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Renovation of Alumni Gymnasium

A Major Qualifying Project
Submitted to the Faculty of
Worcester Polytechnic Institute
In partial fulfillment of the requirements for the
Degree of Bachelor of Science
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Abstract

A conceptual design to adapt the use of Alumni Gymnasium building into a project center for students and faculty at Worcester Polytechnic Institute has been completed. This project reviewed the existing structural conditions of the building and designed a structural system that meets the new functional needs and building seismic code requirements. Cost estimates and construction schedules for the renovation were also developed. The project used Building Information Modeling (BIM) tools and techniques for visualization, documentation and quantification of information.

Authorship

All members contributed to the completion of this project and report. The table below displays the major sections completed by each member.

Section	Author
Abstract	Ehab
Capstone Design	Ehab
Introduction	Ehab
Background	John and Mike
Existing Building Analysis	Ehab and John
Design Development	John and Ehab
Construction Phasing	Mike and Joe
Conclusions and Recommendations	Ehab
BIM models	Joe and John

The signatures below indicate the acceptance of the above.

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Capstone Design Experience Statement

This Major Qualifying Project (MQP) incorporates capstone design experience. It is outlined below in three components: a description of the design problem, the approach to the design problem, and a discussion on addressing the ABET General Criterion's realistic constraints.

Design Problem

With the construction of the new Sports and Recreation Center at WPI, Alumni Gymnasium has lost its usefulness to the WPI community. In recent years, there have been efforts to repurpose the facility to a project center to showcase the various projects at WPI and create space for students to work on their projects as well. WPI engaged the design firm of Goody Clancy, to develop conceptual design and architectural renderings that show some major changes to the functional uses of the building. These changes included the creation of a central showcase atrium, new staircases, an elevator, a robot pit where the pool is currently located, and a pathway to the quadrangle on the west side of the building which required the demolition of the existing Harrington-Alumni connection. The changes to the layout and main function of the building, requires a revision on how the existing structure meets the current demands of the building code. This project reviewed the existing structural conditions of the building and designed a structural system that meets the functional needs and building code seismic requirements for the new use of the building. Building Information Modeling (BIM) tools and techniques were used to document these changes and to prepare a 5D model for the visualization of the construction plan, cost estimating, and site planning.

Alumni Gymnasium served as a prime example of a major renovation of a historic building on the WPI campus. This example can be followed as the functional use of other buildings on campus become outdated and need to be repurposed.

Scope of Work

The scope of work for this project was to review the existing building conditions, integrate the proposed architectural changes, and make necessary improvements to bring the building up to current building code requirements which include seismic considerations. Currently, Alumni Gymnasium does not fully comply with *Massachusetts State Building Code*, and a full investigation of the structural elements of the building was performed to confirm that load requirements were met. BIM was utilized to create a digital model of the existing conditions of Alumni Gymnasium and to gain a deeper understanding for the work that had to be performed. The existing model was used to identify how the existing structure could be integrated with the new structural improvements. In doing so, different alternatives were considered in design that would best fit with the existing structure as well as yield the lowest possible cost. From this model, a new model was developed highlighting the major areas of renovation. Next, designs were developed and included in the new model. Finally, the model was used to prepare a construction schedule and cost estimate for the construction phase of the project. The schedule and cost estimate were linked to the model, through *Autodesk Navisworks* Software [14], to create a 5D model to phase the project according to its major work items. The approach to this work required extensive background research to acquire the documentation needed to provide a solution to this work.

Approach

In order to solve this problem, the project team investigated construction and renovation techniques used in older buildings like Alumni Gymnasium and assessed the current structure of the building before any changes could be proposed. The design work for this building required an extensive phase of documentation of the existing structural condition of the building. Site tours and interviews with WPI Department of Facilities Management staff (Alfred DiMauro, Greg Gregorio, and Chris Salter) were conducted. These individuals have extensive knowledge on the current state of the building and provided information that was critical in understanding the existing condition such as the conceptual architectural design of the building. As a result of the building survey it was determined that a full structural investigation was necessary to ensure all load requirements complied with the *Massachusetts State Building Code.* This investigation included seismic consideration since the current structural system is unreinforced masonry. Building Information Modeling was used as a platform for developing a visual understanding of the planned changes, coordinating and communicating design ideas, and incorporating constructability. Initially, archival research and site tours gave the basis for developing a 3D digital BIM model of the existing Alumni Gymnasium using *Autodesk Revit* software. The model was useful in visualizing the integration of the new proposed design with the current structure and to detect potential spatial interferences as well as in addressing constructability issues. With the creation of the BIM model and with the results from the investigation of the existing structure, new structural designs were developed to address the major areas of renovation. These areas included a steel framing system for seismic loading, a shear wall system at Levels 3 and 2 for the Showcase Atrium, an elevated slab for the Robotics Pit at the existing Pool Level, and an elevator shaft to access all Levels of the building. These solutions were incorporated into the BIM model to develop a new, proposed BIM model for the renovated facility. Finally, the new and existing BIM models were linked in *Autodesk Navisworks* software together with a construction schedule and cost estimate to create a 5D visualization of the construction sequence of the major work activities. For work that was outside the scope of this project's design efforts such as mechanical, electrical, and plumbing, a cost estimate was produced on a square foot basis.

The project team used knowledge from coursework in structural engineering and design, including reinforced concrete and structural steel design; advanced project management; 3D object-oriented parametric software; AutoCAD; and individual research as a basis for the approach to this problem.

Computer Based technology was also utilized in the solution to the design problem. The following software was used to create BIM models of the Alumni Gymnasium, to analyze the existing structure, to develop designs, and to produce an estimate and schedule for the construction phase of the renovation: *Autodesk Revit*, *Autodesk Navisworks*, *SketchUp* [19], *Visual Analysis Software* [18], *Primavera, MECA Wind* [15] and *MECA Seismic* programs [16].

The project team's research supported by these tools was able to develop solutions to the challenges that exist in the renovation of Alumni Gymnasium. These solutions were delivered to the WPI Department of Facilities and the WPI Faculty through this written report and the associated electronic files.

Realistic Constraints

According to ABET General Criterion, capstone design is a major design experience based on several realistic constraints. These were incorporated into this Major Qualifying Project. The following constraints were addressed in completing this MQP: economic, constructability, health and safety sustainability, ethical, social, and political.

Economic

In renovation projects, it can be very difficult to create an accurate cost estimate because of the unclear scope of the work and uncertain conditions that may be encountered. It can range from minimal work to a complete renovation. The project team considered the age of the building, critical work items form the proposed architectural layout, and the proposed budget of $12 million when suggesting designs and solutions. A cost estimate was prepared for this project outlining the major areas of renovation and the corresponding cost items. Also, work that was outside the scope of this project's design efforts such as mechanical, electrical, and plumbing work items was incorporated into the cost estimate but was calculated on a square foot basis.

Also, due to the upcoming celebration of the 150th anniversary of WPI's founding in November 2015, a schedule was created to complete the work a year after construction was assumed to begin in November 2014. This constraint was incorporated in setting the activity durations for the project schedule.

Constructability

Constructability issues were addressed through the use of the BIM Models that provided 3D visualization to facilitate coordination on the use of space and placement of new structural elements in the building. For example, a steel frame designed to account for seismic loading was integrated into the existing building structure with the aid of this BIM model. The placement of beams, columns, braces, and concrete pedestals was coordinated so that no new structural element was clashing with existing structures like staircases and was not visible through windows. Also, the use of standard sections, readily available materials, and repetition of element sizes were also part of the design efforts. This visual communication allowed this project to efficiently utilize the minimal interior space available for major structural elements such as this steel framing system. Also, when designing the slab to cover the existing pool, multiple alternatives were considered. As a result, an open steel web joist system was chosen to support the slab covering the swimming pool using this space to store rainwater that could be used to irrigate the campus quadrangle.

Health and Safety

Health and Safety in a construction/occupancy project of this nature is very important. The proposed designs and recommendations address health and safety concerns because of their compliance with building code requirements. This will promote a healthy and safe environment for the occupants of the building. For example, a seismic upgrade for Alumni Gymnasium was developed so the structure will have sufficient integrity and ductility to sustain a significant earthquake without collapsing and potentially injuring any occupants in or near the structure.

Construction safety is also a major concern for this project because of the building's location on the WPI campus. The space around the building is very limited due to its close proximity to other buildings, and any exterior work must be planned accordingly. This included site planning for materials storage and moving heavy material into the building such as steel beams and columns through the use of a crane. A site plan was prepared identifying areas for material delivery, storage, and crane locations. Demolition coordination was important here as well to ensure the safety of the WPI community during construction. The preparation of the schedule and cost estimate included allowances for the removal of asbestos or other hazardous material from the site. The exterior demolition of the Harrington-Alumni connection was addressed in the schedule by planning the demolition when classes are not in session and providing time and cost allowances for temporary shoring for these areas which is reflected in the schedule and cost estimate.

Sustainability

In the design of the elevated slab over the existing pool, multiple alternatives were considered. The selected design of open steel web joists allowed for the storage of rainwater under the slab in the existing pool. The water collected by a drainage system would be used to irrigate the quadrangle reducing the use of municipal water by the WPI community.

Ethical

In the research phase of the MQP, the project team was able to access confidential information about Alumni Gymnasium such as proposed models for the renovation, historical information, and original plans. The WPI Department of Facilities required each group member to sign a confidentiality release agreement to maintain confidentiality of the work and the report.

In addition to maintaining confidentiality, the project group had to comply with current building codes when developing designs for the proposed renovation. Since the structure is outdated, current standards had to be implemented to comply with these requirements. Seismic considerations were observed in the design phase of this project. Overall, the project group followed Canon 1 of the *American Society of Civil Engineers (ASCE)* which states: Engineers shall hold paramount the safety, health and welfare of the public and shall strive to comply with the principles of sustainable development in the performance of their professional duties [21].

Social

Social constraints are significant in this renovation as the main reason for repurposing Alumni Gymnasium is to create an area for students to collaborate and work on their projects as well as to showcase the work. The issue of construction on campus and the impact on the community were considered in the scheduling of critical items. This project was sensitive to the 150th anniversary of the founding of WPI and the involvement of Public Relations at WPI to promote this renovation. The project schedule was prepared so that the renovation would be complete in time for this anniversary and could be used as a centerpiece for the celebration of the founding of WPI.

Political

Since much of the original structure and masonry work is still present, the project group considered the implications of any alterations to the exterior of the building. Much of the exterior stone work is unique and would be near impossible to replicate or repair if tampered with. The views of project stakeholders such as WPI Alumni and the Worcester Historical Commission were taken into consideration for exterior renovations. This constraint impacted the possible relocation of windows and the location and extent of access openings in the exterior wall. The majority of the work to be completed for this renovation was for the interior of the building. The interior work had to integrate the conceptual architectural design for a project center that showcased the project work of the students at WPI. The building would serve as an attraction for potential applicants as well by promoting the project-based curriculum that WPI is known for. Demolition of the Harrington-Alumni connection and masonry retouching was the extent of the exterior work for this project.

Also, the schedule of the project was affected due to the planned completion date in November 2015 for the 150th anniversary celebration.

Acknowledgements

We would like to thank everyone involved in this MQP. It would not have been as successful as it was without the insight and guidance from all those who contributed especially our advisors Professor Guillermo Salazar and Professor Leonard Albano.

A special thanks to the employees of the WPI Department of Facilities for their help in acquiring documentation and access to Alumni Gymnasium. Specifically, we would like to thank AlFredo DiMauro, Chris Salter, and Glen Grigoire. Their help gave the group a unique insight into the overall vision of WPI, the owner management of a WPI construction project, and the day-to-day operations of a WPI facility.

We would also like to thank Margaret Anderson of the George C. Gordon Library Archives and Stephen Feige from Goody Clancy. They provided valuable help in obtaining proposed drawings of Alumni Gym, original drawings of Alumni gymnasium from 1915, and essential information to understand the original construction.

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1.0 Introduction

Major renovations of historic buildings have many challenges associated with them such as assessing current conditions, acquiring documentation, preserving the existing historic elements of the building, and updating the structure based on the building codes in place. Depending on the level of documentation available, drawings and construction specifications can be lost, difficult to find or understand, or may not be extremely helpful for the intended scope of work. There also may not be enough information available for a structural analysis of the building. Facing this challenge can be even more difficult when major structural changes must be made if the building does not comply with the present building codes. Changes have to be made with the best interest of the community in mind, and preservation techniques must be implemented to safe-keep any architecture or masonry work that is unique to the building.

This project faced these challenges for the renovation of Alumni Gymnasium at Worcester Polytechnic Institute. Built in 1915, Alumni Gymnasium has become a historic landmark for the WPI campus [13]. Due to the recent construction of the Sports and Recreation Center there are now plans to repurpose the building from recreational use into a project center for students and faculty. A conceptual design has been completed. This project reviewed the existing structural conditions of the building and designed a structural system that meets the functional needs and building seismic code requirements for the new use of the building. Cost estimates and construction schedules for the structural renovation were also developed. The project used Building Information Modeling (BIM) tools and techniques to support design and construction planning with visualization, documentation and quantification of information. Initially, site visits and archival research provided a foundation for the initial structural analysis of Alumni Gym. At the same time, these findings were documented by creating a Building Information Modeling of the existing structural conditions and gain an understanding of the scope of work to be completed for demolition and construction. Then, major areas of renovation were targeted for design development using the results from the structural analysis and the architectural renderings that were developed for WPI prior to the start of this project. These areas included seismic design for the overall building, a shear wall system for the proposed Showcase Atrium, an elevated slab over the existing slab to be used as a Robotics Pit, and an elevator shaft to access all Levels. These renderings that are represented in this report, show the proposed use of space in Alumni Gym and required various alternative designs that were considered in order to bring these proposed changes to fruition. Alongside this step, BIM models were utilized to track these changes and linked to the existing structure in a 3D model with the associated schedule and cost for the project to produce a 5D model.

The results of this project could be very useful as a reference for actual renovation of Alumni Gymnasium and other renovation projects that are of similar significance.

2.0 Background

Worcester Polytechnic Institute (WPI) has a long standing tradition in the New England area not only in academics, but in athletics as well. In the early years, WPI did have an athletic program, but there was a lack of support from the school's administrators and these athletes did not have an adequate location to train [5]. The development of WPI's rich athletic history began with the completion of Alumni Gymnasium in 1915. This building was the hub of all athletic activity at WPI, up until the recent completion of the new "Sports and Recreation Center" in 2012 which has currently left Alumni Gym with no immediate propose. Currently WPI wants to shift this building's use to academics by converting it into a Project Center with an estimated budget of $12 million and a timeframe scheduled to begin sometime in late 2014 depending on funding approvals [5].

2.1 WPI Early Athletics

The first WPI athletic team was the 1870 Baseball Team [11]. It was a scrub outfit and it had little to no equipment or even clothing. It mostly played high school teams with their only college opponent being Holy Cross. Although it was not taken seriously until 1885, the next organized sports team to come about was the WPI Football Team. They began play in the mid-eighteen seventies with interclass games, though they also had poor equipment and a lack of training space [11]. These student-athletes did not agree with Principal Thompson at the time, who believed that "shop work" was adequate exercise. In the spring of 1878, the football and baseball teams decided to create a make-shift gym in a grove just north of Washburn Shops [11]. Although this grove was later displaced by the new wing of the shop building, it served as the recreational center of campus for a number of years. This interest in athletics, aroused by the elementary gymnasium, led to the development of track and field sports with the first interclass track meet held on the area adjacent to the Boynton Street Wall in 1879 [11].

In the spring of 1888, WPI was admitted into the New England Intercollegiate Athletic Association (NEIAA), which was a major step in the athletic movement [11]. This was the time-frame where the first recorded inter-college competition was held with WPI taking third place in track and field competitions. This entrance into the NEIAA allowed for the organization of the tennis team in 1888 as well.

With the rise of the WPI athletic movement there was the need for a new building. Many students wanted a gymnasium as this would be the center of "Tech" (the nickname used to describe WPI students) student activities, both athletic and social [12]. Although school administrators only accepted the plans to build Alumni Gymnasium because it would also serve as a benefit to the military program, both students and faculty felt like its construction "would create a civic center of the Institute that would foster spirit and teach men their obligations towards one another, especially the essence of team work" [12].

2.1.1 History Alumni Gymnasium

Alumni Gymnasium was the first central gym to be built for the WPI community and was erected at the same time as Alumni Field in 1915 [5]. This building was placed near the center of campus and provided a home for the expansion of the WPI athletics program at that time. It was considered a state-of-the-art facility as it had five-stories; three above ground and two below, including an underground pool. Interestingly enough, the pool was not completed until 1925, nearly ten years after the completion of Alumni Gymnasium, because there was a debate about whether an ice rink should have been built in that area instead of the current pool [5]. For reference purposes in this report, the sub-basement will be referred to as Level 1, the basement as Level 2, the first floor as Level 3, the second floor as Level 4, and the third floor as Level 5.

Although Alumni Gymnasium is considered an outdated facility by today's standards, when it was built in 1915 there were many distinctive features that made it an impressive structure for the 20th century [5]. The basement floor, or Level 2, was originally a rifle range and a bowling alley for student use. This floor also contains a balcony that overlooks the underground pool in the sub-basement Level where swim practices and meets were held. The first floor includes the main entrance as well as the locker rooms and offices of the physical education department. The second floor holds a basketball and two racquetball courts, which are on each side of the stairwells. The top floor, which is the third floor, features an indoor running track with another balcony overlooking the basketball court below. This can be seen in Figures 1 and 2 below.

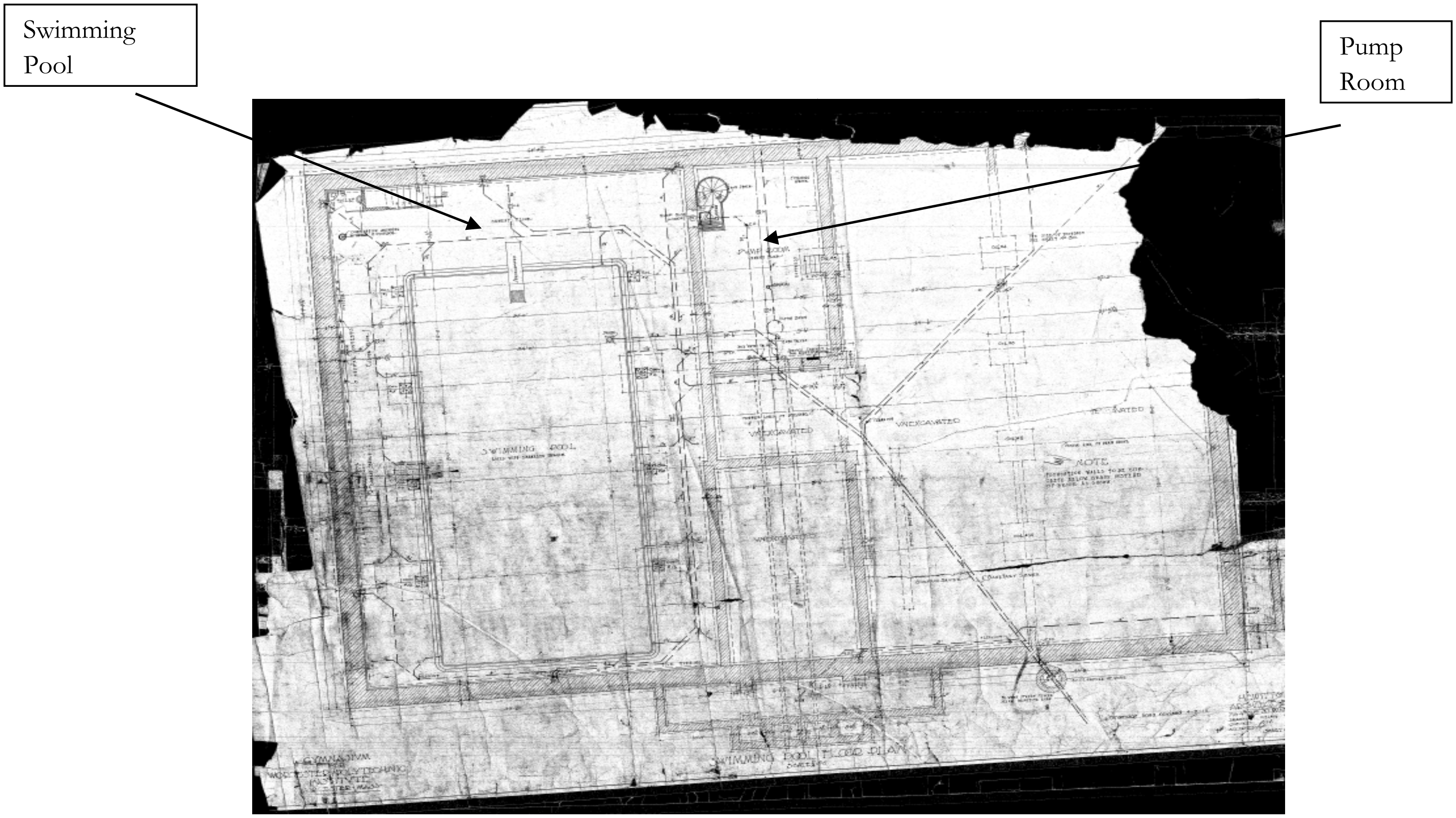


Figure 1 - Original 1915 Level 1 Plan (Sub-Basement Level) - Shows Swimming Pool Dimension

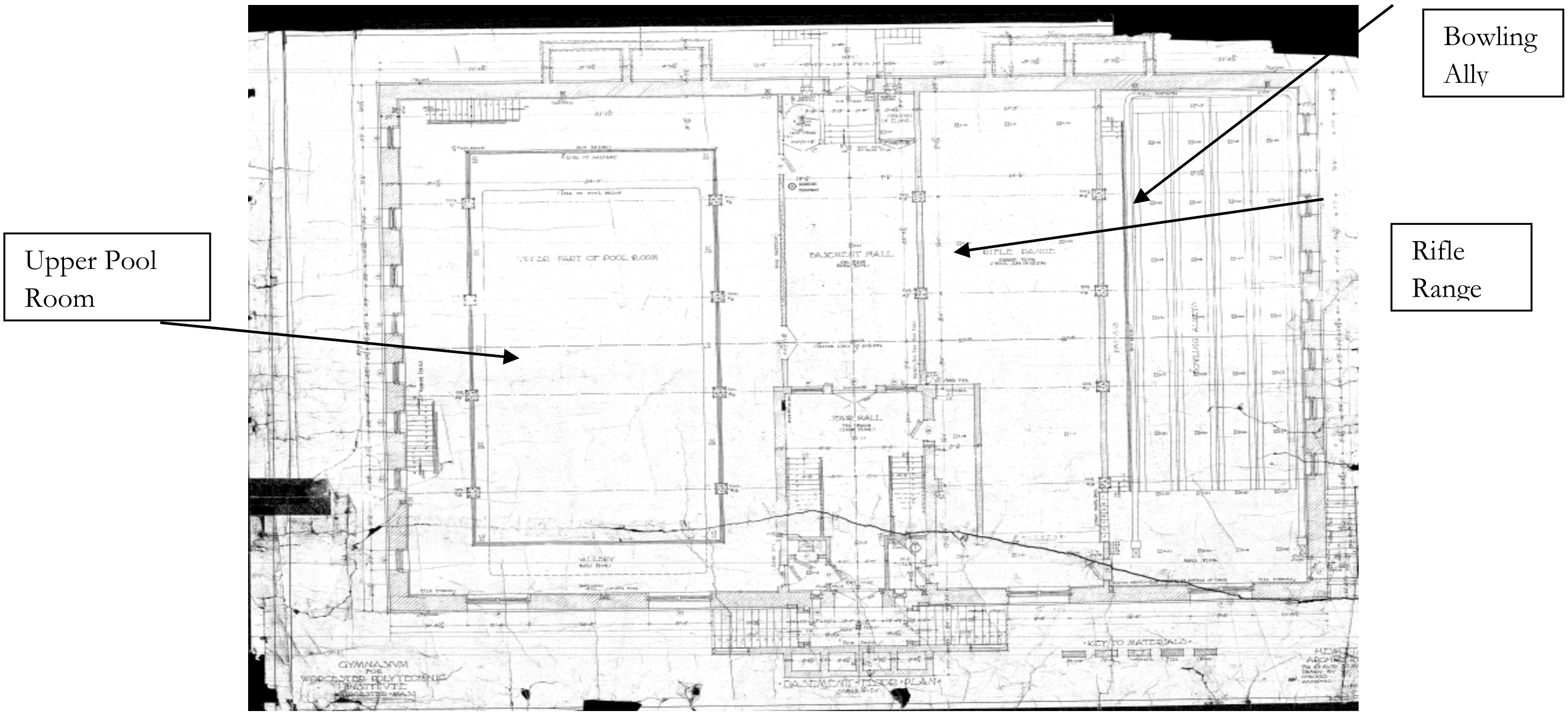
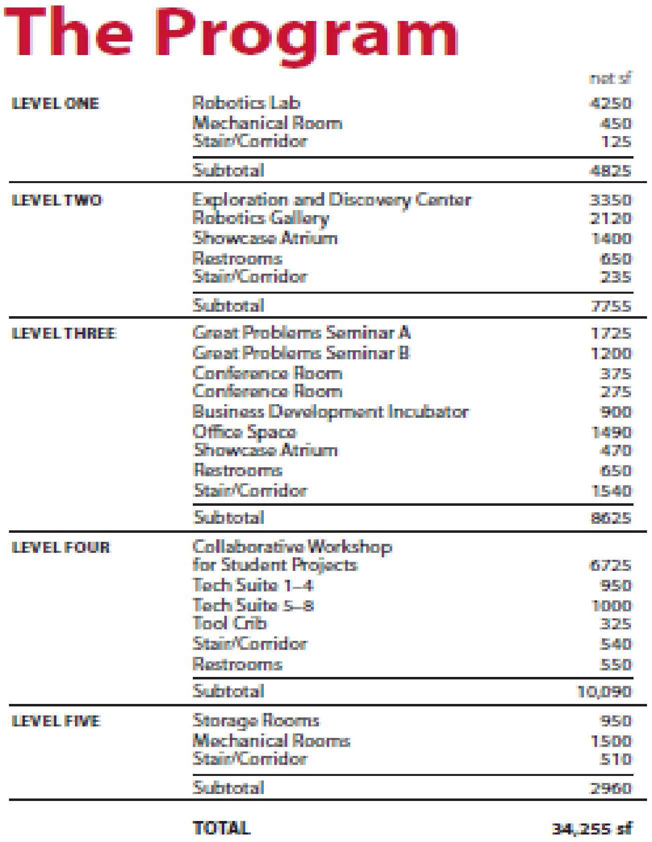


Figure 2 - Original 1915 Level 2 Plan (Base. Level) - Rifle Range and Bowling Alley Dimensions

After over fifty years of Alumni Gymnasium being the main athletic facility, the WPI community decided it needed to update its facilities again [1]. In 1965, construction of Harrington Auditorium began. This building was connected to Alumni Gymnasium in order to increase the convenience for student-athletes and included a new basketball court and seating for spectators. The purpose of this building was to keep up with the school's growing athletic program and to increase the amount of space for physical activity [1]. Continuing with this trend, the locker rooms were expanded in Harrington and a new fitness center was added in Alumni Gymnasium in the 1980's which was later equipped with a weight room in 1992 as it acted as the school's fitness center [5]. The combination of a recent growth in student body population and the increasing awareness of WPI's outdated athletic facilities made it apparent that a new, modern recreational facility would be required on campus to accommodate the growing needs as well as attract future students. In May of 2010, construction of a new, fully-operational, state-of-the-art recreational facility began on Worcester Polytechnic Institute's campus [2]. The $53 million building featured a 29,000 square foot gymnasium, a natatorium containing a 25-meter competition swimming pool, rowing tanks, squash courts, robotics pits, 11,000 square feet of fitness space, and an additional 5,000 square feet of multipurpose rooms. The completion of this facility in 2012 made it apparent that Alumni Gymnasium would no longer be needed as an athletic facility. So began the process by faculty, administrators, and others to re-purpose Alumni into something more beneficial to the WPI community. This led to the hiring of an Architectural firm, Goody Clancy, who developed an architectural program and schematic design. [2].

2.1.2 A Building Reborn

Alumni Gymnasium, a campus landmark since 1915, will be the home of the new "Innovation and Solution Center" at WPI [10]. According to the brochure proposed to WPI by Goody Clancy, Alumni Gymnasium will become a "Virtual Sandbox." It will be converted into a five-level building where students will be able conceive create, and connect ideas. It will include an open, interactive "Collaborative Workshop for Student Projects" and eight tech suites with flexible configurations on Level 4, a robotics laboratory and showcase with an observation deck above on Level 1, a "Business Development Incubator" and new classrooms and workspace for the Great Problems Seminars on Level 3, an "Exploration and Discovery Center" with advanced analytical equipment on Level 2, a "Showcase Atrium" with interactive digital displays highlighting innovations and achievements by alumni and students also on Level 3, and storage rooms on Level 5. These new rooms and workshops are directed at facilitating idea collaboration and giving students the best resources to accomplish work and change the world [10]. As shown in Figure 3 below, this program provides the intended uses and square footages for each new room.



The Program

		net sf
LEVEL ONE	Robotics Lab	4250
	Mechanical Room	450
	Stair/Corridor	125
	Subtotal	4825
LEVEL TWO	Exploration and Discovery Center	3350
	Robotics Gallery	2120
	Showcase Atrium	1400
	Restrooms	650
	Stair/Corridor	235
	Subtotal	7755
LEVEL THREE	Great Problems Seminar A	1725
	Great Problems Seminar B	1200
	Conference Room	375
	Conference Room	275
	Business Development Incubator	900
	Office Space	1490
	Showcase Atrium	470
	Restrooms	650
	Stair/Corridor	1540
	Subtotal	8625
LEVEL FOUR	Collaborative Workshop for Student Projects	6725
	Tech Suite 1–4	950
	Tech Suite 5–8	1000
	Tool Crib	325
	Stair/Corridor	540
	Restrooms	550
	Subtotal	10,090
LEVEL FIVE	Storage Rooms	950
	Mechanical Rooms	1500
	Stair/Corridor	510
	Subtotal	2960
	TOTAL	34,255 sf

Figure 3 - Intended Use and Square Footing for Each Floor

Clancy, Goody. ""A Dynamic Expression of the WPI Plan"" Worcester Polytechnic Institute, 9 Sept. 2013. Web. 9 Sept. 2013.

The transformation of Alumni Gym will also make connections around the WPI campus simple [10]. The plan will serve to horizontally connect the Quadrangle and the future West Promenade (area in front of the campus center) with primary entrances that are handicapped accessible (shown in Figure 4 below). This connection of the two open spaces will take advantage of Alumni Gymnasium's prominent site on the WPI campus by featuring two "front doors" which will create a strengthened presence along the future West Promenade and maintain its distinction on the Quadrangle by re-establishing the historic freestanding character of the building [10]. Although these proposed changes will have a positive impact on WPI campus and make WPI a unique and exclusive university, the proposed changes in structural design as well historical renovation will introduce difficult challenges to overcome.

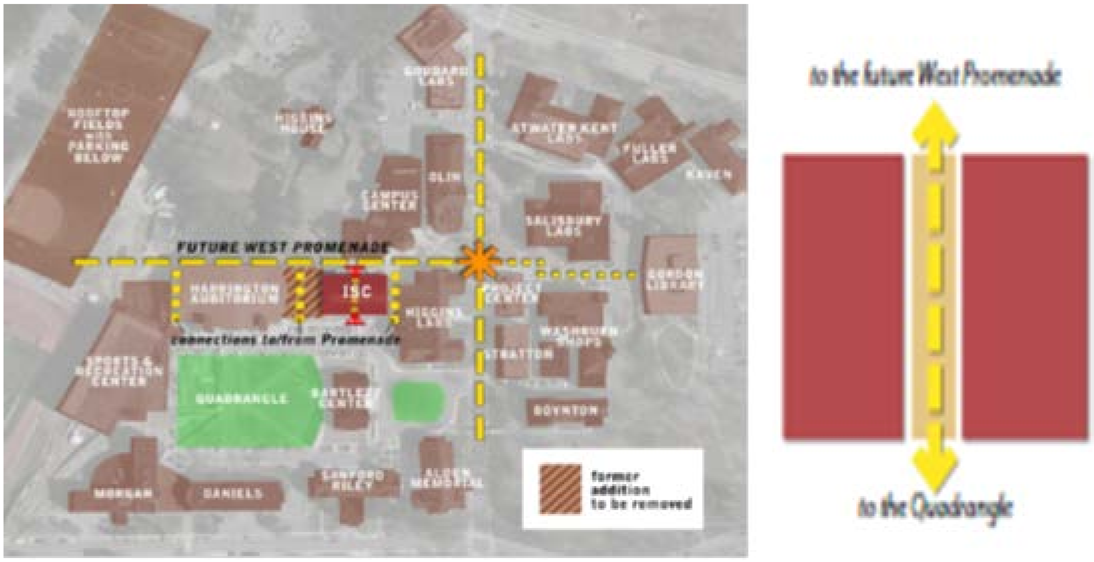


Figure 4 - (Left) Overhead View of WPI campus (Right) Access between Alumni and Harrington to Quad

Clancy, Goody. ""A Dynamic Expression of the WPI Plan"" Worcester Polytechnic Institute, 9 Sept. 2013. Web. 9 Sept. 2013.

2.1.3 Structural Aspects

The design and construction of Alumni Gymnasium was completed according to the guidelines of the *1911 Laws and Ordinances of the City of Worcester* [3]. During the early 20th century, design and construction was performed by "rule of thumb" approaches to sizing structural elements and building codes were a collection of "good practices" [3] Buildings that were three stories tall, similar to Alumni Gymnasium, were required to have brick walls 16 inches thick for the basement and anything below, as well as 12-inch thick walls for the first three floors above ground. The floors as, prescribed in Section 31 of this code, state that when a public assembly is designed, the floor must support no less than 100 pounds per square foot [3]. By following these code requirements and a heavy reliance on engineering judgment and experience for determining maximum loads, many buildings in this era may have been overbuilt [1].

When looking at Alumni Gymnasium, the exterior walls of the first three floors should have a wall thickness between 16 and 24 inches [1]. From visual inspection they seem to be over 24 inches, and this is correct as the true dimensions from the drawings are about 30 inches [1]. This clearly shows that Alumni Gymnasium was "overbuilt" as it has a thicker structural shell than necessary. Unfortunately, some of its others components such as the heating system, plumbing, windows, interior walls, lights, and roof are in need of major renovations and must be brought into compliance with current building codes [5].

2.2 Maintenance of Historic Buildings

Many buildings built in the early 20th century consisted of brickwork, especially in the New England area, as brickwork was the most weather resistant building material at the time [4]. Not only was brick easily manufactured, but it was the most sustainable material because it required the least maintenance. This is why many buildings today that are considered historic are usually stone or masonry. However, like everything else, over time even brickwork starts to deteriorate.

A building is considered historic if it meets three requirements: age (it is at least 50 years old), integrity (must retain historic physical appearance and remain unchanged), and significance (direct association with developments that have or have shaped history) [4]. Renovation approaches for historic buildings generally fall into one of five categories [4]. First, stabilization: a process involving methods that reestablish a deteriorated property's structural stability and weather tightness while sustaining its existing form. Second, preservation: a process involving methods that maintain a property in its present state. Third, rehabilitation: a process involving repairs and alterations to a property that adapt it to a contemporary use while preserving its historic fabric and character.

Fourth, restoration: a process that accurately recovers the appearance of a property at a particular period of time by removing later additions and/or replacing missing features. Or fifth, renovation: a generic term used to define all work that is meant to make new again [4]. For Alumni Gym, categories two and four are the most relevant as they must be met to fully complete this transformation.

2.2.1 Preservation and Restoration Techniques

Alumni Gymnasium is considered a historic building as it meets all three requirements stated above. [4] Many buildings of this nature usually have been damaged by structural reasons or water infiltration. A building of this age has gone through many storms and weather cycles which can deteriorate building components such as the brick mortar, concrete structures like foundations, and the materials that comprise the roof. A series of steps must be followed in order to successfully resolve the problem without damaging or jeopardizing the historic nature of the building as described in categories two and four above. First, if the mortar is missing or loose, the joints should be cleaned out and repointed using a mortar mix which closely matches the composition, joint profile, and color of the original. Second, there must be careful removal of mortar from the joints so as not to damage the brick edges. Third, whenever partial or total foundation replacement is required, the new foundation walls should be faced in materials that match the original in appearance. Fourth, whenever replacement brick or stone is needed, there must be a use of a material that closely matches the original in size, color, and texture. Fifth, whenever masonry has been painted, it must be repainted after removing all loose paint. Sixth, any cleaning should be done with the gentlest method possible and should be stopped at the first evidence of damage to masonry [4]. These preservation steps must be taken when restoring the masonry on Alumni Gym as shown below in Figures 5 and 6. These pictures show the structural shell of Alumni Gym and highlight some of the elements of its historic stonework that will need refurbishing. These items are important to keep in mind as they give Alumni its historic appeal and the campus a historic atmosphere.

Figure 5 - Exterior View - South Side Alumni

Figure 6 - Exterior View - West Side Alumni

The above methods are crucial and specific to maintaining the masonry of an historic building. There are also fundamental concepts that relate to all aspects of historic buildings and in particular to Alumni Gymnasium. First, every reasonable effort should be made to provide a compatible use for a property that requires a minimal alteration of the building, especially when the work has to be approved by the *Worcester Historic Commission* [6]. Second, the distinguishable original qualities or character of a building should not be destroyed, such as the removal or alteration of any historic material or architectural features. Third, all buildings, structures, and sites should be recognized as products of their own time, as in, alterations which have no historical basis and which seek to create an earlier appearance are not necessary. Fourth, changes that may have taken place in the course of time are evidence of the history and development of a building and should be recognized and respected. Fifth, examples of skilled craftsmanship that characterize a building should be treated with sensitivity. Sixth, deteriorated architectural features should be repaired rather than replaced, wherever possible. However, if a replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual qualities. Seventh, the surface cleaning of structures should be undertaken with the gentlest means possible. Eighth, contemporary design for additions to existing structures or landscaping shall not be discouraged. Ninth, wherever possible, new additions or alterations to structures shall be done in such a manner that, if they were to be removed in the future, the essential shape of the original structure would remain the same [4]. These nine concepts listed above address higher level than just masonry restoration. They represent the merging of the past to the present which is a highly sensitive process.

2.2.2 Worcester Historic Commission

One group whose objective is maintaining the integrity of historic buildings in Worcester, MA, is the *Worcester Historic Commission* [6]. The function of this association is to issue certificates of appropriateness, certificates of non-applicability, and certificates of hardship to any construction project or alteration of any historic building. They conduct research about places of historical interest and advise the Planning Board, the Worcester Redevelopment Authority, the Executive Office of Economic Development, and certain national agencies such as the National Park Service and the National Trust for Historic Preservation on all questions involving historic sites. Most importantly, the commission can cause a major delay to any project or alteration involving a historic building regardless if the building has a designated status or not. The Commission can give recommendations to owners of historic buildings in Worcester on issues of preservation and determine what can and cannot be done to the building in order to preserve its historic significance. If the owner does not agree upon receiving these suggestions or the given proposal, the Commission, through the City of Worcester, can delay the beginning of construction for up to one year [6]. Most owners that are faced with this dilemma usually just wait out the delay and then start construction as intended; however, this has a seemingly large effect not only on the planning modifications to the building itself, but on the political perspective as well [6]. Currently, the only portions of Alumni Gym that have to be "kept original" are those parts of the building that can be viewed from a public street, especially the windows. As Alumni Gym's entire North side is visible from Institute Road, these areas would have to be historically preserved.

2.3 How to Analyze an Existing Structure

According to *International Existing Building Code (IEBC) 2009 Edition,* the project scope determines which code provisions the building must comply with. Due to the degree of scope presented so far for renovations to Alumni Gym, it was determined that this project should be classified as a level 3 renovation. A level 3 renovation means that all building systems in Alumni Gym must be analyzed and comply with current building code specifications. Each existing structural system is analyzed to verify compliance with the current codes.

2.4 Structural Evaluation of Buildings

In a building renovation project of this magnitude, and in particular when dealing with a 100 years old facility, an evaluation of the structure is a primary consideration in order to determine the adequacy and suitability and code compliance of the structural systems in place. The major structural systems that are investigated include all existing foundations, floors, columns, and the roof system.

2.4.1 Structural Building Systems

Foundations are the bottom most part of a building's structure; they are placed below grade in order to transfer loads from the upper structure or superstructure into the soil. The primary consideration during design of foundations is to limit differential settlement of the structure. This is to ensure that the above structure is not altered or disturbed by the foundation settling at different elevations. Some ways to limit settlement are to verify adequate soil capacity and to spread the load out over a sufficient area to minimize bearing pressure. Foundations are primarily comprised of strip footings or piers. Footings can either be considered deep footings, or shallow spread footings. The piers can either be founded on deep soil or supported by piles (in this case the pier is a pile cap). The option on which type of footing to use is dependent on the type of soil conditions present at the site. Deep footings can be either wooden piles, steel piles, or pressure injected concrete footings (pifs). Shallow spread footings are usually made from reinforced concrete. Foundation walls sit on footings and are primarily constructed with reinforced concrete, stones, or bricks as they must be designed adequately to resist the gravity loads imposed on it from the above structure and lateral earth pressures.

Floors and walls are horizontal and vertical members, respectively, of buildings that serve a variety of purposes. Other than the obvious purpose of an area for people to walk on or providing shelter from the outside conditions, floors and walls serve to resist both gravity and lateral loads. The gravity loads floors and bearing walls must carry are both dead and live loads. The dead and live loads are determined by a floor's intended uses, which are spelled out in building codes. Floors and non-load bearing walls are supported by beams and columns, which transfer loads down the structure, and eventually make their way into the foundation and soil. Floors and walls also act together to resist lateral loads due to wind and seismic by acting as a system of horizontal and vertical diaphragms. Walls that resist these lateral forces are known as shear walls. In addition to shear walls, beams and columns, constructed as a moment frame can resist against lateral loads. This involves moment connections between beams and columns, and tying the floor into these members.

The roof covers the top of a structure. Generally, the roof must be designed to carry dead and snow loads, which are again determined by the building codes. In addition to gravity loads, the roof serves as a diaphragm to gather lateral loads due to wind and seismic forces and transfer these lateral loads to the resisting shear walls or moment frames. The roof can be constructed from steel, wood, concrete, or any other suitable material and most systems are built as trusses, or a beam/ column assembly.

Understanding the structural system of Alumni Gymnasium served as a basis for the work to be performed. Since this is a renovation project to an existing building, the structural system in place must be understood first before any alterations are made.

