ	SQ, CI, CO, or RE		q =	152 kPa
B =	2.44	m		delta =	75.95 mm
L =		m			
D =	1.22	m			
P =	735	kN			
Dw =	5.49	m			
r =	0.85				

Depth to Soil Layer												
Top (m)	Bottom (m)	Cc/(1+e)	Cr/(1+e)	sigma m' (kPa)	gamma (kN/m^3)	zf (m)	sigma c' (kPa)	sigma zo' (kPa)	delta sigma (kPa)	sigma zf (kPa)	strain (%)	delta (mm)
0.0	1.2				18							
1.2	1.3	0.13	0.04	300	18	0.05	323	23	130	153	2.81	2.808
1.3	1.4	0.13	0.04	300	18	0.15	325	25	130	155	2.71	2.712
1.4	1.5	0.13	0.04	300	18	0.25	326	26	129	156	2.62	2.619
1.5	1.6	0.13	0.04	300	18	0.35	328	28	128	156	2.53	2.527

Figure 44: Coduto's (2001) Classical Method Settlement Spreadsheet

The table below the input and results sections provides the ability to explore the settlement, denoted by delta in the middle of Figure 44 effects at each calculated depth without needing to do it by hand. Figure 45, depicting the Schmertmann Method analysis, equaled the Classic method in its results for allowable bearing pressure, but had a significantly different and lower delta, which represented settlement. It is important to note that these spreadsheets consider total settlement. Custom crafted spreadsheets were developed separately and determine differential and allowable settlement.

SETTLEMENT ANALYSIS OF SHALLOW FOUNDATIONS
Schmertmann Method

Date	March 21, 2008		
Identification	Typical Interior		

Input			Results	
Units	SI	E or SI		
Shape	SQ	SQ, CI, CO, or RE	q =	152 kPa
B =	2.44	m	delta =	44.00 mm
L =		m		
D =	1.22	m		
P =	735	kN		
Dw =	5.49	m		
gamma =	18	kN/m^3		
t =	50	yr		

Depth to Soil Layer Top (m)	Bottom (m)	Es (kPa)	zf (m)	I epsilon	strain (%)	delta (mm)
0.0	1.2					
1.2	1.4	4902	0.1	0.147	0.5505	1.1011
1.4	1.6	4902	0.3	0.241	0.9021	1.8042
1.6	1.8	4902	0.5	0.335	1.2537	2.5073

Figure 45: Coduto's (2001) Schmertmann Method Settlement Spreadsheet

It can be noted that the spreadsheets were set up similarly, gave comparable and useable results, but also used a variety of inputs that were either shared or unique to that particular method. What the results sections were able to do from both the Classical and Schmertmann spreadsheets was provide values that allowed for an understanding of the limits of the soil and foundations.

6.2.3 Implications of Dimensions and Depths

The freedom of the spreadsheet to change one or several inputs at a time allowed for exploration of varying dimensions for the square, spread footing foundations. In general, if a design had a wider foundation, the depth from the surface could be at a much shallower level. Alternatively, under the same loading, a smaller foundation often led to a need for a deeper footing, a larger D value. The distance a foundation was away from the groundwater table made an impact on the settlement properties. These changes can impact the cost of excavation and reinforced concrete materials, constructability, and safety of the project. As the distance between width and depth become closer, the significance for building settlement grew because of the increased stresses on the soil.

An example of this can be seen for the design of a typical interior foundation with a service load of 250 kips. To meet this loading, using the bearing capacity spreadsheet with soil information values the same as seen in previous Figures 43 and 44, it can be determined that a foundation of a depth of 4 feet and width measuring 8 feet would be needed. This size foundation could support an allowable column load of 271 kips. Table 13 details some of the effects of footing dimension and depth and the effects the factors have on bearing capacity and settlement. Example 1 provides an allowable column load of 266 kips, and Example 3 has an allowable column load of 264 kips.

Table 13: Comparison of Three Examples of Changes in Foundation Width and Depth

	Example 1	Example 2	Example 3
FOUNDATION INFORMATION			
Shape	Square	Square	Square
Width, B (ft)	9	8	6.5
Depth, D (ft)	2	4	8
SETTLEMENT - Classical			
Bearing Capacity, q, psf	3384	4511	7122
Settlement, delta, in	4.37	4.11	3.8
SETTLEMENT - Schertmann			
Bearing Capacity, q, psf	3384	4511	7122
Settlement, delta, in	2.37	2.79	3.75

It is important to also note that these examples are exclusive of the reinforcement needed as well as the thickness of the foundations for strength.

As the footing width became smaller and the depth doubled in each instance, the bearing capacity also rose. Between Examples 1 and 2, there was a bearing capacity increase of 24.9 percent, and an increase of 36.7 percent between the second two examples. Interestingly, the settlement for the Classical Method decreased and the Schertmann Method's settlement increased because of the difference in empirical and experimental formula design as well as design application for a specific type of soil; Schmertmann was designed exclusively for sandy soil.

For effects on cost, digging a deeper and narrower foundation would be more expensive. Constructability is assisted by a common depth among all foundations. Varying this depth could potentially introduce problems on the construction site and would require more attentive planning and organization. It was noted previously that a lower bearing capacity, often accounted for by a higher factor of safety, defines a safer foundation because it better protects against uplifting of the soil and permanent damage. In these cases, increasing the depth and decreasing the width goes against the concept of using lower bearing capacities.

6.2.4 Connections with the Super-Structure - Base Plate Selection and Coordination

The structural design finalized several schemes of base plate dimensions to be selected for the geotechnical foundations component. A first option allowed for the smallest base plate possible that would still be able to perform for each sized column. The second option consisted of only two base plates. These plates were designed with the overall range of sizes considered in the first option. No plate would be individual, but could be applied uniquely for appropriate sizing and load capacity. The third and final option was composed only of one base plate, the largest piece that would be used for connections to the foundation.

The ultimate selection was Schedule 2. Several factors were considered in determining which to use, including constructability, safety, and cost. The constructability is based upon the ease of manufacturing and placement of the plates. When there are fewer sizes to keep in order, the plates are easier to keep track of. This also leads to safety. It is important that the correct bearing plate be used because the structural integrity of the building would be in perilous condition if a weaker plate would be used in place of what was designed for a particular column. By consolidating the number of plates into only two sizes, the factor of safety became greater for those that required a smaller plate. Cost also played a factor. The bearing plates are constructed from a sheet of steel, so cutting the same number of smaller plates would use less steel and thus cost less. On the opposite side, selecting the largest size would mean that a significantly larger amount of steel would be unnecessarily used. When using a schedule in the middle of the two extremes, both are taken into consideration and the amount of "excess" steel on a bearing plate would be minimized, as would be the cost.

The main factor in determining placement of foundations was dependent on the type of loading and location of the column it was serving. A typical corner spread footing would be smaller than one for a typical interior load because the corner columns do not receive the same distribution as loads as in the center. With the addition of the braced frame design and uniqueness of the atrium layout, there was a need to compare which loads were most critical. Layout was not sufficient enough of a reason for a foundation to not be replaced. Several situations arose in which the anticipated foundation was not sufficient. For example, on the northeast end of the facility nearest downtown, it had been expected that there would be two typical corner foundations and two exterior stair foundations. This was not so; because the middle third of that wall became a braced frame structure, it necessitated a foundation that could properly distribute the loading.

6.2.5 Selection of Reinforcement

Similar to the requirements of the reinforced concrete structural elements, foundation design requires reinforcement to account for flexure. Constructability was also a factor in selecting the reinforcement sizes and numbers. Only two sizes were selected, a #5 and a #8. The bars are each 0.625 and 1.00 inches in diameter as well as 0.31 and 0.79 square inches in nominal area, respectively. Selecting only two bar sizes becomes easier to separate during construction and prevents possible mix-ups. Additionally, fewer bars are used than if smaller reinforcement was designed. In the same vein, there are more of the larger sized reinforcements so that there are not just one or two throughout the foundation connecting to less surface area than if fewer bars were used in reinforcement. The reinforcement design limits the ability of the foundation to bend and therefore undergo irreversible deformation.

Each footing is reinforced in two directions. In general, Coduto (2001) noted that foundations are designed more conservatively than the superstructure it is supporting; the likelihood of failure in this way is decreased. The over design acts almost as a "back-up" to prevent further catastrophic damage. Additionally, because flexural stresses are considered to be lower, nominal steel design would prevail. Coduto (2001) noted that additional construction costs were minor compared to the cost of the overall system and complete structure. In this instance safety and ethics are a more important factor than benefiting economics.

6.3 Final Design of Foundation System

Figure 46 shows a layout of the different foundations that were designed to meet a number of loading needs. The legend in the figure associates a shape and number with the particular design of its foundation, which can be seen in Table 14.

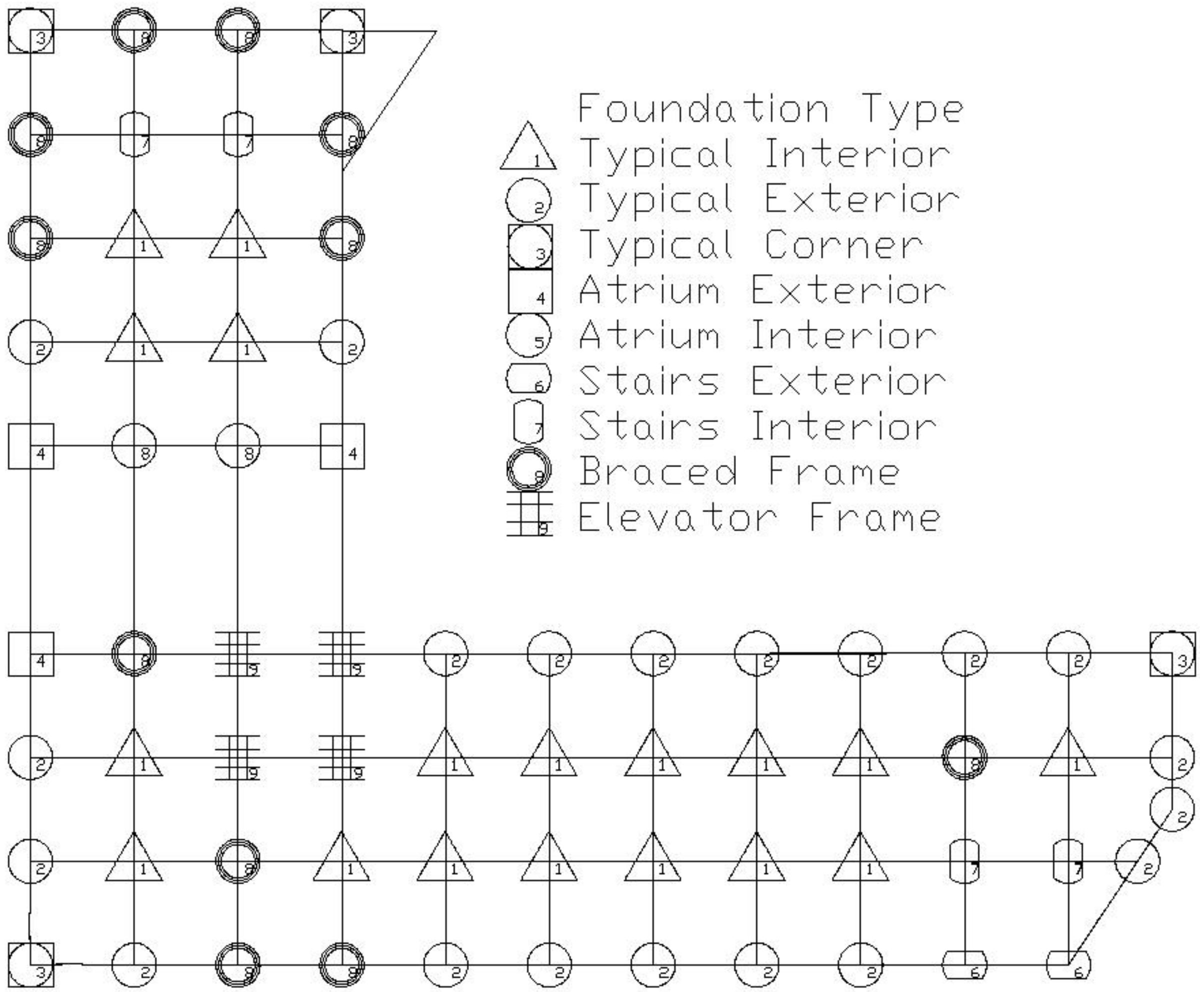


Figure 46: Foundation Type Layout

Figure 46 represents the layout of the foundations, not their actual size, shape or orientation.

Table 14: Foundation Design Summary

Location	#	Width (ft)	Area (sf)	Thickness (ft)	Depth (ft)	# bars	Bar #	Area of Steel (in^2)
Typical Interior	18	8.0	64.00	1.5	4	11	5	3.41
Typical Exterior/Corner	24	7.5	56.25	1.5	4	10	5	3.1
Atrium Interior	0	8.0	64.00	1.5	4	11	5	3.41
Atrium Exteroir	3	7.5	56.25	1.5	4	10	5	3.1
Stairs Interior	4	15.0	225.00	1.5	4	10	8	7.9
Stairs Exterior	4	8.0	64.00	1.5	4	11	5	3.41
Braced Frame	13	9.0	81.00	1.5	4	12	5	3.72
Elevator	4	9.0	81.00	2.75	6	9	8	7.11

Uniformity of design was maintained whenever possible for ease of construction. For example, all but one foundation type have the same thickness and depth. The only location this was different was for the design of the foundation supporting the elevator frame. This foundation exhibited the least amount of bearing pressure out of the options of concentric, which was the selected design, and eccentric loading. A typical, hand-drawn interior foundation design drawing can be seen in Figure 47.

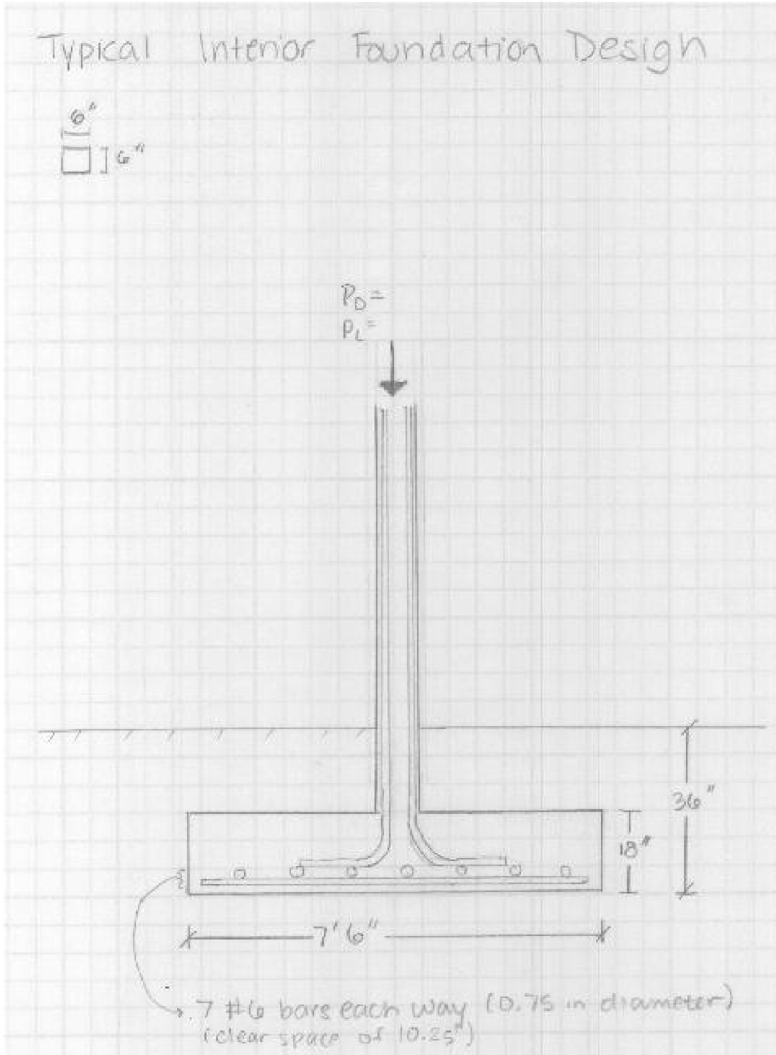


Figure 47: Typical Interior Foundation Design Hand Drawing Result

The hand calculations associated with the design can be found in Appendix 13.3.3.

6.3.1 Design Challenges

Among the foundation design challenges were the elevators. Because of IBC 2006 regulations, the elevators were required to be in a separate structure inside of the main super structure. This proved to be a unique situation compared to other areas because it required not just one but two columns to be accounted for. The same procedures for all other foundations were applied, except for the addition of checking bearing pressure in an eccentric loading situation. Both concentric and eccentric bearing pressure calculations were evaluated. At the conclusion of that step concentric loading had a lower bearing pressure which matched other allowable bearing pressure values, represented by q_a, and was ultimately chosen to be a part of the foundation design.

Especially for elevators, the settlement and differential settlement relationship is extremely important. Though the loadings could potentially be supported by smaller foundations, it was with the settlement concerns in mind that their sizes were increased. A lower bearing capacity is helpful because shear failure can occur if the foundation is too small and the load too large.

Because in nearly all initial design scenarios the settlement was near if not greater than 3 inches, and in two cases close to 4, inches, it was determined that the foundations needed to be larger. As a result, values were recalculated to ensure that the foundations had a lower
Though this does increase the materials cost of the foundation, the integrity of the building has been increased because lowering the maximum bearing capacity means that less settlement is likely, meaning a lesser likelihood that potentially dangerous damage will be sustained due to shear failure.

Raising the value for the foundation sizes allows for greater uniformity among some materials and exaction. For example, nearly all foundations are designed to the nearest foot while others are designed to the half-foot. This is easier for materials manufacturing and constructability. Additionally, only two sizes of reinforcing bars were used, the #5 for many foundations and the #8 for some larger load bearing foundations. One benefit of this is reducing the risk of placing the wrong bars in an inappropriate location.

6.4 Foundations Conclusion

Foundation design is based on a number of factors to not merely prevent failure from occurring but to provide a strong, stable base for the super structure to be able to transfer its loads to the ground which it stands on. The most important factors governing design are bearing capacity pressure and settlement, but even the depth and geometry of shapes are important as they influence the behavior of the former. Though foundations are designed after the super structure, they are the first segment of a project to be constructed due to the importance of holding up the entire structure during construction as well as for decades into the future.

7 Project Management

The project management section of the report contains a cost estimate of the project as well as a construction schedule. The cost estimate was developed in order to gain an understanding of the total cost of the project and compare that cost to a similar project. An owner could use this to determine the feasibility of actually constructing a project. The schedule was developed to gain an understanding of the sequence of events that would be required to complete this project. An owner could use this to determine when to start a project or how much time is required to finish the job.

7.1 Cost Estimate

Performing a cost estimate is a very important part of any construction project in order to understand the feasibility of a project along with the quantity and value of work. Cost estimates must be prepared multiple times during design, planning, and throughout construction. The first cost estimate is usually developed without a full set of plans and specifications. The estimator must use his judgment and knowledge of construction to determine if the project is feasible. When a project scope if fully defined and a set of plans and specifications is finalized a more detailed estimate can be completed.

A cost estimate was developed for the Gateway Park Graduate Housing Project. The price that was determined included the cost of materials, equipment, and labor for the job. The final number included allowances for the overhead and profit of the contractor. Unit costs were determined using the <u>2008 RS Means Square foot Cost Data</u>, the <u>2008 RS Means Building Construction Cost Data</u>, and the <u>2007 RS Means Assemblies Cost Data book</u>. These numbers are based on national averages from construction projects throughout the country. The reference cost data were adjusted based on a location adjustment factor to match the market prices in Worcester Massachusetts.

To make the cost easier to evaluate the project was broken down into seven divisions depending on the type of construction. This format which distributes the cost of the project is called the work breakdown structure. The Uniformat was used in this estimate. It represents costs according to a hierarchy of system elements. (Cullen, 2005) For each division the total cost and the percentage of the total cost is shown in a table called the schedule of values (Table 15). Table 15 is a summary of a more detailed and complete cost estimate that was developed. The subsequent sections provide a breakdown of the schedule of values.

Table 15: Schedule of Values

Schedule of Values

	Description	Total Cost	Cost/Square Foot	Percentage of Total Cost
A	Substructure	**$452,156.46**	**$5.62**	5.37%
B	Shell	**$2,178,556.04**	**$27.10**	25.86%
C	Interiors	**$2,098,830.86**	**$26.10**	24.92%
D	Services	**$2,842,680.00**	**$35.36**	33.75%
E	Equipment and Furnishings	**$653,125.50**	**$8.12**	7.75%
G	Building Sitework	**$198,209.79**	**$2.47**	2.35%
	Subtotal	**$8,423,558.65**	**$104.77**	
	Location Adjustment	**$9,097,443.35**	**$113.15**	
	Contractor Fees	**$11,371,804.18**	**$141.44**	

The cost estimate for this project was performed with a limited amount of plans and specifications. For this reason three different types of estimating methods were used. Some costs were determined based on the size of the building which was defined as 80,400 square feet. The total square footage of the building was multiplied by a cost per square foot of items. Some cost values were determined by assembly and system estimates. This method groups several items into a single unit to make estimating easier. Other parts of the building were estimated based on unit costs. This method is the most accurate and involves establishing a cost for individual elements. In order to complete the cost estimate many assumptions were made as to which type of systems and products would be used. These assumptions were based on what the group believed a similar residence hall would be composed of. A more detailed estimate was performed for the structural steel component because all of the members were explicitly defined by design.

7.1.1 Substructure

As shown in Table 15 the substructure of the building accounts for just about five and a half percent of the total building cost. The building substructure accounts for all of the foundation systems in the building along with the planned slab on grade at the ground level. The breakdown of the foundation costs is shown in Table 16.

Table 16: Substructure Cost

Description	Quantity	Units	Unit Cost	Total Cost
Foundation Wall	507.00	lf	$52.75	$26,744.25
Exterior Column Footings	25.00	Each	$883.68	$22,092.11
Interior Column Footings	19.00	Each	$991.46	$18,837.80
Foundation Wall Strip Footing	507.00	lf	$30.95	$15,691.65
Slab on Grade	80,400.00	sf floor	$4.02	$323,208.00
Atrium Exterior Footing	3	Each	$876.82	$2,630.46
Stairs Interior Footing	4	Each	$3,278.64	$13,114.56
Stairs Exterior Footing	4	Each	$991.46	$3,965.85
Braced Frame Footing	13	Each	$1,204.14	$15,653.87
Elevator Footing	4	Each	$2,055.08	$8,220.33
Dampproofing	507.00	lf	$3.94	$1,997.58
			Total	$452,156.46

Seven different kinds of column footings were designed to support the various columns within the steel frame. Along with the typical interior and exterior column footings there were column footings for the atrium, the stairs, and the braced frame. A different price was calculated for each of these footings. The cost took into account the material excavated, the amount of concrete, the size of the forms, the steel reinforcing, and the amount of material to be backfilled.

A table shown in Appendix 13.4.3 illustrates the detailed cost calculation for a single column footing.

The cost for the foundation wall and the strip foundation was calculated based on the linear footage. The total width of all of the exterior column footings was subtracted from the building perimeter leaving a distance of five hundred and seven feet. All of the space in between the column footings will have a wall with a strip footing to support the building walls. It was assumed that a slab on grade thickness of five inches would be adequate for this building. Five inches was determined based on loading and soil conditions to handle the commercial use on the first floor and the heavy loads caused by the gym.

7.1.2 Shell

According to Table 15, the building shell accounted for about twenty-six percent of the total building cost. The cost of the building shell includes the cost of the superstructure, the exterior enclosures, and the roofing.

Table 17: Shell Cost

Description	Quantity	Units	Unit Cost	Total Cost
B10 Superstructure				
Steel Gravity System	246.12	tons of steel	$3,050.00	$750,666.00
Steel Bracing	48.79	tons of steel	$3,050.00	$148,809.50
Welded Steel Sheer Connections	10,752.00	each	$2.10	$22,579.20
Concrete Floor Slab	1,116.67	cubic yards	$4.68	$5,226.02
Steel Decking	80,400.00	sf floor	$2.28	$183,312.00
B20 Exterior Enclosures				
Exterior Walls	26,936.00	sf wall	$24.35	$655,891.60
Exterior windows (rooms hallways)	282.00	each	$523.00	$147,486.00
Exterior Windows (first Floor)	5,128.50	sf wall	$20.85	$106,929.23
Exterior Doors Glass	6.00	each	$5,700.00	$34,200.00
Exterior Doors Glass	2.00	each	$3,625.00	$7,250.00
Exterior Doors	5.00	each	$1,800.00	$9,000.00
B30 Roofing				
Roof Coverings	20,100.00	sf roof	$5.28	$106,128.00
Roof Openings	50.00	sf	$21.57	$1,078.50
			Total	$2,178,556.04

The cost for the superstructure, including the steel frame, metal decking, and slabs, was calculated based on the tons of steel defined by the structural design. The size of each member in the frame was calculated, and a quantity take-off was used to calculate the total weight of steel in the building. The quantity of steel decking was measured per square feet of floor, and the quantity of concrete by cubic yards. The frame of the building had a total cost of over one million dollars resulting in the largest cost of the building shell. An example of a more detailed cost breakdown of the steel members in included in Appendix13.4.2.

Another substantial part of the shell cost was the exterior enclosure of the building. A brick veneer with metal stud backup was chosen to enclose the building. The brick veneer was chosen to match all the neighboring buildings in the area and the metal studs were the most affordable way to back up the brick enclosure. The exterior enclosure had a total cost of over six hundred and fifty thousand dollars. The exterior wall cost was calculated based on the total square feet of wall area minus the area of the windows. The first floor of the building was designed to have a large amount of glass in order to let in light and advertise the businesses inside. To account for this it was assumed that fifty percent of the first floor enclosure would be glass and the other half brick. The rooms on upper floors were outfitted with the maximum number of five feet by three feet sliding windows that would fit in the dimensions. If a room was 15 feet wide then it would have three windows. If a room was only eight feet wide then you could only fit one window. Only one size window was used to increase constructability and so that money could be saved by buying in bulk.

7.1.3 Interiors

The interior of the building contributed to about twenty-five percent of the total cost. The interior section of cost includes anything related to partitions, doors, fittings, and finishes within the building. The cost breakdown for these items is shown in Table 18.

Table 18: Interior Cost

Description	Quantity	Units	Unit Cost	Total Cost
Partitions single sided	36294.00	sf partition	$3.84	$139,368.96
Partitions double sided	96220.00	sf partition	$5.96	$573,471.20
Interior Doors	203.00	per opening	$533.00	$108,199.00
Interior Doors Retail	4.00	per opening	$10,100.00	$40,400.00
Fittings	47.00	per bathroom	$740.60	$34,808.20
Fittings	661.00	l.f.	$187.50	$123,937.50
Fittings	122.00	each	$49.00	$5,978.00
Stair Construction	18.00	per flight	$9,700.00	$174,600.00
Wall Finishes	80400.00	sf floor	$2.76	$221,904.00
Floor Finishes	80400.00	sf floor	$4.92	$395,568.00
Ceiling Finishes	80400.00	sf ceiling	$3.49	$280,596.00
			Total	$2,098,830.86

The partitions were the most expensive item for the interiors. The partitions were priced by the total square feet of partitions and separated into walls that were two-sided and walls that were one sided. The one-sided partitions were mostly drywall partitions extending along the exterior of the building. The two-sided walls were all of the interior partitions within the structure. For the floors with apartments the amount of wall area was calculated for each apartment type and then multiplied by the number of rooms.

The bathroom fittings were calculated based on the design of a typical bathroom. All of the bathrooms included a towel dispenser, grab bar, mirror, toilet tissue dispenser, towel bar, and medicine cabinet. Each bathroom also included counter tops with cabinets underneath them. The total cost for all of the fittings in one bathroom was calculated to be seven hundred and forty dollars, and that was multiplied by the number of bathrooms. There were forty-four bathrooms in the apartments, and it was assumed that there were three bathrooms on the first floor. For simplicity all bathrooms were assumed to include the same fittings whether they were on the first floor or in the apartments.

The wall and floor finishes were calculated based on a cost per square foot of floor area. This square foot cost was multiplied by the square footage of the building to find the cost to finish all of the floors and walls in the building. It was assumed that the walls were seventy percent paint, twenty-five percent vinyl coverings, and five percent ceramic tile. The vinyl coverings and ceramic tile account for all of the bathrooms and kitchen areas; all of the remaining walls are painted drywall. It was also assumed that the floor coverings were sixty percent carpet, thirty percent vinyl composition tile, and ten percent ceramic tile. The vinyl and tile coverings are located in the kitchens, bathrooms and first floor hallways. The remaining portion of the building is carpeted. The total square foot price was determined based on the percentages of each material used and its square foot cost. Weighted unit cost values were determined for the floor and wall finishes and then they were multiplied by the entire floor area of the building.

7.1.4 Services

Table 15 shows the building services accumulated almost thirty-four percent of the total cost of the building making it the largest division. The building services include conveying systems, plumbing, HVAC, fire protection systems, and the electrical system. The cost breakdown is shown in Table 19.

Table 19: Services Cost

Description	Quantity	Units	Unit Cost	Total Cost
D10 Conveying				
Elevators and Lifts	1.00	each	$170,100.00	$170,100.00
D20 Plumbing				
Plumbing Fixtures	47.00	each	$1,010.00	$47,470.00
Plumbing Fixtures	44.00	each	$1,175.00	$51,700.00
Plumbing Fixtures	47.00	each	$1,530.00	$71,910.00
Plumbing Fixtures	44.00	each	$3,095.00	$136,180.00
Domestic Water Distribution	80,400.00	sf floor	$3.11	$250,044.00
Rain Water Drainage	80,400.00	sf floor	$0.18	$14,472.00
D30 HVAC				
Energy Supply	80,400.00	sf floor	$5.90	$474,360.00
Cooling Generating System	80,400.00	sf floor	$7.56	$607,824.00
D40 Fire Protection				
Sprinklers	80,400.00	sf floor	$2.16	$173,664.00
Standpipes	80,400.00	sf floor	$0.39	$31,356.00
smoke detectors	240.00	each	$174.00	$41,760.00
D50 Electrical				
Electrical Service Distribution	80,400.00	sf floor	$2.32	$186,528.00
Lighting & Branch Wiring	80,400.00	sf floor	$6.27	$504,108.00
Communication & Security	80,400.00	sf floor	$0.84	$67,536.00
Other Electrical Systems	80,400.00	sf floor	$0.17	$13,668.00
			Total	$2,842,680.00

The elevators, plumbing fixtures and smoke detectors were the only services calculated by a unit cost. It was assumed that the plumbing fixtures selected were average quality. The apartments included one kitchen sink, one bathroom sink, a toilet, and a recessed bathtub/shower. The bathrooms on the first floor did not include showers but had the same standard fittings as all of the other bathrooms. The energy supply selected was an oil-fired hot water system with baseboard radiation for a cost of about six dollars per square foot of building floor area. The cooling system selected was a chilled water, air cooled condenser system that cost about seven dollars and fifty cents per square foot of building floor area. The water distribution system, the heating, ventilation, and air conditioning system, the fire protection system, and electrical system were all calculated based on square foot costs. The square foot cost was multiplied by the total square feet of the building floor area that is covered by the service. Since all of these systems service the entire building, their unit costs were multiplied by the total square footage of the building. The unit costs were based on national averages for similar apartment buildings of the same size. All of the environmental systems were selected based on RS Means recommendations for a four to seven story apartment building (RS Means Square Foot Cost Data, 2008).

7.1.5 Equipment and Furnishings

Table 20 shows the cost breakdown for all of the furniture and equipment identified for the building. It indicates that the equipment and furnishings cost about eight percent of the entire building cost.

Table 20: Equipment and Furnishings Cost

Description	Quantity	Units	Unit Cost	Total Cost
Laundry equipment	6.00	each	$3,537.00	$21,222.00
Laundry equipment	6.00	each	$3,437.00	$20,622.00
Kitchen appliances	44.00	each	$620.50	$27,302.00
Kitchen appliances	44.00	each	$2,976.00	$130,944.00
Window treatments	282.00	each	$170.00	$47,940.00
Bed	122.00	each	$445.00	$54,290.00
Desk	122.00	each	$460.00	$56,120.00
End table (small)	192.00	each	$220.00	$42,240.00
Dresser	122.00	each	$485.00	$59,170.00
chairs (large)	79.00	each	$395.00	$31,205.00
Couch	53.00	each	$530.00	$28,090.00
Coffee Table	50.00	each	$280.00	$14,000.00
Tv stand	44.00	each	$590.00	$25,960.00
Kitchen table	47.00	each	$971.50	$45,660.50
chairs	310.00	each	$156.00	$48,360.00
			Total	$653,125.50

The furnishings included standard apartment furniture, apartment kitchen appliances, and laundry equipment for each floor. All of these selections were assumed to be average quality of furniture and equipment. All bedrooms contain a bed, a desk and chair, and a dresser for each tenant. Each kitchen contains an oven, a stove, a refrigerator, and a kitchen table with four chairs. The common rooms each have a couch, an end table, a coffee table, a storage unit, and lounge chairs. Quads have two lounge chairs, doubles have one lounge chair and singles do not have any. On every floor there is a laundry room equipped with two commercial washers and dryers.

7.1.6 Building Sitework

Table 15 shows the cost of the building sitework to be a little over two percent of the total project cost. The building sitework division contains all of the work completed around the building including utilities, parking, roads, sidewalks, excavation, and landscaping. The cost breakdown for this division is summarized in Table 21.

Table 21: Sitework Cost

Description	Quantity	Units	Unit Price	Total Cost
Parking Lot	18,639.00	sf	$4.09	$76,233.51
Curbing	1,142.00	lf	$17.30	$19,756.60
Concrete Sidewalks	508.00	lf	$20.00	$10,160.00
Trenching	1,132.00	lf	$11.80	$13,357.60
Pipe bedding	1,132.00	lf	$1.89	$2,139.48
Water Supply Piping	456.00	lf	$39.05	$17,806.80
Storm Sewer Pipe	511.00	lf	$21.45	$10,960.95
Sanitary Sewer Pipe	102.00	lf	$12.32	$1,256.64
Fuel Distribution	63.00	lf	$6.67	$420.21
Sewer Manhole/ Catch Basins	12.00	ea	$2,350.00	$28,200.00
Lawn and ground cover	31.00	msf	$578.00	$17,918.00
			Total	$198,209.79

The cost of the building sitework was calculated based on the site design that the group performed. The total square footage of the parking lot and the landscape area were calculated using the area command in AutoCAD. The parking lot was assumed to be constructed with six inches of compacted gravel and three inches of bituminous paving. The concrete walkways were assumed to be built with four inches of concrete on top of six inches of compacted gravel. Sidewalks with five foot wide walkways were priced by the linear foot. The amount of granite curbing needed was also calculated using AutoCAD. It was assumed that the project would use granite curbing rather than concrete curbing so it would match the surrounding areas of Gateway Park. It was assumed that the landscape area would be completely covered with topsoil and grass. The units for this area were in thousands of square feet. The group did not complete any landscape design so no allowance for shrubs and plantings was given.

The length of all utilities was calculated using AutoCAD and the site plan that the group developed**.** When the trenching was calculated it was assumed that the average depth of the trench would be around four to five feet and the largest pipe size was twelve inches. This decision was made because the site is flat and the steepest pipe slope was only a two percent decline. The size of the pipe will not have much of an effect on the size of the trench. All of the utility work will require workers to go inside of the trench so it will need to be wide enough for them to work in. No bracing is required on trenching that is less than five feet deep so providing excavation support is not an issue. (Brown, 2002)

7.1.7 Comparison

In order to look at the accuracy of the cost estimate, it was compared to some similar projects in the area. The new residence hall at WPI was the first comparison that was made. The new residence hall is being constructed right down the street from 75 Grove St. Both buildings are similar in size and will have the same purpose: they are both designed to have apartment-style living that includes kitchens and a bathroom. (WPI, 2007) Table 22 compares the cost of two buildings. Cost data from the new residence hall was obtained during a meeting with Professor Salazar. (Salazar, 2008)

Table 22: Building Cost Comparison

	75 Grove Street Graduate Housing	New WPI Residence Hall
Square Footage	80,400.00	103,610.00
Number of Beds	122.00	232.00
Total Cost	$11,371,804.18	$35,000,000.00
Cost / SF	$141.44	$337.81
Cost / Bed	$93,211.51	$150,862.07

The estimated square foot cost of 75 Grove Street is more than half as much as the New Residence hall. The estimated cost per bed is about 40% less for 75 Grove Street. The discrepancy in price was a reflection of the difference between the two projects.

The new residence hall at WPI is a LEED Silver Certified building which can be about a five to ten percent increase in initial cost. The residence hall project was also a fast track project which can be more expensive due to overtime cost and last minute design changes. The new residence hall was designed with high tech study rooms and wireless internet access. (WPI, 2007) One of the biggest differences in the two buildings is the commercial space on the first floor of 75 Grove Street. This space is going to be outfitted by the tenants that will be occupying the areas. This means that the interior cost for this area is much less. The interior cost accounted for about 25% of the total cost and the first floor was not completely finished. Another way to compare the buildings would be to look at just the steel packages. Table 23 shows the comparison of the two buildings.

Table 23: Building Steel Cost Comparison

	75 Grove Street Graduate Housing	New WPI Residence Hall
Weight of steel (lb)	590,000.00	1,000,000.00
Cost of Steel	$1,110,593.00	$2,200,000.00
Square Footage	80,400.00	103,610.00
Lbs / sf of steel	7.34	9.65
Cost / sf of steel	$13.81	$21.23

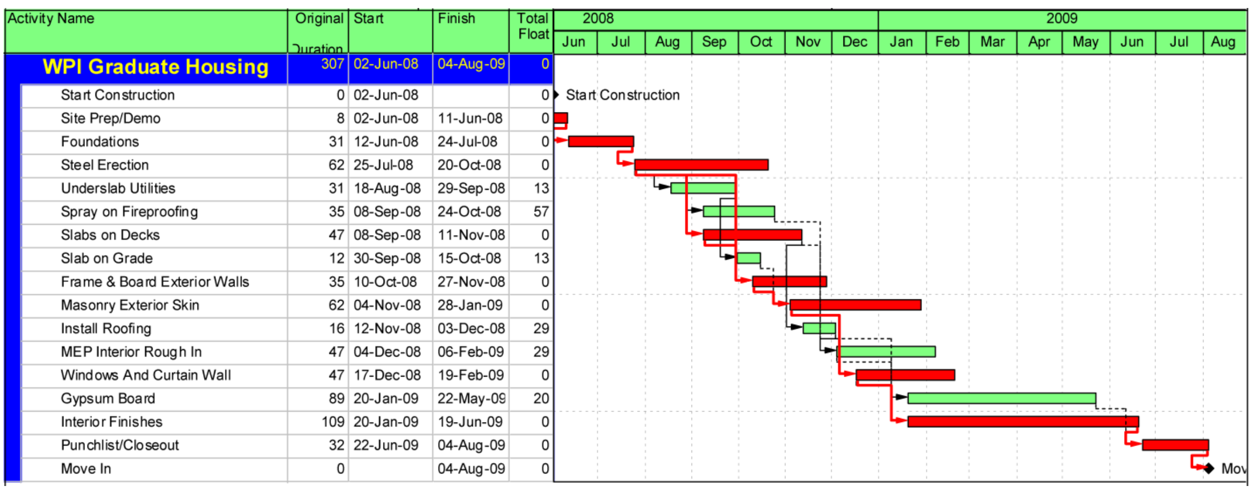
In this comparison the cost per square foot in 75 Grove Street was 33% less than in the new residence hall. This can be explained by the amount of steel used. 75 Grove Street only used 7.34 pounds of steel per square foot while the residence hall used 9.65 pounds per square foot. This could mean that it was designed for greater loads. Another reason for the higher amount of steel could be that it has more floors with a smaller area on each floor. This would result in larger heavier columns on the lower floors to support the loads, and an increased cost per square foot. One more thing to compare the cost to would be RS Means Cost Data.

The <u>2008 RS Means Square Foot Cost Data</u> book has prices for all different types of buildings based on national averages. A four-seven story 80,000 square foot apartment building with a brick exterior and steel frame had a square foot cost of $142.50 per square foot. The cost for the building at 75 Grove Street in very close to this with a square foot cost of $141.44.

7.2 Schedule

Project scheduling is an essential part of every construction project. Without a good plan for construction, contractors can run into all kinds of problems that result in increased time on the job and cost overruns. A project schedule must be prepared prior to construction and updated throughout the construction process. In the construction of buildings the number and variety of trades that are on site at the same time can cause problems with scheduling. A project manager usually has the task of organizing all of the trades so they can complete their work on time without return visits and without getting in the way of one another.

A preliminary schedule for the construction of the graduate housing complex was developed. The schedule was adapted from a master schedule which was used for the construction of new residence hall building at Worcester Polytechnic Institute. (Gilbane Building Company, 2007) The schedule was created in order to understand the planning involved in a project and only contains the major projects and activities that will be completed. The schedule shown in Figure 47 was made using Primavera Project Management software.



Activity Name	Original Duration	Start	Finish	Total Float
WPI Graduate Housing	307	02-Jun-08	04-Aug-09	0
Start Construction	0	02-Jun-08		0
Site Prep/Demo	8	02-Jun-08	11-Jun-08	0
Foundations	31	12-Jun-08	24-Jul-08	0
Steel Erection	62	25-Jul-08	20-Oct-08	0
Underslab Utilities	31	18-Aug-08	29-Sep-08	13
Spray on Fireproofing	35	08-Sep-08	24-Oct-08	57
Slabs on Decks	47	08-Sep-08	11-Nov-08	0
Slab on Grade	12	30-Sep-08	15-Oct-08	13
Frame & Board Exterior Walls	35	10-Oct-08	27-Nov-08	0
Masonry Exterior Skin	62	04-Nov-08	28-Jan-09	0
Install Roofing	16	12-Nov-08	03-Dec-08	29
MEP Interior Rough In	47	04-Dec-08	06-Feb-09	29
Windows And Curtain Wall	47	17-Dec-08	19-Feb-09	0
Gypsum Board	89	20-Jan-09	22-May-09	20
Interior Finishes	109	20-Jan-09	19-Jun-09	0
Punchlist/Closeout	32	22-Jun-09	04-Aug-09	0
Move In	0		04-Aug-09	0

Figure 48: Graduate Housing Building Schedule

The first step to develop the project schedule was to list all of the major activities required to build the project. After the list was compiled, the the duration of the tasks were calculated by comparing this proposed project to the new residence hall at WPI. The new residence hall is 103,610 square feet (WPI, 2007) and the proposed building is 80,400 square feet. It was assumed that the construction of the graduate housing building will be performed at the same rate as the new residence hall because of the similarity of the building type. Both projects were also in the same area so they had the same availability of materials, services, and other local factors. By comparing the square footage ratio of the buildings, duration for each similar activity was approximated for the smaller building. All of the durations for the graduate housing building were slightly smaller than the new residence hall because of the smaller floor space.

Once all of the activities had durations they needed to be arranged in the correct order. In order to complete the project in an acceptable amount of time many of the activities had to overlap each other. It was required to make many assumptions about when certain activities could begin based on their predecessors. All of the activities needed to be linked together based on any constraints that they had.

A start date of June 02, 2008 was chosen for the projects field operations. This is the first Monday in June that would be after school has ended, and people have moved out. It is not completely necessary for students to be moved out because Gateway Park is off campus but this way there would be less of a strain on parking in the surrounding areas. This date was also chosen so that the finish date would allow for the building to be open for the next school year. The last reason for selecting this date was so that the majority of outdoor construction is completed before the winter months. This will allow for indoor construction to go on during the cold season. Many of the long lead items such as steel must be procured early during the design phase of the project so that the notice to proceed is issued and they are delivered to the site on time. The first task in construction would be to perform any site preparations or demolition. The site is clean and open so the only demolition may be to things like utilities, fences, or sidewalks around the site. Site preparation may also include any surveying or mobilization of the contractors. This activity was given a short duration of eight days.

