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Redesigning Stoddard Residence Hall

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REDESIGNING STODDARD RESIDENCE HALL

A Major Qualifying Project Report

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

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Authorship

This page details the work that each student has put into this report. This does not reflect work that is not immediately noticeable in the paper, i.e. architectural design, structural design work, etc. The entries that list Name/Name are different than those that list Collaborative. In the entries with both names, the first name indicates the original writer, whilst the second name refers to the writer who made significant content revisions.

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Cameron Dunaj Cameron Dunaj

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Abstract

This project designed and analyzed a freshman dormitory building to replace the current Stoddard Hall. Objectives included increasing student capacity, building with existing contour of the land and satisfying students' needs. These objectives were met through preliminary research, architectural layout, structural design and a series of cost estimates on areas such as atriums and masonry construction. Research was conducted into building codes, zoning ordinances and RS Means estimating. Structural work was focused on use of W-shape rolled steel for support.

Acknowledgements

We would first and foremost like to thank our advisor for the project, Professor Leonard Albano for his constant feedback, guidance and support. We would also like to acknowledge Mr. Phillip Clay and Mr. Chris Salter for their time, interest and the information they provided us with that proved very useful to our project. Also, Terrence Pellerin of the WPI Facilities Department was a great help in getting us the plan sets to the existing Stoddard Residence Hall. Last, we would like to extend our appreciation to the Worcester City Hall for their help in clarifying zoning ordinances and to the Alpha Chi Rho house for their generous donation of paper throughout the duration of this project.

Capstone Design

In accordance with graduation requirements, this project demonstrated our experience with the elements of capstone design. The scope of our project as a whole fulfilled the capstone design requirement. The specific constraints addressed by the project were: economic; environmental; constructability; health and safety; social; and political.

We fulfilled our economic consideration by doing a cost analysis study of various aspects of the building structure. First, an estimate on the atypical areas was completed to aid in the decision of one layout over another. Second, a series of estimates based on the use of masonry walls were completed. Different options such as load bearing vs. non-load bearing and masonry walls versus drywall were all explored.

Our environmental consideration is evidenced by our desire to maintain the natural landscape of the site. We tried to minimize both cuts into the land and fills to build up the land. This then creates less heavy machinery work, therefore reducing fuel consumption and harmful emissions during the construction of the building.

The constructability aspect of the requirements promotes efficient and economic use of construction resources. This was accomplished by using typical steel sections and standard building materials such as the 8x8x16 inch masonry block. Building with the hill also aided this goal by facilitating access within the site throughout the construction of the building as compared to a deep hole in the ground where access would have been limited to the bottom side of the hill.

Health and safety were integral to the design since they are the driving forces behind building codes and their criteria. For this project, we focused on the International

Building Code and the Massachusetts State Building Code. In addition to structural safety, care was taken to provide handicap accessibility, and adhere to fire safety precautions. Not only were the building codes referenced in such decisions, but also the newer dormitories on campus were used as guides to assure that the building was comparable to the other dormitories.

Certain social aspects of the new dorm were taken into consideration during design. Several examples include: “How will this layout help promote a sense of community?”, “How will this building be an improvement over the previous Complex?”, “How will this building fit in with both the campus and the surrounding neighborhood?” These questions, as well as social aspects impacting students and the needs of WPI as a whole were considered as project goals and constraints. Decisions based upon these goals and constraints were then made to aid in the layout and structural development.

Last, when we encountered conflicts between our design and the provisions of the local zoning ordinances, we had to investigate the political channels available to secure the necessary approvals to proceed with the design. As such, research into the Worcester City Zoning Ordinances provided this project with political background. The ordinances that had a specific impact on this project along with an amendment in the Massachusetts General Law were researched and classified. The result was a buildable height and area.

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1: Introduction

The Stoddard Complex at Worcester Polytechnic Institute (WPI) is a freshman residence hall that currently houses 180 students. The complex is composed of three buildings situated on a lot between Einhorn St. and Hackfeld St. This project details a new building that could replace the Stoddard Complex, while improving upon the original design.

There are many reasons why we feel this replacement is necessary. First and foremost, the current Stoddard Complex does not efficiently use the space provided by the lot. The three buildings are situated in the shape of the letter ‘U’, they occupy about 30% of the total land area of the site, and they house 180 students. At the very least, one building of the same height but with the footprint of the three buildings connected would be able to house more students and thus, more efficiently use the lot. In addition, WPI has been trending towards larger freshman classes over the past few years, and therefore, larger residence halls may soon become a necessity. For this project to be viable, it was determined that the new building should be able to house at least 225 students, a 25% increase in capacity over that of the current buildings. Physically, the Stoddard buildings are inferior to most of the other residence halls on campus. It is one of two freshman residence halls that have not been renovated in the past 15 years. It has no handicap accessibility, and the split level aspect of the floor layouts are a common complaint from students.

Before design had even begun, several decisions had already been made about the proposed building. Like its predecessor, the new residence hall had to accommodate freshmen and as such, the floors consist mostly of doubles. Also, the topography of

Worcester is not flat, and Stoddard is currently located on the side of one of its hills. Rather than try to level the site through cut-and-fill operations, we decided we would rather work with the hill and keep the area looking as natural as possible. Our third major decision before beginning the project was to attempt to ensure the features that make Stoddard unique are not lost. Specifically, Stoddard is widely recognized around campus as its own small community where the students get to know one another well. This is primarily due to the layout of the buildings and the small quad between them. The new building had to preserve that sense of community as well as have its own quad or outdoor common area. This is just a sampling of the goals and decisions made concerning the building layout. Full discussion of these can be found in Chapter 4.

To accomplish the overall goal of this project, several aspects of design were considered. First, the overall process of designing a building and more specifically a WPI dormitory was researched. Building constraints and decisions were then evaluated based on the design goals, city zoning ordinances and building codes. Schematic drawings of two separate layouts were developed and typical areas within each were structurally analyzed using the LRFD method and the American Institute of Steel Construction Manual. Lastly, using RS Means and United Steel Decking and Joists costs, a cost analysis was completed to develop a square foot cost for structural steel and decide upon the most cost effective layout.

2: Background

The main goal of this project was to design a freshman dormitory building to replace of the current Stoddard Residence Hall. To meet this goal, background research on the process of designing a building was required. The next four sections begin by outlining this process and then examining the more specific information required to fulfill this project through a study of current campus trends, determining the needs of WPI, and the methods to developing cost estimates.

2.1: Building Design Process

Whenever there is a proposal or desire for a building to be built, there are a series of steps that are roughly adhered to throughout the development and construction of said building. This process is completed by the owner or client, architects, engineers, and contractors. One particular agency called Spaces for Children (8 Steps, 2007) has described an 8-step process to designing and constructing a building. It goes as follows:

1. **Feasibility Study** – examine the issues that make the project feasible or unfeasible, and overall reasons for construction
2. **Programming -** the process used to arrive at the set of criteria on which the design is based, and by which it is later evaluated; constraints, goals, and decisions required
3. **Schematic Design** – schematic drawings developed along with architectural renderings
4. **Design Development -** process of refining and fixing the design, and working out the details, including the selection of materials and the engineering systems before official construction documentation
5. **Construction Documentation** – a set of plans on which contractors can bid and then build the proposed structure
6. **Bidding and Negotiation** – process in which the project is put out to bid, a contractor is selected, and a construction contract is drawn up between the contractor and the client
7. **Construction Administration** – the physical construction of the building according to said documentation and contracts
8. **Post-Occupancy Training** – training for the individuals hired to run and maintain building/facility (8 Steps, 2007).

Although this is an 8-step process for this agency, it is sufficiently general to apply to most buildings. The only differences can be found in a design-build or design-bid-build project in which the fifth, sixth and seventh steps occur simultaneously with steps three and four in an attempt to fast-track the project.

As mentioned before, there are four main groups of people that are included in this process: owner/client, architects, engineers and contractors. The owner or client will develop step one before approaching the architect and engineer. Often times, the architect will then go ahead with step three while relying on the engineer and owner or client to support them in steps two and four. The engineer, often as a contractor under the architect, will then essentially take over the project on step five and develop a set of plans which the owner or client can then set up for step six. A contractor then completes the project through step seven, always working with the owner or client, architect and engineer. Step eight is then taken over by the owner or client to put the building into use.

For our particular project, we went through steps one through four, looking at the owner's desires (WPI), the needs and constraints of the project, an architectural rendering of the floor plans, and the design development with structural decisions and a cost analysis of different construction options. The next section examines current trends in campuses and campus dormitories to focus on the process of designing a campus dormitory.

2.2: Campus/Dormitory Trends

A valuable resource in the area of campus trends is an organization called ACUHO-I which stands for the Association of College and University Housing Officers – International. ACUHO-I's objective is to provide "innovative, value-driven programs, services, research, and development as well as networking opportunities that help support and evolve the collegiate housing industry" (ACUHO-I, 2007). ACUHO-I has an online database offering guidance and opinions on a variety of topics. It contains, for example, standards on how long it should take a custodian to clean a residence hall, as well as popular trends in daylighting a building.

One such article called "Building Character: The Celebration of Hallowed Halls", written by James Baumann and Jennifer Daddario (2006), highlights approximately one dozen different college residence halls and what makes them unique. For instance, the HUB at the University of Alberta (see Figure 1) is noted for its central location within campus, built around a main concourse with a glass ceiling overhead to allow in ambient light. Likely its most prominent feature is the inclusion of shops on the first floor with the building's residents living on the second and third floors (Baumann, 2006).

Another residence hall of interest is the Hill College House at the University of Pennsylvania see Figure 2). With 90% of the students housed being freshmen, this dormitory is closely related to our project. Although stated as "fortress-like" from the outside, similar to the HUB the building boasts a glass ceiling allowing in large quantities of ambient light. Another aspect to this building is the use of an atrium. As can be seen in Figure 2, the atrium is used as a common area for all students giving an open feeling and plenty of natural light (Baumann, 2006).

Figure 1: The HUB – University of Alberta

Figure 2: Hill College House – University of Pennsylvania

As evidenced by the previous examples, the use of natural light and open spaces is a common theme in newly constructed residence halls. Another important quality for a residence hall is its ability to fit in within its surroundings to provide a building that is structurally and aesthetically similar to the rest of the campus. This will then provide a more uniform looking campus. These trends gave a good foundation for preliminary decisions on the design of our building. The next section examines more specific impacts on this project with the needs of WPI.

2.3: Needs of WPI

To assess the surroundings and the needs of the campus, the Dean of Students can be a valuable resource. In an interview with Phillip Clay, Dean of Students for WPI

(Clay, 2007), he revealed certain aspects of the current Stoddard Residence Hall, the surrounding apartments, and the students' needs that are valuable to the design of a potential new building. He first discussed the original reasons that Stoddard was built in small segmented sections. The goal was to create a sense of community within each building. Then, with the Stoddard complex being situated around a central area or quad, the three buildings can be brought together to enhance this sense of community. Unfortunately, he indicated that due to this segmented structure and the inaccessible nature of the building, it has not been renovated in the past 15 years like Morgan, Daniels and Riley Halls have. Thus, as he described it, it is not a popular building among the students. Last, Mr. Clay discussed the surrounding apartments and the rest of campus and the use of brick and pre-cast concrete to create an older feel to campus. Even the new admissions building, Bartlett Hall (shown in Figure 3) was constructed in this manner. See below for an example. For a full summary of the interview with Mr. Clay, please see Appendix B-3.

Figure 3: Bartlett Center (WPI)

The building design process discussed earlier requires a certain amount of background research to determine feasibility, needs of the client, and needs from the building itself. Project feasibility was not the focus of this project, therefore we focused our background research on campus trends and the needs of WPI. This then paved the way for the project to begin through development of constraints, decisions on the building's structure, constructability and cost effectiveness. The next section will further illustrate the specific needs of WPI through a look at the current Stoddard Residence Hall.

2.4: Existing Stoddard Residence Hall

Stoddard Residence Hall currently consists of three separate buildings (Stoddard A, B and C) that house a total of 180 students. The three buildings currently take up only 30% of the lot. They are arranged in a U-shape opening towards Einhorn Street to create an outdoor common area (also known as the "Stod-quad") between the street and the buildings. The following is a scale drawing of the location of the current Stoddard buildings and walkways, with Einhorn Street running along the right side of the image.

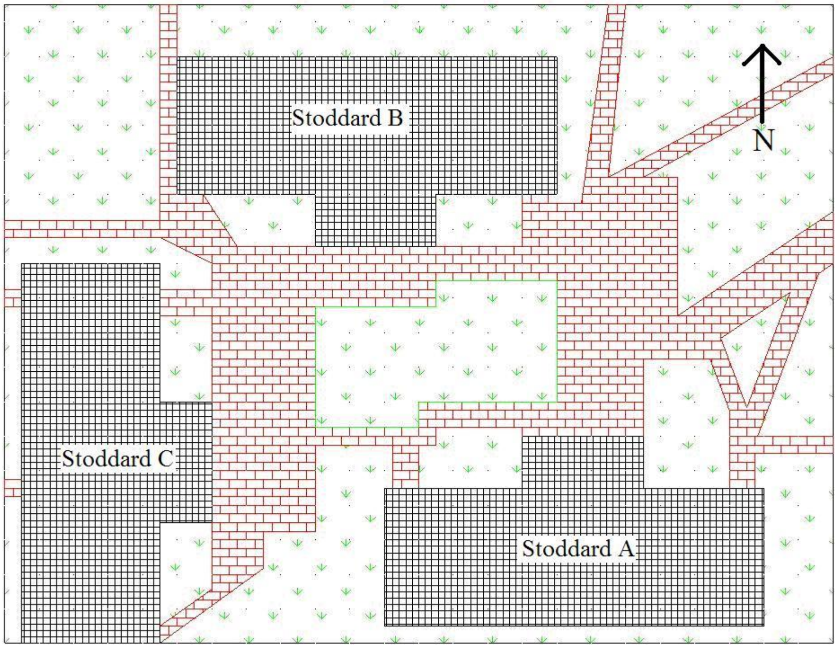


Figure 4: Current Stoddard Lot - Building Placement

The lot is situated on a hill with Einhorn Street at the top of the hill and Hackfeld Street running parallel at the bottom of the hill. The following is a topographical map of the lot. The elevations of the land where the buildings are located could not be determined. However, only the long side of Stoddard C lies relatively perpendicular to the slope of the hill. This is reflected by the gap in the topography contours, since an accurate estimation could not be made.

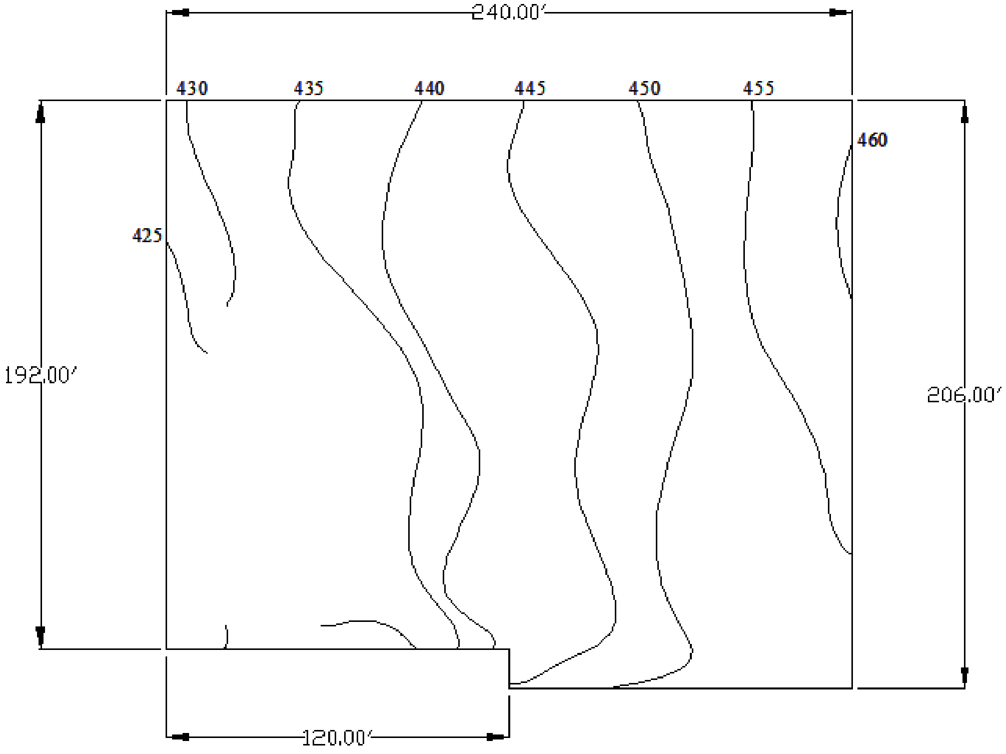


Figure 5: Stoddard Lot Topography Map

To get an idea of the placement and size of these buildings and the extent of the hill, the picture below was taken from Einhorn Street looking down at the three Stoddard buildings. Although all three cannot be completely seen, the edges of Stoddard A and B can be seen at either edge of the picture.

Figure 6: Current Stoddard Buildings

To accommodate this severe a hill within the lot, each building is broken into three pieces and arranged in a terraced or step-like structure. For instance, each building is rectangular and when a person stands at one end of the building, they will have to go down two small flights of stairs before they reach the other end of the building. This then makes handicap accessibility virtually impossible. As it is, there are no elevators or ramps within or around the Stoddard buildings. The following picture shows an elevation view of Stoddard C to illustrate the step-like design of each building.

Figure 7: Stoddard C - Step Design

The goal of this project is to design one dormitory building that can not only replace these three buildings, but provides accessible housing for 25% more than the 180 students it currently houses, retains an outdoor common area, and constructs with the topography of the hill. In following with the design process, to facilitate the schematic design and design development steps, the next two sections will review information on structural framing options and the methods for cost estimates.

2.5: Structural Design Considerations

Buildings, like human beings, are built around and held together by a type of skeleton system. For human beings, these are bones. For buildings, this is the frame. The structural frame is responsible not only for its own weight, but imposed gravity loads, both dead and live along with lateral loads in the form of wind or seismic activity. The type of frame depends on many factors including, but not limited to, the size, location and future use of the proposed building. According to Francis Ching in his book, Building Construction Illustrated, the three main systems of frames are as follows (Ching, 2001):

1. **Structural Frames:** Concrete, steel or timber frames that make use of beams, columns, girders, panels, rigid connections and/or shear planes and diagonal bracing
2. **Concrete and Masonry Bearing Walls:** A system of loadbearing walls made out of concrete or masonry and reinforced to support lateral loads
3. **Metal and Wood Stud Walls:** For smaller 1-3 story buildings making use of wood studs to carry vertical loads and sheathing or diagonal bracing to carry horizontal loads

To maintain our goal of matching our building to the surrounding WPI campus and to meet the campus needs, one of the first two options would need to be used. Wood stud walls are typically used for residential homes or small offices. A building intended to house hundreds of students would need to be larger and more durable than a metal or wood stud wall system can support. The next section will discuss how each of the first two systems function and the design methods for each.

2.5.1: Structural Frames

A structural framing scheme is based around five major components. These components are designed to carry the weight of the building and the pressure from lateral loads in a direct series or load path. The series begins with the slabs that span the floor area, then the beams, which can be made of steel, concrete or timber. The building is arranged into as many typical bay sizes as possible with beams being the infill source to support the main area of each bay. Beams then transfer their loads to perpendicular members called girders. Girders can lie in the same plane as beams but usually lay in between bays to gather beam loads from multiple bays. The girders then transfer their loads directly to vertical members called columns. Each bay is usually designated by a column at each corner. Columns continue through the floors carrying the combined weight of the building to the last major structural components, footings. Footings are larger than the column in area and are responsible for transferring all loads from the superstructure to the supporting soil.

This is a generic description and can be seen illustrated in Figure 8 below. There can be many adaptations to this system such as joists for beams and two way slabs instead of infill beams or piles beneath footings. The overall idea however is to transmit the loads from each structural element of the building to a supporting element in a successive nature. The arrows in Figure 8 denote the load path with the heavier weight arrows indicating larger loads.

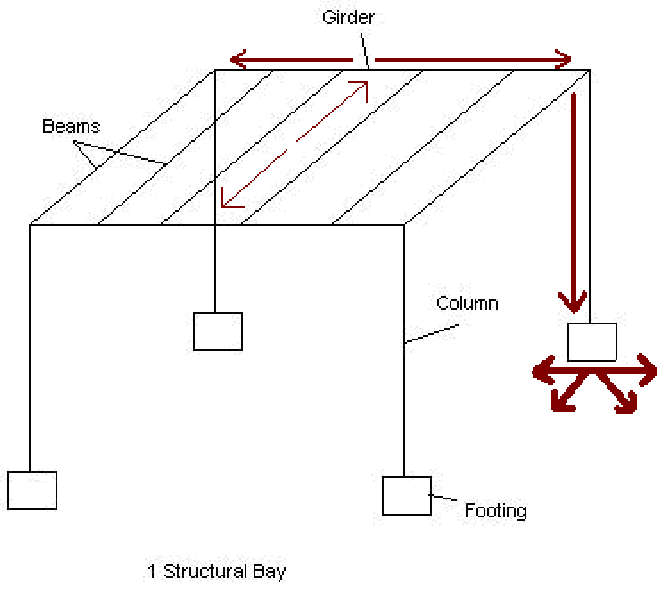


Figure 8: Basic Structural Frame

There are two common systems for handling lateral loads with a structural frame. The first is a rigid system. In the case of steel construction, it is usual for the joints between beams, girders, columns and footings to be made to resist moment forces, whether by welded joints or a series of bolted and welded plates. The second is a braced system. This makes use of diagonal bracing to create shear walls that resist lateral loads and carry them directly to columns leaving the beams and girders to support the gravity loads.

The successive nature of the load path and the options for lateral load resistance are the essentials of this sort of structural framing system. The design of structural frames has two common methods. The first is known as the ASD or allowable stress design method. The second is known as the LRFD or load and resistance factor design method. Both make use of the loads applied to the structural framing system, gravity and lateral and design each member accordingly. The biggest difference lies in the equations used to find appropriate moments. This project will use rolled steel for beams, girders and columns and make use of the LRFD method for member design.

2.5.2: Concrete and Masonry Bearing Walls

Before the development of steel, some of the world's largest structures were built on the principle of masonry bearing walls. The pyramids in Egypt, the cathedrals in Europe and the temples in the Middle East are examples of masonry as building blocks for some of the most complex structures in the world. Like steel and concrete in the present day, masonry throughout the years has been the chief material for structures. A textbook published in 1930 called The Design of Masonry Structures and Foundations by

Clement Williams from the University of Iowa describes the use of masonry structures as such:

> The enduring character of masonry structures, the relative simplicity of the processes involved, the pleasing outlines usually obtained, together with the almost universal availability of the materials and the consequent moderate cost, render masonry construction one of the most important of the civil engineer's activities (Williams, 1930).

Some of the advantages of masonry walls over steel structures are that they are more resistant to the effects of fire, naturally sound-absorbing, and also use their mass as part of their load-carrying capability (Ching, 2001). In a building such as a dormitory where durability, sound-proofing and tight fire control measures are needed, masonry walls are ideal and a system in which the walls can carry their own weight is an advantage rather than having oversized steel members to not only carry the occupant loads but severe loads from the walls too.

Although masonry bearing walls are ideal for some situations such as a dormitory, there is general disagreement among scholars as to the advantage or disadvantages of masonry bearing walls. For instance, many sources will argue that masonry bearing walls are ideal for low-rise buildings due to the shear weight (Ching, 2001, Beall, 1987). However, another textbook on masonry construction called <u>Reinforced Masonry Design</u> by Robert Schneider argues the opposite:

> The development of high-strength concrete block and brick, combined with the improvements in grouting and reinforcing techniques, have made masonry bearing walls practical for such multistory construction…the basic concept here involves that of designing every floor to act as a horizontal diaphragm in transferring wind or seismic loads to the transverse shear walls, which in turn carry these forces to the foundation (Schneider, 1980)

As a functional framing system, masonry bearing walls are strong in compression but weak in tension and shear. The floors transfer lateral loads directly to the walls, and some sort of reinforcement is needed although the weight of the walls aid in the lateral load capacity. As compared to the structural framing option discussed in the last section, bearing walls can replace girders and columns within a system. Beams, joists or supporting slabs can be used to span the distance between the walls. The walls then transfer loads straight down to the foundation. Not all walls in a building have to be load bearing for such a framing scheme. However, in a complete bearing wall system, a significant amount of bearing walls are necessary so that all loads are accounted for. Figure 9 below shows an example of such a bearing wall system.

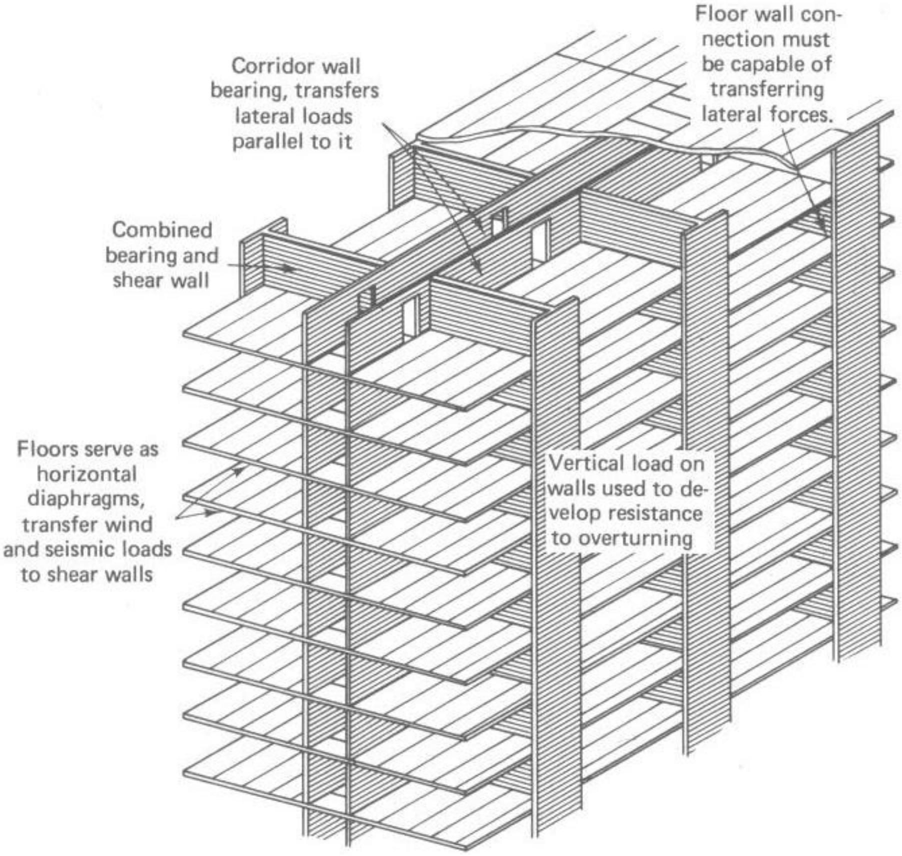


Figure 9: Loadbearing System Skeleton (Schneider, 1980)

Therefore, like the structural framing option, masonry bearing wall structures also follow a distinct load path for transferring loads. As described above, gravity loads are distributed by beams, joists, or slabs directly to the walls and then down to the foundation. “The bearing walls can be considered as continuous vertical members supported laterally by the floor system” (Beall, 1987). Lateral loads are carried from the slabs directly to reinforced shear walls and then down to the foundation. The one major difference however lies in the event of a failure. If one beam or one girder were to fail in a structural frame system, the whole frame will most likely deform but loads will be distributed elsewhere. In the event of the failure of a bearing wall, since it carries all loads from the top to the bottom, an entire section of building could collapse.

Masonry bearing walls also have two design methods: rational analysis and empirical analysis. Rational analysis can be compared to that of the LRFD and ASD methods for steel and concrete design. Beall states the use of rational design as “merely the application of accepted engineering principles already developed for other structural systems and…is based on the properties of the component materials rather than on arbitrary empirical limitations” (Beall, 1987). Empirical design on the other hand, “contains no mathematical formulas…because it was written before any comprehensive testing had been performed and such formulas derived” (Beall, 1987). Empirical design follows general steps outlining the materials to be used, allowable stresses, lateral support requirements, wall thickness and bonding. This project used empirical design to explore the use of masonry bearing walls. The objective was to evaluate the cost effectiveness of masonry bearing walls over a steel and concrete framing system.

2.6: Cost Estimates

According to the Means Estimating Handbook, there are four categories of cost estimates: order of magnitude, square foot, assemblies, and unit price. We also used this handbook to determine the uses and restrictions of each approach. It describes each of the four categories in brief, concise terms (RS Means 2003):

1. **Order of Magnitude Estimates:** The order of magnitude estimate could be loosely described as an educated guess. It can be completed in a matter of minutes. Accuracy is -30% to +50%.
2. **Square Foot and Cubic Foot Estimates:** This type of estimate is most often used when only the proposed size and use of a planned building is known. Accuracy is -20% to +30%.
3. **Assemblies (Systems) Estimate:** As assemblies estimate is best used as a budgetary tool in the planning stages of a project. Accuracy is expected at -10% to +20%.
4. **Unit Price Estimate:** Working plan and full specifications are required to complete a unit price estimate. It is the most accurate of the four types, but is also the most time-consuming. Used primarily for bidding purposes, accuracy is -5% to +10%.

The last three categories have corresponding RS Means manuals providing unit cost data. The Unit Price Estimate would make use of the Building Construction Cost Data; the Assemblies Estimate would make use of the Assemblies Cost Data; and the Square Foot and Cubic Foot Estimates would use the Square Foot Costs. Each RS Means publication is designed to be a “comprehensive, fully reliable source of current construction costs and productivity rates” (RS Means, 2007).

No matter what type of estimate is being completed, according to the Means Estimating Handbook, there are two major components to each estimate. First, one must determine the extent of the specifications and plans provided. This will dictate what type of estimate to use and also how to complete the next major component: quantity takeoff.

Quantity takeoff first lists, counts and measures every item to be priced. Depending on the type of cost estimate, different items will be listed. For example, for a square foot estimate, specific items such as elevators, furniture, equipment and structural steel will be priced by unit and then tallied; whereas in an assemblies estimate, categories such as the foundation, the roof, and the flooring will be identified, classified and counted. The square foot estimates looks at specific specialized items in the building while the assemblies cost method estimates larger aspects. Once these items are tabulated, the list will be organized in such a manner as to allow costs to be assigned to each item. Costs are then tabulated to result in a final cost estimate.

This project consisted of specific structural information and less specific decisions on interior items and finishes. For instance, the elements and costs for a chosen structural scheme consisting of concrete slabs and steel beams and/or joists can be easily tabulated; conversely, individual appliances and pieces of furniture were considered in the dead load of the schemes. Therefore, a square foot estimate is the most practical for a project of this scale. It makes use of the structural square foot costs while estimating the more vague aspects of the building resulting in an estimate of approximately -20% to +30% accuracy.

This project used cost estimates as a base to make decisions on overall building layout, structural framing schemes, and interior construction materials. The cost estimate completed the picture that was developed through the first four steps of designing a building.

3: Methodology

As stated earlier the main goal of this project was to design a freshman dormitory building to replace of the current Stoddard Residence Hall. Using the data gathered in the background research, the means of achieving that goal became more lucid. The process was broken down into two main activities and one smaller activity. It was decided that the best way to design the dormitory was to start by composing architectural design layouts. The next step was to design the structural skeleton that would support the architectural designs. And last, it was decided that further study into areas of interest could add more depth to the project.

3.1: Architectural Building Design

The first step in designing the architectural layouts was to determine the limits of the site. The maximum building dimensions were established through the Zoning Bylaws of Worcester. Though it was possible, and indeed necessary, to bypass these restrictions via the Dover Amendment, realistically, the closer the building adheres to the original restrictions, the better the chance of the Dover Amendment being allowed.

These dimensions, in conjunction with the goal of building with the hill and minimizing cuts give a clear definition of the available space. The next step was to refer to the desires of the owner of the building and design a shape that will fit in the available space. In this case, when planning the overall shape of the building, the desire was to make the building aesthetically blend with the rest of the campus while still maintaining a strong sense of community through an outdoor common area.

The last step of the building design consists of adding all of the details. The main guides during this step are building codes. The codes contain all the restrictions that the design is based upon. At this point the design problem was how to adhere to the codes while meeting the set goal of housing 25% more students than the current complex. Using these constraints, multiple building designs were developed resulting in two alternative layouts. Once the architectural design was complete, the next step was to move on to the structural design of the members.

3.2: Structural Design

For the structural design, the first step was to determine a typical bay size to be used. Twelve different bay sizes, or schemes as they were called, were considered. Of these twelve only one could be chosen so several criteria were selected to determine which scheme was the best. However, before the criteria could even be applied, the schemes served another purpose. By designing schemes with different methods of construction (noncomposite, composite, open-web joist) the conclusion was reached that composite structural design was the best option for this project.

The members of the schemes were designed and then the schemes were compared to each other based on the following criteria: cost of the scheme in dollars per square foot; beam and girder orientation; simplicity of the loads; and the overall constructability of the scheme. Using each criterion, the scheme choices were narrowed successively until only one was left. Structural repetition is a desirable attribute in a building, so once the final scheme was chosen it was used a means of comparison to determine which building layout should be used.

Unfortunately, there was no significant difference between the building layouts in regards to the typical area. Because of this a new selection process had to be used. Since the atriums were the largest room in each building, as well as atypical areas, they became the deciding factor. The members for the atrium areas in both layouts were designed in the same way as the members for the typical areas. Upon completion of the member design for the atriums, the cost of each atrium was evaluated and the building layout selection was made based on those results.

3.3: Further Study: Interior Construction

The last element of our project was to open the door for further study through an analysis of an aspect of interior construction. Masonry walls were decided upon to give us a clearer understanding of this particular part of the dormitory design. The analysis covered two topics within masonry walls: load bearing versus non-load bearing and drywall construction versus cinderblocks.

The analysis of load bearing versus non-load bearing walls was completed in three major steps. The first was to set up a load bearing system by determining where shear walls would be located and by sizing the necessary infill beams. This was completed through background research into masonry wall construction, and a structural analysis of the imposed loads from the rooms. This structural analysis was completed in the same method as that used for the typical area structural design; by using simple beams and tributary areas.

The second step in the analysis of load bearing versus non-load bearing walls was to itemize the materials needed. To keep the estimate focused and simple, only the masonry walls and the structural steel were considered. Using the RS Means Assembly

Costs Data book, square foot costs for the different kinds of masonry used were obtained. For instance, shear walls were reinforced with #5 rebar spaced 32 inches on center in hollow core 8x8x16 inch cinderblocks; whereas the non-load bearing walls were just unreinforced hollow core 8x8x16 inch cinderblocks.

Once each item had been identified and priced, with all steel assumed to be $2500 per ton (R.S. Means, 2006), cost estimates were prepared. Units were identified, quantity was determined and outlined in backup sheets and an overall cost was determined. This overall cost was the cost per scheme. As discussed earlier, one scheme (scheme 5 consisting of two rooms side by side) had been chosen as the most economical and constructible scheme. Therefore, each quantity of steel and masonry was based off the dimensions of one of these schemes. Then, using the area of this scheme (523.55 ft^2), a cost per square foot was determined. In this way, the cost of a non-load bearing system was compared to that of a load bearing system.

The second major topic of study was a comparison between drywall construction and cinderblocks. This was completed in two major steps. The first step was to determine the prices associated with drywall construction and maintenance. This involved an interview with Chris Salter, the associate director of facilities services and the manager of technical trades at WPI along with the RS Means Building Construction Costs book. Mr. Salter was able to give us ballpark figures on the frequency and cost of repairs. He was also able to give us an educated opinion on the benefits and drawbacks to cinderblock construction. Using this expertise, we were then able to create three separate levels of maintenance depending on the type of resident, in this case, freshman students, who would be housed in the dormitory.

This led into the second step to this topic. We assigned values and quantities to each type of repair or maintenance work needed and thus created an initial cost estimate for drywall construction and the yearly maintenance cost. The initial costs covered the type of wall and the steel necessary for construction. For instance, the steel sections for the drywall system were smaller than those for the cinderblock system since drywall is lighter. Therefore the cost covered the cost of beams, girders, columns and drywall with wood studs for the drywall system and heavier beams, girders, columns and cinderblocks for the cinderblock system. From the types of repairs and maintenance identified for each level, a yearly cost estimate was developed, assuming a 3% inflation rate. The two different systems were then plotted against each other to see when the cost of maintenance of drywall would surpass that of cinderblocks. In this way, the average life cycle cost of a drywall system and a cinderblock system were determined along with the cost differential between them on a timeline of 0 to 40 years.

This last study concluded our most detailed analysis of the building design. The next three chapters will go in depth as to the decisions made and the results obtained from the previously outlined processes.