2.4.2 Building Codes

For non-residential and residential structures above 2 families, the following codes and standards govern building construction in Massachusetts:

1. ***International Building Code*** (*IBC*) 2009 Edition

2. ***MA Amendments*** to *IBC-2009*

3. ***Minimum Design Loads for Buildings and Other Structures*** by the American Society of Civil Engineers (*ASCE 7*) 2005 Edition

4. ***International Existing Building Code*** (*IEBC*) 2009 Edition

Since the Alumni Gym is an existing building the construction is only controlled by either Chapter 34 of the *IBC* or the separate *IEBC Code*. In Massachusetts, one of the MA Amendments of the *IBC* is to delete Chapter 34 and adopt the *IEBC* in its entirety. In addition to the above codes, the following material specifications are adopted by reference in the *IBC* and control the design of structural members:

1. Concrete - ***Building Codes Requirements for Structural Concrete*** (*ACI 318-11*) by the American Concrete Institute

2. Masonry - ***Building Code Requirements and Specification for Masonry Structures*** (*TMS 402/ACI 530/ASCE 6*) by the following 3 societies:

The Masonry Society (*TMS 402*)

American Concrete Institute (*ACI 530*)

American Society of Civil Engineers (*ASCE 6*)

3. Structural Steel - ***Specification for Structural Steel Buildings*** (*ANSI/AISC 360*) by:

American National Standards Institute

American Institute of Steel Construction

4. Wood - ***National Design Specification for Wood Construction*** (*NDS*) by:

American Forest & Paper Association

American Wood Council

The above codes and regulations provide the guidelines for which to analyze and create new designs for Alumni Gym. The IBC 2009 and ASCE 7-05 provide guidelines for the determination of load cases that are to be applied to the existing and new portions of the structure. The individual material codes provide analysis and design values for different material properties. The two codes will be used together to guide the design process and solve the various concerns that arise.

2.5 Building Information Modeling

In recent years, great investment has gone into the use of Building Information Modeling (BIM) as a tool for design and construction. BIM is an intelligent model-based process that provides insight through enhanced visualization and promotes integrated solutions for buildings and infrastructure projects. Through the use of BIM technologies, multiple disciplines can come together and collaborate to produce a central model. This model is a 3-Dimensional representation of the project that may incorporate other facets like cost, schedule, or energy analyses. This process allows businesses to build projects faster, more economically, and environmentally conscious [9]. BIM allows contractors of all trades to create a 3D model of their work that can later be compiled into one realistic building model. From there, any detection of clashes (when more than one element is in the same space) is found and resolved before construction begins. This process prevents the waste of extra time and money if a mistake was to be made on it, especially in the current economy. Using

BIM technologies assists in eliminating these mistakes and increases profitability and productivity of the building. Almost half (46%) of the infrastructure organizations, surveyed by Autodesk, are currently using BIM technologies and processes on some part of their infrastructure portfolio; a recent growth from only 27% two years ago. The vast majority (89%) of these companies that currently use BIM for infrastructure report that it is extremely beneficial in keeping a project on time and on budget [9]. They also experience benefits that impact their internal business functions as well.

2.5.1 BIM's Importance in Design

BIM has many key benefits during the design phase of a project. Project scope, schedule, and cost all must be managed well during the design phase as this is the phase where many changes are made to these variables. Through traditional methods, if changes to the variables mentioned are made later in the project, delays can occur and great effort has to be made to upkeep the project. This can cause delays with increased costs negatively affecting relationships between consultants and clients. With BIM these changes to the digital model can be better coordinated, eliminating the possibility of many costly delays [9].

If a client were to decide to change the scope of their project, BIM can conveniently provide the tools necessary to make the changes. When one design value is changed, further calculations to other structural elements do not need to be made as BIM will automatically update the changes throughout the project. This allows the design team effective and speedy delivery of documents and visual elements. With the implementation of the 3D model and the architectural conceptual design provided by Goody Clancy, an architectural firm hired by WPI, future planning and construction can be evaluated more efficiently by the WPI Department of Facilities instead of only having 2D blueprints to rely on.

2.5.2 BIM's Importance in Construction

Another useful feature in BIM is the 5D capability that provides available information on building quality, schedule, and cost [9]. Cost estimating and value engineering can be accelerated especially when updates are made to any plans or estimates. Also, site plans can be prepared and used for communication to minimize the impact of construction operations on the owner. Due to a higher quality of documentation and better construction planning through BIM, administrative and overhead costs can be reduced [9]. Cost estimates and schedules must be developed and then linked to the 3D model to develop the 5D in software like *Navisworks*. The estimates and construction planning would reflect the structural changes proposed as well as the construction methods and site planning necessary to design and plan for this renovation. Altogether, the 5D model can represent the costs of the project from each individual phase throughout the scope.

With Alumni Gymnasium being a renovation project, there are many variables, some of which may not be clear initially, and having the ability to make timely and consistent updates to costs and planning is crucial. Additionally, with the building located in the center of campus, proper planning must be executed so as to not interfere with the campus and the student life.

2.6 LEED Certification

Leadership in Energy & Environmental Design is an innovative measure that is being utilized in the construction and renovation of many building environments. The focus of LEED is to provide building owners and operators the opportunity to implement green design, construction, operations, and maintenance techniques into their specific project [7]. Through these measures, owners can reduce waste, conserve energy, and improve the environmental quality of a building. This can be achieved in a multitude of ways and is applicable to various types of projects:

- New Construction & Major Renovation
- Core & Shell
- Schools
- Retail: New Construction & Major Renovations / Retail: Commercial Interiors
- Healthcare
- Commercial Interiors
- Existing Buildings: Operations & Maintenance
- Homes
- Neighborhood Development [7]

In order to achieve LEED certification, a building goes through a rating system that verifies it has been designed and built using strategies such as sustainable site development, water savings, energy efficiency, materials selection, and indoor environmental quality. There are four levels of LEED certification a building can achieve that depend on the number of points it accrues. The system is a 100-point system plus six points for Innovation and Design and four points for Regional Priority. Buildings receive a higher level of certification depending on how efficiently LEED principles are incorporated into the design and construction of the building [8].

These levels include:

CERTIFIED	SILVER	GOLD	PLATINUM
40-49 Points	50-59 Points	60-79 Points	80+ Points

2.6.1 How to Gain LEED Points

There are five main categories in which a building can earn points in order to reach certification. The number of points that are earned in each category determines the level of certification that the building achieves. Within each credit category, there are prerequisites that must be satisfied to earn points:

- Sustainable site credits
- Water efficiency credits
- Energy & atmosphere credits
- Materials & resources credits
- Indoor environmental quality

Generally, these categories aim to promote proper site development to reduce the impact on the surrounding ecosystem, smarter use of resources like water consumption, more innovative energy strategies in the building, sustainable building materials and recycling waste, and better indoor air quality and access to daylight and views [8]. There are also bonus categories that address innovation in design and operations as well as regional priority credits depending on the geographical location of the building and the environmental priorities of the region. Since Alumni Gymnasium is a very old building, many of these strategies are not in place but can be achieved successfully by observing the systems that are already in place and developing strategies to improve them. The aim was not to create a full LEED study on Alumni Gymnasium but instead to recommend alternatives in design and construction methods that would earn LEED points. Alumni Gymnasium fell under LEED for New Construction and Major Renovation since major work would be done to the structure. Using this guideline, the team was able to recommend ways to earn these points not only to become LEED certified but to promote more sustainable practices in construction. The reason for the incorporation of LEED was due to the precedent that WPI has set in the construction of other buildings on campus. These include East Hall, Faraday Hall, and the Sports and Recreation Center to name a few. This gives WPI a preliminary look into the LEED options available for Alumni Gymnasium.

2.6.2 Benefits of LEED to Alumni Gymnasium

Due to the age of Alumni Gymnasium and the design and construction methods used at that time (circa 1910), the structural and mechanical systems of this building are very outdated. Bringing the infrastructure up to code is one of the most important progressions in the renovation process. Since there are many systems that comprise the building that need to updated, using LEED as a guideline will not only bring the building up to code but also make it an efficient and environmentally friendly system. For example the mechanical and electrical systems are out of date and replacing those systems with new technology will reduce waste, and operations and maintenance costs. Also, renovating the structural portions of the building will prove effective in terms of insulating the building, saving energy, and reducing maintenance costs of the outdated systems as well as provide a healthier, more pleasing environment. One such challenge will be determining the proper materials and methods when renovating the basketball court on the top floor. It is a very open space with thermally inefficient windows and an outdated heating system that has to be run around the clock to maintain a comfortable temperature [1]. Another area for LEED consideration is the elevated slab to cover the existing pool area. There is discussion to use the volume under the slab to store rainwater to use to irrigate the quad in turn reducing municipal water use. Finding alternatives will be very helpful in improving these areas and the other sections of the building while preserving the historic façade on the exterior. Applying LEED strategies in Alumni will also follow the precedent set by other buildings on the WPI campus like East Hall, the Sports and Recreation Center, and Faraday Dormitory. However, because this is a renovation project and not new construction, the application of LEED alternatives must be incorporated efficiently in the design and construction with the constraints of cost and time. This project does not incorporate LEED into all design solutions but instead recommends areas where LEED can be integrated.

3.0 Assessment of Existing Building Conditions

In order to gain an understanding of the extent of this renovation, an assessment of the existing building conditions was conducted. First, background information was gathered on the overall building through archival research. Next, field investigations provided information regarding the existing structural elements that comprise Alumni Gymnasium. These finding were documented in a Building Information Model providing visualization and accurate details for dimensions of the overall building as well as the interior structure. Finally, a structural investigation of these elements was performed with seismic consideration to identify the structural components that met building code requirements and the ones that did not.

3.1 Gathering Information

Developing a 3D model of the existing conditions in Alumni Gym involved an information gathering process that was specific to the building. This information was gained from all available drawings of the building, and inspections of the site, where photographs were taken. Site visits were used to verify conditions stated on drawings, and to acquire any additional information required to analyze the building. Seventeen sheets of the original building drawings were obtained from the "WPI Archive and Special Collection Department" in the WPI Gordon Library. These drawings were the work of Hewitt & Brown Architects and Engineers, and they were dated 1914. It is to be noted that on the available drawings, there are several references to additional drawings sheets that were part of the original set, but are no longer available for unknown reasons. Another set of drawings developed by EYP Architects was given to the group from the WPI Department of Facilities. Further research conducted at the "WPI Archive and Special Collection Department" included obtaining the original construction specifications from 1911, photographs from the actual construction process from 1914-1915, and information from publications of the time.

3.2 Field Investigations

With the aid of existing drawings of Alumni Gym, the structural investigation commenced and investigation of the existing conditions began. First, the location, size, spacing, and material type of all structural systems and their members were documented. The structural systems examined included roof framing, floor framing, exterior bearing wall construction, and foundations.

The roof framing was a truss system that was supported by the exterior brick walls. To understand the roof framing, the roof truss individual members, connections, and spacing that comprise the trusses were measured. In addition, the purlins and deck spans and sizes that span across the truss were noted as well. A laser level was used to determine the joints and their spacing within a typical truss. The laser level was placed on Level 4 (gym floor) and shot up to the joint. A location was marked by tape on the gym floor, and measurements were taken from mark to mark. From this, the truss geometry was determined.

The floor framing was determined by locating and sizing all columns, beams and joists, as well as the holes that existed in the floor. Investigations indicated that Level 4 and 5 framing consists of steel girders and timber beams spanning girder to girder. The species of the timber beams were found from the original construction specifications and along with *ASCE 7-05* the design values of the beam, based on the species of wood, were determined. The girder and column section properties were field measured. Level 3 consists of a concrete slab, supported by concrete beams and columns. The floor slabs on Levels 2 and 1 each bear on grade. Next, the thickness of the exterior brick bearing walls was measured at a window opening at each floor. Finally, to the extent possible, investigations into the size of the foundation walls and footings were completed.

3.3 BIM for the Existing Conditions

BIM was an important aspect to the project as the existing structure of Alumni Gym was analyzed. From research in the "WPI Archives and Special Collection Department" and with the help of WPI Department of Facilities Management, the original 1915 drawings of Alumni Gymnasium were found and an accurate BIM model as seen in Figure 7 was created. However, with limited information available in the original drawings there were numerous elements of construction that were not easily visible.

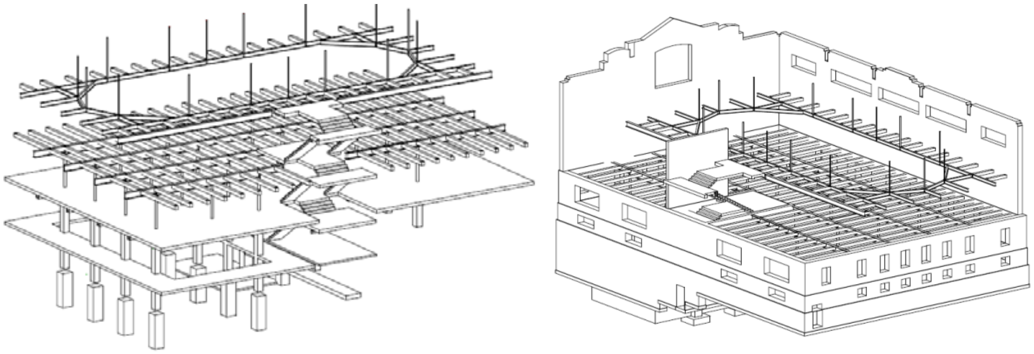


Figure 7 - Exterior View - West Side Alumni

After identifications of the layout of the building, the current version of the 3D model was created with the use of *Revit* which resulted in an existing structural model. Building the BIM model was useful in giving a starting point for the proposed renovation. As an understanding of the existing structure was gained through this visual model, a stronger knowledge of what problems would be encountered and what changes needed to be made was developed. With *Revit,* the Structural model made it easier to view desired areas of the building at any angle.

With the existing model, a reference to proposed renovation ideas was possible. Constraints were identified when implementing the new designs. From the foundation to the concrete and steel columns, to the steel girders, and the timber beams, any material was visualized that was an obstruction to the proposed layout. The model view of the structural system showed what elements were in the way and what upgrades were needed in specific areas.

Through the use of BIM, the project was driven by the 3D model that made it easier to adjust proposed ideas for renovation. Materials of the building that would have to be removed due to interference of the new construction were identified. Along with demolition, the new design was phased with the construction schedule.

3.4 Existing Conditions Analysis

It was essential to document the existing conditions of Alumni in a 3D BIM model to gain an understanding of the structure in place. The 3D model was later used for coordination during design and construction. Additionally 2D drawings were extracted from the 3D model for use during analysis and presentation. After this documentation was completed, an analysis of all structural members and systems was conducted. The analysis identified all structurally deficient areas in Alumni Gym. This provided an understanding of the areas that needed to be further explored, and that needed designs developed as solutions.

The analyses of the structural systems in Alumni Gym were divided into two main groups, gravity loads (vertical forces) and lateral loads (horizontal forces). The types of gravity loads that Alumni Gym was determined to be exposed to were snow, dead, and live. The lateral loads that Alumni Gym was determined to be exposed to were wind and seismic. Also, judgment was important for identifying other loads or for the need to use higher values than in *ASCE 7* that had to be used based on design requirements.

At Alumni Gym, the gravity load resisting building components were roof (purlins and trusses), floors (walls, girders, beams, and columns), and foundations (footings and foundation walls). The snow load and dead loads (of the roof system) are applied to the roof as a pressure (lbs/ft^2) and dispersed across the roof diaphragm. The loads then are distributed as loads per lineal foot (lbs/ft) along the purlins. The purlins act as simply supported beams connected to the top chord of the truss (at the joints of the truss, see Figure 8).

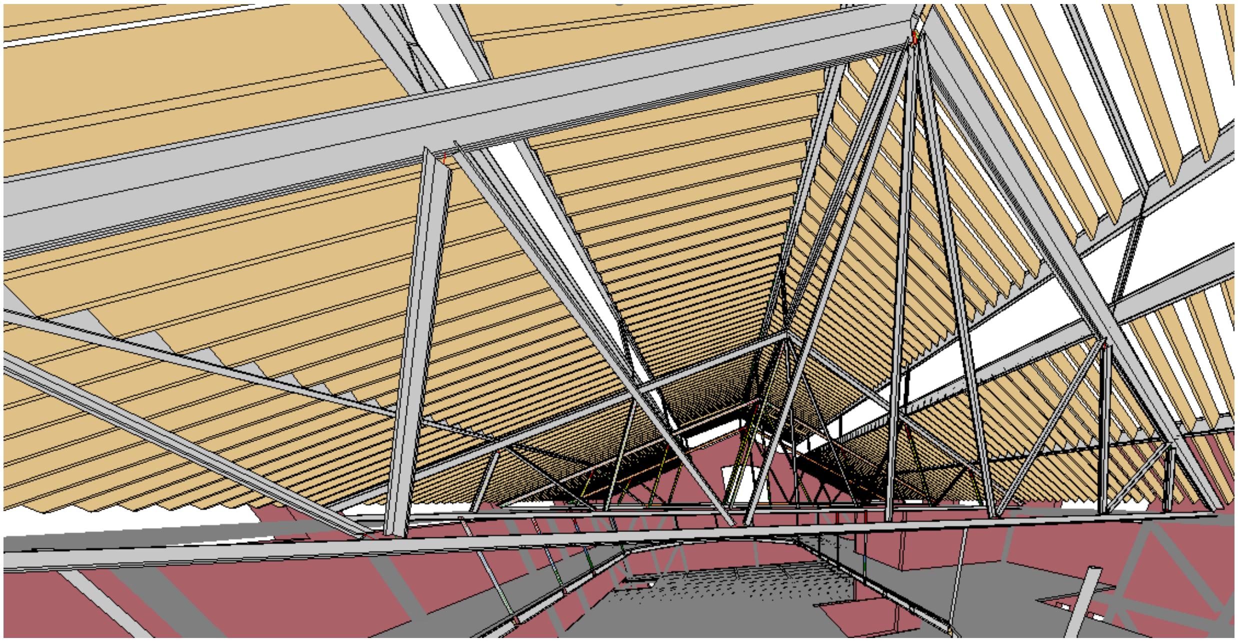


Figure 8 - BIM images of the joints on the truss

The reactions at the end of the roof beams act as point loads on the truss. The point loads travel through the truss members (top chord, bottom chord, and webs) to the end support reactions, bearing on the 1’-9” thick brick wall.

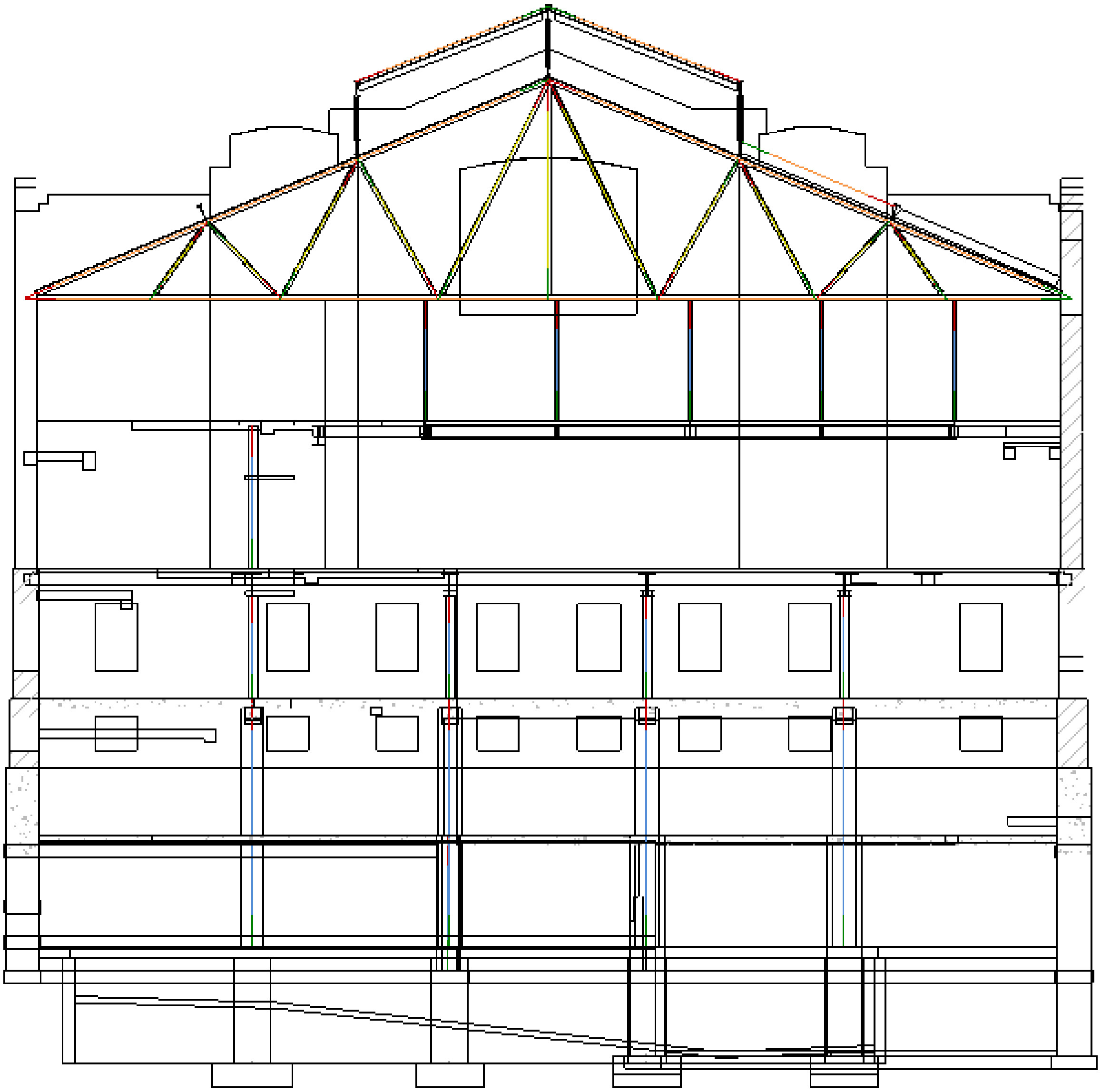


Figure 9 - Section View of Existing Structural System

In terms of the loading pattern on each floor, Figure 9 above displays the existing structural components and their relationship to each other as explained further. Each floor in Alumni Gym has a dead and live load. The dead load applied to the floor was comprised of the weights of the resisting structural members and any appreciable permanent loads (such as mechanical equipment, partition, etc.). The live load applied to the floor was specified from building codes depending on usage. A certain combination of these loads is applied to the floor diaphragm as a pressure (lbs/ft^2). For the framing for Levels 5, and 4, the floor diaphragm transfers the loads to the timber beams. The timber beams are supported at each end by a steel girder, which span column to column (or column to brick bearing wall). For Level 3 framing, and a portion of Level 2 framing, the load path is similar, although a concrete slab, beam, and column system is in use. There are 4 main column lines in the building that all align from floor to floor. The bottom most columns are supported by concrete spread footings that disperse the loads to the soil. The brick bearing walls are supported at their base by a concrete strip footing.

The lateral force resisting system utilizes similar building components to the gravity resisting systems; however, the load direction and resultant stresses are different. Wind blows on the building, and can come from any direction. Consider wind hitting the front exterior wall. The wind exerts a pressure (lbs/ft^2) across the entire wall area. This pressure is gathered by the floor diaphragm, which then brings the load into the exterior walls, located in the direction perpendicular to the front exterior wall. Seismic loads can be analyzed as a dynamic load, or an equivalent static load can be applied across each diaphragm of the building. The diaphragm and resisting walls then resist the seismic loads in the same manner as the wind loads.

3.5 Results of Existing Conditions Analysis

To fully understand the structural capacity of Alumni Gym, the structural shell was analyzed using information from the *International Existing Building Code* (2009). The areas that were analyzed for gravity load compliance were the framing for the roof, Level 5, Level 4, Level 3, and Level 2. In addition, the building's lateral resisting system was checked against the wind and seismic requirements. The following summarizes the group's findings, and highlights the insufficient areas.

3.5.1 Roof Framing

The roof is framed by a series of trusses spaced 24'-7". Each truss is constructed with steel angles, long legs back to back. The roof has purlins (15" I shape) that span truss to truss. There is also an upper portion of the roof, known as a monitor, that is 5 feet higher than the truss ridge, framed with I shapes. Figure 10 below shows the truss and monitor during actual construction.

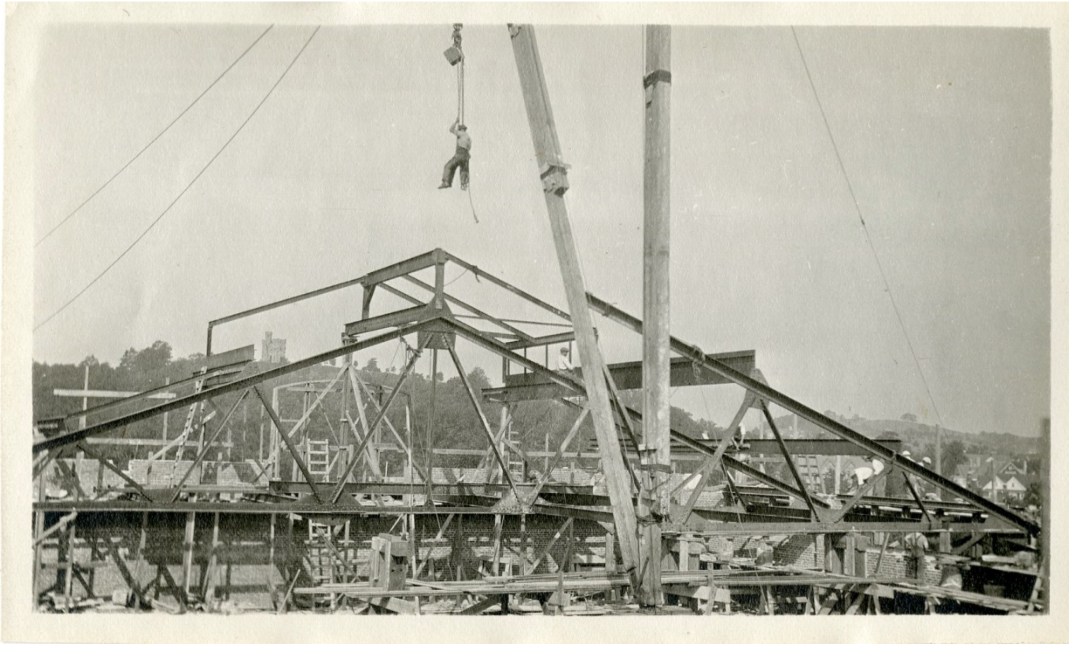


Figure 10 - Original photo of the truss construction

Once the framing of the roof was determined, the geometry could be analyzed for code compliance, using a roof snow and dead load combination from *ASCE7-05* and *IBC 2009*. The roof snow load was determined through values and equations from the *IBC 2009*, and the *MA Amendments to IBC 2009*. The ground snow for Worcester, MA was found to be 55 lbs/ft^2 from *Table 1604.11* in the *MA Amendments*; see Table 1. Through conversion factors from *ASCE 7-05*, the ground snow was converted into a roof snow load P = 39 lbs/ft^2.

Table 1: Table 1604.11 in MA Amendments

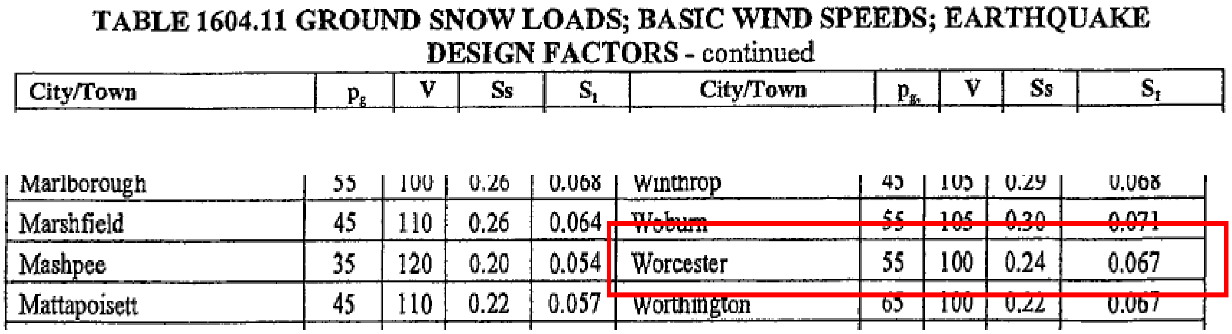


TABLE 1604.11 GROUND SNOW LOADS; BASIC WIND SPEEDS; EARTHQUAKE DESIGN FACTORS - continued

City/Town	p_g	V	Ss	S_1	City/Town	p_g	V	Ss	S_1
Marlborough	55	100	0.26	0.068	Winthrop	45	105	0.29	0.068
Marshfield	45	110	0.26	0.064	Woburn	55	105	0.30	0.071
Mashpee	35	120	0.20	0.054	Worcester	55	100	0.24	0.067
Mattapoisett	45	110	0.22	0.057	Worthington	65	100	0.22	0.067

Next, the roof dead load was determined to be 15 lbs/ft^2, which included the weight of the slate roofing, roof deck, monitor, and mechanical equipment. These loads were then resolved from the diaphragm, onto the purlins according to their spacing, and then as point loads on each truss; see Figure 11.

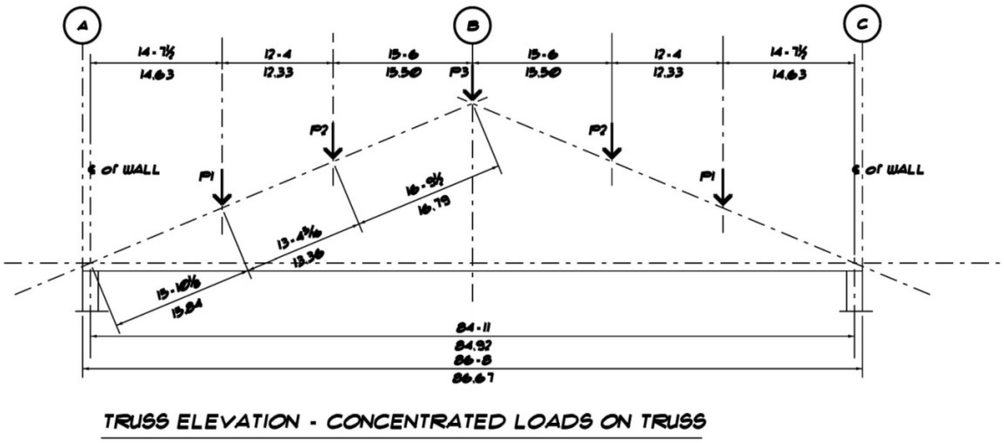


Figure 11 - 2D drawing of concentrated loads on the truss

The stresses in the top, bottom, and web of the truss were computed using the analysis software *Visual Analysis*. Each member's demand was then compared to its capacity. The bottom and top chord are built with LL8x6x3/4. The maximum stress in the top chord was only 40% of capacity, and the max stress in the bottom chord was only 28%. These capacities were based on Allowable Stress Design (ASD). The most critical web was an LL4x4x3/4 and the maximum stress was about 10% of capacity. Overall, the trusses were adequate, and met the current *IBC 2009* code for gravity load capacity.

3.5.2 Level 5 & 4 Framing

The Levels 5 & 4 are framed by steel girders and wood timbers, with wood deck, supported by pipe columns that sit on the concrete columns below. Through field measurements, it was determined that the wood deck was 3” tongue and groove. The wood timbers were full 12”x12”. The steel girders that support the timbers were either an 18”I, in 3 bays, or a 24”I in the widest bay. The 3” wood deck had a maximum span of 7 feet, from timber to timber. The timbers had a maximum span of 16’, from girder to girder. The 18” I girder had a maximum span of 28’, and the 24”I had a maximum span of 34’. A typical bay is displayed in Figure 12 below. Using this information a gravity load analysis was performed on these elements and found that each element met the IBC (2009) standards according to Load and Resistance Factor Design (LRFD) provisions. The floor was computed to have a dead load 18lbs/ft^2 and a live load capacity of 135 lbs/ft^2. The code requires a design live load 100 lbs/ft^2 for spaces designated for use as a mechanical/storage area (Level 5), and assembly area (Level 4).

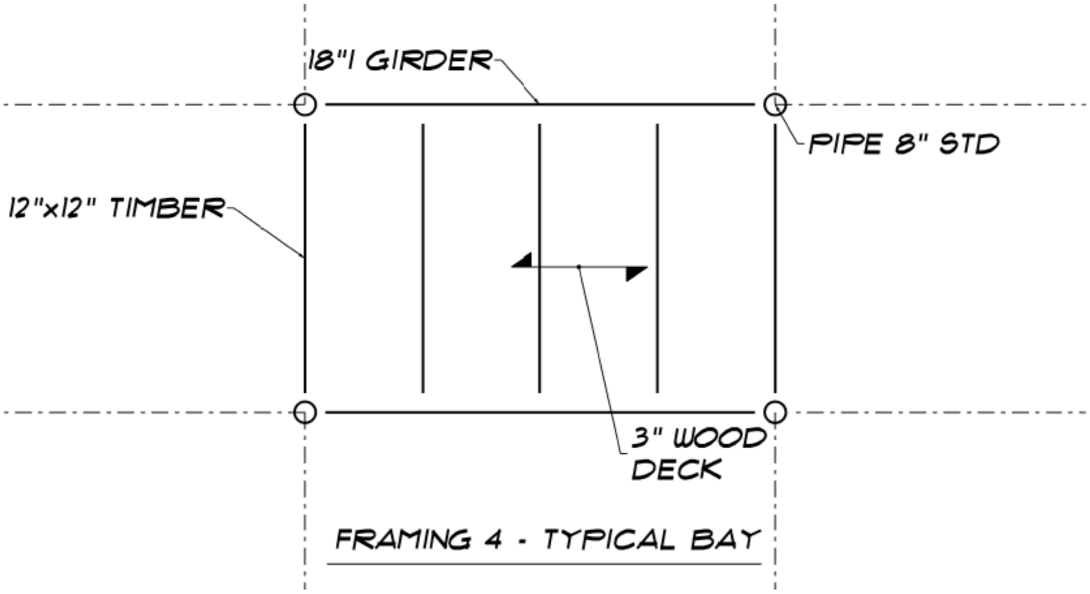
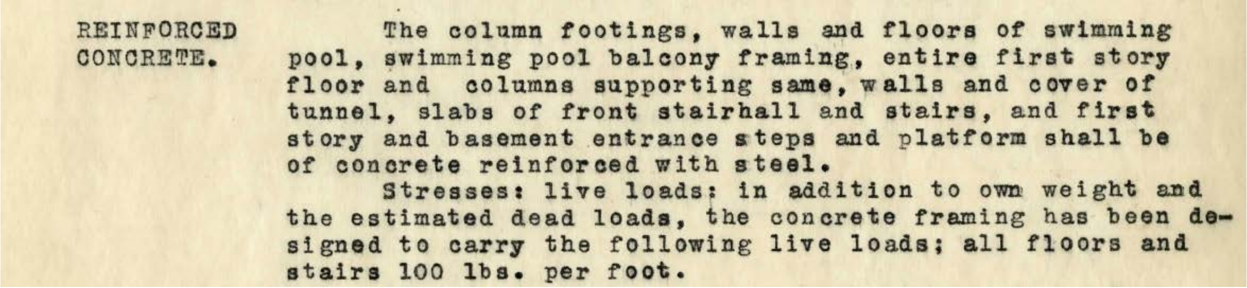


Figure 12 - Typical Bay

3.5.3 Level 3 & 2 Framing

Level 3 and the west half of Level 2 are framed by a monolithic reinforced concrete slab supported by concrete beams and columns, which sit on spread footings, see Figure 13. The slab is a one-way slab system spanning beam to beam. The original construction specifications for Alumni Gym specify that all concrete floors and stairs were designed to carry a live load of 100 lbs/ft^2, in addition to self-weight and dead loads; an excerpt from the original specifications can be seen below.



REINFORCED CONCRETE.

The column footings, walls and floors of swimming pool, swimming pool balcony framing, entire first story floor and columns supporting same, walls and cover of tunnel, slabs of front stairhall and stairs, and first story and basement entrance steps and platform shall be of concrete reinforced with steel.

Stresses: live loads: in addition to own weight and the estimated dead loads, the concrete framing has been designed to carry the following live loads; all floors and stairs 100 lbs. per foot.

Figure 13 - Reinforced concrete specification

To be able to determine the exact capacity of the floor and its supports, the reinforcing steel size and spacing must be known. The original building plans that were obtained for this project do not indicate the required reinforcement information, and the only other way to determine this would be to drill inspection holes in each member to locate the reinforcing. This method was highly impractical for this project, so an exact analysis of the beams and columns could not be done. Also, there are not techniques for imaging the embedded steel. However, an approximate analysis of the slab was done to determine the minimum reinforcing steel requirement. With a dead load of 150 lbs/ft^2 and an assumed live load of 100 lbs/ft^2, the minimum steel required was found to be .64 in^2/ft. This would call for 4 #4 bars at 3 in. spacing for a 12 inch strip of slab. This steel reinforcing can reasonably be assumed to have been used at the time of construction. An exact analysis for the beams and columns could not be performed without knowledge of the exact steel reinforcing and intended method of design such as continuously supported or simply supported. Level 3 framing was found to have met, if not exceed the live load specified for the proposed new usage from *IBC 2009, Table 1607.1*. An image of the slab framing from the BIM model is shown in Figure 14.

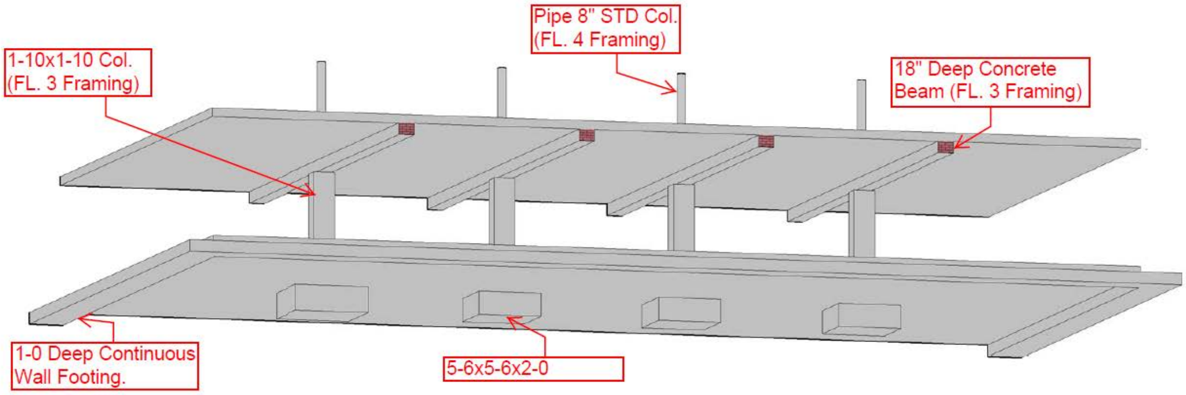


Figure 14 - BIM image of the slab system

3.6 Lateral Loads (Wind & Seismic)

In review of the proposed work and the *International Existing Building Code 2009 (IEBC)*, the complete renovation of the building assigns the building into the category of Chapter 8, Alterations-Level 3. Further, the removal of a substantial part of the Level 3 diaphragm (approximately 12% of the total floor area) requires evaluation of the building for current wind and seismic loads.

The wind and seismic loads on the building were determined in accordance with *IBC 2009 (ASCE 7-05).* The maximum stresses occur within the transverse walls (see Figure 15 for definition of transverse). This is due to the rectangular shape of the building: there is more area at the front and rear elevations to take load, and shorter walls in the perpendicular direction. The loads in the longitudinal direction are 70% (90ft/130ft) of those in the transverse direction. The walls in the longitudinal direction are 44% longer than the walls in the transverse direction. Consequently further analysis of the longitudinal walls was not warranted at the time. The local brick pier stresses (see Figure 16 for brick pier locations) were calculated and compared to allowable values for unreinforced brick masonry. In addition, the overall building stability was checked. The wind loads in the longitudinal direction were not considered as the longitudinal walls resist winds on the left and right sides.

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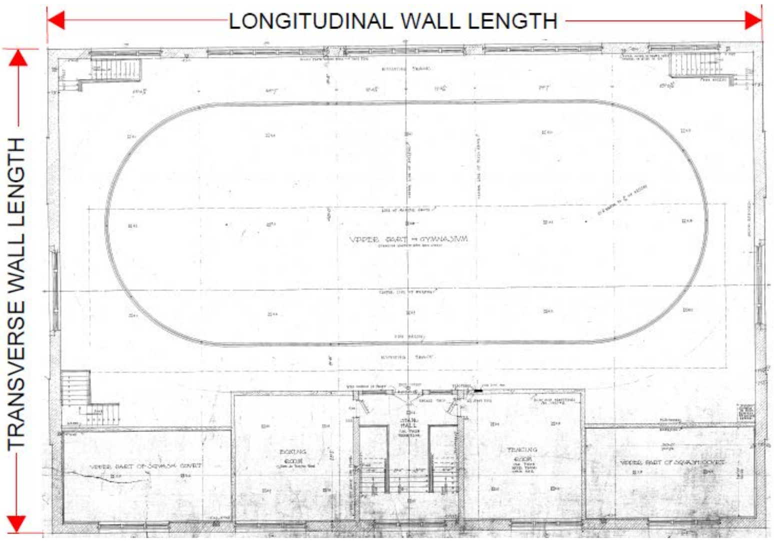


Figure 15 - Definition of Transverse

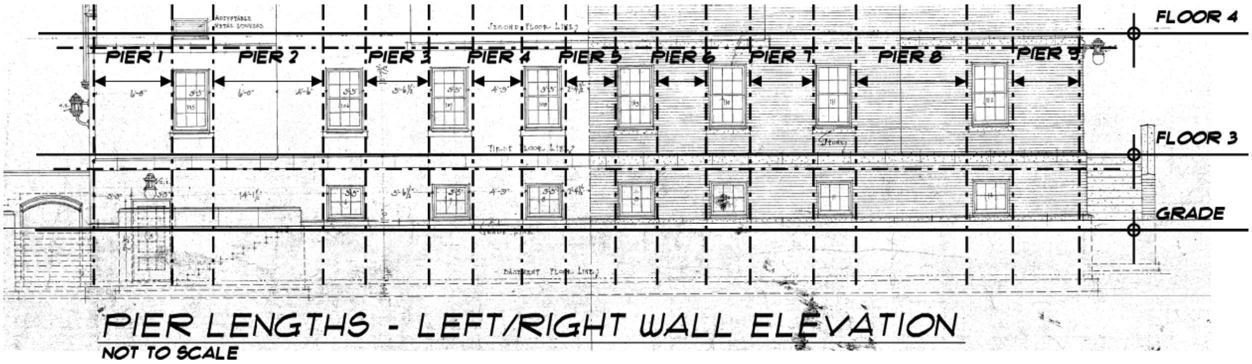


Figure 16 - Brick pier locations

3.6.1 Wind Analysis

The wind pressures on Alumni Gym were determined from the software program *MECA Wind*, in accordance with *ASCE 7-05*. The input for Worcester's basic wind speed was found to be 100 mph, from Table 1604.11 in the *MA Amendments*. The importance factor I, was determined from *ASCE 7-05*, Table 1-1, to be category III as shown in Figure 17. The figure below is an excerpt from *ASCE 7-05*, Table 1-1 that describes the nature of occupancy, for Category III:

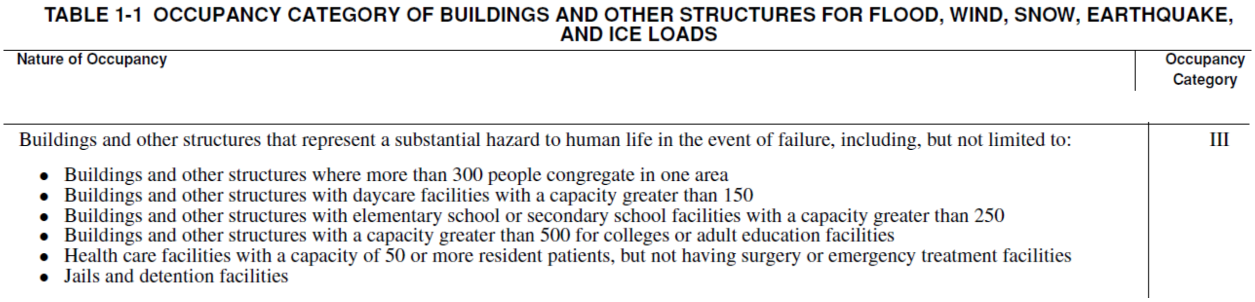
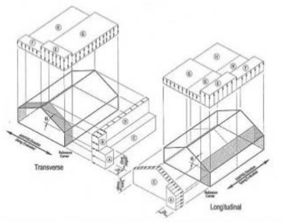


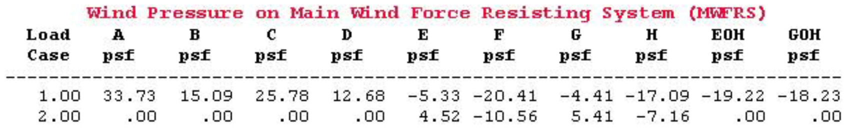
TABLE 1-1 OCCUPANCY CATEGORY OF BUILDINGS AND OTHER STRUCTURES FOR FLOOD, WIND, SNOW, EARTHQUAKE, AND ICE LOADS

Nature of Occupancy	Occupancy Category
Buildings and other structures that represent a substantial hazard to human life in the event of failure, including, but not limited to: • Buildings and other structures where more than 300 people congregate in one area • Buildings and other structures with daycare facilities with a capacity greater than 150 • Buildings and other structures with elementary school or secondary school facilities with a capacity greater than 250 • Buildings and other structures with a capacity greater than 500 for colleges or adult education facilities • Health care facilities with a capacity of 50 or more resident patients, but not having surgery or emergency treatment facilities • Jails and detention facilities	III

Figure 17 - ASCE 7-05, Table 1-1

The building footprint, floor heights, and ridge height were entered and *MECA Wind* computed the following pressures shown in Figure 18. Consistent with the provisions of *ACSE 7*-05, there are different pressures for the roof and walls, and the pressures intensify at the corners.





```
            Wind Pressure on Main Wind Force Resisting System (MWFRS)
 Load     A      B      C      D      E      F      G      H    EOH    GOH
 Case   psf    psf    psf    psf    psf    psf    psf    psf    psf    psf
------------------------------------------------------------------------------
  1.00  33.73  15.09  25.78  12.68  -5.33 -20.41  -4.41 -17.09 -19.22 -18.23
  2.00    .00    .00    .00    .00   4.52 -10.56   5.41  -7.16    .00    .00
```

Figure 18 - Wind Pressures on Alumni Building

The computed wind pressures were then resolved across each diaphragm level, and the shear and moment values at each Level were computed which can be seen in Figure 19 and 20 below. Note that Level 5 is not considered a continuous diaphragm because it is a suspended track, with a large hole in the middle.