The foundations can be started directly after the site preparation and demolition is completed. This will have a duration of 31 days and will be followed by the erection of the steel. Being a relatively small site it is recommended to start erecting the steel once the footings are completely finished. This way the foundation and backfill crews will be out of the way, and there will be more space to stockpile the steel coming to the site. An open site will allow the iron workers to work at a faster pace and not have a crane on site when unnecessary.

Once one quarter of the steel is erected work can begin on the underslab utilities. This means one out of the four floors will be up so the crews working on the utilities can work underneath the steel. Any time after the utilities are in the slab on grade can be placed. As the steel erection reaches its halfway point there will be two floors completed. This means that the slabs on the metal decks can start to be placed. At the same time, the crew spraying the fire proofing onto the steel can begin on the ground floor. By starting in this order the iron workers will always be a floor ahead of the concrete crews placing slabs while they will always be a floor ahead of the crew spraying the fire proofing.

When half of the slabs are placed the carpenters can come in and begin to frame and board the building. After all of the slabs are placed the roofers will have a surface to work on so they can come in and start to install the roof. After half of the framing is completed the carpenters will be far enough ahead of the masons so they can start to install the masonry exterior skin. These three projects are very important at this point in the construction. If everything is on schedule the roofing and skin of the building will be coming together in November. It is important to seal off the building for the winter so construction can resume on the inside of the building throughout the cold weather. The windows should begin to get installed when half of the masonry is installed.

Once the roof is finished and the fireproofing sprayed, the MEP systems can be roughed in to the building. When the building is sealed up, the windows are half installed, and the MEP roughing is half installed, the drywall can be delivered into the building and the interior finishes can begin. The interior construction of the building can make or break the opening date. The longest duration is for interior finishes at 109 days.

The best way to schedule the interior construction is to split the building up into wings. Different trades start in different areas so they work around each other. They also need to be staggered so they can follow each other until construction is completed. The electrician and plumbers will come in first and start in different areas. When they are finished they will move on and the drywall crews will come in. When the drywall is finished it needs to be taped and painted. While everyone is working other trades will be installing things like doors, fixtures, plumbing fittings, lighting equipment and flooring.

Once the interior finishes are completed the last thing to do is a cleanup and punch list. This will involve going through the building and taking care of any unfinished business necessary to complete the project. This will take 32 days to make sure everything is correct and finish up any testing or inspections. It will also take a little while for all of the contractors to get out of the building and get everything clean and ready to be handed over.

Figure 50 shows the relationships that all of the activities have with one another. The activities in red represent the critical path. Anything on the critical path means that it has to be started and finished on or before the time shown. If critical path activities are delayed everything after them will be delayed and the project will not finish on time. A critical path activity is determined by its float. The float is the amount of days that an activity can be delayed without affecting the schedule of the critical path. If an activity has no float it cannot be delayed or it will affect everything after it. The float of each activity is shown in Figure 49. Items that have a float value can be delayed that number of days without adversely affecting other parts of the project. If this project was to follow the schedule represented by the critical path it would finish in a total of 307 days. With a start date of June second, the project would finish on August fourth and have just enough time to open for school.

Activity Name	Original Duration	Start	Finish	Total Float
WPI Graduate Housing	307	02-Jun-08	04-Aug-09	0
Start Construction	0	02-Jun-08		0
Site Prep/Demo	8	02-Jun-08	11-Jun-08	0
Foundations	31	12-Jun-08	24-Jul-08	0
Steel Erection	62	25-Jul-08	20-Oct-08	0
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Spray on Fireproofing	35	08-Sep-08	24-Oct-08	57
Slabs on Decks	47	08-Sep-08	11-Nov-08	0
Slab on Grade	12	30-Sep-08	15-Oct-08	13
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Masonry Exterior Skin	62	04-Nov-08	28-Jan-09	0
Install Roofing	16	12-Nov-08	03-Dec-08	29
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Windows And Curtain Wall	47	17-Dec-08	19-Feb-09	0
Gypsum Board	89	20-Jan-09	22-May-09	20
Interior Finishes	109	20-Jan-09	19-Jun-09	0
Punchlist/Closeout	32	22-Jun-09	04-Aug-09	0
Move In	0		04-Aug-09	0

Figure 49: Activity Start and Finish Dates

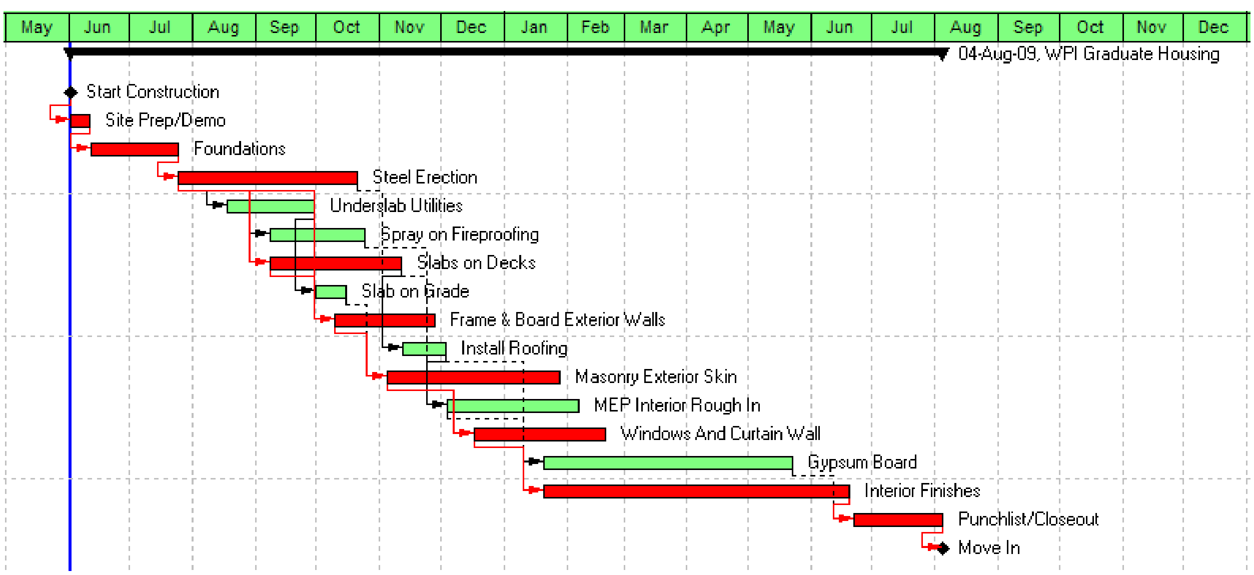

Figure 50: Construction Schedule

8 LEED Based Design

Buildings are one of the country's largest consumers of energy. Annually, buildings in the United States account for about 40% of the nation's total energy consumption. (Varney, 2007) With the rising cost of energy building owners need to start thinking about alternative means of construction and new ways to conserve resources. Changes are being made in the way that buildings are designed and operated.

Green buildings are sustainable structures that use land more efficiently and consume fewer resources than traditional construction. They can also reduce or eliminate negative environmental impacts. The goal of green buildings is to produce less waste while using a smaller amount of water and energy throughout its lifecycle. Green building construction is gaining popularity as the cost of energy rises and environmental regulations become more stringent. More efficient buildings can also reduce operating costs, enhance marketability, and improve worker productivity by improving the indoor environment. (Keenan, 2002)

The system that was developed to determine what is considered a green building is called The Leadership in Energy and Environmental Design (LEED) Green Building Rating System. (U.S. Green Building Council, 2006)This is a rating system based on accepted environmental and energy principals that quantifies a building's "green" status. The LEED Green Building rating system is a voluntary system to evaluate a building's performance as a whole over its entire life cycle.

The LEED Rating System for New Construction is separated into six categories including sustainable sites, water efficiency, energy and atmosphere, materials and resources, indoor environmental quality, and a category for innovation and design processes. (U.S. Green

Building Council, 2006) In each category a building can earn a number of credits. The total number of credits determines the level of green building certification.

8.1 Water Efficiency

Water is the key to all life on this planet. The U.S. population has almost doubled in the last 50 years but its demand for water has tripled. (U.S Environmental Protection Agency, 2008) A government survey has shown that by the year 2013 at least 36 states may run into water shortages. (U.S Environmental Protection Agency, 2008) All of our wastewater is not always treated and sometimes it goes right back into the rivers and streams. There is more water being taken out of the natural water system than the amount that is being put back in, resulting in a water supply deficit. When more than the necessary amount of water is used it increases the life cycle and operational cost of buildings and also sends more wastewater to treatment plants. Conserving water can pay off very quickly and can be accomplished without sacrificing too much money and effort. The LEED Rating System for New Construction offers LEED credit for reducing the amount of water that buildings use and for implementing new technologies to handle and recycle wastewater. (U.S. Green Building Council, 2006)

8.2 Water Use Reduction

LEED credits can be awarded for reducing the total water use by 20%. This will increase the efficiency of the building and lower dependence on the municipal water system and treatment plants. If water use can be reduced by 30% a second LEED credit is awarded. The water use only accounts for water coming from water closets, urinals, lavatory faucets, showers, and kitchen sinks. Irrigation systems are not included in this category. (U.S. Green Building Council, 2006)

One of the easiest ways to cut down on water consumption is to look at the type of plumbing fixtures installed in a building. The Energy Policy Act of 1992 was passed by the U.S. government to control the use of water. It set guidelines for the amount of water used in commercial, residential, and institutional facilities. The flow rate allowed for water closets was 1.6 gallons per flush, urinals was 1.0 gallons per flush, showers were 2.5 gallons per minute, and faucets were 2.5 gallons per minute. (U.S. Department of Energy, 2008) Today new plumbing fixtures are being designed to reduce further the amount of water used and support the new green buildings. The flow rates of conventional plumbing fixtures are compared to new high efficiency plumbing fixtures in Table 24.

Table 24: Flush and Flow Rates

Conventional Flush Fixture	Flow Rate (gpf)	Efficient Flush Fixtures	Flow Rate (gpf)
Conventional Water Closet	1.6	Low-Flow Water Closet	1.1
		Ultra Low-Flow Water Closet	0.8
		Composting Toilet	0
Conventional Urinal	1	Low-Flow Urinal	0.5
		Non-Water Urinal	0
Conventional Flow Fixture	**Flow Rate (gpf)**	**Efficient Flow Fixtures**	**Flow Rate (gpf)**
Conventional Lavatory	2.5	Low-Flow Lavatory	1.8
		Ultra Low-Flow Lavatory	0.5
Kitchen Sink	2.5	Low-Flow Kitchen Sink	1.8
Shower	2.5	Low-Flow Shower	1.8

Some options for alternative plumbing fixtures include automatic fixture sensors and meter controls. Fixture sensors are motion sensors that are installed on sinks and faucets to stop the flow of water when not in use. Meter controls can limit the amount of flow coming from faucets and shower heads. Low flow water closets and urinals are also being installed. These use less water to do the same thing that a conventional toilet would do. Non-water urinals are designed to operate without water by trapping wastewater under a layer of buoyant liquid to eliminate smells. Another option that will result in no wastewater is a composting toilet. These are dry plumbing fixtures that treat waste with a microbiological process. (U.S. Green Building Council, 2006)

To explore how much water may be saved by changing plumbing fixtures, calculations were done to determine the annual water consumption of the building designed by the group. The analysis only focused on the residential area of the building and did not consider the commercial business on the first floor. This was assumed because it was unsure of the number of people who would be using first floor and because the high water demand of the restaurant was not known. It was also assumed that the male to female ratio was 50% and the building was at capacity with 122 permanent year round residences. The usage frequency for each fixture per day was based on average values provided in the LEED-NC v2.2 Reference Guide that are shown in Table 25.

Table 25: Water Fixture Usage

Fixture Type	Uses Per Day
Water Closet Male	5
Water Closet Female	5
Lavatory Faucet (12 sec)	5
Shower (300 sec)	1
Kitchen Sink (60sec)	4

Table 26 shows the annual water consumption of the building with conventional fixtures that comply with the flow rate established by The Energy Policy Act of 1992.

Table 26: Conventional Fixtures Total Annual Volume

Flush Fixture	Daily Uses	Flowrate (gpf)	Duration (flush)	Occupants	Water Use (gal)
Conventional Water Closet Male	5	1.6	1	61	488
Conventional Water Closet Female	5	1.6	1	61	488
Flow Fixture	**Daily Uses**	**Flowrate (gpm)**	**Duration (sec)**	**Occupants**	**Water Use (gal)**
Conventional Lavatory	5	2.5	12	122	305
Kitchen Sink	4	2.5	60	122	1,220
Shower	1	2.5	300	122	1,525
			Total Daily Volume (gal)		4,026
			Days of Operation		365
			Total Annual Volume (gal)		1,469,490

Table 27 shows how the annual water consumption would change if more efficient plumbing fixtures were installed in the apartments. Currently the apartments include one kitchen sink, one lavatory sink, a shower, and a toilet. In the new design the rooms include a low flow toilet, a waterless urinal, a low flow lavatory and kitchen sink, and a low flow shower.

Table 27: Efficient Fixtures Total Annual Volume

Flush Fixture	Daily Uses	Flowrate (gpf)	Duration (flush)	Occupants	Water Use (gal)
Ultra Low-Flow Water Closit Male	1	0.8	1	61	49
Ultra Low-Flow Water Closit Female	5	0.8	1	61	244
Waterless Urinal Male	4	0	1	61	0
Flow Fixtures	**Daily Uses**	**Flowrate (gpm)**	**Duration (sec)**	**Occupants**	**Water Use (gal)**
Ultra Low-Flow Lavatory	5	0.5	12	122	61
Low-Flow Kitchen Sink	4	1.8	60	122	878
Low-Flow Shower	1	1.8	300	122	1,098
			Total Daily Volume (gal)		2,330
			Days of Operation		365
			Total Annual Volume (gal)		850,523

Comparison of Tables 26 and 27 indicates that changing the plumbing fixtures can possibly cut the water consumption from 1,469,490 gallons per year to 850,523 gallons per year. This is about a 42% decrease in water consumption. When considering the installation of a green design the initial cost is not as important as the life cycle cost of a product. This change in design may have a higher initial cost but over time it will save money. The more efficient fixtures will result in a building that consumes almost half as much water as it would have with conventional products. Over a long period of time efficient products will cut down the amount of water used and reduce the operating cost of buildings.

Table 28: Plumbing Fixture Cost Comparison

Efficient Plumbing Fixtures		Standard Plumbing Fixtures	
Bathroom sink	$1,010.00	Bathroom sink	$1,010.00
Kitchen sink	$1,175.00	Kitchen sink	$1,175.00
Recessed Bathtub and Shower	$3,095.00	Recessed Bathtub and Shower	$3,095.00
Low-Flow Water Closit	$1,450.00	Toilet Standard Floor Mount	$1,530.00
Waterless Urinal	$480.00		
Water Economizing Shower Head	$88.50		
Bathroom Sink Faucet Aerator	$20.50		
Kitchen Sink Faucet Aerator	$20.50		
Automatic Sensor for Bathroom Faucets	$395.00		
Total	$7,734.50	Total	$6,810.00

Table 28 shows a cost comparison between a standard apartment with conventional fixtures verses an apartment with more efficient fixtures. These prices were obtained from Green Building: Project Planning and Cost Estimating and the 2008 RS Means Building Construction Cost Data book. The green apartment is equipped with a low flow shower head, a waterless urinal, a low-flow water closet, a low flow bathroom sink with automatic sensors, and a low flow kitchen sink. The difference in cost is just under a thousand dollars. With a total of 44 apartments in the building the total cost to change over to more efficient fixtures would be under 44 thousand dollars. A life cycle cost analysis of efficient plumbing fixtures can be used to determine the savings of this initial added investment over time. According to the Worcester Department of Public Works the cost of water in Worcester is about $0.004 per gallon to pipe in and about $0.005 per gallon to dispose of. (Worcester DPW, 2008) This would result in a cost of about $0.009 per gallon of water used. Table 29 shows the annual water use of the building for both types of fixtures. It also shows the initial cost of each type of fixture and the cost of water per year with each setup. These calculations assume that if water is used in the building then it is also disposed of in the building. Figure 51 compares the two options over time to determine the elapsed time for the new plumbing fixtures to provide economy over conventional fixtures.

Table 29: New Vs. Old Plumbing Fixtures

	New Plumbing Fixtures	Standard Plumbing Fixtures
Annual Building Water Use	850,523	1,469,490
Total Fixture Cost	$340,318.00	$299,640.00
Cost Per Gallon	$0.009	$0.009
Water Cost for 1 year	$7,654.71	$13,225.41

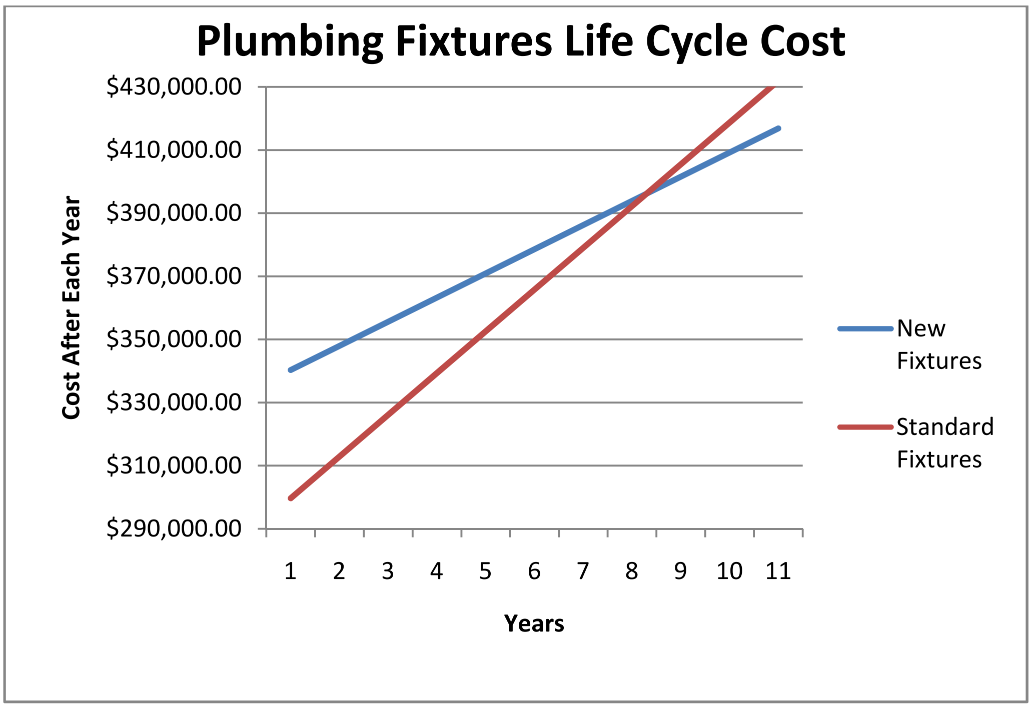

Figure 51: Plumbing Fixtures Life Cycle Cost

The life cycle cost analysis shows the initial cost of each type of fixture along with the cost of water used each year. It shows how the cost of water will add up over 11 years of building use. There was no information on the history of water prices in Worcester so this comparison does not account for an increase in water prices. In addition, the frequency of maintenance required for the two types of fixtures was not known so it was not included.

The high efficiency fixtures have a larger initial cost but this is eventually offset by less money spent on water per year. If the building design was to incorporate high efficiency fixtures it would be able to break even with the cost of standard fixtures after eight years of use. Once this break-even point is reached, every year after the owner will be saving money. To cut down on water costs even more wastewater can be reused to reduce the demand for municipal water.

8.3 Innovative Wastewater Technologies

Another LEED credit for water efficiency involves the use of innovative wastewater technologies. The intent of this credit is to lower the amount of wastewater produced and lower the amount of potable water used in the wastewater stream. Potable water is defined as water that is suitable for drinking. This is similar to the previous LEED requirement that focused on water consumption. This requirement is more directed at lowering wastewater volumes and using non-potable water to convey sewage. There are two options to receive credit for this LEED requirement as shown in Figure 51 (U.S. Green Building Council, 2006)

Option 1	**Option 2**
Reduce potable water use for sewage conveyance by at least 50% through the use of water conserving fixtures or non-potable water.	Treat at least 50% of wastewater on-site to tertiary standards. Treated water must be infiltrated or used on site.

Figure 52: Innovative Wastewater Technologies

One strategy to satisfy Option 1 is to include high-efficiency fixtures, dry fixtures, and non-water urinals that were discussed in the previous section. Storm water and grey water can also be used to convey sewage instead of using potable water. Grey water is defined as wastewater that has not come into contact with sewage. On-site treatment can be done through the use of biological nutrient removal systems, or filtration systems.

In the City of Worcester it is more expensive to dispose of wastewater than to pipe in potable water with costs of $0.004 per gallon and $0.005 per gallon. Collecting rainwater can greatly reduce the use of treated potable water. Collected rainwater is perfect for use in irrigation systems and can even be used as drinking water when properly treated to remove impurities. Rainwater and grey water systems collect water from the roof of a building or from sinks and showers to use it for flushing toilets, irrigation, and other tasks that do not require drinkable water. To use grey water in irrigation systems it must be treated with a commercial filter or sand filter. (Keenan, 2002) Systems can be designed to store rainwater in tanks and then pump it out for later use. Figure 53 shows a basic rain harvesting system that collects water and uses it for toilets, sinks, and washing machines. The diagram shows a building with rain water collectors, a storage tank, and pumps to bring rain water back into the building for use with low flow fixtures in bathrooms.

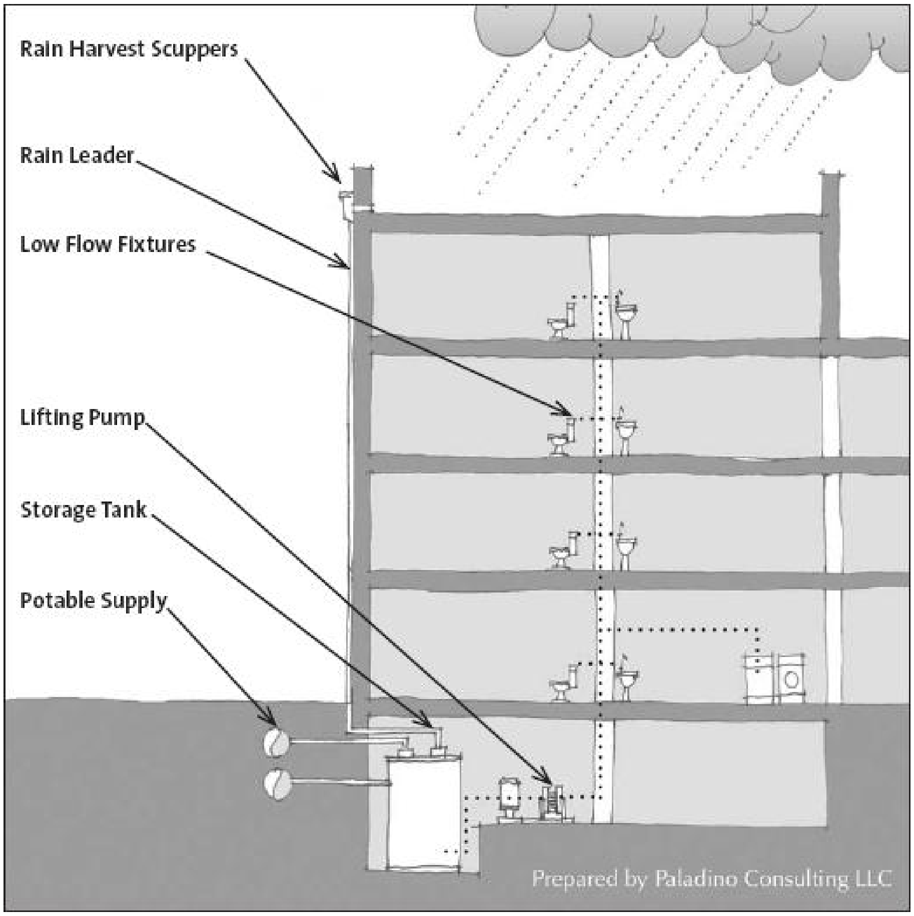

Figure 53: Rain Harvesting System
(U.S. Green Building Council, 2006)

The amount of rainwater that can be collected and used will vary depending on the location of the building, the season and climate, and the capacity of the storage tanks. In order to calculate the rain harvesting volume you need to know the collecting area, the collection efficiency and the average rainfall for the location.

Another way to reduce the amount of potable water used is to adopt a more efficient type of irrigation system. A drip irrigation system is an underground system that is more efficient because less water is lost to evaporation before it reaches the plants. These systems can include timers and sensors so the correct amount of water is delivered to the plants roots. By watering deeper in the ground rather than at the surface, drip irrigation systems use about 20-50% less water than conventional systems. (U.S. Environmental Protection Agency, 2008)

Lowering the amount of water that is wasted in buildings can benefit everyone. Using less water can lower the operating cost, and the life cycle cost of a building. Installing more efficient plumbing fixtures has a higher initial cost but it can pay for itself through water cost savings in less than ten years. If grey water and rainwater are reused in buildings they can lower the amount of wastewater produced and the amount of potable water comsumed, saving even more money. If a building's water consumption is lowered and it finds ways to re-use water, it can earn credits towards LEED certification and ultimately help contribute to saving the environment.

9 Alternative Parking Structure

Parking is a primary concern in any new residential and commercial construction project. For commercial facilities, adequate parking is required to meet the needs of consumers and employees who enter the buildings everyday. For residential facilities, long-term parking is needed for tenants to leave their vehicles overnight and sometimes during the entire week.

The parking for the graduate housing facility at 75 Grove Street must meet both functions as the building includes both residential and commercial areas. Surface parking was designed for the site, yet many of these spaces would be occupied long-term by resident's vehicles. This is unappealing to potential commercial tenants because limited parking is left for daily customers and employees. Therefore, as an area of further study, the concept of additional parking options for the site was investigated.

9.1 Objective and Design Concept

The objective of the additional parking is two-fold. First, the additional space must provide adequate long-term parking for the graduate student tenants who will live in the new building. These students, many of whom have permanent residences outside of the Worcester area and even Massachusetts, will use their car to move to school at the start of each academic year. However, during the work week, these vehicles most likely will remain parked as the graduate students study and conduct research both on the main WPI campus and at Gateway Park. Therefore, ample space must be reserved to accommodate this long-term parking need. Second, since many cars will most likely remain stationary for long periods of time, an adequate parking area must also provide a level of security to protect against potential theft and vandalism.

Currently, there are three parking options for tenants of the proposed facility: planned on-site surface parking, an adjacent lot across Faraday Street, and the parking garage at Gateway Park. Surface parking on the site may be limited, and therefore may not provide enough space for the building residents and commercial tenants. Second, in the redevelopment plan for the Gateway Park District, although the adjacent lot on Faraday Street will be owned by WPI, it is currently used by the adjacent businesses and offers limited protection for overnight parking. Third, the new parking garage at Gateway Park offers ample space and some enclosure for security, but is a two block walk from the proposed new structure at 75 Grove Street.

Therefore, some alternative parking structure was envisioned to provide secure tenant parking for 75 Grove Street. Initially, three areas, which are shown in Figure 53, were selected from the surrounding site as potential locations for some type of parking structure with designs being completed for 2 of the sites. First, a basement level parking garage design was considered under proposed building at 75 Grove Street. Second, a partially sub-grade parking facility was envisioned behind the proposed building. Last, while not designed, the surface parking lot across Faraday Street was considered as the potential location of another parking garage.

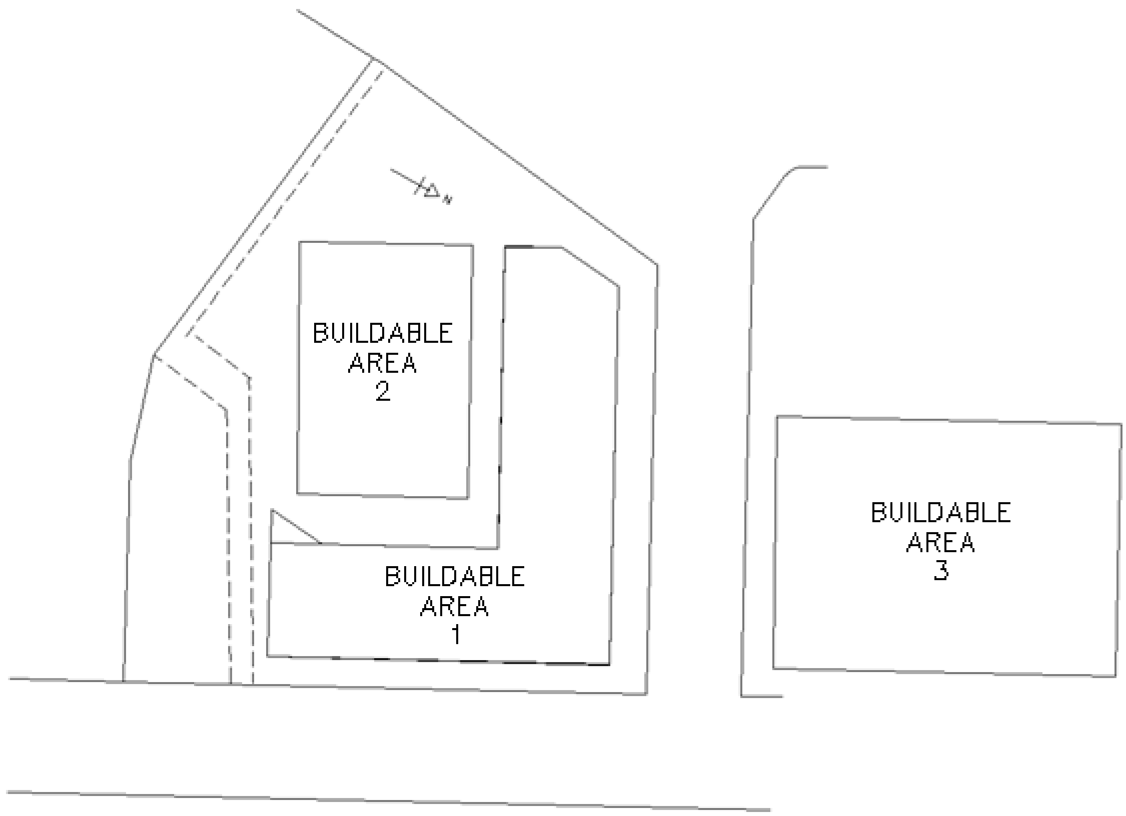

Figure 54: Buildable Areas for an Alternate Parking

9.2 Soil Considerations

Before any designs and layouts could be considered for this parking structure, consideration of the soil conditions at 75 Grove Street must be addressed along with their implications to subsurface excavation and construction. First, as mentioned previously in this report, the site at 75 Grove Street was designated as a “brownfield” by environmental officials due to soil contamination found on the site. The contamination was attributed to the site’s former use as a manufacturing and industrial facility. Table 30 below shows the list of chemicals that were found on the site (Coates, Millbrandt, and Szela; 2000).

Table 30: Contaminants Found at 75 Grove Street

Chemical	Use
2-Methylnaphthlene	Polycyclic aromatic hydrocarbon used for nonstructural caulking compounds and sealants, synthetic resin and rubber adhesives, and wall coverings. It is derived from coal tar.
Arsenic	Polluntant metal obtained from flue dust of copper and lead smelters.
Benzo(a)anthrcene	Polycyclic aromatic hydrocarbon that occurs in coal tar.
Benzo(a)pyrene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
Benzo(b)flouranthene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
Benzo(k)flouranthene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
C9-C36 Aliphatics	
Chrysene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
Dibenzo(a,h)anthracene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
Indeno(1,2,3-cd)pyrene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
C11-C22 Aromatics	
Phenanthrene	Polycyclic Aromatic Hydrocarbons present in coal tar which is used in steel industry, roofing materials, and surface coating.
Thallium	Pollutant metal from flue dust from lead and zinc smelting.

In order to excavate on the site, these materials must be properly removed or contained to prevent health hazards to occupants. For Massachusetts, the Massachusetts Contingency Plan, which is issued by the Massachusetts Department of Environmental Protections (MassDEP), states that remediation measures must, to the best extent possible, return soil quality to conditions prior to the release of chemicals (Buonicore, 1996). Additionally, once listed as a brownfield, a site is given a classification based on the status of its remediation. Currently, 75

Grove Street has a Response Action Outcomes (RAO) class of B1 (Massachusetts Department of Environment Protection, 2008), which means that no remedial actions have taken place since the site poses no current significant risk (Massachusetts Department of Environment Protection, 2001).

The treatment of contaminated soil is also outlined by the state contingency plan. The Contingency Plan states in Section 40.0857 that remedial actions must result "in the reuse, recycling, destruction, detoxification, treatment or any combination thereof of the oil and hazardous material present at the disposal site" and "be implemented in a manner that will not pose a significant risk of harm to health, safety, public welfare or the environment, as described in 310 CMR 40.0900" (Massachusetts Department of Environment Protection, 2008). Standard engineering methods must be used to isolate contaminated soils and any soil containing residual contamination must also be removed if found under the supervision of a licensed site professional (Massachusetts Department of Environment Protection, January 2008). Soils must then be loaded onto roll-off containers of trucks and shipped to a disposal site or plant approved by MassDEP. Therefore, the excavation of contaminated soil alone could cause a project to prove uneconomical. For this reason, the initial design of 75 Grove Street considered footing foundations and a slab on grade to avoid extensive excavation. In order to consider the design of an underground garage, and based on the construction of the WPI Life Sciences and Bioengineering Center on similar soil, it was assumed that construction of a basement could be conducted at 75 Grove Street.

9.3 Basement Level Parking Garage

9.3.1 Design

The first construction option involved the construction of an underground parking level as part of the main graduate housing building. This would consider a building area equal to the footprint of the proposed building. The advantage with this option is that a smaller amount of the green space would be taken up by a basement parking level. Additionally, it was hypothesized that the structure would have the advantage of being more economical since it would only add a basement to the proposed housing structure rather than require a separate building and foundation system.

To begin design, specifications and code requirements for the parking level were compiled from three main sources. The 2006 International Building Code was used for general code requirements ranging from necessary equipment and minimum floor plan dimensions. The text Time-Saver Standards for Building Types was used along with the 2007 Architectural Graphic Standards to determine standard parking space dimensions and requirements for accessible parking. The 2007 Worcester Zoning Ordinance was also used to dimension parking spaces. Table 31 illustrates the major requirements compiled from these references.

Table 31: Design Specifications for Underground Parking Garage

Design Specifications and Standards for Underground Parking Garage		
Source & No.	Description	Page Number
2006 INTERNATIONAL BUILDING CODE		
Parking Garages		
2	Clear height of each floor level in vehicle and pedestrian areas shall not be less than 7 feet.	406.2.2
3	Parking areas shall be provided with exterior and interior walls or vehicle barriers, except at pedestrian or vehicular accesses designed in accordance with Section 1607.7	406.2.4
4	Vehicle ramps shall not be considered as required exits unless pedestrian facilities are provided. Ramps used for both should not exceed a 1:15 (6.67) percent slope.	406.2.5

5	Parking surfaces shall be of concrete or similar noncombustible and non-absorbent materials. Floor areas used for parking shall be sloped to facilitate the movement of liquids to a drain or toward the main vehicle entry doorway.	406.2.6
Enclosed Parking Garages		
1	Shall be limited to the allowable heights and areas specified in Table 503 as modified by Sections 504, 506, and 507	406.4.1
2	A mechanical ventilation system shall be provided in accordance with the International Mechanical Code	406.4.2
3	Low-Hazard Storage S-2 Occupancy	311.3
4	Table 503 For Type 1A Construction Stories=UL and Area=UL	Table 503
5	For Type 1B Construction Stories=11 Area=79,000sqft	Table 503
6	Residential Occupancies and S-2 should be separated by a 1hour or 2hour fire resistant barrier depending on the use of an automatic sprinkler system.	Table 508.3.3
7	A basement and/or the first story above grade plane of a building shall be considered as a separate and distinct building for the purpose of determining area limitations, continuity of fire walls, limitation of number of stories and type of construction when all of the following conditions are met:	509.2
8	Basement is Type 1A Construction and separated by a horizontal assembly with a minimum 3-hour fire resistance rating.	509.2
9	Shaft, Stairway and Ramp enclosures have not less than a 2 hour rating with opening protectives in accordance with Table 715.4	509.2
10	The building above the horizontal assembly shall be permitted to have multiple Group A uses, each with an occupant load of less than 300, or Group B, M, R, or S uses.	509.2
11	The building below the horizontal assembly is a Group S-2 enclosed or open parking garage, used for the parking and storage of private motor vehicles.	509.2
12	Entry lobbies, mechanical rooms and uses incidental to building operation are allowed	509.2
13	Multiple Group A uses will be allowed below the horizontal assembly permitted an automatic sprinkler system is used	509.2
TIME SAVER STANDARDS FOR BUILDING TYPES		
1	The minimum angle of departure to reduce rear bumper or tailpipe dragging is 10 degrees	974
2	The maximum ramp slope is 15%	974
3	A transition slope of 5 percent and 16 feet long must precede and follow a ramp that is intersecting with a public sidewalk.	974
4	Approximate 10 foot elevation between parking levels (Used of 11 ft in design	
5	The edge of the drive way should be a least 6 feet from	974

	the wall	
6	Minimum Ramp width for 2 way traffic is 22 feet	981
8	Table 1: Ramp length for straight ramps (to the nearest foot) Current Ramps has a twelve percent ramp grade and a length of 92 feet.	985
9	Minimum Turning Radius for Curb equals 10 feet with a minimum drive width of 15 feet is required for one way traffic.	993
2007 ARCHITECTURAL GRAPHIC STANDARDS		
1	For Parking Spaces Angled 70 Degrees a minimum drive of 18.4 feet is required for one way traffic	680
2	Minimum Number of Accessible Spaces for a parking lot with 1-25 spaces equals 1 (2 used in design)	82
3	Standards for Accessible Ramps and Walkways	902-903

Initially, it was envisioned that cars would enter the underground parking level from Lancaster Street on the west end of the building. However, this area needed to be designated as loading docks for supplies. Therefore, a new entrance was envisioned on the south side of the building with an entry ramp running from an access road on the south end of the lot to the parking level entrance. The design of the entrance and surrounding space is illustrated in Figure 55. To preserve as much green space as possible, the ramp was enclosed once a minimum height of ten feet was reached. Over this enclosure, landscaping was provided to connect open space to the entrance of the atrium.

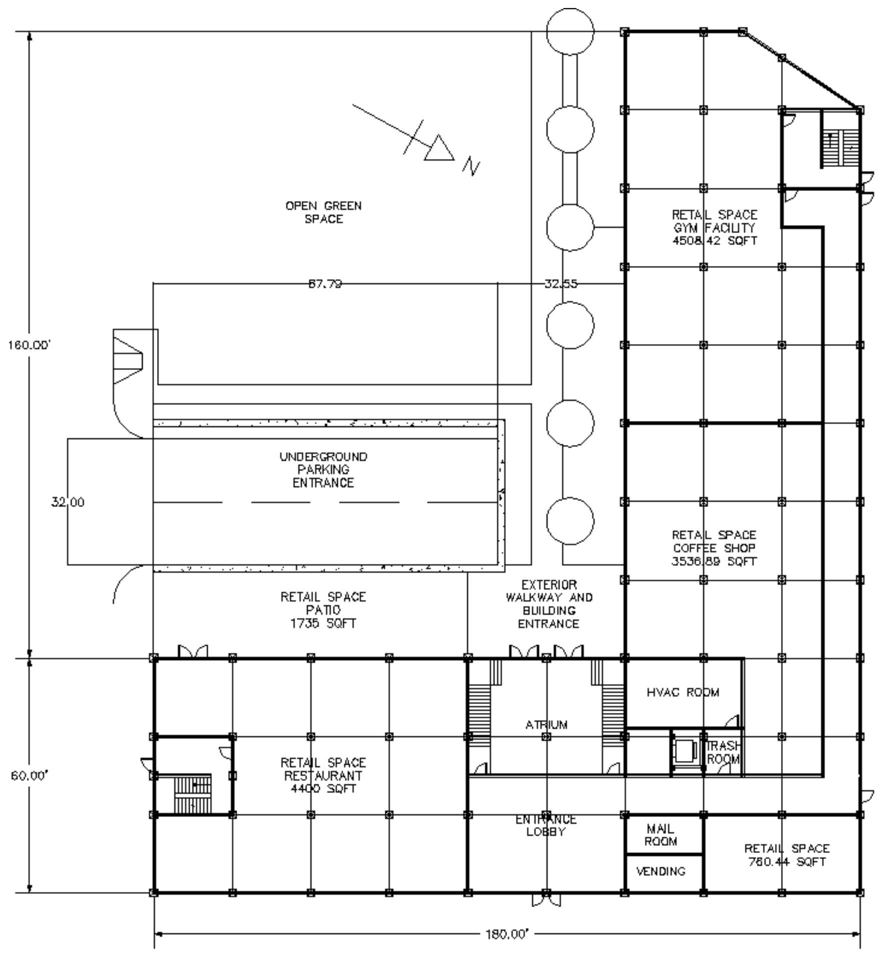

Figure 55: Plan View of Basement Parking at Ground Level

Meanwhile, inside the parking level, design was constrained by the structural layout of columns. Initially, it was envisioned that parking spaces could be placed perpendicular to the direction of travel. This design would have allowed for 29 spaces to be placed in the underground lot. However, the Worcester Zoning Ordinance along with the Architectural Graphic Standards specified that a minimum driveway width of 24 feet was required to facilitate cars pulling out of spaces. The 20-foot by 20-foot bay size in the building ultimately does not meet this requirement. Therefore, the spaces were angled by 70 degrees from the curb to allow for a driveway width of 18.4 feet. The turns illustrated in Figure 56 were designed for a large 10-foot by 18-foot car executing the turns in the parking level. The turning radius was taken as a minimum of 10 feet (De Chiara, 2001). Ultimately, the large vehicle was able to execute all of the turns in the parking facility.

Figure 56 illustrates the final overall design of the underground parking level. The design encompassed 15,600 square feet of space and includes 17 parking spaces. The Worcester Zoning Ordinance required that the number of spaces for this facility be governed as one third of the total units (City of Worcester, February 2007). This number equaled 15 spaces with the current design offering two additional parking spaces. Two of these spaces were designated as handicap accessible yet the configuration of the spaces made many spaces compliant with accessibility standards. As mentioned previously, the number of spaces was limited by the requirement to angle the spaces due to the location of structural columns. Furthermore, additional spaces could not be added along the west segment of the building because vehicles would not be able to make a U-turn under the current design and any reconfiguration of the layout would cause a further reduction in parking spaces.

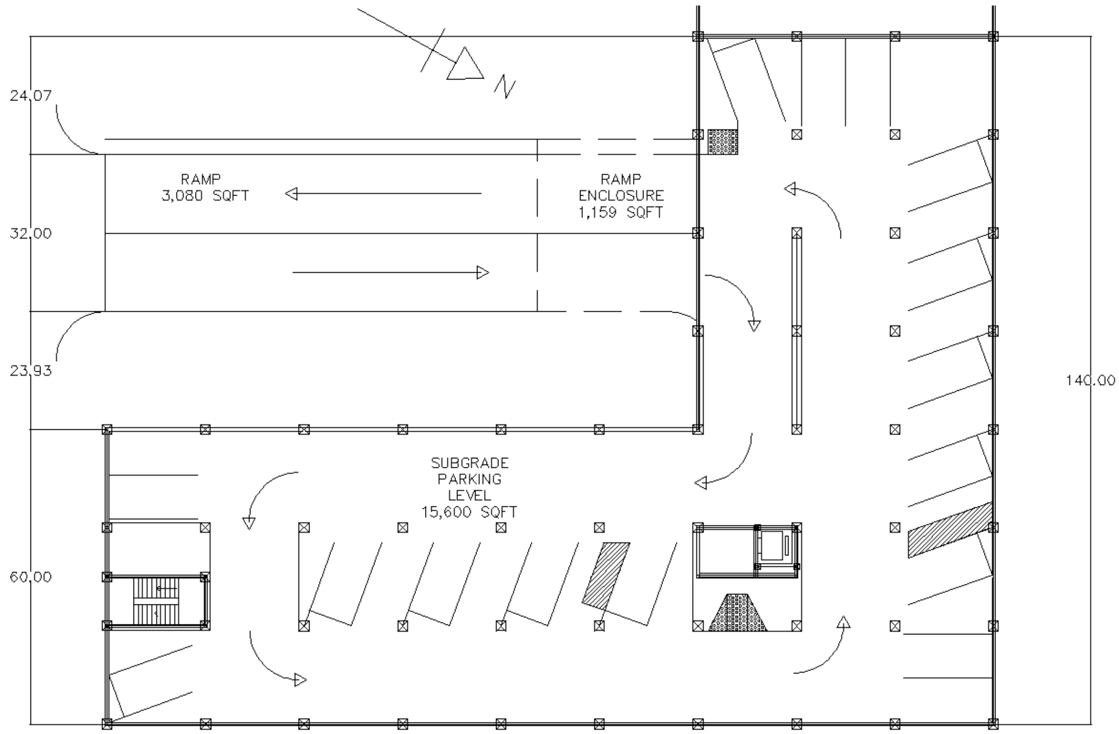

Figure 56: Plan View of Basement Parking at Basement Level

Figure 57 gives detail dimensions for a typical area of the parking level. The driveway was eighteen feet, while parking spaces are dimensioned as nine feet by 18 feet per specification from the Worcester Zoning Ordinance (City of Worcester, February 2007).