4: Architectural Building Design

By defining the process to design and construct a building, and then evaluating a few current trends in campus dormitories and the specific needs of WPI, we were able to begin the schematic drawings of two different possible buildings to replace the current Stoddard Residence Hall. This chapter discusses the development of these drawings through the goals, constraints, and the decisions made concerning the building layout. In reference to the building design process, having completed step one in the background, this section continues through steps two and three (programming and schematic drawings).

4.1: Dormitory Design Goals

The purpose of this project was to design a freshman dormitory building to replace the current Stoddard Residence Hall, including schematic drawings, structural analysis and cost analysis. Within this purpose is a subset of goals for the building design or the schematic drawings alone. These goals, listed below, are based on the information outlined in the background sections on current campus trends and the needs of WPI. They are also discussed in further detail in the following section.

- House a minimum of 225 students
- Increase room size relative to current Stoddard room dimensions
- Include a quad and an atrium
- Minimize environmental impact
- Maximize constructability and maintainability
- Use cost effective systems and materials

First and foremost, to make the project feasible, the building would have to house more students than the current Stoddard Residence Hall which holds only 180 students. Thus, we decided to increase this number by at least 25% or a minimum of 45 additional students, 225 total students. To also improve on the current Stoddard dormitory, the rooms had to be bigger as that is a common complaint among students (Clay, 2007).

However, to keep the uniqueness of Stoddard as compared to other dormitories, a sense of community was established. Thus, defining a quad within the building design became a goal. Then, to hold with current trends, including an atrium within the building design also became a goal to increase ambient light and a sense of openness within the building, also drawing students together from each floor to further enhance the sense of community.

Last, there were goals for constructability, maintainability, cost effectiveness and minimizing the environmental impact. The first two resulted in several decisions concerning building materials which will be later discussed in Section 4.4. Cost effectiveness is discussed throughout the structural analysis in Chapter 5 and expanded upon in Chapter 6. Minimizing the environmental impact took place through building with the hill rather than into or on the hill. This created a step-like or terraced structure, as will be further discussed in Section 4.3. This type of design reduces the impact on the environment in several key areas. First, the natural landscape is kept mostly intact since there will be no extensive cut or fill operations. Reducing cut or fill operations then reduces the heavy machinery work required for construction, therefore reducing fuel consumption and emissions.

With these goals in mind for our project, one other area was evaluated for the impact on the building design. Constraints upon the land in use and the building to be designed were taken into account. The next two sections outline these constraints.

4.2: Design Constraints

City Zoning Ordinances have the most impact on the location of a building within a set property and resulting buildable heights and areas. For the city of Worcester, most of the necessary information was found on its website, http://www.ci.worcester.ma.us/. Property lines for the Stoddard site were found in the "Map and Directions" section using the "Property Values Search". This is an online database of PDF maps of the city used for tax and auditing purposes. Figure 10 shows a sample map provided by the city while Figure 11 is a close-up of our property. Figure 10 provides not only property lines, but the location of known current buildings, streets, bodies of water and topography contours. Once zoomed in as can be seen in Figure 11, dimensions are provided on each property line and elevations on each topography contour.

Figure 10: Worcester City Zoning Map - Property Lines

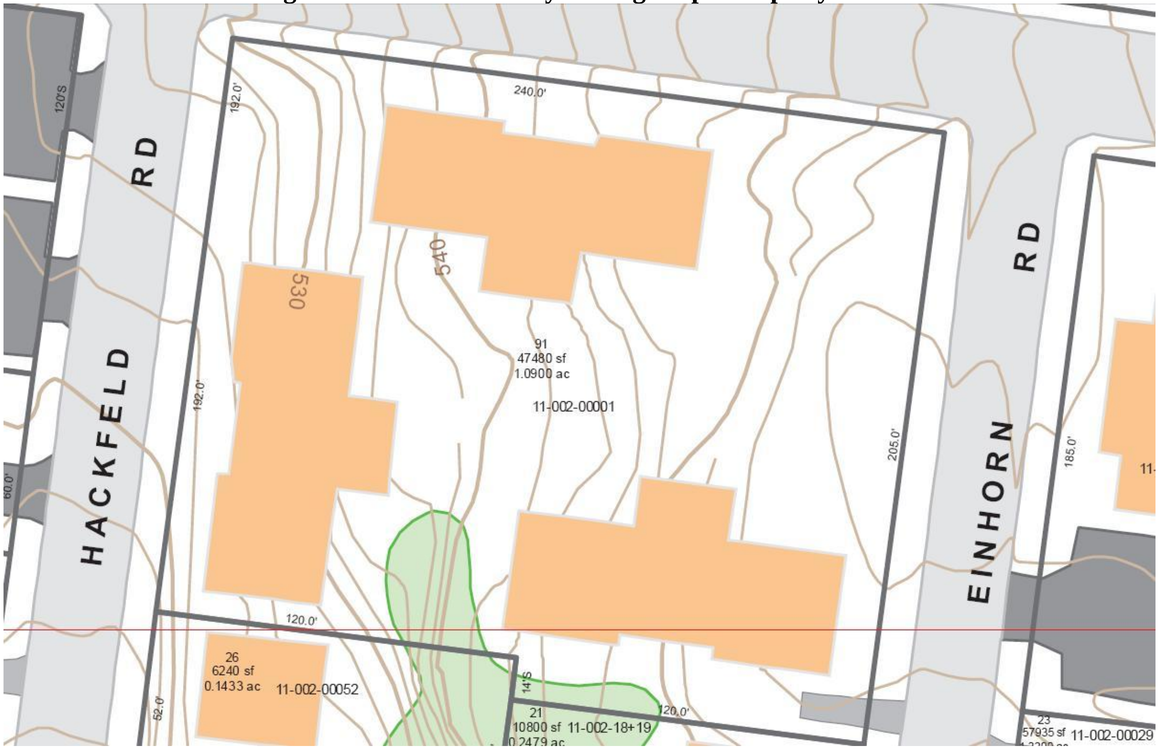


Figure 11: Worcester City Zoning Map - Stoddard Lot

Along with lot or property lines, all areas within the city are divided into specific districts which, in conjunction with property lines, impact their buildable area. There are six types of districts: residence, business, industrial, manufacturing, institutional and airport. Each of these classifications is then further subdivided into sections such as RS-10, RS-7, RL-5, etc. (City of Worcester Zoning Laws, 2007). District maps provided by the city are used to determine within which district a particular piece of property lies. Figure 12 is a sample of one such map.

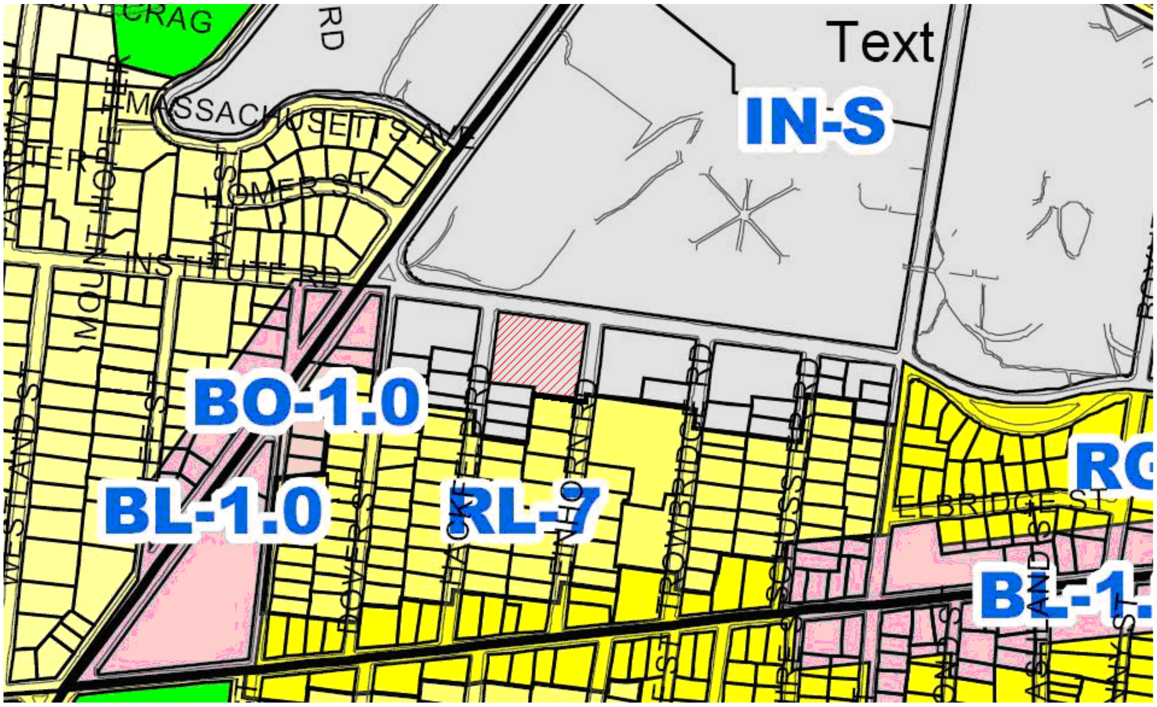


Figure 12: Worcester City Zoning Map - District Zones (Stoddard Lot)

As can be seen in Figure 12, the current Stoddard Residence Hall (hatch area) is in an IN-S district or in other words, an “Institutional, Educational” district. This qualification along with the neighboring districts (RL-7) dictated specific ordinances and restrictions applicable to our particular plot of land. The two features most impacted by the zoning ordinances are the permissible height of the building and the required front/rear yard dimensions or setbacks. Height restrictions are outlined in Table 4.2 of the

Worcester City Zoning Ordinances. Front/rear yard distances are also summarized in Table 4.2, and Article XIII Section 3 Number 7. A summary of these distances and other impacts that will be discussed can be found in Table 1. For a piece of property in an IN-S district, with an abutting RL-7 district, the buildable area is reduced considerably, and the height is limited to two stories or 35 ft. Figure 13 shows the resulting buildable area.

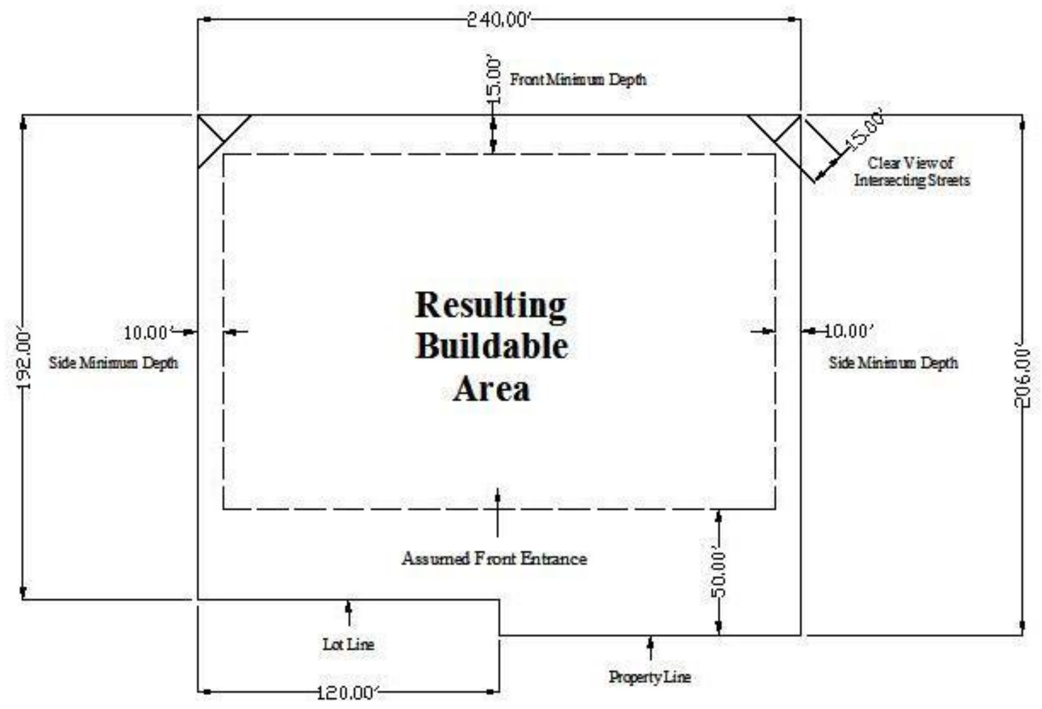


Figure 13: Resulting Buildable Area due to Zoning Ordinances

The buildable area depicted in Figure 13 is 31,020 square feet and would most likely fail to provide housing for more students than the current Stoddard. With only two stories, and 46,200 square feet, it was determined that designing a dormitory of the desired occupancy and the inclusion of a quad, would be extremely difficult, if not impossible with the established building limits. The most common method to appeal any of these restrictions would be to apply to the city for a zoning variance. This variance would then go to the city zoning board of appeals for approval. It is a lengthy process with complicated deadlines and paperwork.

However, there is an amendment to the Massachusetts General Law that impacts institutional buildings and their accompanied zoning ordinances. This amendment is called the Dover Amendment and can be found in the Massachusetts General Law (MGL) Chapter 40A, Section 3. It essentially states that any zoning ordinance may be bypassed for a religious or institutional building provided a reasonable argument is given to and accepted by the city Director of Code Enforcement (MGL, 2007). It also enables the design of religious and institutional buildings to bypass the variance and board of appeals process. Table 1 summarizes the impacts of Worcester City Zoning on our project.

Table 1: Worcester City Zoning Ordinances Areas of Impact

Areas of Impact	Corresponding Ordinance/Law	Summary of Impact
Height Restrictions	WZO Articles 1, Table 4.2, Notes to Table 4.2	Measured from main entrance to highest point, cannot exceed limitations of most restrictive bordering zone (in our case 2 stories and 35 feet)
Front/Rear Yard	WZO Article XIII, Section 3, Number 7, Table 4.2, Notes to Table 4.2	50’ from neighboring lot, front minimum depth 15’, side 10’, rear 10’, must provide clear view of intersecting streets
Overall (Dover Amendment)	MGL Chapter 40A, Section 3	Given a reasonable argument made to Worcester Director of Code Enforcement, any zoning ordinance may be ignored if approved – bypasses variances and board of appeals

Given its all-inclusive nature, the Dover Amendment provides a means to relax most restrictions on height and buildable area. For a description of each impacting ordinance and the Dover Amendment, see Appendix B-1.

As discussed earlier, the permissible height and area of a building on a certain plot of land is dictated mostly by the city zoning ordinances. The second main constraint on building design was the building codes. Building codes are legal documents to regulate building construction and assure the health and safety of the building occupants whether through load design or fireproofing. Every state has its own building code with the 780 CMR Building Regulations and Standards, State of Massachusetts or the MSBC applying to this project. To simplify this project however, we decided to use the International Building Code (IBC) as the predominant building code of reference. The IBC as compared to the MSBC is more universal, and simpler to work with. For instance, the IBC is more up to date being re-published every 3 years while the MSBC has been in effect for approximately 10 years. The IBC is contained in one book, outlined clearly and updated every three years with the most recent version published in 2006.

The subjects within the IBC that constrain the building design can be separated into three distinct areas: general structure, means of egress, and fixtures such as water fountains. The general structure is affected by a variety of code provisions, such as height restrictions, occupant loads, and floor thicknesses. The means of egress pertain to doors, stairs, and elevators; the specific criteria depend on the type of structure being built. Last, the fixtures are objects such as showers, bathrooms and drinking fountains and due to handicap accessibility and the building occupancy, there are specific numbers of each fixture required.

For a student dormitory, the type of building is classified as R-2 and has corresponding building code provisions that can be found in numerous IBC tables. Below is a summary of impacts. A further description of each IBC section or table can be found in Appendix B-2.

Table 2: International Building Code Areas of Impact

Areas of Impact	Corresponding IBC Sections	Summary of Impact (see Appendix B-2 for details)
General Structure	404.5, 1004.4, 1004.5, 1014.3, 1016.1, 1017.3, 1019.1, T503	-Enclosed atriums -Sum of occupant loads determine exit capacities → 2 exits required per floor -Travel paths no longer than 125’ on one floor and no longer than 250’ total -No dead ends longer than 20’
Doors, Stairs, Elevators	1005, 1007.3, 1008.1.1, 1008.1, 1009.6, 2001.2, 3002.4, 3006.4	-Specific egress, stairwell, and doorway widths -Landing sizes -Stairwell dimensions (48” between handrails on stairs, 32” doors, landings the same size as doors, no greater than 12’ vertical rise on stairs, etc.) -Elevator construction
Fixtures	1107.6.2.2, 1109.2, 1109.5, T2902.1	-3 handicap showers -10 handicap rooms for building -1 bathroom per 10 people -1 shower per 8 people -1 drinking fountain per 100 people (50% of drinking fountains must be handicap accessible) -1 service sink

To further assist in the design of the building, there are several aid books that contain guidance on standard sizes of rooms, furniture, fixtures, and other necessary features for the functionality of a building. Such resources include <u>Time Saver Standards</u> (Allen, 1997). Although the <u>Time Saver Standards</u> did not have specific dormitory information, it did have information on standard elevator and bathroom sizes such as a common restroom stall being 30”x 60”. Using these constraints the next section outlines the decisions made based upon these and the goals listed in Section 4.1.

4.3: Design Decisions

Before architectural layouts were begun, the goals and constraints for the building were reviewed. To fulfill the programming step of the building design process, decisions concerning these goals and constraints had to be made. For instance, as discussed earlier, to satisfy student needs and current campus trends, a quad and an atrium were included in the design process. Next, to increase room size, the original Stoddard double person room size was determined from the drawings. At 12 feet by 15 feet, students have 180 square feet. We decided to keep the rooms at 12 feet wide to maximize the number of rooms in a wing but increased the length to 18 feet to provide an additional 36 square feet (216 total square feet) of space. It was then also decided to maintain 12’x18’ as the principle unit size, to provide mostly doubles throughout the building, and to provide triples or singles only where one or two doubles would not fit. These decisions also contributed to constructability through repetition.

The next major decision was to build with the hill rather than into or on the hill to decrease the environmental impact as discussed in Section 4.1. The buildings in the current Stoddard Complex are built with the hill in such a way that all floors are split level so that each floor has the same footprint as the others. See Section 2.4 for a full description. However, since the split level floors were a common complaint for students, the new designs do not contain any split level areas. The new designs are built into the hill in such a way that the top floors cover the largest area of any floor while the basement covers the smallest area of any floor. Where the upper floors are larger than those below them, the overhang is supported directly by the ground. Below is an elevation view to fully display this method. This particular elevation view is specifically the U-Design, as will be discussed in Section 4.5. A topographical map of the lot can be found in Chapter 2.

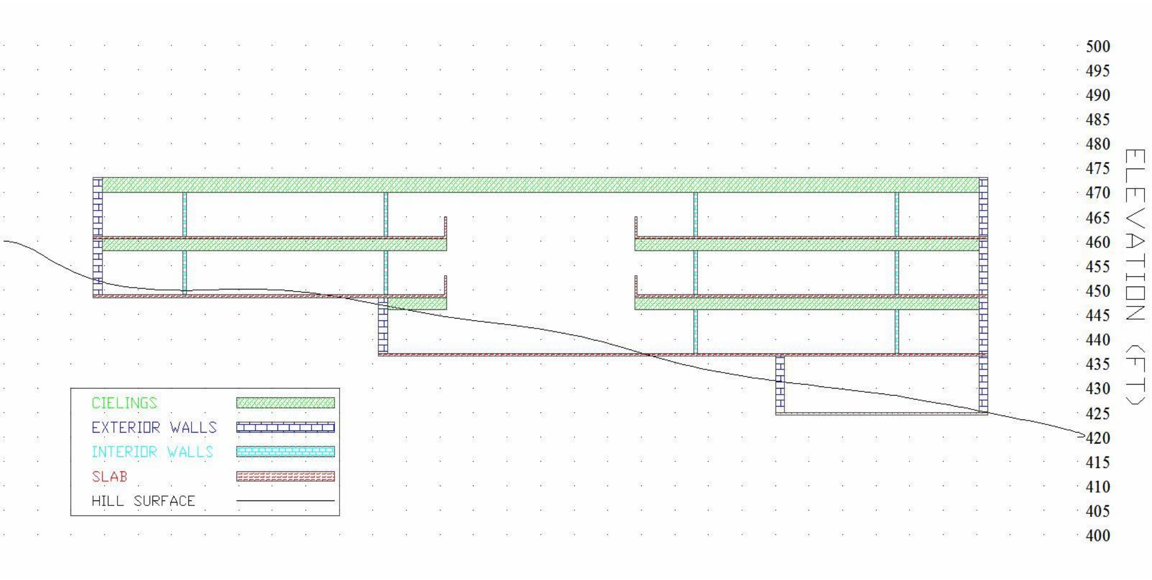


Figure 14: Sample Elevation View (U-Design)

The story height was decided to be 12 feet high, floor to floor. This was based upon the typical ceiling height of a dormitory room ranging between 8 and 9 feet high and allowing for a minimum of 3 feet for floor depth to house the structural framing, mechanical, electrical, plumbing and HVAC utilities.

To increase constructability and maintainability beyond uniform room sizes, certain decisions on the interior of the building were made. First, standard size cinderblock (8 inches x 8 inches x 16 inches) were specified for the walls, allowing for a more durable, long-lasting structure. Brick veneer was selected for the exterior walls to match the surrounding buildings with metal studs for support. Below is a typical cross-section of this exterior wall design. Every interior wall was calculated to be 8 inches thick, and the outside wall would be 24 inches thick to allow for the bricks, studs, interior wall and a cavity between them for insulation and drainage.

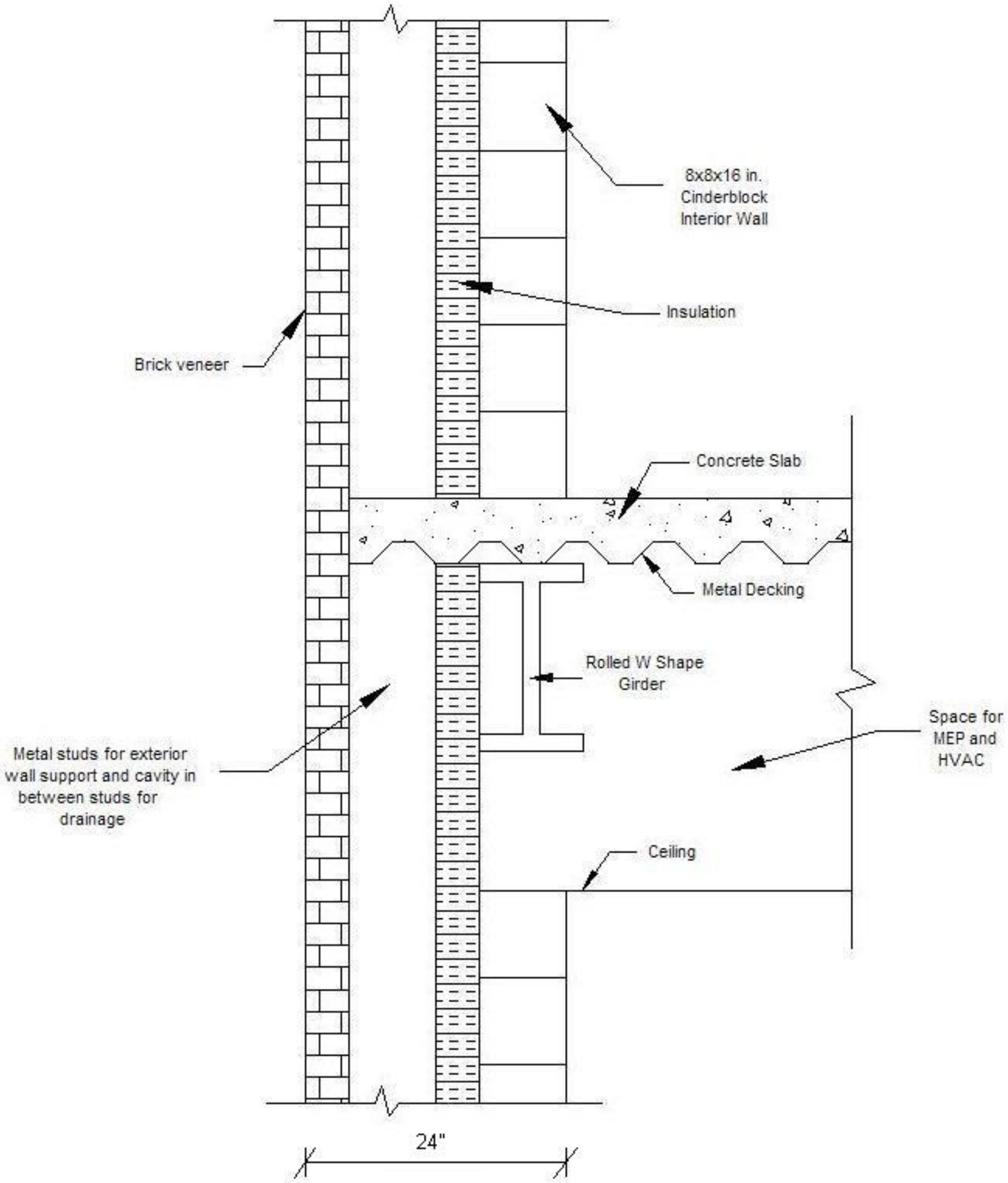


Figure 15: Exterior Wall Cross Section

For the first and main bulk of the design of a steel and concrete structural frame system, these walls were also chosen to be non-load bearing. Non-load bearing walls do not need to be a continuous vertical member thus allowing them to be only 9 feet high (floor to ceiling) rather than 12 feet. This reduced the total weight and number of cinderblocks necessary for the overall building, which reduced cost. It also improved constructability by allowing continuous open space above the suspended ceiling to allow for utilities to easily pass from room to room without having to drill through cinder blocks every 12 feet.

Last, to fulfill the goal of a cost-effective structure, this project evaluated the cost of structural steel for several different schemes and the impact on square foot cost of this steel when some of the decisions listed above are changed. For the results of this cost study see chapters 5 and 6.

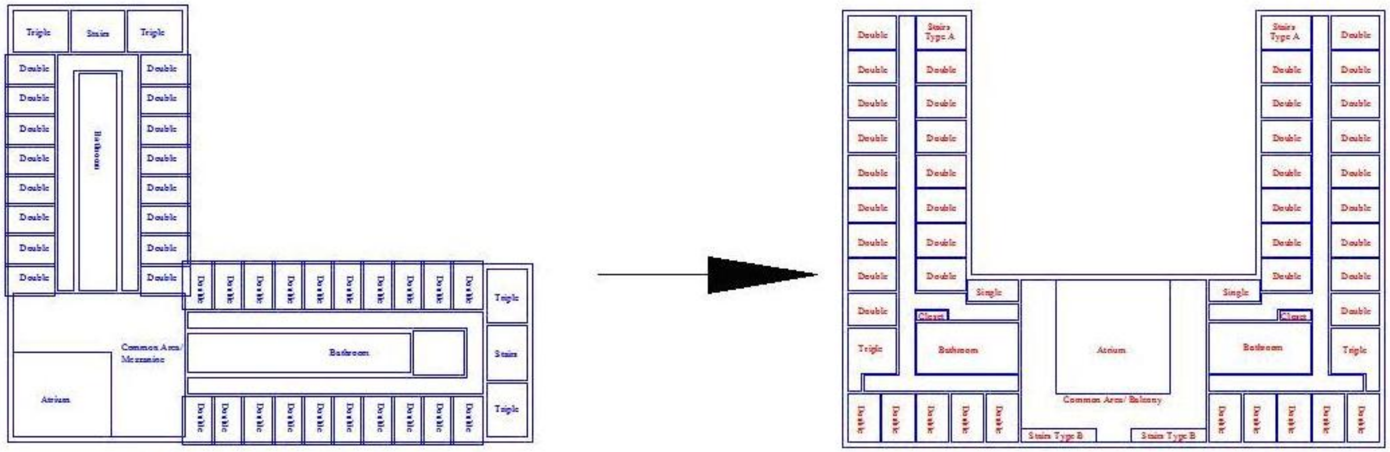
4.4: Layout Development

Although the programming step would normally identify many of the smaller details such as service spaces within a building, the focus of this project was limited to the layout of the individual rooms and common areas. Having begun the initial stages of design in the last section through cross sections of the wall and the discussion of different structural schemes, the bulk of design in the form of the overall building shape was set in motion. During the initial stages of design, the largest factors to influence the proposed layouts were the inclusion of a quad and the slope of the ground on the site. The inclusion of a quad in the building design affected the building footprints. The buildings, already limited in the space that they could occupy, were required to wrap around the quad, which made the footprints elongated, rather than stout shapes. The long narrow spans caused by the quad were also beneficial for allowing more student rooms to be placed in the buildings rather than common spaces or service areas. Each student room requires windows so the long spans created a larger building perimeter, thereby allowing more student rooms.

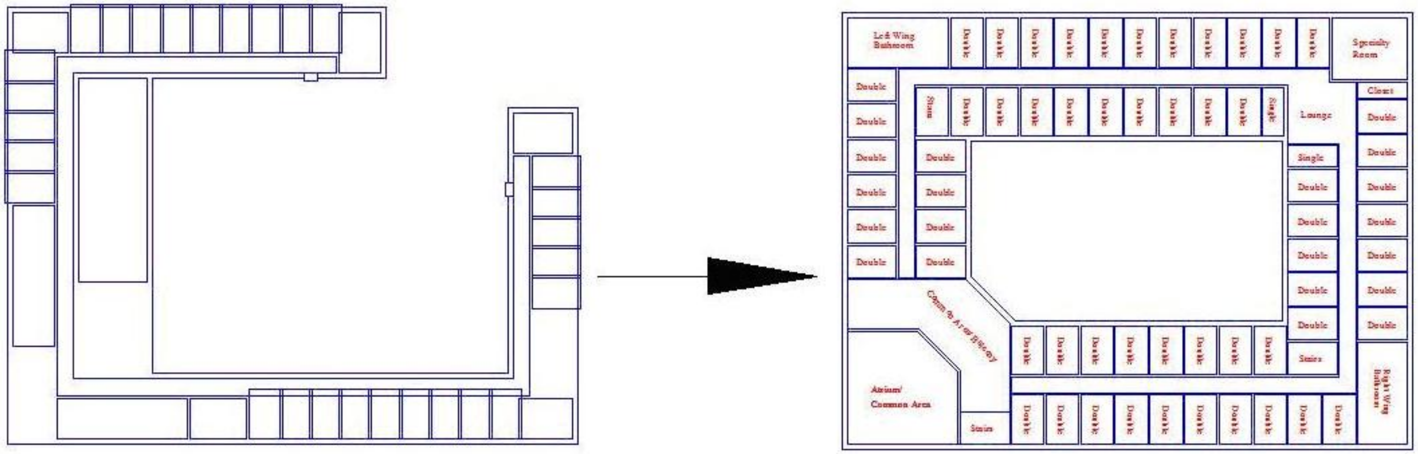
The first two layouts were called the L-Design and G-Design based on the resemblance of the footprints of the buildings to these letters. Both of these layouts were designed with the building edges at least 50 ft. away from the nearest property line in accordance with the zoning regulations.

The limitations based on height and setback were too severe to make the project worthwhile since the goal to increase the number of students housed by 25% could not be met by either layout. Figure 16 shows these original designs that would have been able to house only 210 and 112 students respectively. From this point, it was assumed that for this project to be feasible, the zoning restrictions would need to be relaxed. Because of the Dover Amendment, both the original L- and G-Designs were adapted into two new layouts. The new layouts were intentionally created close to the original limitations to increase the likelihood of them being allowed to fall under the Dover Amendment.

Like the first two, the new designs were named based on the letters that they represented: the O-Design and the U-Design. The O-Design was an expansion of the G-Design; the gap in the Northeast corner was filled so that the building connected to itself and the quad became enclosed by the building. Figure 16 below shows the progression of the L- and G-Designs to their respective U- and O-Designs. Figures 17 and 18 are more detailed, final drawings of the top floors of the U- and O-Designs. This floor is the floor that is two stories above the highest point on the hill. There is a difference between the progression figure and the detailed drawings of the O-Design. The atrium size had to be adjusted in the final stages of the project as will be discussed in Section 5.4



L-Design U-Design



G-Design O-Design

Figure 16: Layout Progression

The O-Design can house 242 students, while still providing a large atrium and other smaller common areas. Unfortunately, the O-Design lacks uniformity and typical areas will have to be very small for them to actually be considered typical.

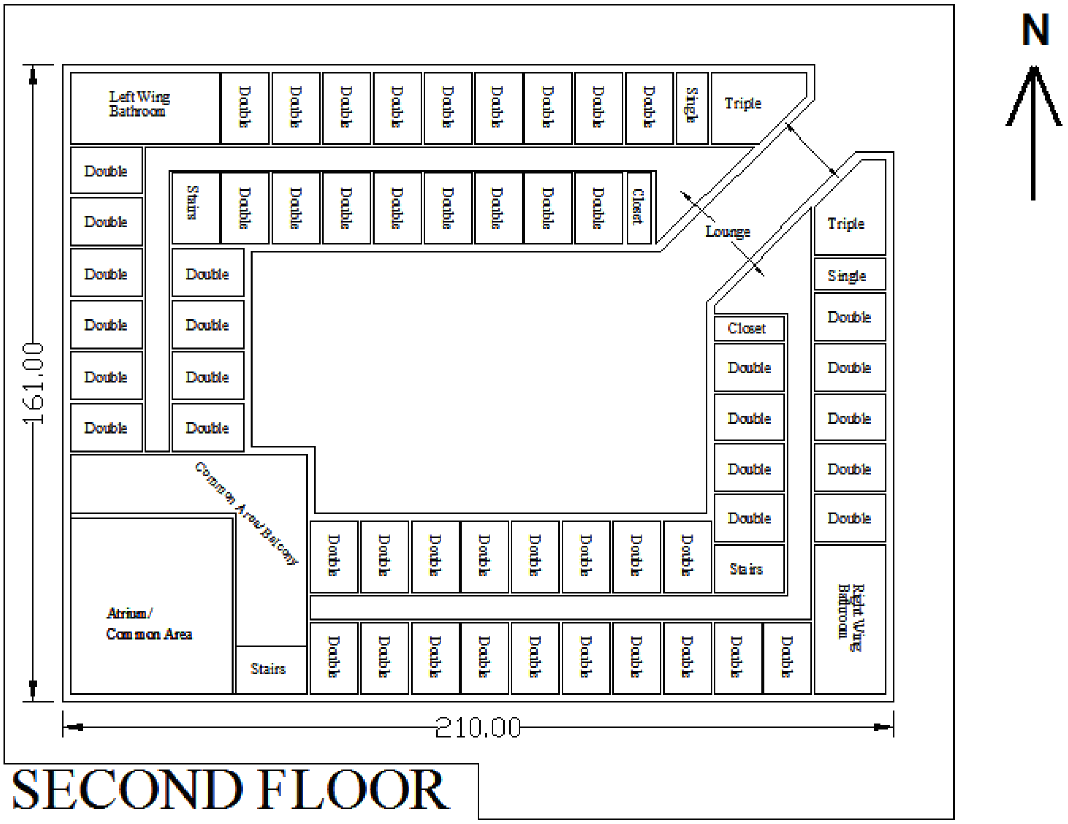


Figure 17: O Design Second Floor

The U-Design was adapted from the L-Design; rather than having two different sized wings perpendicular to each other like the L-Design, the U-Design has two almost-identical wings parallel to each other connected by the atrium. Figure 18 below is a depiction of the top floor of this design, also two stories above the highest point on the hill. The U-Design houses 260 students and the left half of the building is a mirror image of the right which simplifies the structural design and promotes constructability through repetition. An impact of that is that the U-Design lacks common areas, with the exception of the atrium.