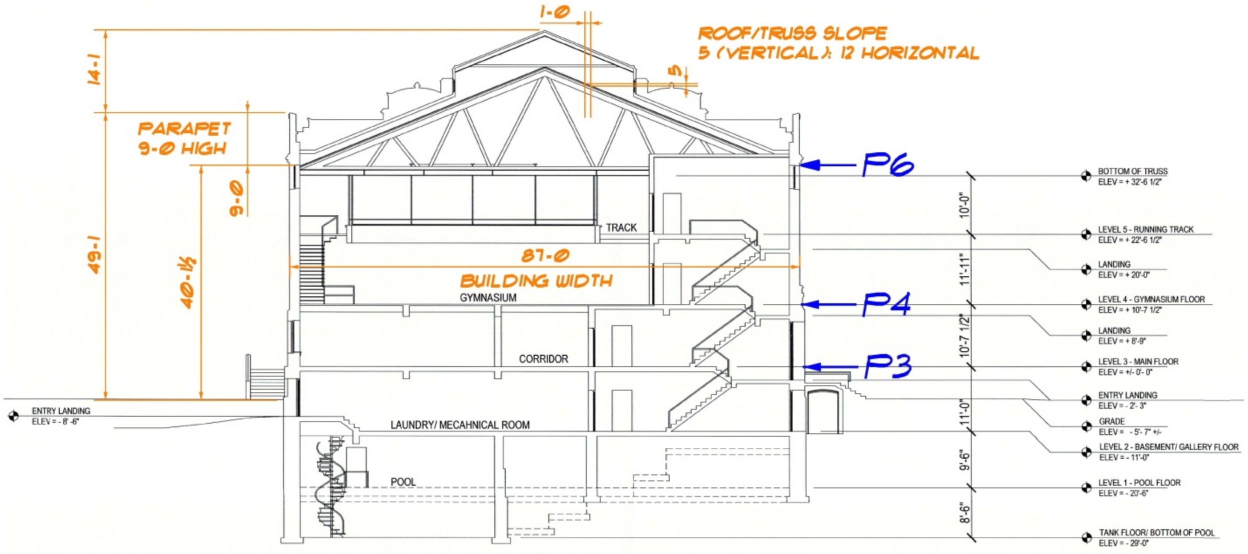


Figure 19 - Resultant Wind Loads on Transverse Walls

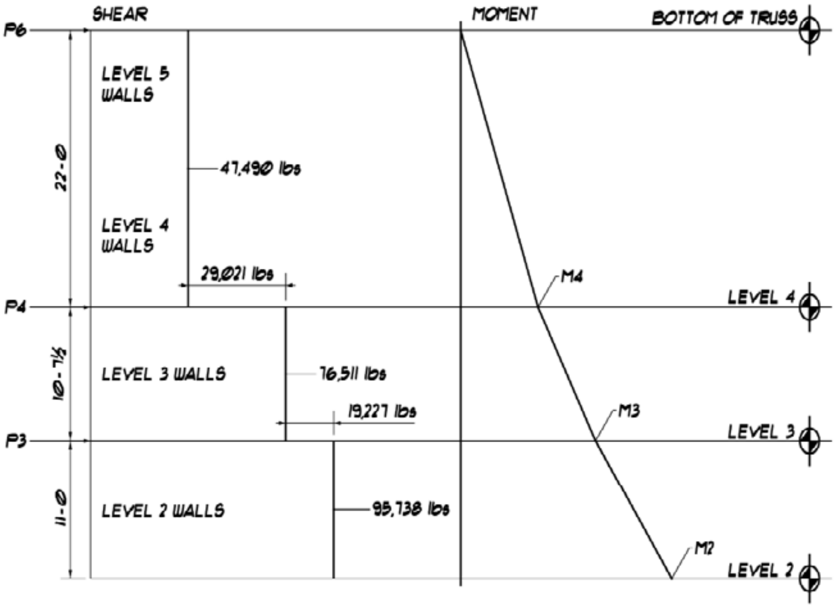


Figure 20 - Shear and Moment Diagrams

With the shear and moment values as presented in Figure 20, brick pier elements were checked for local stresses. When computing the capacity of the brick piers, the design values for brick compressive strength and mortar type were obtained from the brick masonry code which is published by the *Brick Institute of America,* 1969 (earliest brick code available). The smallest of the brick piers, 4'-9" wide (Figure 21), was checked. For brick units with a compressive capacity of 2,000 lbs/in^2, using type N mortar, it was determined capacity of this pier was greater than the demand. A check of overall building stability was computed and found to be under demand, with a factor of safety of 12. The overturning moment is dependent on the lateral wind loads. The resisting overturning moment was computed using the weight of the exterior brick walls. Based on the wind analysis, the overall building, and local pier elements have ample strength to resist current wind loading.

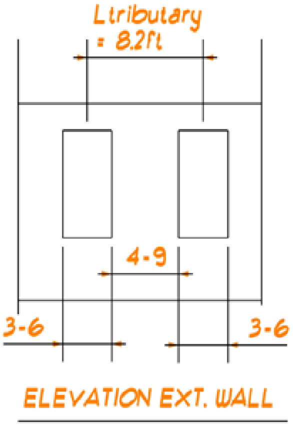
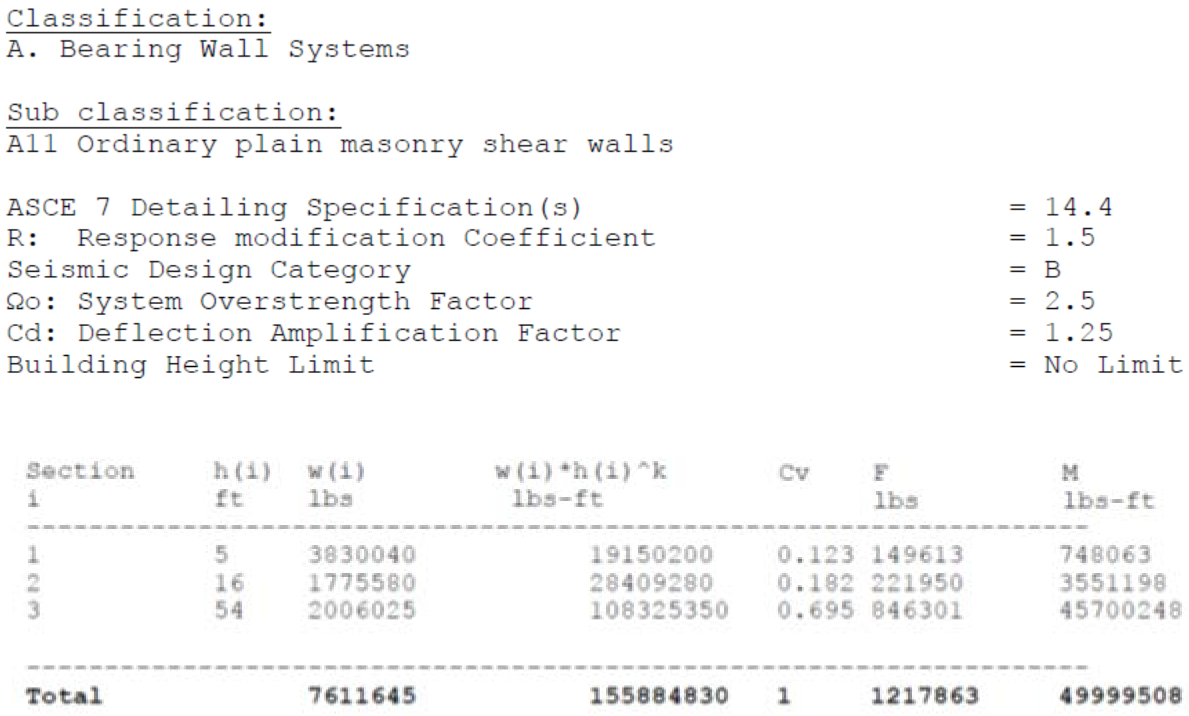


Figure 21 - Check of Flexure in 4-9 Brick Pier Due to Wind

3.6.2 Seismic Analysis

Seismic loads according to *ASCE 7-05* were calculated, and investigated with *MECA Seismic*. The building lateral resisting system was classified as a "bearing wall system." The "response modification coefficient R" was input as 1.5, for unreinforced masonry walls. The base shear and moment are given in Figure 22 below, as well as the moment and shear values at each diaphragm Level.



```
Classification:
A. Bearing Wall Systems

Sub classification:
A11 Ordinary plain masonry shear walls

ASCE 7 Detailing Specification(s)                          = 14.4
R:  Response modification Coefficient                      = 1.5
Seismic Design Category                                    = B
Ωo: System Overstrength Factor                             = 2.5
Cd: Deflection Amplification Factor                        = 1.25
Building Height Limit                                      = No Limit


Section     h(i)  w(i)         w(i)*h(i)^k      Cv    F          M
i           ft    lbs           lbs-ft                 lbs        lbs-ft
----------------------------------------------------------------------
1           5     3830040            19150200   0.123 149613     748063
2           16    1775580            28409280   0.182 221950     3551198
3           54    2006025            108325350  0.695 846301     45700248

----------------------------------------------------------------------
Total             7611645            155884830  1     1217863    49999508
```

Figure 22 - Seismic Pressures on Alumni Building

Using the values obtained from *MECA Seismic*, the end brick wall was then modeled in the finite element analysis software, *Visual Analysis*. The height and width were input, and 1'x1' plate elements were defined across the entire wall. Plates were then deleted to model window openings, and sloping wall segments. The results of the analysis can be seen below in Figure 23. The most critical brick stresses occur at the right and left end of the wall at Level 3 framing. This critical area is shown in blue below, and has a magnitude of 337 lbs/in^2 in tension. The allowable stress for a brick unit with a compressive capacity of 2,000 lbs/in^2, using type N mortar is 19 psi, meaning that the brick piers are highly overstressed due to the seismic loads. When considering building overturning due to seismic loads, the factor of safety is only 2.7. The overturning moment is dependent on the lateral seismic loads. The resisting overturning moment was computed using the weight of the exterior brick walls.

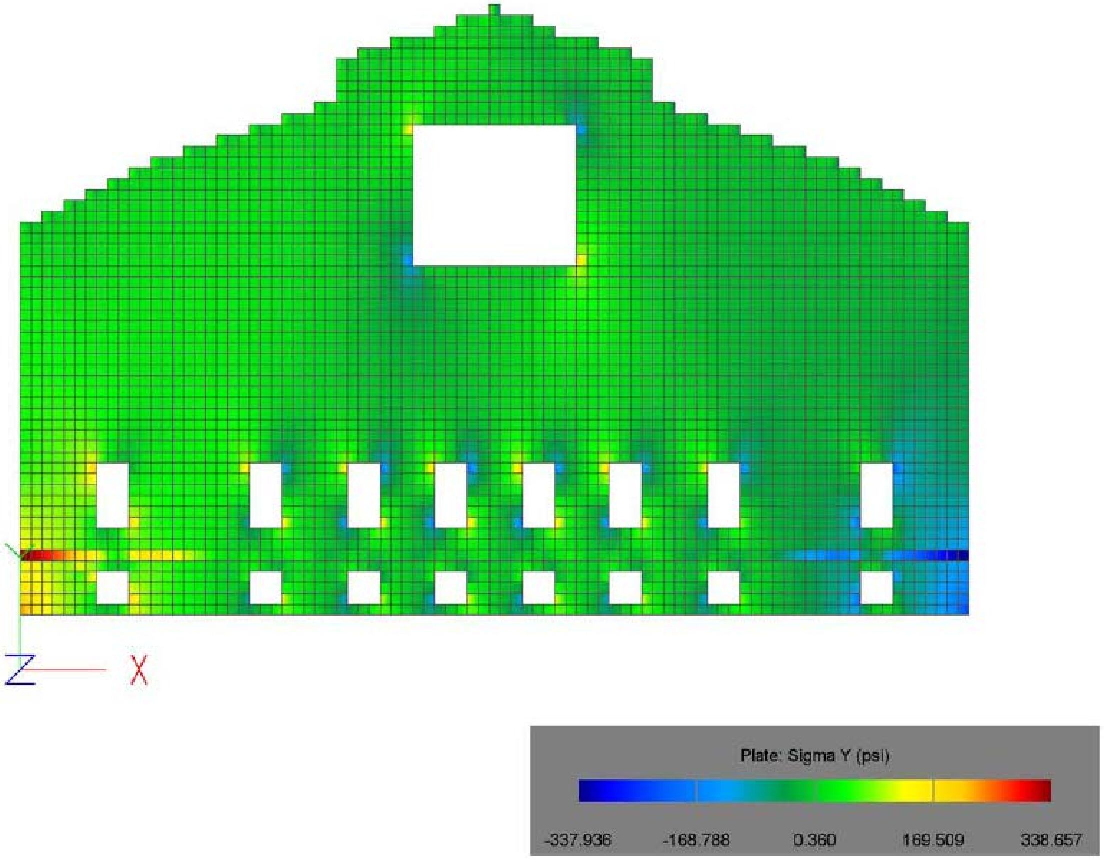


Figure 23 - Results of Visual Analysis

In a case of an earthquake, the consequences of failure in the brick walls could be catastrophic. The brick walls serve as a point of bearing support for the framing at each Level and the roof trusses. Once one pier has been overstressed and compromised, the stress values increase for the adjacent piers, and the effect continues. Failure of the brick walls will cause progressive failure in the floor and roof framing system, which is not a desirable failure mode. In fact, modern code provisions contain explicit information that requires sufficient redundancy in construction to prevent failures by progressive collapse. The seismic analysis revealed a structural deficiency in the seismic lateral resisting system for Alumni, and a new more robust and ductile system was implemented.

One may think the structural shell of Alumni Gym is so strong that it can withstand anything because of the fact it has stood for 100 years. The fact is when an archaic, non-ductile system is analyzed against current building standards, it does not pass. There is a reason why unreinforced masonry construction, as a means for lateral resistance, is not permitted in modern cases. Figure 24 below illustrates the development of a progressive failure and how the magnitude of stresses becomes increased once one pier element fails. The figure shows the new stresses across the entire wall are all over 400 lbs/in^2, well above capacity, and the max stresses are upwards of 1,000 lbs/in^2.

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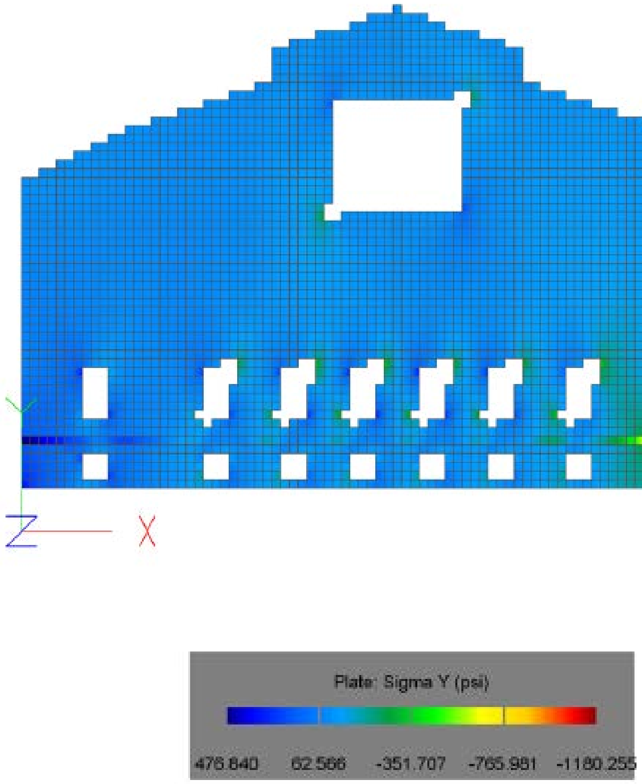

Figure 24 - Progressive Failure

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4.0 Proposed Structural Design

After extensive analysis of the existing structure and determination of the major areas of renovation, structural designs were developed to fit the needs of the newly configured building and to enhance the structural stability of the completed facility. The methods of the new structural design will be presented first in section 4.2, followed by the results and summarized calculations in section 4.3.

4.1 Structural Impact of Proposed Layout and Major Areas of Renovation

The scope of the design work for this MQP was not only based upon the findings made during the structural analysis of the building, but also from the functional needs of the owner as articulated in the layout prepared by Goody Clancy. Goody Clancy proposed some significant changes in the layout of the building that would affect the structural integrity of Alumni as it stands now. Through discussion with WPI Department of Facilities Management and examination of this proposed layout, major areas for renovation were identified and solutions were developed to meet the structural needs of these areas. Since this is a level 3 renovation according to *IEBC 2009 Edition*; all building systems in Alumni Gym must be analyzed and comply with current building code specifications. There were numerous areas that needed to be renovated for the completion of the "Innovation and Solution Center" in Alumni Gymnasium. Some major items that needed to be addressed after the structural analysis of Alumni Gymnasium and study of the existing building model were:

- the need for a seismic upgrade due to the lack of capacity in the unreinforced masonry
- support for the Showcase Atrium on Level 3 that would require cutting openings in the existing floor slab
- an elevated slab over the existing pool to create a Robotics Pit

- an elevator shaft to access all levels of the building
- temporary supports during the demolition of the Harrington-Alumni connection, the existing slab on Level 3, and staircases between Level 2 and 3, and Level 3 and 4

Understanding the structural impact of the proposed layout was important in developing the designs outlined in the following chapter. Through the existing BIM model, a visual understanding of the major areas of renovation was gained. From the existing 3D model of Alumni Gym, a new model was created to display the proposed structural modifications.

Other items that were not addressed in this project included the replacement of deteriorated lintels above the windows on the north side of Alumni. These lintels run horizontally over the beams that span the opening of the windows to the nearest columns and will provide additional structural support. These new lintels will be installed above the new windows in the exterior walls. Although not investigated in depth, strengthening of the existing framing, especially the roof truss system, for HVAC and other mechanical systems may be required. The development of the designs for areas that were investigated is further explained and portrayed in this chapter.

4.2 Design Methods

The scope of the new structural design work includes design of lateral reinforcing system, diaphragm reinforcement, pool floor system, and an elevator shaft. The approach to each design is explained below.

4.2.1 Design of Lateral Load Resisting System

After the structural analysis of the existing structure was completed and the intended uses of the renovated Alumni Gym were determined, design began on the major elements that were required. From studying the *International Existing Building Code* (2009), *International Building Code*

(2009), and due to the nature of the project, a lateral reinforcement system design was needed to support the unreinforced masonry walls. Currently, the roof truss members sit on the brick wall and are not properly supported if there is any lateral movement in the structure. Figure 25 below displays the existing situation using the developed BIM model. It was proposed to use a steel frame to support these roof truss members and brace the brick masonry wall. These frames were designed to support the roof and floors of Alumni in case the masonry walls fail. The existing brick support system will be the system that is loaded under normal conditions, but once the brick fails, the steel system will become loaded, and have the ability to support the building. The reason for this is that the brick has a greater stiffness relative to the steel frame, so the brick will take all of the load until failure.

This was determined to be more feasible than reinforcing the walls with rebar which was more labor intensive to install and less reliable because the behavior of the brick would be unpredictable. In addition to being labor intensive, the insertion of rebar would not solve the fact that the "in-plane" stresses were too high for brick and mortar to withstand. The addition of rebar would not relieve the "in-plane" stresses of the wall. Reinforcing the existing walls would require altering the brick masonry through sawing, drilling, and installing reinforcement. With steel framing, it is simpler to design a system that is predictable and that does not rely on the strength of the bricks to resist lateral seismic loads.

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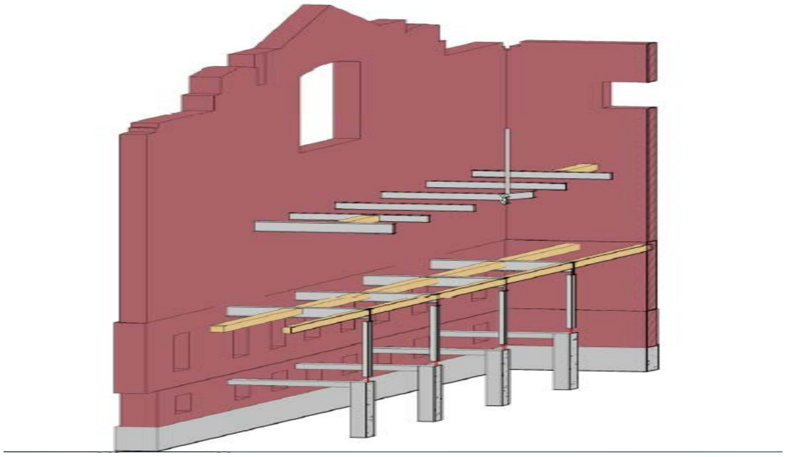


Figure 25 - BIM image of the current exterior wall view

In addition to lateral reinforcement for the overall building, reinforcement was not necessary for the parapet walls on the exterior roof of the building. Currently, they are freely standing unreinforced masonry walls. After checking these walls for wind and seismic loads, it was determined that the parapet walls are not tall enough to gather lateral forces sufficient to require additional reinforcement.

4.2.2 Design of Showcase Atrium

Developing a structural design for the new layout on Level 3 was another area of effort. WPI intends to open the space up on the main floor of the building by creating a Showcase Atrium. Partitions walls and stairs, shown in Figure 26, would have to be demolished to create this corridor and an opening in the existing concrete slab was necessary. This change would affect the lateral stability of the structure because an opening for new staircases would be created. The team designed a framing system to account for this change and resist the lateral load applied by wind and seismic forces. This system is shown in Figure 27.

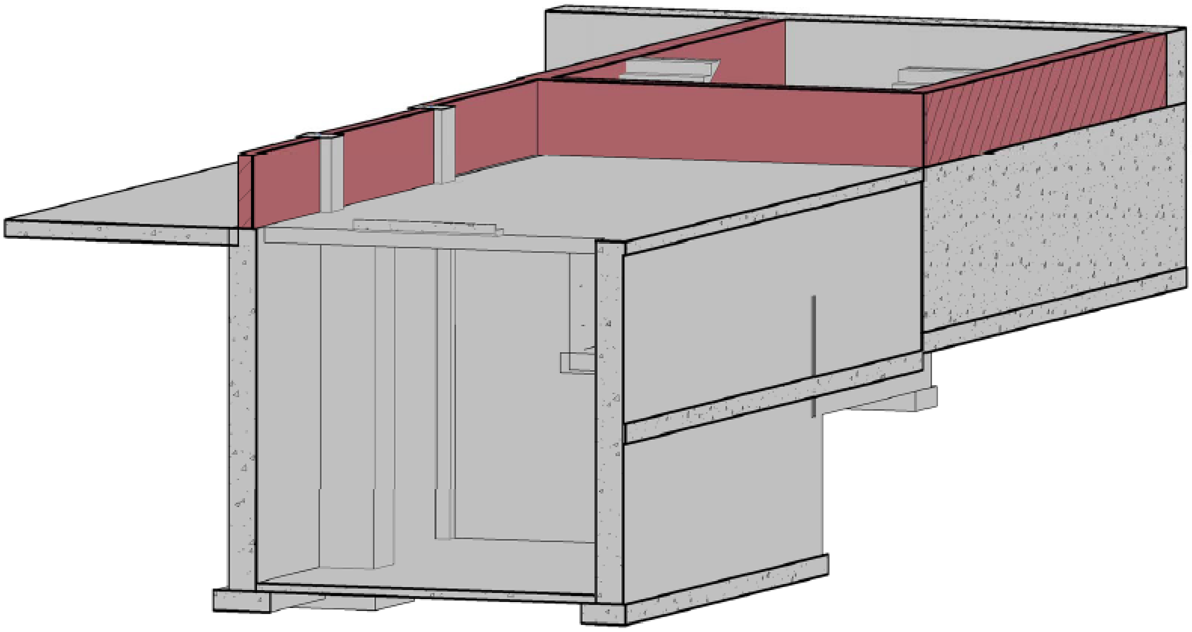


Figure 26 - Existing floor slab to be removed

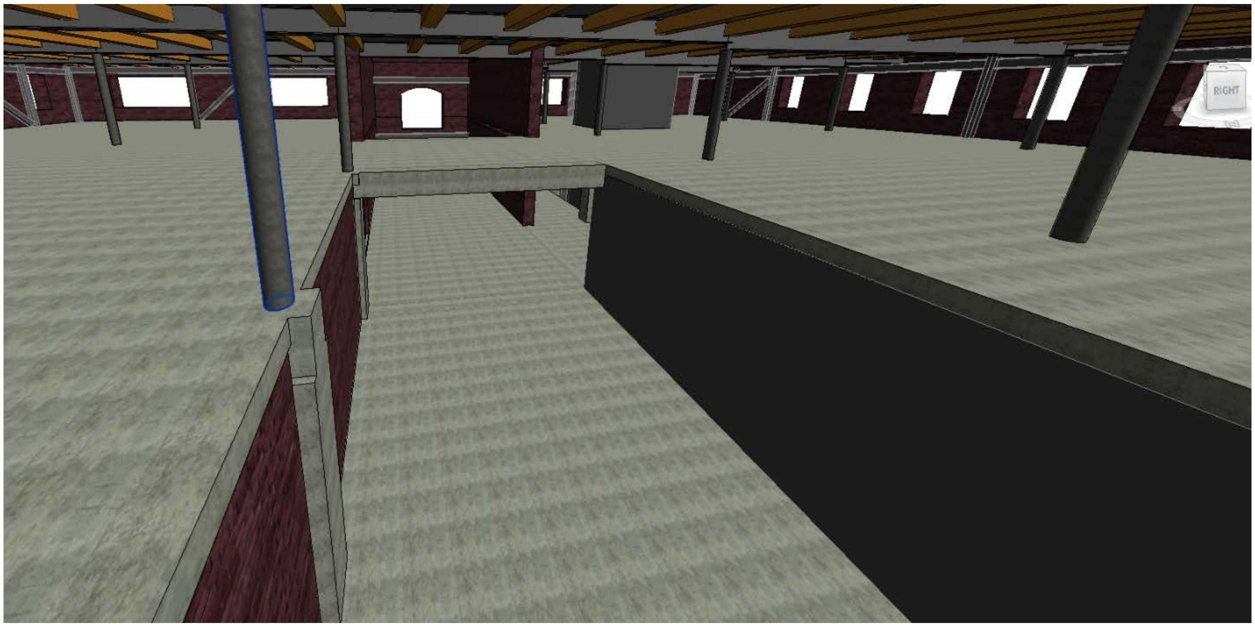


Figure 27 - BIM image of the future Atrium view

From the image above, it can be seen that there are four shear walls that would need to be introduced in order to transfer the load across the Level 3 floor since an opening in the slab is being created. Three of the shear walls are existing brick walls and the fourth would have to be constructed where existing partition walls stand. In addition to the 3D view, Figure 28 below shows a plan view of the 4 newly created shear walls, and their locations. These new shear walls are in place to resist loads that travel in the longitudinal direction of the building. The tributary width of the new shear walls are half way to the end wall and half way to the next shear wall.

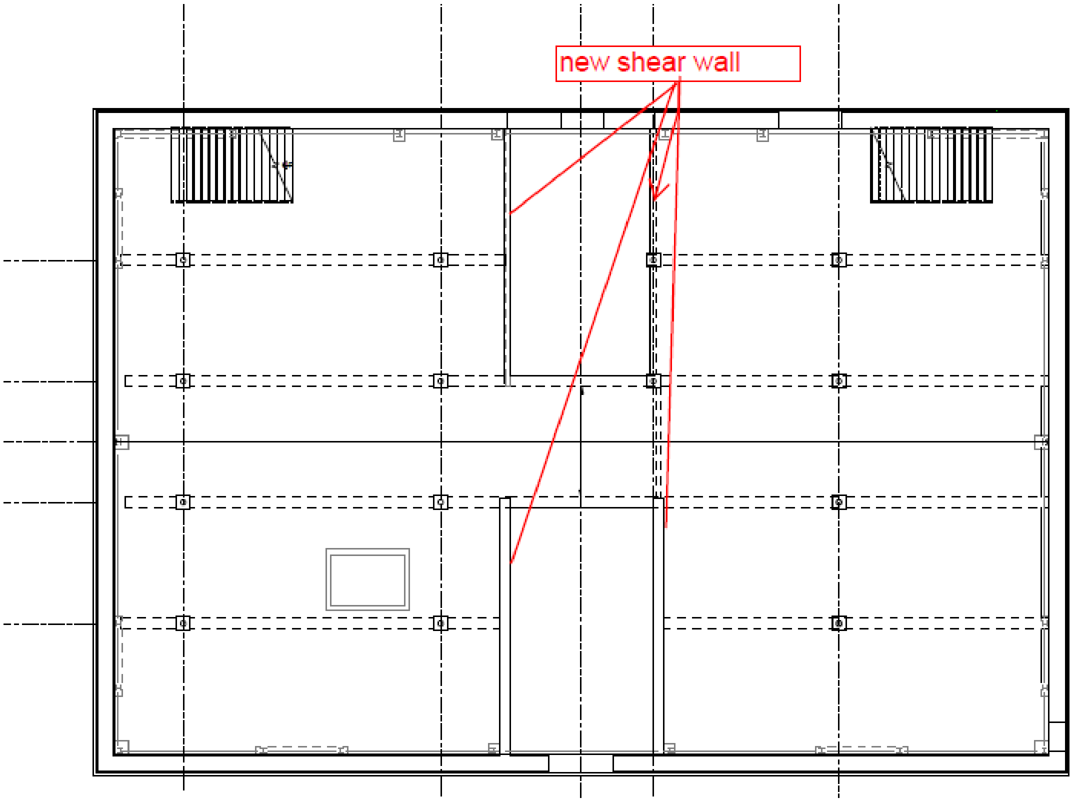


Figure 28 - Plan view of new shear walls

The floor and shear walls would be connected through a mechanical fastener to transfer the load from the floor into the walls. This change in space would open the area up to be more of a display area than a hallway which was the original use of the space.

4.2.3 Design of Pool Floor System

Due to the change in use in the Alumni Gymnasium, the swimming pool as shown in Figure 30 that is currently present will no longer be useful. This area, according to proposed architectural plans provided by Goody Clancy, will be converted into a Robotics Pit. Therefore, an elevated slab has been designed to cover the pool opening to provide a floor for the Robotic Pit. The design of the elevated slab accounted for live loads for the intended use of the area, the self-weight of the slab including reinforcing steel, and metal decking to span between supports.

Initially, a concrete bearing wall system was considered that would span the width of the pool at 16 feet on center. This spacing was set to avoid the existing footings that support the columns around the pool. A design was prepared for this scenario; however, with the intent to store rainwater underneath the slab for the irrigation of the quadrangle, the bearing wall system would not allow for the utilization of all the space under the slab. Therefore, an open web steel joist system was investigated to support the slab and its design loads. The ends of the joists were designed to sit on the edge of the swimming pool where a 12" lip already exists, as shown in Figure 29, and would span the width of the pool (32'-10"). The joists allow for the space under the slab to be completely open and would also be a simpler system than the concrete bearing wall. A bearing wall system would require excavation for footings, and labor and material costs for forming and placing the concrete for the footings and bearing walls. The joists could be fabricated off site and delivered in full pieces for installation on site. Other than the concrete slab, the only concrete work would be for the pedestal for the joints to sit on. Two joists were considered for this design; K-series joists and long span joists. The only concern would be moving the steel joists from the site into the building, and this has been addressed in the construction sequencing discussed in Chapter 5 of this report.

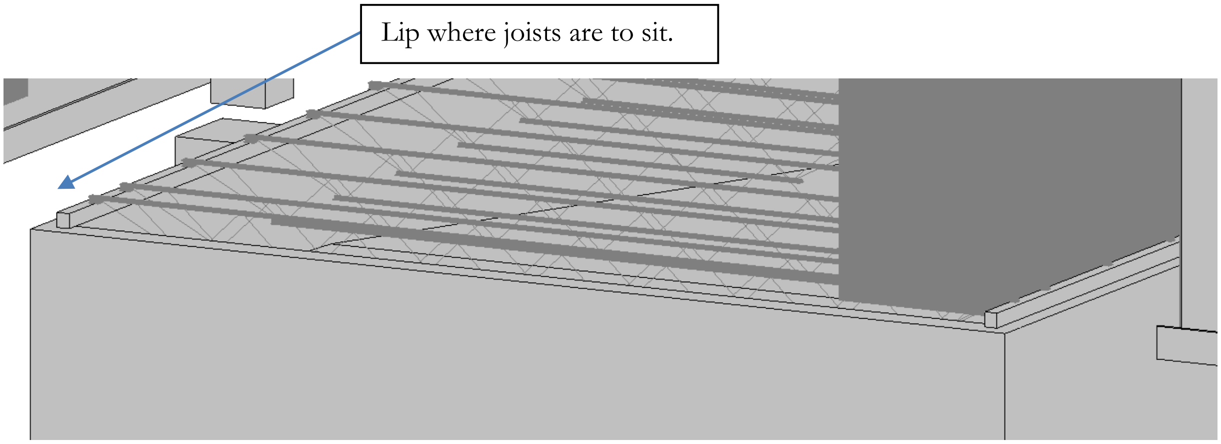


Figure 29 - Edge of pool, joist bearing point

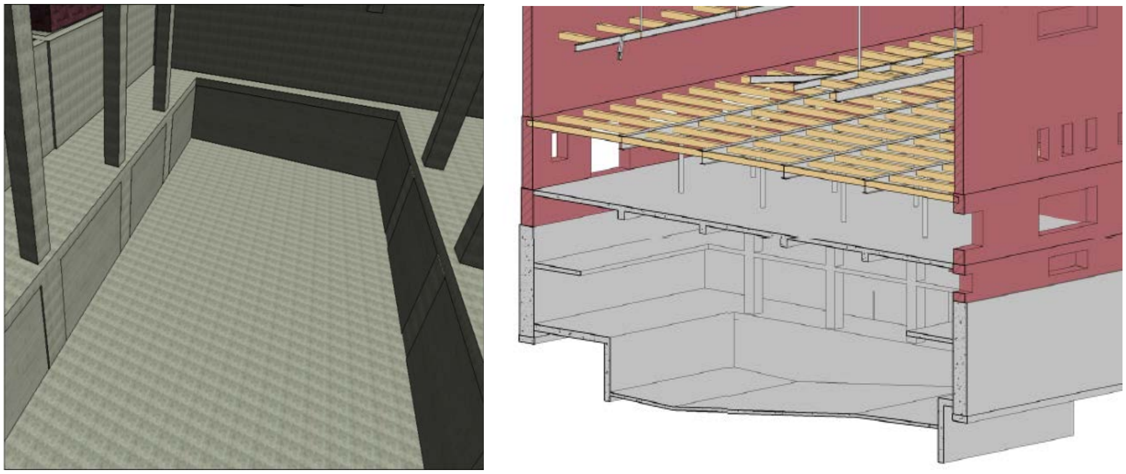


Figure 30 - BIM images of the swimming pool within the existing building

4.2.4 Design of Elevator Shaft

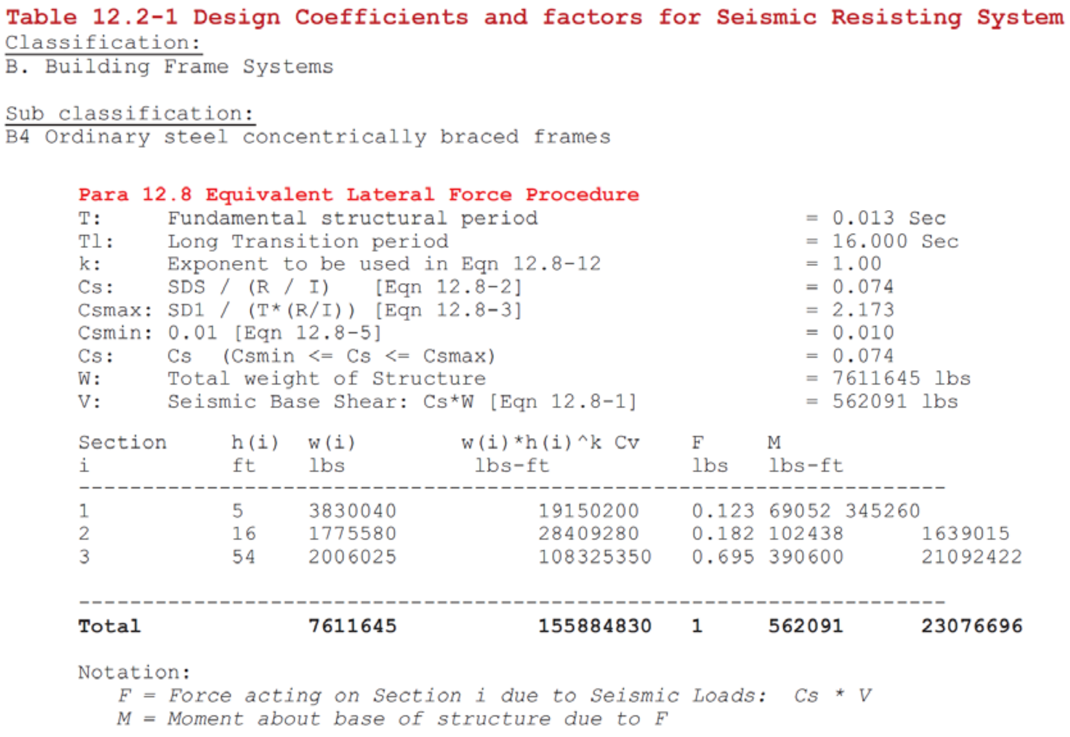
The elevator shaft was designed as a concrete masonry unit shaft. The only load that were applied to the shaft was the self-weight of the concrete masonry units. The shaft was positioned within the building to avoid the floor framing, so the shaft was not required to carry any additional load. The CMU walls of the shaft do not carry any weight of the elevator. This elevator is a hydraulic piston system, so all of the weight of the elevator is carried by the hydraulic piston. If the piston were to fail, the emergency brakes on the elevator box engage the "vertical t guides" at the left and right sides.

4.3 Results of Structural Design

The scope of the new structural design work includes design of lateral reinforcing system, diaphragm reinforcement, pool floor system, and an elevator shaft. The results of each design are displayed below.

4.3.1 New Lateral Load Resisting System

The first step in designing a steel braced frame was to design the frame geometry, which consisted of columns, beams, and braces. The beams were placed at each floor framing level to support the existing beams and trusses that bear on the existing masonry walls. The new columns and braces were then located behind the existing masonry walls, and positioned logically so there were no conflicts with the existing stairs, window and door openings. Once the frame geometry was defined, the seismic loads on the frame were determined through the load calculation program *MECA Seismic*; see Figure 31. This figure from *MECA Seismic* gives the shear and moment applied to the building at each diaphragm level. The dead loads applied to the frame were calculated based on the existing beams and columns that were to be supported by the frame. With dead and seismic loads understood, see Appendix H, the frame was drawn in the structural analysis program *Visual Analysis*, and the loads were applied. The analysis program designed the required member sizes to support the loads, and these sizes can be seen in Appendix J and later on in this section. The following diagrams show the dead and seismic loads for each frame elevation, the frame displacements due to the seismic loads, and the required member sizes. Finally for each elevation, the actual steel shapes as modeled in the BIM model and *Visual Analysis* are displayed in Figures 32-37.



```
Table 12.2-1 Design Coefficients and factors for Seismic Resisting System
Classification:
B. Building Frame Systems

Sub classification:
B4 Ordinary steel concentrically braced frames

      Para 12.8 Equivalent Lateral Force Procedure
      T:      Fundamental structural period                       = 0.013 Sec
      Tl:     Long Transition period                              = 16.000 Sec
      k:      Exponent to be used in Eqn 12.8-12                  = 1.00
      Cs:     SDS / (R / I)    [Eqn 12.8-2]                       = 0.074
      Csmax:  SD1 / (T*(R/I)) [Eqn 12.8-3]                        = 2.173
      Csmin:  0.01 [Eqn 12.8-5]                                   = 0.010
      Cs:     Cs  (Csmin <= Cs <= Csmax)                          = 0.074
      W:      Total weight of Structure                           = 7611645 lbs
      V:      Seismic Base Shear: Cs*W [Eqn 12.8-1]               = 562091 lbs

      Section     h(i)  w(i)        w(i)*h(i)^k Cv    F     M
      i           ft    lbs          lbs-ft           lbs   lbs-ft
      --------------------------------------------------------------------
      1           5     3830040          19150200    0.123 69052 345260
      2           16    1775580          28409280    0.182 102438      1639015
      3           54    2006025          108325350   0.695 390600      21092422

      --------------------------------------------------------------------
      Total             7611645          155884830   1     562091      23076696

      Notation:
         F = Force acting on Section i due to Seismic Loads:  Cs * V
         M = Moment about base of structure due to F
```

Figure 31 -Steel Frame Seismic Loads Screen Image from *MECA Seismic*

In addition to the steel frame, reinforced concrete piers and walls were designed to transfer the loads from the frame into the building foundation walls. Figures 32, 34, and 36 indicate the interaction values for the structural steel members form *Visual Analysis* software and Figures 33, 35, and 37 show the concrete members as well as the steel members and sizes from the BIM model. The concrete walls were needed due to the large shear and uplift reactions the frame produced. A simple concrete pier would not have provided enough bearing area to install a steel base plate large enough to transfer the loads for the braced bays. The columns at the braced bays supported by the new concrete wall will need to be embedded in the wall to resist the uplift reaction. In addition, 9, 0.75", shear studs were added to each steel column web to transfer the shear reactions to the concrete wall as calculated in Appendix J. The connection of the concrete piers and walls to the existing foundation walls were accomplished with steel rebar; #4 bars every square foot (See

Appendix J). The rebar was designed to be doweled and packed with epoxy into the wall, to transfer the loads out into the existing foundation walls and into the soil.