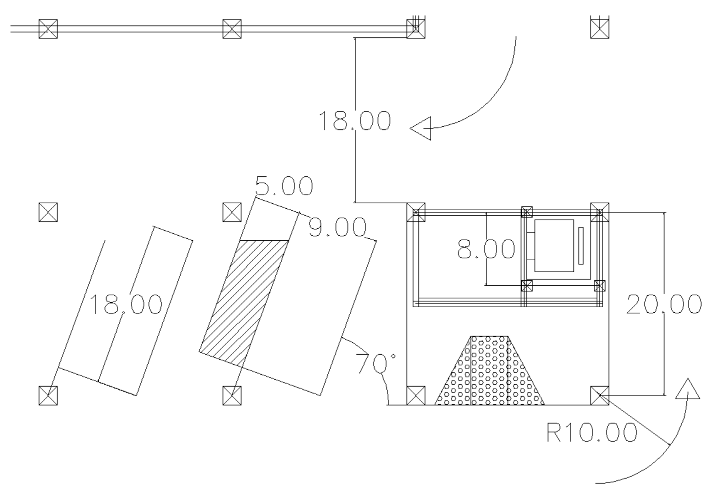

Figure 57: Basement Parking Layout Detail

9.3.2 Cost Considerations

The main concern with the design of such an ambitious parking facility was if the design would be economical and feasible for the overall project. Therefore, using the 2008 RS Means Square Foot Costs, a preliminary cost estimate was calculated for the underground parking garage.

The cost estimate was based on square foot costs of a two-story, 20,000 square foot parking garage that consisted of one level above ground and the other underground. Therefore, cost line items pertaining to the second story (such as roofing) were not included in the estimate. However, an additional concrete beam and slab system to support the first floor was considered in the cost. Table 32, breaks the cost into the various categories along with accounting for contractor and architect's fees. Ultimately, the total cost of the new underground parking level was estimated as roughly $1,056,671. Based on a total of 17 spaces, this cost was broken down to $62,157 per space. Additionally, the cost did not factor in the potential cost of removing and cleaning contaminated soil from the site during excavation. Furthermore, the cost is only a preliminary construction cost, and therefore does not consider any life cycle costs pertaining to the garage.

Table 32: Cost Estimate

Preliminary Cost of Underground Parking Garage		
Category	Cost	
Substructure	$	239,992.43
Shell	$	370,364.83
Interiors	$	42,163.46
Services	$	135,051.75
Equipment	$	6,916.84
Subtotal	**$**	**794,489.32**
Contractor's Fees	$	198,622.33
Architect's Fees	$	63,559.15
TOTAL	**$**	**1,056,670.80**

9.4 Partially Sub-Grade Parking Structure

The second area considered for an alternative parking structure from Figure 54 was the area behind the new graduate housing facility. This would keep construction on the same lot and also provide exclusive use of the garage for tenants and immediate businesses on site. The parking facility could either be its own building or part of an addition to the graduate housing. However, this option also is predicted to be inefficient and costly as it requires the construction of a complete additional building. Furthermore, such a parking structure on this area would remove the green space requested by the client and obstruct the view and natural light for many of the tenant apartments.

The main concern with this area was that another building would remove the green space requested by the client in design, and it would also obstruct natural light from commercial and residential spaces. However, it was envisioned that a partially underground parking level be designed to reduce the obstruction of light to commercial spaces on the first floor and allow green space to remain on top of the structure. Since, the parking garage would be partially above ground, it could be designed as an open parking garage, which would not require it to have a ventilation system. Table 33 below outlines the IBC specifications for open parking garages, with the most important requirement being the minimum area and perimeter of open wall space.

Table 33: Design Specifications

Open Parking Garages		
Item No	Description	2006 IBC Sect.
1	The exterior side of the structure shall have uniformly distributed openings on two or more sides. The area of openings must be at least 20 percent of the perimeter wall area. The aggregate length of the openings considered shall constitute a minimum of 40 percent of the perimeter of the tier. Interior walls shall be at least 20 percent open with uniformly distributed openings.	406.3.3.1
2	Mixed-uses shall be allowed in the same buildings subject to the provisions of Section 508.3, 402.7.1, 406.3.12, 509.3, 509.4, and 509.7	406.3.4
3	Area and height of garage shall be limited as set forth in Chapter 5 for group S-2 occupancy And as further provided for in Section 508.3	406.3.5 and Table 406.3.5 for single use buildings
4	Increases to size can be obtained with increases in openings of exterior walls	406.3.6
5	Exterior walls and openings shall comply with Tables 601 and 602. The distance to an adjacent lot line shall be determined in accordance with Table 602 and Section 704	406.3.7 Fire Separation Distance
6	Open Parking Garages shall meet the means of egress requirements on Chapter 10 when permitting persons other than parking attendants.	406.3.8
7	Standpipes shall be installed where required based on Chapter 9	406.3.9
8	Where required by other sections of code, sprinkler systems shall be installed based on Chapter 9	406.3.10
9	Enclosure of vertical openings shall not be required except as in Section 406.3.8. Ventilation other than natural shall not be required	406.3.11 and 406.3.12
10	Repair Work, parking of buses or trucks, closing of required openings, or dispensing of fuel are prohibited	406.3.13

Based on these requirements, the parking garage was designed as a 100-foot by 175-foot concrete structure with brick facing shown in Figures 58 through 61. First, Figure 58 illustrates the layout of the parking level. Based on design standards and the Worcester Zoning Ordinance, most parking spaces were angled 45 degrees from the curb with some spaces angled 90 degrees from the curb. The beam span of 50 feet allowed significant room for cars to pull into spaces and was accomplished through the use of double tee pre-stressed concrete beams, which are often used for parking facilities. Ultimately, 43 spaces, which included 3 handicapped spaces, were ample to be placed in the layout.

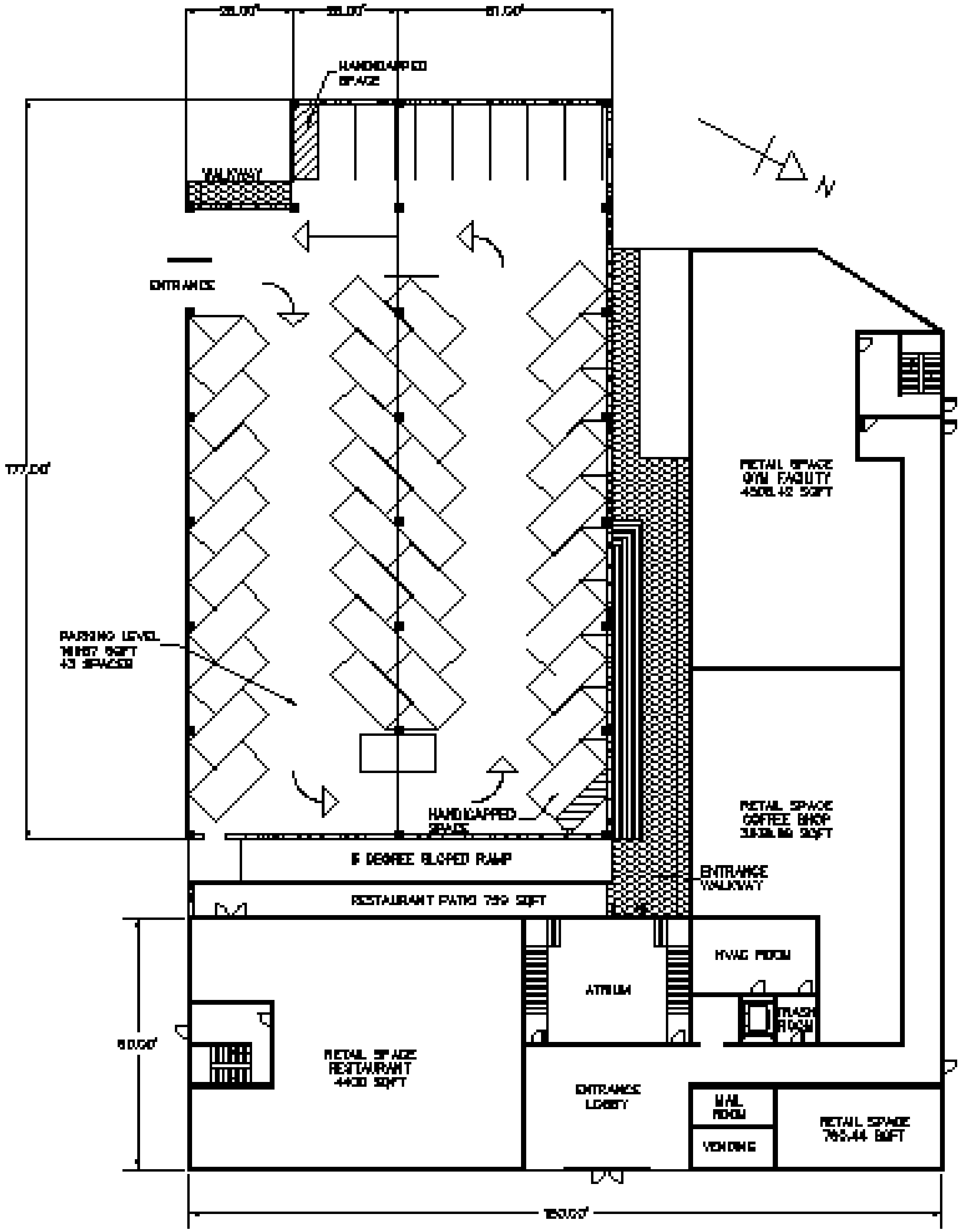

Figure 58: Layout of Structure at Parking Level

Figures 59 and 60 are both elevation views of the parking garage. First, Figure 58 shows the entrance side of the building, which is 7 feet below the current grade of the site. To access the parking level, a sloped road would start at the Grove Street curb and decline till 7 feet is reached. This allows the structure to only rise 5 feet above grade, which is shown in figure with the other elevation view of the building. These figures also show that the building will meet the area and perimeter requirements for an open parking garage with openings on three sides of the building. Forty-six percent of the perimeter is openings, which is above the forty percent requirement and seventy-two percent of the wall area is openings, which is well above the twenty percent minimum.

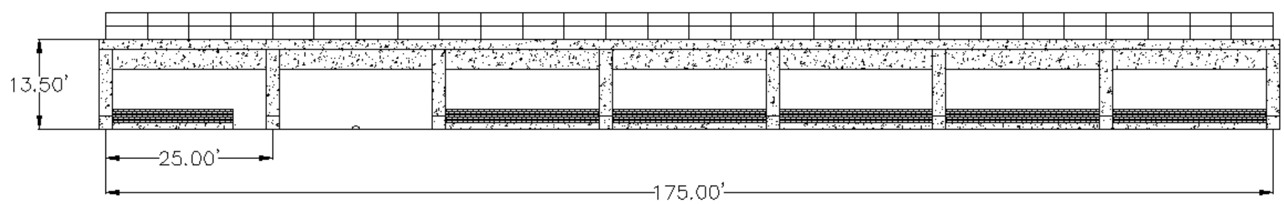

Figure 59: South Elevation of Parking Garage (Section A-A in Figure 57)

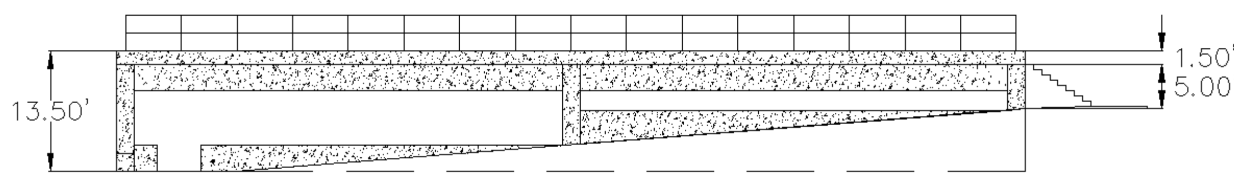

Figure 60: East Elevation of Parking Garage (Section B-B in Figure 57)

The parking structure even addressed the concern of lost green space with the construction of an additional building on the site. Many green buildings make use of a green roof top with grass and plants placed on the rooftop to account for the green space lost during construction. Therefore, the parking facility was designed to support a 1-foot thick layer of soil on its roof, shown in Figure 61. Table 4.1 of the Geotechnical Engineering text by Coduto was used to assume a design soil density of 80pcf (Coduto, 2001). A live load value of 100psf for assembly areas was determined from the IBC. This meant the pre-stressed double-tee beams would be required to support a service load of 180psf. With the aid of the tables provided in the PCI Design Handbook, an 8' by 32' beam, shown in Figure 62, with a 148-S strand pattern and a service load capacity of 199psf, was chosen for design of the parking facility. However, a vapor barrier would need to be placed under the soil layer in order that car exhaust does not kill the overlying grass and plant life.

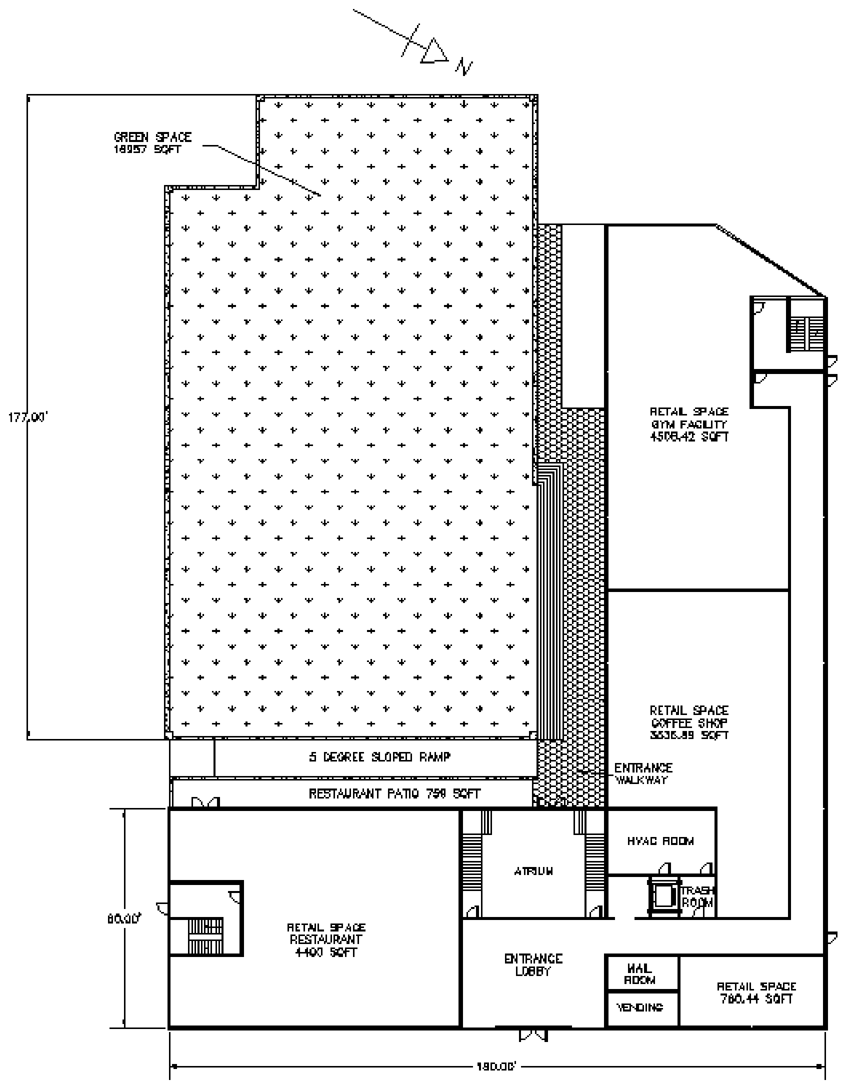

Figure 61: Layout of Structure at Ground Level

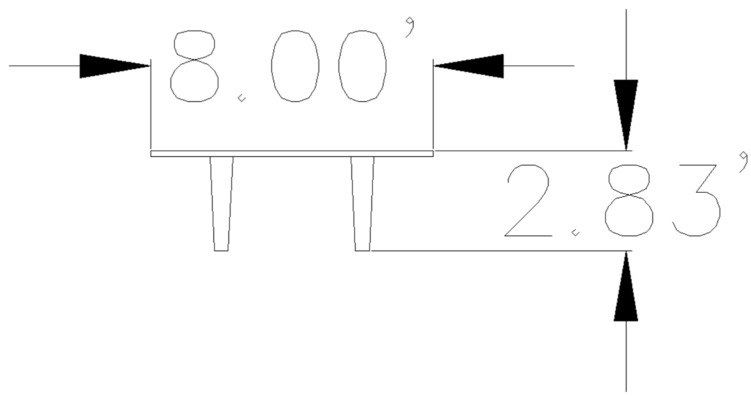

Figure 62: Typical Pre-stressed Concrete Double-Tee Beam

Now that the redesigned parking level addressed the issue of providing minimal loss to green space on the site, the facility was studied to see if more parking was obtained for a more economical cost. The cost estimate for this parking structure was based on RS Means Square Foot Costs for an 85,000 square foot 5-story parking garage. This is because the estimate considers the use of double tee pre-stressed concrete beams along with open walls. However, the estimate for a 24' deep excavation was kept from the previous design as a rough estimate for excavating contaminated soil. Overall, as seen in Table 34, this parking structure is less expensive than the previous proposal by $202,490. Initially, this reduction does not seem very large. However, the cost per space was reduced by 68% to $19,864.67. In the design of new upperclassman WPI residential hall expected to open in 2008, the new parking garage costs roughly $3,000,000 and offers 189 spaces, which breaks down roughly $15,873 per space. Therefore, this new design is significantly more economical than the first design.

Table 34: New Cost Estimate

Preliminary Cost of Underground Parking Garage				
Category		Cost		Design 1 Cost
Substructure	$	122,629.78	$	239,992.43
Shell	$	411,631.12	$	370,364.83
Interiors	$	6,638.60	$	42,163.46
Services	$	101,341.64	$	135,051.75
Equipment	$	-	$	6,916.84
Subtotal	**$**	**642,241.14**	**$**	**794,489.32**
Contractor's Fees	$	160,560.29	$	198,622.33
Architect's Fees	$	51,379.29	$	63,559.15
TOTAL	**$**	**854,180.72**	**$**	**1,056,670.80**
Cost Reduction %		**19%**	Less	

9.5 Conclusion and Implications

Overall, the second parking garage design proved to be the more cost effective method for the design of alternate parking. It not only provided more parking spaces but more valuable green space on the site. It was also more driver friendly with fewer structural columns to impede traffic flow through the parking. Therefore, it was the recommendation of the group that the semi-underground parking facility should be constructed rather than the full basement level parking. While buildable area 3 was not studied in depth since it was located off the site, the adjacent lot also has the potential to become the site of a new parking garage. One disadvantage with this site is that current surface parking would be eliminated temporarily during construction. However, all 3 designs, due to their location between WPI and Gateway Park, have the advantage of providing spaces for both campuses. If further design were to continue in this area, a closer study of the excavation limitations due to contamination must be investigated in order to establish a more accurate cost.

10 Site Development

This facility was designed with the purpose of housing WPI graduate students and families along with several businesses serving those residents, as well as employees of the University and at Gateway Park incubated companies. Though the form and functions of the building may be met with the designs previously discussed, there are necessary support elements that have not been disclosed publicly.

Through the earlier examination of zoning requirements in Worcester and Dr Berkey's expression of the lack of parking in the community, it was established that parking would be an important part of the project to consider. This project would infuse several hundred residents, employees, and customers into an area that previously did not have this level of demand. As a result, a parking plan was developed as a plan to alleviate these issues. Though parking lots seem simple and as an afterthought, they require a substantial design process based on conditions imposed by several organizations. Additionally, parking lot design can have further implications than merely providing a resident a place to park his car for an evening.

A building without energy cannot turn its lights on for workers or provide heat in the freezing days of winter. A residence hall without water does not offer its residents the opportunity to shower, cook, or clean. Once the hall has water, if there is not a method in place to dispose of what has been used, the building would soon become an unpleasant place. At such a technical school as WPI, a lack of Internet access would effectively catapult resident students and companies that need to operate at the speed of industry into the dark ages. Ultimately, the availability and reliability of utilities is paramount to fulfilling the purpose of the facility.

10.1 Parking Layout

Because of Gateway Park's proximity to both the main WPI campus and Worcester's urban center, parking can be limited, as President Berkey (2007) had noted, and potentially poses many inconveniences to those whom the university serves and employs. To alleviate this inconvenience to graduate students living in the proposed residence hall as well as customers of first floor businesses, a parking plan was developed.

10.1.1 Determining the Number of Parking Spaces

Table 4.4 of the ZOCW lists required accessory parking for each type of business, residence, or industry mentioned in the document. Accessory parking can be classified as "an open or enclosed area accessible from a street for the parking of motor vehicles of owners, occupants, employees, customers or tenants of the main building or use" (Village of Valley View Building Department, 2005). Table 35 provides a view of what might be required for the potential services in the graduate housing complex.

Table 35: Applicable Excerpts from ZOCW Table 4.4

Use	Primary Spaces	Per Unit	Number of Units	Required Parking Spaces
Dormitory	0.33	Dwelling Unit	44	15
Food Service	0.50	Person rated occupancy	100	50
Retail Sales and Services	1.00	300 sf. Gross floor area	13,780	46
			TOTAL	111

Though the business district, BG-6.0, that this facility is in does not require any accessory parking, there is a need for handicapped accessible parking closer to the building. Additionally, parking is a convenience for many customers of retail businesses who drive. Considering these factors, it was determined that a limited amount of parking would be provided on site. Not all parking requirements, that is, required in other districts, will be met. Additional parking can be found across Faraday Street on the site of the National Grid's transformer. This parking lot is in the master plan (Campbell, 2008) WPI intends to carry on through the development of Gateway Park. It assumes the creation of 176 spaces on that site available to use by various buildings in the Gateway Park complex.

In order to determine the number of spaces that will be needed, the occupancies and their square footage of floor area were assessed. From the fourth and fifth columns in Table 35 it would be difficult to ascertain the number for parking spaces needed by a restaurant without knowing what the owner's intentions, so the 100-person rated occupancy was assumed. In additionally, zoning requires (ZOCW, 2008) that two loading dock spaces must be provided because of the building's total square footage. The next section discusses other special considerations that must be made when designing a parking plan layout.

10.1.2 Considerations of Developing a Parking Layout

Just as the layout and interior building design necessitated compliance with the requirements of the Americans with Disabilities Act (ADA), so does the parking plan. ADA guidelines (ADA Accessibility Guidelines, 2002) makes note of distance to building, slope and size of parking spaces, ability to maneuver a wheelchair after exiting a vehicle, and nearness to sidewalks among other considerations in designing for the physically disabled.

A right of way weaves through the left side of site as seen in Figure 63. It is necessary to ensure that there is access to both the right of way as well as parking spaces, especially for those who are handicapped. Though the right of way in question does cut through the parking lot and handicapped spaces, there is some parking relatively close to the building a slight distance further away and in the western part of the parking lot – just without continuous access between Grove and Lancaster Streets.

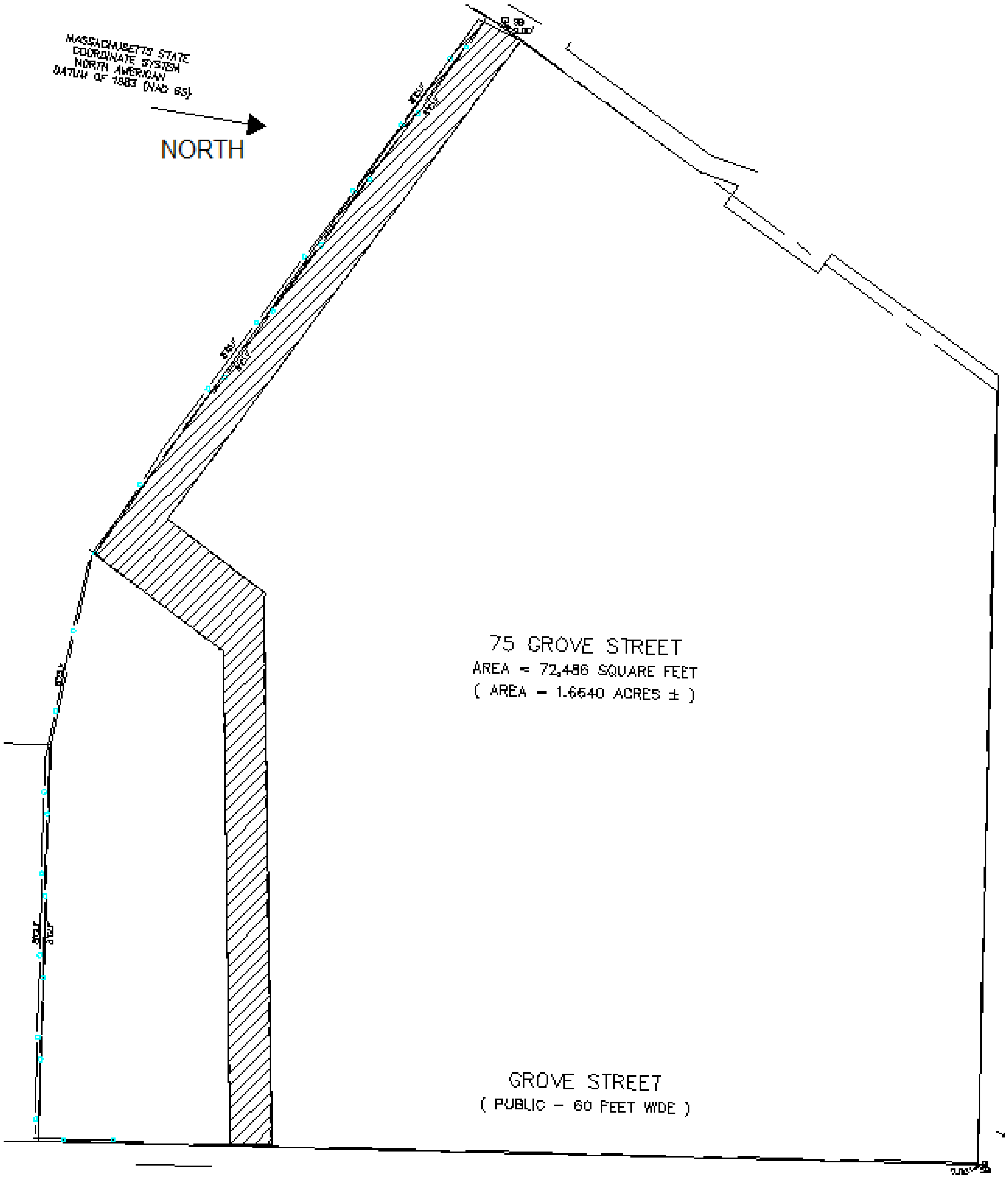

Figure 63: Hatched Section of Site Representing Right of Way

As for the design of the lot, the considerations mentioned previously were followed. A parking lot sounds like a simple design, but even on a currently undeveloped site there are challenges and for certain, many regulations. Though the City Zoning Board evaluates potential development and upholds the requirements of the ZOCW, the board also has the ability to modify the parking plans and to evaluate proposals in regards to drainage. Conventional parking spaces at ninety degrees to the driving aisle are required by Worcester Zoning (ZOCW, 2008) to be 9 feet wide by 18 feet long. Because the final decision was to design a proposal for 28 spaces on the site, the ability to use compact spaces, a ratio of up to 25% of all accessory parking, is an option. This is so because there must be at least ten spaces on a site for use of compact spaces (ZOCW, 2008). However, for ease of design and the presence of supplemental parking on the National Grid site, compact spaces were not taken into consideration. Should an alternative be developed, use of compact spaces could potentially mean that there would be a greater area of green space on the property. With this in mind, 7 spots could be affected. The compact dimensions require only 79% of the same area of conventional parking spaces (128 sf for a compact versus 162 sf of a conventionally sized parking space. If all 7 spots available as a compact space were used in that manner, 238 sf of pavement could potentially be transferred to green spaces. This change in layout could also provide a cost savings of materials and labor required for paving versus landscaping. Shrewsbury Nursery (2007), a nearby sod supplier, sells 9 square foot pieces of sod for $3.89 each. The area in question requires 27 whole pieces for a final cost of $105.03. Meanwhile, the total paving cost would be about $410.00, based on a unit cost of $1.72 per square foot for asphaltic paving for driveways and parking lots, which was obtained from <u>RS Means Site Work and Landscape Cost Data Manual</u> (2003). The unit cost includes a 6" stone base, 2 inches of binder course and 1 inch of topping; it does not include grading, striping, or any other miscellaneous costs associated with paving. Using compact dimensions versus conventional dimensions saves more than $300 on the project – a small number in the grand scheme of the project, but also provides more green space doubling as a pervious surface.

Following guidelines set by the Americans with Disabilities Act (ADA, 2002), the need for proximity to a building entrance and additional space for use of a wheelchair were appropriately applied. The spaces were placed so that customers or students would not need to cross the parking lot to enter the restaurant. Additional handicapped parking could potentially be offered in the lot where the National Grid transmitter is located though distance to entry could potentially be a future issue, particularly in poor weather conditions. The ZOCW does not have any additional guidelines for sizing of a handicapped parking space other than the set dimensions for a conventional parking space, which require that they must be at least 9 feet in width.

Though not regulated by the ZOCW or the ADA, other typical design standards were used. Two Massachusetts municipalities note that drive aisles are designed to be typically 24 feet in width (City of Newton, Town of Dartmouth, 2008). This ensures there is sufficient space for cars to pass by in two directions, for one car to pass another idling car, and for a car to pull out of a spot. An engineer might also not want to place a parking space for this mixed-use facility in a position where the driver must back out directly into traffic.

Landscaping is one subject to which the ZOCW (2008) pays some attention. In Note 6 of *Notes to Table 4.4* of the ZOCW (2008), landscaping is required in all accessory parking lots. It is expected that the exterior of the lot will be landscaped within 5-foot buffer zone between the parking spaces and the property line. Additionally, interior landscaping may be required for the parking lot based on its capacity. If a lot contains more than 16 spaces, additional specifications apply, such as planting trees for every 10 spaces, whether it be existing or proposed. Though the ZOCW designates the necessary landscaping, the specific design of plantings and other landscape architecture was out of the scope of this project. Such areas that require vegetation are noted by "LA" in Figure 64.

It is the hope of WPI administration to have a large open space to counter the brick buildings already standing and to be built in the future surrounding this site. VP Hurd (2007) notes that this ideal would help the University achieve the LEED certification for which the school is hoping, as well as contribute to a more relaxed atmosphere in which residents may enjoy their surroundings.

The ZOCW (2008) requires that there be two loading spaces for trucks for a building of this type and size. Because of the square footage allowance, two spaces are required. These spaces may not be closer than five feet to the property line, be noticeable from the front of the building, nor be smaller than the dimensions of twelve feet by 50 feet (ZOCW, 2008). These requirements forced the footprint of the building to be moved slightly to the south of its original position so as to maintain compliance with other zoning requirements based on frontage area. To complete this design within zoning restrictions, the south driveway must be extended to a minimum length of 18 feet.

10.1.3 Proposed Parking Plan

Though many needs had to be taken into consideration, the parking plan on 75 Grove Street, seen in Figure 64, is designed for 4 handicapped accessible parking spaces, two more than required by the Massachusetts Office on Disability (2003) based on the number of spaces in the lot; 28 conventionally sized parking spaces; and the 2 loading dock spaces. All parking spaces are at a 90-degree angle to the curb inside the lot. This angle was chosen because of ease of layout, the ability to use both driveways as entrances and exits, and because of its perceived prevalence in the neighborhood.

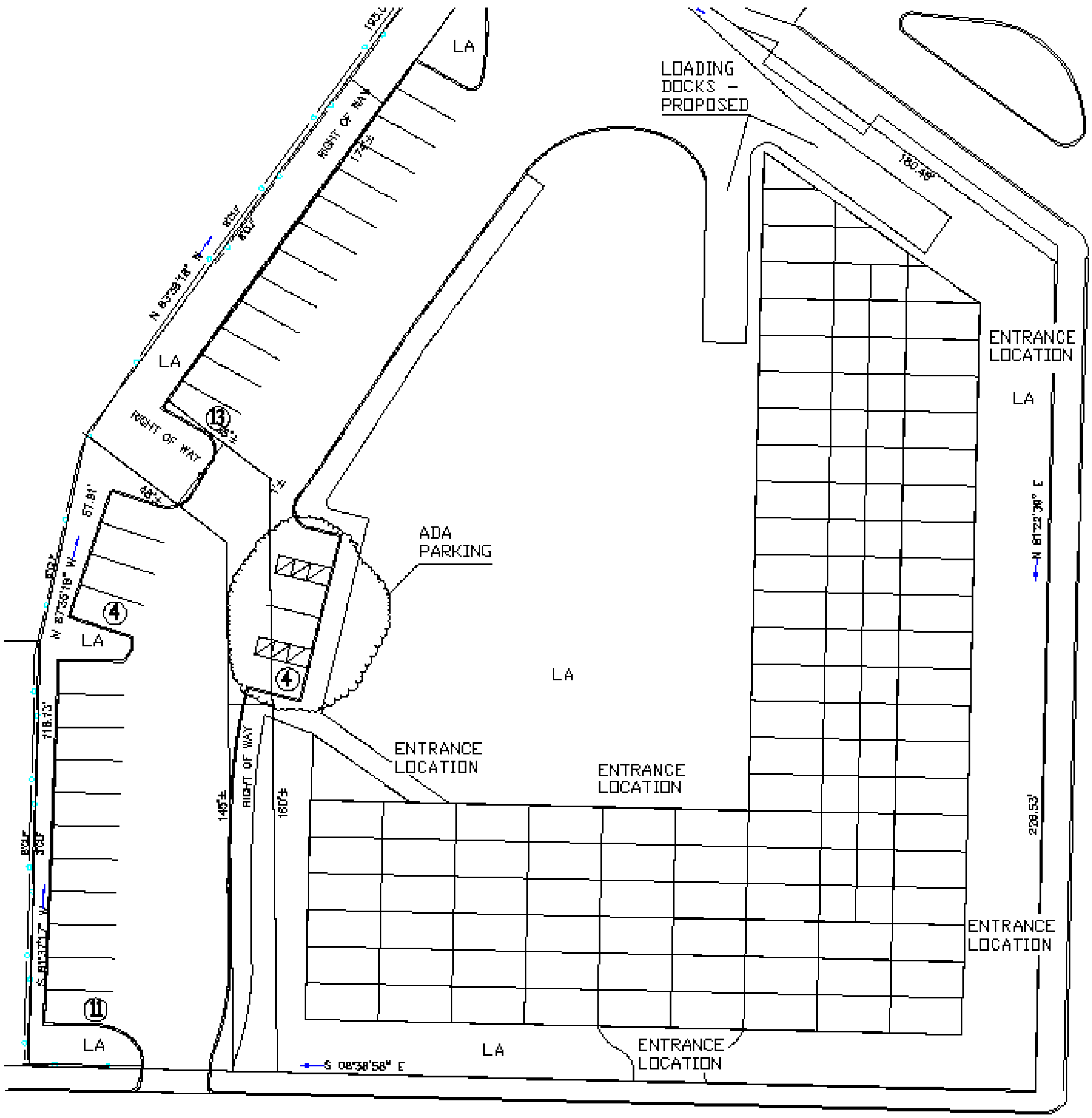

Figure 64: Parking Layout for 75 Grove Street

Though there is retail throughout the building, the handicapped accessible parking is located in only one area of the parking lot. It is located as close as possible with an accessible path to the entrance nearest the parking lot. There are no hindrances to accessibility once inside the facility. Potentially, more handicapped parking can be acquired through zoning variances on Faraday or Grove Streets but was not considered for this design.

Figure 65 shows the supplemental lot at the National Grid Transformer Site that WPI owns. Additionally, Figure 66 is a photo of the site in its current state. The condition of the site is poor with a large presence of cracks and the evidence of aging by the loss of color by oxidation. A fence surrounds much of the area as well as the National Grid Site which would be off limits to development. Gates are also present at many areas. This site seems to be more closed off and would be in the future to regulate those who are allowed to park in the area. Currently this lot is used to service local businesses, including some restaurants. The combination of the two sites provides 208 parking spaces for use, with four set aside on one lot and an undetermined number on the other for handicapped accessibility.

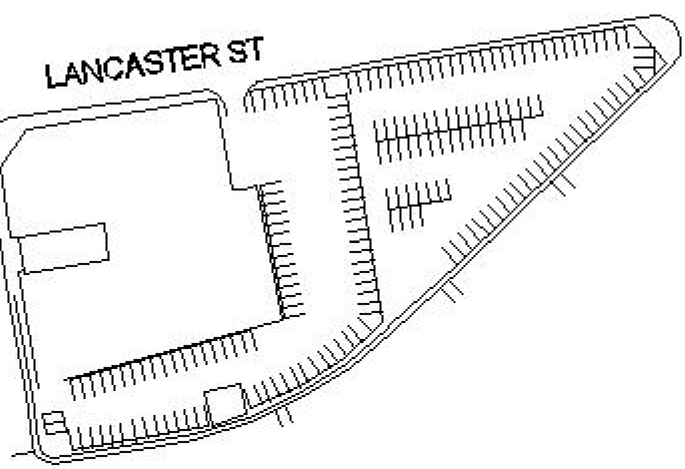

Figure 65: Proposed Parking Plan near Gateway Park and 75 Grove St (Courtesy Crosby, Schlessinger & Smallridge, 2008)

Figure 66: Current Transformer Parking Lot (Obtained from Google Maps March 20, 2008)

10.1.4 Potential Modifications and Implications

One possible change to the parking lot design is to angle the parking spaces while coupling that with a mandated direction for vehicle flow. By implementing angled spaces, usually at an inclination of 45, 60, or 75 degrees, the aisle width can be smaller (Asphalt Paving Association of Iowa (APAI), 2003). There are a number of implications that follow from this change. First, it could potentially result in more green space because a smaller aisle and less paving would be needed. Another implication would include the introduction of a one-way only driveway with vehicles entering from Grove Street and exiting onto Lancaster Street. Additionally, entrance to the site could be restricted only to those entering the Grove Street entrance with a right hand turn to limit the impacts of a road which could potentially produce congestion for those intending to take a left turn onto the property. The current proposal is designed to accommodate traffic entering the site from either Lancaster or Grove Streets in multiple directions.

Another potential change would be to swap the green space with the area that is designated to be parking. This way, parking would be closer to the building entrances no matter where it is on the site. This would be particularly beneficial to those who are handicapped or impaired. Additionally, storm water flow could be affected as all of the impervious area on the site would be continuous with a much smaller percentage of it bordering a pervious area for rainfall to infiltrate. As a result the storm water runoff, explored later in this chapter, would have a lesser environmental impact.

One major change to this site is to limit the number of accessory parking spaces available. It could be limited to only handicapped accessible parking near entrances, parking permits obtained so that there is parking on street in front of the facility but no more than the loading docks on site, or the parking area could take over much of the area that is not in the building foot print, among other potential options. Variances may be obtained with the permission of the zoning board for an alternative like the second possibility. However, convenience for customers and the handicapped was taken into consideration along with Vice President Hurd's hopes for a green escape in an urban setting in the design decision to limit the amount of parking on the site.

Cost differences can come from several areas. One cost factor is the choice of material for curbing. From a survey of the neighborhood the building is in, two types of curbing, asphalt and granite, are commonly used. Using RS Means Site Work 2003 Data, one can notice that there is significant price difference per linear foot between these two systems. Granite curbing 5 inches wide by 16 inches in depth is estimated at $15.80 per linear foot while the asphaltic option has a significantly lower materials and installation cost of $2.06 per linear foot. However, plows can significantly damage asphaltic berm and is believed to be what makes it easier to park on a lawn or drive over from the street (City of Worcester, 2005), so granite curbing has a reputation of being more durable. The type of striping used may also be considered in the cost. Acrylic striping is commonly used for parking lots, and the unit cost of the material is $0.26 per linear foot. Thermoplastic striping is a newer material and is designed to have a longer life span, but also is more than three times the cost of acrylic striping at $0.81 per linear foot.

The timeline of completing the parking lot construction is believed by the APAI (2003) to have benefits when the time comes for building construction. Primary among the reasons cited is the assurance of “constant accessibility [to provide] a firm platform upon which people and materials can operate efficiently, speeding construction” (APAI, 2003). However, the possibility exists that significant damage by the same construction equipment can occur, resulting in a need for potentially expensive repairs. This project would assume that though clearing and grading would be among the site work to take place first, there would be no conscious effort to ensure that the lot has been laid and paved before any other segment of construction

10.1.5 Effect of Parking Design on Other Areas of Site Design

The final parking plan has significant impacts for the rest of the site because of its ability to impact the runoff on the site. It is recommended by the APAI (2003) that the surface be at least at a 2 percent slope. First, this allows for definite drainage on the site and prevents ponding of storm water. When the overall slope of the parking lot was calculated with help of the elevation diagram across it, as seen in Figure 67, the final value was 2.07%. The runoff is directed towards, but not into, the streets or into the pervious surfaces of the site. This slope value is acceptable and design can continue towards the placement of catch basins and other drainage elements including grates.

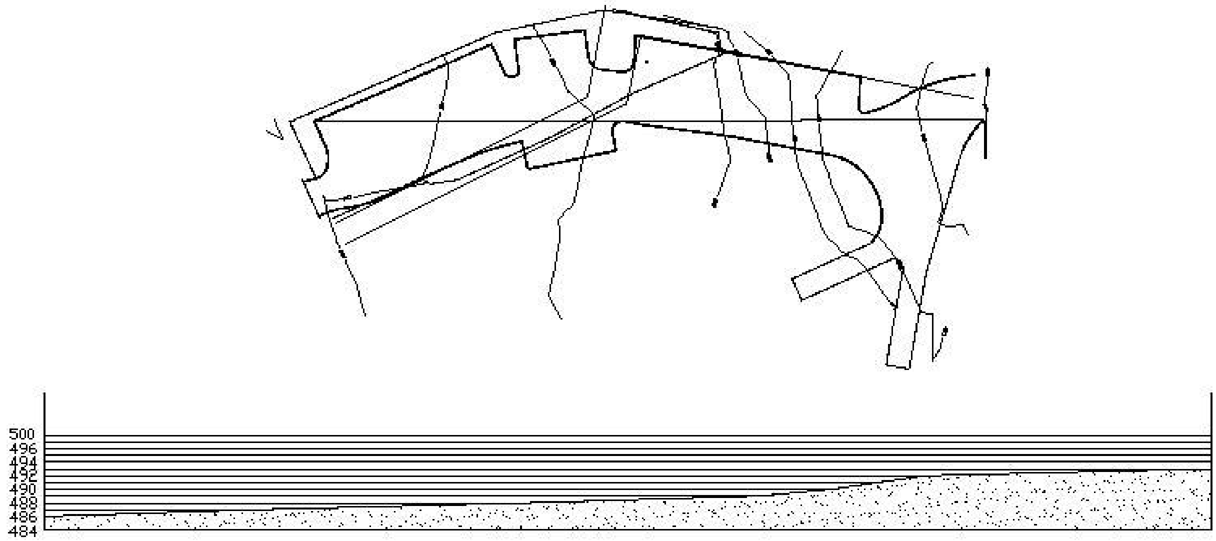

Figure 67: Elevation and Plan Views of Parking Lot (Not to Scale)

The difference in elevation seen in Figure 67 helps with design and placement of other utilities like water and sewer which sometimes rely on gravity to convey water naturally through the system. Additionally, the slope of the parking lot affects the cost of site work, especially grading. If it does not change much from what is currently established on the site, then there is a lesser cost associated. Last, the placement of utilities to be in a serviceable area can be affected by the flow of traffic and presence of necessary parking so that should repairs need to occur on site it is possible to gain access to those spots without a significant disruption to people making use of the facility.