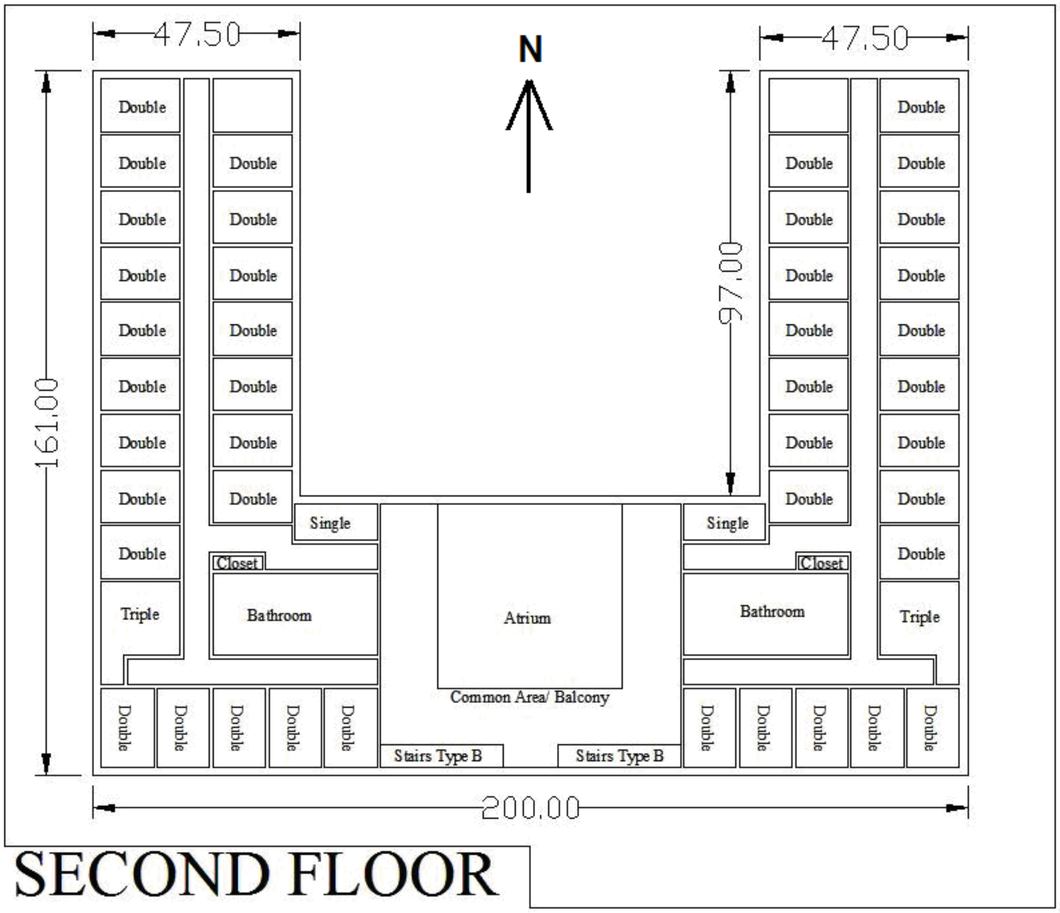


Figure 18: U Design Second Floor

Using these two established layouts, the next chapter discusses the determination of typical bay sizes and the corresponding structural framing. Since both buildings contain uniform room sizes, they were structurally analyzed in the same manner. Chapter 6 evaluated the impact on the structural steel and the resulting change in cost when certain criteria were adjusted. These studies enabled us to make a decision as to which layout would be the most constructible and most cost-effective.

5: Structural Design

There are two parts to the structural design of the building: typical areas and atypical areas. Typical areas are the areas that can be repeated many times throughout the building while atypical areas are relatively unique framing schemes; these have limited application. This chapter looks at the first of these two – typical areas, and is broken down into three sections: the establishment of several bay sizes or "schemes", the sizing of joists and rolled W-shapes (noncomposite and composite), and the cost comparison of several options. Of the twelve schemes that were initially developed, six were pursued for further analysis, and two were chosen for joist design.

5.1: Bay Sizes

In order to design the typical sections of each proposed building (i.e. the O-Design and the U-Design), the typical areas had to be defined. Since both buildings consist of mostly 12'x18' doubles, those were taken as the unit typical bay. Due to relatively heavy loads from the masonry walls (discussed in the next section), the spacing of the infill beams within each typical bay was chosen to be around 4 to 4.5 feet. This spacing dictated the number of infill beams and the load tributary to the beams in each scheme. Twelve framing schemes were developed – six different room arrangements with each having two orientation options for the beams and girders. Figures 19 and 20 below depict these arrangements. The red lines indicate infill beams with the girders running perpendicular to the beams, and the columns are placed at the corners – one at each corner of the bay. The blue hatch indicates interior and exterior walls.

Schemes 1-8

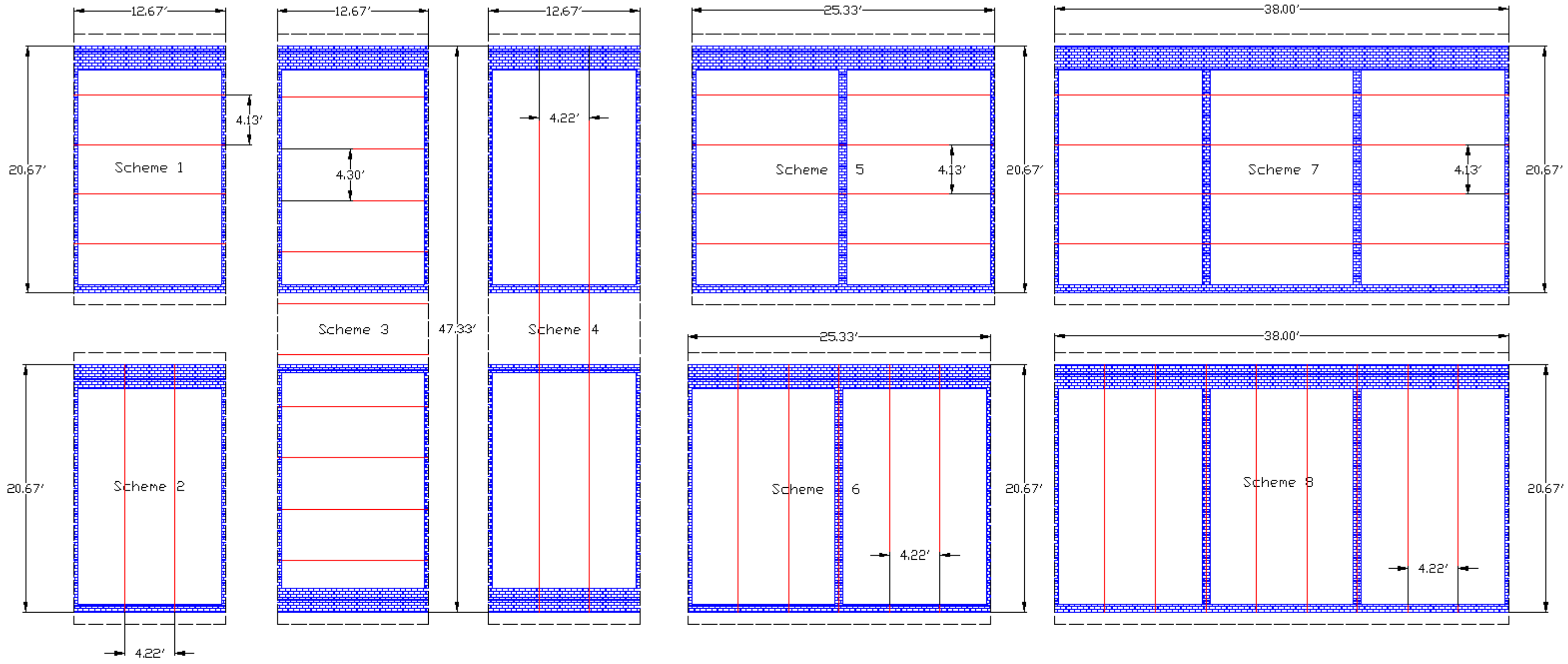


Figure 19: Schemes 1-8

Schemes 9-12

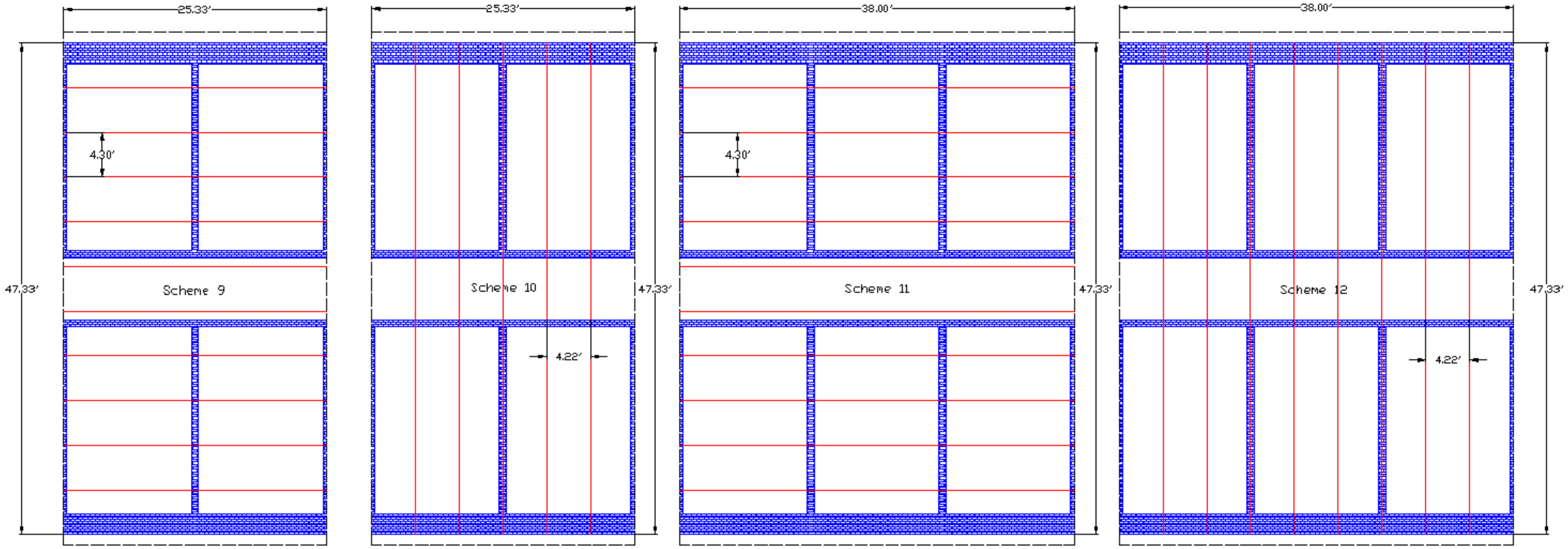


Figure 20: Schemes 9-12

Each of the twelve schemes was analyzed and considered for noncomposite beam and slab designs. The details of the structural design for each of the twelve schemes using rolled W-shapes will be discussed in the next section. The designs were then evaluated to select six schemes that would be considered for composite beam and slab design, and then two out of those six for composite beam, slab and joist design.

To evaluate the different schemes, three major criteria were independently considered in addition to the cost of the steel. The first criterion involved the overall shape and layout of the scheme with a focus on the beam/girder orientation. Since the six were chosen to be representative of the twelve, it was necessary for their selection to cover as broad a base as possible. For instance, schemes 5 and 6 are identical in every way except one: both consist of two rooms, side by side, not spanning the hallway, but one's beams are aligned parallel to the hallway and the other's beams are aligned perpendicular to the hallway (See Figures 19 and 20).

The second criterion was the simplicity of the girder loads. Within the schemes, there are three possible loading situations for the girders. The most desirable situation was presented in the odd-numbered schemes. In these cases, the girder was loaded with two equal, uniform loadings on both sides by the infill beams. Schemes 4, 10, and 12 represent the second most desirable option; the girders were located on the edges of the building and there was still uniformity of the loading, but only to one side. The worst girder loads were present in schemes 2, 6, and 8: the girders bordered the hallway and their tributary area included room loads and the separate and different loads from the hallway. In these situations, eccentric loads are more likely to be present. These loads can be in the form of moment or shear forces, so while the member may still be able to withstand the compressive and tensile forces, it can still fail due to the moment or shear forces. That is why the most desirable options of girders have equivalent, consistent loadings on both sides.

The last criterion considered was the practicality and constructability of the scheme. Members with light loads and short spans are often well under their carrying capacity and members with heavier loads and long spans often have problems with excessive deflections. For instance, schemes 3, 4, 7 and 8 all had very short spans in one direction and very long spans in the other. Thus, the short members were carrying smaller loads than the longer members, the opposite of what is desired. Table 3 below displays the criteria used from each scheme that was used to make a final decision on 6 of the 12 schemes. The schemes presented in blue were those chosen for composite design.

Table 3: Typical Area Scheme Criteria

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**	**10**	**11**	**12**
Total Steel Cost ($/sq.ft)	$7.08	$7.69	$18.29	$26.45	$10.92	$10.78	$19.40	$14.91	$18.16	$28.88	$25.52	$31.73
# Rooms	1	1	2	2	2	2	3	3	4	4	6	6
Girder Simplicity	1	3	1	2	1	3	1	3	1	2	1	2
Spans Hall (Y or N)	N	N	Y	Y	N	N	N	N	Y	Y	Y	Y
Bay Size (sq.ft.)	261.78	261.78	599.56	599.56	523.56	523.56	785.33	785.33	1199.11	1199.11	1798.67	1798.67

The first selections were based solely on cost: the two least expensive, the two most expensive, and two in the middle based on several criteria. This yielded Schemes 1, 2, 10, 12 and two besides those. The rest of the criteria were used to determine these two additional schemes. The girder simplicity was rated on a scale of 1 to 3 (1 being the easiest and 3 being the most difficult).Opting to avoid difficulty, schemes 3, 5, 7, and 9 were chosen. From those four schemes, two had to be eliminated. Scheme 9 also posed many questions being the same size as scheme 10 and yet much less expensive. Thus scheme 9 seemed the most intriguing. Scheme 7 was eliminated due to having three rooms side by side; the beams were required to be quite large with very small girders. It did not seem like a very constructible, repeatable scheme. Scheme 3 was eliminated because it was similar to Scheme 5, but more expensive. From this analysis, schemes 1, 2, 5, 9, 10 and 12 were chosen for composite design.

5.2: W-Shape, Composite, Joist Design

The first step in the design of each framing scheme was to determine the loads. Most of the values were minimum design loads gathered from the International Building Code (IBC) and the Massachusetts State Building Code (MSBC). For instance, the snow load was found to be 35 psf for Worcester, MA according to the IBC, and MEP was assumed to be 5 psf based on the MSBC. Table 4 is a summary of the loads used. The most difficult loads to determine were the dead loads due to the interior and exterior walls. Based on a variety of sources such as the Concrete Masonry Handbook (1980) by the Portland Cement Association and Minimum Design Loads for Buildings (1994) by the American Society of Civil Engineers, the exterior wall consisting of brick finish with metal stud supports and an air cavity for drainage and insulation, was assumed to weigh about 48 psf of vertical wall surface. For interior walls, a standard hollow 8”x8”x16” concrete masonry unit (CMU) consisting of cinder ash also known as a “cinderblock” was determined to weigh approximately 38 psf of vertical wall surface.

Table 4: Load Values, Specifications and References

Load	**Magnitude**	**References Used**
Live	**100 psf**	IBC
Snow	**35 psf**	IBC, MSBC

Dead Load	**Specifications**	**Magnitude**	**References Used**
Concrete Slab	**5”** (mean height) at 145 pcf (see Figure 21 below)	**60 psf**	IBC, Allen (1997), USD
Metal Decking	**2”** LOK Decking; 18 gauge	**2.4 psf**	USD
Interior Walls	8”x 8”x 16” standard hollow unit coal-cinder concrete blocks; multiply by vertical area of wall to get total partition weight	**38psf**	Concrete Masonry Handbook (Portland Cement Association)
Exterior Walls	4” standard brick with metal studs	**48 psf**	ASCE 7
Ceiling	Suspended Acoustical Plaster on Gypsum Lathe (not ceiling tiles and most conservative)	**10psf**	Material Weights, MSBC
MEP		**5psf**	MSBC

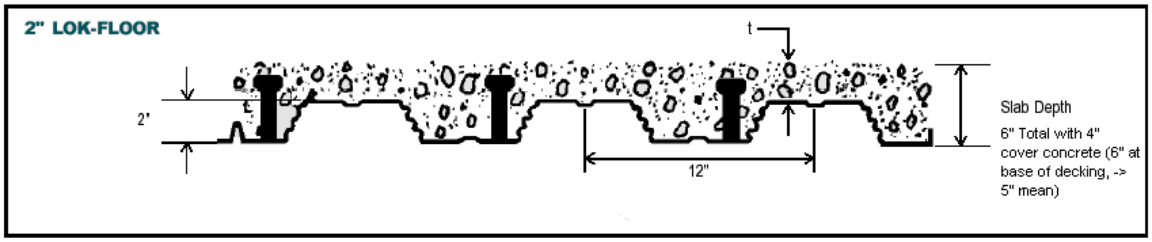


Figure 21: Metal Decking with Concrete Slab Cross Section (United Steel Decking)

Based on the framing schemes developed before-hand, and the above stated loads, beam, girder and column sizes were determined for all twelve schemes assuming non-composite beam and slab construction. Members were then sized for schemes 1, 2, 5, 9, 10 and 12 assuming composite beam and slab construction. These designs were based on the LRFD methods and values that are outlined in the AISC Steel Construction Manual, 13th Edition (2005). Beams and girders were assumed to be simply supported with pinned end connections. The loads were also assumed to be distributed over a 6" slab creating uniformly distributed loads on each steel member. Unshored construction was also assumed, and therefore an analysis of load effects during construction with the wet concrete considered as a live load was completed. Sample hand calculations and samples of the spreadsheet that was developed to facilitate sizing can be found in Appendix D-1, along with a complete list of design moments and steel sizes for each scheme in Appendix D-2. One note on the composite design: due to such small loads and beam sizes for the noncomposite beam and girder designs in scheme 1, the tributary width of the beams was increased for composite design by using less infill beams, thereby placing more of the load on fewer beams.

For the open web joist design, loads that did not have to be distributed over the floor area were not distributed. The motivation for incorporating the open web joists into the process was the idea that by treating the loads in a more specialized way, members could be more appropriately sized. This meant that rather than several uniformly sized members sharing a large load, the members most affected by the load would be larger than those parallel to them. Looking at Figure 23, typically, the dead loads from the walls are distributed over the bay area and shared by the members. In the case of the design for the joists, the dead loads of all the walls are applied directly to the members below them. See Figure 23 for a visual representation of the differences in loading.

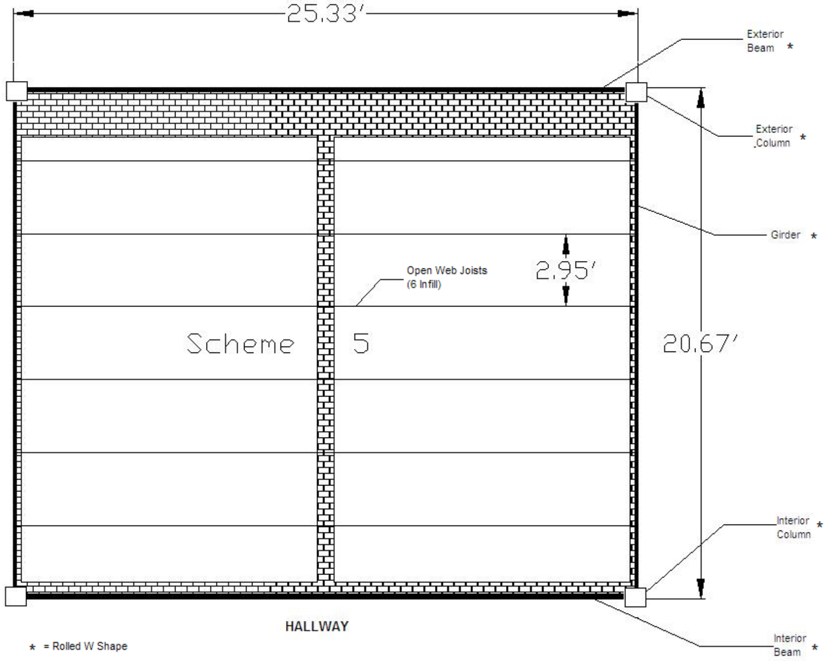


Figure 22: Scheme 5 Joist Design Members

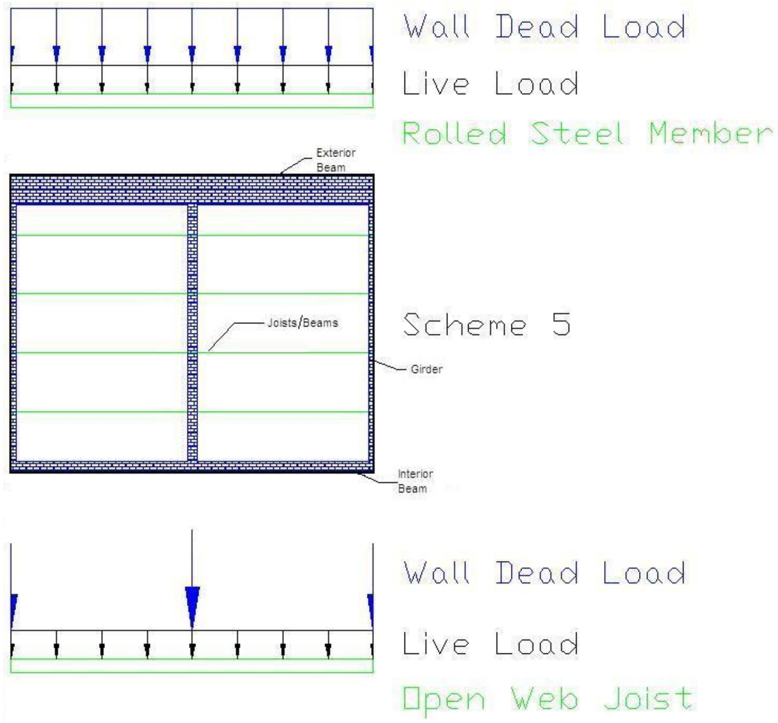


Figure 23: Load Alignment Display

The first members chosen for design were the open web joists themselves, as they spanned areas with the very little direct loading (compared to the members placed directly under the masonry walls). Parallel to the joists on each side were an interior beam and an exterior beam (rolled steel shapes). Perpendicular to these members, and responsible for carrying the load of the joists (and in Scheme 9, the interior beams as well), were the girders. To determine the impact of the loads on the girders, the joist and beam end reactions were applied as point loads on the girder. The spacing of the point loads was then used to convert the concentrated forces into distributed loads along the lengths of the girders. Table 5 is a summary of the beam, girder, column, and joist sizes for the six schemes, including noncomposite and composite design.

Table 5: Summary of Steel Sizes

	Scheme 1	Scheme 2	Scheme 5	Scheme 9	Scheme 10	Scheme 12	Scheme 5 (Joist Scheme)	Scheme 9 (Joist Scheme)
Beam Noncomposite	W6x12	W12x19	W14x26	W14x26	W27x84	W27x84	N/A	W12x40 (E) W12x30 (I)
Beam Composite	W10x15	W10x15	W12x16	W12x16	W21x50	W21x50	W12x22 (E) W12x16 (I)	N/A
Girder Noncomposite	W18x35	W12x22	W21x62	W40x215	W24x76	W33x130	N/A	W40x167
Girder Composite	W14x30	W10x15	W16x36	W33x130	W21x44	W27x84	W14x30	N/A
Column Noncomposite	W10x22 (E) W10x26 (I)	W10x22 W10x26	W16x36 W12x40	W21x68	W14x61	W18x86	N/A	W21x68
Column Composite	W10x22 (E) W10x26 (I)	W10x22 W10x26	W16x36 W10x39	W16x67	W12x53	W14x61	W16x40 (E) W14x38 (I)	N/A
Joist	N/A	N/A	N/A	N/A	N/A	N/A	20K7	18K9

There are noticeable differences in sizes between noncomposite and composite designs. Even the members involved in the joist schemes are significantly smaller than the noncomposite sections. This has a direct affect on the overall cost of each scheme which will be evaluated in the next section.

5.3: Cost Comparison

The cost of steel was assumed to be approximately $2500 per ton and $3 per stud based on prices found in Building Construction Costs Data (RS Means, 2007). Also from RS Means, the costs of the joists were assumed to be $7.25 per foot of length. From these costs, a preliminary cost estimate in dollars per square foot was developed for the structural steel within each scheme.

There were two distinct types of designs developed: noncomposite and composite rolled W-shapes, and noncomposite and composite rolled W-shapes with joists spanning the rooms. Of these cases, composite design was consistently the least expensive option. Schemes 5 and 9 were the only two schemes developed with joists – scheme 5 used a composite design, and scheme 9 used a noncomposite design. The effects of joist design were very small, increasing the cost of composite design in scheme 5 by $0.16 per square foot and decreasing the cost of noncomposite design in scheme 9 by $0.77 per square foot (see Table 6).

Table 6 summarizes the square foot cost estimates for schemes 1, 2, 5, 9, 10 and 12. As can be seen, Scheme 1 has the lowest cost for noncomposite design while Scheme 2 has the lowest cost for composite design. However, Schemes 1, 2, 5 and 5 for the joist design, are all within 4% of each other in square foot cost and therefore do not pose a significant difference. It is also interesting to note that as the square footage of the bays increased, the beam and girder costs increased while the column costs decreased. This will be further discussed in the Conclusions section.

Table 6: Typical Area Structural Steel Cost Comparison

	Scheme 1	Scheme 2	Scheme 5	Scheme 9	Scheme 10	Scheme 12
Column Noncomposite ($/ft^2)	$4.01	$4.01	$3.21	$3.40	$3.05	$2.87
Column Composite ($/ft^2)	$4.01	$4.01	$3.18	$3.35	$2.65	$2.03
Beam and Girder Noncomposite	$7.08	$7.69	$10.92	$18.16	$28.88	$31.73
Beam and Girder Composite	$6.44	$6.16	$7.18	$11.80	$18.68	$20.88
Total Cost Noncomposite	$11.09	$11.70	$14.13	$21.56	$31.93	$34.60
Total Cost Composite	$10.45	$10.17	$10.36	$15.15	$21.33	$22.92
Joist Design Noncomposite	N/A	N/A	N/A	$20.79	N/A	N/A
Joist Design Composite	N/A	N/A	$10.52	N/A	N/A	N/A
Square Footage	261.778	261.778	523.556	1199.111	1199.111	1798.667

The following charts are a visual breakdown of the cost for scheme 5 with joists and scheme 5 without joists. The joists absorb just under half of the beam cost without joists. This seems logical in that the joists are essentially replacing the infill beams within the rooms, leaving one single beam under each wall. It is also interesting to note that the majority of the cost is dictated by the beams when joists are not used.

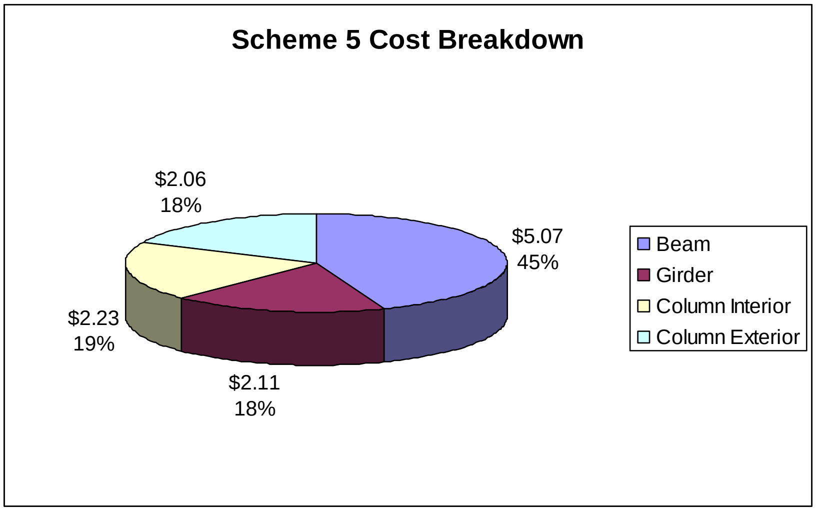


Figure 24: Scheme 5 Cost Breakdown Pie Chart

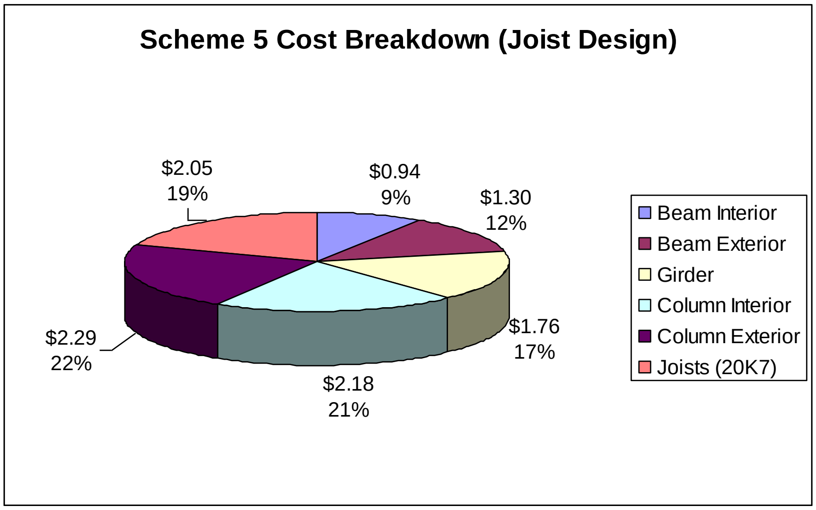


Figure 25: Scheme 5 Cost Breakdown Pie Chart

As stated previously, the overall cost difference (joists vs no joists) is quite small – less than 20 cents per square foot. However, as can be seen by the cost breakdown, joist design requires three different members (joists, interior, and exterior beams) this member diversity, while having no noticeable effect on the cost of materials, will have a larger construction cost. That increase in cost, coupled with the comparable prices eliminates open web joist design as a viable option.

As discussed earlier, there is a significant decrease in cost when composite beam and slab designs are used. Also, all schemes spanning the hallway were dropped due to the fact that there are not that many areas in both buildings where rooms line up with each other across the hallway. This left us with schemes 1, 2 and 5 for composite designs. Although scheme 5 is more expensive than scheme 2 by 19 cents per square foot, scheme 5 is the best option to repeat throughout the building. This is because it uses half as many columns and therefore would reduce the construction cost for columns and footings.

5.4: Atrium Design

The atriums are the largest and most prominent atypical areas in both building designs. For this reason, they were a factor in deciding which building layout was used. The process of designing the atrium was far more difficult than any of the typical areas. Each atrium, in addition to accounting for more volume than any other room, contained an elevator shaft and at least one staircase.

The first step in the atrium design was column placement. Due to the locations of the rooms adjacent to the atrium, most of the column locations were already determined. The new columns were just placed on the corners of the open area of the atrium and where necessary on the staircases and elevator shafts. The next step was horizontal member placement. Both atriums contained floor layouts where the upper levels had ninety degree bends. The placement of the members is depicted in Figures 26 and 27. One of the main considerations for beam and girder placement was that if possible, members should be attached directly to a column rather than another member. This is evident by the placement of the girders as well as several beams in each layout.

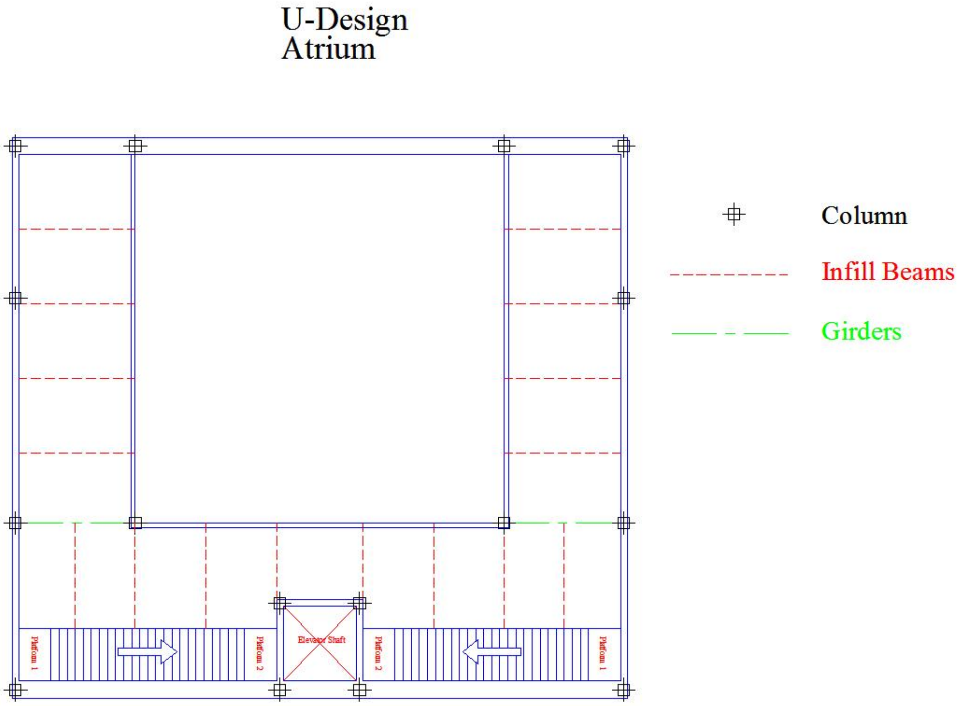


Figure 26: U-Design Atrium

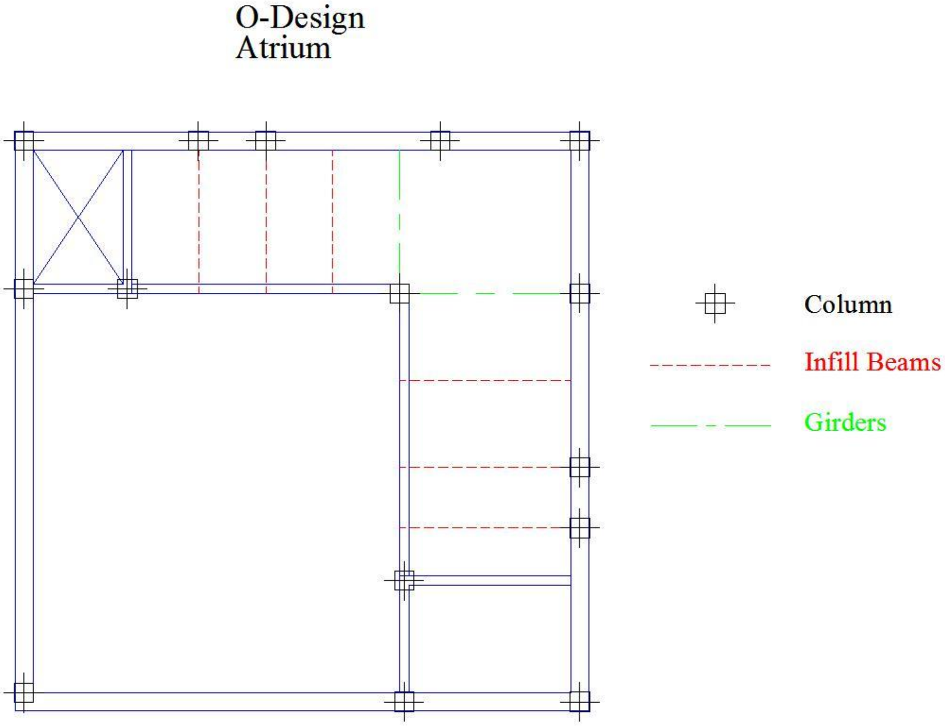


Figure 27: O-Design Atrium

At this point the beams, girders and columns could be designed. However, some information was lacking to make accurate decisions regarding the design of some members. For example, the focal points of the atriums are the large walls of windows that allow natural light in. Dead load values for large scale windows and their bracing were not easily found, but according to Building Constructed Illustrated, insulating window glass has a weight of 6.54 pounds per square foot (Ching, 12.17). The other prominent issue with the designs was that in the U-Design, bathrooms are located directly next the atrium. The bathrooms are typical areas that were not designed, and as such, contribute unknown loads to the atrium members bordering them. As can be seen by Figure 28, the side of the bathroom that borders the atrium is where the toilet stalls are located. According to American Standard, most of their toilets weigh between seventy-five and ninety pounds (American Standard). The American Standard “Town Square” Sink was also chosen as the default sink. Using these estimates it was determined that the dead load on the adjacent atrium member from the bathroom, was about 800 pounds. Table 7 summarizes the load values used for the atrium design.