All new steel columns were designed to be W8 shapes to maximize interior space. The new steel beams were either W10 or W12 shapes to ensure they are concealed within the finish ceiling of each level. The braces were selected as HSS sections, with a depth of 8 inches to maximize the interior space by limiting the intrusion of the braces. The maximum displacement of the steel frame at any of the elevations was 1.4 inches. This deflection limit should be sufficient to prevent the frame from disturbing the masonry wall when fully loaded and displaced.

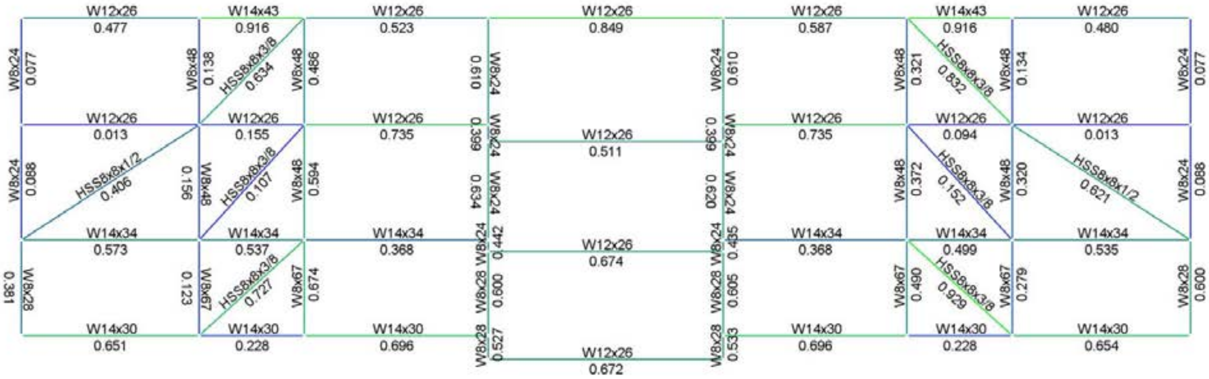


Figure 32 - Front Elevation: Final Sizes & Unity Check

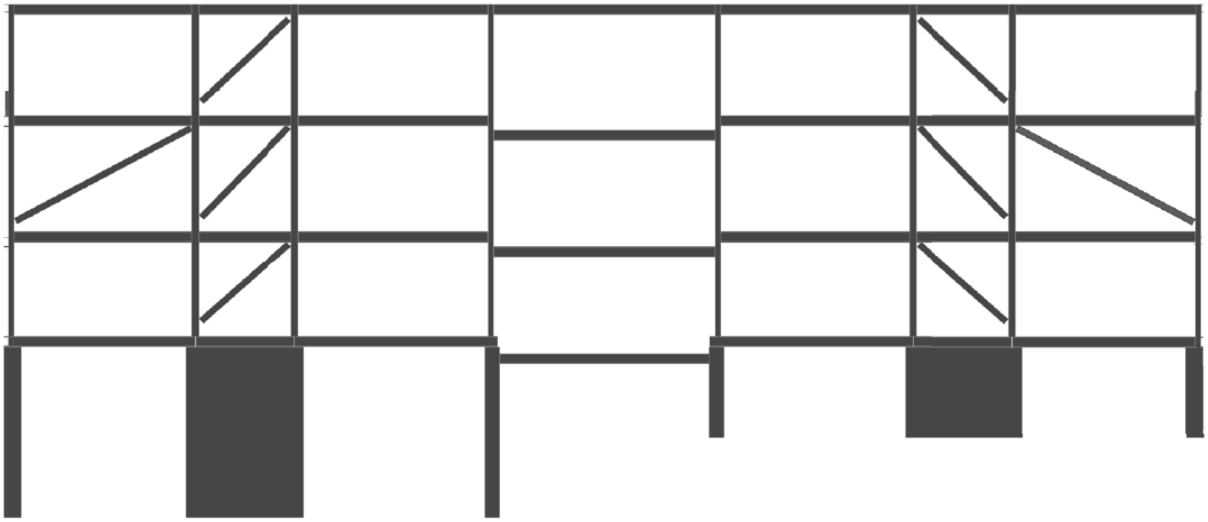


Figure 33 - Front Elevation: BIM View, with Concrete Piers

Figure 34 - Rear Elevation: Final Sizes & Unity Check

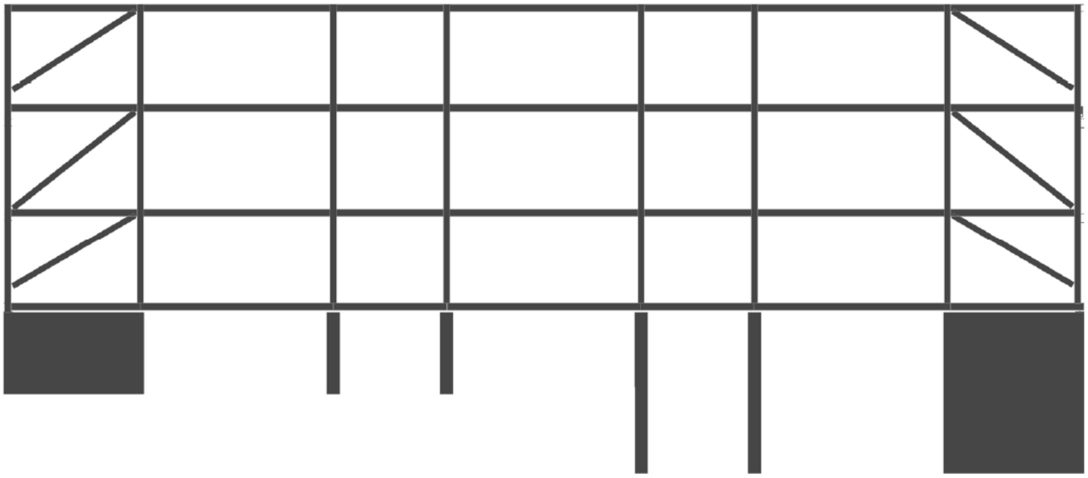


Figure 35 - Rear Elevation: BIM View, with Concrete Piers

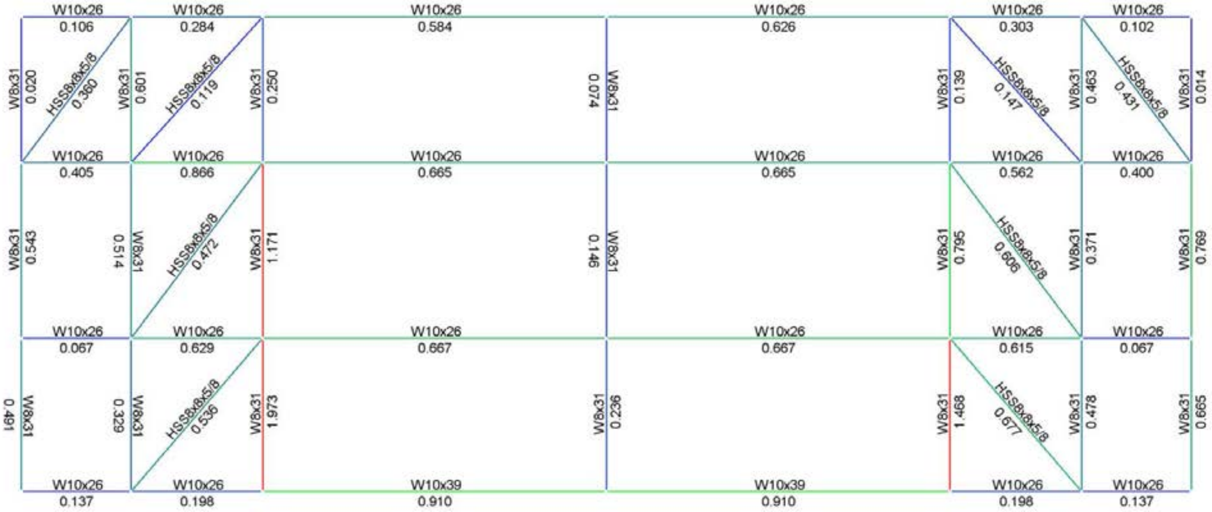


Figure 36 - Left/Right Elevation: Final Sizes & Unity Check

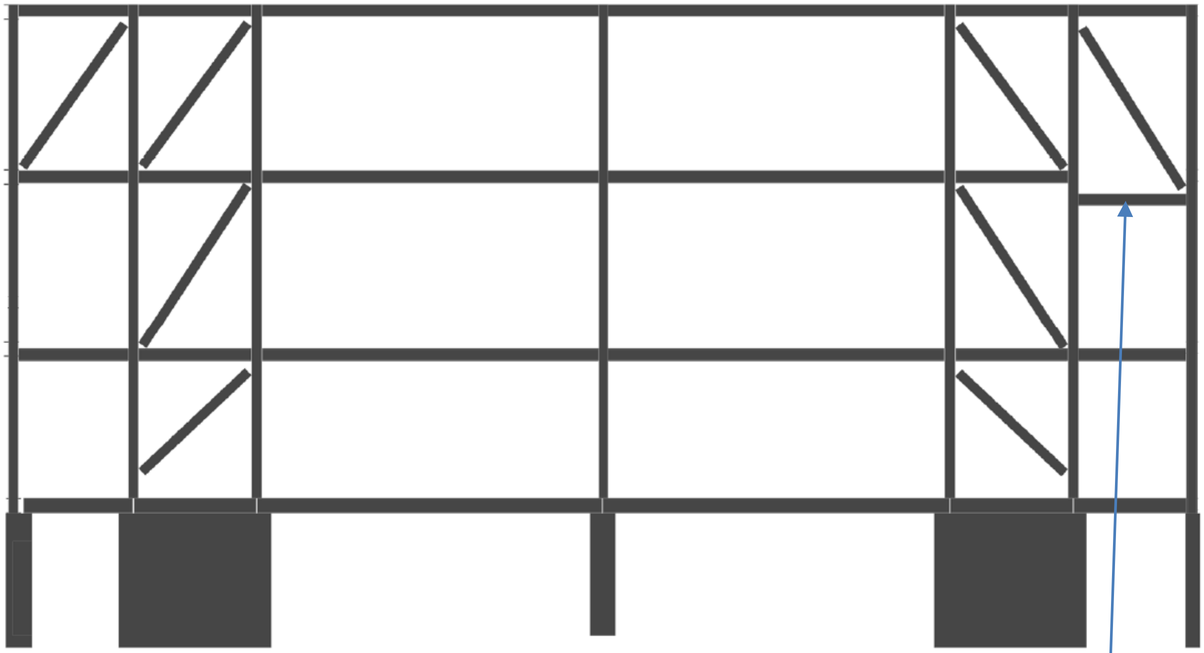


Figure 37 - Left/Right Elevation: BIM View, with Concrete Piers

The beam is lowered to carry the existing stair way framing

4.3.2 Lateral Design for Showcase Atrium (Level 3 Diaphragm)

The next major phase of work was removing a portion of the Level 3 diaphragm. To reinforce this new opening, four new shear walls needed to be introduced at framing Levels 3 and 2. There were three existing masonry walls at this location and these were turned into shear walls by connecting the floor to the walls with a steel angle. One masonry wall was at Level 3 framing, and the other two were at Level 2 framing. The fourth wall was to be installed at Level 3 framing. It was designed to be a Concrete Masonry Unit wall and connected to the diaphragm with a steel angle similar to the other shear walls. The new CMU wall is shown in Figure 38 below, along with the connection angle.

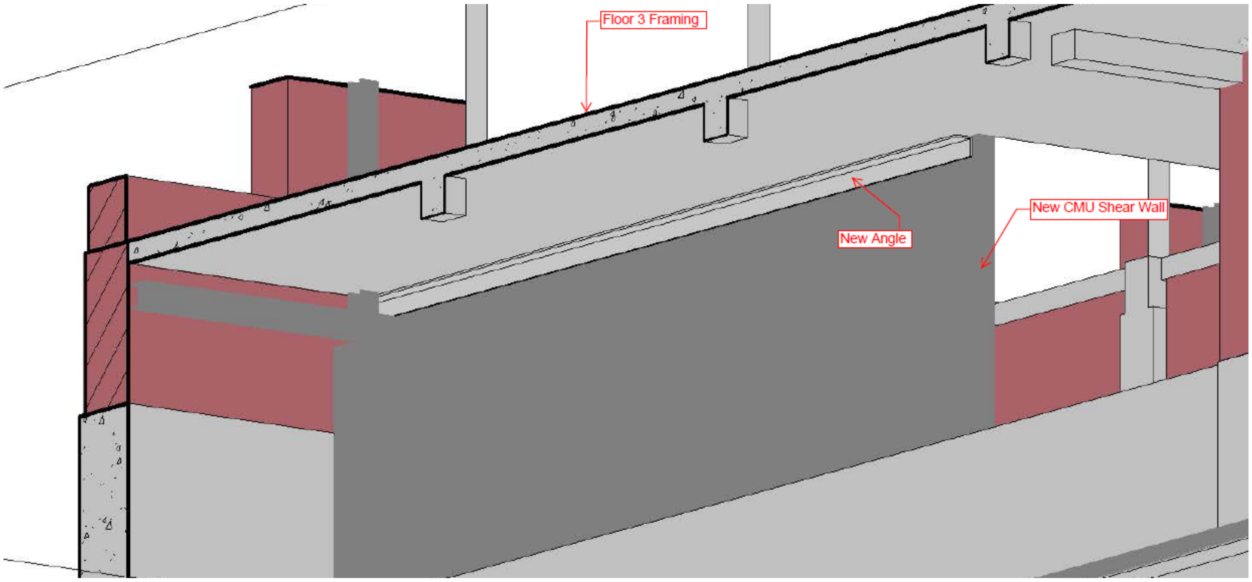


Figure 38 - BIM image of the Level 3 Framing: New CMU Shear Wall & Angle

Calculations were performed for the required steel reinforcing in the new CMU wall, and these calculations can be viewed in Appendix K – Showcase Atrium Design. It was determined that 2 #4 bars, Fy = 60ksi spaced 32 feet apart (in the end pockets of the block) will be sufficient to resist the lateral load. To find this reinforcing, the loads at this diaphragm level were computed, then the moment and tension were found. The minimum steel area was found from this tension force, and an adequate bar size was chosen. The connection was determined to be a L5x5x3/8 , with ¾” diameter steel anchor bolts covered with epoxy spaced every 4 feet. The full calculations can be found in Appendix K.

4.3.3 Pool Floor System

In order to make the pool level space usable, the pool opening had to be covered. This created adequate space for the new intended use of the room to be a Robotics Pit. There were three types of floor systems investigated to meet this need. The first type was a concrete slab supported by concrete bearing walls. The next alternative was to span open web joists across the short distance of the pool, and finally long span steel joists were investigated that also span the short distance of the pool but at larger spacing. Calculations for these designs are available in Appendix L.

Concrete Slab and Wall System:

Design loads for the concrete slab were a live load of 100 lbs/ft^2 and the dead load of the concrete. The final design of the slab resulted in a 7” slab, with tension reinforcing of #4 bars at 12 in. No shear reinforcement was needed. The slab was designed to be supported every 16 feet, at the bearing walls. The bearing walls were designed to be 4” concrete walls with #5 bars at 18”. The wall footing was designed to be a 1-6 by 1-0 deep footing with #5 bars at 22”.

Open Web Joists:

The open web joists were designed to span 32’-10” spaced at 2’-0. The floor had to resist a total load of 408.8 lbs/ft, so a 20K7 series joist was selected. This series of joist has an allowable load capacity of 463 lbs/ft. Design tables provided by *CANAM* [19], a steel joist fabricator, were used for the design of this floor system. These tables include an allowance for the concrete slab and the self-weight of the joist. An alternative joist size was selected to increase the spacing, and reduce the number of joists. The spacing was increased to 3.1', and this required a 20K10 joist. The allowable load capacity for this was 660 lbs/ft, which was still larger than the total load demand of 630.2 lbs/ft. Design Tables and calculations are available in Appendix L.

Long Span Steel Joists:

The final pool floor alternative that was examined was to use long span steel joists. With a span of 32'-10", and spacing of 4'-0, the required joist was a 24LH06 series joist. This joist gave an allowable live load of 617 lbs/ft which was still greater than the demand live load of 400 lbs/ft.

For each of the 3 steel joist options, a steel deck and concrete slab would span from joist to joist to create the floor. Design Tables provided by *New Millennium* [20], available in Appendix L, a metal decking fabricator, were used for selecting the decking. The finish 3.5 inch concrete floor and deck would be level with the existing Level 1. The joists needed a 2.5" bearing depth, which made a 6.5" assembly. The pool edge walls where the joists were to bear has a 1'-0 deep lip. A 5.5" concrete seat needed to be added here to ensure the correct finish floor level. There is also a constraint of the elevator shaft at one of the corners of the pool. The steel joists would sit on an angle attached to the elevator shaft.

The final flooring selection was based off of the lowest steel weight. Table 2 below shows the total weight of each steel floor system.

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Table 2 : Weight of Open Web Joist Systems

Web Joists	Concrete Slab Thickness	Metal Decking	Joist Spacing (ft)	Total Factored Load	Weight of Steel (lbs)
20K7	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	2	408.8	10434.6
20K10	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	3.1	630.2	8857.2
24LH06	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	4	817.6	8976
	🟩	indicates least weight solution			

The concrete floor and bearing wall system was not chosen as the final option because of the extensive work involved in its construction. Installing the footings requires demolition of the existing pool floor, forming concrete walls and a floor; all of which is very costly and timely. The steel joist option only requires removal of the pool edge, and installation of a new 5.5" unreinforced concrete seat. The only purpose of this seat is to bring the floor up to level. This option was determined to be the least intrusive, and it also preserved the entire space of the pool for future use as an irrigation tank. The open web steel joist system is displayed in Figure 39.

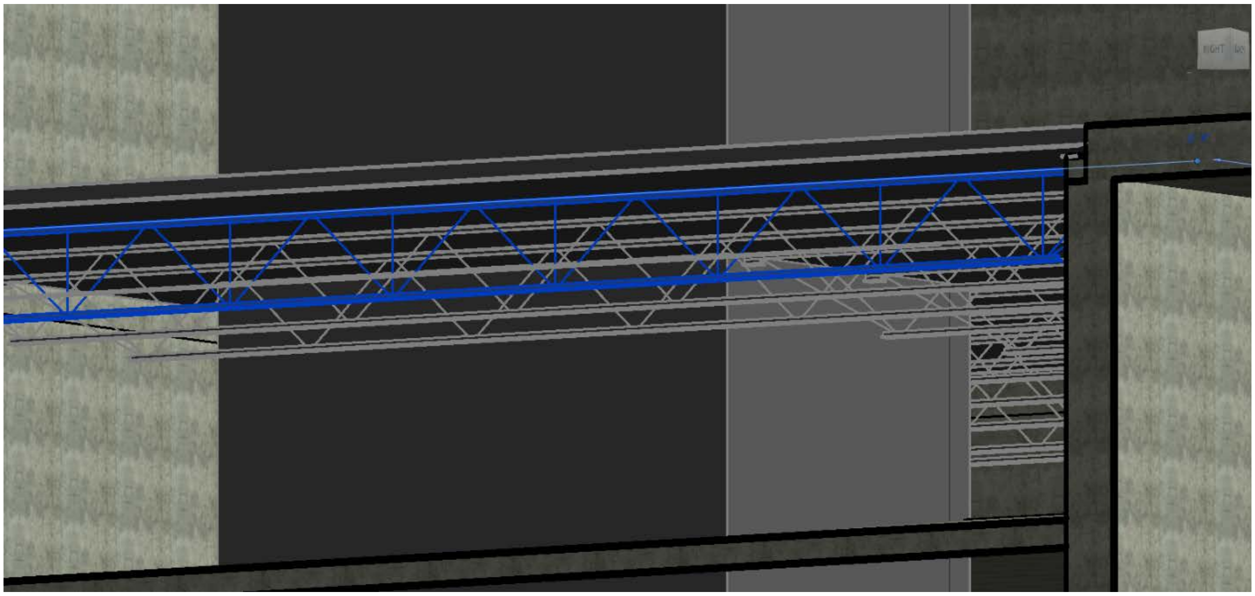


Figure 39 - BIM image of the open web steel joist system

4.3.4 Elevator Shaft

A major objective of the job was to install an elevator in Alumni to make it handicap accessible, as well as provide transport of materials through all 5 Levels. Figures 40, 41, 42, 43, and 44 below are sketches of the Concrete Masonry Unit elevator shaft with steel reinforcing. The calculation for bar sizing and spacing can be seen in Appendix N. There are plans that show the bar sizes and spacing. The elevations show the bond beams required at every 4 feet. The details show typical corner and opening details.

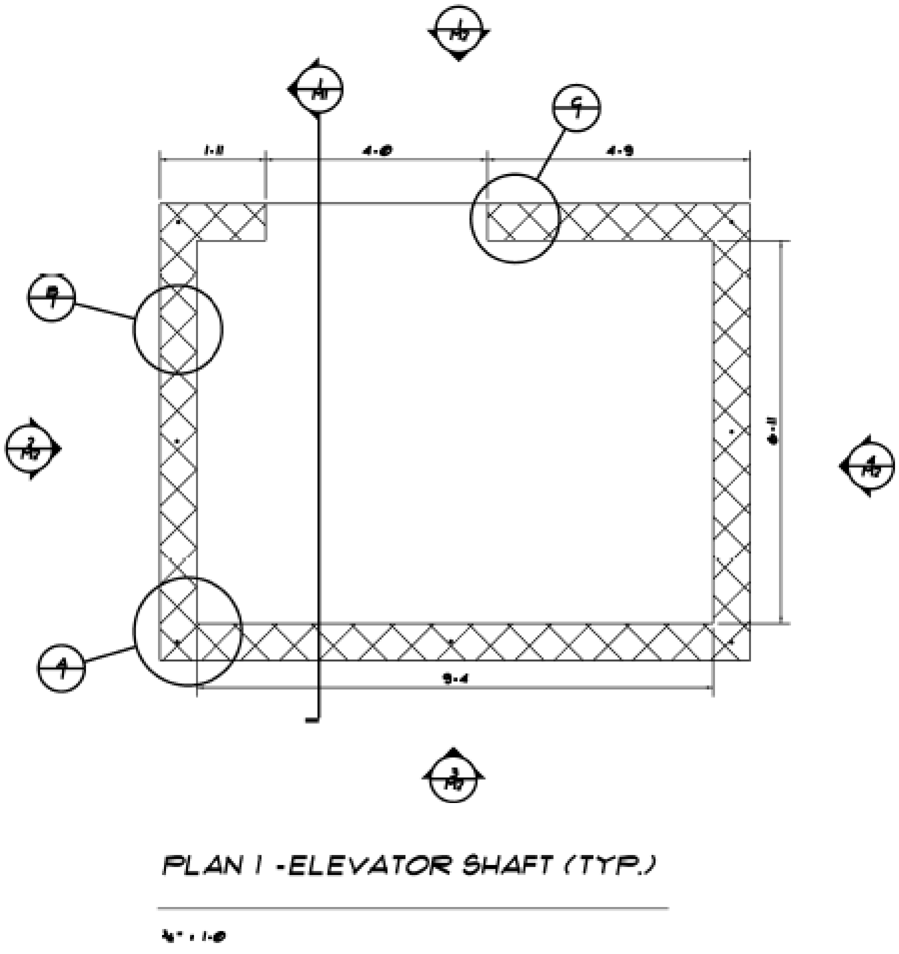


Figure 40 - 2D drawing of elevator CMU shaft

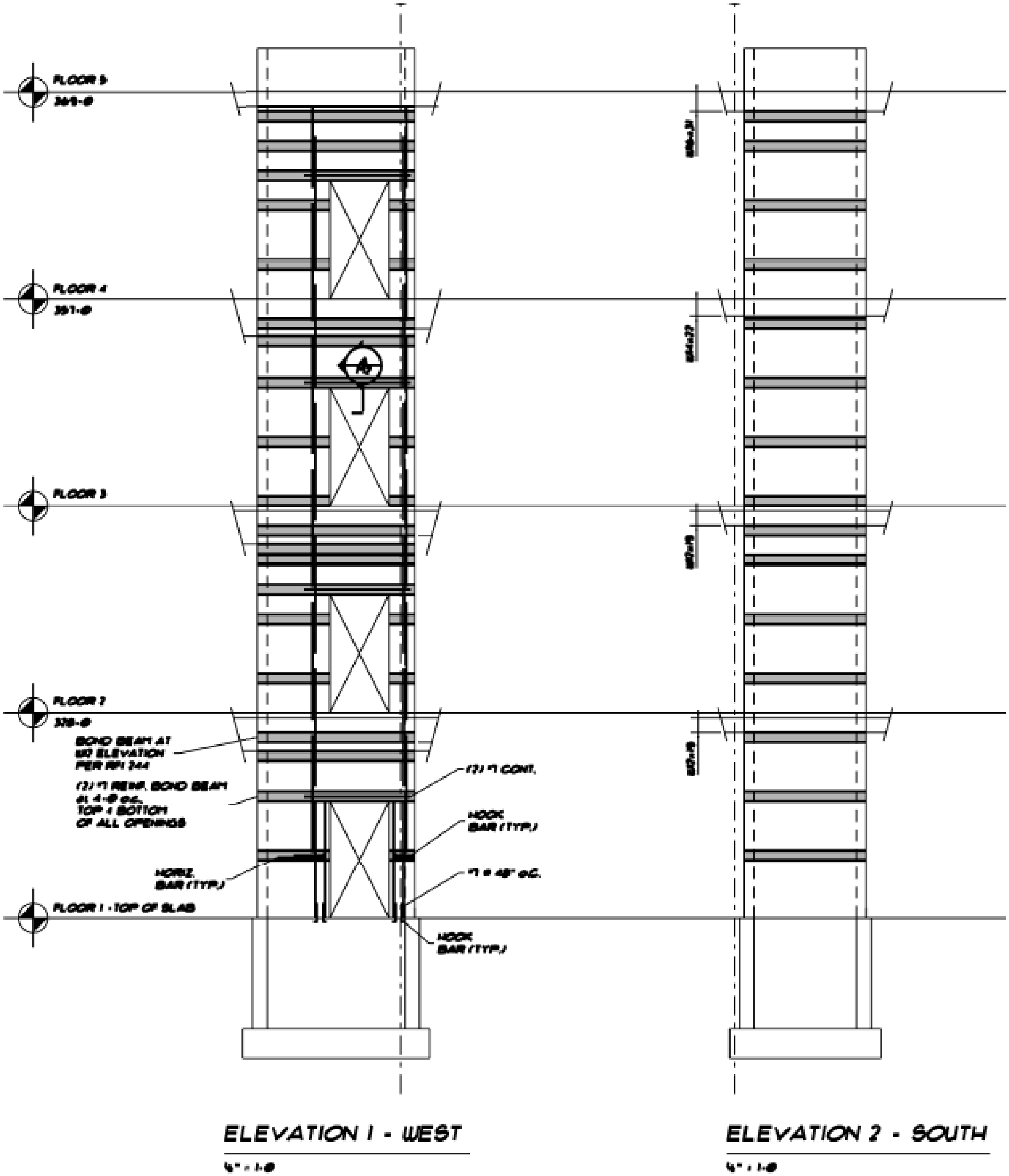


Figure 41 - 2D drawing of east and west direction of elevator CMU shaft

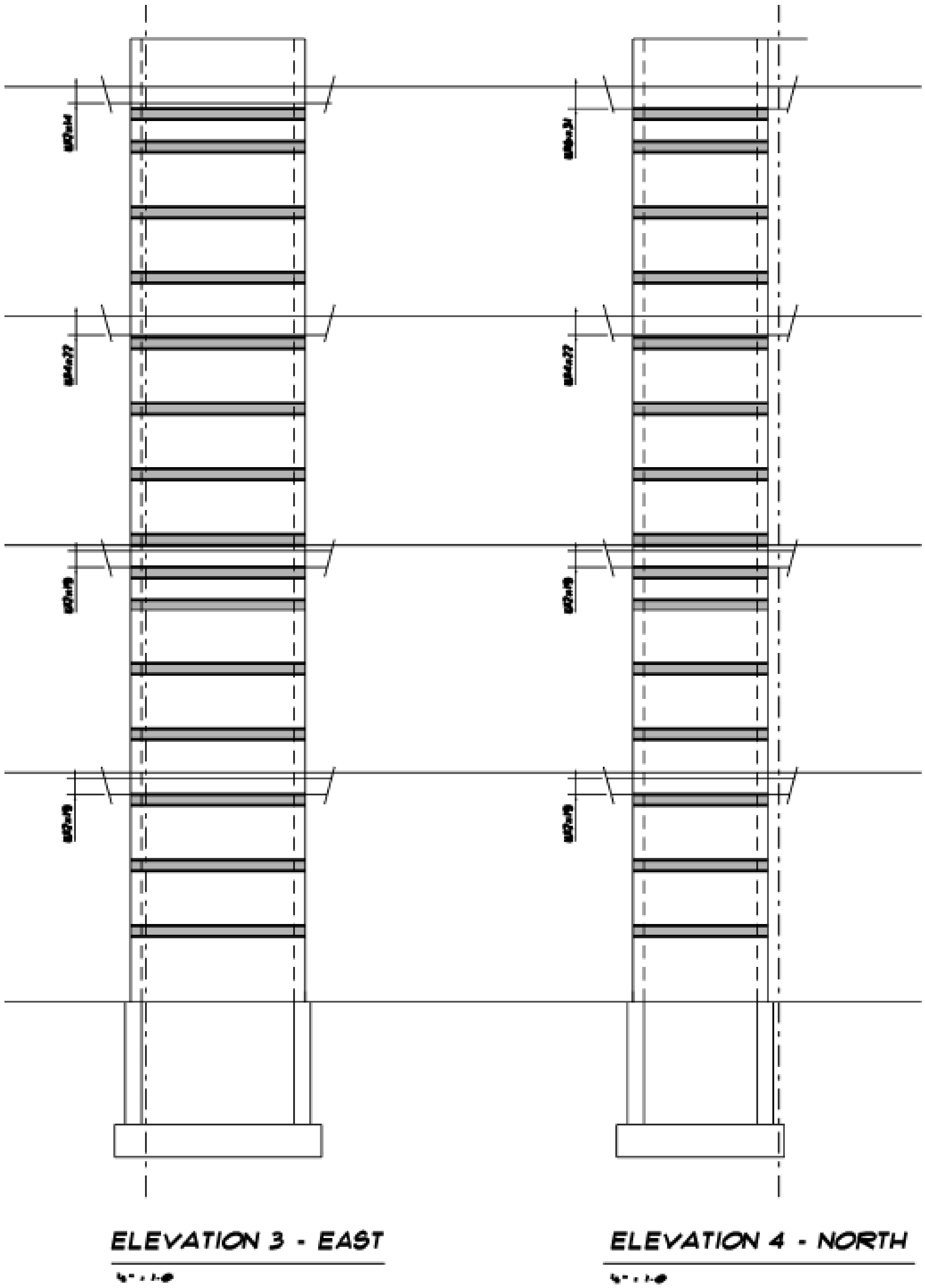
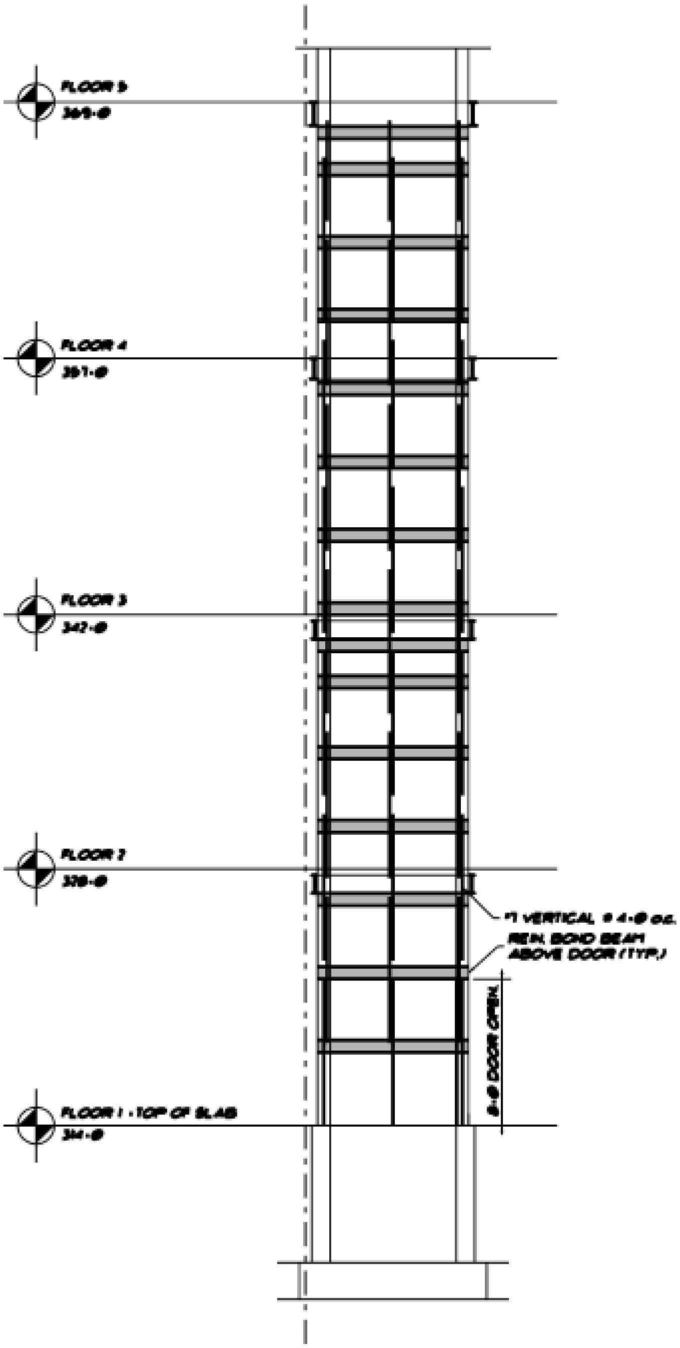


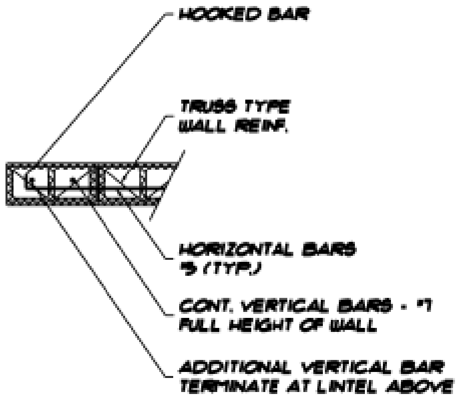
Figure 42 - Another 2D drawing of east and west direction of elevator CMU shaft



SECTION 1

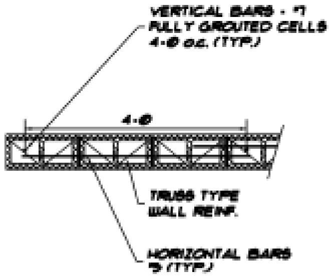
1/4" = 1'-0

Figure 43 - 2D drawing section of east and west direction of elevator CMU shaft



DETAIL C - END CONDITION (TYP.)

¾" = 1-0



DETAIL B - CMU WALL (TYP.)

¾" = 1-0

Figure 44 - 2D detail drawings of CMU walls

5.0 Construction Planning and Cost Estimating

Although structural design is essential to any project, construction planning and cost estimating is the most important phase of any construction project. Construction planning is a part of project management including scheduling and cost estimating. It takes into account resources and methods to ensure that when the project is started it can be completed on time and on budget. This provides the construction management firm the information it needs to define their client's expectations and potential satisfaction. Although construction usually follows design, many projects in today's industry incorporate contractors in the early stages in order to determine the design's constructability.

5.1 Construction Planning and Cost Estimating Methods

Cost estimating and scheduling must be assembled, evaluated, documented, and managed in an organized manner, and for contractors to work effectively, key information must be defined and accumulated at critical times. The process for this renovation began by first understanding the scope and then determining the methods of construction and the most essential items for the project's completion. Then two 3D BIM Models were created, one for the existing structure and one for the new structure. These showed the designed changes clearly, which in turn helped to create a realistic time frame. Next was creating a schedule and determining the relationships between the work activities. The sequential order of these planned activities, assigning realistic durations to each activity, and determining the start and finish dates for each activity was not only crucial for planning the completion of this project, but useful to WPI in their scheduling and planning processes. Lastly, and based on the level of scope definition, was deciding on which type of cost estimate would be possible to prepare. Additionally, proper site planning must be practiced in order to ensure adequate space is allocated for material deliveries and heavy construction equipment such as cranes. For this project, the main concerns for the construction planning were integrating this renovation within the functionality of WPI's campus while keeping the students safe.

5.1.1 Scheduling

The first step in the scheduling process was developing a work breakdown structure (WBS) that identified all the work items that must be completed to renovate Alumni Gymnasium. With the use of BIM, these activities were defined as the model portrayed which undertakings would need to take place first. Activities that required the most time and cost, such as demolition, erection of steel framing, and site logistics were considered the most critical to determine the project's on-time completion. Then activities were arranged according to Construction Specifications Institute (CSI) Masterformat divisions. Then the inter-relationships among them were established. Using the post-2004 forty-eight CSI Master Format Divisions, a Work Breakdown Structure (WBS) was established and the schedule was organized by "General Requirements", "Site Construction", "Concrete", "Masonry", "Metals", "Thermal and Moisture Protection", "Doors and Windows", "Finishes", "Equipment", "Special Construction", "Conveying Systems", "Mechanical", "Electrical", and "Existing Conditions" These divisions helped arrange the project's schedule in an efficient and productive way that allowed the costs and activities to be easily tracked as shown in summarized fashion in Figure 45 below.

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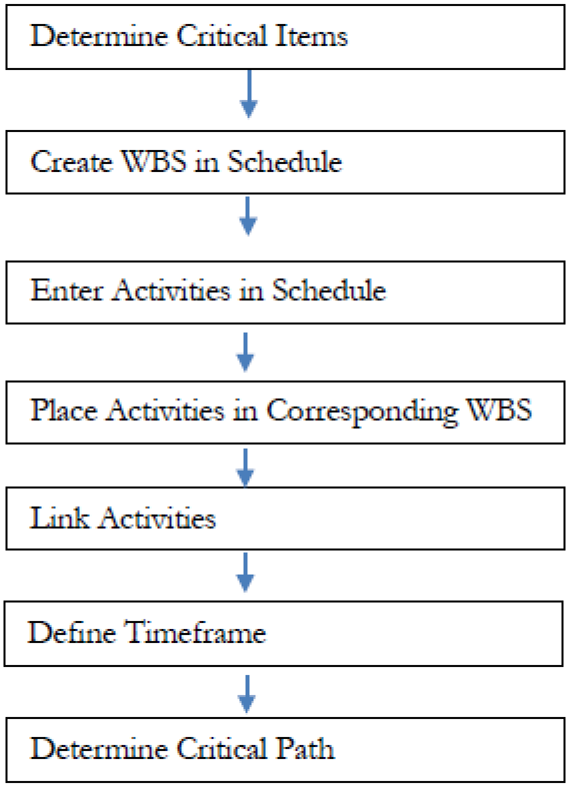

Figure 41 - Scheduling Process

The next step was the use of *Primavera* or Project Scheduling software in preparing a network diagram that showed each activity in the order it must be performed to complete the project. After deciding which items were critical to the renovation, consideration was given to identify which activities would immediately precede each other and which activities should immediately succeed each other. These predecessors assisted in identifying the critical path for the project and the relationships between activities and among activities classified in different WBSs. The connections of all these activities were both a combination of how the work should be done (technical constraints) and how the project team envisioned the work to be done. Since the project team knew that the demolition and steel frame installation were very time sensitive; items that preceded them were considered critical as well. Site logistics were also crucial to the success of the project as to not jeopardize the lives of students as well as to not hinder any campus activities.

Using personal "field experiences" information from previous construction work was utilized to estimate the duration for most of the tasks. This information gave a good idea of how long most other activities would take based on the relationship with their predecessors and successors. For example, in order to install the steel frame, access holes need to be cut in the floor prior to steel installation so this resulted in the access holes being a critical path item. Although linking the activities were based on scope, productivity rates and quantities were taken into account as well to verify the timeframe. Subsequently, the time required to complete each activity was checked by reviewing the work packages. Then the final schedule was created with start, finish, and float times, and the critical path was determined.

5.1.2 Cost Estimating

In order to evaluate the feasibility of the structural designs, the project team first standardized the cost preparation process with the use of *R.S. Means Construction Building Cost Data,* (2013 Edition), the *2014 National Construction Estimator, and R.S. Means Square Footage Costs* (2013 Edition). From an interview with Alfredo DiMauro, WPI Assistant Vice President for Facilities [5], the total construction budget for this project was estimated to be $10-$12 million. Utilizing the newly created BIM Model, quantification of the amount of types of columns, beams, and walls was generated in the form of tabular schedules. These schedules were exported to *Microsoft Excel* and the quantity take-off process was performed. The tabs in *Microsoft Excel* file were labeled "Demolition", "Site", "Structural Components", and "Square Footage". This organization allowed unit pricing costs for each structural item, using the *R.S. Means Construction Building Cost Data. R.S. Means Square Footage Costs* (2013 Edition) was used for items that were considered to be "out of the scope of work" for the design efforts in the MQP, such as the Mechanical, Electrical and Plumbing work. After determining the above costs from the schedule, *2014 National Construction Estimato*r was used for the site estimates as well as the demolition estimates. This not only helped compute an approximate final estimation, but enabled the contribution of each CSI Division to the overall cost. Appendix M breaks down these costs into individual work items.

The project team already knew from the initial site tours that there will need to be numerous changes made to the building to bring it into compliance with the current building code. The building currently doesn’t have appropriate lateral support for seismic conditions, as described in the previous sections, so determining the cost of the steel frame and time spent on addressing this deficiency was critical in computing the estimate of the cost. The collection of data and corresponding cost analysis was based on the level of detail shown on the current drawings and documentation of Alumni Gymnasium as possible, and cost calculations were computed using *Microsoft Excel* Spreadsheets.