10.2 Utilities Design and Associated Implications

For any building to be able to function in this modern day, it is necessary to have the proper utilities installed. Underground location services such as Dig Safe should be employed as soon as possible to ensure that the existing plans and drawings are correct, and that there is nothing that would hinder the upcoming design. Benefits of doing this frequently include fewer change order requests and thus a likely reduction in formerly unforeseeable costs in construction.

The design and layout requirements vary for several of the main utilities and can be separated into three main categories. In the first category, two areas, storm water and waste water systems, both have calculable demands that they will place on a system. A proposed design for the storm water system was developed. Although a solution was not developed for the waste water system, the implications of the expected calculated flow rate of waste water needs were explored. Existing university services and any reliance on outside vendors were explored in telecommunications, the second utilities category. The scope of the project included investigating the set up of Gateway Park's first building's telecommunications services and how they are coordinated by the University. Lastly, the remaining utilities found on the initial site plan from the WDBC (2007), consisting of electric, gas, and potable water, were analyzed based on the procedures for their installation and use. Since the proposed development is close to existing municipal utility lines and already on a small footprint, there is no need to introduce new infrastructure to plan for future development, thus avoiding any additional costs in that area.

10.2.1 Storm Water and Waste Water Design with Calculable Contributions

Storm drainage must first be designed before any other utility layout may take place. This is important because the drains are gravity dependent for proper flow and their placement is paramount. Improper placement and poor or difficult design, which can include obstructions or the need for a turn with a small radius as well as a lack of elevation to provide sufficient slope for flow, can impede the flow. It is imperative to consider both the elevation of the existing site as well as the locations and elevations of existing infrastructure for coordination with municipal hook ups. Additionally, by their purpose and design, storm water drainage systems are affected by the runoff in the area (Colley, 1993).

The *Rational Formula* is a conservative method that is widely used to determine design flow rates for storm water management (Colley, 1993). The Rational Formula is defined by Wanielista (1997) in equation 6.17, or Equation 2 here, as

Equation 2: Rational Formula

$$Q_p = CiA$$

where Q_p is the peak discharge in cubic feet per second (cfs), C is a dimensionless runoff coefficient, i is the rainfall intensity in inches per hour (in/hr), and A is the watershed area in acres (ac). According to Wanielista's Table 6.5 (1997), the site can fall into several descriptors which influence the runoff coefficient, and these are presented in Table 36. Each of the coefficients is based on how the runoff would react to a specific surface. Pervious surfaces allow for water to infiltrate the ground beneath it, while impervious surfaces do not allow for infiltration. A downtown area would consist mostly of rooftops and asphalt pavements, two surfaces that would not, or should not by design, allow flow beneath its surfaces. However, a heavy soil would allow more water to penetrate the surface layer and into deeper areas, very likely reaching the groundwater table beneath, represented by a depth of eighteen feet from the surface on this height.

Table 36: Applicable Runoff Coefficients adapted from Wanielista (1997)

Description of Area	**Runoff Coefficient, C**
Downtown	0.70 to 0.95
Business-Neighborhood	0.50 to 0.70
Residential Multi-Unit, Attached	0.60 to 0.75
Residential Apartment	0.50 to 0.70
Character of Service	
Asphalt/Concrete Pavement	0.70 to 0.95
Roofs	0.70 to 0.95
Lawns, Sandy Soil (Flat)	0.05 to 0.10
Lawns, Heavy Soil (Flat)	0.13 to 0.17

It is best to use a conservative value for C so as to avoid flooding or other potential problems. From a survey of the ranges of values in Table 36, C=0.85, or $C_{impervious}$, is an acceptable approximated value to use for pavement and roofs while C=0.11, or $C_{pervious}$, would be used for the calculations of the pervious, or landscaped, surfaces. Because it is difficult to ensure that the runoff on the different surface types will be separated, it is appropriate to use a weighted C value based on the relative proportion of each area. This process is developed in Table 37.

Table 37: Surface Types and Areas for Hydrological Analysis

SURFACE TYPE	AREA (SF)	AREA (AC)
TOTAL SITE AREA	*72486*	*1.664*
IMPERVIOUS - TOTAL	*41146*	*0.945*
Parking and Driveway	18715	0.430
Rooftop	20400	0.468
Sidewalks	2031	0.047
PERVIOUS - TOTAL	*31340*	*0.719*

With the use of Equation 2 above and the Table 37 values, it can be determined that the weighted value for C=0.53.

Consideration of storm water management introduced several issues throughout the site development process. First, the parking lot was located during layout so that the area that was already a bituminous material on site would be reused. Second, in accordance with the wishes of the WPI administration (Hurd, 2007), an area in the center of the lot as large as possible was utilized for drainage and infiltration purposes. However, design involved the addition of sidewalks, additional impervious surface installation, including the roof area, and the decrease of open space, meaning that there was less surface area to absorb the rainfall. These effects were simulated in the program SMADA (University of Central Florida, 1998) to model storm water runoff flow rates, similar to the rational method. A primary difference between SMADA and the rational method is that the former allows for a very detailed analysis resulting in a hydrograph which more accurately displays the reaction of the area in question compared to the rational method, which has a very rudimentary, triangular shape for its hydrograph.

The program intended to determine the hydrological impact of run-off is SMADA (University of Central Florida, 1998), short for Storm water Management and Design Aid. Table 38 showcases the values that were used in the SMADA analysis, Figure 68 on page 203 is the source by which total rainfall and intensity was determined, and the results can be seen in Figure 69 on page 204. The three bolded headings in Table 38 indicate the sections of SMADA where corresponding data was inserted. SMADA can be applied to a large, regional watershed area or may be applied to areas as small as those which have less than 500 feet of overland flow and may not be technically classified as a 'watershed'.

Table 38: SMADA Values: Inputs and Outputs

Watershed Characteristics		
Total Drainage Area	1.664	acres
Total Impervious Area	0.965	acres
Time of Concentration	6	minutes
Maximum Infiltration Capacity	1	inches
Method	SCS Curve Number	
SCS Curve Number for Pervious	98	
Initial Abstraction Factor	0.2	
Initial Abstraction	1.28	
Rainfall Characteristic		
Total Rainfall Duration	0.1	hour
Time Step for Rainfall	1	minutes
Total Rainfall	0.72	inches
Rainfall Distribution	SCS Type I	
Hydrograph Generation Method	SCS 484 Method 1	

Data obtained from Dion (1993), Wanielista (1997), and Mass Highway (2005) was helpful in developing this analysis for the specified 50-year storm for a duration of 0.1 hours, or six minutes. The length of the storm is this short because it matches the time of concentration assumed for the watershed, otherwise known as the 75 Grove Street site. Wanielista notes that this assumption leads to greater accuracy, especially in the Rational Method. SMADA allows for any of six equations to be used for calculating the time of concentration, but because some of the variables needed to additional computation and variables that were not known during the design process, it was decided to use what Wanielista (1997) explained as the minimum value for time of concentration. Even using an assumed value resulted in a wide array of runoff values from the equations used in SMADA.

This intensity value of 7.2 inches per hour (in/hr) also determined the number of inches that fell in a one-hour storm. Figure 68, adapted from a Mass Highway 2005 report, shows how the values correlate to one another in the Worcester, Massachusetts area. To read the chart, a desired frequency and usually the duration are known to find the intensity in inches per hour, and by algebra later to determine the total rainfall. For example, the design storm in question is considered to be six minutes in length. Following that x-axis value upwards, the next step is to find where it intersects with the line indicating a 50-year storm. Reading where the Y axis intersects both the duration and frequency provides the value for intensity. Likewise, the intensity would only be about 4.1 inches per hour for a two-year storm with a 6-minute duration.

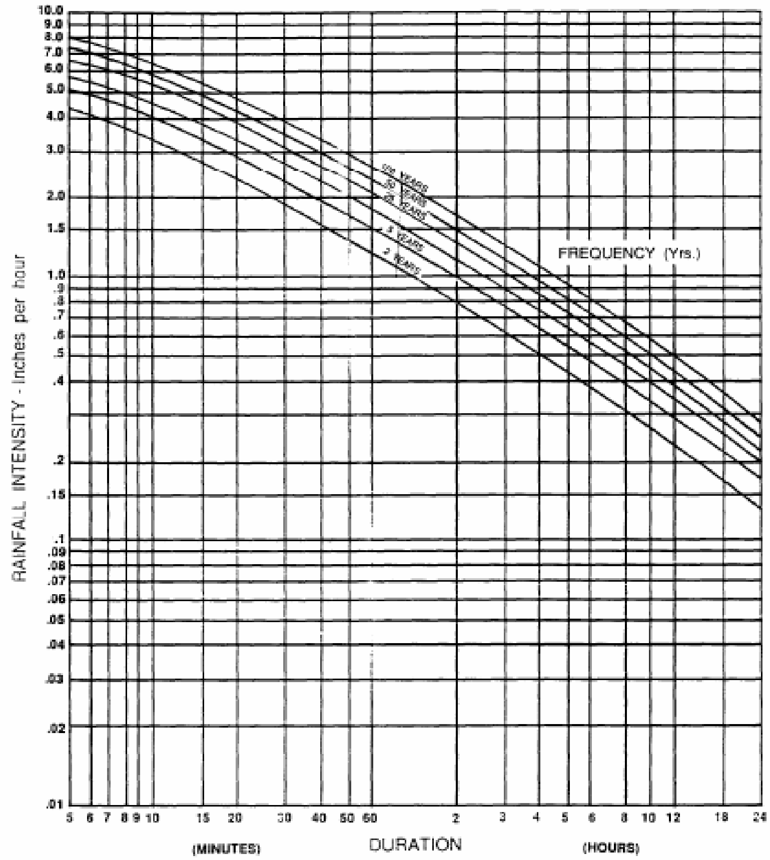

Figure 68: Intensity-Duration-Frequency Chart for Worcester, Massachusetts (adapted from MassHighway, 2005)

It is interesting to note that the hydrograph in Figure 69 below more closely matched the result of the Rational Method when the SCS Curve Number was 98, the value for an *impervious* surface, rather than that of the *pervious* surface, which was estimated to be an SCS Curve Number of 61 (Wanielista, 1997). However, the main purpose of one of hydrology's oldest equations is no longer solely to estimate peak discharge, but also to develop a shape and is based on all factors remaining constant. Such limitations can affect the accuracy of a model, especially when research shows that there are other, more advanced methods to obtain the same results.

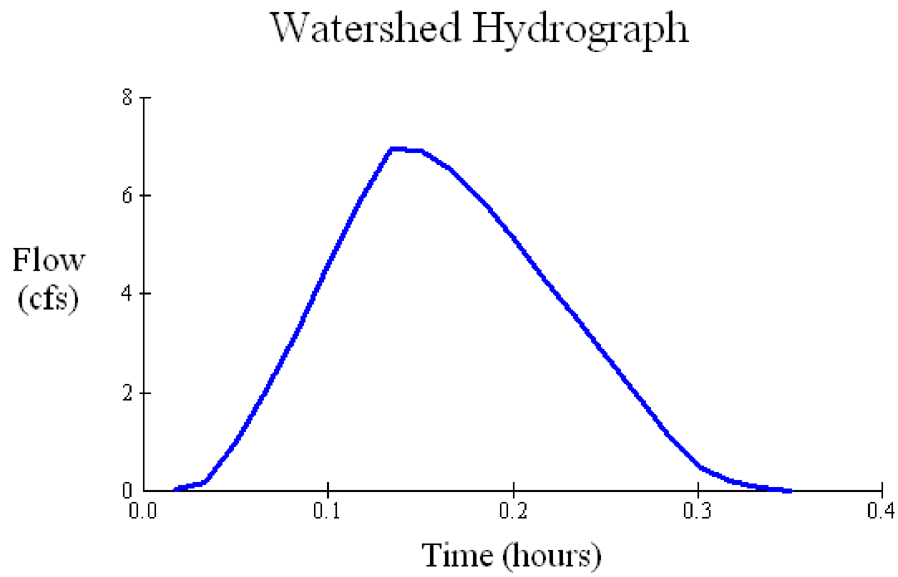

Figure 69: Hydrograph from SMADA Analysis based on data in Table 3

Ten minutes after the storm commences, there is a peak run off flow rate of about 6.9 cubic feet per second (cfs). Utilizing the previously mentioned Rational Method and the same intensity, the peak overland flow rate can be calculated to a value of 6.4 cfs.

Because storm water is not allowed to drain into the city streets, there are three design options to handle the flow (DeFalco, 2008). One option is to direct water to the center or edge of the parking lot where there will be multiple catch basins to route the water from across the site into the city's storm water system. Another option has the same purpose but only a single location is used to collect the runoff. This second option is a grate at the lowest elevation on the site, at the East driveway on Grove Street, to catch all of the water at once before it can exit the site. A third option is fairly conservative and uses a combination of the two. The first option of using multiple catch basins throughout the site was selected because it calls for the least amount of change in grade from the existing conditions and better matches the types of gravity-driven drainage systems used. The parking plan was designed with a slope of 2.07 percent, which meets specifications by Colley (1993) in regards to minimum slopes for parking lot drainage design. Additionally, if for some reason the main drain is blocked there are multiple surface locations, following the shape of the parking lot, acting as “exits” for the water to drain from the impervious surface.

Another design consideration is the placement of the catch basins. These sub-grade structures could have been placed at either side edge of the parking lot, but to avoid any possibility of flooding over the curbing or onto the sidewalks and grass area, placement in the center of the lot was proposed. The grading will decline towards the center from the edge, in an attempt to separate some of the pervious and non pervious sources.   Figure 70 shows the final layout of the drainage plan for the parking lot at 75 Grove Street.

The drainage plan in Figure 70 places catch basins every 50 feet on the site. It is graded to have, or naturally already has, a minimum of a 1% grade in between each structure. This grade goes toward the center of the lot where catch basins, signified by the circle inside a square, were placed. Catch basins were also placed at the bottom of the loading spaces along with an installed slope so that water does not flood the work space. One concern in this area is that any leaking fluids from the truck would enter the drainage system. An alternative to this is reversing the slope towards the grass area where the grass itself can act as a filter before disposing storm water straight into local water systems (Borough of Swarthmore, 2007). The ground retards the rate at which non-desirable liquids are able to get back into the water stream and negatively affect the storm water flow. Colley (1993) also noted that if the design elected to place catch basins further apart than 50 feet, a minimum 2 percent grade must be present between them. Other manners of traditional storm water management, like detention ponds and sand filters, are

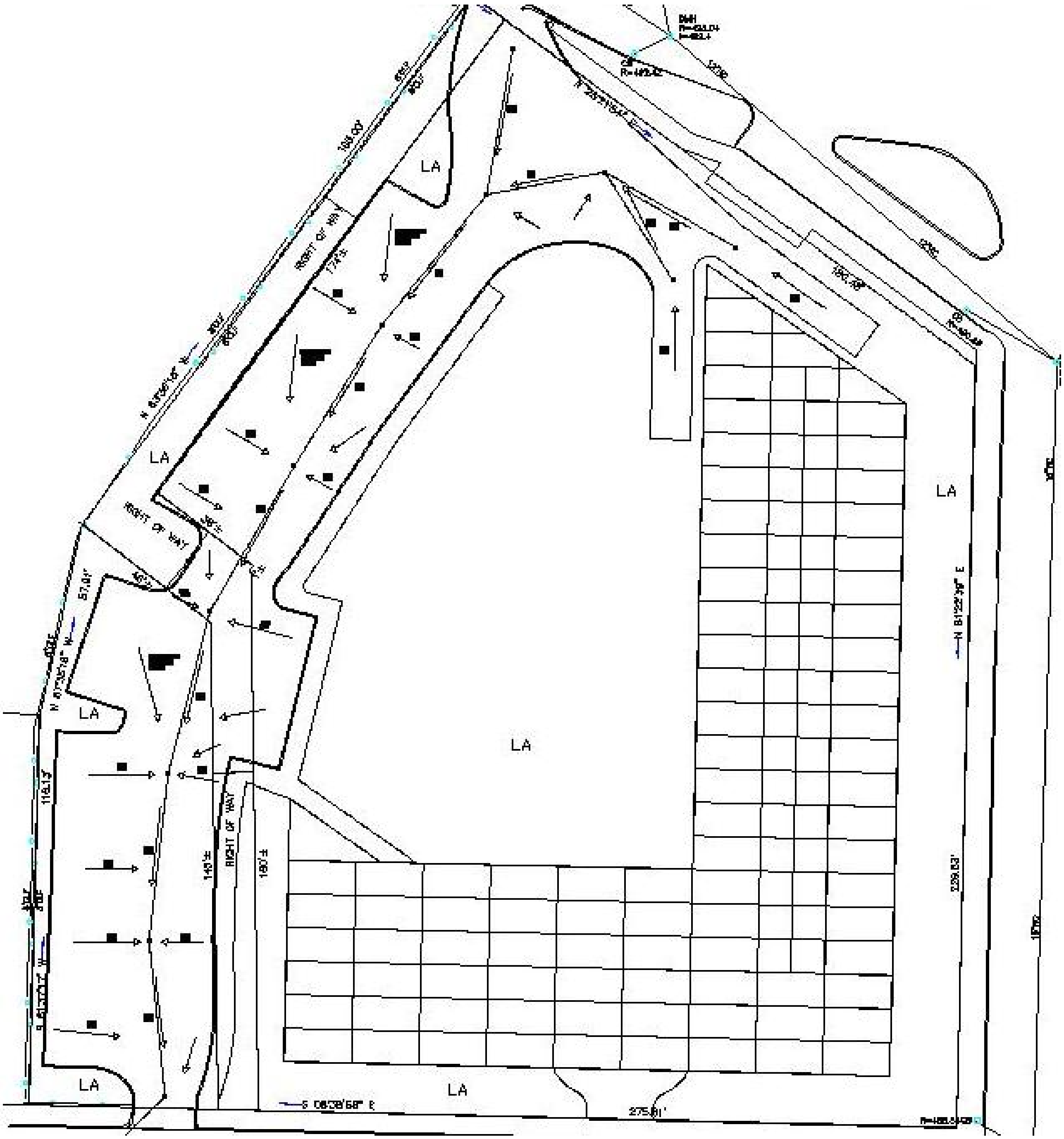

Figure 70: Parking Lot Drainage Plan for 75 Grove Street

not feasible on site because they are restricted by the developed neighborhood and availability of land on site (Brzozowski, 2004). Benefits of using catch basins, note Brzozowski (2004), include that the storm water management system is out of site, that catch basins have the ability to pre-treat water before entering the system for discharge into local bodies of water, and that often times they might be equipped with a type of filter media used in collecting environmentally harmful substances like oil and grease. On the down side, there is some maintenance required to ensure that there is no clogging in the system.

An addition that could reduce some of the effects, including the quantity, of storm water flow is what is called a "green roof". NASA scientist Stuart Gaffin notes that "Maybe the biggest selling point of green roofs is their ability to reduce storm water overflows of sewer systems, because they would retain water and evaporate it rather than letting it runoff" (Stillman, 2005). In the same article, Stillman (2005) also professes the potential cooling capabilities of using a green roof, particularly in an urban environment. Green roof advocates are cited by Stillman (2005) to note other positive effects of a green roof besides ability to reduce run-off, including the potential to lower costs related to heating and cooling, create a roof system with a longer life span, and improved air quality. Specific storm water related benefits potentially include cleaner waterways and depending on municipal or state involvement, tax credits for building owners subject to storm water fees (Stillman, 2005). The Commonwealth of Massachusetts Department of Environmental Protection would have jurisdiction for compliance with environmental regulations, including the possibility of fines, pending the severity of the offense, of up to $25,000 per day. Additionally, civil and criminal lawsuits can be filed (Mass DEP, 2008).

However, there are several issues that prevent immediate implementation of these systems. Cost, in a range of $8-$40 per square foot, variation in the type of plants used in each region, and the need for regular maintenance all come into effect (Lindell, 2007). Additionally, Lindell (2007) notes that construction of green roof systems requires installing a minimum of a membrane, root barrier, nearly four inches of soil, and plantings, which often include grasses and grass-like plants. All of these on top of the building can create a structural problem if the roof and frame are not sufficiently designed to support the additional loading due to the system itself as well as the water it collects. This is a technology which is being used in the academic and institutional sector; Carnegie Mellon is one University practicing this green initiative (Living Roofs at Carnegie Mellon, 2008).

The importance of drainage is felt because when runoff is increased, usually through the introduction of a greater area of impervious surface, flooding in area basins like ponds and streams can occur. Flooding can in turn disrupt the natural habitats of the area, including both plants and animals. Additional problems (Weiskel et al, 2005) often associated with high run off areas are the reduction of ground water recharging, meaning a drop in the groundwater level due to a lack of sufficient infiltration.

While storm water has many paths that it can follow and options like green roofs or less impervious surface areas by which that it can be slowed down, strategies to manage waste water flow from the facility are much more restricted. Colley (1993) notes that anywhere from 60 to 80 percent of water consumed per person can end up as waste. Considering the number of residents and potential customers in this facility, the number could be substantial.

The responsible party for wastewater and sewage management is the City of Worcester Department of Public Works (DPW). A completed *Application for Sewer Connection or Sewer Extension Permit* is required to begin work on the project (DPW Main, 2008). Information needed for submittal includes the number of bedrooms in the facility, the types and numbers of facilities to be served, as well as their expected daily sewage flow values, expected location of sewers to be connected to existing lines, and if any of the discharge could potentially be hazardous.

Liu and Liptak (2000) cite Metcalf and Eddy tables from 1991 denoting typical ranges and values for wastewater flow in selected environments. The typical residential waste water flow rate for a low rise apartment building, which is similar to the proposed graduate housing facility in question, is valued at 65 gallons per unit per day (gal/unit/day). There are 44 dwelling units in the residential portions of the building. Additionally, a restaurant would have an output of 3 gals/unit/day, where the typical unit is a meal (Liu and Liptak, 2000). The rated occupancy of the restaurant for parking was assumed to be 100 people. Assuming that for two hours each at lunch and dinner the restaurant is three quarters full (75 patrons) and ten percent full (10 patrons) for eight more hours of the day, there are a total of 230 meals served. Table 39 provides a schedule of waste water flow rate values based upon the assumed data for both residential and restaurant usage.

Table 39: Waste Water Values to be used for Design

Type	Typical Waste Water Output (gal/unit/day)	Number of Units	Total Waste Water (gal/day)
Residence	65	44	2860
Restaurant	3	230	690
Total Waste Water From Building (gal/day)			3550

In comparison, the wastewater facility used to treat Worcester's sewage has a current capacity of 56 million GPD (Upper Blackstone Water Pollution Abatement District, 2008). Several sources cited a 4-inch diameter pipe be used for connections with the city sewer system, including the town of Queensbury, NY since 2000.

It is important that the sewer system reflect elevations that correspond to current infrastructure. These elevations are available through WBDC (2007). Table 40 lists elevations for both the rims as well as the inlets of nearby sewer manholes. The data is presented in clockwise order, starting at the corner of Lancaster and Faraday Streets. Minimum slopes connecting inlets at the sewer manholes (SMH) should ideally be greater than a value of 0.005 (Worcester Planning Board, 2002).

Table 40: Sewer Manhole Locations and Slope Surrounding 75 Grove Street

Location	Rim Elevation (feet)	Inlet Elevation (feet)	Inlet Slope (%)
Lancaster Street - furthest from site	492.96	479.26	N/A
Lancaster Street - closer to site	492.46	478.94	1.20%
Intersection of Lancaster and Faraday	492.14	478.85	0.28%
Faraday Street	490.07	478.07	0.53%
Intersection of Faraday and Grove	488.45	477.03	0.71%
Grove Street	486.30	476.24	0.27%

Given the data in Table 40 and the desire to maintain the existing elevations throughout the site, the anticipated location for sewer hookup is between elevations 487 and 488 feet. The closest existing SMH is the one on Grove Street. Assuming a rim elevation of 487 feet, a location which is in the middle of the parking lot, near the Grove Street entrance, there is a difference in height of 0.7 feet. This calculation presumes that the inlet elevation differs by the same distance. The estimated distance from the spot to the existing manhole is about 65 feet which allows for a slope of 1.07%; a longer distance would mean a lesser slope while a shorter distance would give a greater slope value. This estimated value is within the range of the permissible slopes and would be acceptable.

10.2.2 Telecommunications

Though usually not installed until the end of the project nor needed until occupancy, telephone, cable, and Internet service providers are important to contact earlier on in the process.

Dion (1993) notes four reasons that this is sound planning, including that equipment and materials not usually stocked will be ordered and arrive in plenty of time, future demands and present capacities can be investigated, adept planning can be completed for future development, and finally, any necessary easements or permits can be acquired in a timely fashion. On the proposed site, an easement exists that could potentially be used for the purpose of servicing telecommunications near the southernmost wall of the building. This project is in a special situation where phone, cable, and Internet are coordinated by an interior department of WPI, Network Operations.

During the design phases of any renovation or new construction project for the University, Network Operations (NetOps) receives documents from which they are able to determine the establishment of telecommunication utilities for the proposed facility. Whoever is in charge of the project draws in the desired connections within the buildings. If the facility is on the main campus of WPI, NetOps is able to establish the connection to the WPI network by cables running underground between buildings. Gateway Park and other satellite locations require a different procedure.

While the establishment of telecommunications *inside* the facility does not change from the original design phase description, WPI Network Engineer Charles Anderson (2008) notes that the delivery of the services themselves to Gateway Park from the WPI Campus requires more coordination. Because it would be extraordinarily expensive, WPI does not have the ability to buy easements or right of way access for placing cables between the main campus and Gateway. As an alternative, the University leases a 5-inch fiber optic cable owned by NSTAR Com. Through this fiber optic cable, NetOps is able to deliver the telecommunications services, Internet, phone, and cable television to locations beyond its 100 Institute Road address. The lease for this cable is for ten years at a time, so it is not a permanent solution, but is sufficient because it is more economical and pragmatic considering the cost and difficulty to gain ownership of easements (Anderson, 2008).

One implication of providing University-owned telecommunication systems is coordination with the businesses and potentially other Internet service providers. Should the retail businesses elect to use an outside provider, this company should not have access to WPI's network. In this instance it would be necessary to separate the telecommunication systems utility closets where one would be business only and the other to provide services to WPI residents. Alternatively, WPI could potentially sell telecommunications services to the retail stores. By doing this, any coordination with outside utility companies can be avoided while in the meantime the University is able to receive some financial return on its investment.

10.2.3 Procedure and Implications of Electrical, Gas, and Water Utilities

Electrical companies often have their own set of requirements for each development needing service. In Worcester, National Grid is the electrical supplier. For condominiums and apartments, the type of building most similar to the proposed graduate residence hall listed on the supplier's website, a special process is in place to apply for and secure electrical service.

Filing a *Work Request Form*, available on the website, is the first step in obtaining service. Once this step is completed, additional forms for easement access and *Request for Electrical Service Information Form* are required, in addition to legal documents stating ownership and documents that give information and an approved plot plan layout (National Grid, 2008 (a)).

Both National Grid and the developer share responsibility in the costs of connecting electricity to the project. National Grid has its own policy that designates responsibilities for portions of the project, which are as detailed as tree cutting on public or private ways and obtaining permits (both the owner's responsibility), and the right to own certain portions of the electric distribution infrastructure on the property (National Grid's ability). National Grid's requirements are extensive, filling a full page checklist of necessities (National Grid Condominium, Apartment or Mobile Home Facility Checklist, 2008 (b)), but within three days of filing a work order the application and energizing processes can begin. Though it is possible to gain installation without municipal approval, this confirmation of acceptance from the City Planning Board is necessary to actually energize, or provide electricity to the facility.

Another utility involved in new developments is natural gas. Gas distribution for a larger building by the gas company is typically accomplished through one main meter (Dion, 1993). Because Worcester uses NSTAR Electric & Gas, a large corporation, WPI does not need to plan for individual tanks and distribution systems for each dwelling unit. However, responsibility from the architect's team is required for the piping system for distribution of gas throughout the new dormitory; NSTAR's responsibility ends at the connection to the meter.

Many of the requirements for electrical distribution also are required by NSTAR for the gas distribution. NSTAR is specific in noting which responsibilities are theirs and which belong to the customer. The customer's responsibilities often include the coordination and action for excavation, ability to document proof of ownership of the property, and the ability to prove the municipality's acceptance of the wiring and site planning. This final step would be approved by the City Planning Board. The company also notes major scheduling implications in a range of

“16 to 30 weeks for large projects including residential and commercial developments” (Work Order Application, 2008).

Depending on what the ultimate utility needs are determined to be, it is a possibility that gas could potentially not be utilized in this project. Factors which limit this may include how the building is heated and what kind of energy will be used for cooking. For both possibilities electric is an option while oil is an additional alternative for heating.

The final utility under design investigation was water. Water has many uses for a facility like the one designed in this project. It can be used for laundry, drinking, washing and bathing, and for other uses such as sprinklers inside and fire hydrants outside. Worcester’s water supply lines are forced, meaning they depend on pumps rather than gravity (DeFalco, 2008).

One important factor to note is that water mains must be looped around a site (Colley, 1993). This is in case a water main has to be shut off at any one point around the loop that the building is still able to have access to water. The new residence hall is in a unique position where it would be acceptable to have water installed only on the south side of the building and connect to the existing pipes on Lancaster, Grove, and Faraday Streets surrounding the site. The implications of this design would be seen especially in cost and scheduling. Less pipe and excavation would be needed. As a result, fewer labor hours would be required. The installation would be completed either in the same time by fewer laborers or in less time by the same number of laborers, resulting in a lower cost for this portion of the project. However, careful coordination is needed with the City of Worcester.

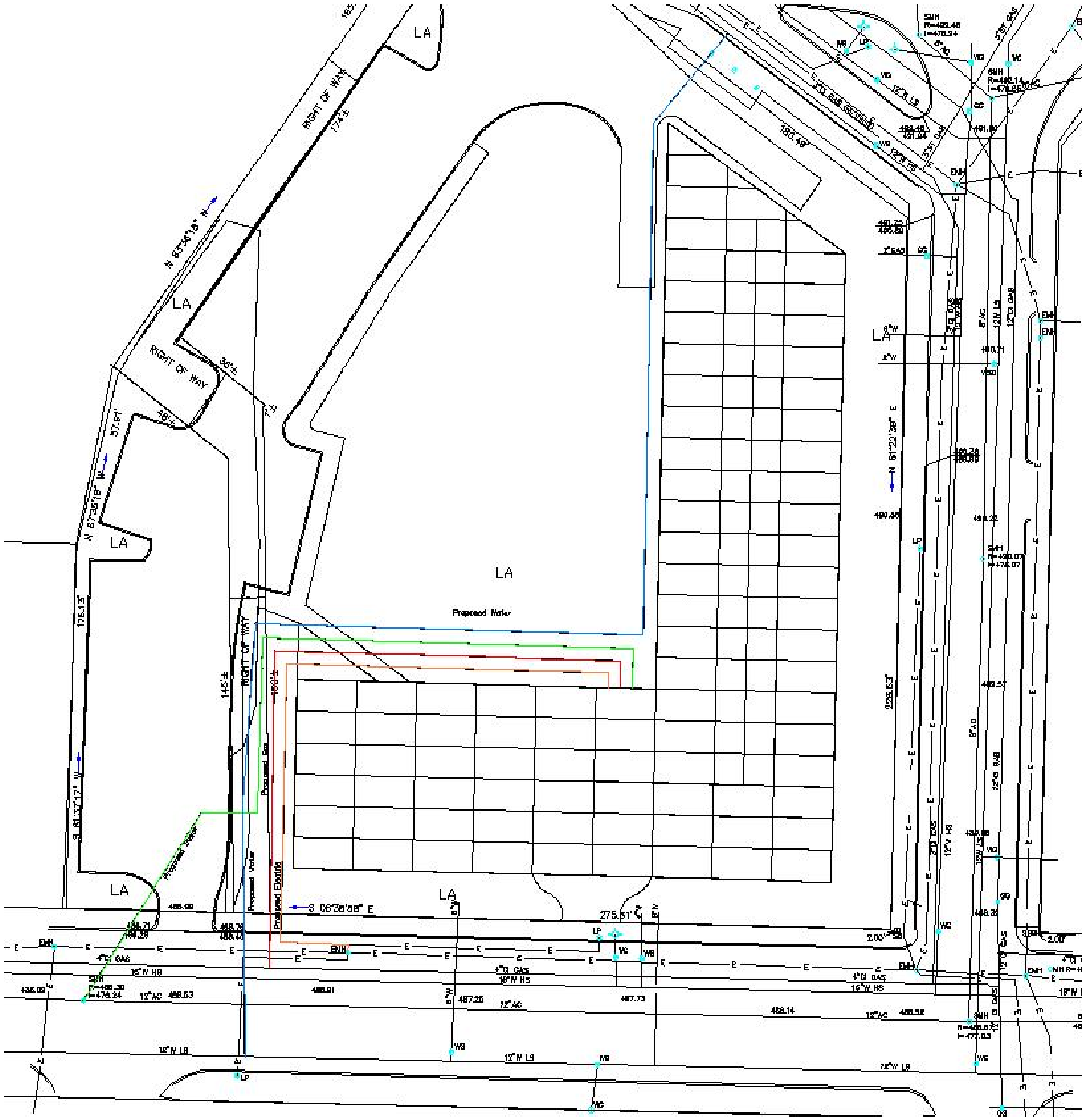

Figure 71: Basic Utilities Layout

Figure 71 is a rendering of the planned utilities layout except for telecommunications services. The thin, colored lines denote each utility. The blue, closest to the center of the lot, is for water; the green, just interior of the blue, is for sewage; electric is orange, which is closest to the building; and red, between the orange and green, designates the gas main.

10.3 Site Development Conclusions

Though the safety considerations needed for a structural or foundation designs are perhaps not as inherent in site development, this is an area that contributes not only to the successful operation of a building and to the welfare of its residents, but it also impacts outside of that facility and into the community. Hundreds of people everyday will shower, study, research, relax with a dinner, go to the gym, and live with modern conveniences afforded our society by hooking up utilities. Outsiders, both Gateway employees and other Worcester residents, are welcomed in by the new businesses on the ground level and made accessible parking spaces and walkways. Additionally, the environmental impacts can be mitigated if there is proper drainage.

11 Conclusion

WPI's growth within the past few years has been demonstrated by new buildings, major renovations, upcoming development, and an increase in enrollment. The Institution has also shown continued dedication to the economic diversity and prosperity of the City through the Gateway Park project.

For each step in the very intensive process of designing a structure, there are a number of technical steps along with other specifications which act as the guardian of appropriate design. While an intensive investigation was completed early in the design process about existing limitations for the shape, size, and placement of the facility, it would have been advisable to complete an investigation to an even greater depth, ensuring that all portions of the project are considered so that one designed late in the process negates a final product developed early on. For one example, the loading dock spaces were unaccounted for until development of the site design was underway and the building's location had been set. However, their installation meant that the building footprint had to be adjusted from its initial location, which upset the initial layout and program that had been established. It is clear here in many ways that civil engineering and architecture are two different fields in the purposes that they serve, especially in terms of developing layout, location of a building, and the location of the accessory design aspects.

While the design of structural components such as girders, columns, and foundations mostly used typical calculation methods studied in previous civil engineering classes, the application of these calculations took on an entirely new dynamic in the context of the design project. They were no longer simply calculations but each problem involved a different concept unique to the building. Calculation data and components had to be designed and redesigned in order to be integrated with the layout, one another, and meet code requirements. Furthermore, all these elements then need to be developed in order to make the project feasible to the client. Ultimately, it was this iterative design process that allowed the design team to gain value and experience.

Cost estimates are an essential part of designing a building. They need to be developed before project begins and also evaluated during the entire construction process. The cost estimate that was designed will allow the owners to see how much the total cost of the project will be in order to do a feasibility study. The cost estimate is also a good way to observe how different parts of the building affect the cost. If an owner wants to change the design before a building is constructed, it is very easy to determine the changes in cost.

The total cost of this construction project was about $11.4 million at $141.00 per square foot. This cost was very close to the $142.50 per square foot cost of an apartment building provided by RS Means. The building services account for thirty-four percent of the cost, along with the interior and the shell of the building each accounting for about twenty-five percent of the total cost. This cost is not exact because it is only a preliminary estimate. There are no exact specifications or sets of plans to define what goes inside of the building. The accuracy of the cost estimate is also limited by the RS Means cost data. An actual cost estimate would involve using cost values determined from contractors and material suppliers. Many assumptions were made on what certain properties of the building would be. These assumptions were made based on the study of similar buildings and the needs of WPI students.

Construction schedules are an important consideration when designing a building. They need to be developed before projects begin and constantly updated throughout the project. Construction schedules are developed to help understand the sequence of events required to complete a building project. The construction of the graduate housing building at 75 Grove Street will take a total of three hundred and seven days. This is a little more than 10 months. The activities were sequenced in order to get the building constructed as fast as possible so costs would be minimized.

Many things had to be considered when developing the schedule. It was designed so that construction would begin as soon as school got out in the spring time. The steel will be erected and the building will be enclosed before the winter weather arrives. This would allow the indoor construction to resume in the cold. Finally the building will be finished with enough time for students to occupy the building one whole school year later. If a construction schedule is not followed a job site can become very confusing. Many trades are coordinated to work at the same time. If the schedule is not correct, or not followed it will greatly affect the duration of construction and result in increased costs.

The proposed building can be improved in many ways if green construction is considered. LEED construction is better for the environment and can save owners money over time. By reducing water consumption and wastewater, a building can cut costs very easily. If the design was to consider using water efficient fixtures the increase in cost would pay itself off in about eight years.

The utility design was a completely new concept that was interesting to learn about. However, in a future project, the layout design of the building would be improved by advanced planning of the location of a service room which could accommodate the tie-ins of the required utilities. This would allow for a single point for distribution both throughout the facility as well as for serviceability.

Adequate parking will always remain a valuable asset to any facility. The alternative parking garage option offers an alternative for residents to park essentially "in their own backyard" rather than having parking at another lot or garage further away. However, with a sub-grade parking level, the additional structure does not remove a green space or "backyard" from the design of the site. Additionally, the preliminary cost estimate shows that the proposed garage is feasible for construction.

Further development is possible for this project in a number of ways. The underground parking garage design explored two options and their implications but further study into excavation requirements and design options could identify further advantages and disadvantages for the design. Deeper investigation utilizing other materials is feasible. The LEED section explores ways in which the facility can become environmentally friendly and how the life cycle cost of the building can be reduced. Site development, in particular drainage, could be expanded upon to gain a greater understanding of what different designs could entail to inhibit danger to the environment as well as functionality.

Completion of this project demonstrates the ability to apply knowledge previously attained to a new and unique situation, to develop creative solutions and seek to understand alternatives and implications of the decisions made when design problems arise. Because of the large scope and projected budget of the project, it is one that unfortunately cannot be brought to fruition in only a few months time. The satisfaction comes with following WPI's motto: *Lehr und Kunst*, or, "Theory and Practice".