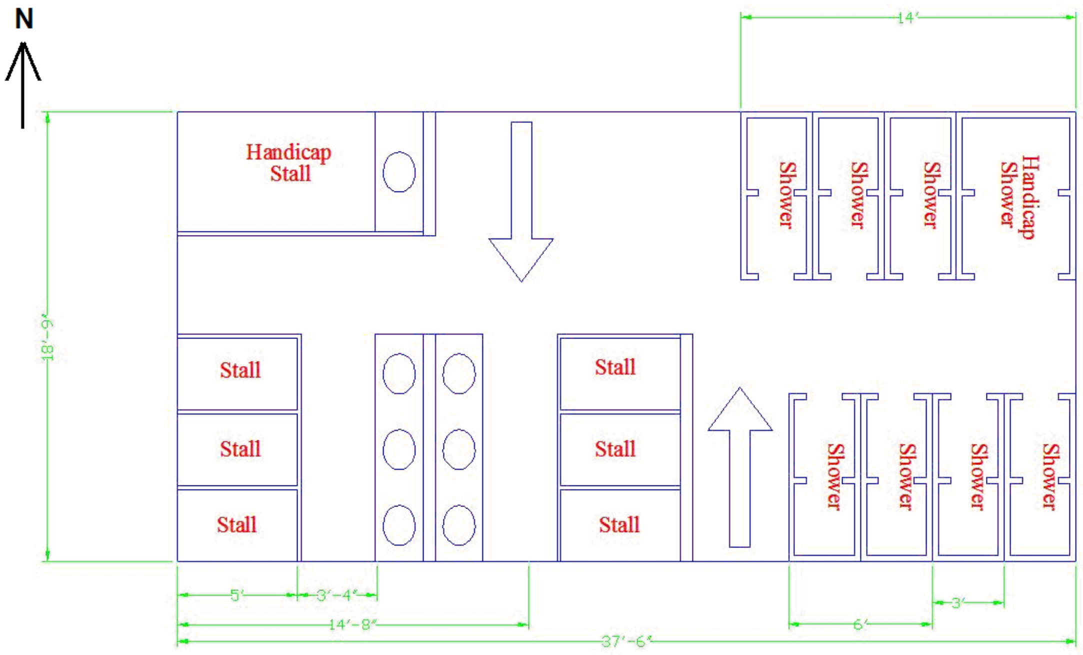


Figure 28: U-Design East Wing Bathroom Layout

Table 7: Atrium Loads

Item	Specifications	Value Used	References Used
Elevator	Elevator Weight	6000 lb	Wikipedia
	Elevator Car Dimensions	5'8" wide, 4'6" deep, 3' wide door opening	2003 IBC
	Elevator Shaft Dimensions	79.5" wide, 88.5" deep	ThyssenKrupp Elevator
Stairs	Dead Load	23.7lb/vertical ft of distance spanned	The Professional Practice of Architectural Detailing
Reinforced Glass	Dead Load	3.28 lb/ft^2	Building Constructed Illustrated
Toilet	Dead Load	100 lb	American Standard
Sink	Dead Load	65 lb	American Standard
Tile Floor	Dead Load	30 lb/ft^2	Nash, pg 128

The last step of the atrium design was to analyze the members to determine an overall cost of the steel. This was accomplished by assuming the steel costs $2500 per ton, the same assumption that was used for the other structural work. The results of the cost comparison revealed that the necessary steel for the U-Design would cost about $146,000, almost $50,000 more than the steel necessary for the O-Design; about $97,000. When the cost of the insulating glass are included, $18.50 per square foot (R.S. Means, 2008), the total cost of the U-Design jumps to about $168,000, which is closer to, but still significantly more than the O-Design cost of around $135,000.

6: Further Study – Interior Construction

Having looked at the structural framing system of the building and choosing one particular building layout, a typical scheme and a type of framing system, to continue the design of a dormitory building, aspects of the interior construction were studied and designed. This chapter will use masonry design as an example of such interior construction. The topic of masonry design is not a subject commonly covered in our civil engineering classes. Therefore, the goal of this chapter is to become familiar with masonry walls and apply their use to our project through a cost estimate of load bearing walls and a life-cycle cost analysis of drywall versus masonry walls.

6.1: Masonry Load Bearing Walls

As discussed in Section 2.5, load bearing walls establish a structural scheme that is distinct from frame construction. The goal of this section is to evaluate the impact on cost per square foot of floor area for typical areas had the masonry walls been load bearing. Scheme 5 will be used as the basis for design with infill beams, one interior load bearing wall and four exterior load bearing walls; exterior meaning exterior to the scheme and not necessarily the building itself.

The first step to create a cost estimate of a load bearing scheme was to determine what is needed in the structural system. Chapter 5 outlines the components of the non load bearing frame. The first component in the load bearing scheme will be infill beams. The loads from these beams will then be transferred to the masonry walls. Therefore, instead of four 25 foot infill beams, there were eight 12 foot infill beams since the interior wall is load bearing and separates the two rooms. There will also be no need for girders or columns in that each load bearing wall will transfer loads directly down to the foundation. This required that all interior walls were floor to floor instead of floor to ceiling, or 12 feet high instead of 9 feet high. Refer to Figure 29 for an illustration of this scheme.

The purpose of this estimate was to get a sense of proportion of the cost difference between the two framing options. It is therefore assumed that the masonry walls are capable of supporting their own weight and that of the imposed loads from the beam since this is a relatively low-rise building (2-4 stories). Having taken care of the gravity loads in this manner, the lateral loads were next evaluated.

Using the Massachusetts State Building Code (MSBC) to obtain approximate wind pressures, the maximum applied wind load was calculated. The city of Worcester falls within Zone 2 in the state of Massachusetts, the type of residency of our building can be classified as Exposure B, and the highest part of the building is 48 feet on the west side. Therefore, according to Table 1611.4 (MSBC, 2007), the reference wind pressure is 17 pounds per square foot. Due to the vertical irregularities of the building, we did not make an estimate of the seismic base shear. As will be seen in the following analysis, the system we developed for lateral load resistance is more than necessary for the wind loads and due to the low seismic activity of this region, should be adequate to resist seismic base shear also.

Rather than using rigid connections as may be considered for a framed system, a system for shear walls was determined. In masonry walls, shear walls can be created by adding reinforcing within the masonry wall in the form of grout and rebar. To create a system of shear walls, we assumed reinforcing in every other partition between rooms and in both sides of the corridors. The exterior walls are only load bearing and thus unreinforced. In a three dimensional representation of Scheme 5 shown without the exterior wall, Figure 29 shows the location of each reinforced wall within the scheme.

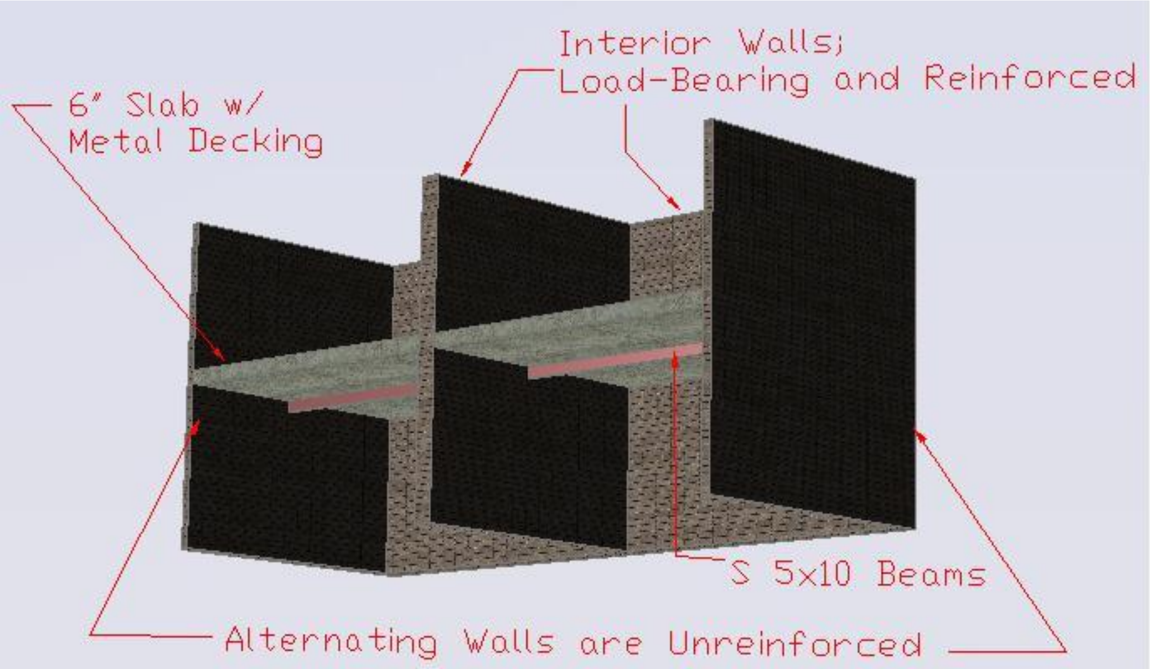


Figure 29: 3D Representation of Load Bearing Wall System

To check the feasibility of such a shear wall system, stress values were determined and compared against the maximum allowable stresses from given masonry walls. A 17 psf wind pressure on the exterior wall would transfer to approximately 4.7 psi on the interior walls. This pressure would be parallel to the running bonds for the walls between the rooms and would be perpendicular to the bonds for the walls bordering the hallways. In her book Masonry Design and Detailing, Beall gives the allowable stresses for the different types of reinforcement (axial, flexural, shear, etc.). For an 8 inch thick hollow core masonry unit wall with the least amount of reinforcement, the wall is capable of resisting at least 50 psi flexural and 150 psi shear. This is well over the 4.7 psi calculated from wind loads and thus capable of carrying such loads.

To keep the cost estimate consistent between the load bearing design and the non-load bearing design, only the steel and masonry costs were tabulated. The RS Means Assemblies Cost Data (RS Means, 2006) was used to determine the cost of the masonry walls with or without reinforcement. The cost of the steel beams was assumed to be $2500 per ton as discussed and used in Chapter 5.

Some decisions were required when choosing the materials for the masonry walls. As discussed earlier, the location of reinforced walls were chosen and can be seen in Figure 29. In addition to the location of reinforced walls, an amount of reinforcement had to be chosen. As outlined by Beall in her book Masonry Design and Detailing, lateral reinforcement is typically #4 or #5 rebar spaced between 16 and 40 inches. To remain conservative and also reasonable for a low-rise building and keeping in mind the allowable stresses discussed earlier, #5 rebar spaced 32 inches on center was chosen. Second, to remain consistent with the loads used in Chapter 5 for the masonry blocks, lightweight 8x8x16 inch hollow core cinderblock was used. Third, whether the walls are load bearing or not, the same finish will be applied and therefore to increase the simplicity of the cost estimate, no finish was specified for both load and non-load bearing walls. Last, to increase the accuracy of the cost estimate, the beams for the load bearing scheme were resized. W12x16's are used in Chapter 5 since they support the weight of the walls. Using the same methods and spreadsheets developed in Chapter 5, S5x10 beams were determined sufficient for the loads. Below is a summary of these decisions:

1. Reinforcement in walls placed in every other room partition and walls spanning the corridors; #5 rebar spaced 32” O.C. used for reinforcement
2. 8x8x16 inch lightweight, hollow core cinderblock used for load bearing and non-load bearing walls
3. No finish applied to walls in either framing scheme
4. Load bearing scheme beams resized to S5x10s

Based upon these decisions, the following cost estimates were completed. There is a transition within the spreadsheets from cost per square foot of wall area to cost per square foot of floor area. The quantities referred to within the tables are square foot of wall area and when multiplied by the cost per square foot of wall area, a straight cost per scheme is obtained. The overall cost is then tabulated and divided by the total square feet of each scheme (523.55 ft^2) to determine a cost per square foot of floor area which is readily comparable to other schemes. This method is used for all of the following cost estimates. See Appendix E-1 for the backup tables that outline the quantities.

Table 8: Loadbearing Wall Cost Estimate

LOADBEARING

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Total Cost
Exterior Concrete Block Wall	8x8x16 Lightweight (105pcf), Unreinforced, No core fill	B2010 110 3440	Square Feet (wall area)	$8.10	304	$2,462.40
Interior Concrete Block Wall	Hollow, 8 inches thick, Lightweight partition, Unreinforced, No finish	C1010 104 6000	Square Feet (wall area)	$8.10	124	$1,004.40
Interior Concrete Block Wall	8x8x16 Lightweight (105pcf), Reinforced (#5 @ 32")	B2010 112 7430	Square Feet	$9.46	552	$5,221.92
Structural Steel	S5x10 Beams		Tons	$2,500	0.48	$1,200.00

Total:	**$9,888.72**
Per Square Feet (floor area):	**$18.89**

Table 9: Nonloadbearing Wall Cost Estimate

NONLOADBEARING

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Total Cost
Exterior Concrete Block Wall	8x8x16 Lightweight (105pcf), Unreinforced, No core fill	B2010 110 3440	Square Feet	$8.10	228	$1,846.80
Interior Concrete Block Wall	Hollow, 8 inches thick, Lightweight partition, Unreinforced, No finish	C1010 104 6000	Square Feet	$8.10	600	$4,860.00
Structural Steel	W12x16 Beams		Tons	$2,500	0.811	$2,027.50
Structural Steel	W16x36 Girders		Tons	$2,500	0.372	$930.00
Structural Steel	W16x36 Exterior Columns		Tons	$2,500	0.216	$540.00
Structural Steel	W10x39 Interior Columns		Tons	$2,500	0.234	$585.00

Total:	**$10,789.30**
Per Square Feet (floor area):	**$20.61**

As can be seen by Tables 8 and 9, the cost per square foot of floor area of a load bearing framing scheme is approximately two dollars less than a non-load bearing scheme. This makes sense in that if masonry walls are going to be used, a system where they can support their own weight may be more cost effective. For this particular cost estimate however, much of the cost is dependent on the decisions that were discussed earlier. For instance, had a different type of reinforcement been used, the cost per square foot of reinforced walls could have increased more than a dollar and thus increased the overall cost per square foot. Therefore although this estimate does show a difference in cost per square foot, it is only a sense of proportion and can be sensitive to a number of factors when a comprehensive analysis is completed. The next section will examine a different aspect of the cost of masonry walls through a comparison with drywall construction.

6.2: Drywall versus Cinderblock

Although masonry block walls are assumed for this project, there are many different types of wall systems such as gypsum and lathe, plywood sheathing and drywall. Drywall is a very common material in buildings since it is lightweight, easy to construct and easy to finish. Drywall however does not provide the durability, fire protection and sound absorbing qualities of cinderblock. The goal of this section is to evaluate the difference in cost between drywall and cinderblock construction and maintenance for the typical areas of our designed building. This cost difference will be evaluated through a life cycle cost analysis of both materials.

The first step to completing this cost estimate was to determine the initial cost difference between the two materials. Using the non-load bearing estimate from the previous section, a cost estimate for the cinderblock system was already completed. For the drywall system, all steel sections had to be resized due to the reduced loads from the interior walls. Again using the same methods and spreadsheets from Chapter 5, it was determined that the beams would remain the same at W12x16s but the girders would be reduced to W16x31s and the columns to W10x22s and W10x26s. Using a fire resistant drywall with wood studs 24 inches on center, the following cost estimate was tabulated. The backup tables used to determine the quantities of each item can be found in Appendix E-2.

Table 10: Drywall Initial Cost

DRYWALL INITIAL COST

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Total Cost
Drywall/Wood Stud Framing	5/8" FR Drywall with 5/8" FR Drywall base layer and 2x4 @24" O.C. Wood Stud Framing	C1010 124 1800	Square Feet	$5.08	1080	$5,486.40
Structural Steel	W12x16 Beams		Tons	$2,500	0.811	$2,027.50
Structural Steel	W16x31 Girders		Tons	$2,500	0.320	$800.00
Structural Steel	W10x22 Exterior Columns		Tons	$2,500	0.132	$330.00
Structural Steel	W10x26 Interior Columns		Tons	$2,500	0.156	$390.00

Total: **$9,033.90**

Per Square Feet: **$17.25**

Table 11: Cinderblock Initial Cost

CINDERBLOCK INITIAL COST

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Total Cost
Exterior Concrete Block Wall	8x8x16 Lightweight (105pcf), Unreinforced, No core fill	B2010 110 3440	Square Feet	$8.10	228	$1,846.80
Interior Concrete Block Wall	Hollow, 8 inches thick, Lightweight partition, Unreinforced, No finish	C1010 104 6000	Square Feet	$8.10	600	$4,860.00
Structural Steel	W12x16 Beams		Tons	$2,500	0.811	$2,027.50
Structural Steel	W16x36 Girders		Tons	$2,500	0.372	$930.00
Structural Steel	W16x36 Exterior Columns		Tons	$2,500	0.216	$540.00
Structural Steel	W10x39 Interior Columns		Tons	$2,500	0.234	$585.00

Total: **$10,789.30**

Per Square Feet: **$20.61**

As expected, due to the decrease in size of the steel sections and the decrease in cost between drywall and cinderblocks, the cost of construction of a drywall system is approximately three dollars less expensive than a cinderblock system. The next step is to provide a cost-time study where the cost of maintenance for each of the respective walls is estimated. To determine the cost of maintenance for each type, both RS Means books and an interview with Chris Salter, the associate director of facilities services and the manager of technical trades at WPI were used. For a full interview summary, see Appendix B-4. Chris Salter was able to give a few ballpark figures on the frequency and nature of repairs for drywall walls (Salter, 2008). From these, specific types of repairs and paint jobs were selected from the RS Means Building Construction Cost Data (RS Means, 2007). Three levels of repair were chosen: conservative, average and low. According to Chris Salter, the nature and frequency of the repairs are dependent on the residents of the building. Therefore, the goal of defining three levels of repair was to give a range of values for a range of residents. The most conservative estimate would fit for the most destructive residents in that it requires the most repairs per year. The average and low would be less destructive residents. For our particular project where this is a freshmen dormitory, a value between the average and conservative levels would be most accurate because the residents would be mostly male 18-19 year olds and as described by Chris Salter, these are some of the most destructive type of residents.

The following tables give an example of the maintenance estimates completed for drywall versus cinderblock. Tables 12 and 13 are the tables used for the conservative level of repair. The purpose of these tables is to provide a cost per year of repairs for each system. This is done through square foot of floor area costs for paint jobs and the frequency of individual repairs of drywall.

Table 12: Drywall Maintenance Summary

DRYWALL MAINTENANCE SUMMARY

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Frequency (years)	Total Cost per Year
Nail Holes	Fill and Sand	09 01 70.10 0100	Each	$0.49	1	300.00	$147.00
Dents	Fill and Sand, Up to 2" Square	09 01 70.10 0120	Each	$9.90	1	15.00	$148.50
Dents	Fill and Sand, 2"-4" Square	09 01 70.10 0130	Each	$19.80	1	5.00	$99.00
Holes	Cut square, Patch, Sand and Finish, 2"-4" square	09 01 70.10 0150	Each	$43.00	1	5.00	$215.00
Holes	Cut square, Patch, Sand and Finish, 4"-8" square	09 01 70.10 0160	Each	$47.50	1	2.00	$95.00
Holes	Cut square, Patch, Sand and Finish, 8"-12" square	09 01 70.10 0170	Each	$60.00	1	0.33	$19.80
Clean	Drywall, Wash	09 91 03.40 0730	Square Feet	$0.13	1080	1.00	$140.40
Paint	One coat, Oil base, Primer or Sealer, Roller	09 91 23.72 0840	Square Feet	$0.36	1080	1.00	$388.80

Total: **$1,250**

Per Square Feet : **$2.39**

Table 13: Cinderblock Maintenance Summary

CINDERBLOCK MAINTENANCE SUMMARY

Item	Details	RS Means Code	Units	Unit Cost	Quantity	Frequency (years)	Total Cost per Year
Paint	One coat, Oil base, Primer or Sealer, Roller	09 91 23.72 2100	Square Feet	$0.36	1080	1.00	$388.80
Clean	Masonry, Smooth Finish, Wash	04 01 30.20 0220	Square Feet	$0.15	1080	0.33	$53.46

Total: **$440**

Per Square Feet: **$0.84**

Due to the durability of the cinderblock walls, the cost per year of repairs is almost two dollars difference. Using the initial costs and these maintenance costs per square foot, a life cycle cost analysis was completed to compare the two systems. Using an online source that tabulates the average inflation rate throughout the years, 3.00% was used as the inflation, or escalation rate for the cost of repairs. In addition to the escalation rate is the discount rate assumed to be 6% for WPI. According to the Federal Prime Rate, for an institution such as WPI, the current rate falls between 5 and 6% (Federal Discount Rate, 2008). Using these two rates, the present worth amount (PWA) factor was calculated and used to find the present worth of annual costs. The following table was developed for the conservative level of repairs. Cost was evaluated at 5 year intervals starting at 5 years after construction through 20 years after construction.

Table 14: Life Cycle Cost Analysis - Conservative

Life Cycle Cost Analysis
General Worksheet
CONSERVATIVE

Cinderblock vs. Drywall	Cinderblock		Drywall	
Discount Rate: 6%	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs /Sq. Ft.				
Wall Construction (Cinderblocks/drywall)	$12.81	$12.81	$10.48	$10.48
Structural Steel	$7.80	$7.80	$6.78	$6.78
Total Initial Costs /Sq. Ft.		$20.61		$17.26

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	5 years			
Paint	3.0%	4.591	$0.74	$3.40	$0.74	$3.40
Clean	3.0%	4.591	$0.10	$0.46	$0.27	$1.24
Holes/Dents	3.0%	4.591	$0.00	$0.00	$1.38	$6.34

Total Annual Costs /Sq. Ft.		$3.86		$10.97
Total Life Cycle Costs		$24.47		$28.23

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	10 years			
Paint	3.0%	8.568	$0.74	$6.34	$0.74	$6.34
Clean	3.0%	8.568	$0.10	$0.86	$0.27	$2.31
Holes/Dents	3.0%	8.568	$0.00	$0.00	$1.38	$11.82

Total Annual Costs /Sq. Ft.		$7.20		$20.48
Total Life Cycle Costs		$27.81		$37.74

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	15 years			
Paint	3.0%	12.014	$0.74	$8.89	$0.74	$8.89
Clean	3.0%	12.014	$0.10	$1.20	$0.27	$3.24
Holes/Dents	3.0%	12.014	$0.00	$0.00	$1.38	$16.58

Total Annual Costs /Sq. Ft.		$10.09		$28.71
Total Life Cycle Costs		$30.70		$45.97

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	20 years			
Paint	3.0%	14.998	$0.74	$11.10	$0.74	$11.10
Clean	3.0%	14.998	$0.10	$1.50	$0.27	$4.05
Holes/Dents	3.0%	14.998	$0.00	$0.00	$1.38	$20.70

Total Annual Costs /Sq. Ft.		$12.60		$35.85
Total Life Cycle Costs		$33.21		$53.11

This analysis shows that after only 5 years, the drywall system will have already exceeded the cost of the cinderblock system by approximately $4 per square foot. This difference then increases in the following years. Using this information along with the costs from an average and low level of repairs, plots of cost versus time were created to illustrate the progression of cost of the two systems. The tables used for the average and low estimates can be found in Appendix E-2.

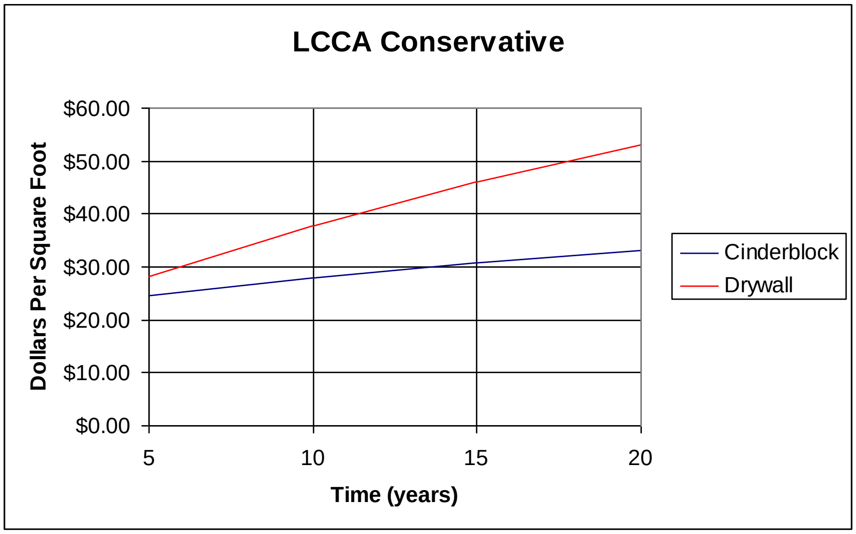


Figure 30: Conservative Estimates for Repair

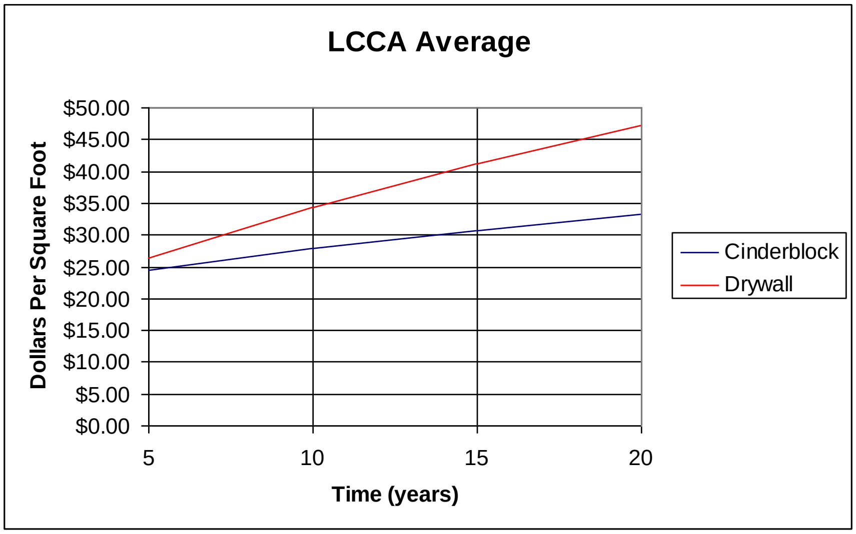


Figure 31: Average Estimates for Repair

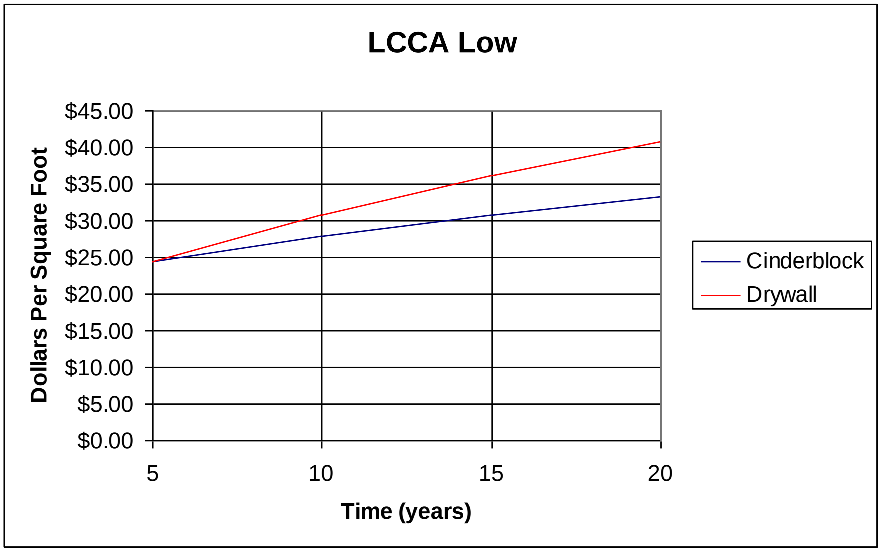


Figure 32: Low Estimates for Repair

Even at the low level of repairs, the cost of the cinderblock system is no more than the drywall system at 5 years and then diverges from there. The choice then becomes that of the owner and is dependent upon the frequency of remodeling and the life desired out of a building. For instance, in a building consisting of responsible, less destructive residents and only if remodeling is to occur every 5 years or less, drywall would make more sense than cinderblock. If however the owner is looking for any sort of longer term dormitory, cinderblocks would be the more cost effective solution according to this cost estimate.

7: Conclusions

The results obtained from our architectural building design, structural analysis and further study into interior construction has led us to three sets of conclusions: schematic drawings of a new dormitory building, a basic structural framing system, and areas for further study. The schematic drawings include floor plans for each of the four floors of the O-Design shape building along with detailed drawings of the atypical areas and one cross section. The structural framing system consists of two pieces: first, a set typical area with a framing scheme of composite beam and slabs, girders and columns and the steel costs associated with such a scheme; second, the framing necessary for the atrium area and the material costs associated with that aspect of the building. Illustrations of these framing systems can be found in Chapter 5. The areas for further study are focused on the use and costs associated with masonry walls, but also include recommendations as to areas that could be pursued more in depth such as lateral load bracing and building materials.

7.1: Schematic Drawings

By outlining the building design process in Chapter 2, we have reached conclusions pertaining to this process and to the schematic drawings completed. Through a trial-and-error period of design, many building layouts were developed, changed or discarded, resulting in two final building designs: the U-Design and the O-Design. All schematic drawings which include a floor plan of each floor and details of the stairs, atriums and bathrooms can be found in Appendix C. To illustrate the final set of schematic drawings, the following figures are the drawings of the main floor for each building design.

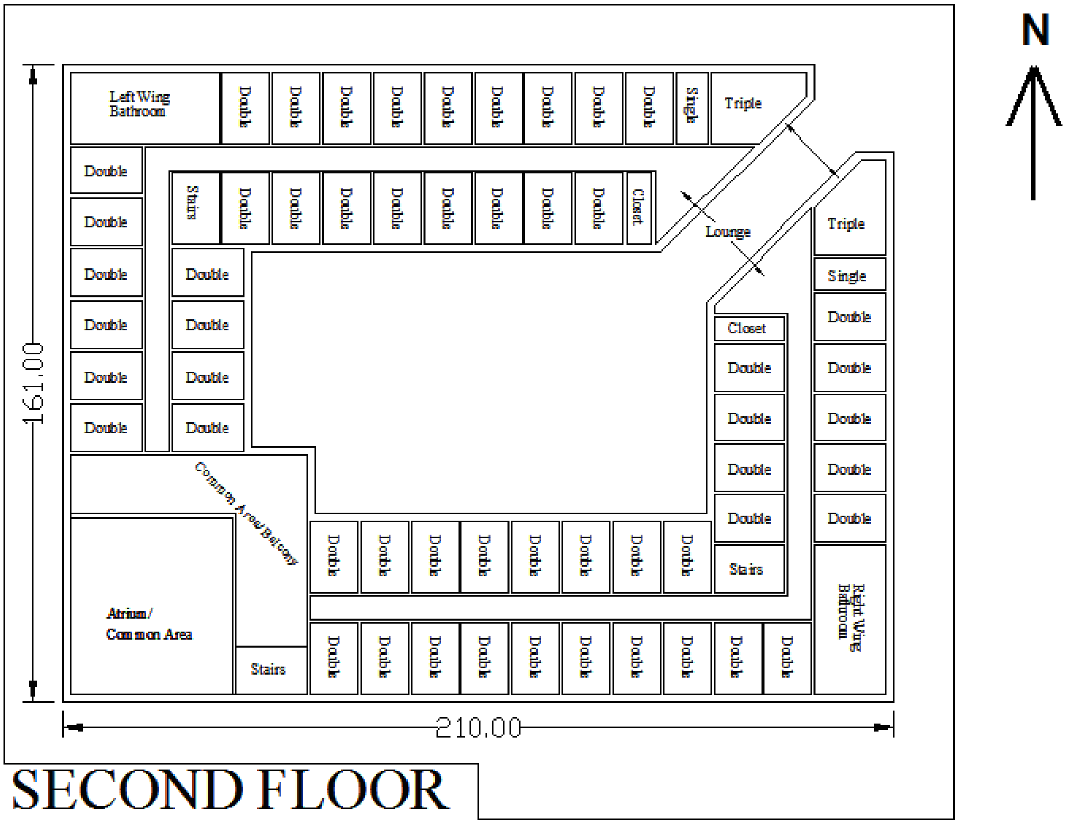


Figure 33: O-Design Main Floor

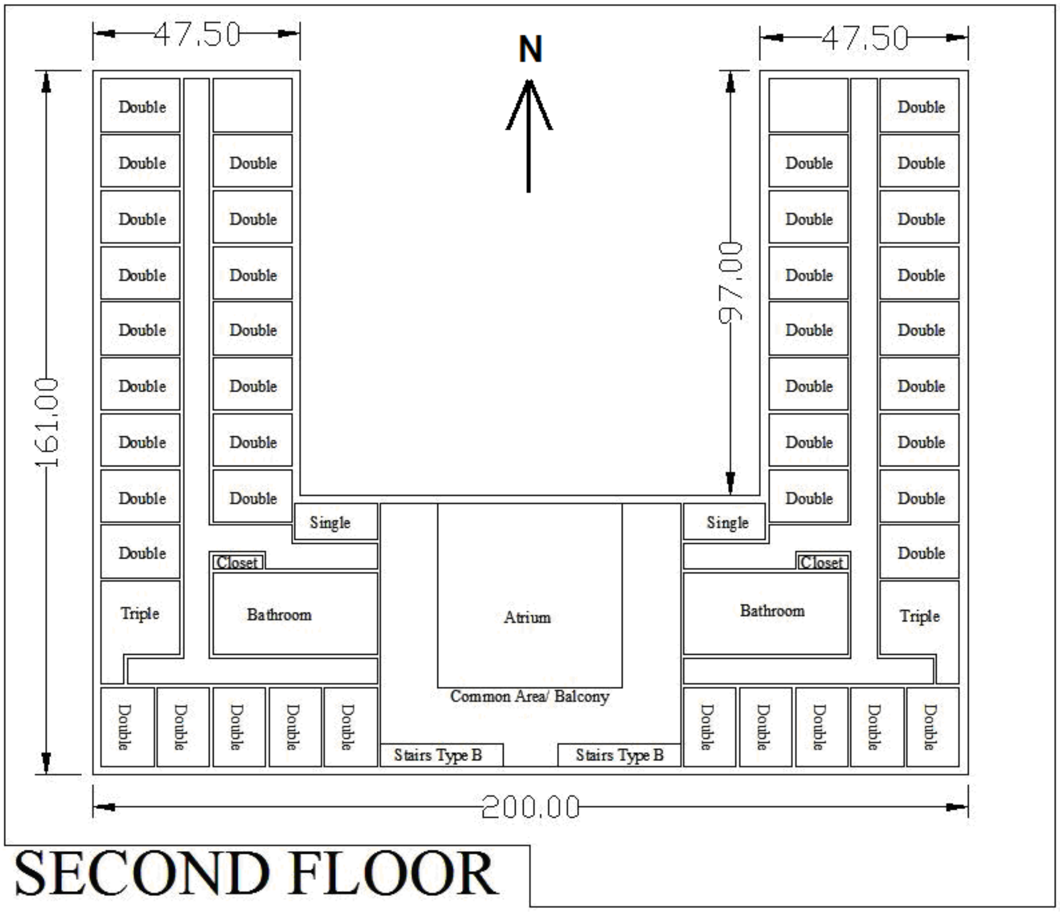


Figure 34: U-Design Main Floor

The trial-and-error period consisted of a time when research on the needs of the client and building constraints was completed at the same time that the building layout was being completed. Therefore, as each new piece of information was gathered, certain building designs had to be changed or scrapped. For instance, all rooms were originally designed to be 10 feet by 15 feet and when the size of the existing Stoddard rooms were discovered to be 12 feet by 15 feet and rather small in comparison to the rooms within Morgan and Daniels Hall, our designs had to adapt to larger rooms, now 12 feet by 18 feet. This is just one example of the pieces discovered that impacted the building layout. We concluded at the end of this aspect of our project that all of these pieces could fit into three major categories: property/lot constraints, building shape/size constraints, and interior construction constraints. Looking back on these, it can be seen that these three categories of constraints are outlined in the building design process in step 2, called programming.

In the end, the U and O-Designs were adapted to meet all of these constraints and were both excellent examples of the goals we were trying to reach. These goals included maximizing the area available, minimizing the environmental impact, and adhering to the clients' needs. Both the U and O-Designs reached these goals by housing over 225 students each, building with the hill rather than into or on the hill, and including a quad and atrium in each design. The next set of conclusions is based on the structural analysis of both of these buildings and the resulting decisions.

7.2: Structural Analysis

The structural analysis can be broken into two main deliverables: the typical framing systems and the atrium framing systems. Each of these systems were originally developed to first choose one building design over the other, then to pick a typical area size and framing scheme, and last to decide upon a certain type of construction.

Unlike the schematic drawings, the typical area framing system did not involve a trial-and-error process, but rather a step-by-step process of elimination. It was determined that to choose the best framing system and type of construction, many options were needed. Thus, twelve framing schemes with three different types of construction were considered. Through a direct process of member sizing and steel cost estimating, twelve schemes and three types of construction were narrowed to one scheme and one type of construction. This process used the LRFD method of design, and it examined noncomposite/composite beam and slab design and open web joist design, thus focused on a structural steel framing system. Different types of framing systems were researched and considered and will be discussed more in depth in Section 7.3. Through this analysis of a structural steel framing system, it was concluded that the most cost effective and constructible typical areas would be two 12 foot by 18 foot rooms side by side, with a column at each corner. All steel sizes would be rolled W-shape, the columns being W10x39s and W16x36s, the girders also being W16x36s and the infill beams being W12x16s, resulting in a cost of $10.36 per square foot.

Since both buildings contained approximately the same amount of these typical areas, another area had to be examined to differentiate the two. This area was the atrium. Taking up more space than any other atypical area within each building and including elevators and stairwells, the atriums were a crucial aspect of each building. Through a structural analysis similar to the one used for typical areas, the framing scheme for each atrium was designed and the cost associated with each was estimated. This cost estimate included only the material costs for the structural steel and the glass for the atrium windows. This was to focus the estimate on differentiating between the two buildings. With the O-Design coming in at $135,000, around $33,000 less than the U-Design which was $168,00, it was concluded that the O-Design was more cost-effective and would therefore be the building of choice.