5.1.3 BIM as a Tool for Construction Planning

The use of BIM tools and techniques for the creation of 4D (3D plus time) and 5D (4D plus cost) models is useful to any construction project. The project team utilized this by first creating two BIM models using Autodesk *Revit* software for Alumni Gym: an existing model and the new proposed model. From these models, tabular quantity schedules for the columns, beams, and walls were created for quantity take offs. After this, the BIM model was imported into Autodesk *Navisworks* and linked with the schedule originally generated using Project Scheduling software. This allowed the link between digital building objects with tasks cost and time durations thus generating the 5D model.

5.1.4 BIM as a Tool for Cost Estimation

Throughout the design, the project team was able to determine the materials that would be needed in the construction of Alumni Gymnasium. With the development of our BIM model, consideration of alternatives for the proposed renovation was easier as with every new alternative a new schedule of beams, columns, and walls were created. These helped the project team determine which design would be most cost effective and kept the project realistic and feasible.

5.1.5 BIM as a Tool for Scheduling

From the creation of the BIM model, a phased schedule for construction was created using the "Phases" function. Since two *Revit* models were created, these phases enabled the construction to be viewed in real time. The existing model only had one phase and that was "Demolition". The new model had 8 phases and they included all the new proposed elements such as: "Shear Wall", "Piers", "Elevator Shaft", "Steel Frame- Front", "Steel Frame-Right", "Steel Frame-Rear", and "Steel Frame-Left". Then, using *Navisworks,* the existing model and new proposed model were linked in *Navisworks* with the *Primavera* schedule. Sets were created and connected to their appropriate work activities. *Navisworks* then used the phases from *Revit* to create a simulation which moved along the schedule linking the activities to the model.

5.2 Construction Planning and Cost Estimating Results

The construction of Alumni Gymnasium was scheduled to begin in November of 2014 as stated earlier from an interview with Mr. DiMauro. Alumni Gym has a solid exterior shell, but in order for it to become the new "Innovation and Solution Center" this building must be gutted out in the sense of removing almost all non-loadbearing walls, floors, and ceilings. Using the CSI Masterformat divisions, a list of over 100 work activities were compiled that were essential to the new renovation of Alumni Gymnasium and its proper completion. After a final pre-construction inspection of the existing building by the winning bid contractor, interior demolition must occur first. This includes removing partition walls, staircases, and any other furnishings. Temporary items and supports must then be implemented during demolition as well to remove the staircases. Finally, structural materials must be fabricated and installed to bring the building up to the current building codes. Although Alumni Gym has been around for almost a century, there were still seismic improvements that Alumni Gym had to meet for building code compliance. The addition of a steel framing system addressed this need. These improvements also included the addition of an elevator which required excavation for footings and the construction of an elevator shaft as shown by Goody Clancy's Architectural Program. The steel framing system, elevator, and footings alone were time and cost consuming. Figure 46 below shows the sequences of the major construction items that a contractor must follow to complete Alumni Gym on time and on budget. This flowchart does not include information for MEP since this work was out of the scope of the project.

Since the demolition of the connector for Alumni/ Harrington was planned for December of 2014, all of the demolition of Alumni Gymnasium must be completed before that time. If not, site logistics and deliveries could be negatively impacted. These site logistics were an important part of the Alumni renovation as WPI is a very active campus and construction will continue even when classes are still in session. Also, the location of Alumni poses a concern since it is located in the center of campus with a tight perimeter and heavily trafficked walking paths. This concluded that having accessible delivery and storage areas was critical in the project's implementation.

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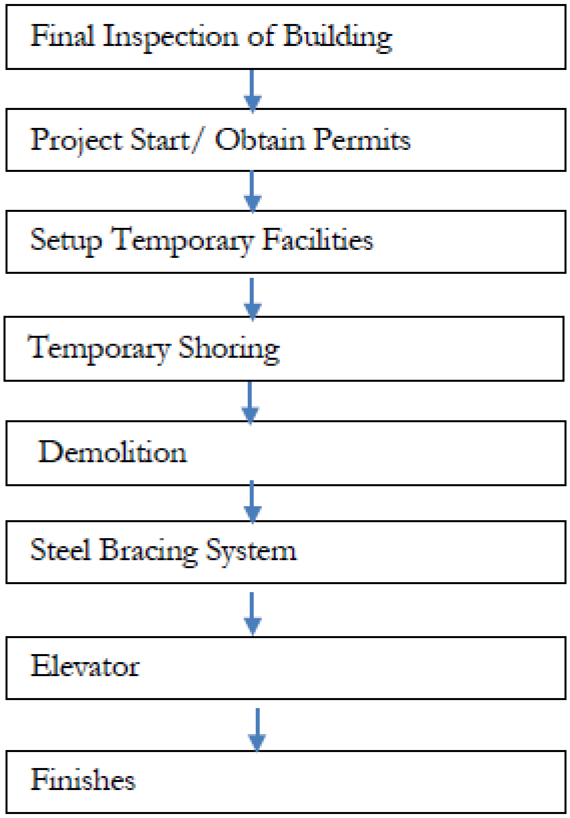

Figure 42 - Construction Flowchart

Demolition will be a major phase of this building and designing temporary supports was crucial to avoid disturbing the structural integrity of the building. Through discussion with WPI Facilities Department and a study of the proposed architectural plans, it was determined that the building connection between Harrington and Alumni Gym will be demolished as well as the removal of portions of the concrete slab and staircases on Level 3 to create an opening in the floor. Therefore, temporary supports for this phase of the project included staging with Laminated Veneer Lumber (LVL) wood beams to maintain the structural integrity of the building. Demolition to parts of a building this old must be handled carefully because predictions cannot be made to what will happen if walls were to be removed. Designing supports to ensure that nothing catastrophic occurs was important not only for the building, but for the safety of the contractor that will be performing the work. Methods for temporary supports were discussed but a sizing of shoring members was not addressed.

5.2.1 Site Plan and Logistics

For the site plan and logistics of the renovation of Alumni Gymnasium there was the concern of the storage of materials and equipment due to a lack of space on the perimeter of the building. After an interview with Alfredo DiMauro, the Assistant Vice President of Facilities (See Appendix A), it was decided that the space behind Harrington Auditorium would be the best place for any heavy equipment and materials to be stored. This area shown in Figure 47, additionally, must be fenced off to prevent injury and trespassing.

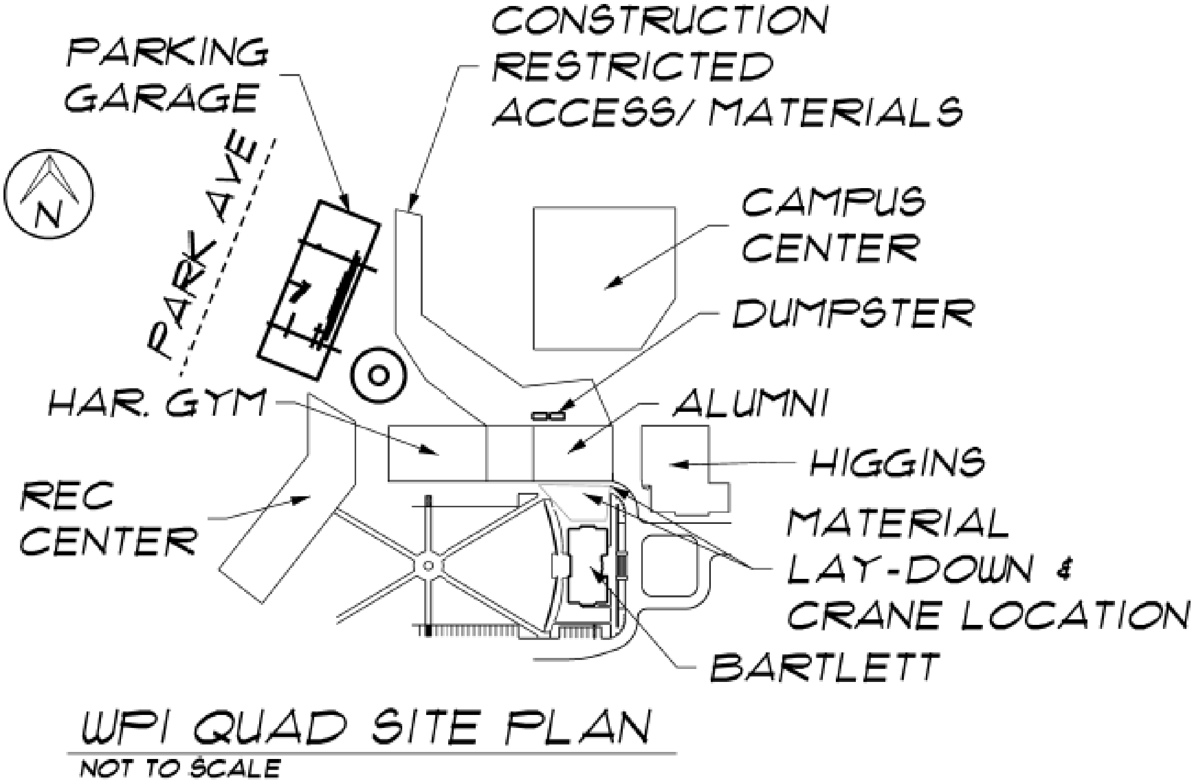

Figure 43- Site Plan

The area in front of Alumni/ Harrington connection (Bartlett Center Parking Lot) will be used for materials storage and/or the position of the job trailer, as to block student traffic completely between the Bartlett Center and Alumni. Second, the walkway on the East Side between Alumni and Higgins should only be closed temporarily for exterior work to be done. An ideal situation would be to perform this work activity when campus is not busy. Although winter break might seem like a good time, exterior work uses scaffolding so the weather in Worcester would not make this safe or cost efficient. A good time to propose for executing this activity as well as the cutting in the access holes for the steel frame would be during the spring break in March 2015. There must be fencing around North and South Side of Alumni at all times. This should extend beyond the building's footprint only as far as necessary to allow for staging (about 10-15 feet).

The best place for deliveries will be to the rear of building. This area is currently fenced off so this protective fencing, which is behind Harrington, must be removed to create a roadway for truck access. The trucks will access this point of the site from the existing road next to the parking garage which is accessed from Park Avenue and Salisbury Street. This area may also have to be excavated and brought to an appropriate grade to ensure safe delivery since the incline is currently steep. If this area is designated for deliveries, a benefit would be that pedestrian traffic in front of the building will not be disturbed and public safety would be less of a concern. Since the pedestrian traffic behind Harrington and in Recreation Center roundabout is not as heavy in the winter as the fields are shut down, important deliveries should be scheduled for that time. Also, it is essential that there is proper procurement for materials to avoid delays as well an influx of material on a job site that already has limited space.

The demolition of the Harrington-Alumni Connection is planned for the fall of 2015 which means that there will be interior demolition going on during the school year. This may cause an issue with the number of dumpsters and their location on campus. The use of only two or three dumpsters at a time in front of Alumni (depending on yardage) is proposed; this will allow more room for pickups and drop-off. Once most of the debris is discarded, a reduction in the number of dumpsters is expected so only one or two should be placed in that location. This will save the construction manager space as well as money during the other phases of project. Since debris will be removed from the back of Alumni for this demolition, fencing-off of the walkway to the Campus Center is advised so as to allow maximum space for all the debris removal.

Since the steel framing system entails the use of a crane, the two optimal places would be either in the area behind Alumni or in the Bartlett Center Parking Lot. A movable crane with either wheels or tracks would be convenient as the framing would have to be delivered to different parts of Alumni, and the crane could be easily moved off site when the framing is complete.

5.2.2 Cost Estimates

With the use of *R.S. Means Construction Building Cost Data,* (2013 Edition), the *2014 National Construction Estimator, and* R.S. *Means Square Footage Costs* (2013 Edition) a construction cost estimate of about $6.7 million dollars was generated. This may seem low given that the project budget is between $10-$12 million. However, after adding in the location factor with the cost of 10% overhead, 10% design fees, and a 10% profit to the total price, the cost was calculated to be $9.8 million. A detailed breakdown for these cost items is provided in Appendix L as well as a summary table shown below in Table 3. This was a more realistic price as contractors bidding this job will most likely want to estimate as low as possible. The highest cost for the estimate came from the "Mechanical" WBS with a cost of about $1.9 million. The second highest was the "Conveying System" (which includes the elevator shaft) at $1 million, with "Demolition" of Alumni Gym costing about $ 0.5million. Although, the "Structural Components" did cost about $200 thousand, they were not a major expense for this project since light weight solutions were made for beams and columns in the framing system as well as for the open web steel joists in the pool slab. The scope of the site cost did not include fill for the access road, but it was focused on utility upgrades and landscaping which were more essential to the completion of the project.

Table 3: Summary Table of Project Cost

Section	Cost
Demolition	$ 2,363,374.00
Square Foot	$ 3,611,285.52
Structural Assemblies	$ 172,155.71
Site	$ 607,699.42
Total Construction Cost	$ 6,754,514.65
Liability Insurance for One year is .24% of Construction Cost	$ 16,437.18
Permits $11 Per $1000 of Construction Cost	$ 75,337.08
10% Design Cost	$ 684,882.57
10% Overhead	$ 684,882.57
10% Profit	$ 684,882.57
Location Factor	1.1
Alumni Gym Total Cost of Completion	$ 9,791,030.28

5.2.3 Schedule

The project duration was calculated based on a start date of 11/10/14 using *Primavera* software. The estimated duration result was 255 working days (about 12 months) which means that this project would be completed by 10/30/15. Since the renovation to Alumni is intended to be completed by the 150th Anniversary of WPI in November of 2015, this schedule would be feasible in comparison to the benchmark provided by WPI and Goody Clancy. The critical path is shown in network form in Table 4 below. It moves along the CSI divisions by month and details the event that will be most time sensitive to this project. The critical path chart is shown in Tabular form in Table 5 below. It identifies demolition and the installation of the new steel frame to be the most critical items. Although many of the other elements of the project, such as the pool slab design and the installation of a new elevator were essential to Alumni's completion, the steel frame was the most critical to complete. The cost for just the critical path activities is also shown and it is about $2 million. Table 6 below shows a summarized schedule by WBS category with the time of each CSI division and at which dates they will be completed and their corresponding budgeted costs. This chart is vital because it provides the construction management team a viable means to divide the work between the different trades that will be on the project at the same time.

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Table 4: Critical Path By Month

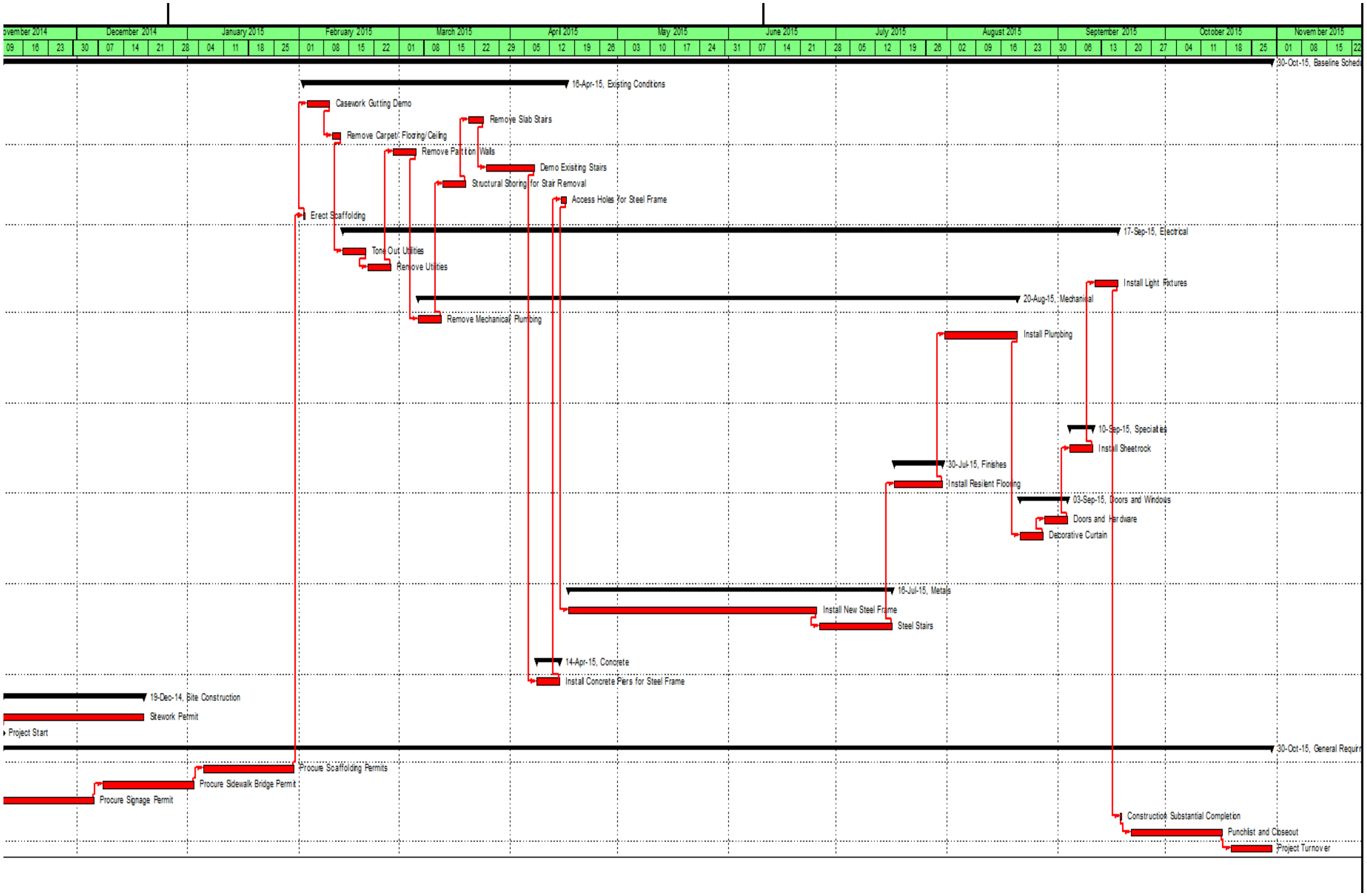
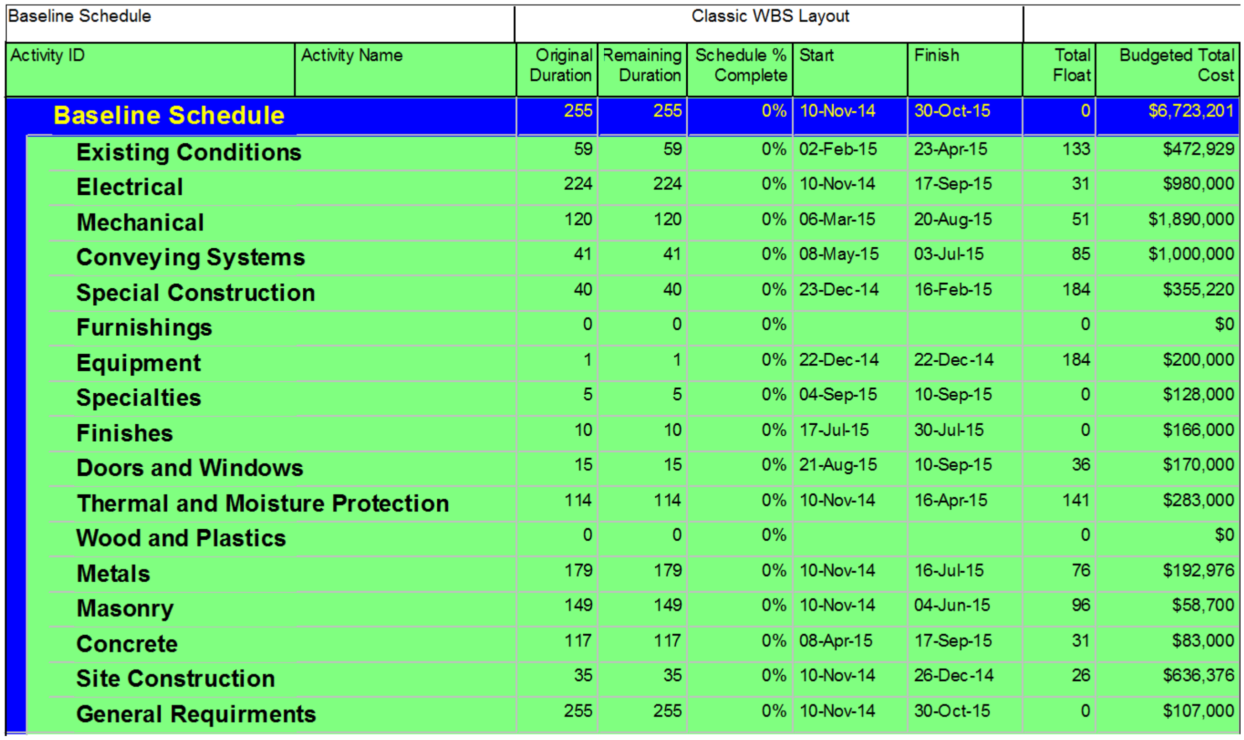


Table 5: Critical Path Activities with WBS and Costs

Baseline Schedule				Classic WBS Layout					
Activity ID	Activity Name	Original Duration	Remaining Duration	Schedule % Complete	Start	Finish	Total Float	Budgeted Total Cost	No
Baseline Schedule		255	255	0%	10-Nov-14	30-Oct-15	0	$1,907,773	
Existing Conditions		54	54	0%	02-Feb-15	16-Apr-15	0	$452,929	
CN 9	Erect Scaffolding	1	1	0%	02-Feb-15	02-Feb-15	0	$1,432	
BD 10	Casework Gutting Demo	5	5	0%	03-Feb-15	09-Feb-15	0	$246,636	
BD 3	Remove Carpet/ Flooring/Ce	3	3	0%	10-Feb-15	12-Feb-15	0	$40,000	
BD 6	Remove Partition Walls	5	5	0%	27-Feb-15	05-Mar-15	0	$80,000	
BD 9	Structural Shoring for Stair R	5	5	0%	13-Mar-15	19-Mar-15	0	$861	
BD 2	Remove Slab Stairs	3	3	0%	20-Mar-15	24-Mar-15	0	$69,000	
BD 8	Demo Exisiting Stairs	10	10	0%	25-Mar-15	07-Apr-15	0	$8,000	
CN 28	Access Holes for Steel Fran	2	2	0%	15-Apr-15	16-Apr-15	0	$7,000	
Electrical		155	155	0%	13-Feb-15	17-Sep-15	0	$420,000	
BD 15	Tone Out Utilities	5	5	0%	13-Feb-15	19-Feb-15	0	$140,000	
BD 5**	Remove Utilities	5	5	0%	20-Feb-15	26-Feb-15	0	$140,000	
CN 19	Install Light Fixtures	5	5	0%	11-Sep-15	17-Sep-15	0	$140,000	
Mechanical		120	120	0%	06-Mar-15	20-Aug-15	0	$420,000	
BD 7***	Remove Mechanical/ Plumb	5	5	0%	06-Mar-15	12-Mar-15	0	$210,000	
CN 20	Install Plumbing	15	15	0%	31-Jul-15	20-Aug-15	0	$210,000	
Conveying Systems		0	0	0%			0	$0	
Special Construction		0	0	0%			0	$0	
Furnishings		0	0	0%			0	$0	
Equipment		0	0	0%			0	$0	
Specialties		5	5	0%	04-Sep-15	10-Sep-15	0	$128,000	
CN 23	Install Sheetrock	5	5	0%	04-Sep-15	10-Sep-15	0	$128,000	
Finishes		10	10	0%	17-Jul-15	30-Jul-15	0	$166,000	
CN 22	Install Resilent Flooring	10	10	0%	17-Jul-15	30-Jul-15	0	$166,000	
Doors and Windows		10	10	0%	21-Aug-15	03-Sep-15	0	$90,000	
FAB 15	Decorative Curtain	5	5	0%	21-Aug-15	27-Aug-15	0	$30,000	
FAB 10	Doors and Hardware	5	5	0%	28-Aug-15	03-Sep-15	0	$60,000	
Thermal and Moisture Prot		0	0	0%			0	$0	
Wood and Plastics		0	0	0%			0	$0	

Table 6: CSI Timescale with Costs



Baseline Schedule		Classic WBS Layout						
Activity ID	Activity Name	Original Duration	Remaining Duration	Schedule % Complete	Start	Finish	Total Float	Budgeted Total Cost
Baseline Schedule		255	255	0%	10-Nov-14	30-Oct-15	0	$6,723,201
Existing Conditions		59	59	0%	02-Feb-15	23-Apr-15	133	$472,929
Electrical		224	224	0%	10-Nov-14	17-Sep-15	31	$980,000
Mechanical		120	120	0%	06-Mar-15	20-Aug-15	51	$1,890,000
Conveying Systems		41	41	0%	08-May-15	03-Jul-15	85	$1,000,000
Special Construction		40	40	0%	23-Dec-14	16-Feb-15	184	$355,220
Furnishings		0	0	0%			0	$0
Equipment		1	1	0%	22-Dec-14	22-Dec-14	184	$200,000
Specialties		5	5	0%	04-Sep-15	10-Sep-15	0	$128,000
Finishes		10	10	0%	17-Jul-15	30-Jul-15	0	$166,000
Doors and Windows		15	15	0%	21-Aug-15	10-Sep-15	36	$170,000
Thermal and Moisture Protection		114	114	0%	10-Nov-14	16-Apr-15	141	$283,000
Wood and Plastics		0	0	0%			0	$0
Metals		179	179	0%	10-Nov-14	16-Jul-15	76	$192,976
Masonry		149	149	0%	10-Nov-14	04-Jun-15	96	$58,700
Concrete		117	117	0%	08-Apr-15	17-Sep-15	31	$83,000
Site Construction		35	35	0%	10-Nov-14	26-Dec-14	26	$636,376
General Requirments		255	255	0%	10-Nov-14	30-Oct-15	0	$107,000

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5.2.4 BIM – New Model and 5D integration

The result of the 5D Model was a success. Due to software limitations the Project Management schedule created with *Primavera* software had to be exported to *Microsoft Project* in order to be integrated into *Navisworks*. Although this had some limitations, the simulation was completed without any problems. Figure 48 below shows the simulation of the demolition of the concrete slab and the stairs on Levels 3 to 4. Figure 49 below shows the installation of the new steel framing system throughout the building as well. Lastly, in Figure 50 the installation of the pool web joists and concrete pedestals are shown. The 5D model, which was the result of integrating the BIM model, the spreadsheet cost estimate, and the Project Scheduling file, shows what the actual construction of Alumni will look like in the near future, the schedule of work activities, and how much it will all cost to complete. This 5D model contributes to the concept of Earned Value Analysis, shown in Figure 51, which allows the contractor to measure the project's process at any point in time, forecasting its completion date and budget as work proceeds.

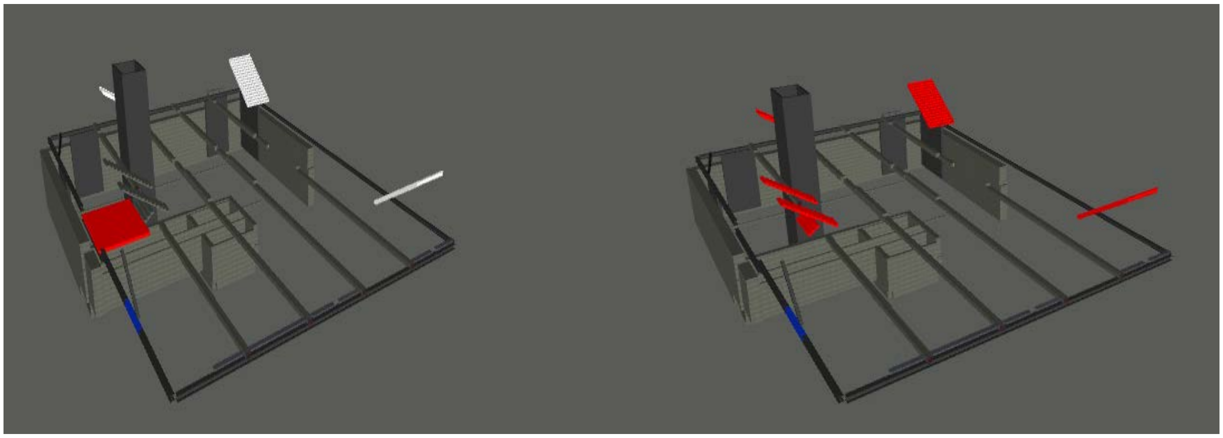


Figure 44 - Demolition of Slab (Left) and Stairs (Right)

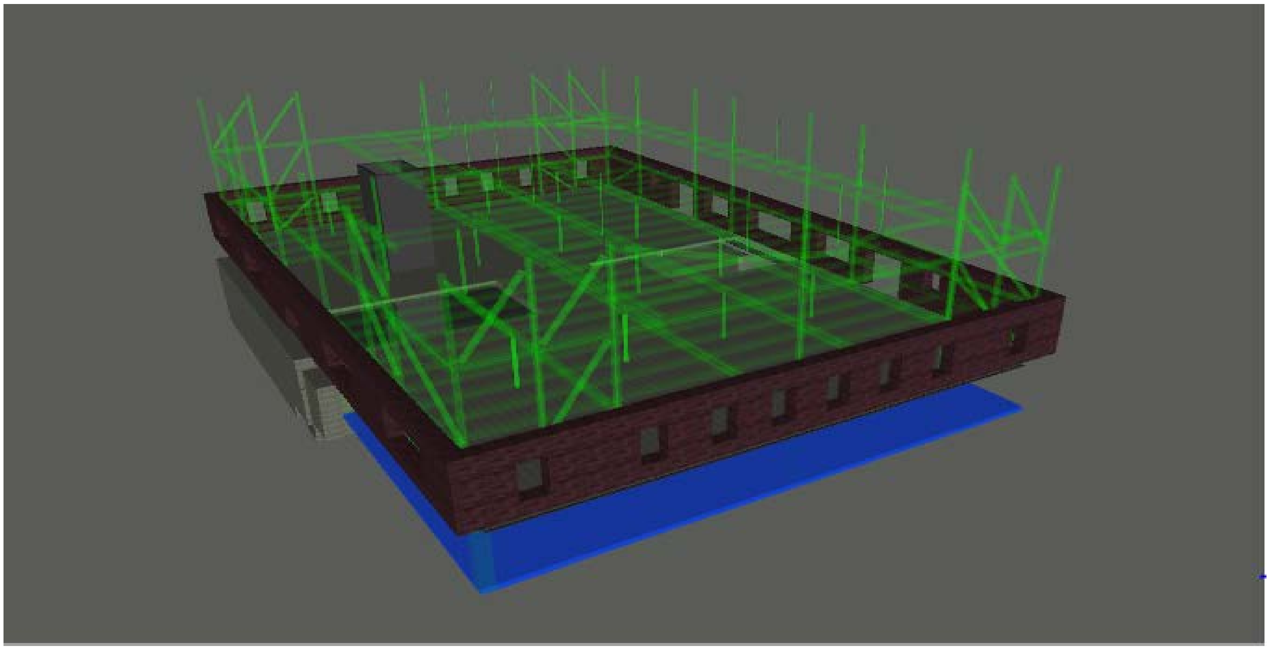


Figure 45 - New Steel Framing System

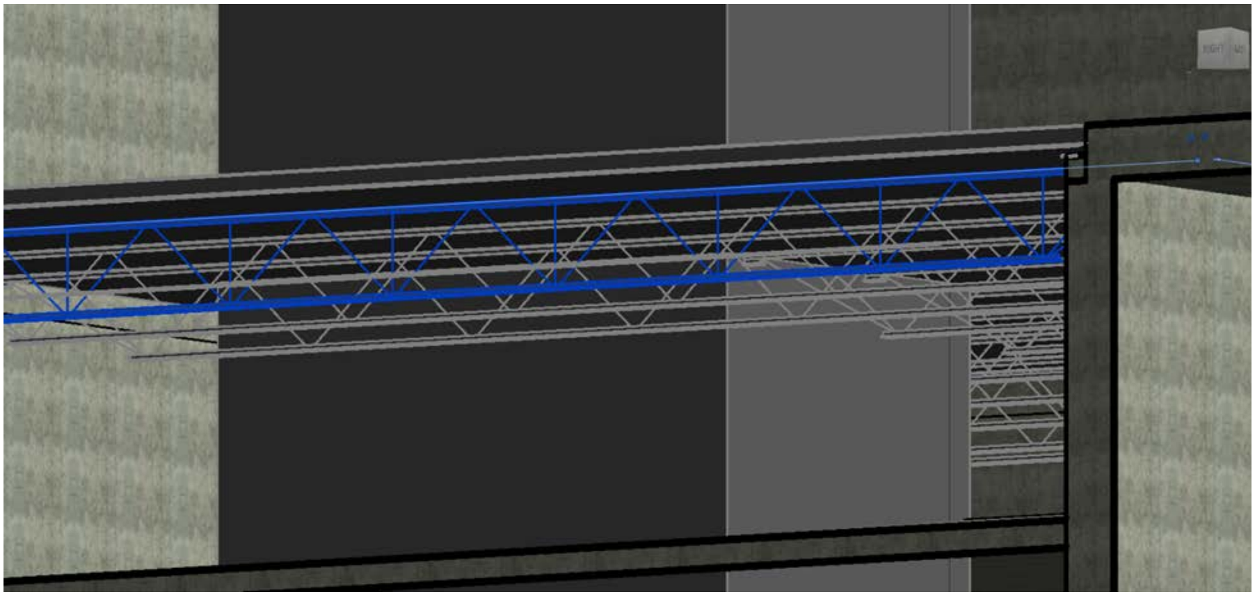
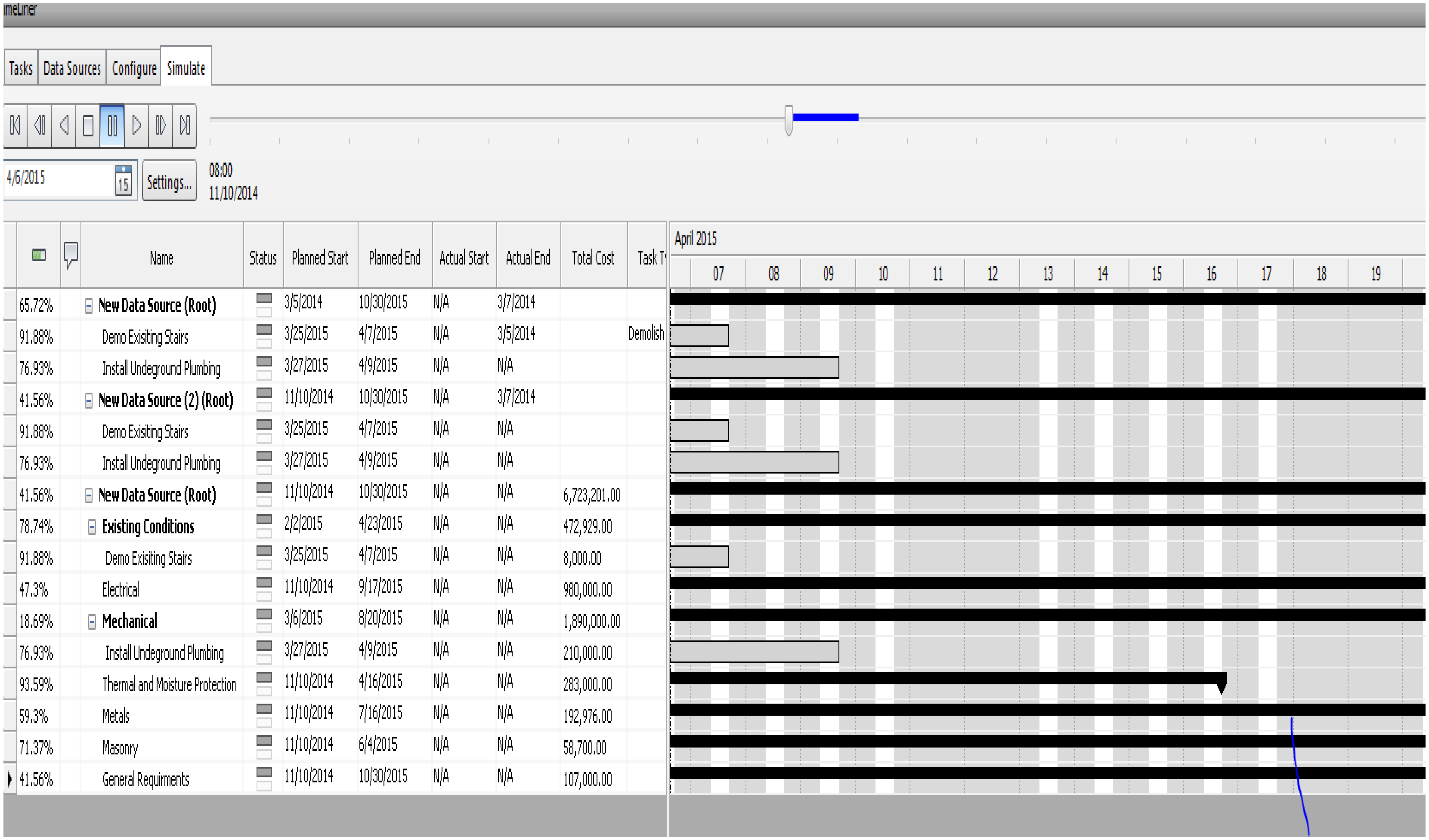


Figure 46 - Open Steel Web Joists at Pool Level



4/6/2015

08:00
11/10/2014

		Name	Status	Planned Start	Planned End	Actual Start	Actual End	Total Cost	Task T
65.72%		⊟ **New Data Source (Root)**		3/5/2014	10/30/2015	N/A	3/7/2014		
91.88%		Demo Exisiting Stairs		3/25/2015	4/7/2015	N/A	3/5/2014		Demolish
76.93%		Install Undeground Plumbing		3/27/2015	4/9/2015	N/A	N/A		
41.56%		⊟ **New Data Source (2) (Root)**		11/10/2014	10/30/2015	N/A	3/7/2014		
91.88%		Demo Exisiting Stairs		3/25/2015	4/7/2015	N/A	N/A		
76.93%		Install Undeground Plumbing		3/27/2015	4/9/2015	N/A	N/A		
41.56%		⊟ **New Data Source (Root)**		11/10/2014	10/30/2015	N/A	N/A	6,723,201.00	
78.74%		⊟ **Existing Conditions**		2/2/2015	4/23/2015	N/A	N/A	472,929.00	
91.88%		Demo Exisiting Stairs		3/25/2015	4/7/2015	N/A	N/A	8,000.00	
47.3%		Electrical		11/10/2014	9/17/2015	N/A	N/A	980,000.00	
18.69%		⊟ **Mechanical**		3/6/2015	8/20/2015	N/A	N/A	1,890,000.00	
76.93%		Install Undeground Plumbing		3/27/2015	4/9/2015	N/A	N/A	210,000.00	
93.59%		Thermal and Moisture Protection		11/10/2014	4/16/2015	N/A	N/A	283,000.00	
59.3%		Metals		11/10/2014	7/16/2015	N/A	N/A	192,976.00	
71.37%		Masonry		11/10/2014	6/4/2015	N/A	N/A	58,700.00	
41.56%		General Requirments		11/10/2014	10/30/2015	N/A	N/A	107,000.00	

Figure 47 - Earned Value Analysis for April 6th, 2015

6.0 Conclusions and Recommendations

The main objective of this project was to design and plan for the renovation of a historical building project. This project provides value to WPI for the actual project because structural solutions were developed, cost and schedule were analyzed, and documentation of the existing structure was performed. The sequence of work and recommendations for expansion of this project are discussed.

6.1 Sequence of Work

The work for this project included multiple phases that were supported by Building Information Modeling tools and techniques. The phases of this project were:

- Existing building documentation
- Existing building structural analysis and building code compliance check
- Identification of modifications for new layout and major areas of renovation
- Development of structural designs to satisfy new layout and building code requirements
- Preparation of construction schedule and cost estimate with time and budget constraints

With BIM authoring tools and techniques all phases of this project were performed in a central model and linked with the schedule and associated cost to develop a 5D model displaying all major structural changes to Alumni Gymnasium. The 5D model allowed the visualization of the construction phase before it takes place in order to identify any changes that might be made to the schedule as well as gain a further understanding of the cost associated with each phase of the project. Initially, documentation of the existing conditions of Alumni was gathered in order to develop a 3D BIM Structural model of the existing structure in order to gain an understanding of the existing structure. This was done through research in the "WPI Archives and Special and Special Collection Department", interviews with and site tours led by WPI Facilities Department Management, and verification of information on original plans in the field. Once the overall structural system was identified, the model was created to gain a further understanding of the structural framing at each Level. The structural system of Alumni is a combination of different systems and materials that included steel, concrete, brick, and wood. Once these systems and materials were identified, a structural analysis of these elements was performed to investigate building code compliance.

The structural analysis performed for this project was an investigation of all major elements that comprised the structure of the building, but it was limited to those that could also be accessed and measured. For example, the pool framing at Level 2 is made up of a concrete beam and column system that could not be fully investigated due to lack of accessibility to measure the members and check the reinforcing. Therefore, these elements were not investigated and are omitted from this report. However, the framing for the other Levels of the structure were analyzed for gravity and lateral loads. Gravity loads that were identified were dead, live, and snow loads; lateral loads were wind and seismic in accordance with *IBC 2009 (ASCE 7-05).* Along with investigating the structural elements of the building individually, the overall structure was analyzed to measure its capacity against seismic forces. This was necessary because it was found that the unreinforced masonry did not have sufficient capacity to resist the seismic load and was out of compliance with building codes. The rest of the structure, however, met current building code requirements and therefore no further reinforcing would be needed for these elements.

Alongside this analysis, identification of the major areas of renovation for the new, proposed layout by Goody Clancy was conducted. This was done using the results of the structural analysis that indicated a seismic upgrade was necessary as well as through study of architectural renderings in *Sketchup* provided by Goody Clancy. These renderings outlined the changes in the use of space that would take place in the renovation of Alumni. Ultimately, the major areas of renovation were identified as follows:

- Seismic upgrade of the existing structure
- Shear Wall System for Showcase Atrium on Level 3
- An elevated slab over the pool opening for a Robotics Pit
- An elevator shaft for accessibility

After identification of these major areas, design development began in order to provide solutions.

Design development was a critical phase in this project because alternatives had to be explored to determine the solution that would best integrate into the existing structure and also have acceptable schedule and cost implications. It was concluded that a structural steel frame would provide the simplest system for a seismic upgrade compared to reinforcing the existing brick and mortar exterior walls. This would satisfy building code requirements for seismic considerations. The development of the other designs as mentioned above were based off the proposed layout. The use of BIM was an integral part of this process because these designs were included in the 3D model which provided a visualization tool to understand how the various systems could be introduced into the building. For example, the steel frame system that was defined within the inside perimeter of the brick walls was oriented so that its elements were not visible through windows or openings. Once completed in the 3D BIM model, the frame was analyzed using *Visual Analysis* software to resize the members with the new orientation. Using these designs, the construction phase of the renovation was developed further to include the construction schedule and cost estimate.