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13 Appendices

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

13.1 Layout Appendix

Category	Description	Resource
Apartments		
	Used Human Dimension and Handicap Standards to develop Apartment Floor Plans	Architectural Graphic Standards p 6-7
	Apartments come in four, two, and one person units. Apartments designed to meet a min sq footage of 200 per occupant.	IBC 2006 Table 1004.1.1
	Habitable spaces, other than a kitchen, shall not be less than 7 feet in any plan dimension. Kitchens shall have a clear passageway of not less than 3 feet between counter fronts and appliances or counter fronts and walls.	IBC 2006 Section 1208.1
	Minimum ceiling height of 7.5 feet	IBC 2006 Section 1208.2
	In each unit, one room shall have an area at least 120 sq ft	IBC 2006 Section 1208.3
Walls		
	Assuming Lightweight Steel Stud Walls	
	Nonbearing Interior Partition walls assumed as 4 inches thick for a 1 hour fire resistance rating.	Architectural Graphic Standards p. 525/ IBC 2006 Code Table 601
	Exterior walls composed of steel studs and brick veneer. Designed for a 2 hour fire resistance rating and assumed as 8 inches thick.	Architectural Graphic Standards p 32-33/ IBC 2006 Table 602
	Walls separating apartments and stairwells shown conservatively as 8 inches in case a higher fire rating wants to be implemented	
Hallways		
	Space of Hallway based on Human dimensions for the passage of 4 people which is 8 ft. Set to 10 ft measured for centerline of walls	Architectural Graphic Standards p 6-7
	Corridors shall be fire resistant and have a minimum width of not less than 44 inches	IBC 2006 Section1017
	Corridors shall not serve as supply, return, exhaust, relief or ventilation air ducts	
Elevators		
	1 per 75 units (42 units in our facility) (120 people) Our design includes 2 (2000 lb) elevators. Inside Shaft dimensions 68 inches by 51 inches. Shaft dimensions 83 inches by 88 inches.	Architects Studio Companion p181/ Architectural Graphic Standards p668

Stairs		
	To be considered part of a means of egress, must have a width of 48 inches minimum between handrails and must incorporate and area of refuge	IBC 2006 Section 1007.3
	The clear width of 48 inches between handrails is not required at exit stairways in buildings equipped throughout with an automatic sprinkler system installed in accordance with Section 903.3.1.1 or 903.3.1.2	IBC 2006 Section 1007.3
	Width shall not be less than 44 inches	IBC 2006 Section 1009.1
	Stair treads and risers shall be of uniform size and shape.	IBC 2006 Section 1009.3.2
	The width of landings shall be not be less than width of stair. Every landing shall have a length in direction of travel not less than stair width	IBC 2006 Section 1009.4
	one Stairway will lead to the roof	IBC 2006 Section 1009.11
	Exit stairways shall be fire resistant and comply with section 706 for exterior walls	IBC 2006 Section 1020.1 - 1020.1.4
Exits		
	Min number of exits for occupant load of 126 = 2 (building has 3	IBC 2006 Section 1019.1
	Exits shall discharge to the exterior of the building (a Max of 50 percent is permitted to egress through areas on the level of discharge if having a fire resistant rating and an unobstructed way and has a sprinkler system	IBC 2006 Section 1024.1
Egress		
	The means of egress shall have a ceiling height of not less than 7.5 feet	IBC 2006 Section 1003.2
	Protruding objects can extend below the 7.5ft ceiling but must provide a headroom of 80 inches	IBC 2006 Section 1003.3.1
	When exits serve more than one story, capacity of exits calculated based on occupant load of each story provided it shall not decrease in the direction of egress travel	IBC 2006 Section 1004.4
	Residential square footage per occupant = 200 sq feet	IBC 2006 Section 1004.1.1
	Square footage per floor = 20,100.00 sqft	
	Occupants per floor = 42 sqft per occupant = avg 478.57 All apartments also meet 200 sq ft individually	
	Assembly (Tables and Chairs) = 15 sqft per occupant	IBC 2006 Section 1004.1.1
	Mercantile at grade = 30 sqft per occupant	IBC 2006 Section 1004.1.1
	Min egress stairway path = 42(.3) = 12.6 inches	
	Min egress plath other components = 8.4	
	Doors should offer a clear width of not less than 32 inches , max width of 48inches, and a min height of 80 inches	IBC 2006 Section 1008.1.1
	Egress Doors should be single hinged swinging	IBC 2006 Section 1008.1.2
	There shall be a floor or landing on each side of a door and be at the same elevation o each side of the door.	IBC 2006 Section 1008.1.4

	Landings shall have a length measured in the direction of travel of not less than 44 inches	IBC 2006 Section 1008.1.5
	Landings shall not have a width not less than the width of the stairway or the door, whichever is greatest. Doors in the fully open position shall not reduce a required dimension by more than 7 inches	IBC 2006 Section 1008.1.5
	Space between two doors in a series shall be 48 inches minimum plus the width of the door swinging into the space	IBC 2006 Section 1008.1.7
	The length of a common path of egress travel in a Group R-2 occupancy shall not be more than 125 feet provided that the building is protected throughout with an approved automatic sprinkler system in accordance with Section 903.3.1.1	IBC 2006 Section 1014.3
	Two exit access doorways are required in boiler, incinerator and furnace rooms where the area is over 500 square feet	IBC 2006 Section 1015.3
	Emergency Escapes not needed in every apartment.	IBC 2006 Section 1026.1
	Exits shall be so located on each story such that the maximum length of exit access travel, measured from the most remote point within a story to the entrance to an exit along the natural and unobstructed path of egress travel, shall not exceed 250 feet with a sprinkler system in the building	IBC 2006 Section 1016.1
Elevations		
	Assuming a Floor to Floor Height of 12 feet.	
	Therefore, the building will have a total height of 42 feet plus roof housing for elevators and stairs, which will fall below the 75 foot IBC spec as a high-rise building.	IBC 2006 Section 403
	For Type I A construction, residential R-2 buildings and mixed-use buildings have an unlimited height restriction.	IBC Section 504 Table 503
Atriums		
	Atrium shall be separated from other areas of the building by a 1 hour fire barrier constructed as in Section 706	IBC 2006 Section 404.5
	Exception, a glass wall can be used to divide the atrium from other areas when an automatic sprinkler system is used	IBC 2006 Section 404.5
Laundry Room		
	Required for 100 sq ft + :Walls have a 1 hour fire rating or fire extinguisher placed in room	IBC Section 508 Table 508.2
Furnace and boiler room		
	Required for 100 sq ft + :Walls have a 1 hour fire rating or fire extinguisher placed in room	IBC Section 508 Table 508.2

13.2 Reinforced Concrete Appendices

13.2.1 Girder Hand Calculations

,507

Girder Design

1. Estimate the Dead Load of the Beam

$L_L = 40$ PSF
$DL = 66.5$ PSF
19' span

Tributary width

$$\frac{288}{2} + 8 + \frac{232}{2} = 238'' = 19.83'$$

Dead load = 1.29 kips/Ft
Live Load = .79 kips/Ft

$1.29 + .79 = 2.08$ kips/Ft

weight of rectangular beam is 10-20% of loads carried

.208 - .416 kips/Ft

h = 8-10 % of the span

h = 1.52' - 1.9'
b = .76' - .95'

weight of Beam
.173 - .27 kip/Ft

estimate the Beam weight at .2 kip/Ft

2. Compute the Factored moment Mu

$$w_u = 1.2(1.29 + .2) + 1.6(.79) = 3.05 \text{ kip/Ft}$$

$$M_u = \frac{w_u l^2}{8} = \frac{(3.05)(19)^2}{8} = 137.63 \text{ Ft-kips}$$

3. compute b and d

$$\frac{M_u}{\phi k_n} = \frac{bd^2}{12{,}000}$$

assume $\phi = .9$ For a Beam

$$k_n = f'_c\,\omega(1 - .59\omega) \qquad \omega = \rho F_y / F'_c$$

assume $\rho = .010$

$$\omega = \frac{(.01)(60.000)}{(3750)} = .16$$

$$K_n = (3750)(.16)(1 - .59(.16)) = 543.36$$

$$\frac{bd^2}{12000} = \frac{M_u}{\phi K_n} = \frac{137.63}{(.9 \times 543.36)} = .281$$

$$bd^2 = 3372 \text{ in}^3$$

try d/b between 1.5 and 2

assume 1 layer of reinforcement

possible choices

$b = 8$	$d = 20$	$h = 20 + 2'' = 22''$
$b = 10$	$d = 18$	$h = 18 + 2'' = 20''$
$b = 12$	$d = 16$	$h = 16 + 2'' = 18''$

Try a rectangular cross section

$b = 12''$ $h = 18''$ $d = 16''$

4. check the Dead Load and revise M_u

weight per foot of Beam

$$(1 \times 1.5 \times 1)\ Ft^3/Ft \times (.15)\ kip/Ft^3 = .3375\ kip/Ft$$

$$w_u = 1.2(1.29 + .3375) + 1.6(.79) = 3.22$$

$$M_u = \frac{w_u \ell_n^2}{8} = \frac{(3.22)(19)^2}{8} = 145.30 \text{ Ft-kips}$$

M_u did not increase more than 10%

5. compute the Area of reinforcement A_s

$$Jd = \left(d - \frac{a}{2}\right) = .875d = (.875)(16) = 14''$$

$$A_s = \frac{M_u}{\phi F_y J d} = \frac{(145.3)\times(12)}{(.9)(60)(14)} = 2.31''$$

6. Minimum Reinforcement

$$A_{s\,min} = \frac{3\sqrt{F'_c}}{F_y}\, b_w d = \frac{3\sqrt{3750}}{(60{,}000)}(12)(16) = .588\ in^2$$

but not less than $A_{s\,min} = 200\, b_w d / f_y = \frac{(200)(12)(16)}{(60{,}000)} = .64\ in^2$

7. Select Steel

$A_{s\,required} = 2.31''$

	A_s
4 No 7 Bars	2.4''
3 No 8 Bars	2.37''
6 No 6 Bars	2.64''
8 No 5 Bars	2.48

choose 4 no 7 Bars

3

8. compute ϵ_t and check weather $f_s = f_y$ is tension controlled

$a = \frac{A_s F_y}{.85 F'_c b} = \frac{(2.4)(60000)}{(.85)(3750)(12)} = 3.76''$

$c = a/B_1 = \frac{3.76}{.85} = 4.4''$

$\epsilon_t = .003 \frac{(d_t - c)}{c} = .003 \frac{(16 - 4.4)}{4.4} = .00791 > .005$

section is tension controlled and $f_s = f_y$ and $\phi = .9$

9. compute M_n and ϕM_n

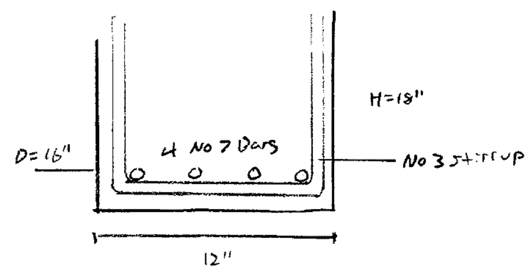
$M_n = A_s F_y (d - \frac{a}{2}) = \frac{(2.4)(60{,}000)\left(16 - \frac{3.76}{2}\right)}{12{,}000} = 169.44$ Ft kips

$\phi M_n = .9(169.44) = 152.5$ Ft-kips

$\phi M_n \geq M_u$

$152.5 \geq 145.3$

design is ok use $b = 12''$ $h = 18''$ $F'_c = 3750$ $F_y = 60{,}000$



13.2.2 One-Way Slab Hand Calculations

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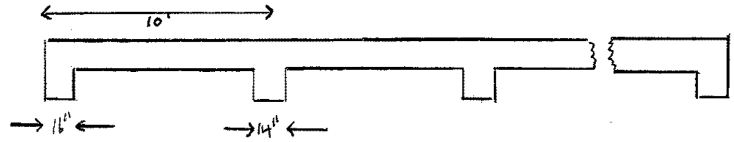
Design oF a 1 way slaB

Concrete Strength = 3750 psi
Reinforcement Strength = 60,000 psi



1 Estimate Floor thickness

End Bay: $\min h = \frac{\ell}{24} = \frac{112''}{24} = 4.67''$ $d = 4.75 - \left(.75 + \frac{.5}{2}\right) = 3.75''$

Interior Bay: $\min h = \frac{\ell}{28} = \frac{120''}{28} = 4.29''$

Try a 4.75" slaB Assuming ¾" clear cover and No. 4 Bars

2 compute the trial unfactored loads

SlaB: $w_D = \frac{4.75''}{12 in/Ft} \times 150\ lb/Ft^3 = 59.38\ lb/Ft^2$

Other Dead loads:

Floor cover .5 psF
Mechanical equip 4 psF
Ceiling 2 psF

Total DL = 65.88 lB/Ft²

Live Load = 40 psF WL For Hotels and Multi Family dwellings - Private rooms and corridors serving them

3. Select Load and strength reduction Factors

Load Combination 9-1 $U = 1.4(D+F) = 1.4(65.88\ lB/Ft^2) = 92.232\ PSF$

Load Combination 9-2 $U = 1.2(D+F+T) + 1.6(L+H) + .5(Lr \text{ or } S \text{ or } R)$

$U = 1.2(65.88\ psF) + 1.6(40) = 143.01\ psF$

4. Select Strength Reduction Factor

Slab is tension controlled $\phi = .90$

5. Check whether the slab thickness is adequate For the moment

$\omega = \frac{\rho f_y}{f'_c} = \frac{(.01)(60{,}000)}{(3750)} = .160$ $\rho = .01 \leq .75\rho_b$

$\phi k_n = \phi[f'_c\,\omega(1 - .59\omega)] = .9[3750 \times .16(1 - .59(.160))] = 489$

First Interior Support $M_u = \frac{w_u \ell_n^2}{10}$

Second Interior Support $M_u = \frac{w_u \ell_n^2}{11}$

Exterior Face of First interior Support

$$l_n = \frac{(97 + 106)}{2} / 12\,in/Ft = 8.46\,Ft$$

$$M_u = \frac{(143.01\ lB/Ft)(8.46')^2}{10} = 1.02\ Ft\text{-}kips/Ft$$

Second interior Support

$$l_n = \frac{(106 + 106)}{2} / 12\,in/Ft = 8.83\,Ft$$

$$M_u = \frac{(143.01\,lB/Ft)(8.83)^2}{11} = .930\ Ft\text{-}kips/Ft$$

Max $M_u = 1.02\ Ft\text{-}kips/Ft$

$$bd^2 = \frac{M_u \times 12000}{\phi k_N} = \quad 12d^2 = \frac{(1.02\,Ft\text{-}kips/Ft)(12000)}{489} \qquad d = 1.44''$$

$d = 1.44'' < 3.75''$ ok

6. check Whether thickness is adequate For Shear

Exterior Face of First interior Support

$$V_u = 1.15\, w_u\, l_n/2 = \frac{(1.15)(143.01\,PSF)(97/12)}{2} = 664.70\ lB/Ft\ oF\ width$$

Typical interior support

$$V_u = \frac{(1.15)(143.01\,PSF)(106/12)}{2} = 726.37\ lB/Ft\ oF\ width$$

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

$$= .75(2\sqrt{3750} \times 12 \times 3.75) = 4134\ lB/Ft$$

$\phi V_c > V_u$ ok $\qquad 4134 > 726.37\ lB/Ft$

use $h = 4.75''$ $d = 3.75''$ and $w_u = 143.01\ psF$

7. Design of Reinforcement

line 1 clear spans l_n . End Bay $l_n = 97$ interior Bay $l_n = 106$ supports $l_n = 101.5$

line 2,3,4 moments

3/4

Line 5 Assume $jd = .925d$ For a slab $\phi = .9$ For tension controlled section

$$A_s = \frac{M_u}{\phi f_y jd} = \frac{(1.02)\times(12000)}{(.9)(60{,}000)(.925\times 3.75)} = .0653 \text{ in}^2/\text{Ft}$$

$$a = \frac{(.0653)\times(60{,}000)}{.85\times 3750\times 12} = .103 \text{ in}$$

$$jd = d - \frac{a}{2} = 3.75 - \frac{.103}{2} = 3.699 \qquad j = \frac{3.699}{3.75} = .9864$$

$$A_s = \frac{(1.02)(12000)}{(.9)(60{,}000)(3.699)} = .0613$$

$$A_{s\,min} = .0018\times 12\times 4.75 = .1026 \text{ in}^2/\text{Ft}$$

No 3 Bars $A = .11 \text{ in}^2$ $d = .375$

Max spacing $= 3h = 3(4.75) = 14.25''$

8 check reinforcement spacing for crack control

$$s = \frac{540}{f_s} - 2.5c_c \quad \text{but not more than} \quad 12\left(\frac{36}{f_s}\right) \text{ in}$$

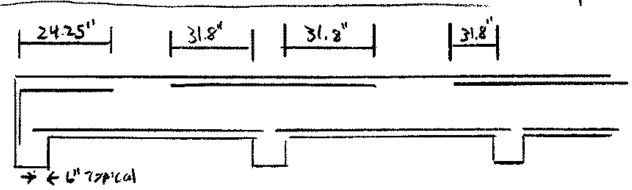
$f_s = .6 f_y = 36 \text{ ksi}$ $\qquad s = \frac{540}{.6\times 60} - 2.5\times .75 = 13.1$

$c_c = .75$

$$s = 12\left(\frac{36}{36}\right) = 12$$

Max Spacing is 12''

9 Select top and bottom Flexural steel p1074



$l_1/4$ $\qquad .3l_1$ or $.3l_2$ $\qquad .3l_2$ or $.3l_3$

$97/4 = 24.25$ $\qquad .3(97)$ $\quad .3(106)$ $\qquad .3(106)$

$\qquad 29.1''$ $\quad 31.8''$ $\qquad 31.8''$

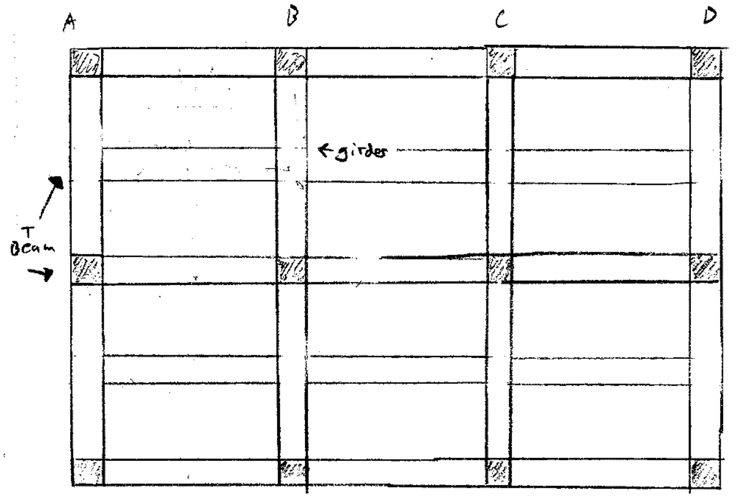
10. Determine the Shrinkage and temperature reinforcement

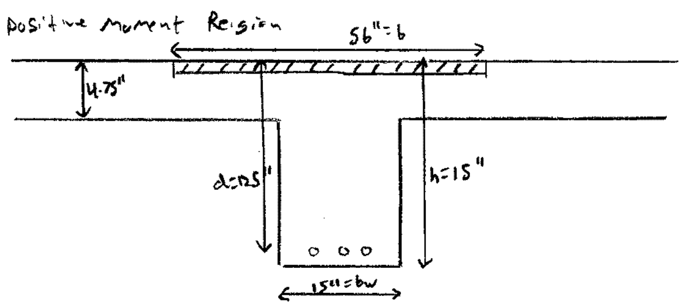
$A_s = .0018bh = .0018(12)(4.75) = .1026\ in^2/Ft$

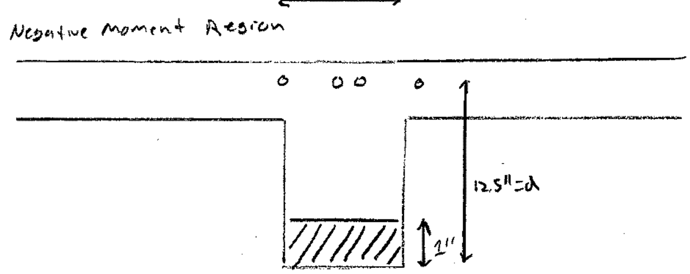
use No 3 Bars at 12" O.C. as Shrinkage and temperature reinforcement

1 l_n Ft	8.08	8.08	8.46	8.83	8.83
2 $w_u l_n^2$	9.34	9.34	10.24	11.15	11.15
3 M coefficients	1/24	1/14	1/10 1/11	1/16	1/11
4 M_u Ft kip/Ft	.389	.667	1.024 ~~.931~~	.697	1.014
5 As read in^2/Ft	.0201	.0337	.0518	.0353	.0513
6 As min in^2/Ft	.1026	.1026	.1026	.1026	.1026
7 choose steel	No3 @ 12"	No3@12"	No3@12"	No3@12"	No3@12"
8 As provide	.11	.11	.11	.11	.11

13.2.3 T-Beam Hand Calculations







1

Design of a Continuous T Beam

1 compute the trial Factored loads on the Beam

Possitive Moment at mid

$$A_T = \frac{216(97/2 + 14 + 106/2)}{12 \times 12} = 176\ ft^2$$

$$L = L_0\left(.25 + \frac{15}{\sqrt{K_{LL} A_T}}\right) = 40\left(.25 + \frac{15}{\sqrt{(2.0)(176)}}\right) = 42\ \text{PSF}$$

Negative Moment

$$A_T = \frac{(97/2 + 14 + 106/2) \times (216 + 16 + 224)}{12 \times 12} = 365.75\ ft^2$$

$$L = 40\left(.25 + \frac{15}{\sqrt{2 \times 366}}\right) = 32.18\ \text{PSF}$$

possitive moment at center

$$A_T = \frac{(97/2 + 14 + 106/2)\,224}{12 \times 12} = 179.7\ ft^2$$

$$L = 40\left(.25 + \frac{15}{\sqrt{(2)(179.7)}}\right) = 41.6$$

Summary of unFactored reduced live loads

Neg moment exterior end pos at midspan and shear at Beam	42 PSF
Neg moment at support B	32.18 PSF
pos moment at mid	41.6 PSF

2 select Method of analysis of Beam and values of Strength Reduction Factor

(a) there are 2 or more spans ✓

(B) the span ratio is $\leq$ 1.2 ✓

(C) the loads are uniformally distributed ✓

(D) the unit LL is not 3X the DL ✓

(E) the members are prismatic

3 Select the Strength Reduction Factors

$\phi = .9$ Flexure tension controlled

$\phi = .75$ Shear

(a) Dead Load

SlaB	60 PSF
Floor ceiling Mech	6.5 PSF
	66.5 PSF

Live Load (Reduced) = 32.18 PSF

$w_u = 1.2 \times 66.5 + 1.6 \times 32.18 = 131.3$ psF

Tributary width

$$\frac{97}{2} + 14 + \frac{106}{2} = 115.5'' = 9.63'$$

Factored load/Ft = 131.3PSF × 9.63' = 1264.42 = 1.26 kips/Ft

weight of Beam estimate

10-20% of Factored loads = .126 - .252

h is 8-10% of l_n = 17" - 22"

b_w is .5 h = 8.5" - 11"

Assume the weight of the Stem to Be .4 kips/Ft

Trial Load/Foot = 1.26 + .4 kips/Ft = 1.66 kips/Ft

4. Choose the actual size of the Beam stem

(a) min depth based on deflections

$$\text{min } h = \frac{l}{18.5} = \frac{240''}{18.5} = 13''$$

(B) min depth based on neg moment at exterior face of interior support

$$\text{Moment} = \frac{w_u l_n^2}{10} \qquad l_n = \frac{216 + 224}{2} = 220'' = 18.33'$$

$$M_u = \frac{(1.66)(18.33)^2}{10} = 55.77 \text{ Ft kips}$$

ρ = .0169 in tension controlled → Table A-5 → ϕk_n = 616 → Table A-3

$$\frac{bd^2}{12{,}000} = \frac{M_u}{\phi k_n} \qquad bd^2 = 12{,}000 \frac{55.77}{616} = 1086.43 \text{ in}^3$$

possible Beam Sizes

b = 6" d = 13.45

b = 8" d = 11.65 → 11.65" + 2.5" = 14.15"

b = 10" d = 10.42

Try an 8" wide By 15" deep extending 10.25" Below the slab Stem with d = 12.5"

(c) check the shear capicity of the T-Beam

$V_u = \phi(V_c + V_s)$

Max Shear From Beam loads at interior end of B3:

$V_u = 1.15\, w_u\, \ell_n/2 \quad = 1.15(1.66)(9) = 17.18$ kips

$V_c = 2\sqrt{F'_c}\, b_w\, d \quad = 2\sqrt{3750}\,(8)(12.5) = 12.25$ kips

$V_s = 8\sqrt{F'_c}\, b_w\, d \quad = 8\sqrt{3750}\,(8)(12.5) = 48.99$ kips

Absolute Max $\quad \phi V_n = .75(V_c + V_s) = .75(12.25 + 48.99) = 45.93$

Max Factored V_u due to applied loads and dead loads is 17.18 kips

The Beam stem has ample capacity use

$b = 8''$
$h = 15''$
$d = 12.5''$

5. Compute the Dead load OF the stem and recompute the Load/Foot

weight/Foot of stem below the Slab $= \dfrac{(8)(10.25)(12)}{(1728)} \times .15 = .085$ kip/Ft

Total Dead load For B3-B4-B3 $\quad \frac{9.7}{2} + 14 + \frac{10.6}{2} = 9.63'$

$w_D = .0665 \times 9.63 \times .085 = .054$ kip/Ft

Live Load For B3 - B4 - B3

Beam B3	$w_L = .042 \times 9.63$	$= .404$ kip/Ft
Neg moment at B	$w_L = .0322 \times 9.63$	$= .310$ kip/Ft
pos moment For B4	$w_L = .0416 \times 9.63$	$= .401$ kip/Ft

Summary of Factored Loads on B3 - B4 - B3

Beam B3	$w_u = 1.2 \times .054 + 1.6 \times .404$	$= .7112$ kip/Ft
Neg moment at B	$w_u = 1.2 \times .054 + 1.6 \times .310$	$= .5608$ kip/Ft
pos Moment For B4	$w_u = 1.2 \times .054 + 1.6 \times .401$	$= .7064$ kip/Ft

6. calculate the Flange width For the positive-moment regions

$.25\, l_n = .25(224'') = 56''$

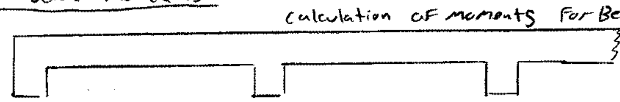
$b_w + 2(8\times6) = 14 + 2\times48 = 110''$

$b_w + \frac{97}{2} + \frac{106}{2} = 8'' + \frac{97}{2} + \frac{106}{2} = 109.5''$

effective width is 56''

7. Compute the Beam Moments

Calculation of moments For Beam B3-B4-B3



1 l_n (Ft)	18'	18'	18.34'	18.67'	18.34'
2 w_u kip/Ft	.7112	.7112	.5608	.7064	.5608
3 $w_u l_n^2$	230	230	189	246	189
4 C_m	1/24	1/14	1/10 1/11	1/16	1/11 1/10
5 $C_m w_u l_n^2$ Ftkps	-9.58	16.43	-18.9	15.38	-18.9

8. Design of Flexural reinforcement

ⓐ As at Max negative moment (First interior support)

$A_s = \frac{M_u}{\phi F_y J d} \times 12000$ Assume $J = .875$ $\phi = .9$

$A_s = \frac{18.9 \times 12000}{(.9)(60{,}000)(.875 \times 12.5)} = .384\ in^2$

$a = \frac{(.384)(60000)}{(.85)(3750)(8)} = .904\ in$

$\frac{a}{d} = \frac{a}{d_t} = \frac{.904}{12.5} = .0723$

$\frac{a}{d_t} < \frac{a_b}{d}$

$.0723 < .503 \rightarrow$ Table A-4

$\frac{a}{d_t} < \frac{a_{tcl}}{d_t}$

$.0723 < .319 \rightarrow$ Table A-4

$A_s = \frac{M_u (12{,}000)}{(.9)(60000)(12.5 - \frac{.904}{2})} = .0184\, M_u$

5 M_u	-9.58	16.43	-18.9	15.38
6 A_s coefficients	.0184	.0177	.0184	.0177
7 A_s (reqd)	.176	.291	.348	.272
8 $A_s > A_{s min}$	NO	NO	NO	NO
9 Bars Selected	2 NO 4	2 NO 4	2 NO 4	2 NO 4
10 A_s provided	.4	.4	.4	.4
11 b_w ok	yes	yes	yes	yes

(B) compute A_s at max pos moment (point B near middle ext span)

$j = .95$ $$A_s = \frac{(16.43)(12000)}{(.9)(60000)(.95\times 12.5)} = .307 \text{ in}^2$$

assume a is less than h_f b is effective flange width = 56"

$$a = \frac{A_s F_y}{.85 F'_c b} = \frac{(.307)(60{,}000)}{(.85)(3750)(56)} = .103 < h_f = 4.75''$$

$$\frac{a}{d} = \frac{a}{d_t} = \frac{.103}{12.5} = .0083$$ Table A-4 $a/d = .503$

$F_s = F_y$ $a/d_t = .0083 < \frac{d}{d_t} = .31$

As at pos moment $\phi = .90$

$$A_s = \frac{(M_u)(12000)}{(.9)(60000)(12.5 - \frac{.0083}{2})} = .0177\, M_u$$

(C) calculate min reinforcement

$$A_{s min} = \frac{3\sqrt{F'_c}}{F_y} b_w d \text{ and } \geq \frac{200\, b_w d}{F_y}$$

$$A_{s min} = \frac{3\sqrt{3750}}{(60000)}(8)(12.5) \text{ and} \geq \frac{(200)(8)(12.5)}{60000}$$

$$A_{s min} = .306 \text{ and} \geq .333 \text{ in}^2$$

(d) calculate the area of steel and select bars

See table use $A_{s min}$ as A_s reqd

9. Check the distribution of the reinforcement

(a) positive Moment region

$c_c = 1.5''$ cover $+ .375''$ stirrup $= 1.875''$

Max Bar spacing

$$S = \frac{540}{F_s} - 2.5c_c \leq 12\frac{36}{F_y} \qquad F_s = .6F_y = (.6)(60) = 36$$

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

$b_w = 8''$ ok

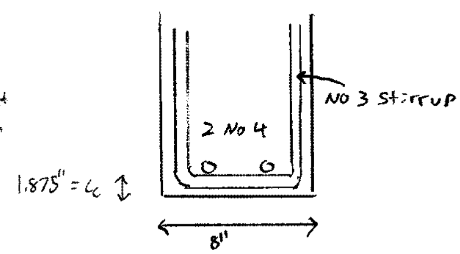
(b) Negative Moment Region

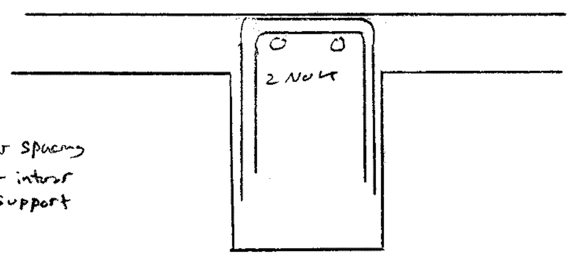
$$S = \frac{540}{F_S} - 2.5c_c = \frac{540}{(.6)(60)} - 2.5 \times 1.875 = 10.3''$$

$c_c = 1.5'' + .375'' = 1.875''$

There are only 2 Bars So none are required in the Slab

Positive Moment Region

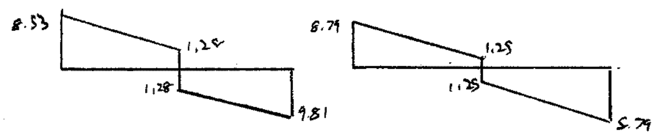




Bar Spacing at interior support

10. Design of shear reinforcement

1	l_n		18'			18.67'	
2	w_u k/Ft		.7112			.7064	
3	w_{Lu} k/Ft		.404			.401	
4	$w_u l_n/2$		6.40			6.59	
5	C_v	1.0	.15 or $.25 \times \frac{.404}{.7112}$ = .142 use .15	1.15	1.0	$\frac{.25 \times .401}{.7064}$ = .142	1.0
6	V_u = $C_v(w_u l_n/2)$	6.40	.96	7.36	6.59	.936	6.59
7	$V_n = \frac{V_u}{\phi}$	8.53	1.28	9.81	8.79	1.25	8.79



(a) Exterior end of B3 $d = 12.5''$

$$\frac{V_u}{\phi} \text{ at } d = 8.53 - \frac{12.5}{108}(8.53 - 1.28) = 7.69 \text{ kips}$$

ACI Sec 11.5.5.1 requires stirrups if $V_u \geq \phi V_c/2$ where

$$V_c = 2\sqrt{f'_c}\, b_w d$$

$$V_c = 2\sqrt{(3750)} \times (8'') \times \frac{12.5}{1000} = 12.25 \text{ kips} \qquad \frac{V_c}{2} = 6.125 \text{ kips}$$

$V_u/\phi = 8.53 > V_c/2 = 6.125$ Stirrups are required

Try a No 3. grade 40 double leg stirrup with a 90° hook enclosing a #4 bar

The max spacing is the smaller of

$$\frac{d}{2} = \frac{12.5''}{2} = 6.25'' \quad \text{and} \quad S = \frac{A_v f_y}{50 b_w} = \frac{(.22)(40000)}{(50)(8'')} = 22''$$

$$\text{or} \quad S = \frac{A_v f_y}{.75\sqrt{f'_c}\, b_w} = \frac{(.22)(40000)}{(.75)\sqrt{3750}\,(8)} = 23.95''$$

use 6'' max spacing

The spacing to support shear is

$$S = \frac{A_v F_y d}{V_u/\phi - V_c} = \frac{(.22)(40000)(12.5)}{(7.69 - 12.25)(1000)} = -24.12$$

use max spacing of 6"

(B) interior end of B3

$$\frac{V_u}{\phi} = 9.81 - \frac{12.5}{108}(9.81 - 1.28) = 8.82 \text{ kips}$$

spasing required

$$S = \frac{(.22)(40000)(12.5)}{(8.82 - 12.25)(1000)} = -32.07$$

stay with max spacing of 6"

(C) ends of Beam B4

calculations are done the same way as B3

use No 3 grade 40 double leg stirups spaced at 6"

11. Check the development lengths and design bar cut-offs

(a) perform preliminary calculations

$d = 12.5"$

$12 d_b = 6"$ for No 4 Bars

$$\frac{l_n}{16} = \frac{216}{16} = 13.5$$

$$\frac{l_n}{16} = \frac{224}{16} = 14$$

d always exceeds $12 d_b$ but $l_n/16$ exceeds d

(B) Select cutoffs for positive moment steel Based on ACI sec 12.1 12.10 12.11 12.12

There are only 2 bars so there is no reason to cut any of them off. they are extending into the supports on both ends.

Spacing and confinement case

the Bars have a c_c and cover of at least d_b and are enclosed by at least minimum stirups. This is case 1

$$l_d = \frac{F_y \alpha \beta \lambda}{20\sqrt{F'_c}} d_b = \frac{(60000)(1)(1)(1)(d_b)}{(20)\sqrt{3750}} = 49 d_b$$

9

For No 4 Bars $d_b = 6''$ and $l_d = 24.5''$

Application of detailing rules to beam B3

Beam B3 must satisfy these Rules

1. Structural integrity
2. Ext of Bars into supports
3. Effect of shear on bending moment diagrams
4. Anchorage, positive moment

Rule 1.

not less than 2 Bars need lap splicing
class A splices at or near supports
Table A-11 No 4 Bars in 3750 psi concrete is $39.2 d_b = 39.2(.5) = 19.6''$

Lap splice 2 Bottom Bars from span B3 at a dist of 19.6" with 2 No 4 Bars from span B4

Rule 2

This is satisfied By Rule #1 with lap splicing at supports

Rule 3

Bars must extend d or $12 d_b$ past the positive moment flectural cutoff points
allready satisfied

Rule 4

Not Applicable with only 2 Bars

(c) Select cutoffs for the positive moment steel in B4

Same as B3 Because reinforcement is the same

(d) Select cutoffs for the negative moment steel at the exterior end of B3

2 No 4 Bars at the exterior end must be anchored to the spandral beam

No 4 Bars

$$l_{dh} = \left(\frac{.02 \beta \lambda f_y}{\sqrt{f'_c}}\right) d_b = \frac{(.02)(1)(1)(60000)}{(\sqrt{3750})} (.5) = 9.8''$$

l_{dh} For No 4 Bar $= (9.8) \times (.7) = 6.86''$

Anchor the top bars to the Spandral Beam with 90° hooks

extend top bars past negative moment point of inflection at
$.108 \ell_n = (.108)(216) = 23.33$ From the Face of Exterior support
must satisfy Rules 1, 2, and 6

Effects of Shear Rule 3B
1/3 of Bars extends to the longest of d, $12d_b$ and $\ell_n/16$
$\ell_n/16$ at 13.5 governs
Cutoff Bars at $23.33 + 13.5 = 36.83 \rightarrow 3'1''$ From Support Face
Rule 3B automatically satisfies rule 1c
Rule 4B requires that the bars extend at least ℓ_d From the Face support
ℓ_d For no 4 Bar $= 2'.5'' < 3'1''$ rule 4B satisfied
cut off all top Bars $3'1''$ From the Face of the exterior support

(e) Select cutoffs for the negative-moment steel at the interior end of B3
The 2 top No 4 Bars will be cut off past the negative moment point of inflection
Fig A-3 $\rightarrow$ $.224 \ell_n = .224(216) = 48.38''$ From the Face of Support
detailing rules 3b and 4b apply

Effects of shear Rule 3b
1/3 of bars must extend $\ell_n/16 = 13.5''$ past the point of inflection
$48.38'' + 13.5'' = 61.88'' \rightarrow 5'2''$
Anchorage rule 4B
Bars must extend ℓ_d past actual cutoff
Not Applicable
Cut off 2 top Bars $5'2''$ From the exterior Face of the First Support.

(f) Select cut offs For the negative moment steel in Beam B4
Fig A-1 negative moment point of inflection $= .24 \ell_n = .24(224) = 53.76''$

Effects of shear Rule 3a
Bars must extend larger of d, $12d_b$, or $\ell_n/16$ past the point of inflection
$53.76'' + 14'' = 67.76 \rightarrow 5'8''$
cutoff top Bars at $5'8''$ From Face of Interior Support

(5) check shear points where bars are cut off in a zone of flexural tension

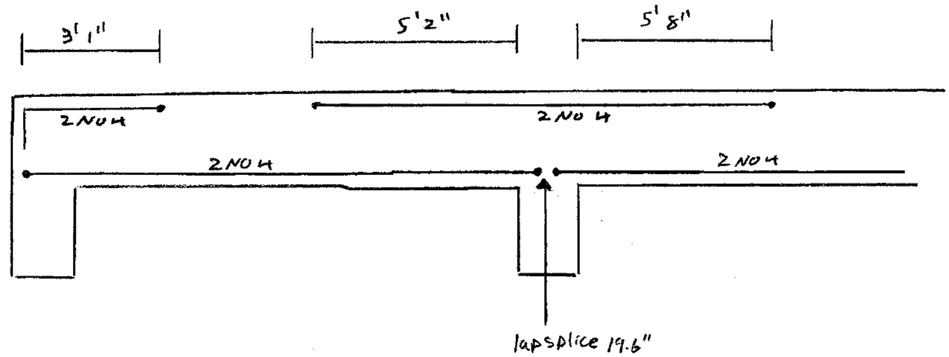
ACI Sec 12.10.5

cutoffs require special consideration if V_u exceeds 2/3 of $\phi(V_c+V_s)$

Not Required

12. Design web face steel

d < 3' so no side face steel is required



13.2.4 Column Hand Calculations

Column Design

Design for a 1st Floor center column because it will have the largest load

Tributary Area = 20' X 20'   4 Stories @ 11'

Floor Weights

Slab = 59.38 PSF X (20'X20') = 23.75 kips
T Beam = .085 kips/Ft X 40' = 3.4 kips
girders = .3375 kips/Ft X 20' = 6.75 kips
→ 33.9 kips

DL = 6.5 psF X (20'X20') = 2.6 kips
LL_{Floor} = 40 psF X (20'X20') = 16 kips
→ 18.26 kips

Snow = 50 PSF X (20'X20') = 20 kips
L_{roof} = 20 PSF X (20'X20') = 8 kips
→ 28 kips

P_u = 4(33.9 kips) + 3(18.26 kips) + 28 kips = 218.38 kips

1. Select Material properties, trial size, and trial reinforcement

F_y = 60ksi
f'_c = 3000
ρ_t = .015

$$A_{g(trial)} \geq \frac{P_u}{.4(f'_c + F_y \rho_t)}$$

$$\geq \frac{218.38}{.4(3.0 + 60 \times .015)}$$

$\geq$ 139.99   try 12" Square

Assume Slenderness is neglected

Try a 12" X 12" Column with Bars in 2 Faces

2. Compute γ

Assume	No. 8 Bars	Dia = 1.0"
	1.5" Clear cover	1.5"
	No. 3 Ties	.375"

$$\gamma = \frac{12 - 2(1.5 + .375 + .5)}{12} = .604$$

Try ρ_t = .01 min value

3. Select Reinforcement

$A_{st} = \rho_t \times A_g = (.01)\times(12" \times 12") = 1.44\ in^2$

Bars	As (in^2)
4 No. 6	1.76
6 No. 5	1.86
8 No 4	1.6 $\quad d_b = .5"$

Try a 12" Square Column with 8 No. 4 Bars

4. Design lap splices

$$l_d = \frac{f_y \alpha \beta \lambda}{20\sqrt{f'_c}} d_b$$

$$l_d = \frac{(60000)(1)(1)(1)}{20\sqrt{3000}} \times .5$$

$$l_d = 27.39"$$

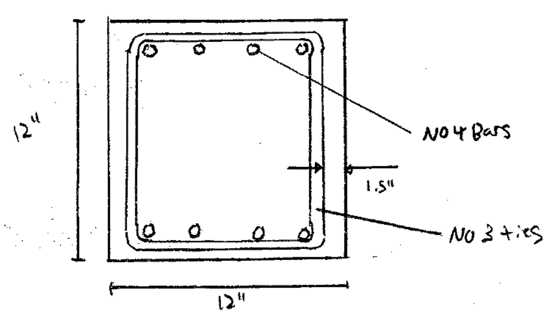
$$1.3\, l_d = (1.3)\times(27.39") = 35.61"$$

5. Select the ties

The required spacing is the smallest of the following

16 Longitudinal Bar diameters = 16 X .5 = 8"
48 tie diameters = 48 X .375 = 18"
least column dimension = 12"

Use No 3 ties at 8"



13.2.5 Flat-Plate Design Hand Calculations

Figure 1

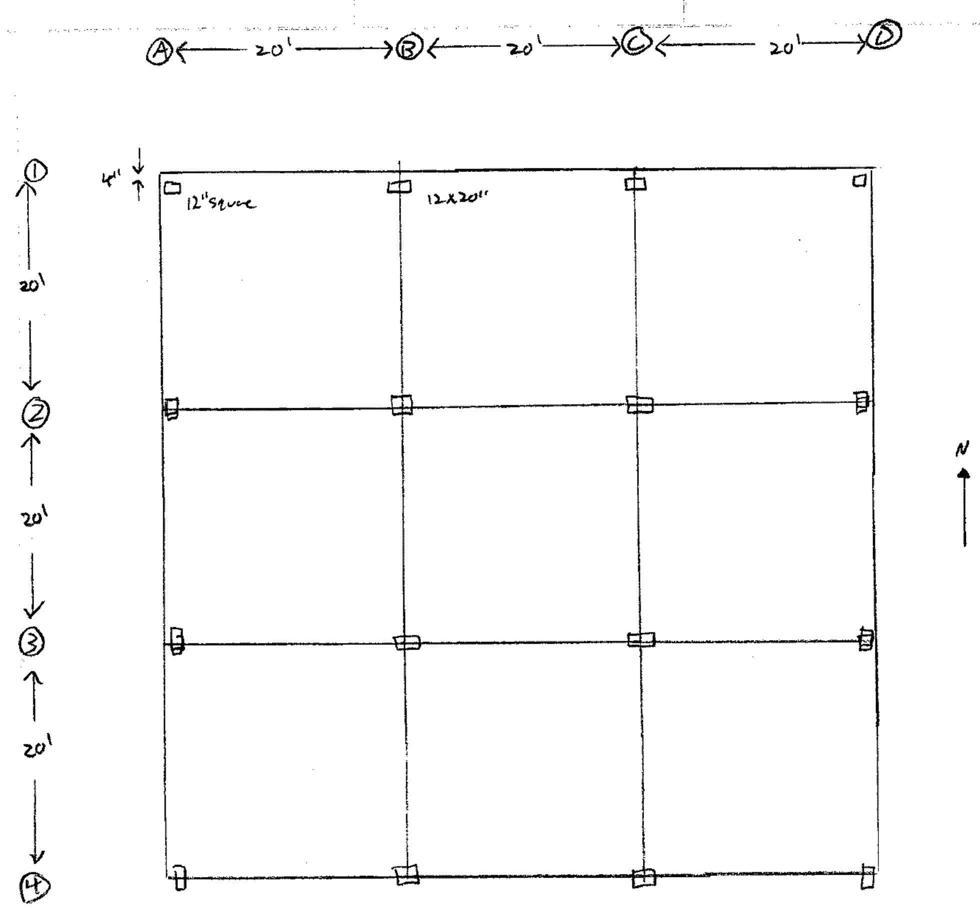


Figure 2

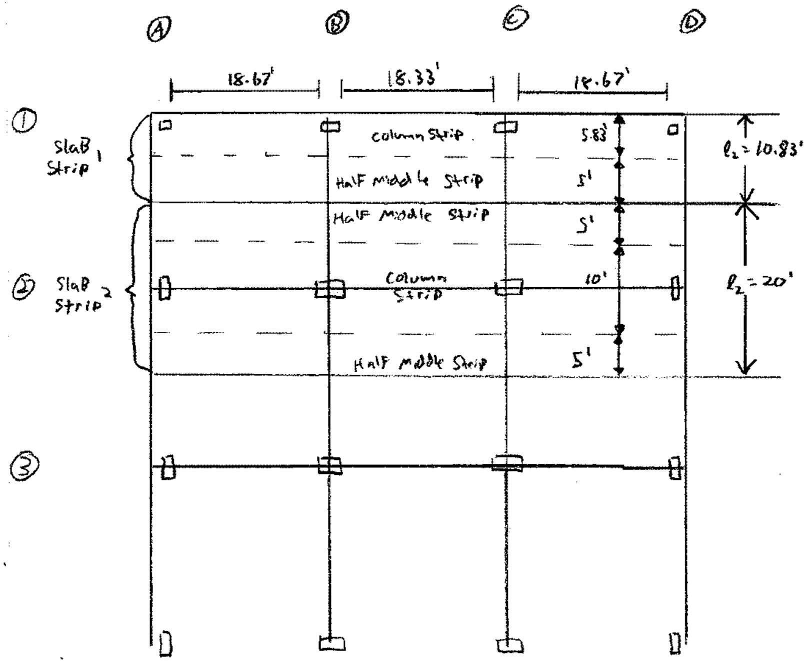
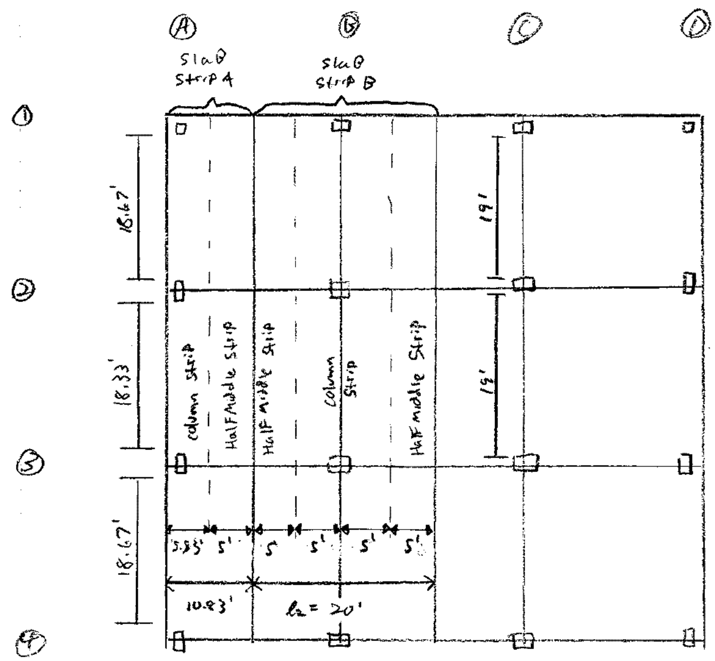


Figure 3



Flat Plate Floor without Beams

Story Height = 11'