This cost estimate along with the square foot estimates from the typical areas was used only as a tool to further the design. We evaluated the material costs of steel and glass to make the most cost effective decisions. We also furthered our design through smaller studies of the aspects of the building. The next section will discuss these studies in our third set of conclusions: areas of further study.

7.3: Areas of Further Study

The last aspect of this project was to further the design of the building through studies of the interior construction. Masonry walls were chosen as an example of such a study. Through this study, several conclusions were reached about the use of masonry walls, along with several recommendations as to areas of study such as future MQPs.

The first part of the masonry study consisted of exploring the cost differential between the uses of load bearing versus non-load bearing walls. In these estimates, only the cost of steel and masonry were considered. The structural framing scheme from the typical area was used for the non-load bearing system and then developed and adapted for the load bearing system. Through a careful analysis of the materials needed and the costs associated with such, the load bearing scheme came in at $18.89 per square foot of floor area and the non-load bearing system was $20.61 per square foot of floor area. These costs were developed by analyzing the one typical scheme consisting of two rooms side by side consisting of 523.55 square feet of floor area. At little under $2 per square foot difference, it was concluded that although a load bearing system could be more cost effective, many of the decisions made, should they be changed, could alter the results of the estimate drastically.

For instance, the lateral load system of a load bearing frame consists of careful placement of shear walls. Through a preliminary study of the placement of such walls and the necessary reinforcement, the cost estimate was able to be completed as stated above. A slight change in the type of reinforcement however could be enough to significantly alter the cost differential. The lateral load support system is a large aspect of any building and requires an in-depth analysis to truly reflect the structural and cost impacts. Although this masonry study allowed us to begin an examination of such lateral systems, it is our recommendation that a thorough study of the lateral load system necessary to resist the wind and seismic loads be completed. This aspect of the design would complete the major aspects necessary to any building design. The first section described the schematic drawings developed; the second section concluded on the most cost effective and constructible gravity load system of the systems considered. Therefore, a lateral load system that could be adapted to this design would complete the big picture of the structural analysis.

The second area of further study into masonry walls was a comparison between the use of drywall and cinderblocks. Initial construction costs were determined and then through background research and a cost estimate, a yearly maintenance cost was determined. Using these initial costs, maintenance costs, an escalation rate of 3% and a discount rate of 6%, a life cycle cost analysis was completed. It was concluded that for this particular dormitory, a cinderblock design would be more economical after only 5 years of service at which point the cost of maintaining a drywall system would greatly exceed the cost of a cinderblock system.

This estimate was based on a number of design decisions about each material. It is therefore our second major recommendation that to fully examine the possibilities of this building, different materials for wall construction should be considered and analyzed. For example, there are many different types of drywall that could overcome some of the negative aspects of the drywall we considered. There are soundproofing techniques and layering techniques to drywall that should be considered before a decision is made. A second example is that of the flooring system. This project considered only concrete slabs. Such cast-in-place slabs produce large dead loads during service and large live loads during construction. Hollow core precast planks however could provide the same durability with higher constructability and less supporting steel since they can support more weight and are built in relatively easy to assemble sections.

The goal of this project was to design a dormitory building to replace the existing Stoddard Residence Hall through the development of schematic drawings, a structural analysis and the use of cost estimates. We reached this goal by developing and choosing one building design, one typical area scheme, one type of framing system, and preliminary studies into interior construction. We maintained our goals of maximizing the space available, minimizing the environmental impact and adhering to the needs of the client all through cost effective and constructible means. To conclude this project, we outlined two specific recommendations for further study that would not only complete the big picture of such a dormitory design, but also present a possible solution to the existing needs of Stoddard Residence Hall.

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Appendix A: Proposal

Project No. LDA-0804

REDESIGNING STODDARD RESIDENCE HALL

Major Qualifying Project Proposal

Submitted to the Faculty

of the

WORCESTER POLYTECHNIC INSTITUTE

in partial fulfillment of the requirements for the

Degree of Bachelor of Science

by

Cameron Dunaj

Amanda Ruksznis

Date: October 11, 2007

Abstract

This project developed a design and cost estimate for a freshman dormitory building to replace the current Stoddard Residence Complex. Three objectives that were met in this project were to build with the existing contour of the property, match the building to the surroundings and satisfy students' needs. The final design consisted of a floor plan, structural frame and several aesthetic components such as walls and landscaping.

Table of Contents

Introduction

The Stoddard Complex at Worcester Polytechnic Institute (WPI) is a freshman residence hall that currently houses 180 students. The complex is composed of three buildings situated on a lot between Einhorn St. and Hackfeld St. This project details a new building that could replace the Stoddard Complex, while improving upon the original design.

There are many reasons why we feel this replacement is necessary. First and foremost, the current Stoddard Complex does not efficiently use the space provided by the lot. The three buildings occupy about 30% of the total land area of the site to house 180 students. At the very least, one building of the same height occupying the same amount of land area would be able to house more students and thus, more efficiently use the lot. In addition, WPI has been trending towards larger freshman classes over the past few years, and therefore, larger residence halls may soon become a necessity. The new building will be able to house at least 225 students, a 25% increase in capacity over the current buildings. Physically, the Stoddard buildings are inferior to most of the other residence halls on campus. It is one of two freshman residence halls that have not been renovated in the past 15 years. It has no handicap accessibility and the floor layouts are a common complaint from students.

Several decisions have already been made about the design of the proposed building. Like its predecessor, the new residence hall would accommodate freshmen and as such, the floors would consist mostly of doubles. Also, the topography of Worcester is not flat, and Stoddard is currently located on the side of one of its hills. Rather than try to level the site through cut-and-fill operations, we decided we would rather work with the hill and keep the area looking as natural as possible. Our third major decision before beginning the project is to attempt to ensure the features that make Stoddard unique are not lost. Specifically, Stoddard is widely recognized around campus as its own small community where the students get to know each other well. This is also partially due to the layout of the buildings and the small quad between them. The new building will preserve that sense of community as well as have its own quad and/or outdoor common area.

Project Scope

The goal of this project is to design a residence hall that will replace the Stoddard Complex with one building that will house at least 25% more students on the same plot. An objective of this design is to minimize the impact on the environment through constructing with the hill rather than extensive cut-and-fill operations. One more objective is to assure that the new building will aesthetically blend with the rest of campus. Most importantly, the building will be for the students, thus the design will reflect general student opinion to create a more appealing residence hall.

Our first objective, to work with the existing topographical features will govern the layout of our design. It will involve research into Worcester Zoning Ordinances and the International Building Code to obtain data on not only the topography of the site but also the property lines and various restricting city ordinances. To increase the number of students housed from 180 to the desired 225 minimum will also require an increase in stories from the top of the hill to the bottom of the hill. Such a design will thus need detailed elevations and separate floor plans for each level.

Designing a building that will be contoured to the hill will also help with the objective to assure that the aesthetics of the building match the rest of campus. Rather than filling the hill and creating a residence hall that dwarfs the surrounding buildings or digging into the hill and creating an underground residence hall, our design will be proportional to the landscape and the surroundings. Care will also be taken in size and shape of the building to reflect the character of WPI buildings. Interviews with key WPI personnel and evaluation of recent WPI projects such as the Bartlett Center and the new residence hall will provide us with information on what is expected of WPI buildings both structurally and aesthetically. By creating a building that is contoured to the hill and fitting to the rest of the campus, we will be well on our way to also satisfying the students' needs. To completely fulfill this last objective, we will also be evaluating current trends in campus living around the United States and also what is unique to the current Stoddard complex such as the "Stod-quad" to give ourselves basic guidelines on the overall design.

Once the research and evaluations discussed above have been completed, at least two layouts encompassing these ideas and governed by the International Building Code and the Worcester Zoning Ordinances will be developed and one will be chosen. The restrictions impacting this choice will be based on such factors as cost, efficiency of space, and overall aesthetics. Finally, to complete and to add feasibility to the project, we will design a structural frame to support this layout and prepare a cost estimate for our proposed structure. Typical (rooms, hallways) and a-typical (elevators, atriums) sections will each be analyzed to determine beam, column and footing sizes and materials (steel and/or concrete) required.

The last stage of the project will consist of more individual areas of study such as flooring, windows, walls, and siding. This will then create a more complete picture of the building. Using the 16 CSI divisions as an outline, a final construction cost estimate for the building as a whole will be developed. The final structural design and cost estimate will be evaluated and determined according to the most current International Building code and certain cost estimating references such as RSMeans.

Capstone Design

In accordance with graduation requirements, this project must demonstrate our experience with the elements of capstone design. The scope of our project as a whole will fulfill the capstone design requirement. The specific constraints addressed by the project will be: economic; environmental; constructability; health and safety; social; and political.

We will fulfill our economic consideration through two aspects. First, the building itself will indirectly bring more students back onto campus, thus making more low-income housing in the area available. Secondly, by analyzing the different costs of our project, we will gain experience with the economics of design and construction.

Our environmental consideration will be evidenced by our desire to maintain the natural landscape of the site. We will try to minimize both cuts into the land and fills to build up the land.

The constructability aspect of the requirements will promote efficient and economic use of construction resources. This will be accomplished by attempting to use typical steel sections and standard building materials. Building with the hill will also aid in this end by allowing easier access within the site throughout the construction of the building as compared to a deep hole in the ground where access would be limited to the bottom side of the hill.

Health and Safety will be integral to the design since they are the driving forces behind building codes. Care will be taken to provide handicap accessibility, and adhere to fire safety precautions, such as ensuring that no room is too far from an exit. Not only will the building codes be referenced in such decisions but also the newer dormitories on campus to assure that this building will be comparable to, if not safer than, the other dormitories.

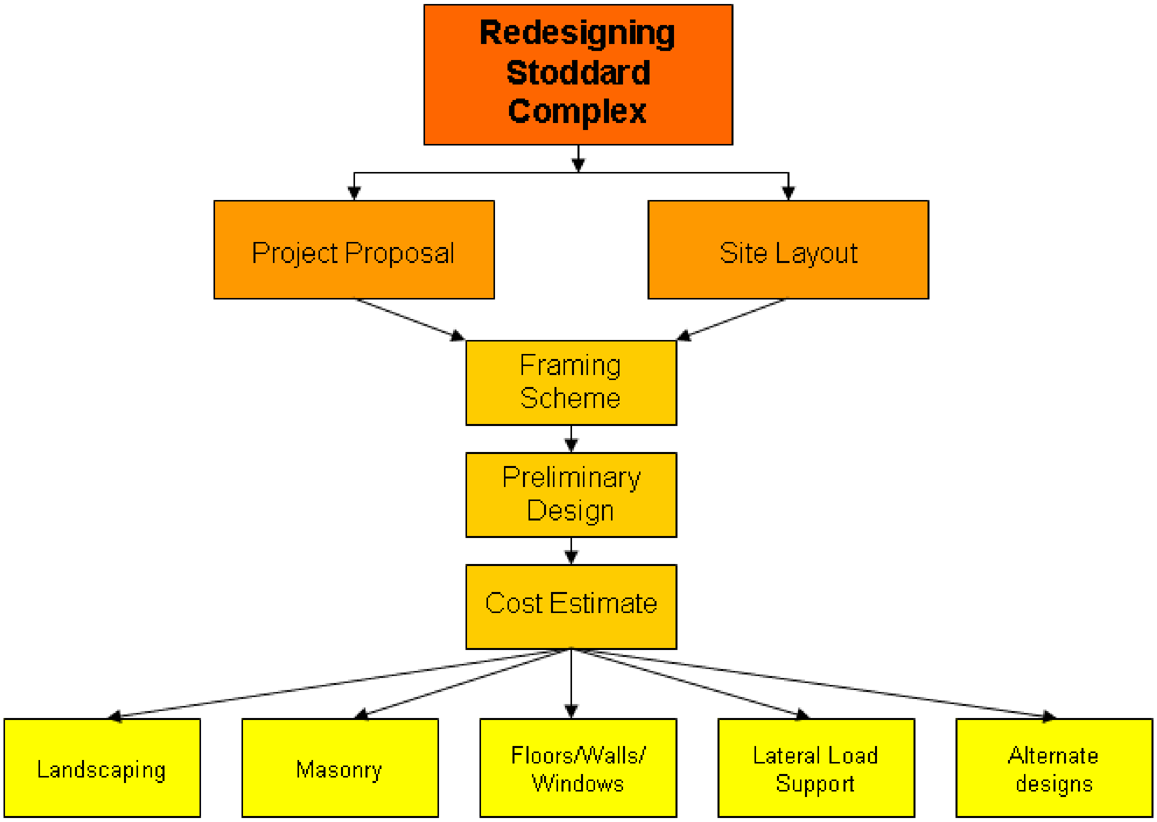
Social aspects of the new dorm will be taken into consideration during design, for example: “How will this layout help promote a sense of community?” The social aspects impacting students, WPI as a whole and the surrounding neighborhood will be considered. The layout will be a reflection of all of these impacts from creating a sense of community for the students and increasing the number of freshmen housed for WPI as a whole, to creating a fitting building with the surroundings for the neighborhood.

Last, if we are unable or unwilling to comply with some of the codes or ordinances, we will have to investigate which political channels one must navigate to secure approvals and proceed. Research into the Worcester City Zoning Ordinances will provide this project with ample political background.

Methodology

To accomplish the above-stated goals and objectives, this project will be broken down into three tiers of work with an adjoining final report as the main deliverable. The first tier consisting of the project proposal and site layouts (detailed floor plans) will be completed in A-term. The second tier consisting of a structural framing scheme for a chosen layout with subsequent preliminary design and cost estimate for that design will be completed by the end of B-term. The duration of C-term will then be devoted to more individual work in focused areas such as landscaping, masonry, floors/walls/windows, lateral loads and alternate designs for the framing scheme. Below is a table describing each of these activities in the terms we have defined followed by a flowchart of the overall process.

Activity	**Definition for this Project**
Site Layout	Architectural – floor plan drawings made to scale of the building on the site according to property lines and zoning ordinances
Framing Scheme	Placement of steel columns, beams and girders to fit layout
Preliminary Design	Sizing of columns, beams, girders, footings to fit framing scheme
Cost Estimate	First, material cost analysis per square foot of preliminary design, then adding in material costs from third tier of work



Site Layout/Floor Plans

The site layout will consist of floor plan drawings made to scale with the lot. At least two different designs will be drawn and considered before one is chosen to move forward with structural design. To create a floor plan, several topics must first be researched. An assessment of Stoddard Residence Complex and the lot in general, research into the architecture and aesthetics of the surrounding buildings, and research of popular trends in campus living must all be completed. This research will provide us with guidelines on what is wrong with the current Stoddard, how we are limited by the lot itself (elevations, zoning, etc.) and last how we can use the previous information to design a modern dormitory that will fit into the rest of campus and match popular trends.

Assessment of the lot can be broken down into four categories that must be addressed. Elevations and property lines must be determined, zoning ordinances affecting the lot must be researched, building codes for dormitories that must be adhered to in a new building must be determined and last, an interview with the Dean of Students should be organized and completed to discuss Stoddard as it is today, and what WPI would expect out of a new residence hall for freshmen.

This interview will also assist in research into the architecture and aesthetics of the surrounding buildings and WPI buildings. This research will help dictate the overall size and shape of the building and consequent atypical areas and exterior finishes that will be discussed in later sections. To complete a site layout that will achieve our project goals, some research into popular trends must be completed. This will at first give us ideas for building shapes and atypical areas such as an atrium style common room, but will also in the end give us a more reasonable and modern building design.

Framing Scheme and Preliminary Design

By the end of A-term, at least two interior layouts will have been completed. The next step as B-term begins will be developing an organized method to sizing beams and columns for given framing schemes. Using structural analysis software such as RISA, different options for framing schemes will be developed to support the designs. This will consist of placing columns and deciding on girder/beam directions and other such floor support systems.

The sizing of the columns, beams, girders and footings will be based on loads researched and found in the International Building Code. At this stage of the project, we will only be evaluating gravity loads. Some decisions will have to be made on flooring, walls and siding to account for the dead loads of each. However, we will be using relatively conservative values so that in C-term as we complete more focused analyses on these areas, potential changes to the structural design will not be severe. Throughout the term, different options on steel/concrete systems will be evaluated on the basis of constructability and cost so that by the end of B-term, one framing scheme will be chosen.

Cost Estimate

Throughout this preliminary design, a material cost analysis of the building design will be completed to aid in the decision of a framing scheme. Once one is chosen for each layout, they will give us a cost per square foot that can then be used as a factor in choosing one of the layouts. Once the layout is chosen and the framing scheme is frozen, this cost estimate will provide us with a benchmark for future decisions. As we begin to break off into smaller areas of design, we will then be able to see the impact on the overall design both structurally and economically. Therefore, cost estimates of the preliminary design will be completed in the second tier of the project, and will also be addressed throughout the duration of the third tier.

Areas of Focus

The last component of the project will be the study of several different smaller topics. There are numerous details to look into when designing a new building from structural design to furniture costs. However, to limit the project to areas that most affect our original goals, depending on time, we will most likely be addressing such areas as landscaping (development of an atrium and quad), masonry, flooring, windows, walls, and lateral loads. The table below lists these areas with the aspects involved for each.

They are in order from the most important or the primary areas to the secondary or least important areas.

Area of Study	Aspects Involved
Lateral Loads	Evaluate different options such as braced frame vs. rigid frame according to lateral loads obtained from building codes
Walls	Research different options such as cinderblocks vs. sheetrock and impacts of each on cost, structural layout, maintenance and fire code
Masonry	Compare exterior finishes to those of the surroundings, and evaluate impact of a few options on structural layout, cost and fire code
Flooring	Research different options such as linoleum vs. carpeting and impacts of each on cost, structural layout and maintenance
Landscaping	Compare landscaping of surrounding area and the rest of campus and placement of retaining walls within the quad
Windows	To provide ample natural light and yet conserve heating/cooling energy, different options for windows will be researched

For each of these topics, research on different available options, current campus trends and cost differences will need to be completed. This research will allow us to make decisions regarding each area and thus in the end, giving us a more complete picture of the building. This step in the design, through drawings and renderings, will assist the reader and all parties interested in viewing our building design as more than a mere structural frame.

Deliverables

There will be two deliverables with the completion of this project. The first will be a final report consisting of background research necessary to the project, a final site layout and structural design, cost estimate of the overall building and the process completed to obtain these. There will also be a set of drawings to accompany the report to show the floor plan, structural layout and rendering of the building.

Schedule

As seen in the Methodology section (see flowchart), this project will have three major sections. Our first major milestone will be the end of A-term when we will have a complete proposal and two site layouts. The next milestone will be the end of B-term when the second tier of work consisting of a framing scheme, preliminary design and preliminary cost estimate will be complete. Up through this point, most of the work will be a collaborative effort. The rest of C-term will then be devoted to more individual areas of study such as landscaping, flooring and masonry. Throughout the duration of the project, a final report will be drafted and will become the main deliverable.

References

27 Hackfeld St, WPI Stoddard Residence Complex Blueprints. May 1969.

City of Worcester. October 2006. City of Worcester. 7 September 2007 <http://www.ci.worcester.ma.us/>

“City of Worcester Zoning Ordinance.” Office of the City Clerk. 6 February 2007. City of Worcester. 1 September 2007 <http://www.ci.worcester.ma.us/cco/clerk/ordinances/zoningord2607.pdf>

International Code Family. International Code Council. 2006 International Building Code. Country Club Hills, IL: ICC Publications, 2006.

Phillip Clay, WPI Dean of Students. Personal Interview. 14 September 2007.

Appendix B-1: Worcester City Ordinances

1. Height Restrictions
    a. "HEIGHT OF BUILDING – The vertical distance from the grade level measured from the center of that face of the building having the main entrance, to a line extended horizontally from the highest point of the building. Chimneys and other similar projections shall not be included in calculating the height." Worcester Zoning Ordinances, Article I, Definitions, pg.16
    b. We define the "main entrance"
    c. Must abide by height restrictions of District RL-7: "In Institutional Zones for educational institutions (IN-S), structures are required to be set back fifty (50) feet from the nearest property line. Any structure constructed between fifty one (51) and one hundred (100) feet from the nearest property line, shall be no higher than the height limitation imposed by the most restrictive abutting zoning district." Worcester Zoning Ordinances, Notes to Table 4.2, pg. 49
2. Front/Rear Yard Definitions/Restrictions
    a. 50' from neighboring lot, not street though (see 1c)
    b. "Clear View of Intersecting Streets – In all districts with front yard set back requirements, in order to provide a clear view of intersecting streets to vehicles, there shall be a triangular area of clear vision formed by the two intersecting streets. The size of the triangular area is to be the minimum front set back for the district. On any portion of a lot that lies within the triangular area, nothing shall be erected, placed, planted or allowed to grow in such a manner as to materially impede vision between a height of two and one-half (2.5) feet and ten (10) feet

    above the grade at the two street center lines. The triangular area shall be formed by connecting three (3) points: the intersection of the two street right of way lines and the two (2) points along each street right of way line, at a distance from the intersecting point which is equal to the required front yard set back." Worcester Zoning Ordinances, Article XIII, Section 3, Number 7, pg. 127

   c. Front Yard Min. Depth 15', Side 10', Rear 10'
   d. We define the "front" as the main entrance – rear is horizontal, side is perpendicular

3. Dover Amendment - http://www.mass.gov/legis/laws/mgl/40a-3.htm
   a. Massachusetts General Law (MGL) Chapter 40A, Section 3
   b. "No zoning ordinance or by-law shall…regulate or restrict the use of land or structures for religious purposes or for educational purposes on land owned or leased by the commonwealth or any of its agencies, subdivisions or bodies politic or by a religious sect or denomination, or by a nonprofit educational corporation; provided, however, that such land or structures may be subject to reasonable regulations concerning the bulk and height of structures and determining yard sizes, lot area, setbacks, open space, parking and building coverage requirements." (MGL Chapter 40A, Section 3)
   c. Bypasses variances and Zoning Board of Appeals, applies to all ordinances
   d. Argument must be made to Worcester Director of Code Enforcement that building has Dover privileges under the Dover Amendment and that it would be "more detrimental to the institution than beneficial to the city to enforce said ordinances" (Jody Kennedy, City of Worcester Zoning Department)

Appendix B-2: Building Code Impacts on Layout

Dormitories – R2 Occupancy
Chapter 4: Special Detailed Requirements Based on Use and Occupancy Section 404 (Atriums)

- Section 404.5 – Enclosure of atriums – atrium spaces shall be separated from adjacent spaces by a 1-hour fire barrier (see section 706 for more details) unless three of the adjacent floors are included in the design of the smoke control system (section 909)

Chapter 5: General Building Heights and Areas

- Table 503 – Assuming maximum fire protected materials for construction (fire rating of 2 hours), then for R-2, Type 1A or B construction (Table 601), height (ft) unlimited, height (stories) 11

Chapter 10: Means of Egress

- Section 1004 – Occupant Load, 1004.4 and 1004.5 – when exits serve more than one floor, only the occupant load of each floor will impact required exit capacity and when exits from above and below converge, exit capacity is sum of two floors

- Section 1005 – Egress Width – 0.2 inches per occupant for stairwells and 0.15 inches per occupant in other exit paths

- Section 1007.3 – Exit Stairways – clear width of 48" between handrails with distinct landings for areas of refuge

- Section 1008.1.1 – Size of Doors – clear width of 32", no more than 48" for swinging doors for exits only (not including individual rooms)

- Section 1008.1 – Landings – must be same elevation on either side of door, width no less than width of door and length no less than 36"

- Section 1009.6 – Vertical Rise – No vertical rise greater than 12' between floor levels or landings

- Section 1014.3 – Common path of egress travel – exception for Group R-2 – shall not be more than 125 ft (hallway leading to stairwell)

- Section 1016.1 – Travel distance limitations – from most remote point to point of final exit, no more than 250' for Group R2 (measure stairwells parallel and tangent to stair treads)

- Section 1017.3 – Dead ends – no dead ends for corridors longer than 20'

- Section 1019.1 – Minimum number of exits – for occupant load of 1-500 per floor, 2 exits required

Chapter 11: Accessibility

- Section 1107.6.2.2 – 3 minimum handicap roll-in showers and 10 handicap rooms
- Section 1109.2 – For every accessible bathroom, there must be one of every fixture of each type that's accessible (toilet, sink, shower)
- Section 1109.5 – Drinking fountains – 50% must be accessible (one low, one high)

Chapter 29: Plumbing Systems

- Table 2902.1 – For R-2 dormitories, 1 bathroom per 10 people, 1 shower per 8 people, 1 drinking fountain per 100 people and 1 service sink

Chapter 30: Elevators and Conveying Systems

- Section 2001.2 – Refer to ASME A17.1, A90.1, and B20.1 for design, construction, installation, alteration, repair and maintenance of elevators
- Section 3002.4 – For buildings four or more stories from grade plane, one elevator must be rated for fire department emergencies and capable of fitting a stretcher (24"x84")
- Section 3006.4 – Machine rooms need to be provided with fire barriers rated no less than the elevator

Appendix B-3: Interview with Phillip Clay

Interview with Phillip Clay
9/14/07 – 3:00pm
Campus Center

Main Questions – What are students looking for? What is WPI looking for? How do you integrate these?

1. Talk to us about the new residence hall – what role did you play in its design and construction?
2. What went into the decision to build a new residence hall? How long has this been in the making?
3. With Worcester not being the safest city around, was getting students on campus an objective?
4. What was WPI looking for in the new building? (might be answered by 2)
5. How did WPI evaluate students needs/desires? What were they? Do you think this will make students want to live on campus?
6. What do you think about the popularity of living in Stoddard? Why? Is there someone in Residential Services we could talk to about Stoddard specifically?
7. We're looking to design a hall for freshmen – mostly doubles with a few singles/triples – no suites/kitchens. What do you think students need/want (based on the new hall) in a dormitory like that?
8. Here are our two basic layouts – built on the hill like the library. What are some aspects that WPI looks for to match the building to the rest of campus? (size, layout, exterior finishes, etc.)
9. Would either of these designs work? Which one, in your opinion would fit with what WPI is looking for?
10. Is there a minimum/maximum for number of students in a dormitory?

Summary of Interview with Phillip Clay
9/14/07 – 3:00pm
Campus Center

On September 14, 2007, we interviewed Philip Clay, the WPI Dean of Students. We felt he was an excellent source due to his involvement with the new upperclassmen residence hall currently being built on campus. As the Dean of Students, he was able to convey to us what WPI was looking for in the new residence hall and how that related to the design and construction of our residence hall.

Mr. Clay began by explaining that one of the most prominent reasons for the construction of the new dorm was WPI's desire to have a larger percentage of students living on campus. Currently, only 43% of undergraduate students live on the WPI campus, a number significantly less than other Worcester schools. One of the biggest reasons that WPI wants more students on campus is because, often times parents of prospective students get worried about the percentage and think that their kids will not be able to obtain housing after their freshman year (the only year that housing is guaranteed). Worcester is still a city, and as such has crime like any other city would so WPI would like to keep its students as close as possible to better protect them. There are some students who want nothing more than to move out and live on their own as soon as their freshman year ends, but there are also those who would rather live in WPI housing throughout their whole college experience. WPI wants the students to feel like they have a choice, not that they must seek off-campus housing just because on-campus housing is not guaranteed. On top of the desire to house more upperclassmen, there are several distinct features that WPI would be expecting in a new building:

- Handicap accessibility
- More/Larger common areas
- Elevator access
- Assurance that the sense of community would be preserved
- Aesthetically pleasing, both inside and out
- Aesthetically fits in with the rest of campus, or at least the buildings in its general vicinity

We then began to discuss how our designs might fit with this picture of what WPI is looking for. Even though we are designing a freshmen residence hall, this issue of housing more upperclassmen is still pertinent because there are some residence halls that house both freshmen and upperclassmen. Our dorm would ideally house more students than the current Stoddard, and therefore, allow more room for upperclassmen in the other residence halls.

In our discussion, the topic of the current Stoddard's pros and cons came up. Currently Stoddard is one of, if not the least desirable freshman dormitory to live in. I (Cameron) informed Mr. Clay of my perspective of having lived in Stoddard myself and from visiting friends in dormitories in other schools. I said that Stoddard is not that bad of a place to live despite popular belief on campus. There is an extremely strong sense of community in the Stoddard Complex, a result of the small floor sizes and the somewhat secluded nature of the dorm. The result of this sense of community is that residents quickly get to know many different students from throughout the complex. Conversely, students living in Stoddard often don't meet as many other students from other residence halls. And as far as the buildings themselves, Stoddard pales in comparison to other dormitories in terms of quality. Mr. Clay then informed us of how Stoddard is just one of two residence halls to not have been renovated in the past 15 years. Before the renovations of Daniels, Morgan and Riley, Stoddard was one of the most desired places to live.

If our plan was enacted, the current Stoddard Complex would be destroyed and replaced with a new building. Mr. Clay agreed that the new building should try to maintain the individuality and sense of community that Stoddard, while at the same time, housing more students and making better use of the plot of land the dormitory lies on.

Appendix B-4: Interview with Chris Salter

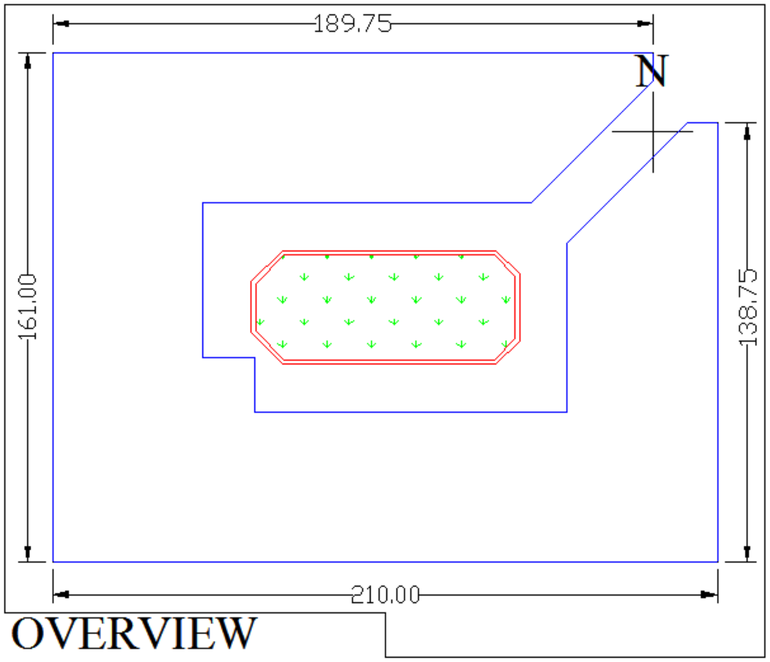
On January 30th, 2008, I (Amanda) interviewed Chris Salter, the associate director of facilities services and the manager of technical trades at WPI. In his position, he is a very informative source regarding the maintenance of WPI dormitories. After spending more than 10 years in this field, based on experience he was able to give me a well grounded opinion of the use of masonry walls versus drywall in campus dormitories.

Mr. Salter began by describing two schools of thought on the use of concrete masonry unit (CMU) walls in campus dormitories. The first school of thought favors drywall and is focused on aesthetics, cost and speed of construction. CMU walls can tend to have an institutionalized feel and are much less flexible to remodeling than drywall. Drywall also goes up quicker and costs less to construct. The second school of thought favors CMU walls for their durability. As Mr. Salter describes a dormitory, it is a “prison for 18 year olds”, and thus will need to withstand an amount of abuse that could be very detrimental to drywall.

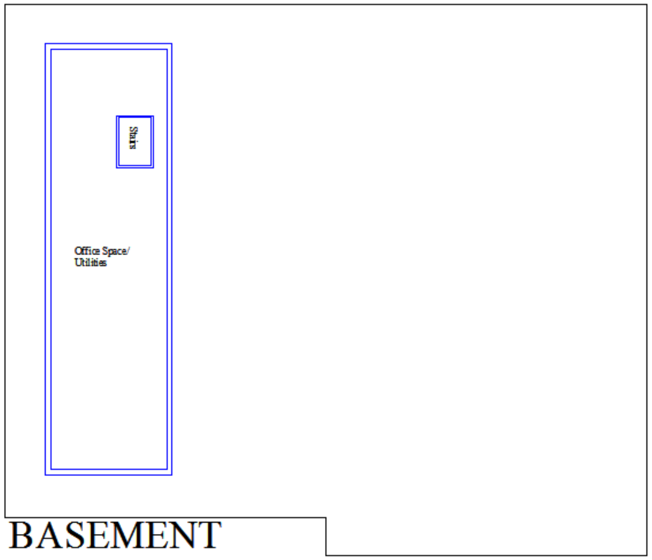
I then asked Mr. Salter if, after his years of experience, he had formed an opinion on these two schools of thought. He strongly favored CMU walls not only for their durability, but also for the potential to be aesthetically pleasing. Mr. Salter said that it came down to attention to detail from the mortar and joint work to the finish coats on the CMU’s. In preparation for the design of the new WPI upperclassmen dormitory, Mr. Salter was able to attend several college dormitory tours around New England. One college that stuck out in his mind was Providence College in Providence, Rhode Island. He described one of their dormitories as being just as aesthetically pleasing as any drywall construction. The attention to detail was apparent not only in the mortar work and finish coats, but also the lighting, color and flooring. All three provided a very "warm" feeling to the dormitory, thereby eliminating the institutionalized feel. As for remodeling, campus dormitories have a much focused purpose in housing students and are thus not remodeled very often, if at all.

Our last area of discussion covered the cost of maintenance for dormitory walls. He said that a typical repair of drywall depends on a lot of factors, such as size and color of the walls. As such, a typical repair can average anywhere from $30-$200 a piece. He said that drywall is "more aggravation than money" and the biggest factor would come from paint. Any small nicks, scratches or scuffs would need to be covered up, thus requiring a new paint job every year. To give me a sense of proportion, I asked about how much it would cost to paint one wing of Morgan Hall. Just the hallways, he decided a paint job would be anywhere from $3,000 to $4,000, not including ceilings or rooms. He did stress however that that was also a ballpark and depends on many different factors.