The cost estimate and schedule had to be prepared with the constraints of time and cost due to the proposed budget and schedule established by WPI. A budget of $10-12 million and 20 month construction schedule were initially estimated for this renovation. The end date was already established to account for the 150th anniversary celebration of WPI's founding. With this in mind, a list of work activities was defined and sequenced to create the schedule, and costs were added to each item. This information was then linked to the 3D BIM model using *Navisworks* software to develop a 5D model that phases the major activities for structural changes. Architectural information was not modeled for the most part nor was it linked between the model and schedule. This information can be further developed using the model that was prepared as part of this MQP.

6.2 Recommendations for Alumni Gymnasium Renovation and Future MQPs

Although the scope of this project encompassed structural analysis and design, Building Information Modeling, construction scheduling, and cost estimating, there is still much more that could be done to provide a full investigation of Alumni. BIM could be further utilized to include site planning or facility management. The current model can be further developed to include the Architectural layout that was proposed for the renovation. Mechanical, Electrical, and Plumbing (MEP) information for the existing systems can be modeled to gain an understanding of the existing conditions and the impacts of the planned much like modeling the existing structural layout. Additionally, for construction purposes, BIM tools and techniques can be used with this BIM model to track construction activities during the project as well as refine the cost estimate as the scope of work becomes more defined. Overall, there are many more BIM tools that can be utilized depending on how much detail is necessary or warranted for this renovation. BIM tools and techniques can be of great use for this project because of its visualization and communication capabilities. With a renovation project, it may be difficult to understand the extent of work and information must be constantly updated as this information becomes clearer. BIM provides a portal to perform these tasks effectively.

Another dimension that could be expanded upon is researching LEED alternatives as well as other alternative designs. LEED could play a major role in this renovation since much of the MEP is outdated and inefficient. A LEED study would identify these areas of concern so that LEED could be implemented as part of the renovation. A LEED study and implementation plan would follow the precedent set on the WPI campus by other newly constructed buildings like the New Sports and Recreation Center, East Hall, and Faraday Hall. However, Alumni would be unique since it would be a renovation that incorporated LEED rather than new construction. This would involve the use of BIM for building energy simulations of the existing building, defining the LEED criteria to be used for planning for LEED and providing useful information that would identify where LEED alternatives can be effectively integrated. This may have significant cost implications since the existing MEP systems must be removed or coordinated with new MEP elements to avoid clashes and properly upgrade the system. BIM could be useful in this application as well because of its clash detection capabilities and ability to model MEP equipment.

In terms of alternative designs, other structural systems could have been analyzed when developing a design for seismic upgrade. Carbon fiber polymer reinforcement is another material used besides steel for seismic reinforcement. Further investigation into the pros and cons of this system as compared to a steel frame would provide a more well-rounded approach to this design. This system was briefly discussed but no true analysis was done on the benefits of this system.

A significant amount of information was collected in this project, but with any project of this size, there are many more areas that could be further studied and explored that may provide more benefit to this project and improve upon the work done. The Alumni Gym "Innovation and

Solution Center" project will have a clear impact on the WPI campus and the attraction of the students to enroll in WPI. This project will not only expand on the WPI project-based curriculum, but it will give a building once the center of campus and rich in history a chance to serve its community once again.

Bibliography

1. Laramee, David C., and Benjamin Mies. *Renovating Alumni Gymnasium for Academic Purpose. Major Qualifying Project.* Worcester Polytechnic Institute, 23 Mar. 2007. Web. 20 Sept. 2013.
2. Mell, Eileen B. (2009). *WPI Trustees Vote to Proceed with Sports and Recreation Center.* WPI Press Release
3. Worcester, MA. *Charter, Laws and Ordinances of the City of Worcester, 1911.* Worcester, MA: The Blanchard Press, 1911.
4. *Guidelines for Renovating Historic Buildings.* The Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings. Web. 26 Sept. 2013.
5. Salter, Christopher. DiMauro, Alfredo Personnel Interview. 2 October, 2013
6. "Worcester Historical Commission Details." *Http://www.worcesterma.gov/boards.* Boards & Commissions | City of Worcester, MA. Web. 04 Oct. 2013.
7. Katz, Ashley. "About LEED." U.S. Green Building Council, 25 July 2012. Web. 14 Oct. 2013.
8. "LEED Rating Systems." *LEED Rating Systems.* U.S. Green Building Council, 25 July 2012. Web. 14 Oct. 2013.
9. "Building Information Modeling in Practice." *Http://www.ddscad.com.* Autodesk Building Solutions, 25 Feb. 2011. Web. 14 Oct. 2013.
10. Clancy, Goody. ""A Dynamic Expression of the WPI Plan"" Worcester Polytechnic Institute, 9 Sept. 2013. Web. 9 Sept. 2013.
11. Taylor, Herbert F. *Seventy Years of the Worcester Polytechnic Institute.* Worcester: December, 1937. Print.
12. Howard, Thomas W. "What Shall the New Gymnasium Do for Tech." *Journal of the Worcester Polytechnic Institute.* Vol. 19. 141-46. Print. 1915-1916.
13. WPI Journal, http://wpialumnimag.epubxp.com/i/211791/23 Pg.22
14. Autodesk. 2014. Products: URL<http://www.autodesk.com/products/autodesk-navisworks-family/overview>
15. MECA Products. Wind. URL<http://www.mecaenterprises.com/MecaWind.html>
16. MECA Products. Seismic. URL<http://www.mecaenterprises.com/MecaSeismic.html>
17. Visual Analysis. 2014 URL<http://www.iesweb.com/products/visualanalysis/>
18. Sketchup. 2014. URL<http://www.sketchup.com/>
19. CANAM.2014. URL<http://www.canam-steeljoists.ws/www/v4/epublica.nsf/va_download/510BE0CAEB44CD9D8525796B004D90E5/$File/eCtPout.pdf>
20. New Millenium. 2014. URL<http://www.newmill.com/pdfs/form-decking.pdf>
21. ASCE Code of Ethics. 2014. URL <http://www.asce.org/uploadedFiles/Ethics_-_New/Code%20of%20Ethics%20October%202010.pdf

Appendix A – MQP Proposal

2. 0 Background

Worcester Polytechnic Institute (WPI) has a long standing tradition in the New England area not only in academics, but in athletics as well. The development of WPI's rich athletic history came from the construction of Alumni Gymnasium in 1915. This building, up until the 2012 the completion of the new "Sports and Recreation Center", was the hub of all athletic activity for WPI. Currently, however, WPI wants to shift this building's use to academics by turning it into a Project Center with an estimated budget of $12 million and a timeframe scheduled to begin sometime in 2015 [5] .

2.1.1 History of Alumni Gymnasium

Alumni Gymnasium was the first gym to be built for the WPI community and was erected at the same time as Alumni Field. This building was placed near the center of campus and was to provide a home for the expansion of the WPI athletics program at that time. It was considered a state of the art facility as it had five-stories, three above ground and two below, including an underground pool. Interestingly enough, the pool wasn't completed until 1925, nearly 10 years after the completion of Alumni Gymnasium. This was because there was a debate about whether an ice rink should have been built in that area instead of the current pool [5].

Although Alumni Gymnasium today is considered an outdated facility, when it was built there were many features that made it a distinctive facility. The basement floor was equipped with a weight room and acted as the school's fitness center. This floor also contained a balcony that overlooks the underground pool in the sub-basement level where swim practices and meets were held. The first floor includes the main entrance as well as the locker rooms and offices of the physical education department. The second floor holds a basketball and two racquetball courts, which are on each side of the stairwells. The top floor, which is the third floor, features an indoor running track with another balcony overlooking the basketball court below.

After over fifty years of being the leader of the WPI athletics, the WPI community decided to update its facilities again. In 1965, construction of Harrington Auditorium began. This building was connected to Alumni Gymnasium in order to increase the convenience for student-athletes and included a new basketball court and seating for spectators. The need for this building was to keep up with the school's growing athletic program and to increase the amount of space for physical activity [1]. Continuing with this thread, the locker rooms were expanded in Harrington and a new fitness center was added in Alumni Gymnasium as well in the 1980's [5].

In May of 2010 construction of a new fully operational, state-of-the-art recreational facility began on Worcester Polytechnic Institute's campus in Worcester, MA. The $53 Million building featured a 29,000 square foot gymnasium, a natatorium containing a 25-meter competition swimming pool, rowing tanks, squash courts, robotics pits, 11,000 square feet of fitness space, and an additional 5,000 square feet of multipurpose rooms. The combination of a recent growth in student body population and the outdated athletic facilities currently offered at WPI made it apparent that a new, state-of-the art recreational facility would be required on campus to accommodate these needs. The completion of this facility in 2012 made it apparent that Alumni Gymnasium would no longer be needed as an athletic facility so the process to change it into something more beneficial to the WPI community began [2].

2.1.2 Structural Aspects

The design and construction of Alumni Gymnasium was completed by the guidelines of the *1911 Laws and Ordinances of the City of Worcester*. During the early 20th century, design and construction was performed by a "rule of thumb" and building codes were a collection of "good practices" [3] Buildings that were three stories tall, similar to Alumni Gymnasium, were required to have brick walls 16 inches thick for the basement and anything below as well as 12 inch thick walls for the first three floors above ground. The floors as prescribed in Section 31 of this code, state that when a public assembly is designed, the floor must support no less than 100 pounds per square foot [3]. From these codes there was clearly a lack of a performance- based approach and with the reliance of engineering solely based on good judgment for maximum loads, many building in this era may have been overbuilt [1].

When looking at Alumni Gymnasium, the walls of the first three floors should have a wall thickness between 16 and 24 inches. From visual inspection they seem to be over 24 inches and this is correct as the true dimensions from the drawings are about 30 inches [1]. This clearly shows that Alumni Gymnasium was built like a "tank "as it has an outstanding structural shell. Unfortunately, some of its others components such as the heating system, plumbing, windows, interior walls, lights, and roof are in need of major renovations and must be brought up to the current building codes [5].

2.2.1 Maintenance of Historic Buildings

Many buildings built in the early 20th century consisted of brickwork. Not only was brick easily manufactured, but it was the most sustainable material that required the least maintenance. But like everything else, over time everything starts to deteriorate [4].

Renovation approaches for Historic Buildings generally fall into one of five categories. First, stabilization: a process involving methods that reestablish a deteriorated property's structural stability and weather tightness while sustaining its existing form. Second, preservation: a process involving methods that maintain a property in its present state. Third, rehabilitation: a process involving repairs and alterations to a property that adapt it to a contemporary use while preserving its historic fabric and character. Fourth, restoration: a process that accurately recovers the appearance of a property at a particular period of time by removing later additions and/or replacing missing features. Or fifth, renovation: a generic term used to define all work that is meant to make new again [4].

2.2.2 Preservation and Restoration Techniques

Alumni Gymnasium was built with bricks and is considered a historic building as it is roughly 100 years old. Many buildings of this nature usually have damage caused by deflection or water infiltration, especially on the roof. There is a series of steps that must be followed in order to successfully resolve the problem without damaging or jeopardizing the historic nature of the building. First, if the mortar is missing or loose, the joints should be cleaned out and repointed using a mortar mix which closely matches the composition, joint profile and color of the original. Second, there must be careful removal of mortar from the joints so as not to damage the brick edges. Third, whenever partial or total foundation replacement is required, the new foundation walls should be faced in materials that match the original in appearance. Fourth, whenever replacement brick or stone is needed, there must be a use of a material that closely matches the original in size, color and texture. Fifth, whenever masonry has been painted, it must be repainted after removing all loose paint. Sixth, any cleaning should be done with the gentlest method possible and should be stopped at the first evidence of damage to masonry [4].

Figure 48 - Exterior View - South Side Alumni

Figure 49 - Exterior View - West Side Alumni

These methods above are crucial in maintaining the masonry of an historic building. Some fundamental concepts that relate to all aspects of historic buildings and in particular to Alumni Gymnasium are: First, every reasonable effort should be made to provide a compatible use for a property that requires a minimal alteration of the building. Second, the distinguishable original qualities or character of a building should not be destroyed, such as the removal or alteration of any historic material or architectural features. Third, all buildings, structures, and sites should be recognized as products of their own time, as in, alterations which have no historical basis and which seek to create an earlier appearance are not necessary. Fourth, changes that may have taken place in the course of time are evidence of the history and development of a building and should be recognized and respected. Fifth, examples of skilled craftsmanship that characterize a building should be treated with sensitivity. Sixth, deteriorated architectural features should be repaired rather than replaced, wherever possible. However, if a replacement is necessary, the new material should match the material being replaced in composition, design, color, texture, and other visual qualities. Seventh, the surface cleaning of structures should be undertaken with the gentlest means possible. Eighth, contemporary design for additions to existing structures or landscaping shall not be discouraged. Ninth, wherever possible, new additions or alterations to structures shall be done in such a manner that, if they were to be removed in the future, the essential shape of the original structure would remain the same [4].

One of the most effective ways of maintaining the integrity of historic buildings in Worcester, MA is through the *Worcester Historic Commission*. The function of this association is to issue certificates of appropriateness, certificates of non-applicability, and certificates of hardship to any construction project or alteration of an historic building. They conduct research about places of historical interest and advice the Planning Board, the Worcester Redevelopment Authority, the Executive Office of Economic Development, and other city agencies such as the National Park Service and the National Trust for Historic Preservation on all questions involving historic sites. Most importantly, this commission can cause a major delay to any project or alternation involving a historic building. They can give recommendations to owners of historic buildings in Worcester on issues of preservation and determine what can and cannot be done to the building in order to preserve its historic significance. If the owner doesn’t agree upon these suggestions or the given proposal, the commission, through the city of Worcester, can delay the beginning of construction for up to a year [6]. Most owners that are faced with this dilemma usually just wait out the delay and then start construction; however, this has a seemingly large effect not only on the modifications to the building itself, but political perspective as well [6].

2.3.1 Structural Evaluation of Buildings

In a building renovation project of this magnitude, an evaluation of the structure must be a primary consideration in order to determine the adequacy and suitability of the structural systems in place, and if they meet building code. The major structural systems that are to be investigated include all existing foundations, floors, walls, and roofs.

2.3.2 Structural Building Systems

Foundations are the bottom most part of a building's structure; they are placed below grade in order to transfer loads from the upper structure into the soil. The primary consideration during design of foundations is to limit differential settlement of the structure. This is to ensure that the above structure is not altered or disturbed by the foundation settling at different elevations. Some ways to limit settlement are to ensure adequate soil capacity and to spread the load out over a sufficient area to minimize bearing pressure. Foundations are primarily comprised of footings and walls. Footings can either be considered deep footings, or shallow spread footings. The option on which type of footing to use is dependent on the type of soil conditions present at the site. Deep footings can be either wooden piles, steel piles, or pressure injected concrete footings (pifs). Shallow spread footings are usually made from reinforced concrete. Foundation walls sit on footings and are primarily constructed with reinforced concrete, stones, or bricks as they must be designed adequately to resist the gravity loads imposed on it from the above structure.

Floors and walls are horizontal and vertical members, respectively, of buildings that serve a variety of purposes. Other than the obvious purpose of an area for people to walk on or providing shelter from the outside conditions, floors and walls serve to resist both gravity and lateral loads. The gravity loads a floor as well as a wall must carry are both dead and live loads. The dead and live loads are determined by a floor's intended uses, which are spelled out in building codes. Also, Floors and walls are supported by beams and columns, which transfer loads down the structure, and eventually make their way into the foundation and soil. Floors and walls also act together to resist lateral loads by acting as a diagram. With the combination of floor and roof geometry, these members can act as rigid members to resist wind and seismic loading. In addition to the floor and wall diaphragm system to resist lateral loading, beams and columns, constructed as a moment frame, can resist against lateral loads as well.

The roof is the highest member of a structure. Generally, the roof must be designed to carry dead and snow loads, which are again determined by the building codes. The roof can be constructed from steel, wood, concrete, or any other suitable material and most systems are built as trusses, or a beam/ column assembly.

2.3.3 Building Codes

Building construction in Massachusetts is controlled by the following building codes. For Non-residential and residential structures above 2 families, the following codes govern building construction:

1. *International Building Code* (IBC) 2009 Edition

2. *MA Amendments* to IBC-2009

3. ***Minimum Design Loads for Buildings and Other Structures*** by the American Society of Civil Engineers (ASCE 7) 2005 Edition

4. ***International Existing Building Code*** (IEBC) 2009 Edition

Since the Alumni Gym is an existing building the construction is only controlled by either Chapter 34 of IBC or the separate IEBC Code. In Massachusetts, one of the MA Amendments of the IBC is to delete Chapter 34 and adopt the IEBC in its entirety. In addition to the above codes, the following material codes are adopted by reference in the IBC and control the design of structural members:

1. Concrete - ***Building Codes Requirements for Structural Concrete*** (ACI 318-11) by the American Concrete Institute

2. Masonry - ***Building Code Requirements and Specification for Masonry Structures*** (TMS 402/ACI 530/ASCE 6) by the following 3 societies:

   The Masonry Society (TMS 402)

   American Concrete Institute (ACI 530)

   American Society of Civil Engineers (ASCE 6)

3. Structural Steel - ***Specification for Structural Steel Buildings*** (ANSI/AISC 360) by:

   American National Standards Institute

   American Institute of Steel Construction

4. Wood - ***National Design Specification for Wood Construction*** (NDS) by:

   American Forest & Paper Association

   American Wood Council

2.5.1 Building Information Modeling

In recent years, great investment has gone into the use of Building Information Modeling (BIM) as a tool for design and construction. BIM is an intelligent model-based process that provides insight and solutions for buildings and infrastructure projects. This software allows businesses to build projects faster, more economically, and environmentally conscious [9]. BIM allows contractors of all trades to create a 3D model of their work that can later be compiled into one realistic building model. From there, any detection of clashes (when more than one element is in the same space) is found and resolved before construction begins. This software prevents the waste of extra time and money if a mistake was to be made on sit, especially in the current economy. Using BIM assists in eliminating these mistakes and increases profitability and productivity of the building. Almost half (46%) of the infrastructure organizations, surveyed by Autodesk, are currently using BIM technologies and processes on some part of their infrastructure portfolio; a recent growth from only 27% two years ago. The vast majority (89%) of these companies that currently use BIM for infrastructure report that it is extremely beneficial in keeping a project on time and on budget [9]. They also experience benefits that impact their internal business functions as well.

2.5.2 BIM's Importance in Design

BIM has many key benefits during the design phase of a project. Project scope, schedule, and cost all must be managed well during the design phase as this is the phase where many changes are made to these variables. Through traditional methods, if changes to the variables mentioned are made later in the project, delays can occur and great effort has to be made to upkeep the project. This can cause delays with increased costs negatively affecting relationships between consultants and clients. With BIM these changes can be made and immediately eliminate many costly delays [9].

If a client were to decide to change the scope of their project, BIM can conveniently provide the tools necessary to make the changes. When one design value is changed, further calculations to other structural elements do not need to be made as BIM will automatically update the changes throughout the project. This allows the design team effective and speedy delivery of documents and visual elements.

Due to the nature of our project, BIM will be useful if any changes need to be made to the structural shell of the facility such as relocating windows, updating gravity loads to meet code requirements, or designing for lateral stability which is currently non-existent in the structure. It will also help determine the constructability of various designs and the integration into the existing structure.

2.5.3 BIM's Importance in Construction

Another useful feature in BIM is the available information on building quality, schedule, and cost [9]. Cost estimating and value engineering can be accelerated especially when updates are made to any plans or estimates. Also, site plans can be prepared and used for communication to minimize the impact of construction operations on the owner. Due to a higher quality of documentation and better construction planning through BIM, administrative and overhead costs can be reduced [9].

With Alumni Gymnasium being a renovation project, there are many variables, some of which may not be clear initially, and having the ability to make constant updates to costs and planning is crucial. Additionally, with the building being in the center of campus, proper planning must be executed as to not interfere with the campus and the student life.

3.0 Methodology

3.1.1 Existing Conditions Analysis

The first objective for our project is to document the existing conditions of Alumni in a 3D BIM model and 2D CAD drawings. After this documentation is complete, an analysis of all structural members and systems will be conducted. This analysis will identify all structurally deficient areas in Alumni, and provide direction as to what needs to be redesigned.

Developing a model of the existing conditions in Alumni Gym involves an information gathering process specific to the building. This information will be gained from any available old drawings of the building, and inspection visits to the site. Site visits will be used to both verify conditions stated on old drawings, and to get any additional information that is required to analyze the building. In the case of our MQP, there were only old Architectural drawings available, so a thorough investigation into the structural systems in place will need to be done.

The structural investigation will consist of locating and noting size and spacing of all structural systems and their members. These structural systems will include roof framing, floor framing, exterior bearing walls, and foundations. To understand the roof framing, the roof truss individual members, connections, and spacing will be measured. In addition, the purlins and deck spans and sizes will need to be noted as well. This will involve a visual inspection from the floor 5, and if possible, use of hydraulic lifts to get a closer look at the trusses. The floor framing will be determined by locating and sizing all columns, beams and joists, as well as locating any holes that exist in the floor diaphragm. Preliminary investigations indicate Levels 4 and 5 framing consists of steel girders and timber beams spanning girder to girder. To properly analyze the timber beams, a sample of the wood will be sent to a wood scientist to determine the species. The girders are supported down to the floor by steel columns. Inspection holes will have to be cut in the sheetrock walls in order to view the columns buried in the walls. Level 3 consists of a concrete slab, supported by concrete beams and columns. Level 2 and 1 each bear on grade. Next, the thickness of the exterior brick bearing walls will need to be measured at a window opening at each floor. Finally, to the extent possible, investigations into the size of the foundation walls and footings will be done.

Once the above mentioned information is obtained, drafting of the 2D and 3D models will commence. AutoCAD and MicroStation Power Draft will be used to draw the 2D drawings, and Revit will be used to draw the 3D model. These models will serve as our existing set, and be used in the analysis and eventually the redesigning process.

According to *International Existing Building Code (IEBC) 2009 Edition,* the size of project scope determines which codes the building must comply with. Due to the degree of scope presented so far for Alumni, it was determined that this project fell under the description of a level 3 renovation. A level 3 renovation means that Alumni must be analyzed and comply with current building code specifications. Each existing structural system will be analyzed to understand if they are in accordance with the current codes. The checks of the structural systems are divided into two main load checks, gravity loads, and lateral loads.

3.1.2 Gravity Load Analysis

1. *Check of Existing Roof Load Capacity*
    a. Calculate roof snow load
    b. Calculate dead weight of roof structure and all superimposed dead loads on roof
    c. Analyze roof structure by one of two ways:
        i. Measure and document each truss member size and span, and conduct a truss analysis using current code design loads.
        ii. Determine design loads from early 1910s building codes and compare to current code design loads.
2. *Check Floor Framing Load Capacity*
    a. Calculate dead load for each floor
    b. Calculate live load for intended new usage of space
    c. Check the existing floor framing for loads

3.1.3 Lateral Load Analysis

1. *Check of Unreinforced Masonry Walls*
    a. Calculate wind load
    b. Calculate seismic load
    c. Check walls to support these loads

These checks will identify the deficient areas of the building, and give our group an understanding of what areas need to be redesigned to meet current building codes. After this analysis is complete, a clearer scope will be identified, and re-design can take place.

3.2.1 Building Information Modeling

While we are determining the solutions for renovating Alumni Gym, the uses of BIM will help us define a final project and project scope. BIM will allow us to have a 3D model of the building so we can see exactly what changes will need to be done and what structural challenges we will face.

3.2.2 BIM for the Existing

As we analyze the existing Alumni Gym structure, BIM will be a very important aspect to our project. Although we may not currently have all the information required for a BIM model, our team will go in the field and collect information about the current at Alumni Gym to create an accurate BIM model. Since there are numerous elements of construction that are not visible to the naked eye, we plan to have some selective demolition done in the building so we could see the unknown structural materials. As soon as we identify the layout of the building, we will create the current version of our 3D model with the uses of Revit Architecture and Revit Structures.

In relation to the proposed layout provided by Goody Clancy, we will match the site to the desired format such as the floor level names and scales. We will then begin designing the building on Revit based off of the dimensions and materials we encounter as we investigate the site.

Building the BIM model is useful for the future of our project because it gives us a starting point for the proposed renovation. As we see what materials are where, we will have a better idea of what problems we will encounter and what changes need to be made. The Structural and the Architectural versions will be linked together which makes it easier to view desired areas of the building at any angle.

3.2.3 Proposed Model

After discussion and research of what the owner wants, we will create a BIM model off of the existing model we've created. This model will be an important benefactor for WPI to use for its future proposal and renovation.

3.2.4 Alternative Designs

As we encounter different situations regarding the structure and changes that are needed, we will create different alternatives as sections in the BIM model. Each alternative we analyses will be set as a separate drawing for viewing purposes.

3.2.5 Cost Estimation

Throughout the design, we will be able to simplify the quantity and the quality of the materials used in the construction of Alumni Gymnasium. With the help of the *RS Means Building Cost* and the development of our model, we will be able to estimate the unit prices for the materials and what would be needed for the replacement of materials. With the development of this 3D model, considering all the alternatives for the proposed renovation, we will estimate a cost for the desired alternative in order to make this project realistic and feasible.

3.2.6 Schedule

With the creation of the BIM model we will create a schedule for construction alternatives. We will create a schedule for the timing of the construction renovation and for site logistics of transporting and storing material.

3.3.1 Design Development

Our largest contribution to the WPI community will be the development designs for the change in use of Alumni Gym. Our group will focus on specific areas for our designs, but if other issues are to arise during this phase, we will work to solve them as well. This phase of the project is extremely crucial because the designs we develop will determine the cost, schedule, and integrity of the building.

3.3.2 Design of Lateral Reinforcement

After the structural analysis is completed and the intended uses of the renovated Alumni Gym are determined, the group will begin design on the major elements that are required. From studying the *International Building Code* (2009) and due to the nature of the project, a lateral reinforcement system design is needed to support the unreinforced masonry walls. Currently, the roof truss members sit on the brick wall and are not properly supported if there were any lateral movement in the structure. Our group proposes to use steel columns to support these roof truss members, spanning vertically from the truss down to the basement in sections. The design of these column members will help support the roof of Alumni in case the masonry walls fails laterally because it will be able to withstand the weight of the roof if the walls collapse. This was determined to be more feasible than reinforcing the walls with rebar which is more labor intensive in our opinion. We aim to show the benefits of our system over using rebar for reinforcement in our report.

In addition to lateral reinforcement for the overall building, reinforcement will be necessary for the parapet walls on the exterior roof of the building. Currently, they are freely standing unreinforced masonry walls. After checking these walls for wind and seismic loads, our group will develop a design to reinforce these parapet walls. We propose to support these walls with angle braces that will brace the walls in case of failure due to these failure methods. Reinforcing these elements is important because they are part of the aesthetic appeal of the building and protecting this element will help preserve the historic architecture of Alumni.

3.3.3 Design of Elevated Slab

Due to a change in use in the Alumni Gymnasium, the swimming pool that is currently present is no longer useful. This area, according to proposed architectural plans, will be converted in a showroom to display students' projects. Therefore, our group proposes to design an elevated slab that will cover the area the swimming pool currently occupies. We will design for gravity loads according to code for the intended use of the area and to resist any stresses due to self-weight since it will be elevated above the swimming pool.

3.3.4 Design of New Stairway

Another change that our group will be developing a design for is a new stairway on the South side of the building. WPI intends to open the space up on the main floor of the building by creating a central corridor that runs from the main entrance to an exit in the rear. Partitions walls will have to be demolished to create this corridor and an opening in the exterior wall on the South side will have to be created. From this exterior wall opening, there will be a staircase to enter or exit the building. Our group will use building codes to determine the type of stairway that is needed in this location. Criteria will include handicap accessibility, depth, width, and height of each stair, number of stairs needed, and overall dimensions of the stairway. We will want a design that complies with current codes and that meshes well with the existing structure to create an aesthetically pleasing view.

3.3.5 Design of Temporary Supports

Demolition will be a major phase of this building and designing temporary supports will be crucial to avoid disturbing the rest of the structure. Through discussion with WPI Facilities and study of proposed architectural plans, it has been determined that the connection between Harrington and Alumni Gym will be demolished as well as partition walls within Alumni. Therefore, our group must design temporary supports for this phase of the project whether it be shoring or temporary frames so that the structural integrity of the building is protected. Demolition to parts of a building this old must be handled carefully because we cannot predict what will happen if walls were to be removed. Designing supports to ensure that nothing catastrophic occurs is important not only for the building, but for the safety of the contractor that will be performing the work.

3.4.1 Construction

Cost estimating and scheduling are two important aspects of construction. This information must be assembled, evaluated, documented, and managed in an organized manner, and for them to work effectively, key information must be defined and accumulated at critical times. Also, determining the sequential order of the planned activities, assigning realistic durations to each activity and determining the start and finish dates for each activity is crucial to the success of the project. They both will give the owner an idea of the price for the required renovations and how to finish the project on time.

3.4.2 Cost Estimating

In order to evaluate the feasibility of our alternative designs, we will first standardize the cost preparation process with the use the *R.S. Means Construction Building Cost Data* (2012 Edition) and CSI Master Format divisions to organize our information and keep everything consistent. We will go through each division of the CSI Master Format and do quality and quantity takeoffs for any items that will be essential to the renovation and determine the required amount. Using the *R.S. Means Construction Building Cost Data* (2012 Edition) we will look into the unit pricing costs for each item as well as the square foot costs of similar buildings compared size to Alumni Gymnasium. This will give us an idea of how much material will be needed to complete the project and how much it will all cost. This will also allow us to compute an approximate continuity as well as make adjustments to the final price using the location factor.

Since WPI as well as this project team already know from our first two site tours that there will need to be numerous changes made to the building to bring up it to the current building code, we both have similar objectives and methods that will help us plan according. The building currently doesn't have appropriate lateral support, as described in the previous sections, so determining the cost of the material and time spent on fixing this problem will be critical in computing the most accurate estimate as possible. Since our estimate isn't going to be exact we are aiming for a level within 10% of the actual price when outside companies bid the project. Our collection of data and cost analysis will be as precise to the current drawings and documentation of Alumni Gymnasium as possible and we will present the estimate in the most convenient format for WPI. These steps will enable us to keep track of our work easily and make it simple to fix any discrepancy or inaccuracy in a timely fashion.

3.4.2 Scheduling

The first step in our scheduling process will be to develop a work breakdown structure (WBS) that identifies all the work items that must be completed to renovate Alumni Gymnasium. We will consider activities that require the most time and cost, such as demolition, as well as monitor items that we feel might change while studying the structure. This will help us arrange the WBS in an efficient and easy way to follow when discussing the possible removal of a floor or the temporary support of a beam (shoring) during construction.

The next step will be to use Primavera in preparing a drawing (network diagram) that shows each activity in the order it must be performed to complete the project. After deciding which items will be critical to the renovation, we will consider which activities immediately precede each activity and which activities immediately follow each other. This will help us create the essential critical path for the project and the timeframe for each activity. The connection of all these activities will be a combination of how the work must be done (constraints) and how we want the work to be done.

Subsequently, we will determine the time, cost, and resources required to complete each activity by reviewing the work packages and then finally compute the schedule to determine start, finish, and float times. We will perform a forward pass to determine the early starts and finishes as well as a backward pass to determine late starts and finishes. This will be key in determining the differences between the start and finish times which determine the float time and the critical activities.

Lastly, we will analyze the costs and resources for the project by computing the cost per day for each activity and for the entire project as well as the labor-hours per day we think will be necessary. We will then incorporate this data into BIM and display the time and cost schedule for all the activities.

Bibliography for Proposal

22. Laramee, David C., and Benjamin Mies. *Renovating Alumni Gymnasium for Academic Purpose. Major Qualifying Project.* Worcester Polytechnic Institute, 23 Mar. 2007. Web. 20 Sept. 2013.
23. Mell, Eileen B. (2009). *WPI Trustees Vote to Proceed with Sports and Recreation Center.* WPI Press Release
24. Worcester, MA. *Charter, Laws and Ordinances of the City of Worcester, 1911.* Worcester, MA: The Blanchard Press, 1911.
25. *Guidelines for Renovating Historic Buildings.* The Secretary of the Interior's Standards for Rehabilitation and Guidelines for Rehabilitating Historic Buildings. Web. 26 Sept. 2013.
26. Salter, Christopher. Personnel Interview. 2 October, 2013
27. "Worcester Historical Commission Details." *Http://www.worcesterma.gov/boards.* Boards & Commissions | City of Worcester, MA. Web. 04 Oct. 2013.
28. Katz, Ashley. "About LEED." U.S. Green Building Council, 25 July 2012. Web. 14 Oct. 2013.
29. "LEED Rating Systems." *LEED Rating Systems.* U.S. Green Building Council, 25 July 2012. Web. 14 Oct. 2013.
30. "Building Information Modeling in Practice." *Http://www.ddscad.com.* Autodesk Building Solutions, 25 Feb. 2011. Web. 14 Oct. 2013.

Appendix B – Meeting with Fred Dimauro

Meeting with Fred DiMauro

Key Meeting Points:

- Construction Plan
  - Original idea was to tear down Alumni/ Harrington Connector first (fall 2014) and then begin renovating Alumni Gym.
    - Due to lack of funding this will not happen.
  - Another idea was to store storm/ rain water in the Alumni pool and use it to irrigate the quad
    - Seems unlikely as it is not cost efficient
  - 18- 20 months of construction → 10- 12 million dollar range
    - Due to funding the project cannot start until they have saved 8 million; currently have 3 million and are reaching out the trustees for donations
  - Next November 150th anniversary→ kickoff 150th anniversary with this project
    - This is likely start date, but it all relies on funding
- Site Logistics
  - Space available for storage, equipment, and dumpsters will be the Alumni/ Bartlett Center parking spaces and the grass hill near Higgins House.
    - Quad connector can also be used if needed
  - Deliveries can be made either through the front of Alumni or the back of Alumni
- Structural Challenges
  - Raised curb 6" around pool
    - Must be removed in order to place slab
  - Have not spoken to the Worcester Historical Commission as it is out of his area of expertise
    - WHC only applies to portions of building visible from a city street; biggest issue will be the windows if they must be kept original
  - Building square footage is being reconfigured; if the ratio of the cost for renovation per square footage is less than a certain number, certain building improvement that would have to be used to bring Alumni up to the current building code can be avoided.

Appendix C – Level 3 Framing Concrete Slab

	Concrete Slab Check:				
	1-ft Strip Method				
1.00	**Minimum Slab Thickness**				
	Both ends continuous				
	Solid one-way slabs				
	minimum thickness, h	=	L/28		
		=	15*12/28		
			6.43	in	**< 9in; OK**
	*ACI 318-08, Table 9.5(a) Minimum Thickness of Nonprestressed Beams or One-Way Slabs				
2.00	**Loads**				
	Dead Load (DL)	=	(150*9/12)+(150*2/12)		
			137.5	lbs/ft per ft of slab	
	use DL	=	150	lbs/ft^2	
	Live Load (LL)	=	100	lbs/ft^2	
	*IBC 2009, Table 1607.1				
	w total	=	250	lbs/ft per ft of slab	
3.00	**Reactions**				
	R1		15*250/2		
	R1	=	1875	lbs	
4.00	**Shear Check**				
	ΦVc	=	(.75*(f'c)^.5)*12*7.5		
	Req. f'c	=	(1875/(.75*12*7.5))^2		
			772	lbs	<2,000 psi

4.00	**Minimum Reinforcement**				
	Asmin	=	200bd/fy		
			200*12*8/30000		
			0.64	in^2 per ft of slab	
	**1" cover per Contract Deisgn Specifications, 1914*				
	**ACI 318-08, 10.5 - Min. Rein. Of Flexural Members*				
	ACI Reinforcement:				
	#5 @ 5.5"; As = .67				
5.00	**Moment Capacity**				
	a	=	.67*30000/(.85*2000*12)		
		=	0.99	in	
	Mcapacity with Asmin	=	Asfy(d-(a/2))		
		=	.67*30000(7.5-.99/2)		
		=	126090	in-lbs	
			10508	ft-lbs	
6.00	**Ultimate Load**				
	10508	=	(1/10)wul^2		
	wu	=	10508*10/(15^2)		
			467	lbs/ft	
	Dead Load	=	150	lbs/ft per ft of slab	
	1.2*DL+1.6LL	=	467		
	LL	=	(467-1.2*150)/1.6		
		=	179		
	Assuming Asmin, LL capacity is 179 lbs/ft^2				
	*Building Specifications state that floor is designed for DL and LL= 100psf				

Appendix D – Level 4 Framing (Timber Beams)

1.00	**Typical 12x12 Wood Beam**						
	b	=	12	in			
	d	=	12	in			
	A	=	144	in^2			
	S	=	(12*12^2)/6	in^3			
		=	288	in^3			
	I	=	(12*12^3)/12	in^4			
			1728	in^4			
	spacing	=	6	ft			
	Tw	=	6	ft			
	span	=	16	ft			
2.00	**Calculate Dead & Live Loads**						
	Deck: 3" Wood + 1" Flooring						
		=	4*12*.25				
		=	*12*	*lbs/ft^2*			
	Beam: 12"x12"						
	wt/ft	=	12*12*.25				
		=	36	lbs/ft			
	wt/ft^2	=	36/6				
		=	*6*	*lbs/ft^2*			
			18	*lbs/ft^2*	*; use 20 lbs/ft^2*		
	Wdead	=	6*20				
			120	*lbs/ft*			
	Wlive	=	6*100				
		=	*600*	*lbs/ft*			
	Wtotal	=	*720*	*lbs/ft*			

3.00	**Calculate Stresses, fv & fb**						
	Wtotal	=	720	lbs/ft			
	R	=	720*16/2	lbs			
			5,760	lbs			
	d/2	=	6	in			
	V @ d/2	=	5760-6*720/12	lbs			
			5,400	lbs			
	fv	=	1.5V/A				
		=	1.5*5400/144				
		=	56.25	lbs/in^2			
	M	=	(wL^2)/8				
		=	(720)(16^2)/8				
			23,040	ft-lbs			
	fb	=	M/S				
			23040*12/288				
			960	lbs/in^2			
4.00	**Member Check**						
	Design Values from NDS, Table 4D						
	Assume Douglas-Fir #1						
	Fv	=	170	lbs/in^2	>	56.25	**ok**
	Fb	=	1350	lbs/in^2	>	960	**ok**
5.00	**Deflection**						
	E	=	1,600,000	lbs/in^2			
	Δ	=	(5wL^4)/(384EI)				
		=	(5*720*1728*16^4)/(384*1600000*1728)				
		=	0.384	in			
	16*12/.384	=	500				
	L/500	=	0.384				

Appendix E- Level 4 Framing (Steel Girders)

1.00	**Steel Girder (Col #6 to Col #7) - W18x76 (worst case)**					
	b	=	11	in		
	d	=	18.2	in		
	A	=	22.3	in^2		
	S	=	146	in^3		
	I	=	1330	in^4		
	spacing	=	16	ft		
	Tw	=	16	ft		
	span	=	28	ft		
2.00	**Calculate Dead & Live Loads**					
	Wdead	=	16*20			
			320	*lbs/ft*		
	Wlive	=	16*100			
		=	1600	*lbs/ft*		
	Wtotal	=	*1920*	*lbs/ft*		

3.00	**Calculate Stresses, fv & fb**					
	Wtotal	=	1920	lbs/ft		
	R	=	1920*28/2	lbs		
			26880	lbs		
			26.9	k		
	M	=	(wL^2)/8			
		=	(1920)*(28^2)/8			
			188160	ft-lbs		
			188	ft-k		
	fb	=	M*12/S			
			188*12/146			
			15.5	k/in^2		
	(Fy=33k/in^2)					
	Fb	=	20.0	k/in^2	**ok**	
	fv	=	V/(tw*d)			
		=	26.9/(.425*18.2)			
		=	3.5	k/in^2		
	Fv	=	13	k/in^2	**ok**	
4.00	**Deflection**					
	E	=	29,000,000	lbs/in^2		
	Δ	=	(5wL^4)/(384EI)			
		=	(5*1920*1728*28^4)/(384*29000000*1330)			
		=	0.69	in		
	28*12/.69	=	487			
	L/487	=	0.69			

Appendix F – Existing Columns

1.00	**Typical Pipe 8 STD (8.63")**				
	Area	=	7.85	in^2	
	r	=	2.95	in	
	ln	=	11.0	ft	
2.00	**Load on Column**				
	(2x reaction from steel girder on column)				
	Girder R	=	26.9	k	
	2R	=	53.8	k	
3.00	**Slenderness Ratio**				
	kl	=	1*11		
			11.00	ft	
4.00	**Available Strength in Axial Compresion (kips)**				
	ASD:				
	Pn/Ωc	=	148	k	**>53.8k OK**

Appendix G – Wind Analysis

1.00	**Wind Load P6**				
	Wind on Sloping Roof:	=	14ft*12.68lb/ft^2		
		=	177.5	lb/ft	*per ft of wall
	Wind on Wall:	=	[9+(22/2)](25.78)		
		=	515.6	lb/ft	
2.00	**Wind Load P4**				
	Wind on Wall	=	((22/2)+(10.6/2))*(25.78)		
		=	420.2	lb/ft	
3.00	**Wind Load P3**				
	Wind on Wall	=	((10.6/2)+(11/2))*(25.78)		
		=	278.4	lb/ft	
4.00	**Increased Wind Load at Corners**				
	2a region from end wall				
	At "A" w	=	33.73	lb/ft^2	
	At "C" w	=	25.78	lb/ft^2	
	Difference	=	7.95	lb/ft^2	; use 8.00
	At "B" w	=	15.09	lb/ft^2	
	At "D" w	=	12.68	lb/ft^2	
	Difference	=	2.4	lb/ft^2	
5.00	**P6 at Corner**				
	Roof	=	14*2.4		
		=	33.6	lb/ft	
	Wall	=	14*2.4		
		=	33.6	lb/ft	
6.00	**P4 at Corner**				
	Wall	=	16.3*8		
		=	130.4	lb/ft	
7.00	**P3 at Corner**				
	Wall	=	10.8*8		
		=	86.4	lb/ft	

8.00	**Wind to Level 4 Walls (Old Floor 2)**				
	(P6)				
	Diaphragm Span	=	127.33	ft	
	Loads at Exterior Transverse Wall (L=86.67ft)				
	Calculate R1 & R2 for P6 Load				
	R1 = R2	=	(693*127.33/2)+(193.7*34.8/2)		
			47490	lbs	
	Check Shear Stress in Wall				
	fv	=	47490/(86.67*1.75*144)		
			2.2	lb/in^2	
	V per foot of Wall	=	47490/86.67		
			548	lb/ft of wall	
9.00	**Wind to Level 3 Walls (Old Floor 1)**				
	(P4)				
	Diaphragm Span	=	127.33	ft	
	Loads at Exterior Transverse Wall				
	L of Wall	=	86.67-windows		
	L of Wall at left side	=	86.67-7*3.5		
			62.2	ft	
	L of Wall at right side	=	86.67-8*3.5		
			58.7	ft	
	Calculate R1 & R2 for P4 Load				
	R1 = R2	=	(420.2*127.33/2)+(130.4*34.8/2)		
			29021	lbs	
	Check Shear Stress added to Wall				
	fv	=	29021/(58.7*2.3*144)		
			1.5	lb/in^2	
	V per foot of Wall	=	29021/86.67		
			334.8	lb/ft of wall	