$F'_c = 4{,}000$

columns are 12"x12" and 12"x20"

1. Select the design method, load combinations, and strength reduction Factor

ACI Section 13.6.1

(A) 3 consecutive spans each way ✓

(B) longer span / shorter span between 1 and 2 ✓

(C) Span lengths differ by not ≫ 1/3 longer span ✓

(D) columns offset up to 10% ✓

(E) Uniformally distributed loads ✓

(F) unfactored live load < 2x DL ✓

(G) No Beams ✓

gravity load combinations

$U = 1.4D + 1.7L$ Flexure $\phi = .9$ Shear $\phi = .85$

2. Select the thickness

(a) determine thickness to limit deflections

Panel 1-2-A-B

$$\text{Max } \ell_n = 20' - (6" + 10") = 224"$$

$$\text{min } h = \frac{\ell_n}{33} = \frac{224"}{33} = 6.78"$$

Panel 1-2-B-C

$$\text{max } \ell_n = 20' - (20") = 220"$$

$$\text{min } h = \frac{220"}{33} = 6.67"$$

Panel 2-3-A-B

$$\text{max } \ell_n = 20' - (16") = 224"$$

$$\text{min } h = \frac{224"}{33} = 6.78"$$

Panel 2-3-B-C

$$\text{max } \ell_n = 220"$$

$$\text{min } h = \frac{\ell_n}{36} = \frac{220"}{36} = 6.11"$$

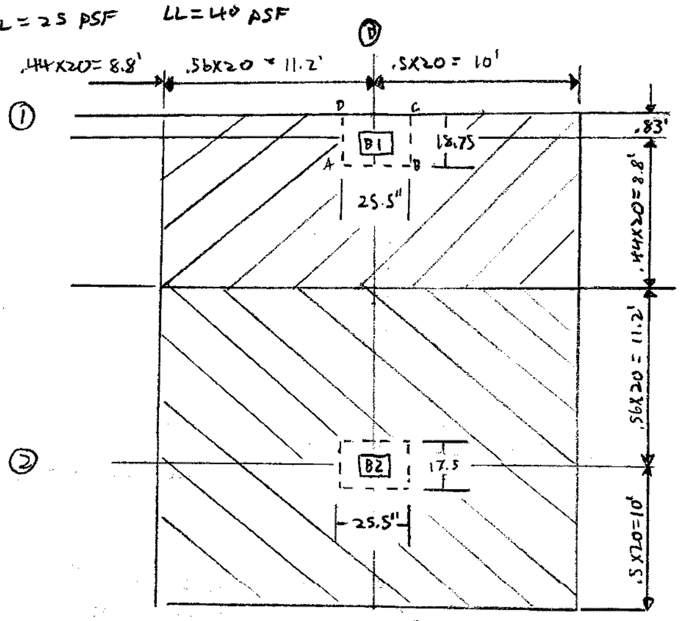
Try h = 7.00"

(B) check the thickness for shear

Column B1

lines of zero shear are at .44 L from the center of the edge of corner column

DL = 25 PSF   LL = 40 PSF



Tributary Areas slab strip A   Span A1-A2

width: line of zero shear = 8.8' From A 11.2' From B

Edge dist = .833'

length: line of zero shear = 8.8' From 1 and 11.2' From B

Edge dist = .833'

Span A-2-A3

width: Same as A1-A2

length: 20' From centerline of column 2 to 3

zero shear at .5x20 = 10' From 2 and 3 lines

Tributary Areas For slab strip B   span B1-B2

width: 20' From center line of A-B

line of zero shear at .56x20 = 11.2' From line B

width is 20' From center lines of B and C

zero shear is 10' From lines B and C

Length is equal to A1-A2

End dist = .833

3

Span B2 - B3

width: same as B1 - B2

line of zero shear at 11.2' toward A and 10' to C

length: Equal to A1 - A2

$$w_u = 1.4\left(\frac{7.00}{12} \times 150 + 25\right) + 1.7(40) = 225.5 \text{ psf}$$

Average $d = 7'' - 1.5'' = 5.5''$

Column B2:

$$b_o = 2\left(12 + 2 \cdot \frac{5.5}{2} + 20 + 2\,\frac{5.5}{2}\right) = 86 \text{ in}$$

$$V_u = 225.5\left[(11.2+10)(11.2+10) - \frac{17.5 \times 25.5}{144}\right]$$

$V_u = 100.65$ kips

13-15

$$\phi V_c = .85\left(2 + \frac{4}{\beta_c}\right)\sqrt{f'_c}\; b_o d$$

$$\phi V_c = .85\left(2 + \frac{4}{20/12}\right)\sqrt{4000}\,(86)(5.5)$$

$\phi V_c = 111.88$ kips

13-16

$$\phi V_c = .85\left(\frac{\alpha_s d}{b_o} + 2\right)\sqrt{f'_c}\; b_o d$$

$$\phi V_c = .85\left(\frac{40 \times 5.5}{86} + 2\right)\sqrt{4000}\,(86)(5.5)$$

$\phi V_c = 115.9$ kips

13-17

$$\phi V_c = \phi 4 \sqrt{f'_c}\; b_o d = (.85)(4)(\sqrt{4000})(86)(5.5)$$

$\phi V_c = 101.7$ kips

$\phi V_c > V_u \qquad 101.7 > 100.65$

column D1:

$b_o = 18.75 + 25.5 + 18.75 = 63\text{ in}$

$V_u = .2255 \left[(11.2' + 10')(8.8' + .83') - \left(\frac{18.75 \times 25.5}{144}\right)\right]$

$= 45.29\text{ kips}$

Factored wall load

$(1.4 \times .3 \times 21.2) = 8.9\text{ kips}$

$V_u = 45.29 + 8.9 = 54.19\text{ kips}$

ϕV_c is the smallest of the following

$\phi V_c = .85\left(2 + \frac{4}{20/12}\right)\sqrt{4000}\,(63)(5.5) = 81.96\text{ kips}$

$\phi V_c = .85\left(\frac{20 \times 5.5}{63} + 2\right)\sqrt{4000}\,(63)(5.5) = 86.04\text{ kips}$

$\phi V_c = .85(4)(\sqrt{4000})(63)(5.5) = 74.51\text{ kips}$

$\phi V_c = 1.72(54.19) = 93.21\text{ kips}$

This is ok But if ϕV_c is < 1.8 - 2 times V_u at exterior columns the slab may have inadequate shear capacity

increase the slab to 7.5"

(C) compute Final value of w_u

$w_u = 1.4\left(\frac{7.5}{12} \times 150 + 25\right) + 1.7(40) = 234.25 \qquad 235\text{ psf}$

3. Compute the moments in a slab strip along column line 2

Shown in Table 1

Neg + Pos Moments For East-West Slab Strip 2

Table 1

	A2		B2			C2			D2
1. l_1 (ft)		20			20			20	
2. l_n (ft)		18.67			18.33			18.67	
3. l_2 (ft)		20			20			20	
4. w_u (ksf)		.235			.235			.235	
5. $M_o = w_u l_2 l_n^2/8$		204.8			197.4			204.8	
6. M_o coefficients	-.26	.52	-.7	-.65	.35	-.65	-.7	.52	.26
7. + - M_o	-53.2	106.5	-143.4	-128.3	69.1	-128.3	-143.4	106.5	-53.2
8. M_o Sum	53.2		13.1			13.1			53.2

Neg and Pos moments For East west Slab strip 1

Table 2

	A2		B2			C2			D2
1. l_1		20			20			20	
2. l_n		18.67			18.33			18.67	
3. l_{2edge}		10.83			10.83			10.83	
4. w_u		.235			.235			.235	
5. M_o		110.9			106.9			110.9	
6. Mo Coeficents	-.26	.52	-.7	-.65	.35	-.65	-.7	.52	-.26
7 Neg + Pos Moments	-28.8	57.7	-77.6	-69.5	37.4	-69.5	-77.6	57.7	-28.8
8 Colum Mom From Slab	28.8		7.1			7.1			28.8
9 Wall Load		.42			.42			.42	
10 Wall Mo		18.3			17.6			18.3	
11 Neg + Pos Mo For wall	-4.8	9.5	-12.8	-11.4	6.16	-11.4	-12.8	9.5	-4.8
12 Column Mo From wall	4.8		1.4			1.4			4.8
13 Total column moments	33.6		8.5			8.5			33.6

Neg and Pos Moments For North South Slab Strip B

Table 3

	B1		B2			B3
1. l_1 (Ft)		20'			20	
2. l_n (Ft)		19'			19'	
3 l_2 (Ft)		20'			20'	
4. W_u (kSF)		.235			.235	
5. M_o $(W_u l_2 l_n^2/8)$		223.3			223.3	
6 Mo coeficents	-.26	.52	-.70	-.65	.35	-.65
7 Neg + pos Moments	-58.1	116.1	-156.3	-145.1	78.2	-145.1
8 Σ column moments	58.1		17.2			17.2

Negate and positive moments For North - South slab Strip A

Table 4

	A1			A2		A3
1. ℓ_1		20			20	
2. ℓ_n		18.67			18.33	
3. ℓ_2		10.83			10.83	
4. w_u		.235			.235	
5. = Mo		110.9			110.9	
6. Mo coeficents	-.26	.52	-.7	-.65	.35	-.65
7. Negt Pos Mo	-28.8	57.7	-77.6	-72.1	38.8	-72.1
8. colum Mo From slab loads	28.8		7.07			7.07
9. Wall load		.42			.42	
10. Wall Mo		18.3			17.6	
11. Neg and pos Mo For wall load	-4.8	9.5	-12.8	-11.4	6.16	-11.4
12. Column Mo From wall load	4.8		1.4			0.0
13. Tot column Mo	33.6		8.47			7.07

Line 8 Table 1 Eq 13-14

$$M_{col} = .07[(1.4 \times 118.75) + .5(1.7 \times 40) \times 20 \times 18.33^2 - (1.4 \times 118.75) 20 \times 18.67^2]$$

$$M_{col} = 13.1 \text{ Ft-K}$$

4. compute the Moments in the slab strip along column line 4

Shown in Table 2

Line 8 Table 2

$$M_{col} = .07[(1.4 \times 118.75) + .5 \times 1.7 \times 40) 10.83 \times 18.33^2 - (1.4 \times 118.75) 10.83 \times 18.67^2$$

$$M_{col} = 7.07 \text{ Ft-K}$$

line 9

w_L For wall $= 1.4 \times .3 = .42$ Kip/Ft

Line 10

Static Moment of Wall

$$Mo_{wall} = \frac{w \ell_n^2}{8} = \frac{(.42)(18.67^2)}{8} = 18.3$$

$$\frac{(.42)(18.33^2)}{8} = 17.6$$

5. Compute the moments in the slab strip along column line B

Spans columns B1, B2, B3 Shown in table 3

6. Compute the moments in the slab strip along column line A

Spans between A1, A2, A3 Shown in Table 4 and Follows step 4

7. Distribute the Neg and Pos moments to column and middle strips and design the reinforcement ; strips spanning East and west 1 and 2

(a) divide the slab strips into middle and column strips

Shown in Figure 2

(B) divide the moments between the column and middle strip and design reinforcement

Table 5 Shows calculations

Line 6 Table 5

$As = \frac{Mu}{\phi F_y J d}$

(a) compute d

assume N05 bars $d = 7.5'' - \frac{3}{4}'' - \frac{1}{2}$ Bar diameter

$d = 6.44$ See Figure 4

(b) As reqd

Largest $Mu = 96.23$ $J = .925$

$$As\ Reqd = \frac{(96.23)(12{,}000)}{(.9)(40{,}000)(.925)(6.44)} = 5.38''^2$$

(c) compute a and a/d, check tension control

$$a = \frac{As\ F_y}{.85 f'_c\ b} = \frac{(5.38)(40000)}{(.85)(4000)(10 \times 12)} = .53''$$

$$\frac{a}{d} = \frac{.53}{6.44} = .082$$

$\phi = .9$

$d_t = d = 6.44''$

$$c = a/\beta_1 = \frac{.53''}{.85} = .624\ \text{in}$$

$$\epsilon_t = \frac{(d_t - c)}{c} \times .003 = \frac{(6.44 - .624)}{.624} \times .003 = .028$$

$\epsilon_t = .028 > .005$

(d) compute jd and As constraint

$$jd = d - \frac{a}{2} = 6.44 - \frac{.53}{2} = 6.18$$

$$A_s = \frac{M_u\,(12000)}{(.9)(40000)\,(6.18)}$$

$$A_s = .0539\ M_u\ (\text{Ft-kips})$$

line 7

$A_{s\,min} = .002bh$

Edge column strip

$A_{s\,min} = .002(5.83 \times 12)\,7.5 = 1.05\ in^2$ $\quad 7.5 \times 2 = 15''$ max Bar spacing

$$\text{Min \# of Bar spaces} = \frac{5.83 \times 12}{15} = 4.66 \qquad \text{min 5 Bars}$$

Other strips

$A_{s\,min} = .002(10 \times 12) \times 7.5 = 1.8\ in^2$

Minimum 8 Bars

Bar choices shown in Table 5 Row 8

Figure 4

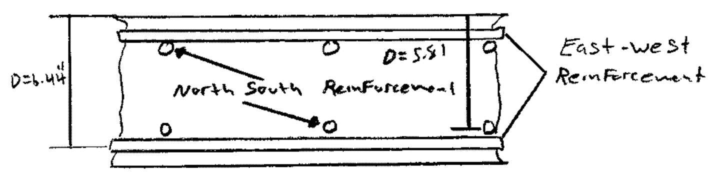


Table 5

	Column Strip 10'	Middle Strip 10'	Column strip 10'	Middle Strip 10'	Edge Column Strip 5.83
Exterior Neg moments	A3 □		A2 □		A1 □
1. Slab moment	-53.2		-53.2		-28.8
2. Mo coeficients 0.0	1.00	0.00 0.0	1.00	0.00 0.0	1.00
3. Mo to column + midstrips	-53.2	0.0	-53.2	0.0	-28.8
4. wall Moment					-4.8
5. Total Moment	-53.2	0.0	-53.2	0.0	-33.6
6. As required	2.87	0.0	2.87	0.0	1.81
7. Min As	1.8	1.8	1.8	1.8	1.05
8. Steel	10 No 5	10 No 4	10 No 5	10 No 4	10 No 4
9. As provided	3.1	2.0	3.1	2.0	2.0
End span Pos Mo					
1. Slab Moment	106.5		106.5		57.7
2. Mo coeficients .2	.6	.2 .2	.6	.2 .4	.6
3. Mo to column + midstrips 21.3	63.9	21.3 21.3	63.9	21.3 23.08	34.62
4. wall Moment					9.5
5. Total Moment	63.9	42.6	63.9	44.38	44.12
6. As required	3.45	2.30	3.45	2.39	2.38
7. Min As	1.8	1.8	1.8	1.8	1.05
8. Steel	8 No 6	8 No 5	8 No 6	8 No 5	8 No 5
9. As provided	3.52	2.48	3.52	2.48	2.48
First Int Neg Mo	□ B3		□ B2		□ B1
1. Slab moment	-128.3		-128.3		-69.5
2. Mo coeficients	.75	.125 .125	.75	.125 .25	.75
3. Mo to column and midstrips	-96.23	-16.01 -16.01	96.23	-16.01 -17.38	-52.13
4. wall Moment					-11.4
5. Total Moment	-96.23	-32.02	-96.23	-33.39	-63.53
6. As required	5.19	1.73	5.19	1.80	3.43
7. Min As	1.8	1.8	1.8	1.8	1.05
8. Steel	12 No 6	10 No 4	12 No 6	10 No 4	8 No 6
9. As provided	5.28	2.0	5.28	2.0	3.52
Interior pos Moments					
1. Slab Moment	69.1		69.1		37.4
2. Mo coeficients	.6	.2 .2	.6	.2 .4	.6
3. Mo to column + midstrips	41.46	13.82 13.82	41.46	13.82 14.96	22.44
4. Wall Moment					6.16
5. Total Moment	41.46	27.64	41.46	28.78	28.56
6. As required	2.24	1.49	2.24	1.55	1.54
7. Min As	1.8	1.8	1.8	1.8	1.05
8. Steel	12 No 4	9 No 4	12 No 4	9 No 4	9 No 4
9. As provided	2.4	1.8	2.4	1.8	1.8

8. Distribute the Neg + pos Moments to the column and middle strips and design the reinforcement; Strips Spanning north and South (Strips A + B)

(a) divide slab strips into middle and column strips

Shown in Figure 3

(B) Divide the moments between the column and middle strips, and design the reinforcement

Table 6 shows calculations

Line 6 Table 6   d is smaller for North - South Steel

Assume NO5 Bars

$d = 7.5 - .75 - 1.5(.625) = 5.81''$

(a) compute trial As

Largest $M_u = -117.2$

$$A_{s\,reqd} = \frac{(.117.2)(12000)}{(.9)(40000)(.925)(5.81)} = 7.27''^2$$

(b) compute a and a/d and check tension control

$$a = \frac{A_s F_y}{.85 f'_c\, b} = \frac{(7.27)(40000)}{(.85)(4000)(10 \times 12)} = .71''$$

$$\frac{a}{d} = \frac{.71}{5.81} = .122 \qquad \phi = .9$$

(c) compute jd and the constant for As

$$jd = d - \frac{a}{2} = 5.81 - \frac{.71}{2} = 5.46''$$

$$A_s = \frac{M_u(\text{Ft kips})(12000)}{(.9)(40000)(5.46)} \qquad A_s\,(in^2) = .0611\, M_u\,(Ft \cdot kips)$$

Line 7

For Column Strips Min As and # of bars is the same as Table 5

Middle Strip between A and B $A_{s\,min} = .002(10 \times 12) \times (7.5) = 1.8 in^2$

Min 8 Bars

Middle Strip between D and C Same as between A and B

Bar choices Shown in Table 6 line 8

11

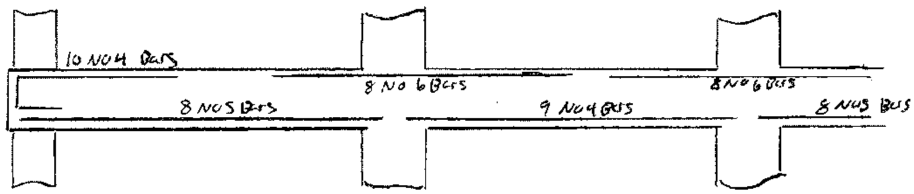
Table 6

	Edge Column Strip 5.83'	Middle Strip 10'	Column Strip 10'	Middle Strip 10'	Column Strip 10'	
Exterior Negative Moments	□ A1		□ B1		□ C1	
1. Slab Moment	-28.8		-58.1		-58.1	
2. Moment Coefficients	1.0	0.0	1.0	0.0	1.0	
3. Moment to column t midstrips	-28.8	0.0	-58.1	0.0	-58.1	
4. Wall Moment	-4.8					
5. Total Moment in strip	-33.6	0.0	-58.1	0.0	-58.1	
6. As Required	2.05	0.0	3.55	0.0	3.55	
7. Min As	1.05	1.8	1.8	1.8	1.8	
8. Choose Steel	11 No 4	10 No 4	12 No 5	10 No 4	12 No 5	
9. As Provided	2.2	2.0	3.72	2.0	3.72	
End Span positive Moments						
1. Slab moment	57.7		116.1		116.1	
2. Moment coefficients	.6	.4 .2	.6	.2 .2	.6	.2
3. Moment to column t mid strips	34.6	23.1 23.2	69.7	23.2 23.2	69.7	23
4. Wall moment	9.5					
5. Total moment in strip	44.1	46.3	69.7	46.4	69.7	
6. As Required	2.69	2.83	4.26	2.84	4.26	
7. Min As	1.05	1.8	1.8	1.8	1.8	
8. Choose steel	9 No 5	10 No 5	10 No 6	10 No 5	10 No 6	
9. As provided	2.79	3.1	4.4	3.1	4.4	
First interior Negative Moments	□ A2		□ B2		□ C2	
1. Slab moment	-77.6		-156.3		-156.3	
2. Moment Coefficients	.75	.25 .125	.75	.125 .125	.75	.12
3. Moment to column t midstrips	-58.2	-19.4 -19.5	-117.2	-19.5 -19.5	-117.2	-19.
4. wall Moment	-12.8					
5. Total moment in strip	-71	-38.9	-117.2	-39	-117.2	
6. As Required	4.34	2.38	7.16	2.38	7.16	
7. Min As	1.05	1.8	1.8	1.8	1.8	
8. Choose steel	10 No 6	12 No 4	12 No 7	12 No 4	12 No 7	
9. As Provided	4.4	2.4	7.2	2.4	7.2	
Interior Positive Moments						
1. Slab moment	35.8		78.2		78.2	
2. Moment Coefficients	.6	.4 .2	.6	.2 .2	.6	.2
3. Moment to Column t Mid strips	23.3	15.5 15.6	46.9	15.6 15.6	46.9	15.
4. wall Moment	6.16					
5. Total Moment in strip	29.5	31.1	46.9	31.2	46.9	
6. As required	1.80	1.90	2.87	1.91	2.87	
7. Min As	1.05	1.8	1.8	1.8	1.8	
8. Choose steel	10 No 4	10 No 4	10 No 5	10 No 4	10 No 5	
9. As provided	2.0	2.0	3.1	2.0	3.1	
Typical Int Negative Moment	□ A3		□ B3		□ C3	
1. Slab Moment	-72.1		-145.1		-145.1	
2. Moment Coefficients	.75	.25 .125	.75	.125 .125	.75	.12
3. Moment to column t Mid Strips	-54.1	-18 -18.1	-108.8	-18.1 -18.1	-108.8	-18.
4. wall moment	-11.4					
5. total Moment in strip	-65.5	-36.1	-108.8	-36.2	-108.8	

Table 6

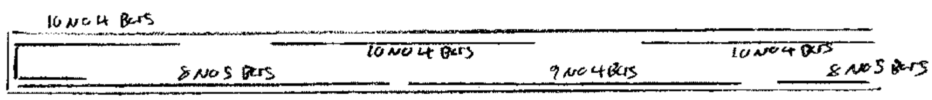
6.	As Required	4.00	2.21	6.65	2.21	6.65
7.	As Min	1.05	1.8	1.8	1.8	1.8
8.	choose steel	13 No5	12 No4	12 No7	12 No4	12 No7
9.	total As provided	4.03	2.4	7.2	2.4	7.2

Reinforcement For strips spanning East-west

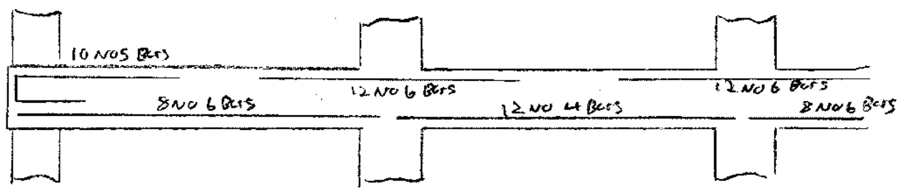


(a) Edge Column Strip Line 1

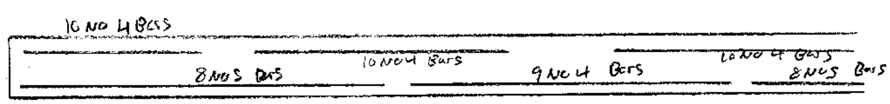
Figure 5



(B) Middle Strip between lines 1 and 2



(C) column Strip along line 2



(D) Middle Strip Between lines 1 and 2

13

Reinforcement For Strips Spanning North-South

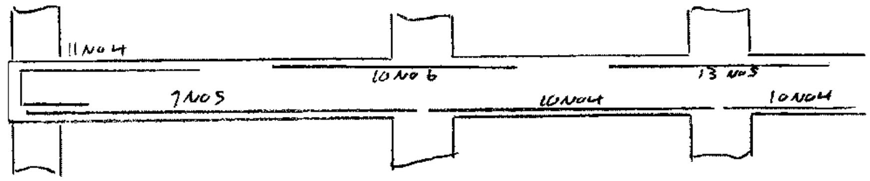
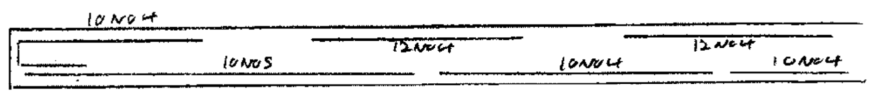
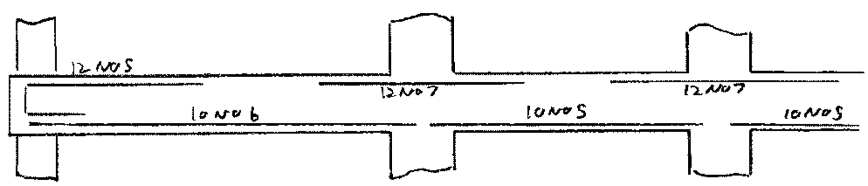


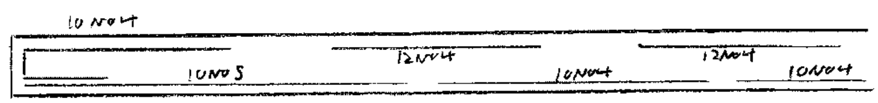
Figure 6 (a) Edge Column Strip - Lines A or D



(B) Middle Strip Between lines A and B or C and D



(C) Column Strip along lines B and C



(D) Middle Strip between lines B and C

9. Check the shear at the exterior columns For combined Shear and moment transfer

use column B1 Because it has a large tributary Area

(a) locate the critical shear perimeter

$d_{avg} = 6.25''$ $\quad \frac{d}{2} = 3.13''$ $\quad b_1 = 19.13''$

$b_2 = 26.25$

(B) locate the centroid of the shear perimeter

$$Y_{ab} = \frac{2 \times (19.13 \times 6.25) \times 19.13/2}{2(19.13 \times 6.25) + (26.25 \times 6.25)} = 5.67''$$

$C_{ab} = 5.67''$ $\quad C_{cd} = 13.46''$

$C_{CB} = C_{AD} = \frac{26.25}{2} = 13.13''$

(c) compute the shear and the moment about the centroid of the shear perimeter

Column B1

$V_u = .235\left[(11.2+10.0)(8.8+.83) - \frac{19.13 \times 26.25}{144}\right]$

$V_u = 47.16$ kips

Shear due to wall load outside the critical perimeter

$V_{uw} = \left(19.13 - \frac{26.25}{12}\right) \times 1.4 \times .3\,\text{kip/Ft} = 7.12$ kips

total $V_u = 54.28$ kips

moment transfered to slab about Z-Z $= .3 M_0$ Table 4 line 5

$M_0 = 223.3(.3) = 66.99$

moment of edge panel loads about axis W-W of column B1 Table 3 line 7, 13

$77.6 - 69.5 + 1.4 = 9.5$

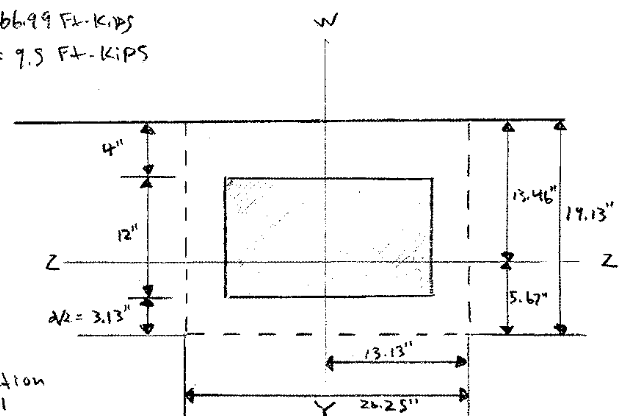
connections at B1 must be designed for

$V_u = 54.28$ kips

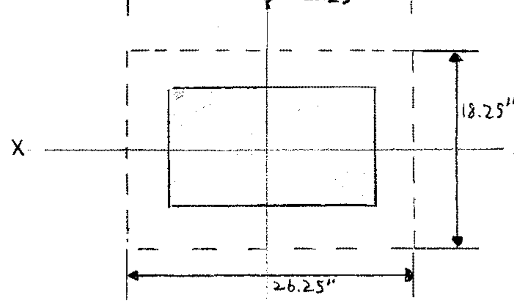
$M_{zz} = 66.99$ Ft-kips

$M_{ww} = 9.5$ Ft-kips

Figure 7



(a) critical section column B1



(B) critical section column B2

(d) compute ϕV_c and $V_u / \phi V_c$

use $b_o = 2 \times 19.13'' + 26.25'' = 64.51$

$$\phi V_c = \phi 4 \sqrt{f'_c}\, b_o\, d$$

$$\phi V_c = (.85)(4)(\sqrt{4000})(64.51)(6.25)$$

$$\phi V_c = 86.7 \text{ kips}$$

$$V_u / \phi V_c = \frac{54.28}{86.7} = .626$$

(e) determine the Fraction of the moment transferred by Flexure γ_f

Moments about the Z-Z axis:

$$\gamma_f = \frac{1}{1 + 2/3 \sqrt{b_1/b_2}}$$

$$\gamma_{f_1} = \frac{1}{1 + 2/3\sqrt{\frac{19.13}{26.25}}} = .637 \qquad \gamma_{f_2} = \frac{1}{1 + 2/3\sqrt{\frac{26.25}{19.13}}} = .562$$

ACI Section 13.5.3.3 if $V_u/\phi V_c < .75$ γ_f can be increased to 1.0

Take $\gamma_f = 1.0$

Moments about the W-W axis:

γ_f can be increased up to 25% if $V_u/\phi V_c \leq .4$

no increase can be made in γ_{f2}

Moment transferred by Flexure is $\gamma_{f2} M_u = (.562)(9.5) = 5.34$ Ft-kips

(F) Design the reinforcement required for moment transfer by Flexure

Moments about the Z-Z axis

width effective For Flexure $= c_2 + 3h = 20'' + 3(7.5'') = 42.5''$

moment: $1.0 \times 66.99 = 66.99$ Ft-kips

assume $jd = .925\, d$

$$a_s = \frac{M_u}{\phi F_y j d} = \frac{(66.99)(12000)}{(.9)(40000)(.925)(6.25)} = 3.86 \text{ in}^2$$

the steel provided in step 8 was 12 No. 5 Bars in a column strip of 10' = 120" roughly 10" on center

Bars within the 42.5" effective width can be used For the moment transfer place 6 column strip bars in this region and add 5 Additional bars giving $A_s = 3.9 in^2$ in the effective width

compute a and re-compute A_s

$$a = \frac{A_s F_y}{.85 f'_c b} = \frac{(3.9)(40000)}{(.85)(4000)(42.5)} = 1.08 \text{ in}$$

$$A_s = \frac{M_u}{f_y(d - a/2)} = \frac{(66.99)(12000)}{(.9)(40000)(6.25 - 1.08/2)} = 3.9 \text{ in}^2$$

The steel chosen has adequate capacity

$$\frac{a}{d} = \frac{1.08}{6.25} = .1728$$

$$\frac{a_b}{d} = \beta_1 \left(\frac{87{,}000}{87{,}000 + f_y}\right) = .85\left(\frac{87{,}000}{87{,}000 + 40000}\right) = .582$$

$$.375 \times a_b/d = .375 \times .582 = .218 \geq a/d = .1728 \qquad \gamma_f = 1.0$$

It is not necessary to transfer any of the moment about axis Z-Z by shear

Moment about the W-W axis

effective width = $12 + 4 + (1.5 \times 7.5) = 27.25''$

For moment = 5.34 Ft-kips

The bars selected are adequate as long as they are uniformly distributed

(b) Compute the shear stresses

$$V_v = \frac{V_u}{b_o d} \pm \frac{\gamma_{v1} M_{u1} c}{J_{c1}} = \pm \frac{\gamma_{v2} M_{u2} c}{J_{c2}}$$

$M_{u1} \rightarrow$ Z-Z axis $\quad M_{u2} \rightarrow$ W-W axis

$b_o = 64.51''$

$\gamma_{v1} = 1 - \gamma_{f1} = 1 - 1 = 0$

$\gamma_{v2} = 1 - \gamma_{f2} = 1 - .562 = .438$

The second term drops out leaving

$$J_{c2} = 2(b_1 d) c_{CB}^2 + \frac{b_2 d^3}{12} \quad \frac{b_2^3 d}{12}$$

$$J_{c2} = 2(19.13 \times 6.25)\, 13.13^2 + \frac{26.25 \times 6.25^3}{12} + \frac{26.25^3 \times 6.25}{12}$$

$$J_{c2} = 51{,}179 \text{ in}^4$$

$$v_u = \frac{(54.28)(1000)}{(64.51)(6.25)} \pm 0.0 \pm \frac{(.438)(9.5)(12{,}000)(13.13)}{(51{,}179)}$$

$v_u = 135 \pm 0.0 \pm 13$

$v_u = 148$ psi at B and 122 psi at A

There is no shear reinforcement in the slab so

$\phi V_n = \phi V_c = \phi V_c / b_o d$ From step d $\phi V_c = 86.7$ kips

$$\phi V_n = \frac{(86.7)(1000)}{(64.51)(6.25)} = 215 \text{ psi}$$

$v_u < \phi V_n$ the shear is ok in this column - slab connection

10. Check the Shear at an interior Column For combined Shear and Moment transFer

Tables 1 and 3 indicate that moments of 13.1 and 17.2 Ft-kips are transferred From the Slab to column B_2 From strip 2 and Strip B

(a) locate the critical Shear perimeter Figure 7

$b_o = 2(18.25 + 26.25) = 89''$

(b) Locate the centroid of the Shear perimeter
the centroids pass through the center of the sides

(c) compute the Forces to be transferred

$$V_u = .235\left[(11.2+10)(11.2+10) - \frac{26.25 \times 18.25}{144}\right]$$

$V_u = 104.8$ kips

Moments to be transferred come From tables 1 and 3

diff in negative moments on the 2 sides of B2

$143.4 - 128.3 = 15.1$ Ft-kips

$156.3 - 145.1 = 11.2$ Ft-kips

The Forces transferred to the column are

$V_u = 104.8$ kips $M_{u1} = 11.2$ Ft-kips $M_{u2} = 15.1$ Ft-kips

(d) compute the Fraction of the moment transferred by Flexure

$$\gamma_{F_1} = \frac{1}{1+2/3\sqrt{\frac{18.25}{26.25}}} = .623 \qquad \gamma_{F_2} = \frac{1}{1+2/3\sqrt{\frac{26.25}{18.25}}} = .556$$

ACI Sec 13.5.3.3 γ_F can be increased by 25% if $V_u/\phi V_c \leq .4$

$$\phi V_c = \phi 4\sqrt{f'_c}\, b_o d = (.85)(4)(\sqrt{4000})(89)(6.25) = 119.6 \text{ kips}$$

$$\frac{V_u}{\phi V_c} = \frac{104.8}{119.6} = .876 \qquad V_u/\phi V_c > .4$$ so γ_F cannot increase about either axis

(e) Compute the torsional moment of inertia, J_c

$$J_{c1} = 2\left(\frac{b_1 d^3}{12}\right) + 2\left(\frac{d\, b_1^3}{12}\right) + 2(b_2 d)\left(\frac{b_1}{2}\right)^2$$

$$J_{c1} = 2\left(\frac{(18.25)(6.25)^3}{12}\right) + 2\left(\frac{(6.25)(18.25^3)}{12}\right) + 2(26.25)(6.25)\left(\frac{18.25}{2}\right)^2$$

$$J_{c1} = 34{,}396 \text{ in}^4$$

$$J_{c2} = 2\left(\frac{26.25 \times 6.25^3}{12}\right) + 2\left(\frac{6.25 \times 26.25^3}{12}\right) + 2(18.25)(6.25)\left(\frac{26.25}{2}\right)^2$$

$$J_{c2} = 59{,}208 \text{ in}^4$$

(F) Design the reinforcement for moment transfer

By inspection the slab reinforcement is already adequate

(g) compute the shear stresses

Max stress occurs at the corner

$$b_o = 2(18.25 + 26.25) = 89''$$

$$V_u = \frac{104.8}{89 \times 6.25} + \frac{(1-.623)(11.2)(12)(9.13)}{34{,}396} + \frac{(1-.556)(15.1)(12)(13.13)}{59{,}208}$$

$V_u = .2197$ ksi $\rightarrow$ 220 psi

$\phi V_c = (119.6)2 = \rightarrow$ 239 psi

$\phi v_c > v_u$ the Shear is ok at the column

11. Check the shear at a corner column.

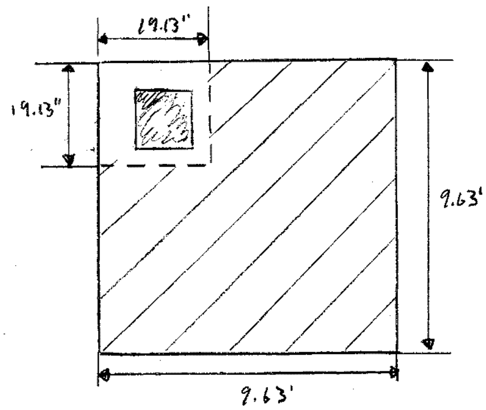
The moments transfered from the slab to the corner column are 28.8 and 33.6 from tables 2 and 4

Two way shear

(a) Locate the critical perimeter

Figure 8

2 way shear



(b) Locate the centroid

$$\bar{X} = \frac{(19.13)(6.25)\ (19.13/2)}{(2)X\ (19.13)X(6.25)} = 4.78'' \text{ From the inside corner}$$

(C) compute the forces to be trans fered

$$V_u = .235\left[(.44 X 20 + .83) X (.44 X 20 + .83) - \frac{19.13 X 19.13}{144}\right]$$

$V_u = 19.14$ kips

Shear due to wall load

$$v_u = \left[(8.8 + .83) + (8.8 + .83) - \frac{2 X 19.13}{12}\right] X\ 1.4\ X .3 \text{ kips/Ft}$$

$V_u = 6.75$ kips

Total shear = 19.14 + 6.75 = 26.15 kips

For strip 1: $M_o = 110.9 X .3 = 33.27$ Table 2
For strip A: $M_o = 110.9 X .3 = 33.27$ Table 4

(d) determine the Fraction of the moment transferred by Flexure

For a square column $\gamma_v = .40$
For a square critical section assume $\gamma_F = .6$ ACI Sec 13.5.3.3
γ_F may increase by 1.0 if $V_u/\phi V_c \leq .5$ and $\rho < .375\rho_b$

Effective width = 4" + 12" + (1.5 X 7.5) = 27.25"

$b_o = 19.13 \times 2 = 38.26''$

$\phi V_c = \phi 4\sqrt{f'_c}\, b_o d = (.9)(4)\sqrt{4000}\,(38.26)(6.25) = 54.44$ kips

$$\frac{V_u}{\phi V_c} = \frac{26.15}{54.44} = .480 < .5 \qquad \text{use } \gamma = .6$$

(e) design reinforcement for moment transfer by Flexure

.6 X 10 = 6   Put 6 No. 4 Bars within 27.25" of corner in strip 1
.6 X 11 = 6.6 → 7 put 7 No. 4 Bars within 27.5" of corner in strip A

(f) compute the torsional moment of inertia J_c

$$J_c = \frac{19.13 \times 6.25^2}{12} + \frac{6.25 \times 19.13^2}{12} + (19.13 \times 6.25)\left(\frac{19.13}{2} - 4.78\right)^2$$
$$+ (6.25 \times 19.13)(4.78)^2$$

$J_c = 5722 \text{ in}^4$

(g) compute the shear stress

$$V_u = \frac{26.15}{(38.26)(6.25)} \pm \frac{(1-.6)(33.27)(12)(4.78)}{5722} \pm \frac{(1-.6)(33.27)(12)(4.78)}{5722}$$

$V_u = .376$ ksi = 376 psi

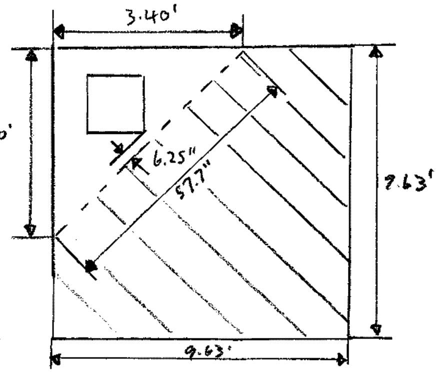
One way Shear

(a) Locate the critical section

Shown in Figure 9

onewa7 shear

Figure 9



(b) compute the shear on the critical section

$V_u = .235\,[(8.8+.83)(8.8+.83) - 3.40^2/2] = 20.4$ kips

Shear due to wall

$V_u = [(9.63 - 3.4) + (9.63 - 3.4)] \times 1.4 \times .3 = 5.23$

Total $V_u = 20.4 + 5.23 = 25.63$ Kips

(c) ϕV_c For the critical Section

$\phi V_c = \phi 2\sqrt{f'_c}\, bd = (.85)(2)(\sqrt{4000})(57.7)\left(\frac{6.25}{1000}\right) = 38.77$ kips

$\phi V_c > V_u$ The slab is ok in one way shear

13.3 Foundation Appendices

Included in this section are references not shown in any previous sections.