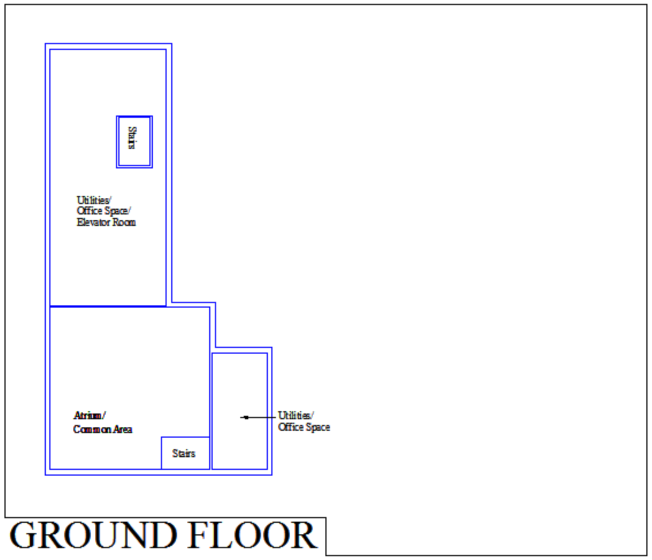
Appendix C-1: Building Drawings – O Design



Notes: All Retaining walls are of equal thickness (1/2')
Walkway has a uniform 10' width around courtyard (except in NE and SW corners)
Walkway is located 3' from building face (except in corners)

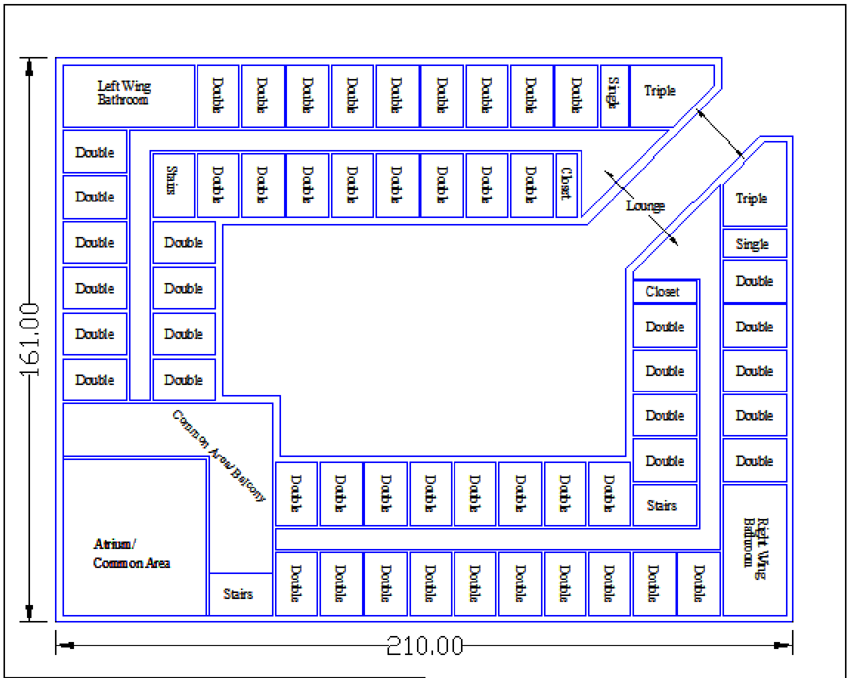


Notes: This floor has two exits to the street
All Exterior walls are of equal thickness (2')



Notes:

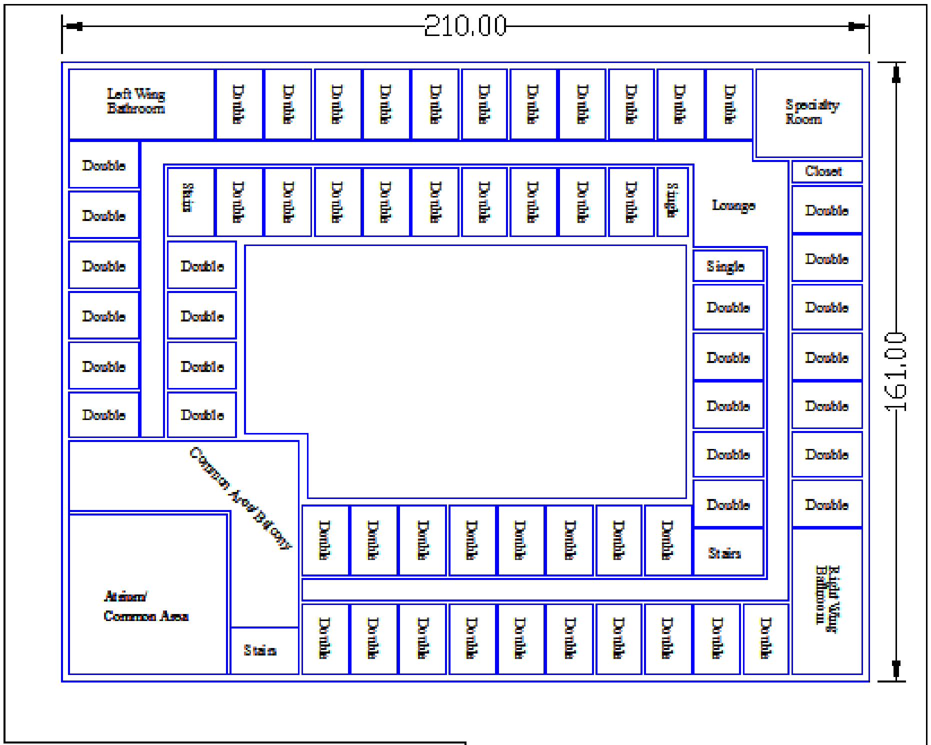
Atrium staircase is not walled
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (9")
Atypical areas are shown in greater detail on other sheets



SECOND FLOOR

Unless Otherwise Noted:

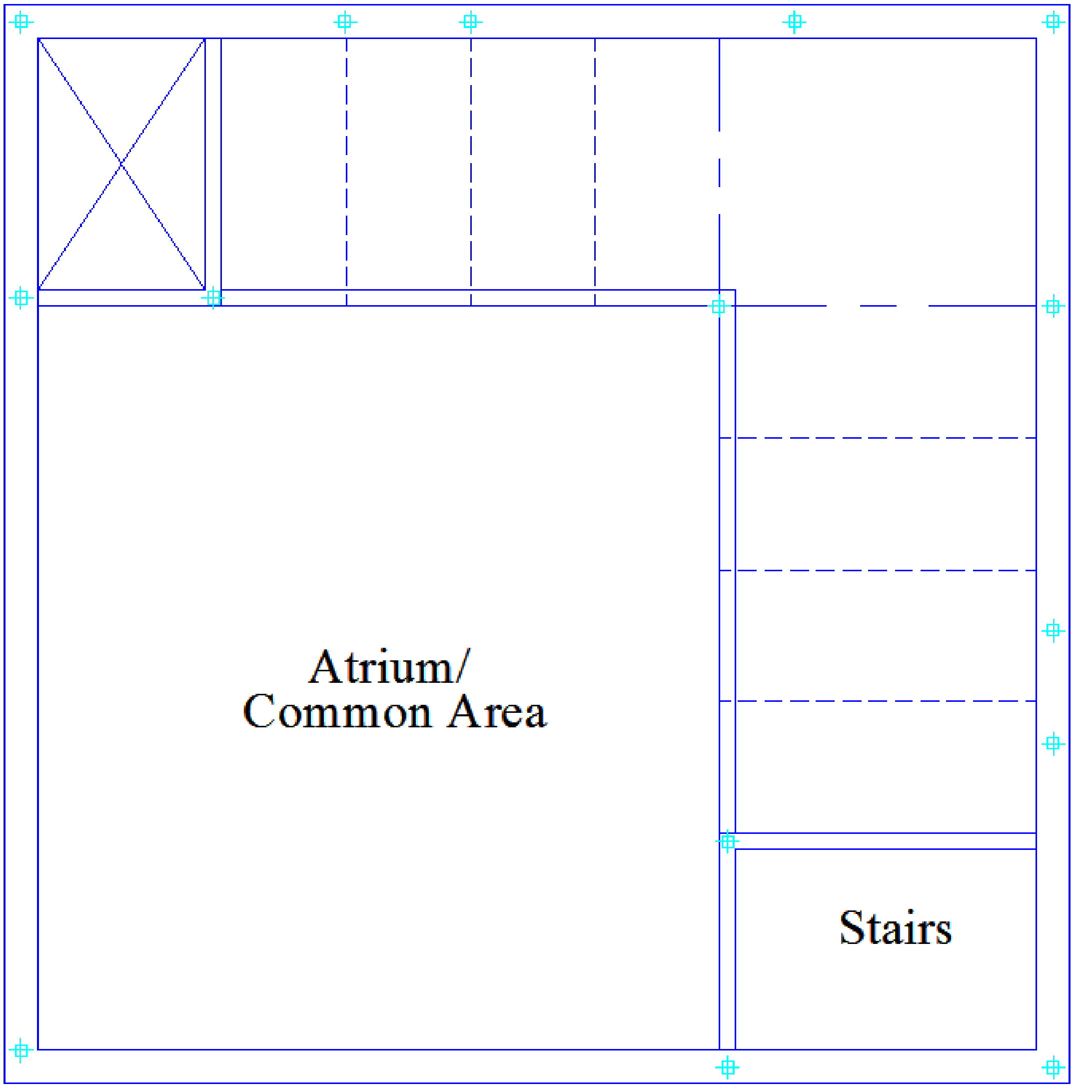
All Triples are of equal size (360 sq. ft.)
All Doubles are of equal size (216 sq. ft.)
All Singles are of equal size (144 sq. ft.)
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (9")
All Hallways are 6' wide
Janitorial Closets are 108 sq. ft.)
Atypical areas are shown in greater detail on other sheets
54 Doubles + 2 Singles + 2 Triples = 116 Students on this floor



THIRD FLOOR

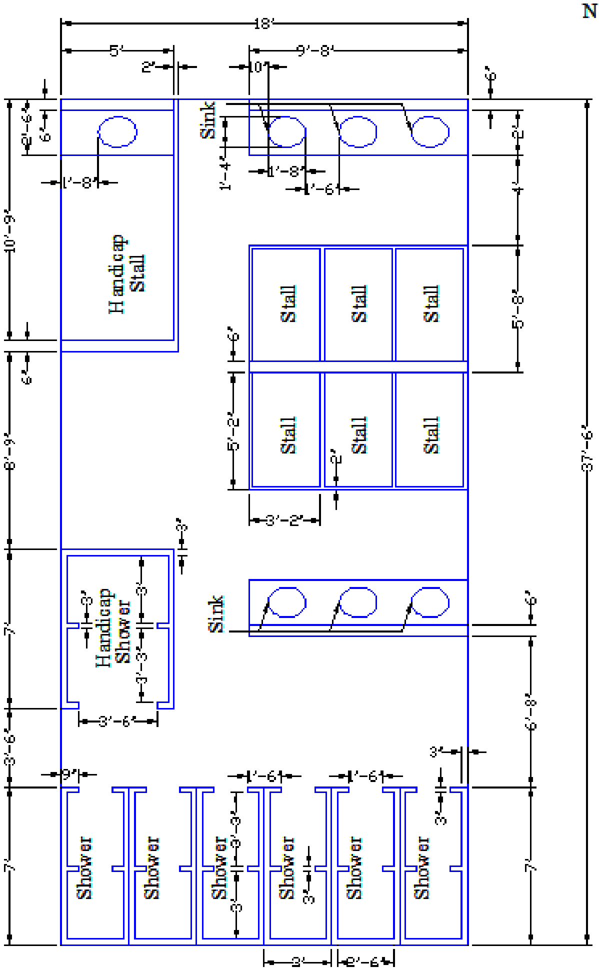
Unless Otherwise Noted:

All Doubles are of equal size (216 sq. ft.)
All Singles are of equal size (144 sq. ft.)
Specialty Room is 625.625 sq. ft.
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (9")
All Hallways are 6' wide
Janitorial Closets are 108 sq. ft.
Atypical areas are shown in greater detail on other sheets
60 Doubles + 2 Singles = 122 Students on this floor



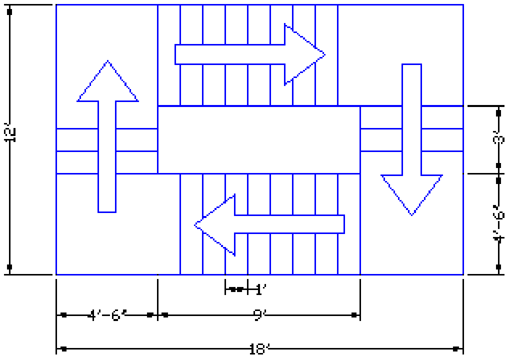
Notes: Allotment for safety barrier - 1'
Adequate space has been left in the NW corner for an elevator

Right Wing Bathroom



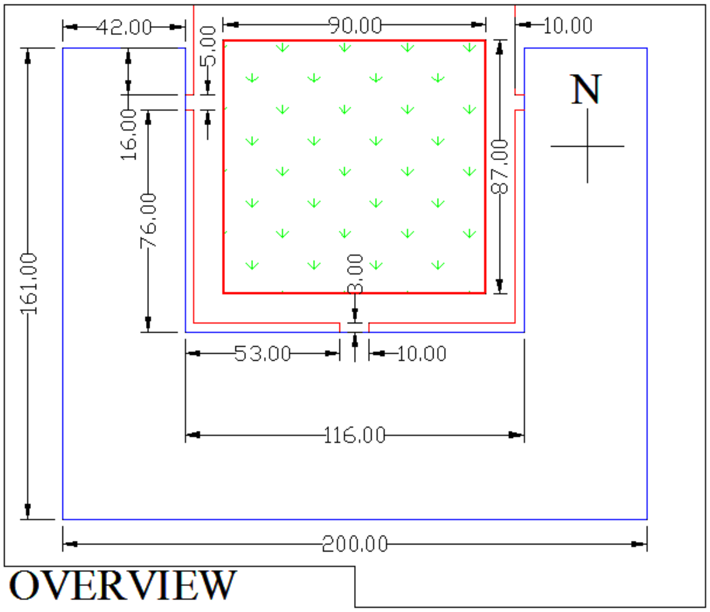
Notes: All Stalls are of equal dimensions (60" x 36") (does not include Handicap Stall)
All Stall walls are of equal thickness (2")
All Sinks are of equal dimensions (elliptical: 20" and 16" diameters)
All Sinks are of equal distance apart (18") (does not include Handicap Stall)
All Showers contain two areas (Shower and Changing Room) divided by a 3" wall
All Showers of equal dimensions (30" x 36") (does not include Handicap Shower)
All Changing Rooms are of equal dimensions (39" x 30") (does not include Handicap Shower)
All Shower walls are of equal thickness (3")

Stairs

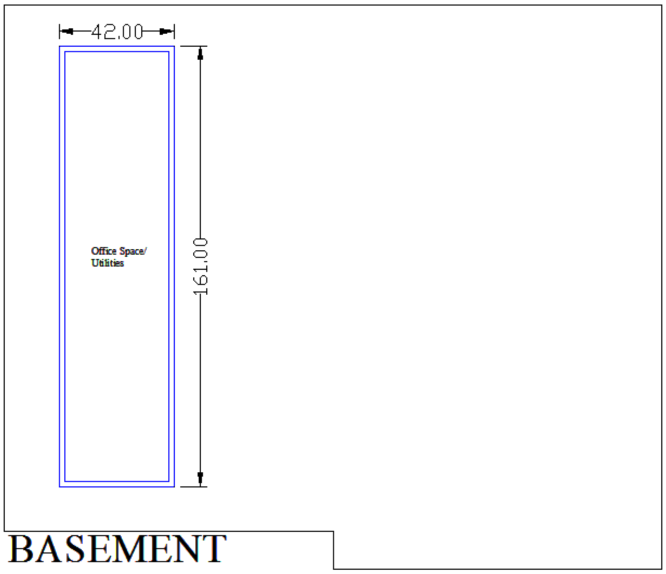


Notes: All Stairs are of equal dimensions (12" x 54" x 6")
Platform 1 and Platform 2 have a vertical distance of 5'
Platform 2 and Platform 3 have a vertical distance of 2'
Platform 3 and Platform 4 have a vertical distance of 5'

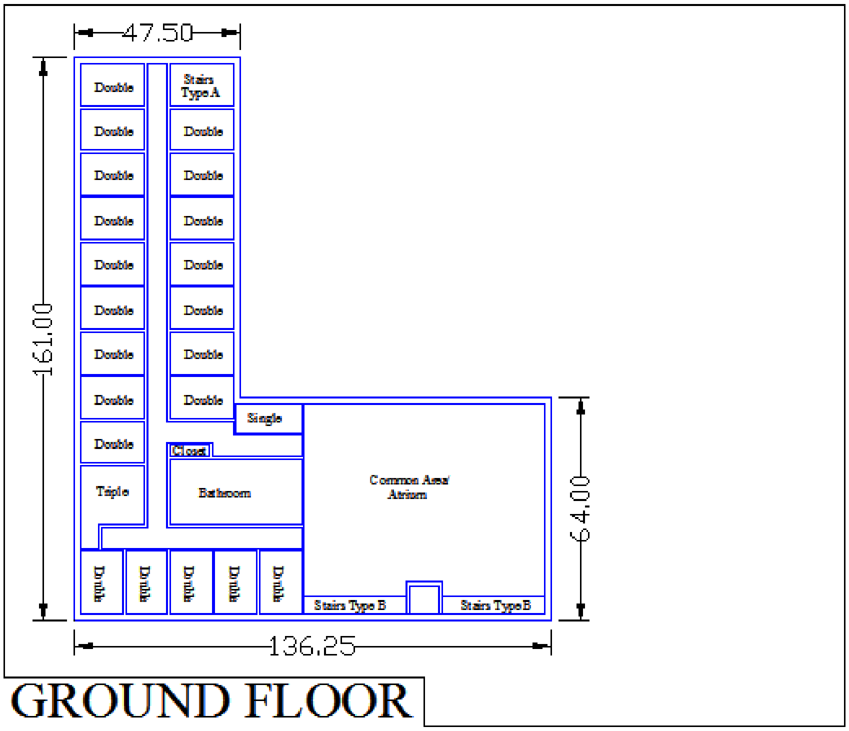
Appendix C-2: Building Drawings – U Design



Notes: All Retaining walls are of equal thickness (1/2')
Walkway has a uniform 10' width around courtyard
Walkway is located 3' from building face

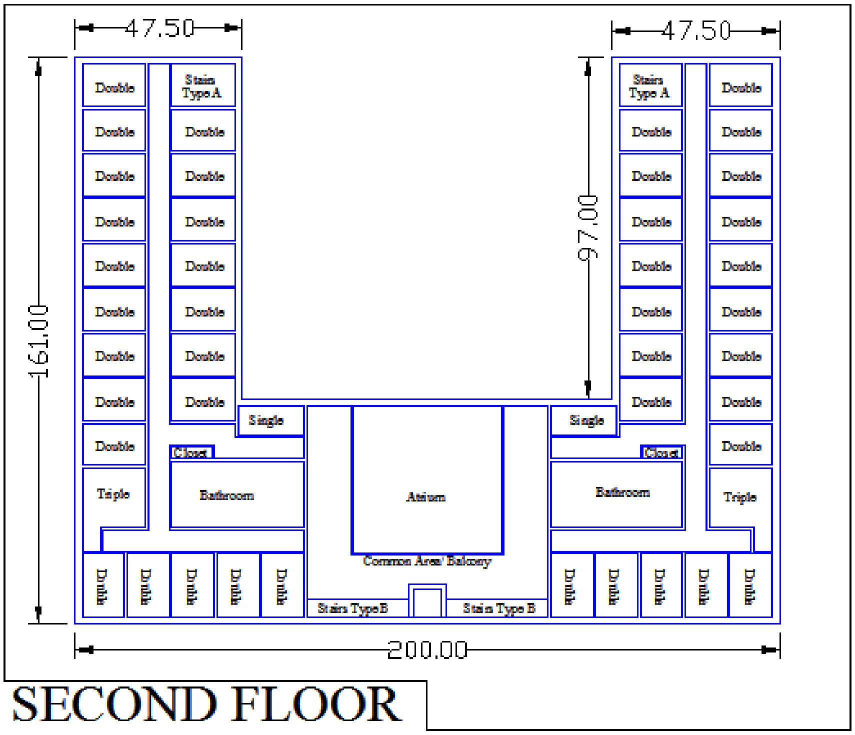


Notes: This floor is not connected to the rest of the building
All Exterior walls are of equal thickness (2')



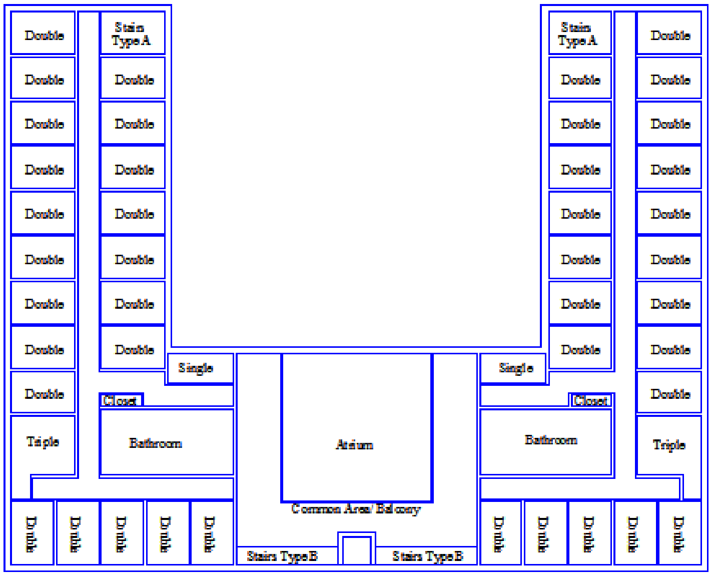
GROUND FLOOR

Notes: Triples are 15' x 20 ' (South) and 22' x 14' (North)
All Doubles are of equal dimensions (10' x 15')
All Singles are of equal dimensions (11' x 8')
Janitorial Closet - 8' x 7'
Kitchenette - 7'4" x 21'
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (1')
All Hallways are 6' wide
Atypical areas are shown in greater detail on other sheets
2 Triples + 22 Doubles + 2 Singles = 52 Students on this floor



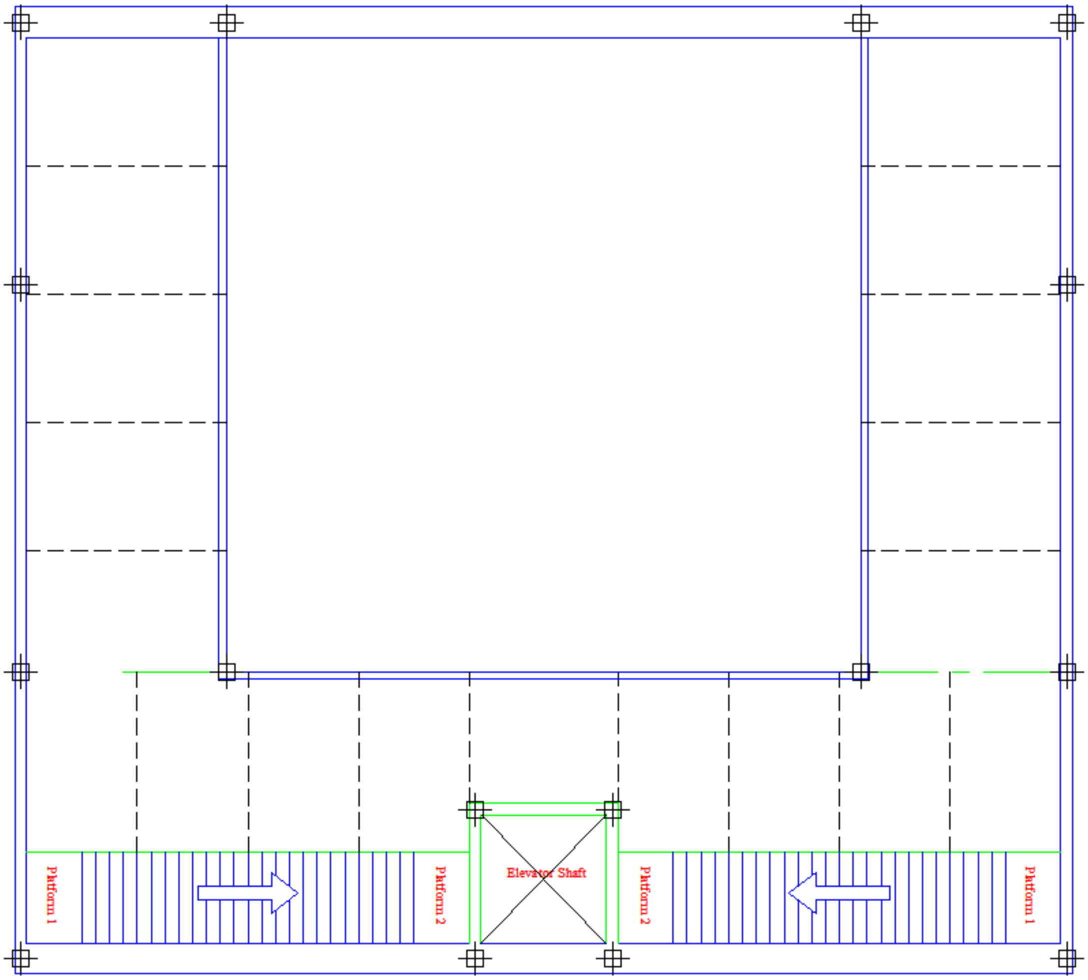
SECOND FLOOR

Notes: Triples are 15' x 20 ' (South) and 22' x 14' (North)
All Doubles are of equal dimensions (10' x 15')
All Singles are of equal dimensions (11' x 8')
All Janitorial Closets are of equal dimensions - 8' x 7'
All Kitchenettes are of equal dimensions - 7'4" x 21'
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (1')
All Hallways are 6' wide
Atypical areas are shown in greater detail on other sheets
4 Triples + 42 Doubles + 4 Singles = 104 Students on this floor

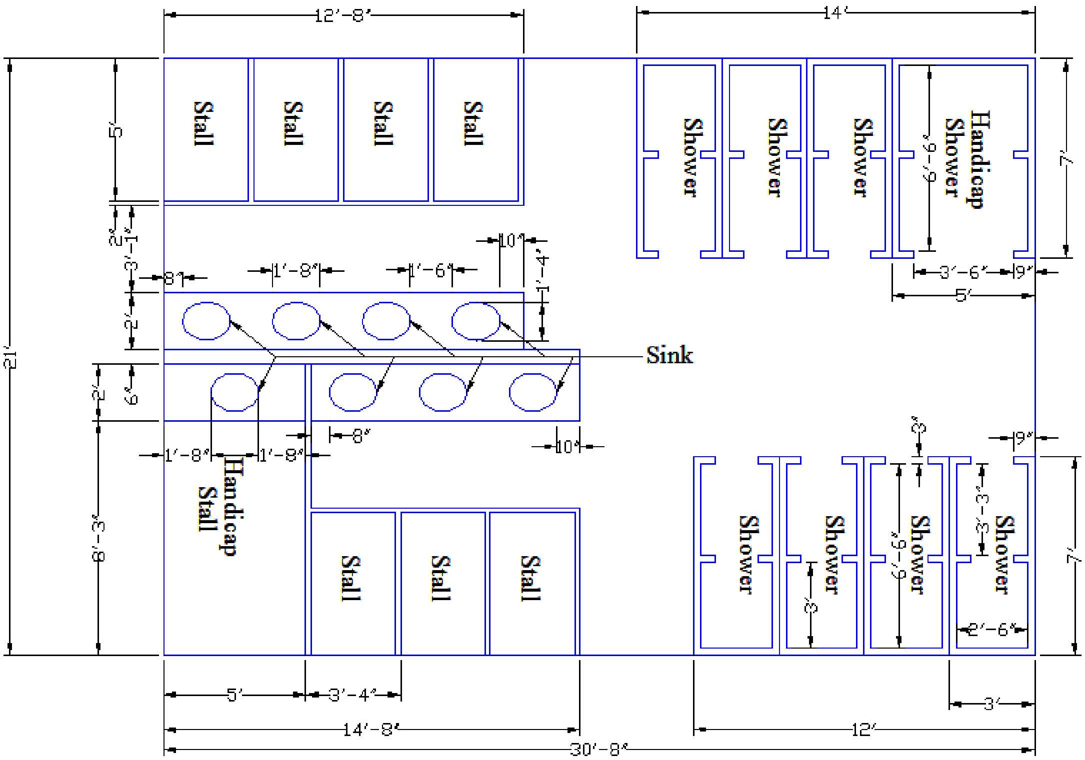


THIRD FLOOR

Notes: All Triples are of equal size (337 sq. ft.)
All Doubles are of equal size (216 sq. ft.)
All Singles are of equal dimensions (144 sq. ft.)
Janitorial Closets are of equal size (36.56 sq. ft.)
All Exterior walls are of equal thickness (2')
All Interior walls are of equal thickness (9")
All Hallways are 6' wide
Atypical areas are shown in greater detail on other sheets
2 Triples + 42 Doubles + 2 Singles = 92 Students on this floor



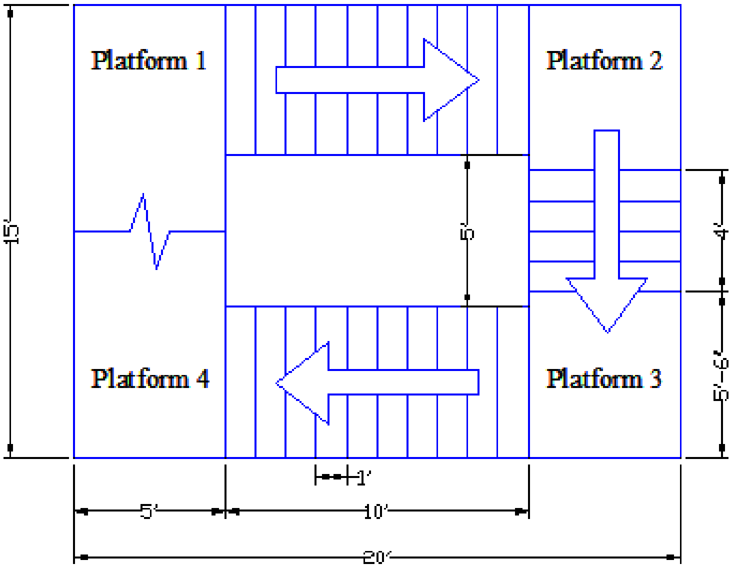
ATRIUM/COMMON AREA



Left Wing Bathroom

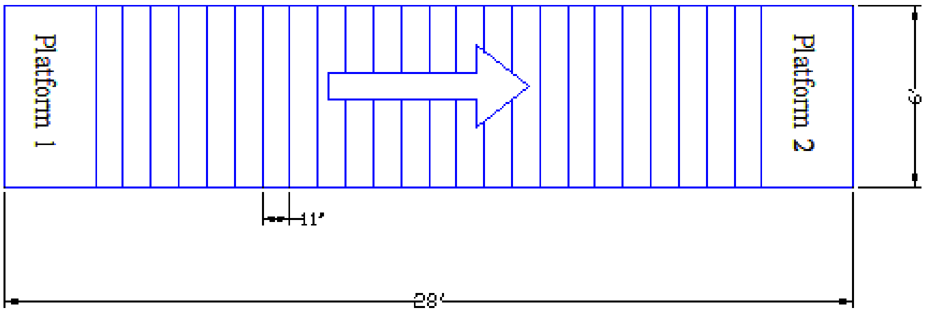
Notes: All Stalls are of equal dimensions (60" x 36") (does not include Handicap Stall)
All Stall walls are of equal thickness (2")
All Sinks are of equal dimensions (elliptical: 20" and 16" diameters)
All Sinks are of equal distance apart (18") (does not include Handicap Stall)
All Showers contain two areas (Shower and Changing Room) divided by a 3" wall
All Showers of equal dimensions (30" x 36") (does not include Handicap Shower)
All Changing Rooms are of equal dimensions (39" x 30") (does not include Handicap Shower)
All Shower walls are of equal thickness (3")

Stairs Type A



Notes: All Stairs are of equal dimensions (12" x 60" x 6")
Platform 1 and Platform 2 have a vertical distance of 5'
Platform 2 and Platform 3 have a vertical distance of 2'
Platform 3 and Platform 4 have a vertical distance of 5'

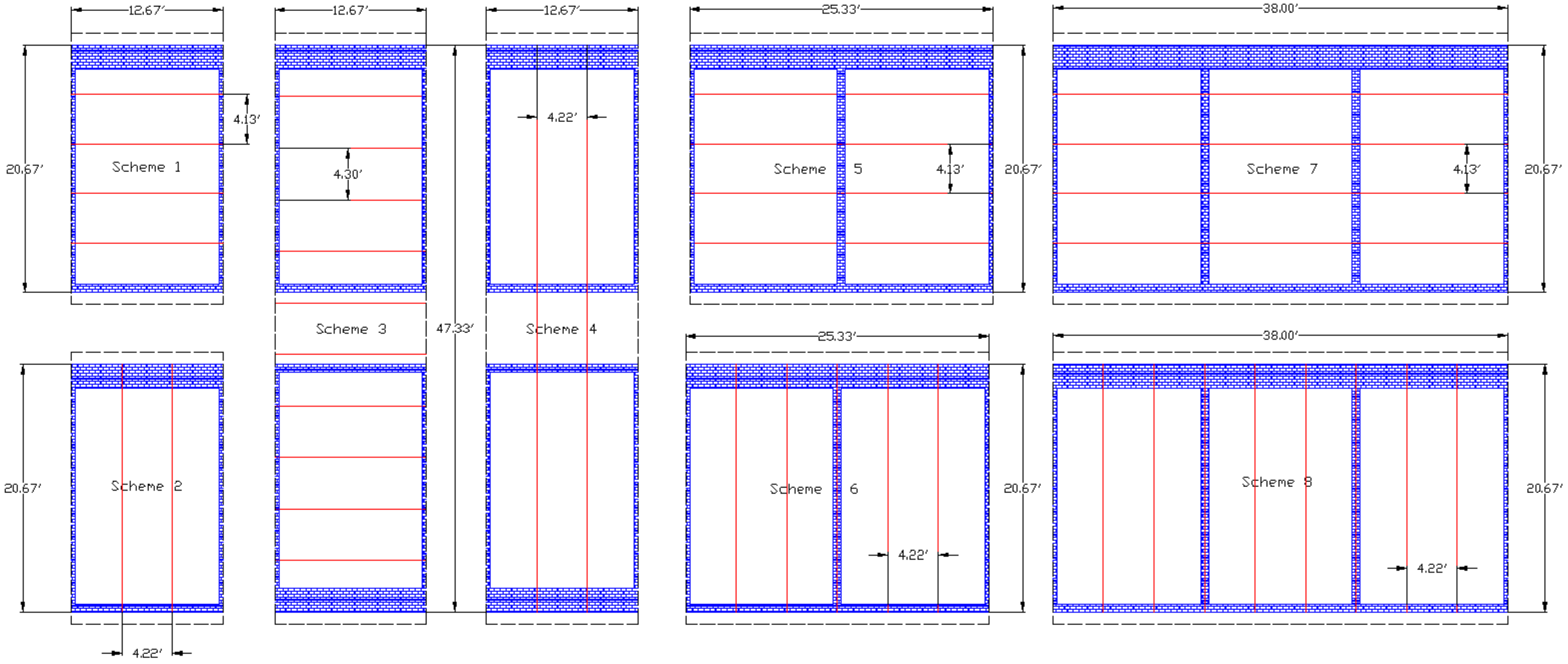
Stairs Type B



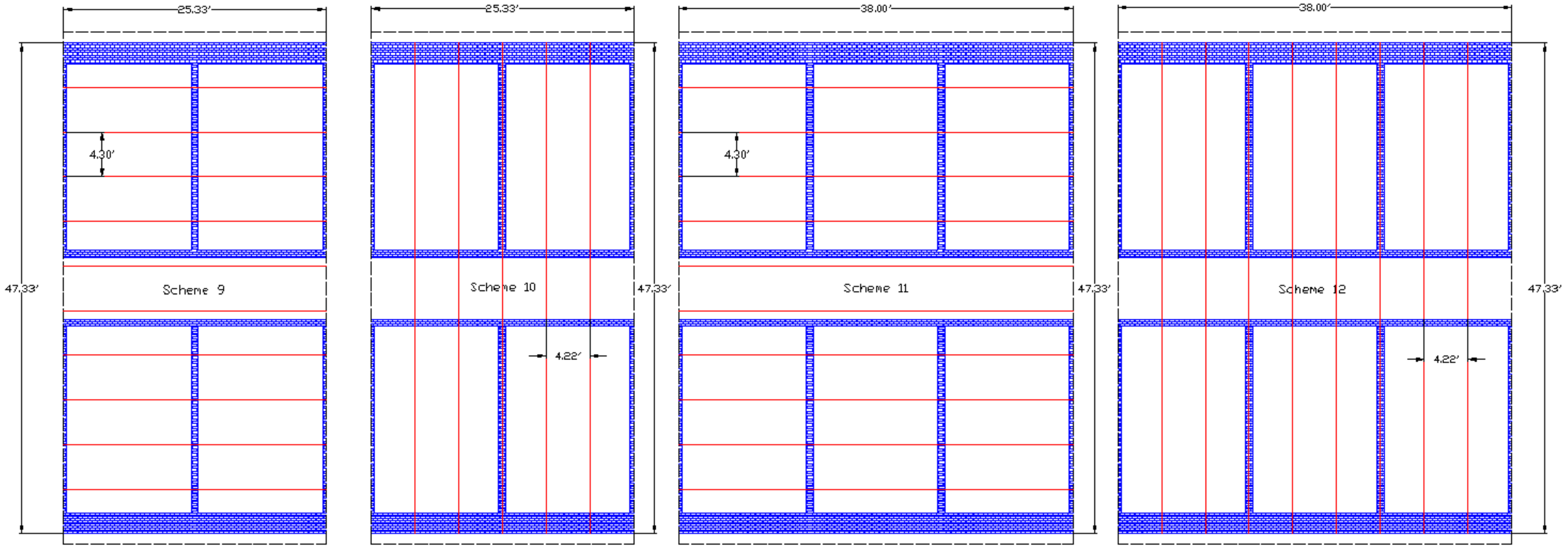
Notes: All Stairs are of equal dimensions (11" x 72" x 6")
Platform 1 and Platform 2 have a vertical distance of 12'