10.00 Wind to Level 3 Walls (Old Basement)

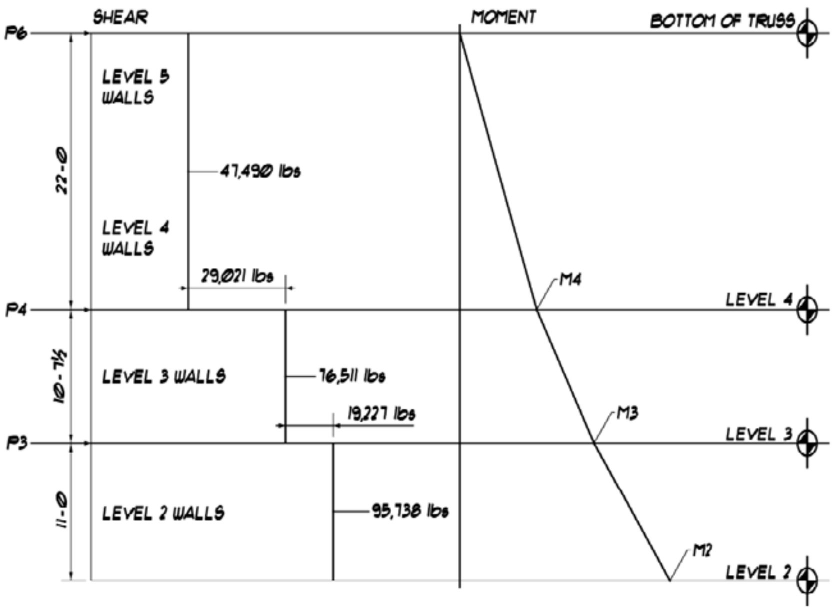
(P3)

Calculate R1 & R2 for P3 Load

R1 = R2 = (278.4*127.33/2)+(86.4*34.8/2)

19228 lbs

11.00 Shear & Moment Calculations



M4 = 47490*22

= 1,044,780 ft-lbs

M3 = (47490)*(22+10.6)+29021*10.6

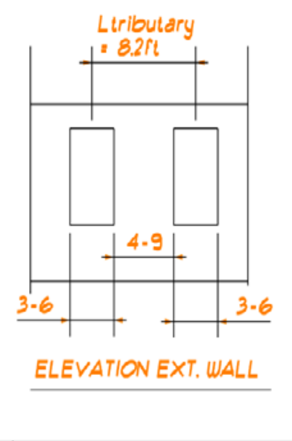
= 1,855,797 ft-lbs

M2 = (47490)*(22+10.6+11)+(29021)*(10.6+11)+(19227*11)

= 2,908,915 ft-lbs

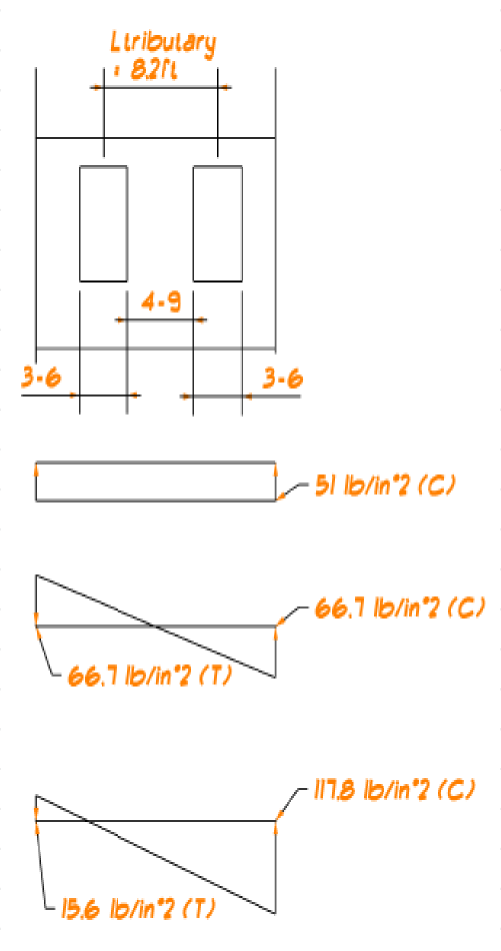
12.00	**Transverse Walls - Basement Level**				
	Check Shear				
	V	=	95738	lbs	
	Wall thickness	=	29	in	
	Total Wall Length	=	87.5	ft	
	Pier Lengths	=	6.83	ft	
			10.5	ft	
			5.5	ft	
			4.75	ft	
			4.75	ft	
			4.75	ft	
			5.5	ft	
			10.5	ft	
			6.83	ft	
			60	ft	of brick wall
	*Solid Brick Fully Grouted/Mortared				
	fv	=	95738/(60*12*29)		
		=	4.6	lb/in^2	
	Fv	=	.5(f'm)^.5	</=	28lb/in^2
	*N type mortar				
	*No inspection				
	*Brick Institute of America, 1969				
	Required f'm:				
	.5(f'm)^.5	=	4.6		
	Required f'm	=	84.6	lb/in^2	
	Brick with 2,000 lb/in^2 units & Type N mortar;				
	f'm	=	530	lb/in^2	>84.6; **OK**

13.00	**Check Flexure at Piers**				



	Shear per ft of wall	=	95738/87.4		
			1095	lbs/ft	
	Shear to Pier	=	1095*8.2		
		=	8979	lbs	
	Shear Stress in Pier				
	fv	=	8979/(4.75*12*29)		
		=	5.4	lbs/in^2	
	Moment Distribution by I (stiffness fraction)				
	% to each Pier	=	(L Pier^3)/(Σ(L Pier^3))		
	L Pier^3	=	318.6		
	L Pier^3	=	1157.6		
	L Pier^3	=	166.4		
	L Pier^3	=	107.2		
	L Pier^3	=	107.2		
	L Pier^3	=	107.2		
	L Pier^3	=	166.4		
	L Pier^3	=	1157.6		
	L Pier^3	=	318.6		
	Σ(L Pier^3)	=	3606.7		

	% to 4-9 Pier	=	(4.75^3)/(3606.7)		
		=	0.030		
	M to 4-9 pier	=	.03*2908914.6		
		=	87267.4	ft-lbs	
	S of 4-9 pier	=	29*((4.75*12)^2)/6		
			15703.5	in^3	
	fb	=	87267.4*12/15703.5		
		=	66.7	lbs/in^2	T or C
	% to 10-6 Pier	=	(10.5^3)/(3606.7)		
		=	0.32		
	M to 10-6 pier	=	.32*2908914.6		
		=	930,852.7	ft-lbs	
	S of 10-6 pier	=	29*((10.5*12)^2)/6		
			76734	in^3	
	fb	=	930852.7*12/76734		
		=	145.6	lbs/in^2	T or C
	Add Gravity Load to 4-9 pier				
	Brick Unit wt for 12" wall	=	120	lb/ft^3	
	Brick Wall wt	=	1.75*120*49*8.2		
		=	84378	lbs	
	fc	=	84378/(4.75*12*29)		
		=	51.0	lb/in^2	C



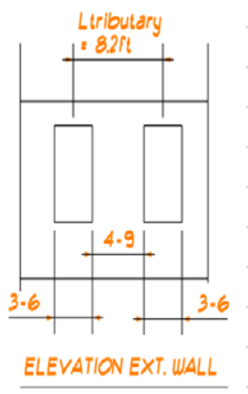
Flexure in Wall			
fm	=	.32f'm	
Req'd f'm:			
117.8	=	.32f'm	
f'm	=	368.1	lbs/in^2
f'm from BIA, 1969	=	530	lbs/in^2
for 2,000 lb/in^2 units & Type N Mortar			
Tension check:			
Ft	=	19	ksi > 15.6 ksi ; **OK**

14.00	**Building Stability**				
	M Overturning (Wind)				
	Mot	=	2,908,915	ft-lbs	
	M Resisting to Stabilize:				
	Calculate wt of brick walls:				
	Brick Wall Gross Area	=	86.7*49		
		=	4248.3	ft^2	
	Window Area	=	8*3.5*6		
			168	ft^2	
	Net Wall Area	=	4080.3	ft^2	
	wt of brick wall	=	4080.3*120*1.75		
		=	856,863	lbs	
	Mres.	=	856863*(86.7/2)		
		=	37,145,011	ft-lbs	
	F.S. = Mres./Mot	=	37145011/2908915		
		=	12.8		

Appendix H – Seismic Analysis

1.00	**Transverse Walls - Basement Level**					
	Check Shear					
	V	=	182680	lbs		
	Wall thickness	=	29	in		
	Total Wall Length	=	87.5	ft		
	Pier Lengths	=	6.83	ft		
			10.5	ft		
			5.5	ft		
			4.75	ft		
			4.75	ft		
			4.75	ft		
			5.5	ft		
			10.5	ft		
			6.83	ft		
			60	ft	of brick wall	
	*Solid Brick Fully Grouted/Mortared					
	fv	=	182680/(60*12*29)			
		=	8.7	lb/in^2		
	Fv	=	.5(f'm)^.5	</=	28lb/in^2	
	*N type mortar					
	*No inspection					
	*Brick Institute of America, 1969					
	Required f'm:					
	.5(f'm)^.5	=	8.7			
	Required f'm	=	303	lb/in^2		
	Brick with 2,000 lb/in^2 units & Type N mortar;					
	f'm	=	530	lb/in^2	>303; **OK**	

Check Flexure at Piers



Shear per ft of wall = 182680/87.4
2090 lbs/ft

Shear to Pier = 2090*8.2
= 17138 lbs

Shear Stress in Pier
fv = 17138/(4.75*12*29)
= 10.4 lbs/in^2

Moment Distribution by I (stiffness fraction)

% to each Pier = (L Pier^3)/(Σ(L Pier^3))

L Pier^3 = 318.6
L Pier^3 = 1157.6
L Pier^3 = 166.4
L Pier^3 = 107.2
L Pier^3 = 107.2
L Pier^3 = 107.2
L Pier^3 = 166.4
L Pier^3 = 1157.6
L Pier^3 = 318.6

Σ(L Pier^3) = 3606.7

	% to 4-9 Pier	=	(4.75^3)/(3606.7)			
		=	0.030			
	M to 4-9 pier	=	.03*13760685/2			
		=	206410.3	ft-lbs		
	S of 4-9 pier	=	29*((4.75*12)^2)/6			
			15703.5	in^3		
	fb	=	206410.3*12/15703.5			
		=	158	lbs/in^2	T or C	
	% to 10-6 Pier	=	(10.5^3)/(3606.7)			
		=	0.32			
	M to 10-6 pier	=	.32*13760685/2			
		=	2,201,709.6	ft-lbs		
	S of 10-6 pier	=	29*((10.5*12)^2)/6			
			76734	in^3		
	fb	=	2201710*12/76734			
		=	344	lbs/in^2	T or C	
	Add Gravity Load to 4-9 pier					
	Brick Unit wt for 12" wall	=	120	lb/ft^3		
	Brick Wall wt	=	1.75*120*49*8.2			
		=	84378	lbs		
	fc	=	84378/(4.75*12*29)			
		=	51.0	lb/in^2	C	
	fm	=	158+51			
			209.0	lb/in^2	C	
	fm	=	-158+51			
			-107.0	lb/in^2	T	
	Flexure in Wall					
	fm	=	.32f'm			
	Req'd f'm:					
	209	=	.32f'm			
	f'm	=	653	lbs/in^2		
	f'm from BIA, 1969	=	530	lbs/in^2		
	for 2,000 lb/in^2 units & Type N Mortar					
	Tension check:					
	Ft	=	19	ksi < 107 ksi ; **NG**		

	Building Stability					
	M Overturning (Seismic)					
	Mot	=	13,760,685	ft-lbs		
	M Resisting to Stabilize:					
	Calculate wt of brick walls:					
	Brick Wall Gross Area	=	86.7*49			
		=	4248.3	ft^2		
	Window Area	=	8*3.5*6			
			168	ft^2		
	Net Wall Area	=	4080.3	ft^2		
	wt of brick wall	=	4080.3*120*1.75			
		=	856,863	lbs		
	Mres.	=	856863*(86.7/2)			
		=	37,145,011	ft-lbs		
	F.S. = Mres./Mot	=	37145011/13760685			
		=	2.7			

Appendix I – Truss Analysis

Truss					
Check of Bottom Chord:				Notes	
LL8x6x3/4					
Ag = 19.88 in^2					
Max Chord Force =	144312	lbs	(T)	*from Truss analysis	
Tensile yielding in the gross section:					
Pn =	(fyAg)/Ωt			*AISC Chapter D	
Pn =	35000*19.88/1.67			*use fy = 35ksi	
Pn =	416647	lbs			
Capacity > Demand ------ OK					

Appendix J – Steel Frame Design

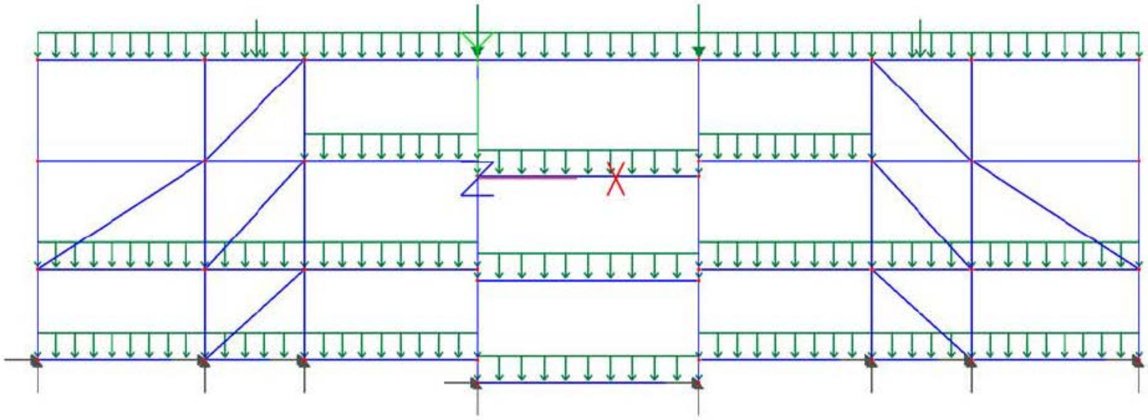


Figure 50 - Front Elevation: Dead Loads

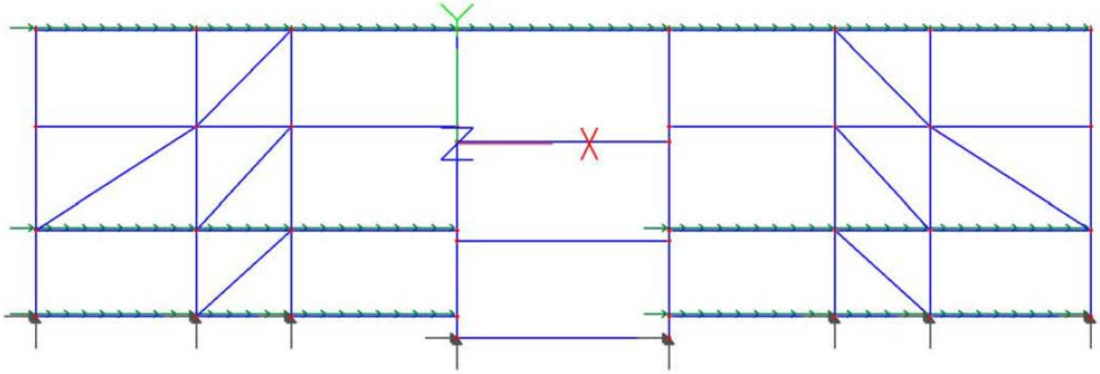


Figure 51 - Front Elevation: Seismic Loads

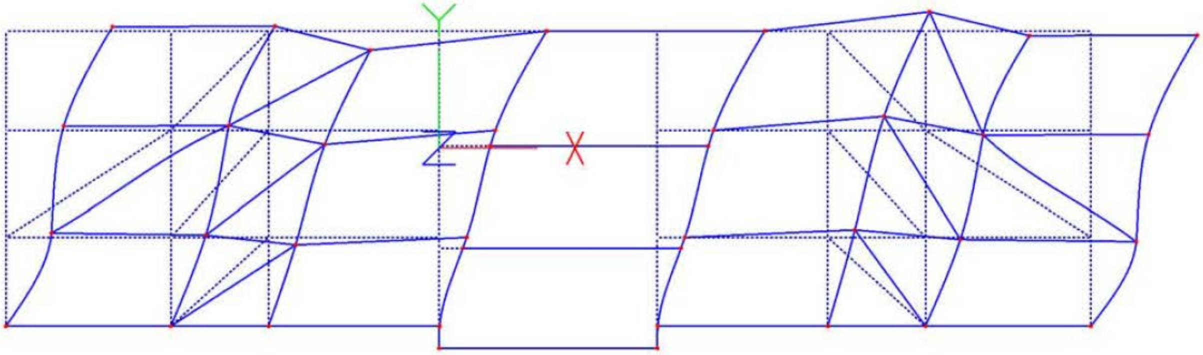


Figure 52 - Front Elevation: Seismic Displacements

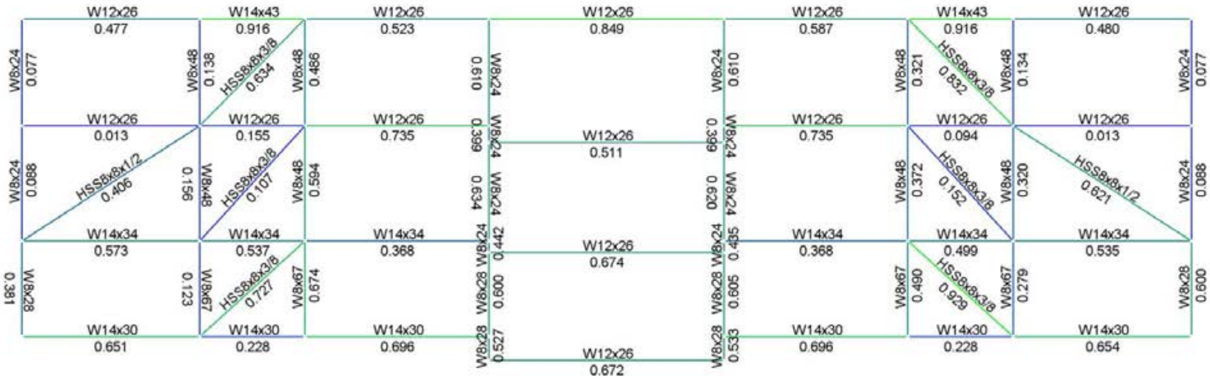


Figure 53 - Front Elevation: Final Sizes & Unity Check

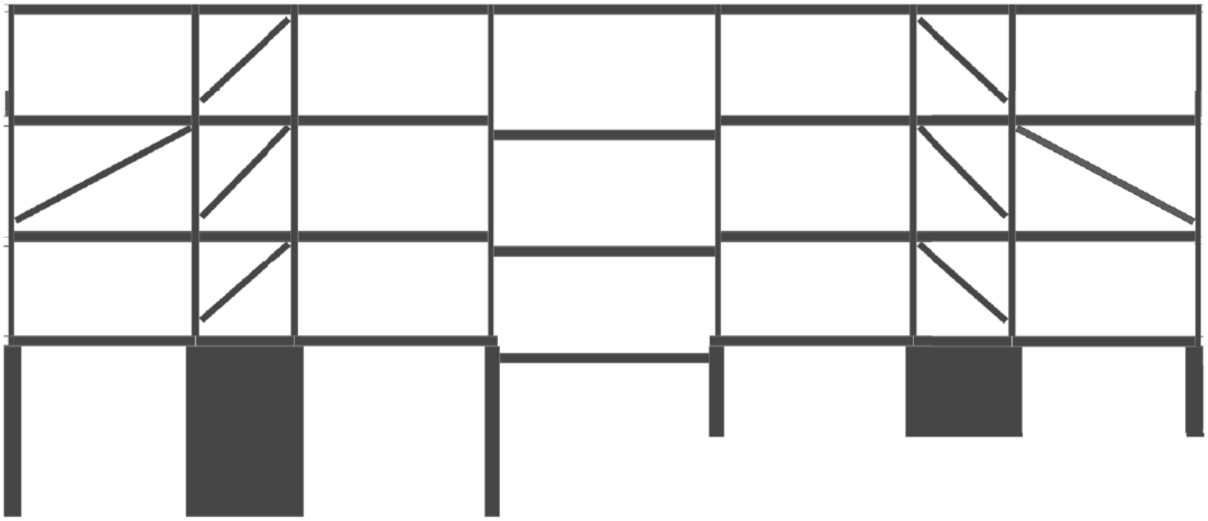


Figure 54 - Front Elevation: Revit View, with Concrete Piers

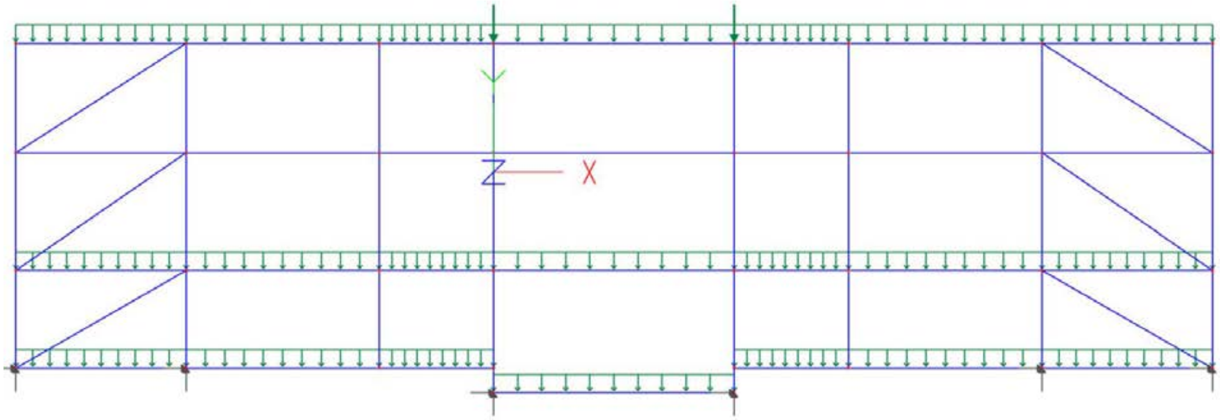


Figure 55 - Rear Elevation: Dead Loads

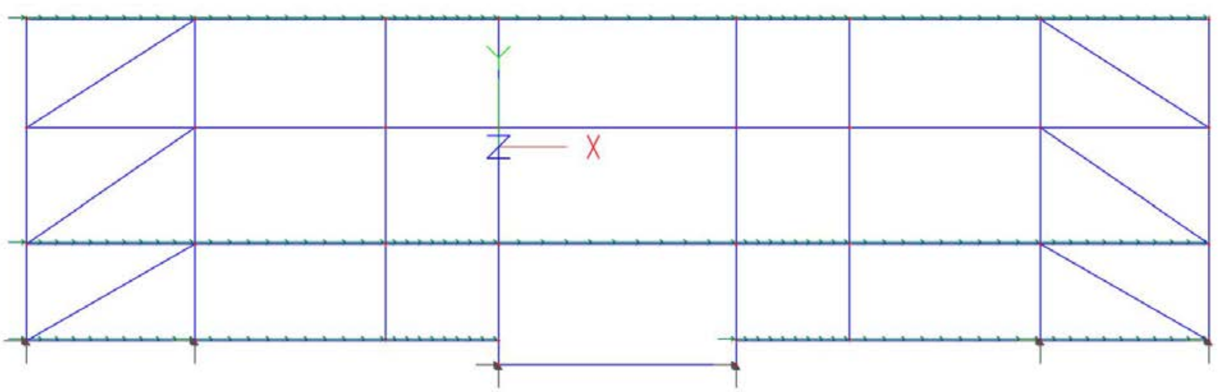


Figure 56 – Rear Elevation: Seismic Loads

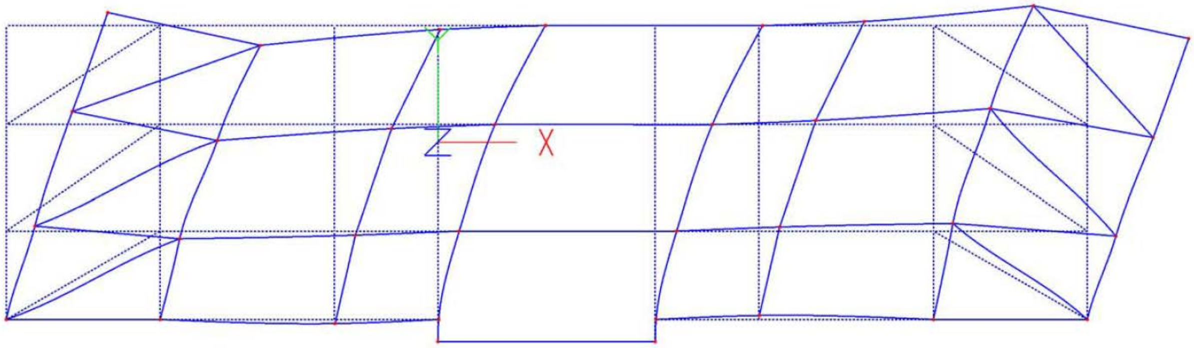


Figure 57 - Rear Elevation: Seismic Displacements

Figure 58 - Rear Elevation: Final Sizes & Unity Check

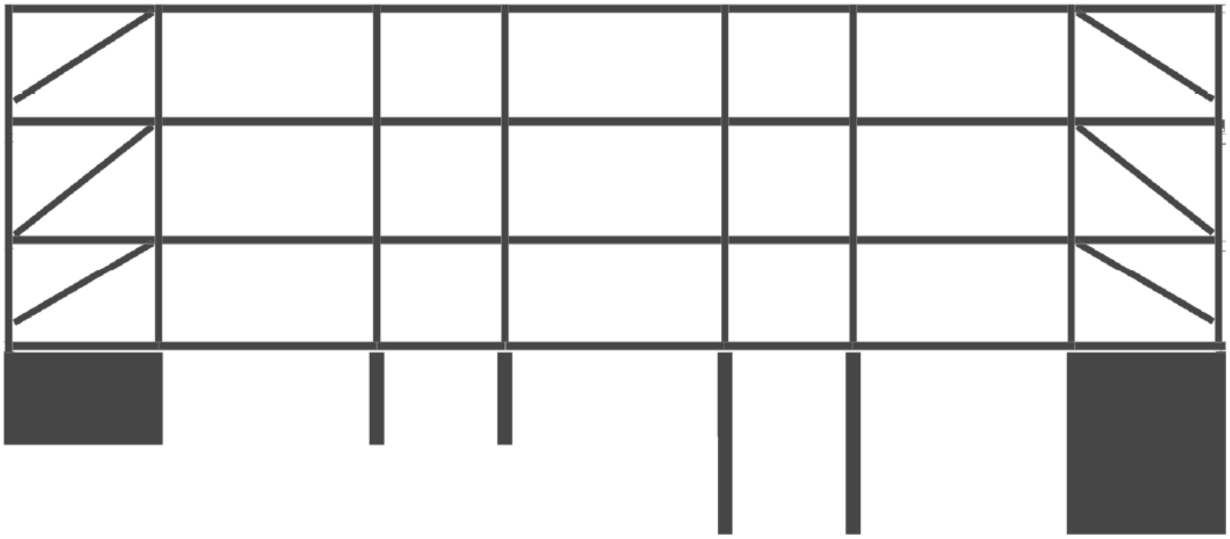


Figure 59 - Rear Elevation: Revit View, with Concrete Piers

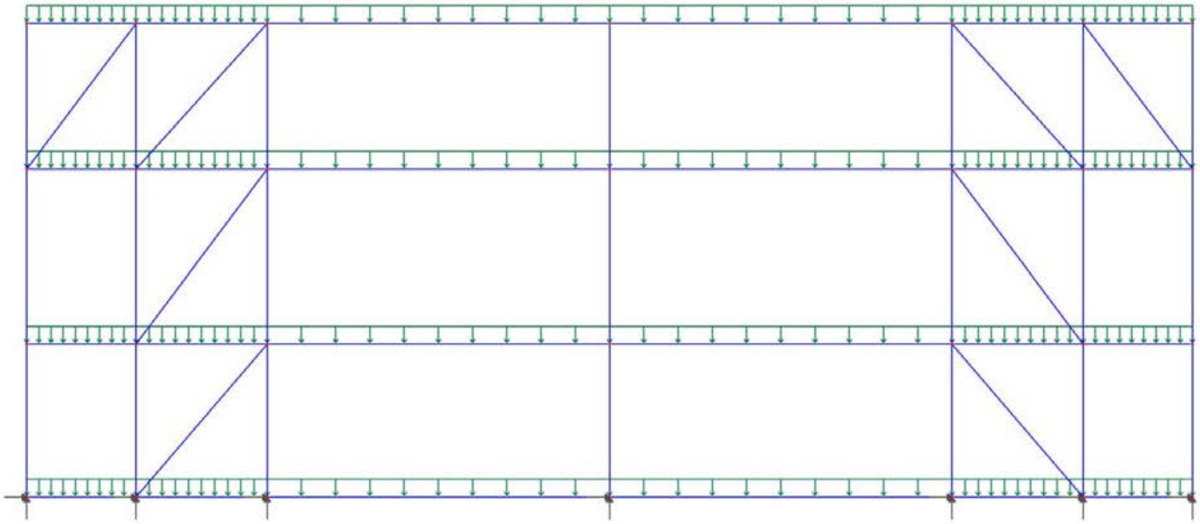


Figure 60 - Left/Right Elevation: Dead Loads

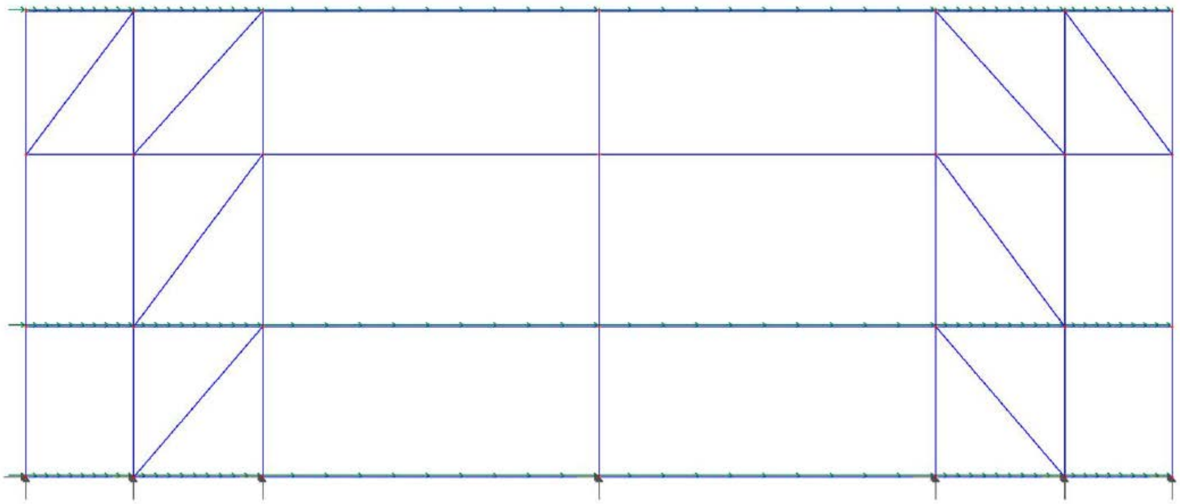


Figure 61 - Left/Right Elevation: Seismic Loads

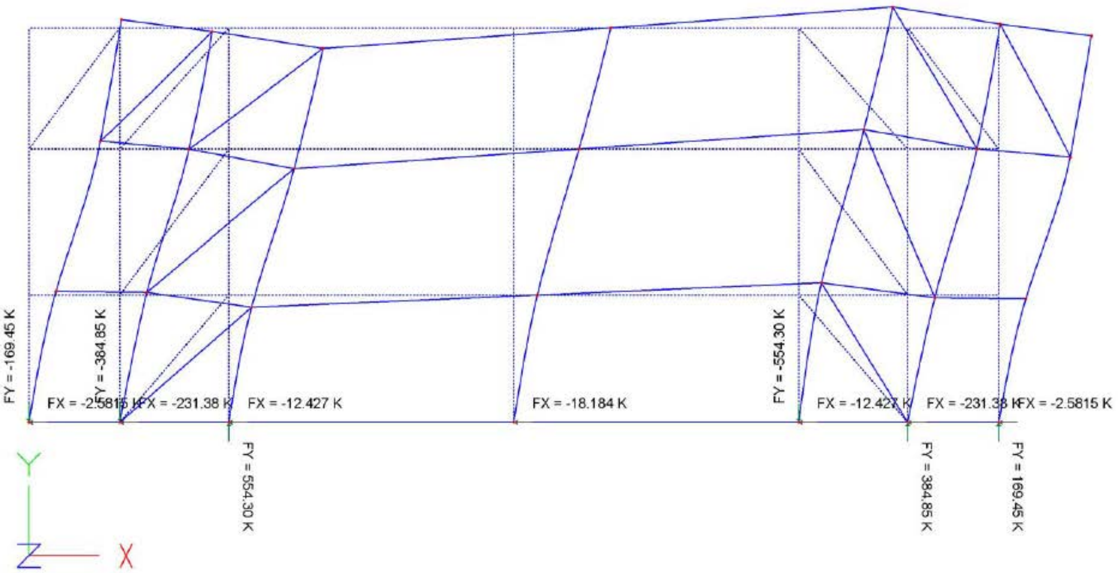


Figure 62 – Left/Right Elevation: Seismic Displacements

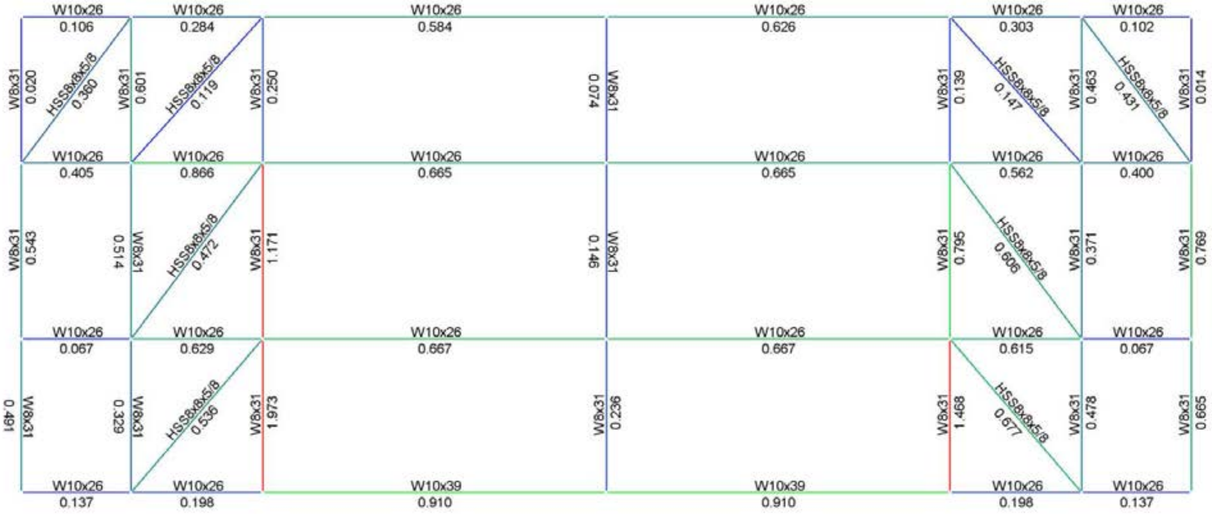


Figure 63 - Left/Right Elevation: Final Sizes & Unity Check

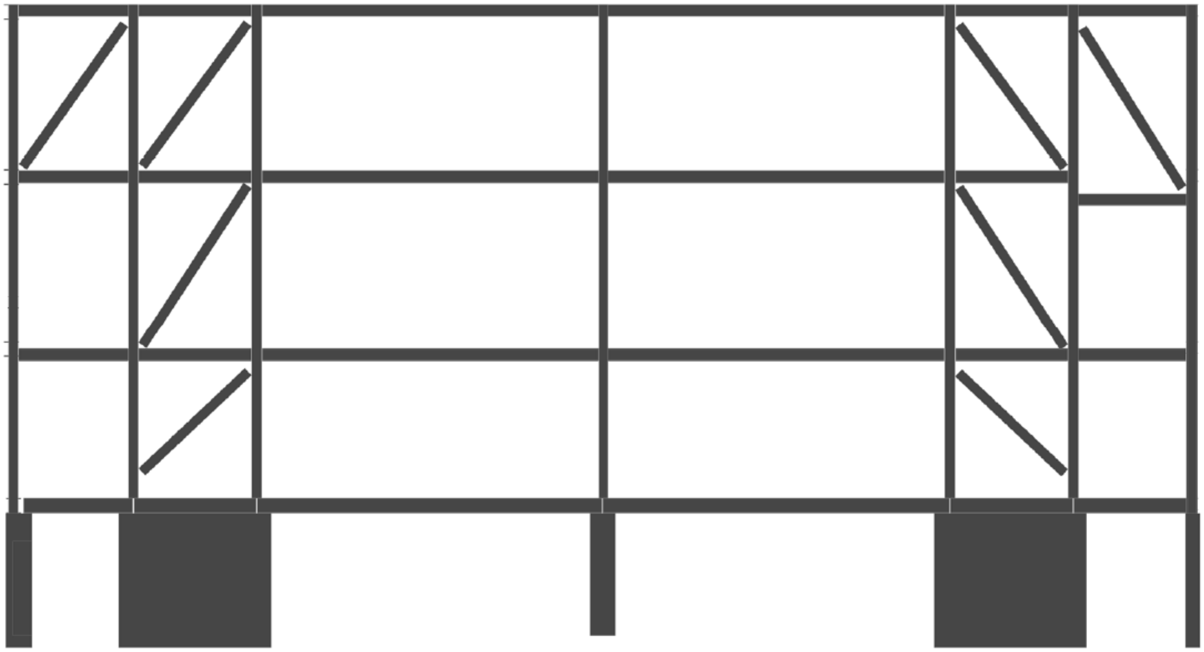


Figure 64 - Left/Right Elevation: Revit View, with Concrete Piers

Studs for shear				
Working Loads				
V	=	229.6	k	
For .75" diamter shear stud with no deck:				
Qn	=	21	k	table 3-21, page 3-209
Ωy	=	2.31		section I6.1 page 101, spec
Qn/Ω	=	21/2.31		
	=	9.1	k/stud	
For 229.6 k				
# studs	=	229.6/9.1		
	=	26	studs	
in 3 rows #/row	=	26/3		
	=	9	studs/row	
Bolts for tension				
Working Loads				
T	=	586.5	k	
Considering only E.Q. tension, neglecting dead load:				
check 1.5" bolts				
Pn/Ω	=	79.5	k	table 7-2, page 7-23
# bolts	=	586.5/79.5		
		8	bolts	(worst case)
Load Case		*Tension*		
E+x	=	586.5	k	
.6D + .7E	=	388.3	k	
D + .7E	=	373.4	k	
use (8) 1.5" bolts				

Concrete Pier Connections

Shear and Uplift Resultant Load:					
R	=	630	k		
Try #4					
Asfy	=	24	k		
Area of new wall to be doweled into existing:					
Area	=	90	ft^2		
Load per SF	=	7	k/SF		
#4 every sqaure foot					

Appendix K – Showcase Atrium Design

Shear Wall Calculations:				
Loads				
F	=	69000		
load per foot wall	=	531	lbs/ft	
Tw	=	37.5	ft	
V	=	19904	lbs	
L wall	=	34		
shear stress in wall	=	6	psi	
Moment	=	199038	ft-lbs	
Tension	=	6220.0	lbs	
Load Factor, 1.6T	=	9952	lbs	
CMU Wall Reinf.				
As	=	9952/60000	in^2	
	=	0.166		
use 2 #4 spaced at 32ft (at end pockets of wall)				
Connection				
v per ft wall	=	585	lbs/ft	
load per anchor	=	2342	lbs	use .75"
spaced at 4-0				
use .75" epoxy anchors at 4-0				
use L5x5x3/8				

Appendix L – Elevated Pool Slab Design

Elevated Pool Slab Design						
Dimensions of pool area						
32'-10"	X	67'-4"				
			67'-4"			
clear span	=	16'				
Slab Thickness						
L/28	=	6.857142857				
Trial Thickness						
7"						
Dead Load	=	Wc*t/12				
		87.5	psf			
Live Load	=	100	psf			
Factored Load	LRFD					
DL	=	105	psf			
LL	=	160	psf			
Total Load (W)	=	265	psf			
Factored Moments at critical sections						
Interior support						
M	=	1/9*W*L^2				
		7.54	ft-kips			
midspan						
M	=	1/14*W*L^2				
		4.85	ft-kips			
Exterior support						
M	=	1/24*W*L^2				
		2.83	ft-kips			
Minimum Reinforcement						
As	=	Mu/ϕfy(d-a/2)				

Stress block,a	=	1	in
effective depth,d	=	7in-1in	
		6	in
at interior support			
As	=	(C33*12)/((0.9*60)*(6-(1/2)))	in^2
		0.305	in^2
Check assumed a			
a	=	Asfy/0.85f'cb	
f'c	=	4000	psi
a	=	0.45	in
Second trial,a=0.45			
As	=	(C33*12)/((0.9*60)*(6-(0.45/2)))	
		0.29	in^2
a for other sections			
a	=	0.45*0.29/0.305	
		0.43	in
at midpsan			
As	=	Mu/ϕfy(d-a/2)	
		0.19	in^2
at exterior support			
As	=	Mu/ϕfy(d-a/2)	
		0.11	in^2
As req'd for Shrinkage and temperature			
As	=	0.0018*12*t	
		0.15	in^2
Check Shear			
Vc	=	2λsqrt(f'c)*bd	
		9107.4	lbs
ϕVc	=	0.75*Vc	
		6830.5	lbs
Vu	=	1.15*WL/2-W*d/12	
		2305.5	lbs

Design strength of slab is adequate						
No shear reinforcement required						
Use No.4 bars	0.2	in^2				
at interior support						
As	=	0.29	in^2			
# bars required	=	As/As(#4bars)				
		1.45	bars			
		use 2	bars			
Spacing	=	12 in strip/#bars				
		6	in spacing			
at mid span						
As	=	0.19	in^2			
# bars	=	0.95	bars			
		use 1	bar			
spacing	=	12	in spacing			
at exterior support						
As	=	0.11	in^2			
# bars	=	0.55	bars			
		use #4 bar @ 12 in spacing				
Shrinkage and Temperature						
As	=	15	in^2			
		use #4 bar @ 12 in	<	18 in max spacing		OK

Bearing Wall Design for Deepest End of Pool					
Height of Deep End Bearing Wall =	96	in			
Tributary Width (Tw)					
16'					
Length of Bearing Wall	ft				
32'-10"					
197/6					
	unbraced length				
Minimum wall thickness					
Lu					
Lu/25 or 4"	3.84	in			
	try 4 in.				
Dead Load	=	(Wc*t/12)*Tw			
		1400	lb/ft		
Live Load	=	1600	lb/ft		
Total Service Load	=	Ptotal			
		98500	lbs		
		98.5	kips		
	LRFD				
Factored Load					
DL	=	1680	lb/ft		
LL	=	2560	lb/ft		
Total Load (W)	=	4240	lb/ft		
		139	kips		

Design axial strength of concrete wall						
tw	=	4 in				
Leff	=	4tw				
		16	in			
Ag	=	Leff*tw				
		64	in^2			
Pn	=	0.55ϕf'cAg[1-(KLu/32tw)^2]				
		43.12	kips	<	139	N.G.
Try tw	=	6	in			
L eff	=	4tw				
		24	in.			
Ag	=	144				
Pn	=	166.32	>	139	kips	OK
Determine vertical and horizontal bars						
Vertical # 5 bars Grade 60	0.31	in^2				
As	=	0.0012tw(12")				
		0.0864	in^2			
spacing	=	12(A(#5bar)/As)				
		43	in			
or 3tw or 18" max						
3tw = 18"						
Use #5 bars @ 18" o.c.						
Horizontal # 5 bars Grade 60						
As	=	0.002tw(12")				
		0.144	in^2			
spacing	=	26	in			
Use #5 bars @ 18" o.c.						
Note about openings:						

*Equivalent of reinforcement should be added at the sides of the openings. Diagonal bars should be included at the corners to control the cracking that will occur there. ACI Code 13.4.2: openings of any size may be located in the area common to intersecting middle strips.