13.3.1 Bearing Stress Spreadsheet – Typical Interior

BEARING CAPACITY

STEP ONE				
Minimum Embendment Depth, D	24.00	in	Coduto, T8.1	
*can choose to be a deeper depth as Coduto's T8.1 value represents a minimum				
STEP TWO				
groundwater depth from surface, Dw				
see Soil Profile for shallowest occurance				
Dw	18.00	ft	5.49	m
STEP THREE				
Factor of Safety; Typical range is 2.5 to 3.5	3.00			
STEP FOUR				
Obtain Allowable Bearing Capacity				
Shape	Square			
Normal Load, P	169.36	kips	753.35	kN
Use Bearing.xls from Coduto with specified values below and from previous steps. For other variables in the file including "B" and "D", their values may vary as long as the "P" value by the Terzaghi Method meets the required loading specified in the beginning of STEP FOUR. "L" is not necessary for a square spread footing foundation.				
Effective cohesion, c'	0	psf	**Specified by Maguire Group's Geotechnical Report, Table 5	
phi	32	deg		
Unit weight of water, gamma γ (E)	62.4	pcf		
Unit weight of water, gamma γ (SI)	9.80	kN/m^3		
Allowable bearing pressure, qa (from reference)	4239.00	psf		
From Bearing.xls, enter values below				
B	8.00	ft	2.44	m
D	4.00	ft	1.22	m
P allowable (not used for spreadsheets)	271.00	kips	1205.47	kN
	*Round above values to nearest 1/4 foot			
STEP FIVE				
Allowable total settlement, δa	1.00	in	Coduto, T2.1	
S, column spacing	20.00	ft	6.10	m
Allowable angular distortion, Θa	0.002	degrees	Coduto, T2.2	
Allowable differential settlement, δDa	0.04	in		
Select proper ratio				
δD/δ	1.10		Coduto, T7.5	
Is settlement requirement met?	NO, USE REVISED δD VALUE			
Revised δa value	0.91			

STEP SIX				
Choose appropriate ratio or revised δa value	0.91			
Settlement Analysis of largest applied loading				
Length of Foundation, L (if square, L=B)	8.00	ft	2.44	m
rigidity factor	0.85			
Use Classic Method Spreadsheet by Coduto	*Use referenced document			
maximum q, bearing pressure (SI)	155	kPa		
maximum q, bearing pressure (E)	3237.24	psf		
delta value (SI)	77.52	mm		
delta value (E)	3.05203992	in		
compare settlement values (δ), less than δa?	NO, CHOOSE LOWER q VALUE			
Use Schmertmann Spreadsheet by Coduto	*Use referenced document			
maximum q, bearing pressure (SI)	155	kPa		
maximum q, bearing pressure (E)	3237.24	psf		
delta value (SI)	45.31	mm		
delta value (E)	1.78390001	in		
compare settlement values (δ), less than δa?	NO, CHOOSE LOWER q VALUE			
Select maximum bearing pressure of the methods if both comparisons agree, otherwise select the bearing pressure that does have δ less than δa	3237.24	psf		

STEP SEVEN		
Lowest value of qa from Steps 4 and 6	3237.24	psf
Express as a multiple of 500 lb/ft^2	3000.00	psf

FINAL ALLOWABLE BEARING PRESSURE	**3000.00**	**psf**

13.3.2 Foundation Design Spreadsheet – Typical Interior

FOUNDATION DESIGN

DESIGN OF FOUNDATIONS - SQUARE FOOTINGS

Unfactored Normal Load, Pu	169,360.00	lb	
Factored Moment, Mu	0.00	in-lb	0, unless specified
Width of foundation, B	96.00	in	From q(a) results
Factored Live Load,	121,600.00	lb	
Factored Shear Load,Vu	0.00	lb	0, unless specified
Column width, c1 (b_f)	7.96	in	
Column width, c2 (d)	9.71	in	
Thickness of Foundation, T	18.00	in	T must be a multiple of 3
Depth of foundation, D	48.00	in	
Effective depth, d	14.69	in	
Reinforcing bar diameter, db	0.31	in	
Compressive strength of concrete F'c	4,000.00	psi	
Yield strength of steel, Fy	60,000.00	psi	
Resistance factor, phi, Φ	0.85		

Design for Shear		
Two-Way Shear - If moment present		
Vuc for c1	28,707.74	lb
Vuc for c2	28,436.14	lb
Largest Shear Value for present moment?	28,707.74	lb
Two-Way Shear - *If applied shear load present in same direction as Mu*		
Vuc for c1	28,707.74	lb
Vuc for c2	28,436.14	lb
Largest Shear Value for load in same direction as Mu?	28,707.74	lb
Largest Two-Way Shear Value?	28,707.74	lb
Nominal 2-way Shear capacity on concrete, critical section		
unit length, bo, for c1	22.65	in
unit length, bo, for c2	24.40	in
Nominal Shear Capacity, Vnc or Vc, for c1	84,174.39	lb
Satisfactory Design for Shear?		
phi*Vnc, so that Vuc $\leq \Phi V_{nc}$	71,548.23	lb
	YES, CONTINUE DESIGN	

One-Way Shear		
Shear Force on Critical Surface		
Vuc for c1	74,302.67	lb
Vuc for c2	72,086.00	lb
Largest Vuc for c1 and c2?	74,302.67	lb
Nominal shear load capacity		
bw	192.00	in
Vnc	356,765.64	lb
Satisfactory Design for Shear?		
phi*Vnc, so that Vuc $\leq \Phi V_{nc}$	303,250.79	
	YES, CONTINUE DESIGN	

Design for Flexure and Required Steel		
Find Steel Area		
Base Plate Width, bcp	12.00	in
Cantilever distance, l	43.01	in
Factored moment, Muc	1,171,578.06	in-lb
Gross Cross Sectional Area, Ag	1,728.00	in^2
Check Minimum Steel Area	2.54	in^2
Clear Space between bars - assumed	1.00	in
Check Development Length		
(c+Ktr)/db	11.29	Ktr=0 for spread footings
Value for (c+Ktr)/db, may not be >2.5	2.5	
Select Alpha	1.00	
Select Beta	1.00	
Select Gamma	0.80	
Development Length for Calculated Value	5.04	in
Development Length for Value of 2.5	22.77	in
Choose Appropriate Development Length Ratio	22.77	

Solve for required length ld, must be greater than 12"	22.77	in	
Minimum Area of Steel for Each Direction, As	3.11	in^2	Note: 60 Grade
Final Minimum Steel Area (choose largest of previous answers)	3.11	in^2	
Required Steel Area, As	1.49	in^2	
Is the required steel area sufficient?	NO, USE MINIMUM STEEL VALUE		
Develop a bar scheme	11.00	#5	
Cross Sectional As for Selected Scheme ea. Direction	3.41	in^2	See Adapted Table Below
Does this satisfy the minimum steel area?	YES		
Clear Space between bars - actual	7.00	in	
Supplied Development Length, (Ld)supplied	40.01	in	
Is this length greater than required length?	YES, DESIGN IS COMPLETE		

Development Length Factors Table	
Alpha α - Reinforcement Location	
Horiz. Reinf. >12" fresh conc. Below bar	1.3
All other cases	1.0
Beta β - Coating	
Epoxy Coated, Cover < 3db, clear spacing < 6db	1.5
Other epoxy coated bars/wires	1.2
Uncoated bars or wires	1.0
Gamma γ - Reinforcement	
#6 and smaller bars	0.8
#7 and larger bars	1.0
Lambda λ - Lightweight Concrete	
Normal Concrete (ltwt not allowed for foundations)	1.0

Design Data for Steel Reinforcing Bars (Adapted from Coduto T.1)

Bar Size Designation	Dia. (db)	Cross Sectional Area
(English, #)	(in)	(in^2)
#3	0.375	0.11
#4	0.500	0.20
#5	0.625	0.31
#6	0.750	0.44
#7	0.875	0.60
#8	1.000	0.79
#9	1.128	1.00
#10	1.270	1.27
#11	1.410	1.56
#14	1.693	2.25
#18	2.257	4.00

13.3.3 Hand Calculations

HAND CALCULATION EXAMPLE OF A SQUARE SPREAD FOOTING FOUNDATION WITH A SINGLE CENTRALLY LOCATED COLUMN

$P_u = 86K$

D (Table 8.1) = 18in (minimum)

$D_w = 18$ ft or 216 in

B (by BEARING.xls) = 6.25 ft or 75 in where $c = 0$, $\phi = 32°$, $\gamma = 62.4$, $F = 3$

$f'_c = 4{,}000$ psi

$f_y = 60{,}000$ psi

assume no applied moment or shear loads.

- determine thickness based on 2-way shear analysis.

Try $T = 12$in

$d = T - 1$ bar diameter $- 3$in

$d = 12 - 1 - 3$

$d = 8$ in

$$V_{uc} = \left(\frac{P_u}{4} + \frac{M_u}{c+d}\right)\left(\frac{B^2 - (c+d^2)}{B^2}\right)$$

$M_u = 0$ (as assumed above)

$$V_{uc} = \left(\frac{86{,}000\text{lb}}{4} + 0\right)\left(\frac{(75)^2 - (12 + 8^2)}{(75)^2}\right)$$

$V_{uc} = (21{,}500 \text{ lb})(0.9865)$

$V_{uc} = 21{,}209.75$ lb

$V_{nc} = 4 b_o d \sqrt{f'_c}$

$b_o = c + d = 12 + 8 = 20$in

$V_{nc} = (4)(20\text{in})(8\text{in})(\sqrt{4{,}000\text{psi}})$

$V_{nc} = 40{,}478$ lb

$\phi V_{nc} = (0.85)(40{,}478 \text{ lb})$

$\phi V_{nc} = 34{,}407$ lb

is $\phi V_{nc} > V_{uc}$?

$34{,}407 > 21{,}210$

✓ yes

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

$$M_{uc} = \phi K_n \left(\frac{bd^2}{12{,}000}\right) \quad \text{(by Mac Gregor)}$$

$$\phi K_n = \phi [f'_c \omega (1 - 0.59\omega)]$$

$$\omega = \frac{\rho f_y}{f'_c} \quad \text{when } \rho = 0.01$$

$$\omega = \frac{(0.01)(60{,}000)}{4{,}000} = 0.15$$

$$\phi K_n = (0.9)[(4{,}000)(0.15)(1 - 0.59(0.15))]$$

$$\phi K_n = 492.21$$

$$M_{uc} = (492.21)\left(\frac{(75)(8^2)}{12{,}000}\right)$$

$$M_{uc} = 196.884 \text{ ft·kip}$$

$$A_s = \left(\frac{4{,}000 \times 75}{1.176 \times 60{,}000}\right)\left(8 - \sqrt{64 - \frac{2.353(196.884)}{(0.9)(4000)(75)}}\right)$$

$$A_s = (4.2517)(8 - \sqrt{64 - .00171580716})$$

$$A_s = (4.2517)(8 - 7.999892761)$$

$$A_s = 4.5595 \times 10^{-4} \text{ in}^2$$

Check minimum steel

$$A_{s\,min} \geq 0.0018\, A_g$$

$$A_{s\,min} \geq (0.0018)(12'')(75'')$$

$$A_{s\,min} \geq 1.62 \text{ in}^2$$

$A_{s\,min}$, $1.62\text{ in}^2 > A_s$, $4.5595 \times 10^{-4}\text{ in}^2$

→ Use $A_{s\,min}$

Using Coduto Table 9.1

6 #5 1.86 in²

$$\text{Clear Space} = \left(\frac{B}{n+1}\right) - 1''$$

$$= \frac{75''}{(6+1)} - 1''$$

$$= \frac{75''}{7} - 1''$$

$$\text{Clear space} = 9.714''$$

Check development length

$l_{d_{supplied}} = l - 3$

A) $l_{d_{supplied}} = 33.52 - 3$
$= 30.52 in$

B) $l_{d_{supplied}} = 32.645 - 3$
$= 29.645 in$

$l = \frac{B - c}{2}$

for column dimensions
7.96in x 9.71in

$l = \frac{75 - 7.96}{2}$ $l = \frac{75 - 9.71}{2}$

A) $l = 33.52 in$ B) $l = 32.645 in$

$\frac{c + K_{tr}}{d_b}$, where $K_{tr} = 0$

(column) → $\frac{c + K_{tr}}{d_b}$

A) $\frac{7.96 + 0}{0.625} = 12.736$
(use 2.5)

B) $\frac{9.71 + 0}{0.625} = 9.71$
(use 2.5)

$$l_d = (d_b)\left(\frac{3}{40}\right)\left(\frac{f_y}{\sqrt{f'_c}}\right)\left[\frac{\alpha \beta \gamma \lambda}{\left(\frac{c + K_{tr}}{d_b}\right)}\right]$$

$$l_d = (0.625)\left(\frac{3}{40}\right)\left(\frac{60,000}{4,000}\right)\left[\frac{(1)(1)(0.8)(1)}{(2.5)}\right]$$

$l_d = 0.225$

$l_d < l_{d_{supplied}}$, ok

Design complete.

13.4 Cost Estimate Appendices

13.4.1 Typical WBS Division

B Shell						
B10 Superstructure						
Steel Gravity System		246.12	tons of steel	$3,050.00	$750,666.00	$9.34
Steel Bracing		48.79	tons of steel	$3,050.00	$148,809.50	$1.85
Welded Steel Sheer Connections	0.75" Diameter 3.1875" long	10,752.00	each	$2.10	$22,579.20	$0.28
Concrete Floor Slab	Lightweight Concrete 110psf 4.5 thick floor fill	1,116.67	cubic yards	$4.68	$5,226.02	$0.07
Steel Decking	Composite Deck 2" deep 22 gauge	80,400.00	sf floor	$2.28	$183,312.00	$2.28
B20 Exterior Enclosures						
Exterior Walls	Brick verneer/metal stud backup, standard brick, running bon	26,936.00	sf wall	$24.35	$655,891.60	$8.16
Exterior windows (rooms hallways)	alluminum sliding 5'X3' insulated	282.00	each	$523.00	$147,486.00	$1.83
Exterior Windows (first Floor)	50% of exterior is glass, 5/8" thick, 2 lites 3/16" float, clear	5,128.50	sf wall	$20.85	$106,929.23	$1.33
Exterior Doors Glass	Alum. & glass, full vision, 6'X10' double	6.00	each	$5,700.00	$34,200.00	$0.43
Exterior Doors Glass	Alum. & glass, full vision, 3'X10' Single	2.00	each	$3,625.00	$7,250.00	$0.09
Exterior Doors	Steel 18 ga. 3'x7'	5.00	each	$1,800.00	$9,000.00	$0.11
B30 Roofing						
Roof Coverings	Built up tar and gravel with flashing, perlite/EPS composit ins	20,100.00	sf roof	$5.28	$106,128.00	$1.32
Roof Openings	skylight, 25sf, single glazing	50.00	sf	$21.57	$1,078.50	$0.01
				Total	$2,178,556.04	$27.10

13.4.2 Typical Steel Section Cost

Steel Total Without Bracing								
Beam, Girder, or Column	Girder	Beam	Corner Column fl 1	Corner Column fl 2-4	Interior Column fl 1	Interior Column fl 2-4	Exterior Column fl 1	Exterior Column fl 2-4
Size	W14X26	W10X15	W10X26	W10X26	W10X33	W10X26	W10X26	W10X26
Number	488.00	612.00	7.00	21.00	32.00	96.00	33.00	99.00
Length	20.00	20.00	13.00	11.00	13.00	11.00	13.00	11.00
LF of Steel	9,760.00	12,240.00	91.00	231.00	416.00	1,056.00	429.00	1,089.00
Unit Weight plf	26.00	15.00	26.00	26.00	33.00	26.00	26.00	26.00
Weight (tons)	126.88	91.80	1.18	3.00	6.86	13.73	5.58	14.16
Material Cost/ton	$2,100.00	$2,100.00	$2,100.00	$2,100.00	$2,100.00	$2,100.00	$2,100.00	$2,100.00
Material Cost	$266,448.00	$192,780.00	$2,484.30	$6,306.30	$14,414.40	$28,828.80	$11,711.70	$29,729.70
Loc Material Cost	$264,049.97	$191,044.98	$2,461.94	$6,249.54	$14,284.67	$28,569.34	$11,606.29	$29,462.13
Labor Cost/ton	$325.00	$325.00	$325.00	$325.00	$325.00	$325.00	$325.00	$325.00
Labor Cost	$41,236.00	$29,835.00	$384.48	$975.98	$2,230.80	$4,461.60	$1,812.53	$4,601.03
Loc Labor Cost	$49,730.62	$35,981.01	$463.68	$1,177.03	$2,690.34	$5,380.69	$2,185.91	$5,548.84
Equipment Cost/ton	$165.00	$165.00	$165.00	$165.00	$165.00	$165.00	$165.00	$165.00
Equipment Cost	$20,935.20	$15,147.00	$195.20	$495.50	$1,132.56	$2,265.12	$920.21	$2,335.91
Loc Equipment Cost	$25,247.85	$18,267.28	$235.41	$597.57	$1,365.87	$2,731.73	$1,109.77	$2,817.10
Total Cost/ton	$2,590.00	$2,590.00	$2,590.00	$2,590.00	$2,590.00	$2,590.00	$2,590.00	$2,590.00
Total Cost	$328,619.20	$237,762.00	$3,063.97	$7,777.77	$17,777.76	$35,555.52	$14,444.43	$36,666.63
Loc Total Cost	$356,223.21	$257,734.01	$3,321.34	$8,431.10	$19,271.09	$38,542.18	$15,657.76	$39,746.63
Total Inc O&P Cost/ton	$3,050.00	$3,050.00	$3,050.00	$3,050.00	$3,050.00	$3,050.00	$3,050.00	$3,050.00
Total Inc O&P Cost	$386,984.00	$279,990.00	$3,608.15	$9,159.15	$20,935.20	$41,870.40	$17,009.85	$43,178.85
Loc Total Inc O&P Cost	$419,490.66	$303,509.16	$3,911.23	$9,928.52	$22,693.76	$45,387.51	$18,438.68	$46,805.87

13.4.3 Typical Footing Cost

Location	#	Width (ft)	Area (sf)	Thickness (ft)	# bars	Bar #	Area of Steel (in^2)	Length of Bar (in)
Typical Interior	19	8.0	64.00	1.5	11	5	3.41	40.01
Typical Exterior/Corner	25	7.5	56.25	1.5	10	5	3.1	37.46
Atrium Interior	0	8.0	64.00	1.5	11	5	3.41	38.99
Atrium Exteroir	3	7.5	56.25	1.5	10	5	3.1	35.99
Stairs Interior	4	15.0	225.00	1.5	10	8	7.9	81.50
Stairs Exterior	4	8.0	64.00	1.5	11	5	3.41	40.01
Braced Frame	13	9.0	81.00	1.5	12	5	3.72	44.50
Elevator	4	9.0	81.00	2.75	9	8	7.11	37.70

Typical Interior

		Materials	Instalation	Unit Cost	Quantity	Total Cost/ footing
excavation	cy	$0.00	$11.25	$11.25	4.5	$50.63
hand trim	sf	$0.00	$0.73	$0.73	64.00	$46.72
compact backfill	cy	$0.00	$3.04	$3.04	1.75	$5.32
formwork	sf	$0.65	$4.03	$4.68	48	$224.64
reinforcing	ton	$895.00	$0.50	$895.50	0.2295174	$205.53
anchor bolts	lf	$0.92	$3.34	$4.26	6	$25.56
concrete	cy	$95.52	$0.00	$95.52	3.5555556	$339.63
place concrete	cy	$0.00	$18.18	$18.18	3.5555556	$64.64
screed finish	sf	$0.00	$0.45	$0.45	64.00	$28.80
					Total	$991.46

13.5 Structural Steel Spreadsheets Appendices

13.5.1 Sample Beam and Girder Design

Spreadsheet for Preliminary Beam and Girder Design Gravity System

Infill Floor Beam Calculations	**Conclusion**	**20 X 20 Bay 3 Infill Beams - W10X15**	**BEAM OK but need to check slender for compression with Fy=50ksi**

Data Imput Boxes are Highlighted in Blue while Data Output Boxes are Highlighted in Yellow

1.) DIMENSIONS:

		Number of Beams +1	4
Structural Bay Length (feet)	20	Infill Beam Span (feet)	20
Strucutral Bay Width (feet)	20	Infill Beam Spacing (feet)	5
		Tributary Width (feet)	5

2.) Calculate the Effective Beam Length

b_e (inches) = trib width	60	OR	b_e (inches) = Span/4	60	Lesser Value Governs	60

3.) SERVICE LOADS

DEAD LOADS		**LIVE LOADS**	
Concrete Slab (including Ponding) plf	198	Occupancy Live Load Floor plf	200
Steel Decking plf	20		
Ceiling plf	5	Roof Live Load plf	100
		Snow Live Load plf	250
Mechanical plf	25	Governing	250
Insulation plf	7.5		
Total Dead Load plf	255.5		

4.) FACTORED LOAD COMBINATIONS

a) 1.4(DL) =	357.7	c.) 1.2(DL) + 1.6(Lr or S) =	706.6	Governing Load Combination plf	706.6 w
b) 1.2(DL)+1.6(LL) =	626.6				

5.) DESIGN MOMENT Mu

Infill Beams are Simply Supported

$Mu = w(L^2)/8$

Mu (k-ft) 35.33

6.) DETERMINE A TRIAL BEAM SIZE

Assume a (in.)= 1

t_s(in.) = 4.5

Y_2 (in.)= 4

Select a beam from Steel Manual Tables 3-19 and 1-1

Steel Section	W10X15	Weight plf	15	
PNA	7			
øMn(ft-k)=	92.3	>	35.33	=Mu (ft-k)
Y_1 (in)=	2.6			
ΣQn (k)=	55.1			
Ix (in^4)=	68.9			

7.) CHECK BEAM FOR UNSHORED CONSTRUCTION DEFLECTION

Ponded Concrete(plf)	198	E(ksi)	29000
Steel (plf)	35		
Construction LL (plf)	100		
Total (plf)	333		

Δc (in.) 0.59997

					OK OR FAILS?	
Δc (in.)	0.59997	<	0.75	Δc max (in.)	OK	Go to Step 8 to check and then If OK go to Step 9

8.) CALCULATE Ix NEEDED FOR UNSHORED CONSTRUCTION

Ix (in^4) 55.11724

From Steel Manual Table1-1

Steel Section						
Ix (in^4)=		>	55.11724	Governing Ix	68.9	in^4

9.) CALCULATE THE MOMENT CAPACITY OF BEAM FOR UNSHORED CONSTRUCTION

Beam is assumed to be braced laterally all along the span by shear studs and decking

Total load (plf)	333
Lb (ft)	0
Lp (ft)	2.861083
Lr(ft)	8.6089174
Lr(ft) (Conservative)	7.611232
Mu (k-ft)	16.65

For Beam	W10X15
Cb	1
E	29000
r_{ts}	1.01
J	0.104
c	1
h_o	9.72
Sx	13.8
Iy	2.89
Fy	50
Cw	68.3
Zx	16
r_y	0.81

if Lb≤Lp

øMn	=øMp=øFy*Zx		Mp	
	60	k-ft	800	k-in

if Lp<Lb<Lr

øMn	71.83441	k-ft

if Lb=Lr

øMn	71.83441	k-ft

if Lb>Lr

Fcr	#DIV/0!	ksi
øMn	#DIV/0!	k-ft

Governing øMn	60	>	16.65

Conservative Procedure

if Lb≤Lp

øMn	=øMp=øFy*Zx		Mp	
	60	k-ft	800	k-in

if Lp<Lb≤Lr

øMn	74.320002	k-ft

if Lb>Lr

Fcr	#DIV/0!	ksi
øMn	#DIV/0!	k-ft

Governing øMn	60	>	16.65

10.) CALCULATE THE NEW a, Y_2, AND øMn

Assuming	a =	1	
	Y_1=	2.6	in
	ΣQn=	55.1	kips
	f'c=	3000	psi

a_{new} =	0.360131	in
Y_2=	4.319935	in

From Steel Manual Table 3-19

Y_2	øMn
4	92.3
4.5	94.4
Interpolate	93.64373

Section W10X15

øMn= 93.64373 ft-k

Note: May need to interpolate for this step >>>>>>>

øMn= 93.64373 > 35.33 =Mu

OK OR FAILS?

OK

11.) CHECK STRENGTH OF ONE SHEAR STUD

Diameter of studs 0.75 in Fu 65 ksi

f'c 3 ksi

Decking Yes Assume Decking Perpendicular to Beam With 1 Strong Stud per Rib

From Steel Manual Table 3-21

Qn 17.1 ksi Page 16.1-87

Qn < Rg*Rp*Asc*Fu 1 Rg OK OR FAILS?

17.1 < 17.229672 0.6 Rp OK

e mid-ht < 2

12.) CALCULATE THE NUMBER AND SPACING OF SHEAR STUDS

N= 6.444444 studs spacing=L/N 30 in

Need an even Number of Studs

Use 8 studs 30 ≥ Min = 6ds 4.5 in

30 ≤ Max= 8ts 36 in

OK

13.) CALCULATE LOWER BOUND MOMENT OF INERTIA

Interpolate from Table 3-20

I_{LB} = 145.119 in^4

Y_2	øMn
4	140
4.5	148
Interpolate	145.11895

14.) CHECK DEFLECTION DUE TO DEAD LOAD

Beam Section W10X15

Beam Weight 15 plf

Δ_D Limit L/360 or 1"max in

0.6666667 in USE: 1 in

Dead Service Load 270.5 plf

Δ_D 0.231392 in

OK OR FAILS? OK

0.231392 < 1

15.) CHECK DEFLECTION DUE TO LIVE LOAD

Δ_D Limit: L/360 or 1"max in

0.666667 in | USE: 1 in

Live Service Load: 250 plf

Δ_D 0.213855 in

OK OR FAILS? OK

0.213855 < 1

16.) CHECK DEFLECTION DUE TO UNSHORED CONSTRUCTION

w_c= (Ponded Con.) + (Steel) + (Con. LL)

w_c= 333 plf

Δc (in.) 0.59997

OK OR FAILS?

Δc (in.) 0.59997 < 0.75 Δc max (in.) OK

17.) CHECK WEB LOCAL BUCKLING

From Steel Manual Table 1-1

Fy 50 ksi

For W10X15 h/t_w 38.5 ≤ 3.76□(E/Fy)

OK OR FAILS?

38.5 ≤ 90.552791 OK

18.) CHEAR SHEAR

	h/t_w	38.5	≤	2.24□(E/Fy)			
		38.5	≤	53.946344			

From Steel Manual Table 1-1

d=	10	in		Aw=d t_w=	2.3	^2
t_w=	0.23	in		ø=	0.6	
w =	724.6	plf				
V=	7.246	kips	øVn=	øFyAw	69	kips

7.246	≤	69	OK OR FAILS?	
			OK	Checked 3/26/08

19.) COST ESTIMATE

NOTE: PRELIMINARY (REAL WILL USE RS MEANS)

Beam Weight	15	plf	Span	20	ft
Beam Spacing	5	ft	No. of Studs	8	
Price per ton	3050	$	Cost pet Stud	2.1	$/stud
Cost/SqFt	4.74	Dollars			
Structural Bay Area	400	sqft			
Cost of Bay	1897.2	Dollars			

13.5.2 Sample Column Design

Spreadsheet Calculations for Preliminary Column Design

1.) SERVICE LOADING IN PSF

Roof Loading

Roof Loading			
Dead			
	Roof Slab	41.25	psf
	Structural Steel and Deck	9.6	psf
	Ceiling	1	psf
	Mechanical	5	psf
	Insulation	1.5	psf
Environ			
	Snow	50	psf
	Rain		psf
Live			
	Live	20	psf

Floor Loading

Floor Loading			
Dead			
	Concrete Slab	41.25	psf
	Structural Steel and Deck	9.6	psf
	Ceiling	1	psf
	Mechanical	5	psf
	Insulation	1.5	psf
Live			
	Live	40	psf

Wall

Wall		
Exterior Wall		psf

2.) TYPE OF COLUMN

Type	Interior	
Tributray Area at Each Floor	400	in^2
Exterior Wall Tributary Area at Floor	0	in^2

Assume 2 Column Stacks

Note: May be different between floors

3.) TOTAL SERVICE LOADING FOR COLUMN

At Floor: Roof

Total Dead Load	23.34	k
Total Live	8	k
Total Snow	20	k
Total Rain	0	k

Load = Σ((psf)(in^2))

At Floor: 4, 3 ,2

Total Dead Load	70.02	k
Total Live	48	k
Total Snow	0	k
Total Rain	0	k

Load = Σ((psf)(in^2))

For Column: Floor

Total Dead Load	93.36	k
Total Roof Live Load	8	k
Total Floor Live Load	48	k
Total Snow Load	20	k
Total Rain	0	k

4.) LOAD COMBINATIONS

1.4D	130.704	k
1.2D + 1.6L + 0.5(Lr, S, or R)	198.832	k
1.2D + 1.6(Lr, S, or R) + 0.5L	168.032	k

Governing Value 198.832 k

5.) APPROPRIATE COLUMN SIZES

For Column on : 3 Floor

Unbraced Length L: 13 ft

From Steel Manual Table C-C2.2

K= 1

5.1 Slenderness Ratio

E 29000 ksi

Fy 50 ksi

Assume r_y 2 in

KL/r_y 78

≤	4.71√(E/Fy)	113.4318	Short to Intermediate Column	Go to A
≥	4.71√(E/Fy)	113.4318	Long Column	Go to B

5.2 Critical Stress

A: Short to Intermediate Column

KL/r_y 78

Fe	47.04447	ksi
Fy/Fe	1.062824	
Fcr	32.04617	ksi

B Long Column

KL/r_y

Fe	#DIV/0!	ksi
Fcr	#DIV/0!	ksi

Fcr 32.04617 ksi

5.3 Calculate Trial Area

Pu 198.832 k

Ay ≥ Pu/0.9Fcr

Ay ≥ 6.893943 in^2

5.4 Select a Trial Column Size

Section	W10X33	
Ay	9.71	in^2
r_y	1.94	

KL/R	80.41237	≤	4.71√(E/Fy)	113.4318			

5.5 Calculate Critical Stress

A: Short to Intermediate Column			**B Long Column**		
KL/r_y	80.41237		KL/r_y		
Fe	44.26414	ksi	Fe	#DIV/0!	
Fy/Fe	1.129583		Fcr	#DIV/0!	
Fcr	31.16313	ksi			

Fcr	31.16313	ksi

5.6 Calculate øPn

øPn=	øFcr*Ay	272.3346	k	≥	Pu=	198.832	k

6.) Prelim Cost Estimate

Cost per Ton	3050	$	Unit Wht	26	plf
$	515.45	Cost per Column			

13.5.3 Sample Un-braced Frame Design

Unbraced Frame, Member Design

Frame Girder

Beam Dimensions

Size	W10X15				
Area	4.41	in^2	E	29000	ksi
Ix	68.9	in^4	Fy	50	ksi
Iy	2.89	in^4	Cb	1	
Sx	13.8	in^3	J	0.104	
Zx	16	in^3	c	1	
r_x	3.95	in	h_o	9.72	
r_y	0.81	in	Cw	68.3	
r_{ts}	1.01	in			

Service Loads

	Pu			Mnt			Mlt	
Dead	0.045	k	Dead	9.924	k-ft	Dead	0	k-ft
Live	0.024	k	Live	1.254	k-ft	Live	0	k-ft
Snow	0.043	k	Snow	1.328	k-ft	Snow	0	k-ft
Wind	0.77	k	Wind	0	k-ft	Wind	51.534	k-ft
EQ	1.06	k	EQ	0	k-ft	EQ	70.704	k-ft

Factored Loads

	Pu		Mnt		Mlt	
Case 1 1.4(D)	0.063	k	13.8936	k-ft	0	k-ft
Case 2 1.2(D)+1.6(L)+0.5(Lr or S)	0.1139	k	14.5792	k-ft	0	k-ft
Case 3 1.2(D) +1.6(Lr or S) + (0.5L or 0.8W)	0.1348	k	14.6606	k-ft	0	k-ft
	0.7388	k	14.0336	k-ft	41.2272	k-ft
Governing	0.7388	k	14.6606	k-ft	41.2272	k-ft
Case 4 1.2(D)+1.6W+0.5L+0.5(Lr or S)	1.3195	k	13.1998	k-ft	82.4544	k-ft
Case 5						

1.2(D) + 1.0(E) + 0.5(L) + 0.2(S)

	1.1346	k	12.8014	k-ft	70.704	k-ft
Governing	1.3195	k	14.6606	k-ft	82.4544	k-ft
	Pu		Mnt		Mlt	

Column Action

Kx	1.3	Lx	8	ft
Ky	1	Ly	0	ft

Ky(Ly)/ry	0	Larger Governs		
Kx(Lx)/rx	31.59494	31.59494	8	Lx or Ly

Determine Fcr

E	29000	ksi	Fy	50	ksi

Slenderness Ratio 31.59494	≤	4.71Ö(E/Fy)	113.4318	Short to Intermediate Column	Go to A
	≥	4.71Ö(E/Fy)	113.4318	Long Column	Go to B

A: Short to Intermediate Column

KL/r	31.59494	
Fe	286.7232	ksi
Fy/Fe	0.174384	
Fcr	46.48057	ksi

B Long Column

KL/r	0	
Fe	#DIV/0!	ksi
Fcr	#DIV/0!	ksi

Fcr 46.48057 ksi

Determine φPn

φ	0.9		Ay	≥	Pu/0.9Fcr	
φPn	=	φFcr(Ay)	Ay	≥	0.031542	in^2
	=	184.4814 k				

Check Pu/φPn Ratio

Pu/φPn	0.007152	≤	1	OK? Y

Find Mn

		Lb (ft)	8	Lp (ft)	2.861083	Lr(ft)	8.608917		Lr(ft)	7.611232		
								Conservative Procedure				
Cb	1	if Lb≤Lp						if Lb≤Lp				
E	29000			øMn	=øMp=øFy*Zx	Mp			øMn	=øMp=øFy*Zx	Mp	
r_{ts}	1.01				60	k-ft	800	k-in		60	k-ft	800 k-in
J	0.104	if Lp<Lb<Lr						if Lp<Lb≤Lr				
c	1			øMn	38.74369	k-ft			øMn	34.27918	k-ft	
h_o	9.72	if Lb=Lr										
Sx	13.8			øMn	38.74369	k-ft						
Iy	2.89											
Fy	50	if Lb>Lr						if Lb>Lr				
Cw	68.3			Fcr	39.39616	ksi			Fcr	31.68094	ksi	
Zx	16			øMn	40.77503	k-ft			øMn	32.78977	k-ft	
r_y	0.81											
				Governing øMn	38.74369				Governing øMn	34.27918		

Calculate Mu*

1) Calculate B1

Cm	0.6					OK?
Pu	1.3195	B1	0.600626	≤	1	Y
Pe	1266.158					

2) Calculate B2

	1	Number of Columns on Floor in the Frame
ΣPu	1.3195	Sum of Factored Axial Loads for All Columns on Floor for the Frame
ΣPe	1266.158	

B2 1.001043

3) Mu* =(B1*Mnt)+(B2*Mlt)

91.34595

Interaction Equation

(Pu/2φPn) + (Mu*/φMn)≤1.0

			OK?
2.668341	≤	1	N

13.5.4 Sample Base Plate Design

Column Bearing Plate Design

Given Information

Column Location: Interior

Column Section: W10X33

b_f	7.96	in	f'c	3	ksi
d	9.71	in			
			F_y	36	ksi

Loading

P_u 198.832 k

Method One: Plate is Same Dimension as Footing	Method Two: SQRT(A2/A1)≥2	Method Three: Concrete Pedestal Wider on each side than base plate
A) Determine Plate Area	A) Determine Plate Area	A) Determine Plate Area
A_1 ≥ 129.9556 sq in	A_1 ≥ 64.97778 sq in	A_1 ≥ 129.9556 sq in
A_1 ≥ 77.2916 sq in	A_1 ≥ 77.2916 sq in	A_1 ≥ 77.2916 sq in
Use Larger 129.9556	Use Larger 77.2916	Use Larger 129.9556
B.) Optimize Plate Dimensions	B.) Optimize Plate Dimensions	Plate Assumed as 12 X 12 in; A_1 ≥ 97.46667
Δ 1.42825	Δ 1.42825	Pedestal 4 in wider
N 12.82806 Use 14 in	N 10.21981 Use 10 in	Use 10 X 10 Plate
		A_2 256
		sqrt(A_2/A_1) 1.333333; sqrt(A_2/A_1) 1.4
B 9.28254 Use 12 in	B 7.72916 Use 8 in	
C.) Compute Required Thickness	C.) Compute Required Thickness	B.) Optimize Plate Dimensions
		Δ 1.42825
m 2.3877 in	m 0.3877 in	

5

n 2.8
16 in

OK
?

1
9
ΦC*Pp 257
.04 ≥ 8.
8 Y

x 0.7
659
58

U
S
E

λ 1.1
796
77 ≤ 1 1

Y: use
#

λn' 2.1
978
91

N: use
1

l=max(
m, n,
λn') 2.8
16

t 0.7
611
38 U
s
e 0.
8
7
5 in

SOLUTION:

A 12 X 1ft 2" X 7/8"
Plate

5

n 0.8
16 in

OK
?

19
ΦC*Pp 244
.8 ≥ 8.8
32 Y

x 0.8
042
56

U
S
E

λ 1.2
434
61 ≤ 1 1

Y:
us
e #
N:
us
e 1

λn' 2.1
978
91

l=max(
m, n,
λn') 2.1
978
91

t 0.8
608
88 U
s
e 0.8
75 in

SOLUTIO
N:

A 10 X 8"" X 7/8"
Plate

N 11.
300
77 Use 12 in

B 8.1
222
22 Use 10 in

sqrt(
A_2/A_1) 1.36
626 o
k
? Y

C.) Compute Required
Thickness

m 1.3
877
5 in

n 1.8
16 in

OK
?

ΦC*Pp 250
.84
54 ≥ 198.
832 Y

x 0.7
848
73

US
E

λ 1.2
104
38 ≤ 1 1

Y:
use
#
N:
use
1

λn' 2.1
978
91

l=max(
m, n,
λn') 2.1
978
91

t 0.7
029
12 Use 0.75 in

SOLUTION:
A .75 X 10" X
1' Plate

13.5.5 Typical Connection Design

Design of Bolted Connections

Connection Location/Description:

Bolt Selection and Dimension:

Bolt:	A325	
Diameter:	0.75	
Threaded:	N	
Nominal Shear Stress Fv	48	KSI (Table J3.2) in AISC Manual p16.1-104
ø	0.75	for shear

Bolt Capacity:

øRn	= ø(Fv)(Ab)	
Ab	0.441786	sq in
øRn	15.90431	k

Number of Bolts Required:

No. Bolts	= Vu/øRn	
Vu	19.188	K
	=w(L^2)/2 or other value	
No. Bolts	1.206465	
USE	2	Bolts

Determine the Geometry of the Angle:

	1.25	in
		Minimum Edge Distance from Hole Center to Edge of Angle (Table J3.4 in AISC Manual p16.107)

3 in

Standard Gauge for Hole Center to Center Spacing

2 in

Standard Guage for Hole Center to Interior Edge of Angle

<u>Determine the Thickness of the Angle:</u>

Lc1	0.8125	in
Lc2	2.125	in
Fu	58	ksi
Fy	36	ksi
ø	0.75	for shear

øRn $\leq ø(1.2*(L_c)*t*(Fu) \leq ø(2.4*d_{bt}(Fu))$

Upperbound

øRn 78.3

Lowerbound

øRn 42.4125 ≤ 78.3

or

øRn 110.925 ≤ 78.3

Governing 42.4125

Thickness of Bolt 0.158956 in

<u>Angle Shear Rupture</u>

Anv =[(height of angle)-((# of Bolts)((9diameter of bolt)+1/8"))]t

3.75 t

ø(0.6Fu)*(Anv) 97.875

t 0.196046 in

Angle Shear Yield

Agv	=(height of angle)t							
	5.5							
ø(0.6Fy)*(Agv)	89.1							
t	0.215354	in						

Block Shear

Mechanisim 1				Mechanisim 1				
A_{nt}	1.0625	t		A_{nt}	1.0625	t		
A_{nv}	1.9375	t		A_{nv}	4.25	t		
øRn	>	19.188	k	øRn	>	19.188	k	
t	0.247248	in		t	0.122105	in		

Governing Thickness

t	0.247248	in	
Use	0.25	in	Angle

Check Bolt Bearing on Beam Web

				Beam		
				Section	W16X26	
Lc	2.125	in		tw	0.25	in
				Fu	65	ksi
LHS	0.6375		Smaller Govern			
RHS	0.45		0.45			
	21.9375	>	19.188	k	OK?	

Check Bolt Bearing on Beam Web

				Beam		
				Section	W24X55	
Lc	2.125	in		tw	0.395	in
				Fu	65	ksi
LHS	1.00725		Smaller Govern			
RHS	0.711		0.711			
	34.66125	>	19.188	k	OK?	

Final Angle Design

3.5" X 3.5" X 0.25" with a 5.5" depth

13.5.6 Sample Parking Garage Cost Estimate

Preliminary Cost Estimate for an Sub grade Parking Level										
		Square Footage		Perimeter		Floor to Floor Height				
	Ramp		sqft			12	ft			
	Ramp Enclosure		sqft			13.5				
	Parking Level	17437	sqft	558						
Square Foot Costs Based on a 100,000 sqft building with 10' height. Adjusted for a 20,000 sqft building which is close to our design										
Category		Item	Cost per S.F.	Ratio for sqft Reduction	New Cost per S.F.	Cost				
A.) SUBSTRUCTURE										
		Standard Foundation	$ 1.28	1.057554	$ 1.35	$ 23,603.93				
		5" Slab on Grade	$ 1.22	1.057554	$ 1.29	$ 22,497.49				
		24' Excavation	$ 4.15	1.057554	$ 4.39	$ 76,528.36				
				1.057554						
				1.057554		**$ 122,629.78**	**Total**			
				1.057554						
B.) SHELL				1.057554						
	Superstructure			1.057554						
		Dble Tee Beam and Col	15.69	1.057554	$ 16.59	$ 289,332.52				
				1.057554						
	Exterior Enclosure			1.057554						
		Extior Walls (Cost per S.F. Wall)	$ 2.94	1.057554	$ 3.11	$ 54,215.27				
		Exterior Doors	$ -	1.057554	$ -	$ -		2 Exterior Doors		
		Neoprene Membrane	$ 1.99	1.057554	$ 2.10	$ 36,696.73				
				1.057554		**$ 380,244.52**	**Total**			
C.) INTERIORS				1.057554						

		Partitions (Con Blk)		1.057554	$ -	$ -		Partition around elevator =71.67 feet			
		Interior Doors		1.057554	$ -	$ -		3 Doors			
		Concrete stairs	$ 0.25	1.057554	$ 0.26	$ 4,610.14		2 Flights			
		Paint	$ 0.11	1.057554	$ 0.12	$ 2,028.46					
				1.057554			**Total**				
				1.057554		**$ 6,638.60**					
				1.057554							
D.) SERVICES				1.057554							
	Conveying			1.057554							
				1.057554	$ -	$ -					
				1.057554							
	Plumbing			1.057554							
		Drainage	$ 0.15	1.057554	$ 0.16	$ 2,766.09					
		Electric Water Heater	$ 0.07	1.057554	$ 0.07	$ 1,290.84					
		Roof Drains	$ 1.27	1.057554	$ 1.34	$ 23,419.52					
				1.057554							
	HVAC			1.057554							
				1.057554	$ -	$ -					
				1.057554							
	Fire Protection			1.057554							
		Standpipe	$ 0.07	1.057554	$ 0.07	$ 1,290.84					
				1.057554							
	Electrical			1.057554							
		Electrical Service	$ 0.23	1.057554	$ 0.24	$ 4,241.33					
		Lighting	$ 2.65	1.057554	$ 2.80	$ 48,867.51					
		Communication/Security	$ 0.11	1.057554	$ 0.12	$ 2,028.46					
		Emergency generator	$ 0.05	1.057554	$ 0.05	$ 17,437.05					
				1.057554							
				1.057554		**$ 101,341.64**	**Total**				
				1.057554							
E.) EQUIPMENT & FURNISHINGS				1.057554							
		tickets/automatic gates	$ -	1.057554	$ -	$ -					
						$ -	**Total**				
F.) SPECIAL CONSTRUCTION											
		N/A									
						$ -	**Total**				

G.)BUILDING SITEWORK										
		N/A								
						$ -	**Total**			
H.) STORY ADJUSTMENT										
			0.45	2	0.9	**31386.6**	2	ft additional height		
					$ 34.98					
				Subtotal		$ 642,241.14	**Total**			
				Contractor's Fees	25%	$ 160,560.29				
				Architect's Fees	8%	$ 51,379.29				
				Total		**$ 854,180.72**				
		Preliminary Cost of Underground Parking Garage								
		Category	Cost							
		Substructure	$122,629.78							
		Shell	$411,631.12							
		Interiors	$ 6,638.60							
		Services	$101,341.64							
		Equipment	$ -							
		Subtotal	**$642,241.14**							
		Contractor's Fees	$160,560.29							
		Architect's Fees	$ 51,379.29							
		TOTAL	**$854,180.72**							

13.6 Project Proposal

Project Number: LDA 0803

DESIGN OF WPI GRADUATE STUDENT HOUSING 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

Joseph Frascotti

Michael J. Richard

Mary Kate Toomey

Date: October 26, 2007

Approved:

Prof. L. D. Albano, Major Advisor

Introduction

On September 17, 2007, Worcester Polytechnic Institute (WPI) and the Worcester Business Development Corporation (WBDC) officially opened the new WPI Life Sciences and Bioengineering Center at Gateway Park. WPI President Dennis D. Berkey spoke of the new facility as playing “a vital role in Worcester’s economic development and in WPI’s ability to make a difference in the world” (“WPI Opens Gateway Park”, Press Release, September 17, 2007). However, this new research facility is only the first step in the larger redevelopment of the Gateway Park District. The Gateway Park Development Plan incorporates space for cutting edge research, commercial facilities for life science companies, and residential units for the employees and scientists who will work at Gateway. A portion of these scientists will include graduate students from WPI. As part of the Gateway Park Development Plan, housing is intended to meet the living requirements of these anticipated graduate student researchers and the other Gateway Park employees. The task of the project team will be to explore developing one of the parcels into a mixed use facility that will house both residential and retail space in order to support the new Gateway Park community.

The scope of work for the graduate housing project will include tasks that encompass the development process from conceptual design to construction planning. First, a design layout and concept for the building and site will be developed based on criteria such as zoning laws, building codes, and client needs. This will be followed by an engineering section that will consider structural systems, their members, and structural foundations. Next, implications of a construction plan and schedule will be furnished to understand what results might be if there is deviation from a schedule. A cost estimate will be developed based on the conceptual design and construction process. Additional areas and alternative options for the facility will be investigated individually by each member of the group. Site and utility design will be studied for the project, while a basement parking garage design will be researched as a possible alternative. Finally, LEED certification criteria will be investigated to determine design alternatives for reduced life-cycle costs and energy consumption.

Background

Gateway Park

Gateway Park is a developing twelve acre mixed-use destination for life sciences and biotech companies as a partnership between Worcester Polytechnic Institute and the Worcester Business Development Corporation. The WBDC is a non-profit business organization who serves as a leading innovator in economic development throughout Worcester resulting in job creation and tax based expansion (About WBDC, 2005). The current plan includes eight buildings including 500,000 square feet (sf) of lab space, 241,000 sf of condominiums, several retail establishments, parking garage, and possibly graduate housing. These buildings are expected to have an affordable rent of $20-30 per square foot (Gateway Park Facts and Figures, 2007).