Appendix C-3: Typical Area Schemes

Schemes 1-8



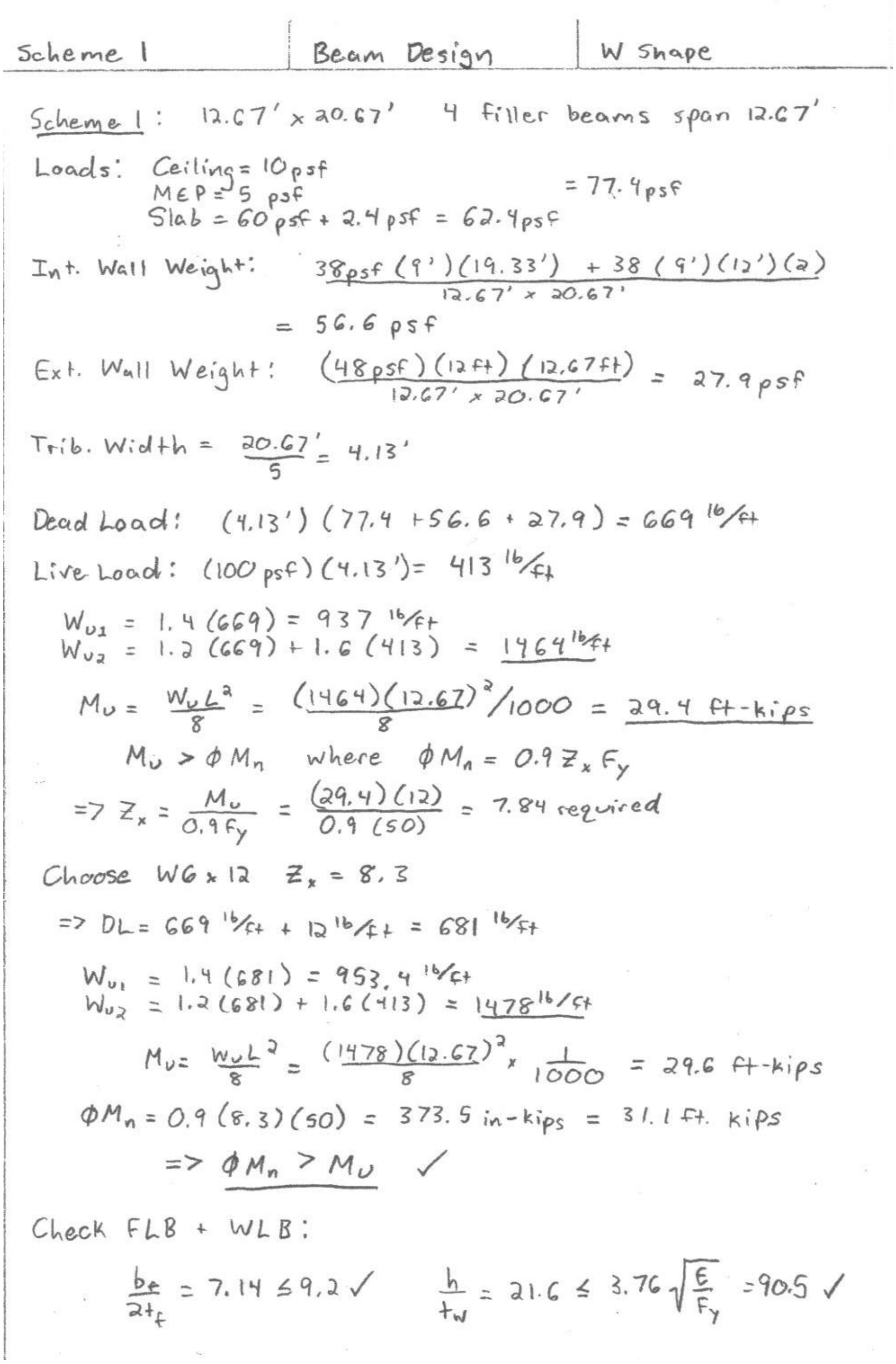
Schemes 9-12



Key:

Black = Scheme Boundaries and Dimensions
Blue = Interior and Exterior Wall Areas
Red = Infill Beams

Appendix D-1: Hand Calculations and Design Spreadsheets



Scheme 1	Beam Design	W Shape

Scheme 1: 12.67' × 20.67'   4 filler beams span 12.67'

Loads: Ceiling = 10 psf
MEP = 5 psf
Slab = 60 psf + 2.4 psf = 62.4 psf
= 77.4 psf

Int. Wall Weight: $\frac{38\,psf\,(9')(19.33') + 38\,(9')(12')(2)}{12.67' \times 20.67'}$

$= 56.6\ psf$

Ext. Wall Weight: $\frac{(48\,psf)(12\,ft)(12.67\,ft)}{12.67' \times 20.67'} = 27.9\ psf$

Trib. Width = $\frac{20.67'}{5} = 4.13'$

Dead Load: $(4.13')(77.4 + 56.6 + 27.9) = 669\ ^{lb}/_{ft}$

Live Load: $(100\ psf)(4.13') = 413\ ^{lb}/_{ft}$

$W_{u1} = 1.4\,(669) = 937\ ^{lb}/_{ft}$
$W_{u2} = 1.2\,(669) + 1.6\,(413) = \underline{1464\ ^{lb}/_{ft}}$

$M_u = \frac{W_u L^2}{8} = \frac{(1464)(12.67)^2}{8}/1000 = \underline{29.4\ ft\text{-}kips}$

$M_u > \phi M_n$ where $\phi M_n = 0.9\, Z_x F_y$

$\Rightarrow Z_x = \frac{M_u}{0.9 F_y} = \frac{(29.4)(12)}{0.9\,(50)} = 7.84$ required

Choose W6 × 12 $Z_x = 8.3$

$\Rightarrow DL = 669\ ^{lb}/_{ft} + 12\ ^{lb}/_{ft} = 681\ ^{lb}/_{ft}$

$W_{u1} = 1.4\,(681) = 953.4\ ^{lb}/_{ft}$
$W_{u2} = 1.2\,(681) + 1.6\,(413) = \underline{1478\ ^{lb}/_{ft}}$

$M_u = \frac{W_u L^2}{8} = \frac{(1478)(12.67)^2}{8} \times \frac{1}{1000} = 29.6\ ft\text{-}kips$

$\phi M_n = 0.9\,(8.3)(50) = 373.5\ in\text{-}kips = 31.1\ ft.\ kips$

$\Rightarrow \underline{\phi M_n > M_u}$ ✓

Check FLB + WLB:

$\frac{b_f}{2t_f} = 7.14 \le 9.2$ ✓ $\frac{h}{t_w} = 21.6 \le 3.76\sqrt{\frac{E}{F_y}} = 90.5$ ✓

Scheme 1

Check deflection:

$$\Delta_D = \frac{5 w_D L^4}{384 EI} = \frac{5\left(681/1000\right)(12.667)^4 \overset{\text{conversion factor}}{(1728)}}{384(29000)(22.1)}$$

$$\Delta_D = 0.615 \text{ in} < 1'' \text{ max} \checkmark$$

$$\Delta_L = \frac{1}{2}\left(\frac{5 w_L L^4}{384 EI}\right) = \frac{1}{2}\left[\frac{5\left(413/1000\right)(12.667)^4(1728)}{384(29000)(22.1)}\right] = 0.187 < 1'' \text{max} \checkmark$$

Unshored Construction:

Live Load: $145\text{pcf}\left(\frac{5}{12}\right)(4.13)\overset{\text{ponding}}{(1.1)} = 274 \text{ lb/ft}$ concrete
$20\text{psf}\,(4.13) = 82.6 \text{ lb/ft}$ workers

Dead Load: 12 lb/ft

$$W_u = 1.2(12) + 1.6(274 + 82.6) = 585 \text{ lb/ft}$$

$$M_u = \frac{W_u L^2}{8} = \frac{(585)(12.67)^2}{8}\left(\frac{1}{1000}\right) = 11.7 \text{ ft-kips}$$

$$\phi M_n = 31.1 \text{ ft-kips} > 11.7 \text{ ft-kips} = M_u \checkmark$$

Deflection:

$$\Delta_c = \frac{5 w_{D+L} L^4}{384 EI} = \frac{5\left(274 + 82.6 + 12/1000\right)(12.667)^4(1728)}{384(29000)(22.1)}$$

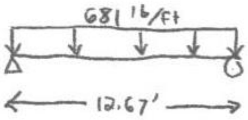
$$\Delta_c = 0.333 \text{ in} < 1.5 \text{ in. max} \checkmark$$

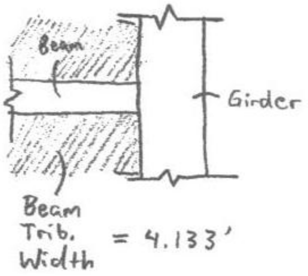
$$\Rightarrow \boxed{W6 \times 12}$$

Scheme 1

From beam design:

Total DL = 681 lb/ft





=> Distributed Load on Girder:

$(681\ \text{lb/ft})(12.67')$

$= 8{,}626$ lb point load on girder

Due to slab, beam point loads will be considered distributed

$$\Rightarrow \frac{8628\ \text{lb}}{4.133\ \text{ft}} = \underline{2{,}087\ \text{lb/ft}}\quad DL$$

Repeat for live load: $\dfrac{413\ \text{lb/ft}\ (12.67')}{4.13\ \text{ft}} = \underline{1266\ \text{lb/ft}}$ LL

$$W_{U1} = 1.4(2087) = 2922\ \text{lb/ft}$$
$$W_{U2} = 1.2(2087) + 1.6(1266) = \underline{4530\ \text{lb/ft}}$$

$$M_U = \frac{W_U L^2}{8} = \frac{(4530)(20.67)^2}{8}\ \frac{1}{1000} = 242\ \text{ft-kips}$$

$$Z_x = \frac{(242)(12)}{0.9(50)} = 64.5 \text{ required}$$

Choose 18x35 $Z_x = 66.5$ => $DL = 2087 + 66.5 = 2153.5$

$$W_{U1} = 1.4(2153.5) = 3015\ \text{lb/ft}$$
$$W_{U2} = 1.2(2153.5) + 1.6(1266) = \underline{4610\ \text{lb/ft}}$$

$$M_U = \frac{(4610)(20.67)^2}{8}\ \frac{1}{1000} = 246\ \text{ft-kips}$$

$$\phi M_n = \frac{0.9(66.5)(50)}{12} = 249\ \text{ft-kips} > 246\ \text{ft-kips}$$

$$\Rightarrow \underline{\phi M_n > M_U}\ \checkmark$$

Check FLB + WLB:

$$\frac{b_f}{2t_f} = 7.06 \le 9.2 \checkmark \qquad \frac{h}{t_w} = 53.5 \le 3.76\sqrt{\frac{E}{F_y}} = 90.5 \checkmark$$

Scheme 1

Check deflection:

$$\Delta_D = \frac{5 W_D L^4}{384 EI} = \frac{5(2154/1000)(20.667)^4(1728)}{384(29000)(510)} = 0.598'' < 1''_{max} \checkmark$$

$$\Delta_L = \frac{1}{2}\left(\frac{5 W_L L^4}{384 EI}\right) = \frac{1}{2}\left[\frac{5(1265/1000)(20.67)^4(1728)}{384(29000)(510)}\right] = 0.176'' < 1''_{max} \checkmark$$

Unshored Construction:

trib. width girder

$$\text{Live Load: } 145_{pcf}\left(\tfrac{5}{12}\right)(6.33)(1.1) = 421\ ^{lb}/_{ft}$$

$$20_{psf}(6.33) = 127\ ^{lb}/_{ft}$$

metal decking

$$\text{Dead Load: } 12\ lb/ft\ (\text{beam}) + 35\ ^{lb}/_{ft}\ (\text{girder}) + 2_{psf}(6.33) = 60\ ^{lb}/_{ft}$$

$$W_U = 1.2(60) + 1.6(421 + 127) = 949\ ^{lb}/_{ft}$$

$$M_U = \frac{W_U L^2}{8} = \frac{(949)(20.67)^2}{8}\ \frac{1}{1000}$$

$$M_U = 50.1 \text{ ft-kips}$$

$$\phi M_n = 249 \text{ ft-kips} > 50.1 \text{ ft-kips} = M_U \checkmark$$

Deflection:

$$\Delta_c = \frac{5 W_{D+L} L^4}{384 EI} = \frac{5\left(^{421+127+60}/_{1000}\right)(20.667)^4(1728)}{384(29000)(510)}$$

$$\Delta_c = 0.169'' < 1.5''\ max \checkmark$$

$$\Rightarrow \boxed{W\ 18 \times 35}$$

Scheme 5 | Open Web Joist Design

Scheme dimensions: 25.33' x 20.67'   Joists span 24.67'

Try 4 Joists → Trib area = 4.13'

D_L: Ceiling + Slab + MEP = 77.4 psf   Int. Wall $= \frac{(38)(9)(4.13)}{25.33} = 55.8$ plf

$(77.4)(4.13) = 320.0$ plf

$D_L = (320) + (55.8) = 375.8$ plf

$L_L = (100_{psf})(4.13') = 413$ plf

$w_u = 1.2(375.8) + 1.6(413)$

$450.96 + 660.9 = 1112$ plf

Treat span as 25' (pg 22, American National Standard SJI-K-1.1)

- 1112 plf is too large, Try 6 Joists → Trib Area = 2.95'

D_L: $(77.4)(2.95) = 228.33$ plf   Int. Wall $= (38)(9)(2.95)/(24.67) = 40.90$ plf

$D_L = (228.33) + (40.90) = 269.23$ plf

$L_L = (100)(2.95) = 295$ plf

$w_u = 1.2(269.23) + 1.6(295)$

$323.08 + 472 = 795$ plf

Try 20K7 Joists – weight = 9.3 plf

New $D_L = 269.23 + 9.3 = 278.53$ plf $\rightarrow$ $w_u = 1.2(278.53) + 1.6(295) = 806$ plf < 811 plf ✓

Interior Beam Design   Beam spans 24.67'   Trib Area $= \left(\frac{2.95}{2}\right) + \left(\frac{6.67}{2}\right) = 4.81'$

D_L: Int. Wall Perp. $= \left[\frac{18-(2.95 \times 6)}{2}\right](38)(9)/(24.67) = 2.08$ plf

Int. Wall Above $= (38)(9) = 342$ plf $(77.4)\left(\frac{2.95}{2}\right) = 114.17$ plf

$D_L = 342 + 2.08 + 114.17 = 458.3$ plf

$L_L = (100)(4.81) = 481$ plf

$w_u = 1.2(458.3) + 1.6(481) = 1320$ plf

$M_u = \frac{w_u l^2}{8} \rightarrow M_u = \frac{(1320)(24.67)^2}{8(1000)} = 100.4$ Ft-kips $M_u > \phi M_n$ where $\phi M_n = .9 Z_x f_y$

$\rightarrow Z_x = \frac{M_u}{.9 F_y} \rightarrow Z_x = \frac{(100.4)(12)}{(.9)(50)} \rightarrow Z_x = 26.78$

Column Design

Int Columns: Support ½ Girder, 1 Interior Beam   Trib Area $= \left(\frac{20.67}{2} + \frac{6.67}{2}\right)(25.33) = 346\ ft^2$

Roof – D_L: $77.4 + 40 + 8 = 125_{psf} \rightarrow 125 \times 346 = 43250$ lb

S_L: $35_{psf} \times 346\ ft^2 = 12110$ lb

$w_u = 1.2(43250) + 1.6(12110) = 71.28^k$

4th – D_L: $(474)(24.67) + (487)(20.67/2) = 16727$ lb

L_L: $(481)(24.67) + (4225)(20.67/2) = 55532$ lb

$w_u = 1.2(16727) + 1.4(55532) = 97.82^k$

3rd – Same as 4th – 97.82^k

$\Sigma w_u = (97.82)(2) + (71.28) = 267^k$

Scheme 5	Exterior Beam Design	

Exterior Beam - spans 24.67' Trib. area: 2.95/2 = 1.48'

D_L: Int. Wall Perp. = 2.08 plf Int. Wall Above = 342 plf Ext. Wall = (48)(12) = 576 plf

(77.4)(1.48) = 114.55 plf → D_L = 2.08 + 342 + 576 + 114.55 = 1035 plf

L_L = (100)(1.48) = 148 plf

$$w_u = \begin{matrix} 1.4(1035) = 1449 \text{ plf} \\ 1.2(1035) + 1.6(148) = 1479 \text{ plf} \end{matrix} \rightarrow w_u = 1479 \text{ plf}$$

$$M_u = \frac{w_u l^2}{8} \rightarrow M_u = \frac{(1479)(24.67)^2}{(8)(1000)} \rightarrow M_u = 112.5 \text{ ft-kips} \rightarrow Z_x = \frac{(112.5)(12)}{(.9)(50)} \rightarrow Z_x = 30.00$$

Girder Design - spans 20.67' Trib width = 25.33'

$$\text{Joist } D_L = \frac{(277.46)(25.33)}{2.95} = 2382 \text{ lb} \rightarrow 2382/20.67 = 115 \text{ plf}$$

D_L = 115 + 342 = 457 plf

L_L: Joist - (295)(24.67)(12) = 87332 lb/20.67' = 4225 plf

w_u = 1.2(457) + 1.6(4225) = 7308 plf

Column Design

Ext. Columns: Support $\frac{1}{2}$ Girder, 1 Exterior Beam Trib Area = $\left(\frac{20.67}{2}\right)(25.33)$ = 262 ft^2

Roof - D_L: (125)(262) = 32750 lb

S_L: (35)(262) = 9170 lb

> w_u = 1.2(32750) + 1.6(9170) = 53.97^k

4th - D_L: (1067)(24.67) + (487)(20.67/2) = 31109 lb

L_L: (148)(24.67) + (4225)(20.67/2) = 47317 lb

> w_u = 1.2(31109) + 1.6(47317) = 113.04^k

3rd - Same as 4th - 113.04^k

Σw_u = (113.04)(2) + (53.97) → Σw_u = 280^k

Scheme 9 | Open Web Joist Design

Room Web Joists Span 24.67', 6 Joists with trib. width of 2.76'

D_L = Ceiling + Slab + MEP = 77.4 psF

$77.4 \times 2.76 = 213.7$ plf

Int. Wall = $\frac{(38)(9)(2.76)}{(24.67)} = 38.3$ plf

$D_L = (213.7) + (38.3) = \boxed{262.\text{ plF}}$

$L_L = (100)(2.76) = \boxed{276\text{ plF}}$

$\Big\rangle\; w_u = 1.2(252) + 1.6(276) = 744$ plf

Try 18K9 Joists $d = 18$in weigh 10.2 plF

New $D_L = 282 + 10.2 = 262.2$ plf

$w_u = 1.2(262.2) + 1.6(276) = 756.2$ plF < 825 plF ✓ $\boxed{\text{Use 18K9 Joists}}$

Int. Beam Design Span 24.67', trib. width = 4.72'

D_L: 77.4 psF

$77.4 \times 4.72 = 365.3$ plF

Int. Wall (Perp.) = $\frac{(.72)(38)(9)}{24.67} = 10.0$ plF

Int. Wall (Above) = $(38)(9) = 342$ plF

$D_L = 365.3$ plF + 10 plF + 342 plF $\rightarrow D_L = 717$ plF

$L_L = (100)(4.72) \rightarrow L_L = 472$ plF

$w_u = \begin{array}{l} 1.4(717) = 1004 \\ 1.2(717) + 1.6(472) = 1616 \text{ plf} \end{array}$

$M_u = \frac{w_u \ell^2}{8} \rightarrow M_u = \frac{(1616)(24.67)^2}{8} = 123$ Ft-kips

$\phi M_n = (.9)(Z_x)(F_y) \rightarrow (123)(12) = (.9)(Z_x)(50) \rightarrow Z_x = 32.8\text{ in}^3$

Try W14x22 $Z_x = 33.2$, $I_x = 199\text{ in}^4$

$D_L = 717 + 22 = 739$ plf

$w_u = 1.2(739) + 1.6(472) = 1642$ plF

$M_u = \frac{(1642)(24.67)^2}{8(1000)} = 125$ Ft-kips $\rightarrow \phi M_n = (.9)(33.2)(50)/(12) \rightarrow \phi M_n = 124.5$ $\phi M_n > M_u$ X

Try W12x26 $Z_x = 37.2$, $I_x = 204$

$D_L = 717 + 26 = 743$ plF $\rightarrow w_u = 1.2(743) + 1.6(472) = 1647$

$M_u = \frac{1647(24.67)^2}{8000} = 125.3$ $\phi M_n = \frac{(.9)(37.2)(50)}{12} = 139.5$ $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓

$\Delta_D = \frac{5(w_D)L^4}{384EI} \rightarrow \Delta_D = \frac{(5)(.743)(24.67)^4(1728)}{(384)(29000)(204)} \rightarrow \Delta_D = 1.04$ in X

Try W12x30 $Z_x = 43.1$ $I_x = 238$ WLB ✓ FLB ✓

$D_L = 717 + 30 = 747 \rightarrow w_u = 1.2(747) + 1.6(472) = 1652$

$M_u = \frac{(1652)(24.67)^2}{8(1000)} \rightarrow M_u = 125.7$ ft-kips $\phi M_n = \frac{(.9)(43.1)(50)}{12} = 161.6$ ft-kips $\phi M_n > M_u$ ✓

$\Delta_D = \frac{(5)(.747)(24.67)^4(1728)}{(384)(29000)(238)} = .90$ in < 1 in max ✓

$\Delta_L = \frac{1}{2}\,\frac{(5)(472)(24.67)^4(1728)}{(384)(29000)(238)} = .28$ in < 1 in max ✓

Unshored Construction: Live Load: $(145)(\frac{5}{12})(4.72)(1.1) = 313.7$ $(20)(4.72) = 94.4$ $\rightarrow$ Live Load = $\boxed{408.1\text{ plF}}$

Dead Load: 30 plF

$w_u = 1.2(30) + 1.6(408.1) \rightarrow w_u = 689$ plF

$M_u = \frac{(689)(24.67)^2}{8(1000)} = 52.42$ Ft-kips $\phi M_n = 161.6$ ft-kips $\rightarrow \phi M_n > M_u$ ✓

$\Delta_c = \frac{(5)(.438)(24.67)^4(1728)}{(384)(29000)(238)} = .53$ in < 1.50 in ✓ $\boxed{\text{Use W12 x 30}}$

Ext. Beam Design Spans 24.67' trib width = 2.38'

D_L: 77.4 psf × 2.38' = 184.2 plf Int Wall (Perp) = $\frac{(.72)(38)(9)}{(24.67)}$ = 10.0 plf

Ext. Wall = (48)(9) = 432 plf Int. Wall (Above) = (38)(9) = 342 plf

Dead Load: 184.2 + 10 + 432 + 342 = 968.2 plf

Live Load: (100)(2.38) = 238 plf

W_u = 1.2(968.2) + 1.6(238) = 1543 plf
1.4(890.8) = 1247 plf

$M_u = \frac{(1543)(24.67)^2}{8(100)}$ = 117.3 Ft-kips $117.3 = \frac{(.9)(Z_x)(50)}{12} \rightarrow Z_x = 31.3$

Try W14x22 $Z_x = 33.2$ $I_x = 199$

D_L = 891 + 22 = 913 plf → w_u = 1.4(913) = 1278
1.2(913) + (1.6)(138) = 1316 plf

$M_u = \frac{(1316)(24.67)^2}{8(1000)}$ = 100 ft-kips $\phi M_n = \frac{(.9)(33.2)(50)}{12}$ = 124.5 ft-kips $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓

$\Delta_D = \frac{(5)(913)(24.67)^4(1728)}{(384)(29000)(199)} \rightarrow \Delta_D$ = 1.31 > 1 in max ✗

Try W14x26 $I_x = 245$ $Z_x = 40.2$

D_L = 968 + 26 = 994 plf → w_u = 1.4(968) + 1.6(238) = 1772 plf

$M_u = \frac{(1772)(24.67)^2}{8(1000)}$ = 135 ft-kips $\phi M_n = \frac{(.9)(40.2)(50)}{12}$ = 151 ft-kips → $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓

$\Delta_D = \frac{(5)(.917)(24.67)^4(1728)}{(384)(29000)(245)} \rightarrow \Delta_D$ = 1.07 > 1 in max ✗

Try W12x40 $Z_x = 57$ $I_x = 307$

D_L = 968 + 40 = 1008 plf → w_u = 1.4(1008) = 1296.4
1.2(1008) + 1.6(238) = 1590

$M_u = \frac{(1590)(24.67)^2}{8(1000)}$ = 121 ft-kips $\phi M_n = \frac{(.9)(57.0)(50)}{12}$ = 214 ft-kips $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓ $\Delta_D = \frac{(5)(1.008)(24.67)^4(1728)}{(384)(29000)(307)} \rightarrow \Delta_D$ = .94 in < 1 in max ✓

$\Delta_L = \frac{(5)(.238)(24.67)^4(1728)}{(2)(384)(29000)(307)} \rightarrow \Delta_L$ = .01 in < 1 in max ✓

Unshored Construction: Live Load - $(145)(\frac{5}{12})(2.38)(1.1)$ = 158.2 20(2.38) = 47.6 L_L = 206 plf
Dead Load = 40 plf

W_u = 1.2(40) + 1.6(206) = 378 plf

$M_u = \frac{(378)(24.67)^2}{8000}$ = 28.8 ft-kips $\phi M_n = \frac{(.9)(51.2)(50)}{12}$ = 192 ft-kips $\phi M_n > M_u$ ✓

$\Delta_c = \frac{(5)(.246)(24.67)^4(1728)}{(384)(29000)(307)}$ = .23 in < 1 in max ✓ $\boxed{\text{Use W12x40}}$

Girder Design Span 47.33ft trib width = 25.33'

Joist D_L: $\frac{(262\text{ plf})(24.67)}{(2.76')} = 2342\text{ plf} \times (12 \times 2.76) = 21{,}358\text{ lb}$

Int. Beam: $\frac{(747)(24.67)}{(4.72)} = 3904\text{ plf} \times (2 \times 4.72) = 36857\text{ lb}$

Ext. Beam: $\frac{(1008)(24.67)}{(2.38)} = 10448\text{ plf} \times (2 \times 2.38) = 49735\text{ lb}$

$107950\text{ lb}/47.33' = 2281\text{ plf}$

Int. Wall: $(38)(9) = 342\text{ plf}$

Dead Load = $\boxed{2623\text{ plf}}$

Joist L_L: $(276)(24.67)(12) = 81707\text{ lb}$

Int Beam L_L: $(472)(24.67)(2) = 23288\text{ lb}$

Ext. Beam L_L: $(238)(24.67)(2) = 11743\text{ lb}$

$116738\text{ lb}/47.33' = \boxed{2466\text{ plf}}$

$w_u = 1.2(2623) + 1.6(2466) \rightarrow w_u = 7093\text{ plf}$

$M_u = \frac{(7093)(47.33)^2}{8(1000)} = 1986\text{ ft-kips} \rightarrow 1986 = \frac{(.9)(Z_x)(50)}{12} \rightarrow Z_x = 530$

Try W27x178 $Z_x = 570$ $I_x = 7020$

$D_L = 2623 + 178 = 2801$ $w_u = 1.2(2801) + 1.6(2466) = 7307$

$M_u = \frac{(7307)(47.33)^2}{8(1000)} = 2046\text{ ft-kips}$ $\phi M_n = \frac{(.9)(570)(50)}{12} = 2138$ $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓ $\Delta_D = \frac{(5)(2801)(47.33)^4(1728)}{(384)(29000)(7020)} \rightarrow \Delta_D = 1.56 > 1$ ✗

Try W36x150 $Z_x = 581$ $I_x = 9040$

$D_L = 2623 + 150 = 2773$ $w_u = 1.2(2773) + 1.6(2466) = 7273$

$M_u = \frac{(7273)(47.33)^2}{8(1000)} = 2037\text{ ft-kips}$ $\phi M_n = \frac{(.9)(581)(50)}{12} = 2179$ $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓ $\Delta_D = \frac{(5)(2.773)(4733)^4(1728)}{(384)(29000)(9040)} = 1.19\text{ in} > 1\text{ in}$ ✗

Try W40x167 $Z_x = 693$ $I_x = 11600$

$D_L = 2623 + 167 = 2790$ $w_u = 1.2(2790) + 1.6(2466) = 7294$

$M_u = \frac{(7294)(47.33)^2}{8000} = 2042\text{ ft-kips}$ $\phi M_n = \frac{(.9)(693)(50)}{12} = 2599$ $\phi M_n > M_u$ ✓

FLB ✓ WLB ✓ $\Delta_D = \frac{(5)(2790)(47.33)^4(1728)}{(384)(29000)(11600)} \rightarrow \Delta_D = .94$ ✓

$\Delta_L = \frac{(5)(2466)(47.33)^4(1728)}{(2)(384)(29000)(11600)} \rightarrow \Delta_L = .41$ ✓

Unshored Construction: Live Load = $[(145)(\frac{5}{12})(1.1) + (20)](25.33) \rightarrow$ Live Load = 2190 plf

Dead Load = 167 plf

$w_u = 1.2(167) + 1.6(2190) \rightarrow w_u = 3704\text{ plf}$

$M_u = \frac{(3704)(47.33)^2}{8(1000)} \rightarrow M_u = 1037\text{ ft-kips}$ ϕM_n 2599 $\phi M_n > M_u$ ✓

$\Delta_c = \frac{(5)(2.357)(47.33)^4(1728)}{(384)(29000)(11600)} = .79 < 1.5\text{ in}$ ✓ $\boxed{\text{Use W40x167}}$

Scheme 9 | Column Design

Colums support Girders & Ext Beams, Each column: $\frac{1}{2}$ Girder, full beam

Trib. Area = (25.33)(23.67) = 599 Ft^2

Roof - D_L: Roof – 77.4 + 40 (decking) + 8 (assumed) = 125 psf x 599 ft^2 = 74875 lb

S_L: 35 psf x 599 Ft^2 = 20965 lb

$W_u = 1.2(74875) + 1.6(20965) = 123.4^k$

4th - D_L: (1008 plF)(24.67 Ft) + (2790 plf)(23.665 ft) = 90893 lb

L_L: (238 plf)(24.67 Ft) + (2466 plF)(23.665 ft) = 64,229 lb

$w_u = 1.2(90893) + 1.6(64229) \rightarrow W_u = 211.8^k$

3rd - Same as 4th, $w_u = 211.8^k$

$\Sigma w_u = (211.8)2 + 123.4 = 547^k \rightarrow \boxed{\text{USE W21x68}}$

Table 4-1

Scheme 9 | Cost Estimating

18K9 - \$7.25/Ft

18K9's span 24.67' → (24.67')(7.25) = \$178.86 / Joist

\$178.86 x 12 Joists = \$2146.29

\$2146.29/1199 Ft^2 = \$1.79 / Ft^2

W12 x 30 - \$2500/ton = \$1.25/lb

↳ 30lb/Ft x \$1.25/lb = \$37.50/Ft → \$37.50/Ft x 24.67 Ft/beam = \$925.13/beam

\$925.13/beam x 2 beams = \$1850.25

\$1850.25/1199 Ft^2 = \$1.54/Ft^2

W12x40 - \$1.25/lb

↳ 40lb/Ft x \$1.25/lb = \$50/ft → \$50/ft x 24.67 Ft/beam = \$1233.50/beam

\$1233.50/beam x 2beams = \$2467

\$2467/1199 Ft^2 = \$2.06/Ft^2

W40 x 167 - \$1.25/lb

↳ 167 lb/ft x \$1.25/lb = \$208.75/Ft → \$208.75/ft x 24.67 ft/beam = \$5149.86/girder

\$5149.86/girder x 2 girders = \$10,299.73

\$10,299.73/1199Ft^2 = \$8.59/Ft^2

W21x68 - \$1.25/lb

↳ 68 lb/Ft x \$1.25/lb = \$85/Ft → \$85/Ft x 24Ft/column = \$2040/column

\$2040/column x 4 columns = \$8160

\$8160 /1199Ft^2 = \$6.81/Ft^2

Redesigning Stoddard Complex - Composite Beam and Girder Design

BEAM DESIGN

Ceiling + MEP + Slab	77.4psf	
Live Load	100 psf	*Must look up in manual (depends on beam size)

	Bay Size	Description
Scheme 1	12.67x20.67	4 filler beams, beams span 12.67 ft
Scheme 2	12.67x20.67	2 filler beams, beams span 20.67 ft
Scheme 5	25.33x20.67	4 filler beams, beams span 25.33 ft
Scheme 9	25.33x47.33	10 filler beams, beams span 25.33ft.
Scheme 10	25.33x47.33	5 filler beams, beams span 47.33 ft
Scheme 12	38x47.33	8 filler beams, beams span 47.33 ft

	Scheme 1	Scheme 2	Scheme 5	Scheme 9	Scheme 10	Scheme 12	
Beam Size	W10x15	W10x15	W12x16	W12x16	W21x50	W21x50	
Beam Depth (in)	10.000	10.000	12.000	12.000	20.800	20.800	
Beam Weight (lb/ft)	15.000	15.000	16.000	16.000	50.000	50.000	
Beam Span (L in ft.)	12.667	20.667	25.333	25.333	47.333	47.333	
Trib. Width (ft)	6.889	4.222	4.133	4.303	4.222	4.222	
Bay Area	261.778	261.778	523.556	1199.111	1199.111	1798.667	
ts (in)	6.000	6.000	6.000	6.000	6.000	6.000	
be (in)	82.667	50.667	49.600	51.636	50.667	50.667	
Fy (ksi)	50.000	50.000	50.000	50.000	50.000	50.000	
# Filler Beams	2	2	4	10	5	8	
DESIGN FOR SERVICE LOADS							
Interior Wall Weight (lbs)	14820.000	14820.000	29640.000	59280.000	59280.000	88920.000	
Int. Wall Weight (psf)	56.613	56.613	56.613	49.437	49.437	49.437	
Exterior Wall Weight	7296.000	7296.000	14592.000	29184.000	29184.000	43776.000	
Ext. Wall Weight (psf)	27.871	27.871	27.871	24.338	24.338	24.338	
Total DL (lb/ft)	1115.200	683.510	669.120	650.509	638.293	638.293	
LL (lb/ft)	688.889	422.222	413.333	430.303	422.222	422.222	
Wu1 (lb/ft)	1561.280	956.914	936.768	910.713	893.610	893.610	
Wu2 (lb/ft)	2440.462	1495.767	1464.277	1469.096	1441.507	1441.507	
Mu	48.945	79.857	117.468	117.854	403.702	403.702	
Zx required	13.052	21.295	31.325	31.428	107.654	107.654	
Zx chosen beam	13.600	13.600	20.100	20.100	110.000	110.000	
DL w/beam (lb/ft)	1130.200	698.510	685.120	666.509	688.293	688.293	
Wu3 (lb/ft)	1582.280	977.914	959.168	933.113	963.610	963.610	
Wu4 (lb/ft)	2458.462	1513.767	1483.477	1488.296	1501.507	1501.507	
Mu w/beam (ft-k)	49.306	80.818	119.008	119.394	420.505	420.505	
0.9ZxFy is Mn (ft-k)	51.000	51.000	75.375	75.375	412.500	412.500	
FLB	7.410	7.410	7.530	7.530	6.100	6.100	*Check that FLB < 9.2
WLB	38.500	38.500	49.400	49.400	49.400	49.400	*Check that WLB < 90.5
Y2	5.000	5.000	5.000	5.000	5.000	5.000	
T3-19 0.9Mn	96.500	96.500	118.000	118.000	850.000	850.000	
Actual "a"	0.261	0.426	0.466	0.447	5.697	5.697	
Actual Y2	5.869	5.787	5.767	5.776	3.152	3.152	
Interpolate x1	5.500	5.500	5.500	5.500	3.000	3.000	
Interpolate x	5.869	5.787	5.767	5.776	3.152	3.152	
Interpolate x2	6.000	6.000	6.000	6.000	3.500	3.500	
Interpolate y1	98.500	98.500	120.000	120.000	740.000	740.000	
Interpolate y2	101.000	101.000	122.000	122.000	768.000	768.000	
T3-19 0.9Mn	100.347	99.934	121.069	121.105	748.495	748.495	*Check that Mu w/beam is less than Mn
w	124.800	124.800	124.800	124.800	124.800	124.800	
f'c	3000.000	3000.000	3000.000	3000.000	3000.000	3000.000	
E	2414.807	2414.807	2414.807	2414.807	2414.807	2414.807	
Asc	0.4418	0.4418	0.4418	0.4418	0.4418	0.4418	
Qn	18.802	18.802	18.802	18.802	18.802	18.802	
Sum of Qn	55.100	55.100	58.900	58.900	736.000	736.000	
Number of Studs	3	3	4	4	40	40	
Full/Partial	Partial	Partial	Partial	Partial	Full	Full	
Interpolate x1	5.500	5.500	5.500	5.500	3.000	3.000	
Interpolate x	5.869	5.787	5.767	5.776	3.152	3.152	
Interpolate x2	6.000	6.000	6.000	6.000	3.500	3.500	
Interpolate y1	166.000	166.000	228.000	228.000	2410.000	2410.000	
Interpolate y2	176.000	176.000	239.000	239.000	2510.000	2510.000	
I (in^4)	173.386	171.735	233.877	234.079	2440.341	2440.341	
ΔD (in)	0.130	0.576	0.936	0.910	1.098	1.098	*Check that both deflections are under 1"
ΔL (in)	0.040	0.174	0.282	0.294	0.337	0.337	
CHECK CONSTRUCTION LOADS							
LL Concrete (lb/ft)	457.824	280.602	274.694	285.972	280.602	280.602	
LL Workers	137.778	84.444	82.667	86.061	84.444	84.444	
LL const (lb/ft)	595.602	365.046	357.361	372.033	365.046	365.046	
DL const. (lb/ft)	15.000	15.000	16.000	16.000	50.000	50.000	
Wc1 (lb/ft)	21.000	21.000	22.400	22.400	70.000	70.000	
Wc2 (lb/ft)	970.963	602.074	590.978	614.453	644.074	644.074	
Mu w/beam (ft-k)	19.473	32.144	47.410	49.293	180.377	180.377	*Check that Mu w/beam is less than Mn
T3-19 0.9Mn	100.347	99.934	121.069	121.105	748.495	748.495	
ΔC (in)	0.070	0.313	0.510	0.530	0.662	0.662	*Check that construction deflection is under 1.5"
CALCULATE COST							
Cost ($/ft^2)	$2.93	$4.65	$5.07	$4.87	$16.00	$16.00	*$2500 per ton + $3 per stud
Square Footage	261.778	261.778	523.556	1199.111	1199.111	1798.667	
Total Cost	$766.50	$1,216.50	$2,653.33	$5,837.33	$19,190.00	$28,785.00	

Redesigning Stoddard Complex - Composite Beam and Girder Design

GIRDER DESIGN

Ceiling + MEP + Slab	77.4psf	
Live Load	100 psf	*Must look up in manual (depends on beam size)
W6x12 supporting hallway		

	Bay size	Description
Scheme 1	12.67x20.67	4 filler beams, beams span 12.67ft
Scheme 2	12.67x20.67	2 filler beams, beams span 20.67ft
Scheme 5	25.33x20.67	4 filler beams, beams span 25.33ft
Scheme 9	25.33x47.33	10 filler beams, beams span 25.33ft.
Scheme 10	25.33x47.33	5 filler beams, beams span 47.33ft
Scheme 12	38x47.33	8 filler beams, beams span 47.33 ft

	Scheme 1	Scheme 2	Scheme 5	Scheme 9	Scheme 10	Scheme 12
Girder Size	W14x30	W10x15	W16x36	W33x130	W21x44	W27x84
Girder Depth (in)	13.800	10.000	15.900	33.100	20.700	26.700
Girder Weight (lb/ft)	30.000	15.000	36.000	130.000	44.000	84.000
Beam Size	W10x15	W10x15	W12x16	W12x16	W21x50	W21x50
Beam Depth (in)	10.000	10.000	12.000	12.000	20.800	20.800
Beam Weight (lb/ft)	15.000	15.000	16.000	16.000	50.000	50.000
Girder Span (L in ft.)	20.667	12.667	20.667	47.333	25.333	38.000
Beam Span (ft)	12.667	20.667	25.333	25.333	47.333	47.333
Trib. Width Beam (ft)	4.133	4.222	4.133	4.303	4.222	4.222
Trib. Width Girder	12.667	13.333	25.333	25.333	23.667	23.667
Bay Area	261.778	261.778	523.556	1199.111	1199.111	1798.667
ts (in)	6.000	6.000	6.000	5.000	5.000	5.000
Fy (ksi)	50.000	50.000	50.000	50.000	50.000	50.000
# Filler Beams	2	2	4	10	5	8
DESIGN FOR SERVICE LOADS						
Beam Dead Load (lb/ft)	1130.200	698.510	685.120	666.509	688.293	688.293
Beam Unit Load (lb)	14315.867	9313.462	17356.371	16884.897	16289.600	16289.600
Effective Dead Load (lb/ft)	3463.516	1861.910	4199.122	3923.955	3858.063	3858.063
Beam Live Load (lb/ft)	688.889	422.222	413.333	430.303	422.222	422.222
Beam Unit Load (lb)	8725.926	5629.630	10471.110	10901.010	9992.593	9992.593
Effective Live Load (lb/ft)	2111.111	966.667	2533.333	2533.333	2366.667	2366.667
Wu1 (lb/ft)	4848.922	2606.674	5878.771	5493.537	5401.288	5401.288
Wu2 (lb/ft)	7533.996	3780.959	9092.280	8762.079	8416.342	8416.342
Mu	402.232	75.829	485.427	2453.869	675.178	1519.150
Zx required	107.262	20.221	129.447	654.365	180.047	405.107
Zx chosen beam	47.300	16.000	64.000	467.000	95.400	244.000
DL w/beam (lb/ft)	3493.516	1876.910	4235.122	4053.955	3902.063	3942.063
Wu3 (lb/ft)	4890.922	2627.674	5929.171	5675.537	5462.888	5518.888
Wu4 (lb/ft)	7569.996	3798.959	9135.480	8918.079	8469.142	8517.142
Mu w/beam (ft-k)	404.154	76.190	487.733	2497.558	679.413	1537.344
0.9ZxFy is Mn (ft-k)	177.375	60.000	240.000	1751.250	357.750	915.000
FLB	8.740	7.410	7.970	6.730	7.220	7.780
WLB	45.400	38.500	56.800	51.700	53.600	52.700
Y2	5.000	5.000	5.000	4.000	4.000	4.000
T3-19 0.9Mn	396.000	96.500	513.000	3090.000	746.000	1700.000
Actual "a"	1.140	0.135	0.682	2.477	0.896	1.712
Actual Y2	5.430	5.932	5.659	3.762	4.552	4.144
Interpolate x1	5.000	5.500	5.500	3.500	4.500	4.000
Interpolate x	5.430	5.932	5.659	3.762	4.552	4.144
Interpolate x2	5.500	6.000	6.000	4.000	5.000	4.500
Interpolate y1	396.000	98.500	532.000	2880.000	722.000	1610.000
Interpolate y2	412.000	101.000	552.000	2950.000	746.000	1660.000
T3-19 0.9Mn	409.754	100.662	538.352	2916.625	724.492	1624.388
w	124.800	124.800	124.800	124.800	124.800	124.800
f'c	3000.000	3000.000	3000.000	3000.000	3000.000	3000.000
E	2414.807	2414.807	2414.807	2414.807	2414.807	2414.807
Asc	0.4418	0.4418	0.4418	0.4418	0.4418	0.4418
Qn	18.802	18.802	18.802	18.802	18.802	18.802
Sum of Qn	442.000	55.100	529.000	1920.000	649.000	1240.000
Number of Studs	24	3	29	103	35	66
Full/Partial	Full	Partial	Full	Full	Full	Full
Interpolate x1	5.000	5.500	5.500	3.500	4.500	4.000
Interpolate x	5.430	5.932	5.659	3.762	4.552	4.144
Interpolate x2	5.500	6.000	6.000	4.000	5.000	4.500
Interpolate y1	919.000	166.000	1400.000	14400.000	2270.000	6580.000
Interpolate y2	973.000	176.000	1470.000	14800.000	2370.000	6800.000
I (in^4)	965.421	174.650	1422.232	14609.288	2280.384	6643.308
ΔD (in)	0.512	0.215	0.421	1.081	0.547	0.960
ΔL (in)	0.155	0.055	0.126	0.338	0.166	0.288
CHECK CONSTRUCTION LOADS						
LL Concrete (lb/ft)	841.806	1373.472	1683.611	1683.611	3145.694	3145.694
LL Workers	253.333	413.333	506.667	506.667	946.667	946.667
LL const (lb/ft)	1095.139	1786.806	2190.277	2190.278	4092.361	4092.361
DL const. (lb/ft)	75.968	60.237	134.065	224.197	324.263	364.263
Wc1 (lb/ft)	106.355	84.332	187.690	313.876	453.968	509.968
Wc2 (lb/ft)	1843.384	2931.173	3665.321	3773.481	6936.894	6984.894
Mu w/beam (ft-k)	98.416	58.786	195.687	1056.784	556.493	1260.773
T3-19 0.9Mn	409.754	100.662	538.352	2916.625	724.492	1624.388
ΔC (in)	0.172	0.211	0.231	0.644	0.619	1.085
CALCULATE COST						
Cost ($/ft^2)	$3.51	$1.51	$2.11	$6.93	$2.67	$4.88
Square Footage	261.778	261.778	523.556	1199.111	1199.111	1798.667
Total Cost	$919.00	$396.03	$1,104.00	$8,309.67	$3,206.67	$8,772.00

*Check that FLB <9.2
*Check that WLB <90.5

*Check that Mu w/beam is less than Mn

*Check that both deflections are under 1"

*Check that Mu w/beam is less than Mn

*Check that construction deflection is under 1.5"

*$2500 per ton + $3 per stud

Redesigning Stoddard Complex - Composite Beam and Girder Design

Joist Design

*Must look up in manual (depends on beam size)

	Scheme 5 Interior Beam	Scheme 5 Exterior Beam	Scheme 5 Girder
Beam/Girder Size	W12x16	W12x22	W14x30
Beam/Girder Depth (in)	12.000	12.300	13.800
Beam/Girder Weight (lb/ft)	16.000	22.000	30.000
Span (L in ft.)	24.667	24.667	20.670
Trib. Width (ft)	4.810	1.480	25.330
Bay Area	523.571	523.571	523.571
ts (in)	6.000	6.000	6.000
be (in)	57.720	17.760	303.960
Fy (ksi)	50.000	50.000	50.000
Joist Size	Six 20K7	Six 20K7	Six 20K7
DESIGN FOR SERVICE LOADS			
Total DL (lb/ft)	458.300	1035.000	457.000
LL (lb/ft)	481.000	148.000	4225.000
Wu1 (lb/ft)	641.620	1449.000	639.800
Wu2 (lb/ft)	1319.560	1478.800	7308.400
Mu	100.360	112.471	390.313
Zx required	26.763	29.992	104.084
Zx chosen beam	37.200	29.300	110.000
DL w/beam (lb/ft)	474.300	1057.000	487.000
Wu3 (lb/ft)	664.020	1479.800	681.800
Wu4 (lb/ft)	1338.760	1505.200	7344.400
Mu w/beam (ft-k)	101.820	114.479	392.236
0.9ZxFy is Mn (ft-k)	139.500	109.875	412.500
FLB	7.530	4.740	8.740
WLB	49.400	41.800	45.400
Y2	5.000	5.000	5.000
T3-19 0.9Mn	118.000	271.000	396.000
Actual "a"	0.400	7.154	0.570
Actual Y2	5.800	2.423	5.715
Interpolate x1	5.500	2.000	5.500
Interpolate x	5.800	2.423	5.715
Interpolate x2	6.000	2.500	6.000
Interpolate y1	120.000	198.000	412.000
Interpolate y2	122.000	210.000	429.000
T3-19 0.9Mn	121.200	208.149	419.306
w	124.800	124.800	124.800
f'c	3000.000	3000.000	3000.000
E	2414.807	2414.807	2414.807
Asc	0.4418	0.4418	0.4418
Qn	18.802	18.802	18.802
Sum of Qn	58.900	324.000	442.000
Number of Studs	4	18	24
Full/Partial	Partial	Full	Full
Interpolate x1	5.500	2.000	5.500
Interpolate x	5.800	2.423	5.715
Interpolate x2	6.000	2.500	6.000
Interpolate y1	228.000	372.000	973.000
Interpolate y2	239.000	399.000	1030.000
I (in^4)	234.598	394.836	997.496
ΔD (in)	0.581	0.769	0.069
ΔL (in)	0.294	0.054	0.300
CHECK CONSTRUCTION LOADS			
LL Concrete (lb/ft)	319.665	98.358	1683.390
LL Workers	96.200	29.600	506.600
LL const (lb/ft)	415.865	127.958	2189.990
DL const. (lb/ft)	16.000	22.000	30.000
Wc1 (lb/ft)	22.400	30.800	42.000
Wc2 (lb/ft)	684.583	231.133	3539.983
Mu w/beam (ft-k)	52.067	17.579	189.057
T3-19 0.9Mn	121.200	208.149	419.306
ΔC (in)	0.529	0.109	0.315
CALCULATE COST			
Cost ($/ft^2)	$0.94	$1.30	$1.76
Square Footage	523.571	523.571	523.571
Total Cost	$493.33	$678.33	$919.13

*Check that FLB < 9.2

*Check that WLB < 90.5

Mn

*Check that Mu w/beam is less than Mn

I

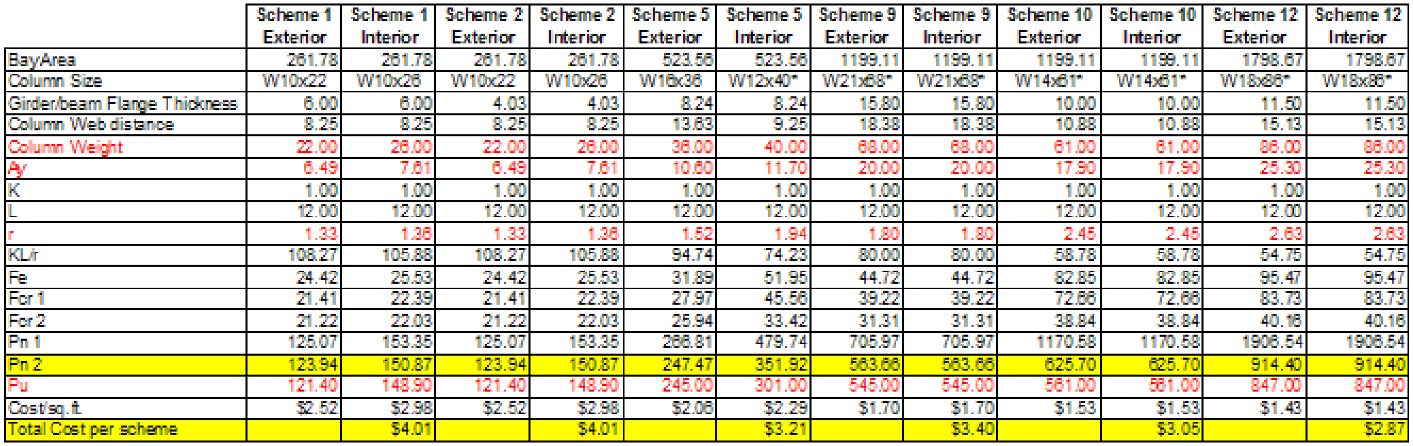
*Check that both deflections are under 1"

*Check that Mu w/beam is less than Mn

*Check that construction deflection is under 1.5"

*$2500 per ton + $3 per stud

Redesigning Stoddard Complex - W Shape Column Design

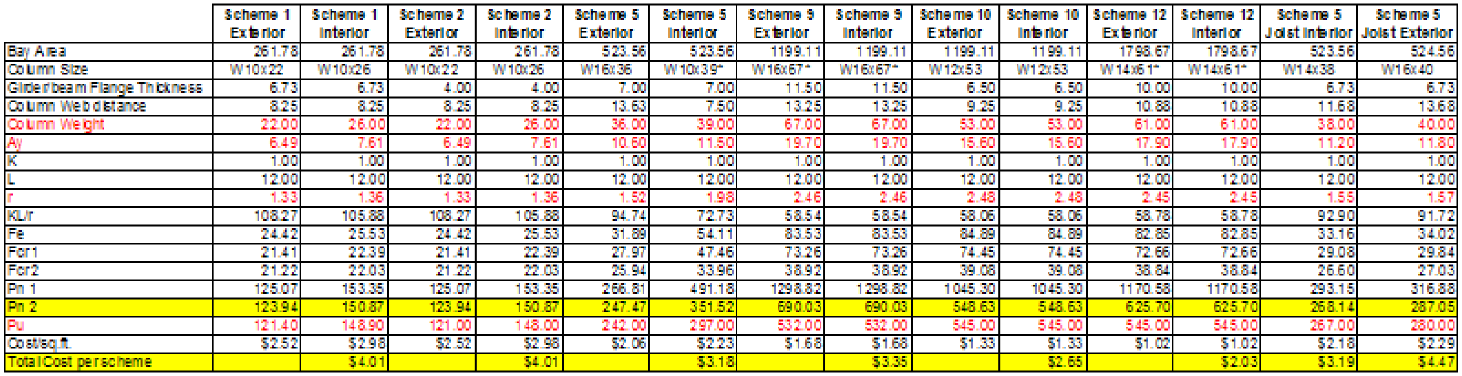


	Scheme 1 Exterior	Scheme 1 Interior	Scheme 2 Exterior	Scheme 2 Interior	Scheme 5 Exterior	Scheme 5 Interior	Scheme 9 Exterior	Scheme 9 Interior	Scheme 10 Exterior	Scheme 10 Interior	Scheme 12 Exterior	Scheme 12 Interior
BayArea	261.78	261.78	261.78	261.78	523.56	523.56	1199.11	1199.11	1199.11	1199.11	1798.67	1798.67
Column Size	W10x22	W10x26	W10x22	W10x26	W16x36	W12x40*	W21x68*	W21x68*	W14x61*	W14x61*	W18x86*	W18x86*
Girder/beam Flange Thickness	6.00	6.00	4.03	4.03	8.24	8.24	15.80	15.80	10.00	10.00	11.50	11.50
Column Web distance	8.25	8.25	8.25	8.25	13.63	9.25	18.38	18.38	10.88	10.88	15.13	15.13
Column Weight	22.00	26.00	22.00	26.00	36.00	40.00	68.00	68.00	61.00	61.00	86.00	86.00
Ay	6.49	7.61	6.49	7.61	10.60	11.70	20.00	20.00	17.90	17.90	25.30	25.30
K	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
r	1.33	1.36	1.33	1.36	1.52	1.94	1.80	1.80	2.45	2.45	2.63	2.63
KL/r	108.27	105.88	108.27	105.88	94.74	74.23	80.00	80.00	58.78	58.78	54.75	54.75
Fe	24.42	25.53	24.42	25.53	31.89	51.95	44.72	44.72	82.85	82.85	95.47	95.47
Fcr 1	21.41	22.39	21.41	22.39	27.97	45.56	39.22	39.22	72.66	72.66	83.73	83.73
Fcr 2	21.22	22.03	21.22	22.03	25.94	33.42	31.31	31.31	38.84	38.84	40.16	40.16
Pn 1	125.07	153.35	125.07	153.35	266.81	479.74	705.97	705.97	1170.58	1170.58	1906.54	1906.54
Pn 2	123.94	150.87	123.94	150.87	247.47	351.92	563.66	563.66	625.70	625.70	914.40	914.40
Pu	121.40	148.90	121.40	148.90	245.00	301.00	545.00	545.00	561.00	561.00	847.00	847.00
Cost/sq. ft.	$2.52	$2.98	$2.52	$2.98	$2.06	$2.29	$1.70	$1.70	$1.53	$1.53	$1.43	$1.43
Total Cost per scheme		$4.01		$4.01		$3.21		$3.40		$3.05		$2.87

If greater than 113, use Fcr 1
If less than 113, use Fcr 2

*Increase in size to account for flange width of girders (connection issues)

Redesigning Stoddard Complex - Composite Column Design



	Scheme 1 Exterior	Scheme 1 Interior	Scheme 2 Exterior	Scheme 2 Interior	Scheme 5 Exterior	Scheme 5 Interior	Scheme 9 Exterior	Scheme 9 Interior	Scheme 10 Exterior	Scheme 10 Interior	Scheme 12 Exterior	Scheme 12 Interior	Scheme 5 Joist Interior	Scheme 5 Joist Exterior
Bay Area	261.78	261.78	261.78	261.78	523.56	523.56	1199.11	1199.11	1199.11	1199.11	1798.67	1798.67	523.56	524.56
Column Size	W10x22	W10x26	W10x22	W10x26	W16x36	W10x39*	W16x67*	W16x67*	W12x53	W12x53	W14x61*	W14x61*	W14x38	W16x40
Girder/beam Flange Thickness	6.73	6.73	4.00	4.00	7.00	7.00	11.50	11.50	6.50	6.50	10.00	10.00	6.73	6.73
Column Web distance	8.25	8.25	8.25	8.25	13.63	7.50	13.25	13.25	9.25	9.25	10.88	10.88	11.68	13.68
Column Weight	22.00	26.00	22.00	26.00	36.00	39.00	67.00	67.00	53.00	53.00	61.00	61.00	38.00	40.00
Ay	6.49	7.61	6.49	7.61	10.60	11.50	19.70	19.70	15.60	15.60	17.90	17.90	11.20	11.80
K	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
L	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00	12.00
r	1.33	1.36	1.33	1.36	1.52	1.98	2.46	2.46	2.48	2.48	2.45	2.45	1.55	1.57
KL/r	108.27	105.88	108.27	105.88	94.74	72.73	58.54	58.54	58.06	58.06	58.78	58.78	92.90	91.72
Fe	24.42	25.53	24.42	25.53	31.89	54.11	83.53	83.53	84.89	84.89	82.85	82.85	33.16	34.02
Fcr1	21.41	22.39	21.41	22.39	27.97	47.46	73.26	73.26	74.45	74.45	72.66	72.66	29.08	29.84
Fcr2	21.22	22.03	21.22	22.03	25.94	33.96	38.92	38.92	39.08	39.08	38.84	38.84	26.60	27.03
Pn 1	125.07	153.35	125.07	153.35	266.81	491.18	1298.82	1298.82	1045.30	1045.30	1170.58	1170.58	293.15	316.88
Pn 2	123.94	150.87	123.94	150.87	247.47	351.52	690.03	690.03	548.63	548.63	625.70	625.70	268.14	287.05
Pu	121.40	148.90	121.00	148.00	242.00	297.00	532.00	532.00	545.00	545.00	545.00	545.00	267.00	280.00
Cost/sq.ft.	$2.52	$2.98	$2.52	$2.98	$2.06	$2.23	$1.68	$1.68	$1.33	$1.33	$1.02	$1.02	$2.18	$2.29
Total Cost per scheme		$4.01		$4.01		$3.18		$3.35		$2.65		$2.03	$3.19	$4.47

If greater than 113, us
If less than 113, use F

*Increase in size to account for flange width of girders (connection issues)

ATRIUM CALCS O-DESIGN

Member Size	W8X18	W8X18	W8X18	W8X18	W12X16	W 8X18	W8X35	W8X40	W10X33	W10X22	W 12X19
Span (ft)	6.75	12.5	13.5	16	16.25	19	24	24	24	19	16
Cost of Steel ($/lb)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Member Weight (plf)	18.0	18.0	18.0	18.0	16.0	18.0	35.0	40.0	33.0	55.0	19.0
Cost/Member	$151.88	$281.25	$303.75	$360.00	$325.00	$427.50	$1,050.00	$1,200.00	$990.00	$1,306.25	$380.00
Number of Members per Atrium	3	3	3	12	3	3	2	2	26	3	3
Cost	$455.63	$843.75	$911.25	$4,320.00	$975.00	$1,282.50	$2,100.00	$2,400.00	$25,740.00	$3,918.75	$1,140.00

Member Size	W14X22	W12X22	W16X31	W18X35	W14X30	W 18X35	W21X44	W21X62	W24X84	W27X94
Span (ft)	19	16	19	19.375	41.75	45.5	19.375	19.375	29.75	31.5
Cost of Steel ($/lb)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Member Weight (plf)	22.0	22.0	31.0	35.0	30.0	35.0	44.0	62.0	84.0	94.0
Cost/Member	$522.50	$440.00	$736.25	$847.66	$1,565.63	$1,990.63	$1,065.63	$1,501.56	$3,123.75	$3,701.25
Number of Members per Atrium	9	3	3	3	3	3	6	3	3	3
Cost	$4,702.50	$1,320.00	$2,208.75	$2,542.97	$4,696.88	$5,971.88	$6,393.75	$4,504.69	$9,371.25	$11,103.75

Horizontal Member Cost	$66,663.28
Column Cost	$30,240.00
Total Cost	$96,903.28

Size (ft^2)	42.5
Number of Windows per Atrium	48
Cost of Windows (\$/ft^2)	18.50
Total Window Cost	$ 37,740.00
Total Material Cost	$ 134,643.28

ATRIUM CALCS U-DESIGN

Member Size	W8X18	W8X18	W8X18	W12X45	W10X15	W10X15	W10X19	W10X33	W10X39	W10X45
Span (ft)	8.75	9.25	9.83333333	24	12	13.25	13.25	24	24	24
Cost of Steel ($/lb)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Member Weight (plf)	18.0	18.0	18.0	45.0	15.0	15.0	19.0	33.0	39.0	45.0
Cost/Member	$196.88	$208.13	$221.25	$1,350.00	$225.00	$248.44	$314.69	$990.00	$1,170.00	$1,350.00
Number of Members per Atrium	6	3	6	2	18	30	6	24	2	2
Cost	$1,181.25	$624.38	$1,327.50	$2,700.00	$4,050.00	$7,453.13	$1,888.13	$23,760.00	$2,340.00	$2,700.00

Member Size	W10X60	W16X31	W12X26	W14X40	W18X35	W18X40	W21X44	W30X108	W33X141
Span (ft)	24	42	18	16.375	29.3333333	25.625	29.3333333	42	42
Cost of Steel ($/lb)	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25	1.25
Member Weight (plf)	60.0	31.0	26.0	40.0	35.0	40.0	44.0	108.0	141.0
Cost/Member	$1,800.00	$1,627.50	$585.00	$818.75	$1,283.33	$1,281.25	$1,613.33	$5,670.00	$7,402.50
Number of Members per Atrium	2	3	6	6	6	6	6	6	3
Cost	$3,600.00	$4,882.50	$3,510.00	$4,912.50	$7,700.00	$7,687.50	$9,680.00	$34,020.00	$22,207.50

Horizontal Member Cost	$111,124.38
Column Cost	$35,100.00
Total Steel Cost	$146,224.38

Size (ft^2)	50
Number of Windows per Atrium	24
Cost of Windows ($/ft^2)	18.50
Total Window Cost	$ 22,200.00
Total Material Cost	$ 168,424.38

Appendix D-2: Design Moments, Deflections and Chosen Sizes

BEAMS	System	Chosen Size	Applied Moment (ft-k)	Design Moment (ft-k)	Dead Load Deflection (inches)	Live Load Deflection (inches)	Construction Deflection (inches)
Scheme 1	Noncomposite	W6x12	29.7	31.1	0.616	0.187	0.334
	Composite	W10x15	49.3	100.3	0.13	0.14	0.07
Scheme 2	Noncomposite	W12x19	81.1	92.6	0.765	0.23	0.418
	Composite	W10x15	80.8	99.9	0.576	0.174	0.313
Scheme 3	Noncomposite	W6x12	29.8	31.1	0.599	0.194	0.347
Scheme 4	Noncomposite	W27x84	431.9	915	0.987	0.288	0.614
Scheme 5	Noncomposite	W14x26	119.9	150.8	0.907	0.27	0.5
	Composite	W12x16	119	121.1	0.936	0.282	0.51
Scheme 6	Noncomposite	W12x19	81.1	92.6	0.765	0.23	0.418
Scheme 7	Noncomposite	W21x55	276.3	472.5	1.028	0.293	0.585
Scheme 8	Noncomposite	W12x19	81.1	92.7	0.765	0.23	0.418
Scheme 9	Noncomposite	W14x26	120.3	150.8	0.882	0.281	0.519
	Composite	W12x16	119.4	121.1	0.91	0.294	0.53
Scheme 10	Noncomposite	W27x84	431.9	915	0.987	0.288	0.614
	Composite	W21x50	420.5	748.5	1.098	0.337	0.662
Scheme 11	Noncomposite	W21x55	277.1	472.5	1.001	0.305	0.606
Scheme 12	Noncomposite	W27x84	431.9	915	0.987	0.288	0.614
	Composite	W21x50	420.5	748.5	1.098	0.337	0.661

GIRDERS	System	Chosen Size	Applied Moment (ft-k)	Design Moment (ft-k)	Dead Load Deflection (inches)	Live Load Deflection (inches)	Construction Deflection (inches)
Scheme 1	Noncomposite	W18x35	244.2	249.4	0.589	0.176	0.317
	Composite	W14x30	404.2	409.8	0.512	0.155	0.172
Scheme 2	Noncomposite	W12x22	103	109.9	0.32	0.085	0.153
	Composite	W10x15	76.2	100.7	0.215	0.055	0.211
Scheme 3	Noncomposite	W36x150	1273.4	2178.8	0.905	0.273	0.542
Scheme 4	Noncomposite	W14x30	174.1	177.3	0.28	0.081	0.148
Scheme 5	Noncomposite	W21x62	493.3	540	0.46	0.135	0.242
	Composite	W16x36	487.7	538.4	0.421	0.126	0.231
Scheme 6	Noncomposite	W18x55	415	420	0.91	0.239	0.44
Scheme 7	Noncomposite	W24x84	756.5	840	0.403	0.113	0.205
Scheme 8	Noncomposite	W30x99	940.7	1170	1.04	0.27	0.515
Scheme 9	Noncomposite	W40x215	2538	3615	0.973	0.295	0.567
	Composite	W33x130	2498	2916	1.081	0.338	0.644
Scheme 10	Noncomposite	W24x76	700.8	750	0.628	0.18	0.336
	Composite	W21x44	679.4	724.5	0.547	0.166	0.619
Scheme 11	Noncomposite	W44x290	3827	5288	0.941	0.263	0.524
Scheme 12	Noncomposite	W33x130	1589	1751	1.007	0.285	0.545
	Composite	W27x84	1537	1624	0.96	0.288	1.085

Appendix E-1: Bearing Wall Cost Estimate Backup Sheets

NONLOADBEARING

Item	Details	Length (ft)	Height (ft)	Square Feet	Total Square Feet
Exterior Concrete Block Wall	Unreinforced	25.33	9.00	228	228
Interior Concrete Block Wall	Unreinforced Partitions between individual rooms	41.33	9.00	372	Sum Reinforced Interior Walls: 600
Interior Concrete Block Wall	Unreinforced Partitions between rooms and hallway	25.33	9.00	228	

Item	Details	Span (ft)	# Members	Total Linear Feet	Total Weight (tons)
W12x16	Beams	25.33	4	101.33	0.811
W16x36	Girders	20.67	1	20.67	0.372
W16x36	Exterior Columns	12.00	1	12.00	0.216
W10x39	Interior Columns	12.00	1	12.00	0.234

Quantity Used in Summary Sheet

LOADBEARING

Item	Details	Length (ft)	Height (ft)	Square Feet	Total Square Feet
Exterior Concrete Block Wall	Unreinforced	25.33	12.00	304	304
Interior Concrete Block Wall	Unreinforced Partitions between individual rooms	20.67	12.00	248	124
Interior Concrete Block Wall	Reinforced Partitions between individual rooms	20.67	12.00	248	Sum Reinforced Interior Walls: 552
Interior Concrete Block Wall	Reinforced Partitions between rooms and hallway	25.33	12.00	304	

Item	Details	Span (ft)	# Infill Beams	Total Linear Feet	Total Weight (tons)
S5x10	Beams spanning the rooms	12.00	8	96	0.48

Quantity Used in Summary Sheet

Appendix E-2: Cinderblock vs. Drywall Cost Estimate Backup Sheets

DRYWALL INITIAL BACKUP

Item	Details	Length (ft)	Height (ft)	Square Feet	Total Square Feet
Drywall	Wood Stud Framing 2x4 @24" O.C.	120.00	9.00	1080	1080

Item	Details	Span (ft)	# Members	Total Linear Feet	Total Weight (tons)
W12x16	Beams	25.33	4	101.33	0.811
W16x31	Girders	20.67	1	20.67	0.320
W10x22	Exterior Columns	12.00	1	12.00	0.132
W10x26	Interior Columns	12.00	1	12.00	0.156

CINDERBLOCK INITIAL BACKUP

Item	Details	Length (ft)	Height (ft)	Square Feet	Total Square Feet
Exterior Concrete Block Wall	Unreinforced	25.33	9.00	228	228
Interior Concrete Block Wall	Unreinforced Partitions between individual rooms	41.33	9.00	372	Sum Reinforced Interior Walls: 600
Interior Concrete Block Wall	Unreinforced Partitions between rooms and hallway	25.33	9.00	228	

Item	Details	Span (ft)	# Members	Total Linear Feet	Total Weight (tons)
W12x16	Beams	25.33	4	101.33	0.811
W16x36	Girders	20.67	1	20.67	0.372
W16x36	Exterior Columns	12.00	1	12.00	0.216
W10x39	Interior Columns	12.00	1	12.00	0.234

CINDERBLOCK MAINTENANCE BACKUP

Item	Details	Length (ft)	Height (ft)	Total Square Feet
Paint	All walls	120.00	9.00	1080
Clean	All walls	120.00	9.00	1080
Regrout	All walls	120.00	9.00	1080

Life Cycle Cost Analysis
General Worksheet AVERAGE

Cinderblock vs. Drywall	Cinderblock		Drywall	
Discount Rate: 6%	Estimated Costs	Present Worth	Estimated Costs	Present Worth
Initial Costs /Sq. Ft.				
Wall Construction (Cinderblocks/drywall)	$12.81	$12.81	$10.48	$10.48
Structural Steel	$7.80	$7.80	$6.78	$6.78
Total Initial Costs /Sq. Ft.		$20.61		$17.26

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	5 years			
Paint	3.0%	4.591	$0.74	$3.40	$0.74	$3.40
Clean	3.0%	4.591	$0.10	$0.46	$0.27	$1.24
Holes/Dents	3.0%	4.591	$0.00	$0.00	$0.98	$4.50

Total Annual Costs /Sq. Ft.		$3.86		$9.14
Total Life Cycle Costs		$24.47		$26.40

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	10 years			
Paint	3.0%	8.568	$0.74	$6.34	$0.74	$6.34
Clean	3.0%	8.568	$0.10	$0.86	$0.27	$2.31
Holes/Dents	3.0%	8.568	$0.00	$0.00	$0.98	$8.40

Total Annual Costs /Sq. Ft.		$7.20		$17.05
Total Life Cycle Costs		$27.81		$34.31

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	15 years			
Paint	3.0%	12.014	$0.74	$8.89	$0.74	$8.89
Clean	3.0%	12.014	$0.10	$1.20	$0.27	$3.24
Holes/Dents	3.0%	12.014	$0.00	$0.00	$0.98	$11.77

Total Annual Costs /Sq. Ft.		$10.09		$23.91
Total Life Cycle Costs		$30.70		$41.17

Annual Costs /Sq. Ft.	Inflation Rate	PWA w/ Inflation	20 years			
Paint	3.0%	14.998	$0.74	$11.10	$0.74	$11.10
Clean	3.0%	14.998	$0.10	$1.50	$0.27	$4.05
Holes/Dents	3.0%	14.998	$0.00	$0.00	$0.98	$14.70

Total Annual Costs /Sq. Ft.		$12.60		$29.85
Total Life Cycle Costs		$33.21		$47.11

Life Cycle Cost Analysis
General Worksheet LOW

Cinderblock vs. Drywall	**Cinderblock**		**Drywall**	
Discount Rate: 6%	**Estimated Costs**	**Present Worth**	**Estimated Costs**	**Present Worth**
Initial Costs /Sq. Ft.				
Wall Construction (Cinderblocks/drywall)	$12.81	$12.81	$10.48	$10.48
Structural Steel	$7.80	$7.80	$6.78	$6.78
Total Initial Costs /Sq. Ft.		$20.61		$17.26

Annual Costs /Sq. Ft.	**Inflation Rate**	**PWA w/ Inflation**	**5 years**			
Paint	3.0%	4.591	$0.74	$3.40	$0.74	$3.40
Clean	3.0%	4.591	$0.10	$0.46	$0.27	$1.24
Holes/Dents	3.0%	4.591	$0.00	$0.00	$0.56	$2.57

Total Annual Costs /Sq. Ft.		$3.86		$7.21
Total Life Cycle Costs		$24.47		$24.47

Annual Costs /Sq. Ft.	**Inflation Rate**	**PWA w/ Inflation**	**10 years**			
Paint	3.0%	8.568	$0.74	$6.34	$0.74	$6.34
Clean	3.0%	8.568	$0.10	$0.86	$0.27	$2.31
Holes/Dents	3.0%	8.568	$0.00	$0.00	$0.56	$4.80

Total Annual Costs /Sq. Ft.		$7.20		$13.45
Total Life Cycle Costs		$27.81		$30.71

Annual Costs /Sq. Ft.	**Inflation Rate**	**PWA w/ Inflation**	**15 years**			
Paint	3.0%	12.014	$0.74	$8.89	$0.74	$8.89
Clean	3.0%	12.014	$0.10	$1.20	$0.27	$3.24
Holes/Dents	3.0%	12.014	$0.00	$0.00	$0.56	$6.73

Total Annual Costs /Sq. Ft.		$10.09		$18.86
Total Life Cycle Costs		$30.70		$36.12

Annual Costs /Sq. Ft.	**Inflation Rate**	**PWA w/ Inflation**	**20 years**			
Paint	3.0%	14.998	$0.74	$11.10	$0.74	$11.10
Clean	3.0%	14.998	$0.10	$1.50	$0.27	$4.05
Holes/Dents	3.0%	14.998	$0.00	$0.00	$0.56	$8.40

Total Annual Costs /Sq. Ft.		$12.60		$23.55
Total Life Cycle Costs		$33.21		$40.81