The first building constructed was the life sciences and bioengineering center. This was a forty million dollar project that WPI will use for graduate education and research in the life sciences. The structure is a combination of a renovated industrial building that is connected to a new state–of-the-art-lab facility with a green courtyard in the middle. The new building is a four-story lab facility that will be used for research in wet life sciences, regenerative medicine, molecular nanotechnology, biosensors, plant systems, tissue engineering, and un-tethered healthcare (WPI Life Sciences and Bioengineering Center, 2007). The lab rooms are flexible as they can be adapted to fit the biotech industry's changing research needs. The renovated industrial building will house faculty offices, meeting rooms, and other amenities. Offices will include the WPI Corporate and Professional Education Department and the WPI Bioengineering Institute. The WPI Bioengineering Institute is a research center for biology, biotechnology, biomedical engineering, chemistry, biochemistry, and chemical engineering. This building will also house some businesses and commercial tenants along with Massachusetts Biomedical Initiatives, an organization that promotes the startup of biomedical companies.

The main goal of Gateway Park is to develop leading–edge research programs and foster the growth of life science, biotechnology, and bio/chemical engineering. It will serve as a destination for many large and small companies and establish a site for transfer of technology and knowledge between the commercial sector and WPI.

Finally, Gateway Park will provide immediate job creation and help to develop the city of Worcester. The graduate housing complex will specifically help this goal with jobs during construction, permanent hourly and managerial positions in retail, and maintenance and operations staff. The City of Worcester will benefit by the creation of more downtown housing and activity, as residents will be able to frequent businesses in the area.

75 Grove Street

The Gateway Park District is located off of Exit 18 from Interstate 290 West in Worcester, Massachusetts. The site of the proposed graduate housing is found at 75 Grove Street, abutting both Faraday and Lancaster Streets, as seen in Figure 1. Currently, the 72,488 square foot lot is being used minimally for excess parking by nearby establishments. To the north of the site and across Faraday Street there is a large parking lot used for nearby businesses along with an electric substation operated by National Grid. The substation includes electrical transformers and a brick building. A pre-existing Marriott Courtyard Hotel is located to the east of the site and across Grove Street. To the south, the lot is bordered by The Worcester Armory and the Massachusetts Veterans Shelter, alongside the North High Garden Condominiums. Finally, the west side of the lot is bordered by Lancaster Street with residential houses across the street.

Figure 72: Site Aerial Photo as pictured in Google Maps on October 8, 2007.

75 Grove Street was selected as the location for this Major Qualifying Project over any of the other planned Gateway Park development sites because its design and development could be of direct use to WPI. During a September 12, 2007 interview, the University's Vice President of Business Development and General Counsel D'anne Hurd made note that the development schedule of Gateway Park calls for a more immediate focus on commercial and laboratory space. However, university-owned housing is still a major component that will be addressed. As the housing development plans are secondary to research facilities that are still in line to be built, the group will be able to design creatively and with minimal restrictions. Also, the timeline of WPI's development plans at Gateway may offer the opportunity for the concept produced by the team to have a greater influence on the actual design process initiated by the University. Finally, the conceptual design of this site will give the University a preliminary concept for the lot to showcase to the City and the Worcester Business Development Corporation.

There are many factors that will go into site development considerations. These areas include parking, use of open space, drainage and utilities. There is a challenge in meeting the first two objectives combined on one lot. Alternative parking methods and locations will need to be sought to meet the needs of the building. Vice President Hurd and other members of the WPI administration intend that open space will be integrated into the design in order to create a welcoming and inviting living environment within the Gateway Park District. Utilities and drainage will need to be coordinated with what exists in areas both within and around the lot. While this project will not involve contacting the providers of gas, electric, water, and sewer along with other City departments, it will ensure that the proper considerations are taken into account in the design.

The site at 75 Grove Street was previously owned by the Logan, Swift, and Brigham Envelope Company. A first building was constructed in 1889 extending from Grove Street along Faraday Street. In 1897 the company built an additional building on the Lancaster Street side. Ten years later, the company merged with nine other envelope companies and an addition was added to the building on the south side of the existing structure. In the 1970's the company was sold to Parker Affiliates and was renovated into office space. The building was ultimately torn down in 1999 (Szela, et al, 2000).

The abandoned lot at 75 Grove Street was designated as a brownfield because it was used by a previous owner as part of the manufacturing industry. A brownfield is a property that may be contaminated by a potential presence of pollutants, chemicals or hazardous substances (US Environmental Protection Agency, 2007). Many of the chemicals found on the 75 Grove Street site were typical in the metal industry. The envelope industry located on this site was not in the category that typically released these chemicals. Some chemicals found were polycyclic aromatic hydrocarbons that are present in coal and tar, arsenic, which is a chemical used in metal working, and thallium, which is a pollutant metal delivered from lead and zinc (Szela, et al, 2000). These chemicals would prove hazardous to tenants in any future structure, and therefore a cleanup process was necessary before any new construction could begin on the site.

The cleanup effort was funded by a $200,000 sub-grant from the city of Worcester. Cleanup of the site was completed in March 2006 and included the removal of contaminated soil as well as groundwater monitoring. (City of Worcester Provides $200,000 Sub grant to Clean Up 31 Gateway Park Property, 2007)

2.3 Zoning and Implications

Six points highlight the purpose of the Zoning Ordinance of the City of Worcester (ZOCW). Among the main purposes served by the ZOCW are preserving the health, safety, and general welfare of the public as well as to comply with the City's plans for progress and growth. Prevention of over concentration of population and land use, promotion of natural environmental development and historical preservation, and encouragement of economic development and housing for persons of all income level are also cited as goals of the ZOCW (Zoning Ordinance of the City of Worcester, 2007).

It is important that a structure complies with all Zoning Ordinance requirements for a variety of reasons. First, if there are problems with the application process, then the possibility exists that the development cost, project cost, and project schedule could be negatively affected. The owner benefits from compliance with the ZOCW because a project can be completed within budget and time frame constraints. Additionally, any violation of ordinance regulations is subject to a fine of $300 (ZOCW, 2007).

Implications of the ZOCW will be explored. Different building options could possibly necessitate changes to be in accordance with the ordinances as the ZOCW has the ability to limit design options. Topics that may require extensive research into zoning requirements include height restrictions, business and residential district guidelines, parking space minimums, and building setbacks, among others. In instances where the project design is well within zoning requirements, it will be important to take aspects of the local neighborhood into account. An example of this type of consideration is building height; if most buildings are no more than five stories, then a ten floor building would not be considered. Because zoning regulations are so strict, it is sometimes necessary to fill out extensive paperwork, especially if a variance or special permission is needed. The ZOCW does not allow for any alteration or erection without proper permits. However, this project will explore only options that are in accordance to the ZOCW that will not needing special permit processes.

Services

Services that will be offered within the new structure extend beyond the basic residential setup. Considering that the housing is in close proximity to a business district, the proposed building will cater to both commercial and residential needs. Small retail will be housed on the ground floor while upper levels are reserved solely for housing purposes.

Retail will include several types of business for graduate student residents, employees of Gateway Park, and others in the area. One store will be a coffee shop, likely a well known national brand like Dunkin Donuts or Starbucks. A casual dining restaurant, similar to a Panera, is also projected. Since this building is a distance of nearly three quarters of a mile from the main WPI campus, facilities there may not be convenient for use of students in the new building. Because of this consideration, a workout facility and an ATM for a national bank will also be included on the lower level.

The residential set up, referring to singles, doubles, suites, or family style residences, will be determined based upon comparisons with other graduate housing set ups on campuses around the country. Specific number of residents will be in relation to the allowable square footage designated for living space in the facility. Currently, WPI's vision of the facility calls for roughly 70,000 sf of living space and 20,000 sf of retail space; this criteria will serve as a starting baseline for the group to develop the design (Hurd, September 12, 2007).

Scope of Work

Overview

The scope of the project involves the development of a conceptual design for a graduate housing facility through layout, engineering, and construction planning. Table 1 gives a basic overview of the various tasks and services that the design team will provide. Descriptions for each task are then described in the following sections.

Building Layout

Since the facility and lot have only been the subject of preliminary discussion for the Gateway District, a building footprint and floor layout has not be decided upon by WPI. The only set criterion for the future facility is an estimated 70,000 sf for residential space and 20,000 sf for retail space. Therefore, the first task of the group in the project scope is to develop a general layout of the site and building plan. Layout design will involve general criteria such as aesthetics, accessibility, functionality, building code requirements, zoning, and architectural standards.

The general footprint of the building will lie on the Northeast corner of the lot at the intersection of Grove Street and Faraday Street. The building will form the general shape of a backwards “L”, or the Greek letter “Gamma”, when looking at the structure from above. This orientation and footprint has been selected for three reasons. First, the building location on the site allows for businesses on the ground floor to have street side windows for advertising and visibility. Second, by placing the building in the Northeast corner of the lot, a common semi-public green space can be created for the businesses and residents along the West and South sides of the site. The third reason is to allow a maximum amount of natural lighting throughout the day to penetrate the greatest amount of units possible.

Table 41: Project Scope Overview

1. Layout Design	The group will develop a footprint of the building along with a preliminary layout of residential, business, public spaces, and access ways in the buildings. The layout will also consider the location of the structural bays.

2. Engineering Design	
2.1 Exteriors	Exterior curtain walls will be designed based off the building layout in order to establish the distribution and magnitude of gravity loads for the structural system.
2.2 Structural System	The group will design the structural building frame of the facility in order to sustain gravity loading. One structural steel system and one reinforced concrete system will be studied and an assessment made on which is a more beneficial design. Variables such as structural bay size, the size and shape of members and columns, connections, and floor compositions will be looked at and implications assessed. Once a final frame is decided upon based on the critical gravity loads, lateral loading of the finished frame will be investigated to make necessary adjustments to the frame. The repetition of standards bay and member sizes will be utilized except in special case areas of the frame. Calculations and drawings will be furnished for the completed structure.
2.3 Foundation System	A foundation system will be designed in order to support and carry loads from the structural frame in the form of a footing and slab-on-grade foundation. Components of the foundation will include column footings, wall footings, and the slab on grade. Requirements for an elevator will also be considered in the design. Structural calculations and drawings will be produced for the foundation system.
3 Construction Plan and Schedule	The group will develop a construct plan and schedule based on major project milestones in order to obtain an initial estimate of the duration for the construction process. Labor hours, material purchasing and delivery, and installation time will all be considered as variables for the schedule.
4 Cost Estimate	Based on the conceptual design and construction schedule, a preliminary cost estimate for the building will be completed. Implications of cost and options for lowering cost will be then studied.
5. Site and Utility Planning	A building cannot function without being connected to necessary utilities and drainage. Therefore, utility connections for the site and building will be designed and integrated with the building plan by one team member.
6. Basement Level Parking	Due to the need for additional, secure, overnight parking for graduate residents, a basement level parking garage will be designed as an option for the facility. Implications for the structural and foundation systems along with cost will be investigated by one team member.
7. LEED Certification	To reduce cost and improve energy efficiency, the LEED program will be researched. LEED alternatives for the design and construction of the facility will then be proposed by one team member.

General building codes, standards, and current site plans must also be addressed to develop the building footprint and layout. Zoning laws will be investigated to determine such factors as maximum allowable square footage for the building and maximum height requirements, among others. Current site plans will be studied to find such entities as rights of way on the property and underground utilities. City and other applicable specifications like the Americans with Disabilities Act (ADA) will be used to meet standards for such concerns as sidewalks and accessibility. Architectural standards and building codes will be used in the design of floor layouts and elevations so that areas such as hallways, rooms, and stairwells are designed properly.

Aesthetics, accessibility, and functionality will all be considered from the point of view of the resident, business owner, and consumer who will be using the facility when completed. The building and grounds must be aesthetically appealing in order to entice people to live and work there. Therefore, the layout must connect the various sectors and uses of the building into a whole unit. Additionally, the building must be functionally designed so that it can meet the daily and emergency needs of its inhabitants and first responders. Functionality includes designing appropriate spaces for future users; in this case business owners, single graduate students, and graduate students with families. Accessibility is closely linked to functionality in the sense that the facility cannot function without proper access to spaces such as parking, loading space, utility space, and emergency exits.

Finally, the layout of the building and site must consider constructability and cost feasibility. Even though a budget has not been furnished to the project team, consideration will be made during design to work toward a realistic budget that is comparable to similar facilities. Such considerations include the use of repeating residential units and structural bays and standard structural building sections. The building layout must also be designed at the conceptual level with consideration to constructability. For example, having ample room on the site to place framing elements and exterior walls would be a factor in constructability. Another factor would be the ability of contractors to move and place equipment efficiently on the site to construct the facility. Additionally, the four story design of the building does not present an issue in altering construction techniques to build at unusual heights.

Engineering Design

Exteriors

Extending from the design of the building layout, the exterior surfaces such as the curtain walls and roofing will be designed. This, in addition to the interior floor layouts, will allow for the magnitude and distribution of gravity loads to be developed, which will be necessary for the design of the structural system. The team will develop a technique to design a brick-faced building to match other historic buildings in the area. The use of glass will be emphasized to allow for the use of natural light in interior spaces. Interfaces between exterior walls and the structural system will be designed after the building frame has been analyzed.

Structural System

Another design element of this project based upon layout is the structural system. The use of structural bays will dictate the layout of residential units and business spaces. After a comparison of the frame and layout, adjustments will made to better integrate the two and fit the structural frame to the layout. The frame will mainly be composed of a grid with repeating standard structural bays. However, atypical areas, such as the restaurant and elevator spaces, will be looked at as special cases. Variables for the system include structural bay size, shape and size of structural members, loads, and floor composition. For gravity loading, the group will complete the design of one structural steel frame and one reinforced concrete frame. A decision will then be made as to which is the best structural frame for use in the structure. This decision will be made concurrently with the cost estimate (see Section 3.4). The chosen system will then be designed for lateral loading with necessary adjustments being made to framing members. Finally, the group will design standard connections for the structural frame. Engineering calculations along with structural drawings for the final frame will be produced by the group.

Foundation System

Once the structural frame is designed for the building, a foundation can be developed to transfer loads from the frame to the ground. The project team will design a footing foundation for the graduate housing facility. The design of the footings and foundation will be based on soil data from the Gateway Park Geotechnical Report done by the Maguire Group in 2005. Components of the structure will include column footings, wall footings, foundation walls, and the concrete slab on grade. Attention will also be given to foundation requirements for the facility's elevators. Calculations and foundation drawings will be produced as a deliverable.

Miscellaneous Items

Once the structural and foundation systems have been designed, miscellaneous items such as stairwells, elevator shafts, and catwalks will need to be designed and integrated into the structural system.

Cost Estimate

The team will be developing a cost estimate to include the total price of the building project. The goal of the group is to come up with a design that will meet the needs of WPI while keeping the cost as low as possible. Some of the factors that will influence the price will be the cost of furnishings, materials, and construction.

At each step of the design process, the materials and services required will be evaluated 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 divisions list. All of the cost estimate will be based on current market prices. The group will develop a hard cost for the project including the construction of the building, the furnishings and equipment, and the site work. The base construction and special equipment costs, including heating, ventilating, and air conditioning (HVAC), electrical, fire protection, and plumbing systems, will be based on the typical square footage cost of similar buildings. Additionally, costs of other aspects of the project that are not within the design scope will be obtained from a cost estimating book. The group will be using the *2007 RS Means Square Foot Cost* book for a building that is similar to the one that is this project's focus.

When estimating cost for the retail space it will be assumed that these areas of the building will be outfitted by the tenants. They will be provided with an unfurnished area that includes the basic utilities and building systems that are required for the type of use. This will depend on the tenant needs and could include things like access to bathrooms, plumbing lines, and a grease trap for the kitchen.

Construction Plan and Schedule

Construction schedule is an important aspect of a project and of particular interest to a University for a residence hall. It needs to be completed on time so students may be able to move in. In order to obtain an estimate on the duration of the construction process for the facility, a preliminary construction plan and schedule will be developed by the project team. Criteria used in the formation of the schedule will include such items as required labor hours, production and delivery of construction materials, and the installation time. Implications to cost will be assessed and used in the preliminary cost estimate. The schedule will only involve the major milestones and those points that are expected to impact the critical path.

Site and Utility Planning

In one industry, it is believed that “site design is a major opportunity to influence the outcome of a project” because there are many variables that can play into the process (Flannery, 2000). Flannery (2000) notes that having a proper site design can impact the schedule and cost of a project. Ultimately, the site design is important in determining the positive state of traffic and parking conditions, utilities layout, and drainage systems.

The design will meet all zoning ordinances, including parking. Being in a downtown area, parking is challenging and will be provided on-site as well as on the National Grid transformer site just to the north. Setbacks will also be considered. An easement and right of way exist on the property and must be creatively incorporated into the site design.

Utility design will consider existing utilities on and surrounding the lot. Coordination of water, gas, electrical, sewer, and telecommunication locations will be performed.

Lastly, drainage needs for the site will be investigated and designed for if the current grading and infrastructure are insufficient. A storm water protection plan will also be considered for environmental impact.

Basement Level Parking Alternative

Since parking availability is usually a major concern in urban areas along with security needs for personal and family vehicles, a basement parking garage will be designed as a potential alternative for the facility. This garage will be a supplement to the surface parking for permanent residence living in the building and allow residents reserved and secure spaces for overnight and long term parking. The number of spaces will be based on research of zoning regulations. Implications to the structural and foundation design will be assessed along with the alternative's implications to building cost. Deliverables will include research on underground parking and soil on the site; layout drawing; structural calculations and plans; and implications to cost and total building design.

LEED Certification

One of the group members will investigate the alternatives of green building construction. Green buildings are sustainable structures that use land more efficiently and consume fewer resources than normal buildings. The goal is to produce less waste while using a smaller amount of water and energy. Green building construction is gaining popularity as the cost of energy rises and environmental regulations become more stringent.

The system that was developed to determine what is considered a green building is called The Leadership in Energy and Environmental Design (LEED) Green Building Rating System. This is a rating system based on accepted environmental and energy principals that quantifies a building's "green" status.

Requirements to become LEED certified will be investigated; in particular, the focus will be different construction options and design changes could be to meet the LEED certification requirements. A group member will also be exploring the effects that green construction will have on the cost of construction and operation of the building. The life cycle costs will be compared to determine if LEED certification will save money for the owners over a longer period of time. The main areas of environmental focus will be a sustainable site, water efficiency, energy and atmosphere, materials and resources, and indoor environmental quality.

Project Schedule

The research and conceptual design process for the graduate housing facility will extend from the last week in August of 2007 to the first week of March in 2008. The following schedule breaks down this design period by academic week and identifies the tasks and deliverables that will be looked for each week.

Week 1 (9/3): Research and select project ideas for MQP.

Week 2 (9/10): Collect information on Gateway Park Development District. Evaluate prospective sites to determine what obstacles may impede project development.

Week 3 (9/17): Meet with Vice President D'Anne Hurd on WPI's ideas and visions for Gateway Park. Select a site to develop in Gateway Park and begin to formulate scope.

Week 4 (9/24): Begin formatting project scope and conceptual layout. Begin research on areas that will impact the ultimate design process. Research the history of the chosen site at Gateway Park.

Week 5 (10/1): Develop individual scope areas.

Week 6 (10/8): Continue project proposal and design of building and site layouts. Research the architectural standards for the design of the facility. Submit final project proposal. Create a draft format, introduction, and background for MQP.

Week 7 (10/22): Finalize and freeze conceptual building layout. Begin work on the structural building frame with the design of the exterior curtain walls. Determine gravity loads for floors and wall systems. Begin to evaluate costs for materials. Continue writing MQP with section on the building layout.

Week 8 (10/29): Begin the design of the structural frame both in structural steel and reinforced concrete based on gravity loads. Start with floor systems, beams, girders, and columns for gravity loads. Compile research on building code and specification requirements for the structural frame. Complete calculations for both frames. Begin to develop cost estimate analysis on structural frame components.

Week 9 (11/5): Calculate preliminary structural member shapes and sizes for both structural system frames. Based on an assessment of positive and negative implications from variables such as material and member sizes, the group will select either a steel or concrete gravity system design for the facility.

Week 10 (11/12): Integrate lateral loads on the frame into the final gravity design and resize structural elements where applicable. Design standard connections for structural members. Continue work on the cost estimate based on progress in the structural frame. Compile calculations and structural drawings for the structural frame design.

Week 11 (11/26): Begin work on the foundation system by collecting research on specifications and requirements for a footing foundation. Elements will include typical interior and exterior column footings, the foundation wall, and the footing for the foundation wall. These designs will be based on a geotechnical report for Gateway Park. Complete the design calculations for the footing foundation, with the design of all components. Complete the foundation drawings for the facility. Continue writing the MQP by completing the structural frame section. Begin to research preliminary construction plan and schedule for major project milestones with variables including material production time, labor hours, and installation times.

Week 12 (12/3): Finish foundation design with the compiling of calculations and drawings. Based on the engineering data, the group will complete the preliminary cost estimate. Continue with writing the MQP by completing the foundation and cost estimate sections.

Week 13 (12/10): Complete preliminary construction plan and schedule. Submit group contributions to MQP which include layout, structural frame design, foundation design, and cost estimate. Begin individual contributions to the project with research in site and utility planning, LEED Certification, and underground parking. Submit a scope and work breakdown for each section that will be completed. Continue writing the MQP with introduction to individual project submissions.

Week 14 (1/7): Make revisions to group contributions based on feedback from initial submittal. Begin to investigate any issues that arise from revisions and feedback. Continue with individual project submissions.

Week 15 (1/14): Develop finalized cost estimate for primary structure based on revisions. Continue research, writing, and individual design,

Week 16 (1/21): Continue individual contributions to the project with design calculations and drawings for site planning, possible options for LEED Certification, and calculations and drawings for underground parking.

Week 17 (1/28): Complete calculations and research for individual sections of the MQP. Begin an alternative cost estimate along with plan and schedule for the facility that includes options and alternatives studied in individual contributions.

Week 18 (2/4): Complete individual contributions for the MQP by writing sections for LEED Certification, Site and Utility Design, and Underground Parking.

Week 19 (2/11): Begin to finalize the MQP report along with the compilation of all calculations and drawings for appendages. Begin to address additional issues that arose during the project.

Week 20 (2/18): Complete all revisions of sections to MQP. Finalize any additional issues that arose during the project as promptly as possible.

Week 21 (2/25): Submit final draft of the MQP with all revisions and corrections to advisor. Submit CDR form electronically to Registrars Office

Capstone Criteria

The American Board of Engineering and Technology, commonly referred to as ABET, requires that certain areas of competency must be presented in a capstone design project in order to display the knowledge attained throughout the years of schooling. It is particularly meant to put the technical engineering knowledge to use within eight "realistic constraints" (ABET Engineering Accreditation Commission, 2007) modeled upon what real world engineering will entail.

The first of these constraints to be met is economic. As the University is only able to spend a specified budget amount on the project, cost could potentially be a problem. The group's goal is to eliminate unnecessary cost in the project and design as efficiently as possible to produce a reasonable cost estimate. Areas that will play a major role in the economics of the project will include materials, structural bay sizes, alterations suggested in consideration of LEED recognition, and the alternative construction of basement parking.

Environmental considerations will be made in two forums. First, exploring the LEED possibilities could potentially affect many aspects of design including materials, construction processes and recycling, and energy conservation. Secondly, drainage design will be developed to prevent any flooding, erosion, pollution, or other any other damage.

There are two areas in which sustainability will be met. The first is environmental, which was previously mentioned. Alternatively, sustainability refers to the ability of a structure to survive through time. Since the facility being designed is for long term use by the university, it must therefore be a permanent structure with a long term life cycle. The retail spaces will be minimally developed so that, in the event there is a change in tenant, there is no need to demolish the interior.

The constructability constraint is to be met by using industry standards, like, for example, a commonly used column size. Non-standard shapes will be avoided whenever possible. Ultimately, the building must be designed so that it can be constructed realistically and practically.

As the facility will be designed with the use of industry and professional standards, there should be no ethical question that there will be a collapse. Additionally, the space inside the rooms will be comparable to graduate student housing at WPI and other national institutions. The ability of the University to promote living and doing business in the facility will be a primary non-technical priority.

Health and safety considerations will be made in regards to emergency requirements for the structure, including fire exits. The International Building Code, most recently published in 2007, will be used to design and satisfy building requirements, especially structural safety.

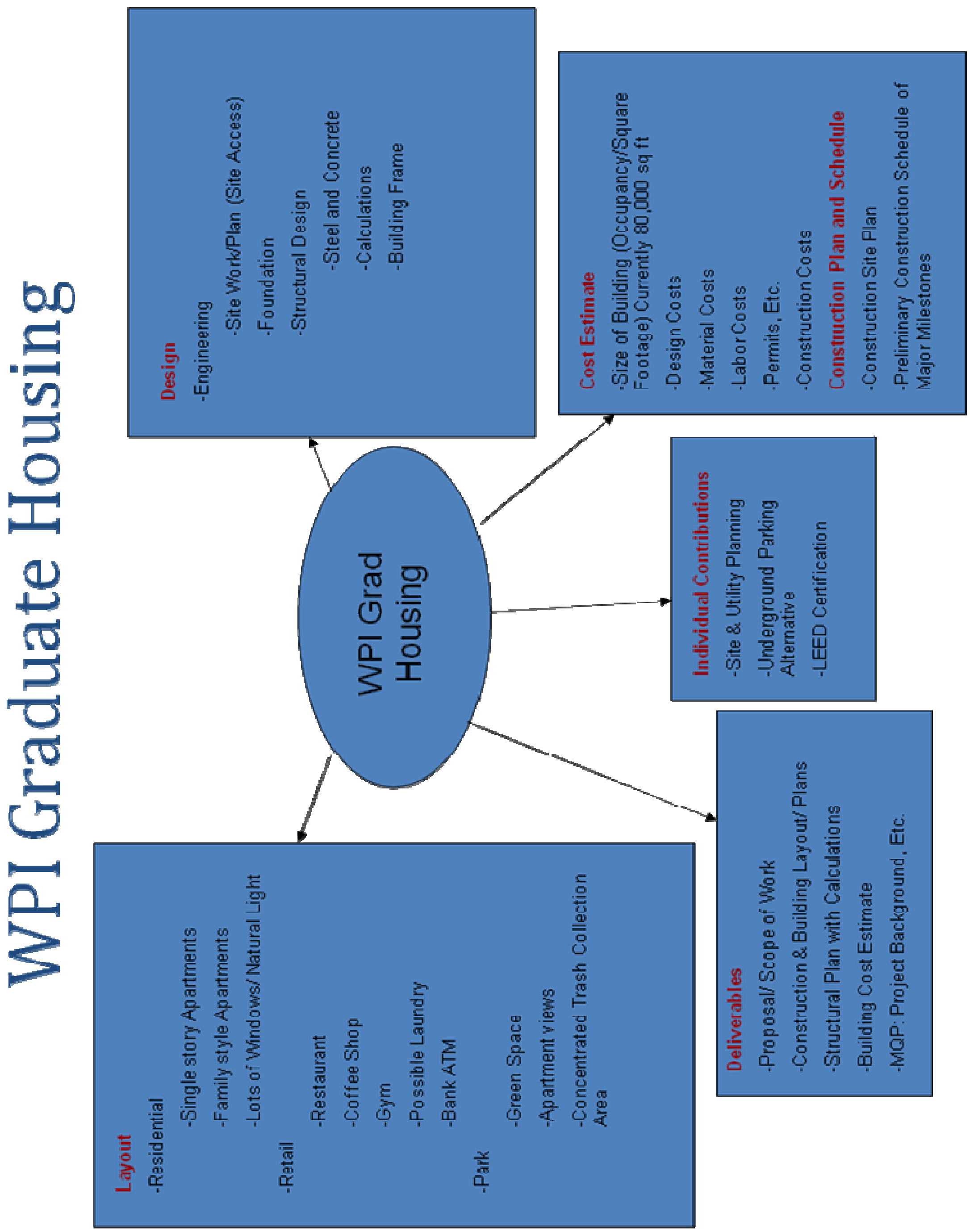
While social considerations are not directly related to the engineering design, the facility envisioned and designed by the team will help to revive an area of Worcester that with development will bring new people and businesses to the region. The design of green space and retail space also attempts to create a vibrant and pleasing environment for the people of the area.

One of the reasons that this MQP was selected was that the project presented the ability to help the University continue to uphold its relationship with the leadership of the City of Worcester. The presentation of this completed project serves political purpose by marking the intention of WPI to continue to bring in high technology employees and residents to Worcester.

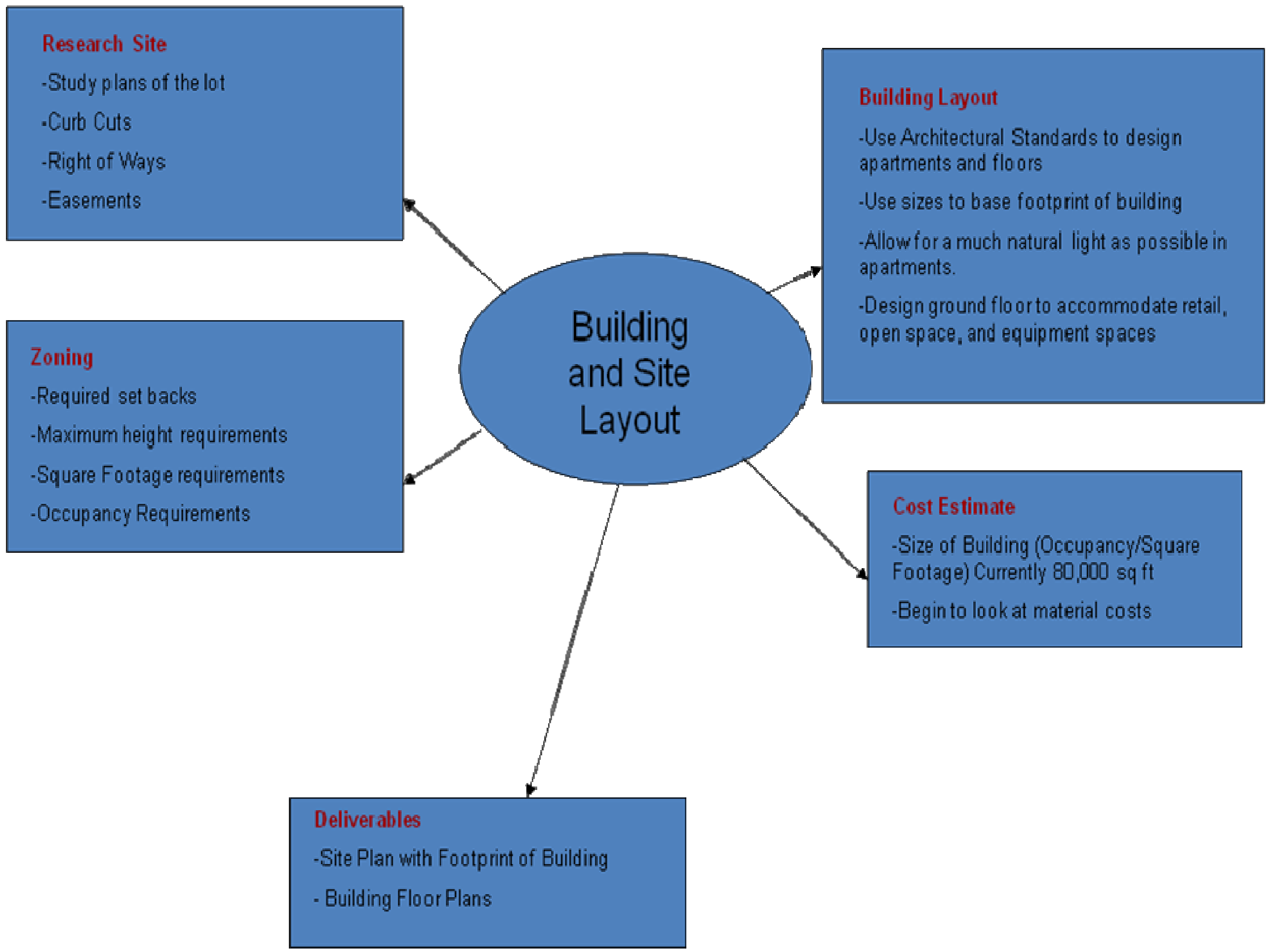
Conclusion

Overall, the project team hopes to develop the design of a graduate housing facility that will meet the needs of graduate students who will be researching and working at Gateway Park. The group's objective is to furnish a base design along with a preliminary cost and construction schedule for the potential client, Worcester Polytechnic Institute. This allows the client to have a baseline proposal for the currently vacant site at 75 Grove Street. Additionally, the group intends to showcase the advantages of the design in hopes that it will be used for the future development of the University and City.

Appendix A: Project Organizational Chart



WPI Graduate Housing (Cont.)



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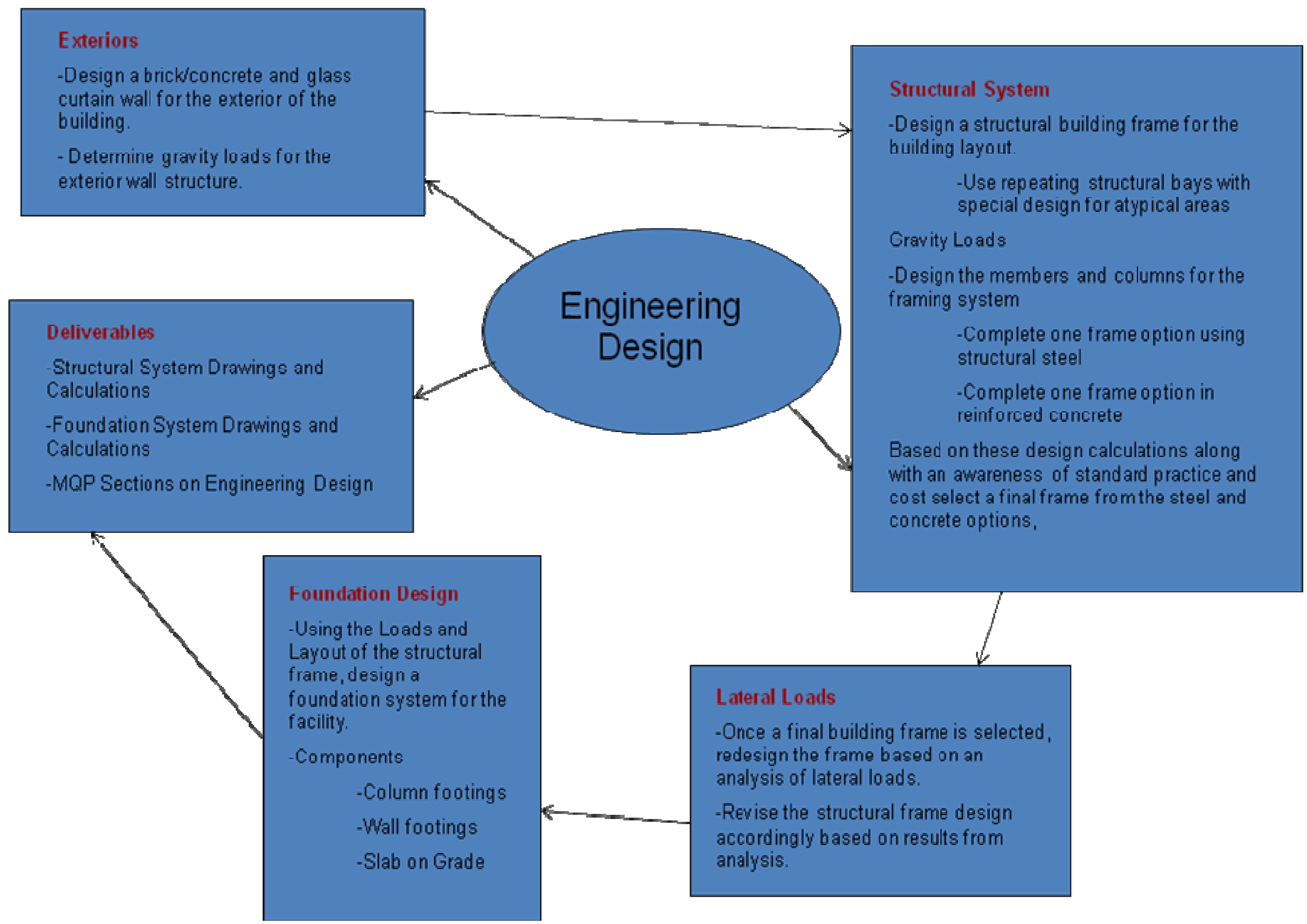

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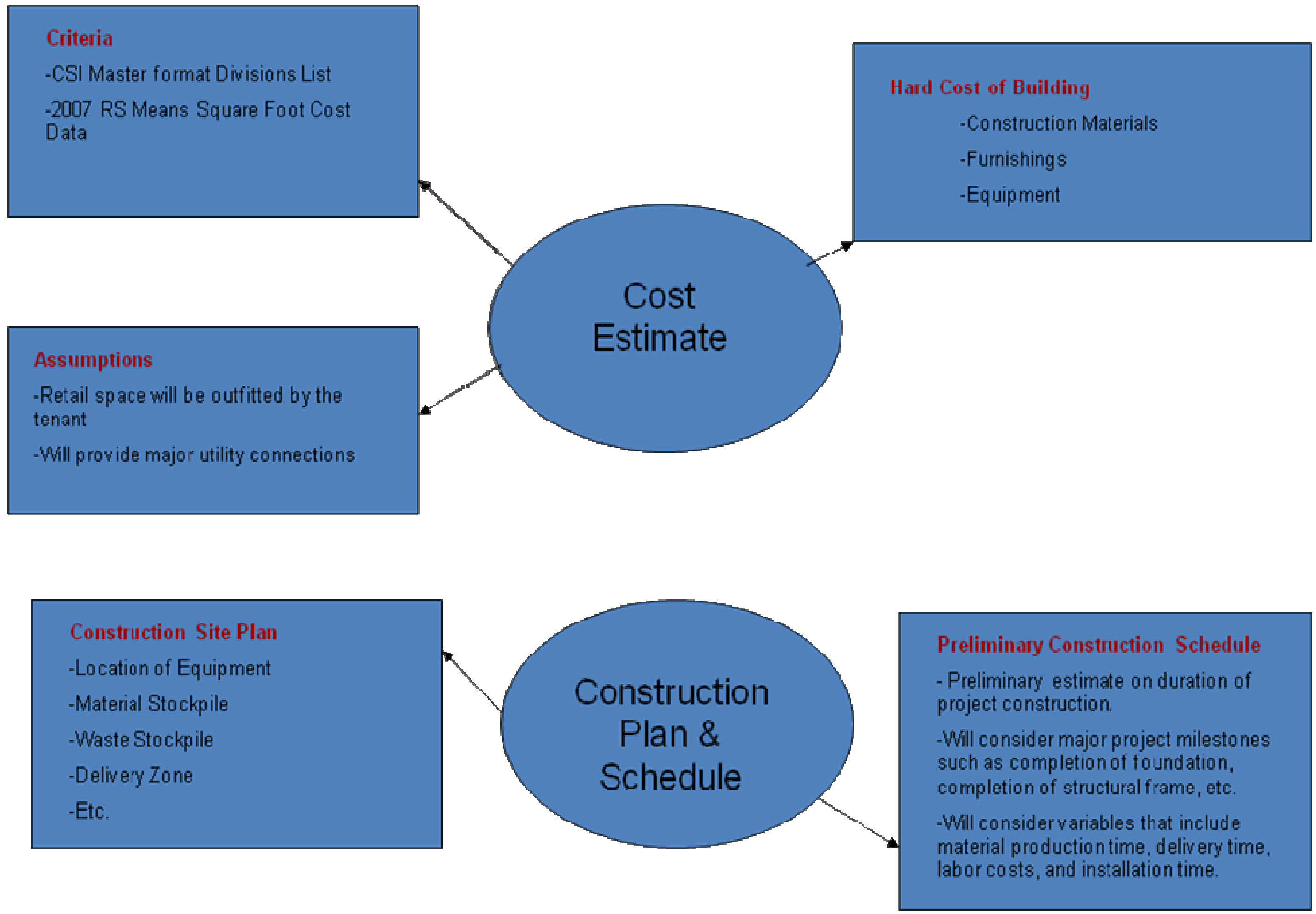

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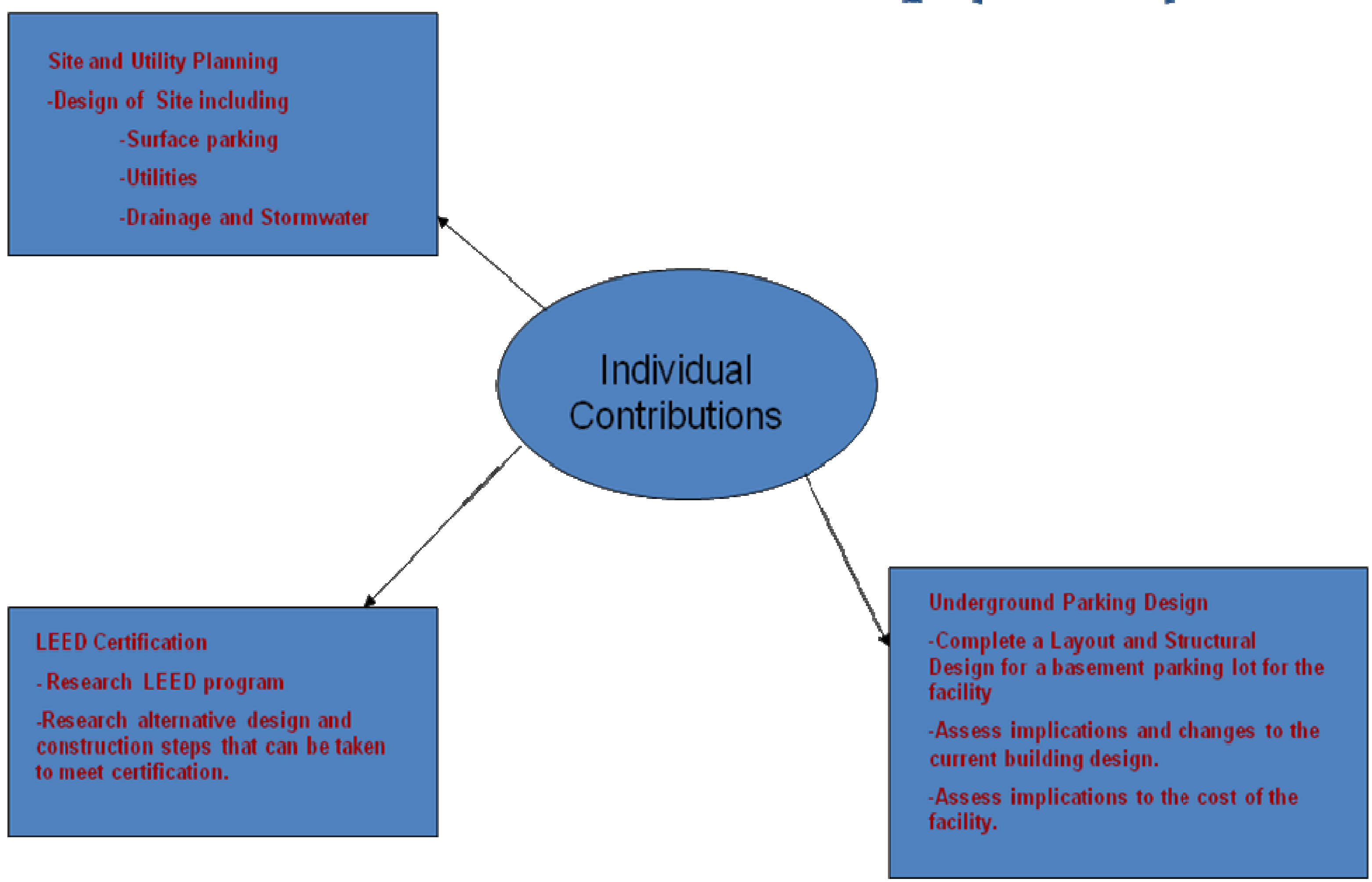

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