Footing Design for Deepest Bearing Wall (8')								
Sevice Dead Load		1400	lb/ft	for slab				
		600	lb/ft	for wall				
Sevice Live Load		1600	lb/ft					
Allowable soil bearing								
qa	=	3000	psf					
for sandy gravel and/or gravel								
Must verify in field								
Depth to frost line								
N/A since pool is already below grade (assume 3' to bottom of footing)								
Soil unit weight		=	110	pcf				
Concrete								
f'c	=	4000	psi					
Concrete cover								
3" per ACI								
Thickness of footing								
1.5tw	=	1.5*6"						
		9	in.					
Determine effective soil bearing, qe								
qa - (ftg. wt) - (soil wt)								
3000 psf - (9"*150 pcf) - (27"*110pcf)								
2640	psf							
Determine width of footing								
Ptotal	=	Pd + Pl						
		2000 + 1600 lb/ft						
		3600	lb/ft					

Determine req'd width of footing, wf

wf = Ptotal/qe

1.4 ft

Use 1ft - 6 in.

Determine soil bearing pessure fo strength design, qu

qu = (1.2Pd + 1.6Pl)/wf

3306.7 psf

Determine minimum depth of footing, dmin, based on shear

using #5 bar with diameter, 5/8"

d = footing thickness - concrete cover - 1/2 Bar diameter

d = 9" - 3" - 0.5*(5/8")

5.7 in

Vu = qu[(wf/2)-(tw/2)-(d/2)]

869.7 lbs

Check dmin

dmin = Vu/0.85*2*sqrt(f'c)*12

0.67 in < 5.7 in. OK

Determine factored soil pressure moment, Mu, at face of wall

M = qu(Footing overhang)(footing overhang/2)

413.3 ft-lb

Mu/ϕbd^2 = 18.9 psi < 190.3 psi

Use ρmin = 0.0033

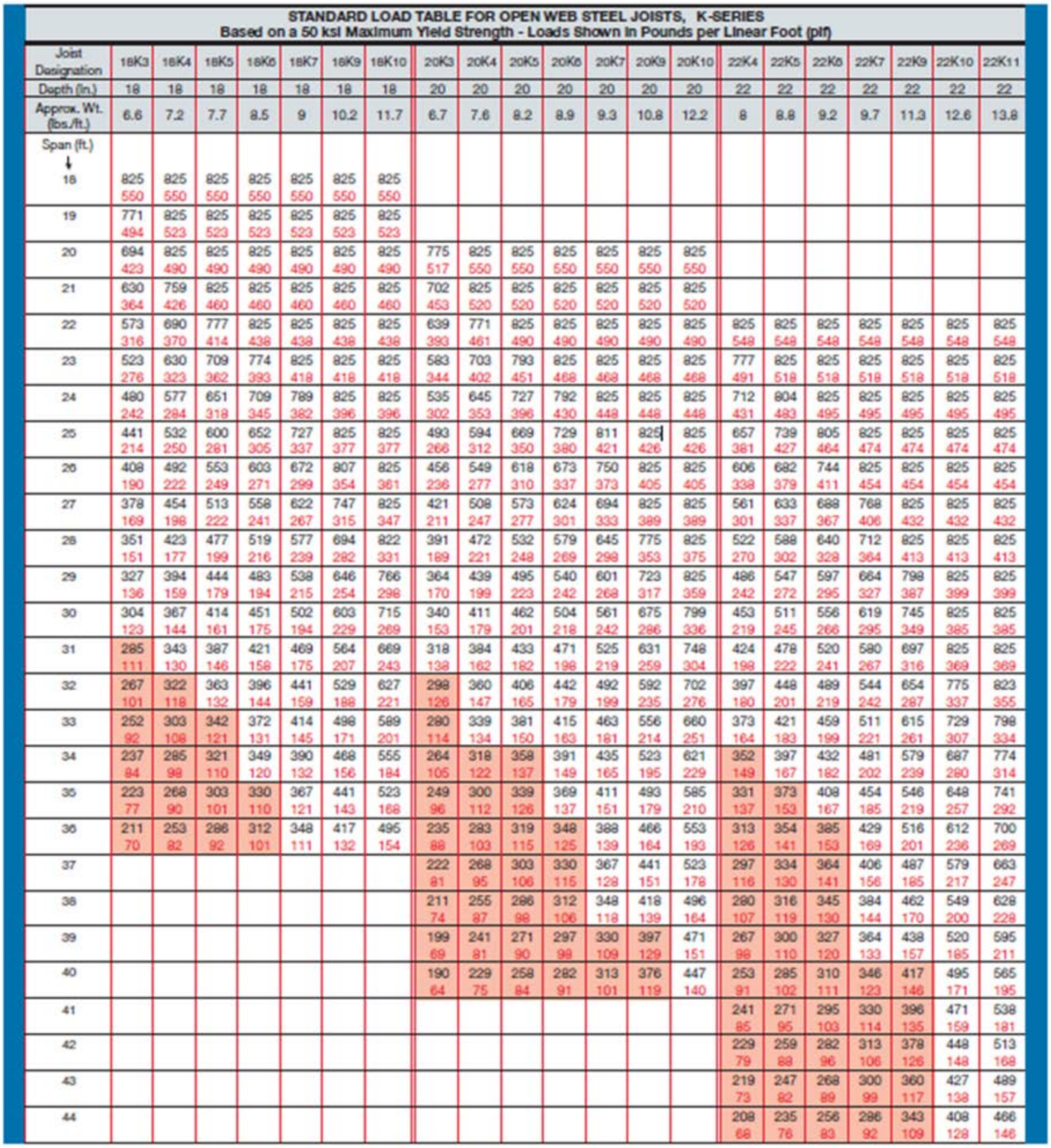
As = ρbd

0.17 in^2

Spacing	=	12"(As_per_bar/As)					
		21.97	in				
Use #5 bars @ 21" spacing							
Shrinkage and Temp. reinforcement							
As	=	0.0018bh					
		0.292	in^2				
Number of bars = As/As_per_#4 bar							
	1.458	bars					
Use 2 - #4 longitudinal temperature/shinkage bars							

Span									
32' - 10"									
Tw	=	2	ft						
Loading Conditions w/ 3.5" slab									
Dead Load Normal Weight Concrete + Metal Decking									
1.0 FD, 1.0 FDV Deck									
		37	psf						
	=	74	lb/ft						
Live Load		100	psf						
	=	200	lb/ft						
LRFD	=	1.2D+1.6L							
		408.8	lb/ft						
Check 20K7 Steel Joist for 33' span									
Factored Load Capacity		=	463	lbs/ft					
Unfactored Live Load Capacity			=	181	lbs/ft				
Factored Live Load Capacity			=	271.5	lbs/ft	>	200	lbs/ft	OK
Check with added self weight									
9.3	lbs/ft								
	USE 20K7 Steel Joists @ 2' o.c.								

LRFD

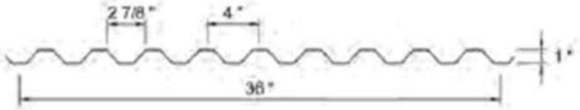


STANDARD LOAD TABLE FOR OPEN WEB STEEL JOISTS, K-SERIES
Based on a 50 ksi Maximum Yield Strength - Loads Shown in Pounds per Linear Foot (plf)

Joist Designation	18K3	18K4	18K5	18K6	18K7	18K9	18K10	20K3	20K4	20K5	20K6	20K7	20K9	20K10	22K4	22K5	22K6	22K7	22K9	22K10	22K11
Depth (in.)	18	18	18	18	18	18	18	20	20	20	20	20	20	20	22	22	22	22	22	22	22
Approx. Wt. (lbs./ft.)	6.6	7.2	7.7	8.5	9	10.2	11.7	6.7	7.6	8.2	8.9	9.3	10.8	12.2	8	8.8	9.2	9.7	11.3	12.6	13.8
Span (ft.) ↓																					
18	825 550	825 550	825 550	825 550	825 550	825 550	825 550														
19	771 494	825 523	825 523	825 523	825 523	825 523	825 523														
20	694 423	825 490	825 490	825 490	825 490	825 490	825 490	775 517	825 550	825 550	825 550	825 550	825 550	825 550							
21	630 364	759 426	825 460	825 460	825 460	825 460	825 460	702 453	825 520	825 520	825 520	825 520	825 520	825 520							
22	573 316	690 370	777 414	825 438	825 438	825 438	825 438	639 393	771 461	825 490	825 490	825 490	825 490	825 490	825 548	825 548	825 548	825 548	825 548	825 548	825 548
23	523 276	630 323	709 362	774 393	825 418	825 418	825 418	583 344	703 402	793 451	825 468	825 468	825 468	825 468	777 491	825 518	825 518	825 518	825 518	825 518	825 518
24	480 242	577 284	651 318	709 345	789 382	825 396	825 396	535 302	645 353	727 396	792 430	825 448	825 448	825 448	712 431	804 483	825 495	825 495	825 495	825 495	825 495
25	441 214	532 250	600 281	652 305	727 337	825 377	825 377	493 266	594 312	669 350	729 380	811 421	825 426	825 426	657 381	739 427	805 464	825 474	825 474	825 474	825 474
26	408 190	492 222	553 249	603 271	672 299	807 354	825 361	456 236	549 277	618 310	673 337	750 373	825 405	825 405	606 338	682 379	744 411	825 454	825 454	825 454	825 454
27	378 169	454 198	513 222	558 241	622 267	747 315	825 347	421 211	508 247	573 277	624 301	694 333	825 389	825 389	561 301	633 337	688 367	768 406	825 432	825 432	825 432
28	351 151	423 177	477 199	519 216	577 239	694 282	822 331	391 189	472 221	532 248	579 269	645 298	775 353	825 375	522 270	588 302	640 328	712 364	825 413	825 413	825 413
29	327 136	394 159	444 179	483 194	538 215	646 254	766 298	364 170	439 199	495 223	540 242	601 268	723 317	825 359	486 242	547 272	597 295	664 327	798 387	825 399	825 399
30	304 123	367 144	414 161	451 175	502 194	603 229	715 269	340 153	411 179	462 201	504 218	561 242	675 286	799 336	453 219	511 245	556 266	619 295	745 349	825 385	825 385
31	285 111	343 130	387 146	421 158	469 175	564 207	669 243	318 138	384 162	433 182	471 198	525 219	631 259	748 304	424 198	478 222	520 241	580 267	697 316	825 369	825 369
32	267 101	322 118	363 132	396 144	441 159	529 188	627 221	298 126	360 147	406 165	442 179	492 199	592 235	702 276	397 180	448 201	489 219	544 242	654 287	775 337	823 355
33	252 92	303 108	342 121	372 131	414 145	498 171	589 201	280 114	339 134	381 150	415 163	463 181	556 214	660 251	373 164	421 183	459 199	511 221	615 261	729 307	798 334
34	237 84	285 98	321 110	349 120	390 132	468 156	555 184	264 105	318 122	358 137	391 149	435 165	523 195	621 229	352 149	397 167	432 182	481 202	579 239	687 280	774 314
35	223 77	268 90	303 101	330 110	367 121	441 143	523 168	249 96	300 112	339 126	369 137	411 151	493 179	585 210	331 137	373 153	408 167	454 185	546 219	648 257	741 292
36	211 70	253 82	286 92	312 101	348 111	417 132	495 154	235 88	283 103	319 115	348 125	388 139	466 164	553 193	313 126	354 141	385 153	429 169	516 201	612 236	700 269
37								222 81	268 95	303 106	330 115	367 128	441 151	523 178	297 116	334 130	364 141	406 156	487 185	579 217	663 247
38								211 74	255 87	286 98	312 106	348 118	418 139	496 164	280 107	316 119	345 130	384 144	462 170	549 200	628 228
39								199 69	241 81	271 90	297 98	330 109	397 129	471 151	267 98	300 110	327 120	364 133	438 157	520 185	595 211
40								190 64	229 75	258 84	282 91	313 101	376 119	447 140	253 91	285 102	310 111	346 123	417 146	495 171	565 195
41															241 85	271 95	295 103	330 114	396 135	471 159	538 181
42															229 79	259 88	282 96	313 106	378 126	448 148	513 168
43															219 73	247 82	268 89	300 99	360 117	427 138	489 157
44															208 68	235 76	256 83	286 92	343 109	408 128	466 146

Span									
32' - 10"									
Tw	=	3.1	ft	0.0833					
Loading Conditions w/ 3.5" slab									
Dead Load Normal Weight Concrete + Metal Decking									
1.0 FD, 1.0 FDV Deck									
	=	37	psf						
		114.1	lb/ft						
Live Load		100	psf						
	=	308.3	lb/ft						
LRFD	=	1.2D+1.6L							
		630.2	lb/ft						
Check Steel Joist 20K10 for 33' span									
Factored Load Capacity including self weight				=	660	lbs/ft			
Unfactored Live Load Capacity			=	251	lbs/ft				
Factored Live Load Capacity			=	376.5	lbs/ft	>	308.3	lbs/ft	OK
weight of joist									
12.2	lbs/ft								

1.0 FD, 1.0 FDV DECK



SECTION PROPERTIES

Gage	Fy (ksi)	Coverage (in)	Thickness (in)	Weight (psf)	Ip (in⁴/ft)	In (in⁴/ft)	Sp (in³/ft)	Sn (in³/ft)
26	60	36	0.0179	0.96	0.040	0.040	0.067	0.071
24	60	36	0.0238	1.28	0.057	0.057	0.098	0.103
22	60	36	0.0295	1.57	0.073	0.073	0.130	0.134
20	60	36	0.0358	1.91	0.088	0.088	0.167	0.165

Height	1 in.
Fy (minimum)	60 ksi
Modulus of Elasticity	29500 ksi

CONSTRUCTION SPANS

Total Slab Depth (in.)	Gage	Normal Weight Concrete (145 pcf)				Light Weight Concrete (110 pcf)			
		Concrete Weight (psf)	Maximum Construction Clear Span (ft.-in.)			Concrete Weight (psf)	Maximum Construction Clear Span (ft.-in.)		
			Single	Double	Triple		Single	Double	Triple
2 1/2	26	25	3 - 3	4 - 9	4 - 9	19	3 - 4	5 - 0	5 - 1
	24	25	4 - 3	6 - 3	6 - 4	19	4 - 5	6 - 8	6 - 9
	22	25	5 - 2	7 - 9	7 - 8	19	5 - 5	8 - 3	8 - 4
	20	25	6 - 1	8 - 9	8 - 1	19	6 - 4	9 - 7	8 - 10
3	26	31	3 - 2	4 - 6	4 - 7	24	3 - 3	4 - 9	4 - 10
	24	31	4 - 2	5 - 11	6 - 0	24	4 - 4	6 - 4	6 - 5
	22	31	5 - 0	7 - 3	7 - 2	24	5 - 3	7 - 10	7 - 9
	20	31	5 - 11	8 - 3	7 - 7	24	6 - 2	8 - 11	8 - 2
3 1/2	26	37	3 - 1	4 - 4	4 - 4	29	3 - 2	4 - 7	4 - 7
	24	37	4 - 0	5 - 8	5 - 9	29	4 - 2	6 - 1	6 - 2
	22	37	4 - 10	6 - 11	6 - 9	29	5 - 1	7 - 5	7 - 3
	20	37	5 - 9	7 - 9	7 - 2	29	6 - 0	8 - 5	7 - 9
4	26	43	3 - 0	4 - 2	4 - 2	33	3 - 2	4 - 5	4 - 6
	24	43	3 - 11	5 - 5	5 - 6	33	4 - 1	5 - 10	5 - 11
	22	43	4 - 9	6 - 7	6 - 5	33	5 - 0	7 - 2	7 - 0
	20	43	5 - 6	7 - 5	6 - 10	33	5 - 10	8 - 1	7 - 5
4 1/2	26	49	2 - 11	4 - 0	4 - 1	38	3 - 1	4 - 3	4 - 4
	24	49	3 - 10	5 - 3	5 - 3	38	4 - 0	5 - 8	5 - 8
	22	49	4 - 7	6 - 4	6 - 2	38	4 - 10	6 - 10	6 - 8
	20	49	5 - 3	7 - 1	6 - 6	38	5 - 8	7 - 8	7 - 1
5	26	55	2 - 11	3 - 10	3 - 11	42	3 - 0	4 - 2	4 - 3
	24	55	3 - 9	5 - 0	5 - 1	42	3 - 11	5 - 6	5 - 6
	22	55	4 - 6	6 - 1	5 - 11	42	4 - 9	6 - 8	6 - 6
	20	55	5 - 1	6 - 10	6 - 4	42	5 - 7	7 - 6	6 - 10

Notes

1. Section properties are calculated using the AISI Cold Formed Steel Design Specifications, 1996 Edition.
2. Loads and maximum construction spans are based on the SDI Design Manual for Composite Decks, Form Decks and Roof Decks, Publication No. 30.
3. Minimum interior bearing length shall be 3". Minimum exterior bearing length shall be 1 1/2".

ALLOWABLE SUPERIMPOSED UNIFORM LOADS

Slab Depth (in.)	Reinforcement		Uniform Load (psf)										
			Clear Span (ft. - in.)										
	Mesh	As	2 - 6	2 - 9	3 - 0	3 - 6	4 - 0	4 - 6	5 - 0	5 - 6	6 - 0	6 - 6	7 - 0
2 1/2	6 x 6 W 1.4 x W 1.4	0.028*	94	77	65	48	36	29	23	19	16	13	12
	6 x 6 W 2.1 x W 2.1	0.042	138	114	96	70	54	42	34	28	24	20	17
	6 x 6 W 2.9 x W 2.9	0.058	187	154	129	95	73	57	46	38	32	27	23
3	6 x 6 W 1.4 x W 1.4	0.028*	126	104	88	64	49	39	31	26	22	18	16
	6 x 6 W 2.1 x W 2.1	0.042	187	154	130	95	73	57	46	38	32	27	23
	6 x 6 W 2.9 x W 2.9	0.058	254	210	176	129	99	78	63	52	44	37	32
3 1/2	6 x 6 W 2.1 x W 2.1	0.042*	400	348	292	214	164	130	105	87	73	62	53
	6 x 6 W 2.9 x W 2.9	0.058	400	400	391	287	220	174	140	116	97	83	71
	4 x 4 W 2.9 x W 2.9	0.087	400	400	400	400	325	257	208	172	144	123	106
4	6 x 6 W 2.1 x W 2.1	0.042*	400	400	366	269	206	163	132	109	91	78	
	6 x 6 W 2.9 x W 2.9	0.058*	400	400	400	363	278	219	177	147	123	105	
	4 x 4 W 2.9 x W 2.9	0.087	400	400	400	400	400	325	263	217	183	156	
4 1/2	6 x 6 W 2.1 x W 2.1	0.042*	400	400	400	324	248	196	158	131	110	94	
	6 x 6 W 2.9 x W 2.9	0.058*	400	400	400	400	335	265	214	177	149	127	
	4 x 4 W 2.9 x W 2.9	0.087	400	400	400	400	400	394	319	263	221	188	
5	6 x 6 W 2.9 x W 2.9	0.058*	400	400	400	400	393	311	251	208	174		
	4 x 4 W 2.9 x W 2.9	0.087	400	400	400	400	400	400	374	309	260		
	4 x 4 W 4.0 x W 4.0	0.120	400	400	400	400	400	400	400	400	350		

Notes:
1. *(As) does not meet ACI criteria for temperature and shrinkage reinforcement (0.0018Ac).
2. Uniform loads shown are based on reinforcement mesh being draped over supports for all slab depths over 3"
3. If uncoated deck is used, the weight of the slab must be deducted from the uniform loads
4. Uniform loads are based on three span conditions and ACI moment coefficients.
5. Deck gages recommended are for normal weight concrete and based on SDI criteria for unshored spans

Recommended Gage Key: 26 Gage | 24 Gage | 22 Gage | 20 Gage

NEW MILLENNIUM
BUILDING SYSTEMS

Span

32' - 10"

Tw = 4.0 ft 0.0833

Loading Conditions w/ 3.5" slab

Dead Load Normal Weight Concrete + Metal Decking

1.0 FD, 1.0 FDV Deck

= 37 psf

148.0 lb/ft

Live Load 100 psf

= 400.0 lb/ft

LRFD = 1.2D+1.6L

817.6 lb/ft

Check Steel Joist 24LH06 for 33' span

Factored Load Capacity including self weight = 906 lbs/ft

Unfactored Live Load Capacity = 411 lbs/ft

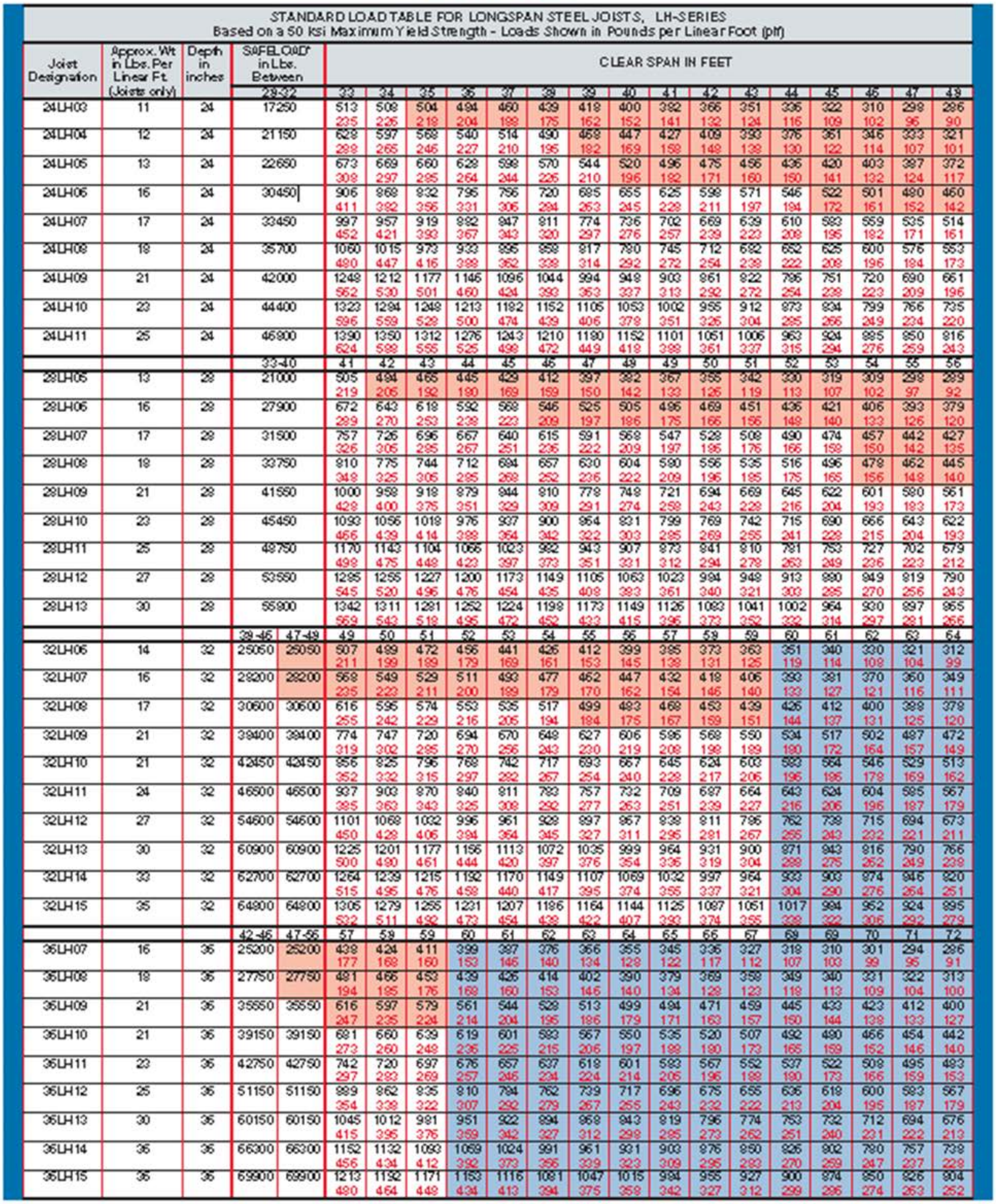
Factored Live Load Capacity = 616.5 lbs/ft > 400.0 lbs/ft OK

weight of joist

16 lbs/ft

LONGSPAN STEEL JOISTS, LH-SERIES

LRFD

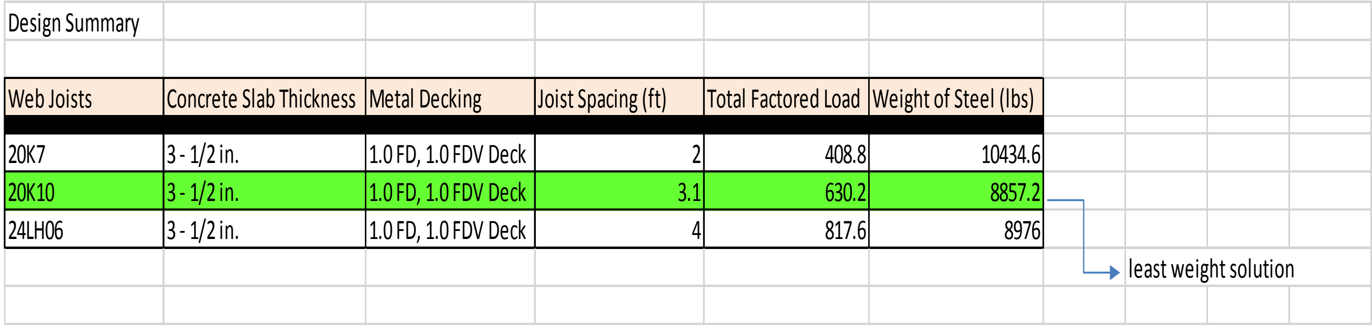


STANDARD LOAD TABLE FOR LONGSPAN STEEL JOISTS, LH-SERIES
Based on a 50 ksi Maximum Yield Strength - Loads Shown in Pounds per Linear Foot (plf)

Joist Designation	Approx. Wt in Lbs. Per Linear Ft. (Joists only)	Depth in inches	SAFE LOAD* in Lbs. Between		CLEAR SPAN IN FEET															
			28-32		33	34	35	36	37	38	39	40	41	42	43	44	45	46	47	48
24LH03	11	24	17250		513 235	508 226	504 218	494 204	460 188	439 175	418 162	400 152	392 141	366 132	351 124	336 116	322 109	310 102	298 96	286 90
24LH04	12	24	21150		628 288	597 265	568 246	540 227	514 210	490 195	468 182	447 169	427 158	409 148	393 138	376 130	361 122	346 114	333 107	321 101
24LH05	13	24	22650		673 308	669 297	660 285	628 264	598 244	570 226	544 210	520 196	496 182	475 171	456 160	436 150	420 141	403 132	387 124	372 117
24LH06	16	24	30450		906 411	868 382	832 356	795 331	756 306	720 284	685 263	655 245	625 228	598 211	571 197	546 184	522 172	501 161	480 152	460 142
24LH07	17	24	33450		997 452	957 421	919 393	882 367	847 343	811 320	774 297	736 276	702 257	669 239	639 223	610 208	583 195	559 182	535 171	514 161
24LH08	18	24	35700		1060 480	1015 447	973 416	933 388	895 362	858 338	817 314	780 292	745 272	712 254	682 238	652 222	625 208	600 196	576 184	553 173
24LH09	21	24	42000		1248 562	1212 530	1177 501	1146 460	1096 424	1044 393	994 363	948 337	903 313	861 292	822 272	786 254	751 238	720 223	690 209	661 196
24LH10	23	24	44400		1323 596	1284 559	1248 528	1213 500	1182 474	1152 439	1105 406	1053 378	1002 351	955 326	912 304	873 285	834 266	799 249	766 234	735 220
24LH11	25	24	46800		1390 624	1350 588	1312 555	1276 525	1243 498	1210 472	1180 449	1152 418	1101 388	1051 361	1006 337	963 315	924 294	885 276	850 259	816 243
			33-40		41	42	43	44	45	46	47	48	49	50	51	52	53	54	55	56
28LH05	13	28	21000		505 219	484 205	465 192	445 180	429 169	412 159	397 150	382 142	367 133	355 126	342 119	330 113	319 107	309 102	298 97	289 92
28LH06	16	28	27900		672 289	643 270	618 253	592 238	568 223	546 209	525 197	505 186	486 175	469 166	451 156	436 148	421 140	406 133	393 126	379 120
28LH07	17	28	31500		757 326	726 305	696 285	667 267	640 251	615 236	591 222	568 209	547 197	528 186	508 176	490 166	474 158	457 150	442 142	427 135
28LH08	18	28	33750		810 348	775 325	744 305	712 285	684 268	657 252	630 236	604 222	580 209	556 196	535 185	516 175	496 165	478 156	462 148	445 140
28LH09	21	28	41550		1000 428	958 400	918 375	879 351	844 329	810 309	778 291	748 274	721 258	694 243	669 228	645 216	622 204	601 193	580 183	561 173
28LH10	23	28	45450		1093 466	1056 439	1018 414	976 388	937 364	900 342	864 322	831 303	799 285	769 269	742 255	715 241	690 228	666 215	643 204	622 193
28LH11	25	28	49750		1170 498	1143 475	1104 448	1066 423	1023 397	982 373	943 351	907 331	873 312	841 294	810 278	781 263	753 249	727 236	702 223	679 212
28LH12	27	28	53550		1285 545	1255 520	1227 496	1200 476	1173 454	1149 435	1105 408	1063 383	1023 361	984 340	948 321	913 303	880 285	849 270	819 256	790 243
28LH13	30	28	55800		1342 569	1311 543	1281 518	1252 495	1224 472	1198 452	1173 433	1149 415	1126 396	1083 373	1041 352	1002 332	964 314	930 297	897 281	865 266
			39-46	47-48	49	50	51	52	53	54	55	56	57	58	59	60	61	62	63	64
32LH06	14	32	25050	25050	507 211	489 199	472 189	456 179	441 169	426 161	412 153	399 145	385 138	373 131	363 125	351 119	340 114	330 108	321 104	312 99
32LH07	16	32	28200	28200	568 235	549 223	529 211	511 200	493 189	477 179	462 170	447 162	432 154	418 146	406 140	393 133	381 127	370 121	360 116	349 111
32LH08	17	32	30600	30600	616 255	595 242	574 229	553 216	535 205	517 194	499 184	483 175	468 167	453 159	439 151	426 144	412 137	400 131	388 125	378 120
32LH09	21	32	39400	39400	774 319	747 302	720 285	694 270	670 256	648 243	627 230	606 219	586 208	568 198	550 189	534 180	517 172	502 164	487 157	472 149
32LH10	21	32	42450	42450	856 352	825 332	796 315	768 297	742 282	717 267	693 254	667 240	645 228	624 217	603 206	583 196	564 186	546 178	529 169	513 162
32LH11	24	32	46500	46500	937 385	903 363	870 343	840 325	811 308	783 292	757 277	732 263	709 251	687 239	664 227	643 216	624 206	604 196	585 187	567 179
32LH12	27	32	54600	54600	1101 450	1068 428	1032 406	996 384	961 364	928 345	897 327	867 311	838 295	811 281	786 267	762 255	738 243	715 232	694 221	673 211
32LH13	30	32	60900	60900	1225 500	1201 480	1177 461	1156 444	1113 420	1072 397	1035 376	999 354	964 336	931 319	900 304	871 288	843 275	816 262	790 249	766 238
32LH14	33	32	62700	62700	1264 515	1239 495	1215 476	1192 458	1170 440	1149 417	1107 395	1069 374	1032 355	997 337	964 321	933 304	903 290	874 276	846 264	820 251
32LH15	35	32	64800	64800	1305 532	1279 511	1255 492	1231 473	1207 454	1186 438	1164 422	1144 407	1125 393	1087 374	1051 355	1017 338	984 322	952 306	924 292	895 279
			42-46	47-56	57	58	59	60	61	62	63	64	65	66	67	68	69	70	71	72
36LH07	16	36	25200	25200	438 177	424 168	411 160	399 153	387 146	376 140	366 134	355 128	345 122	336 117	327 112	318 107	310 103	301 99	294 95	286 91
36LH08	18	36	27750	27750	481 194	466 185	453 176	439 168	426 160	414 153	402 146	390 140	379 134	369 128	358 123	349 118	340 113	331 109	322 104	313 100
36LH09	21	36	35550	35550	616 247	597 235	579 224	561 214	544 204	528 195	513 186	499 179	484 171	471 163	459 157	445 150	433 144	423 138	412 133	400 127
36LH10	21	36	39150	39150	681 273	660 260	639 248	619 236	601 225	583 215	567 206	550 197	535 188	520 180	507 173	492 165	480 159	466 152	454 146	442 140
36LH11	23	36	42750	42750	742 297	720 283	697 269	676 257	657 246	637 234	618 224	601 214	583 205	567 196	552 188	537 180	522 173	508 166	495 159	483 153
36LH12	25	36	51150	51150	889 354	862 338	835 322	810 307	784 292	762 279	739 267	717 255	696 243	675 232	655 222	636 213	618 204	600 195	583 187	567 179
36LH13	30	36	60150	60150	1045 415	1012 395	981 376	951 359	922 342	894 327	868 312	843 298	819 285	796 273	774 262	753 251	732 240	712 231	694 222	676 213
36LH14	36	36	66300	66300	1152 456	1132 434	1093 412	1059 392	1024 373	991 356	961 339	931 323	903 309	876 295	850 283	826 270	802 259	780 247	757 237	738 228
36LH15	36	36	69900	69900	1213 480	1192 464	1171 448	1153 434	1116 413	1081 394	1047 375	1015 358	984 342	955 327	927 312	900 299	874 286	850 274	826 263	804 252

† Errata correction posted by SJI 02/16/2007.

	Dimensions of pool area						
	32'-10"	X	67'-4"				
	20K10 Joist @ 3.1 ft o.c.						
	# of Joists Needed						
	Pool Length/spacing		=	21.7			
			use	22			
	Total weight of joists						
	# of joists * self weight for 33' span			=	8857.2	lbs	
	12.2	lbs/ft					
	24LH06 Joist @ 4ft o.c.						
	# of Joists Needed						
	Pool Length/spacing		=	16.8			
			use	17			
	Total weight of joists						
	# of joists * self weight for 33' span			=	8976	lbs	
	16	lbs/ft					
	20K7 @ 2 ft o.c.						
	# of Joists Needed						
	Pool Length/spacing		=	33.7			
			use	34			
	Total weight of joists						
	# of joists * self weight for 33' span			=	10434.6	lbs	
	9.3	lbs/ft					



Design Summary

Web Joists	Concrete Slab Thickness	Metal Decking	Joist Spacing (ft)	Total Factored Load	Weight of Steel (lbs)
20K7	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	2	408.8	10434.6
20K10	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	3.1	630.2	8857.2
24LH06	3 - 1/2 in.	1.0 FD, 1.0 FDV Deck	4	817.6	8976

least weight solution

Appendix M – Cost Breakdown

Section	Cost
Demolition	$ 2,363,374.00
Square Foot	$ 3,611,285.52
Structural Assemblies	$ 172,155.71
Site	$ 607,699.42
Total Construction Cost	$ 6,754,514.65
Liability Insurance for One year is .24% of Construction Cost	$ 16,437.18
Permits $11 Per $1000 of Construction Cost	$ 75,337.08
10% Design Cost	$ 684,882.57
10% Overhead	$ 684,882.57
10% Profit	$ 684,882.57
Location Factor	1.1
Alumni Gym Total Cost of Completion	$ 9,791,030.28

Site/ Logistics	S.F Cost	S.F	Unit Cost	Units	Total cost
Signage 1.25" Letters, 12" Long (NCE 321)			$ 5.79	20	$ 115.80
Temporary Power (NCE 322)	$ 2.22	34.255			$ 76.05
Portable Toilets Deluxe per month (NCE 322)			$ 120.00	12	$ 1,440.00
Hydraulic Truck Canes 80 Ton per Hour (NCE 322)			$ 334.00	1600	$ 534,400.00
Self- Powered Boom-Lift 31'-40' per month (NCE 327)			$ 1,780.00	10	$ 17,800.00
Scaffolding Rental 21' Wide with Base Plates per month (NCE 332)			$ 179.00	8	$ 1,432.00
Temporary Shoring 500SF per Month (NCE 332)			$ 287.00	3	$ 861.00
Chain Link Fence 501 to 701 Feet (NCE 334)	$ 1.86	14000			$ 26,040.00
6'x 24' Gates (NCE 334)			$ 321.00	6	$ 1,926.00
Cleanup (NCE 335)	7.17	34.225			$ 245.39
Temporary Utilities (BBC 16)	36	34.255			$ 1,233.18
Fall Protection Equipment (BBC 18)	3.26	5000			$ 16,300.00
Personnal Protective Equipment (BBC 17)			290	20	$ 5,800.00
Total					$ 607,669.42

Quantity	Length/ Volume	Cost	Total Cost
4	1@2.17CY, 1@1.11CY, 1@1.05CY, 1@2.07CY	$100/CY	$ 2,140.00
6	1@1.33CY, 1@.71CY, 1@.75CY,1@0.77CY, 1@1.45CY, 1@1.5CY	$100/CY	$ 2,151.00
10	10@ 34.04'	60.5	$ 13,795.50
12	11@34.04', 1@35.125'	111	$ 35,633.07
4	2@34.04', 2@35.125'	55.5	$ 5,064.25
60	15@18.26',15@9.52', 15@19.49', 15@22.8'	169.5	$ 44,329.13
6	2@12.92, 2@12.33, 2@12.05	55.75	$ 8,022.50
22	22@33	13.8	$ 11,132.61
8	7@4.1CY, 1@4.1CY	$100/CY	$ 5,278.00
5	1@8.58CY, 1@13.478CY, 2@ 8.99CY,1@11.84CY	$100/CY	$ 7,687.81
273.813786 CY		109 for 1 CY	$ 29,845.70
2112.28 SF		3.35 SF	$ 7,076.14
			$ 172,155.71
Steel	$2500/Ton		
Concrete	$100CY		

RS Means 2013 Square Foot Costs (pg 102-103)						
College, Classroom, 2-3 Story						
Item	S.F Cost	S.F	Unit Cost	Units	Total cost	
Elevators			38,750	each	$ 38,750.00	
Total					*$ 38,750.00*	
HVAC	19	34,255			$ 650,845.00	
Total					$ 650,845.00	
Electrical						
Electrical Service	4.58	34255			$ 156,887.90	
Lighting and Wiring	12.59	34255			$ 431,270.45	
Communications	6.77	34255			$ 231,906.35	
E. Generator	0.68	34255			$ 23,293.40	
Total					*$ 843,358.10*	
Interiors						
Partitions	7.23	34255			$ 247,663.65	
Interior Doors	5.27	34255			$ 180,523.85	
Fittings	4.76	34255			$ 163,053.80	
Stair Construction	5	34255			$ 171,275.00	
Wall Finishes	3.74	34255			$ 128,113.70	
Floor Finishes	4.86	34255			$ 166,479.30	
Ceiling Finishes	6.57	34255			$ 225,055.35	
Total					*$ 1,282,164.65*	
Plumbing						
Plumbing Fixtures	15.67	34255			$ 536,775.85	
Oil fired Hot Water Heater	2.25	34255			$ 77,073.75	
Roof Drains	0.59	34255			$ 20,210.45	
Total					*$ 634,060.05*	
Fire Protection						
Sprinklers	3	34255			$ 102,765.00	
Standpipes	0.3	34255			$ 10,276.50	
Total						
Stone Refurbishing						
Cut and Repoint Brick	7.4	5534.57			$ 40,955.82	
Total					*$ 40,955.82*	
Roofing						
Roof Coverings	2.74	2960			$ 8,110.40	
Roof Total					*$ 8,110.40*	

Demolition	S.F Cost	S.F	Unit Cos	Units	Total cost
Masonry Building (pp338 2014 National Construction Estimator)	4.52	34255			$ 164,832.60
Plaster Walls (pp104 2014 National Construction Estimator)	0.44	34255			$ 15,072.20
Carpet (pp 101 National Construction Estimator)	7.38	755			$ 5,571.90
Concrete Slab Reinforced Removal (BBC pg 32)	29	2400			$ 69,600.00
Casework Demo Gutting (BBC 344)	7.2	34255			$ 246,636.00
Roof Demo (pp 338NCE)	114	2960			$ 337,440.00
Ceiling Demo (pp339 NCE)	0.98	34255			$ 33,569.90
Access Holes (pp340 NCE)	3.68	10			$ 36.80
Asbestos Surveying (341 NCE)			90	8	$ 720.00
Asbestos Removal (342 NCE)	70.9	5000			$ 354,500.00
Dumpter Rental 30 C.Y. Capacity (33 BBC)			890	12	$ 10,680.00
Debris Removal (Wheelbarrow) (340 NCE)	19.17	15000			$ 287,550.00
Debris Removal (Trash Chutes) (340 NCE)	25.38	15000			$ 380,700.00
Remove Framing (33 BBC)	353.7	1000			$ 353,700.00
Total					$ 2,260,609.40

Appendix N – Elevator Shaft Calculations

Design of CMU Elevator Shaft			
wt of wall	=	4 stories*1ft*10ft*90lbs/ft^3	
	=	3600	lbs
fa	=	.25f'm*(1- (xx/(yy*r)^2	
fa	=	3600/(12*8)	
	=	37.5	lbs/in^2
I	=	(bh^3)/(12) + Ad^2	
Ad^2	=	2*1.5*12*3.2^2	
		368.64	
A	=	2*1.5*12	
	=	36	
r	=	(368.6/36)^.5	
		3.2	
(1- (xx/(yy*r)^2	=	1-(120/(140*3.2))^2	
		0.93	
solve for f'm:			
fa	=	.25f'm*(1- (xx/(yy*r)^2	
Req'd f'm	=	37.5*4/.93	
		161	lbs/in^2
units = 1,900 lbs/in^2 & Type N mortar			
f'm = 1,350 lbs/in^2 > Req'd f'm = 161 lbs/in^2			
Reinforcing			
Code: 1.17.3.2.3.1 Minimum Reinforcement Requirements			
Vertical Reinforcement	=	0.2	in^2
Provide reinf. within:			
16" of openings			
8" of movement joints			
8" of end walls			
maximum spacing of 120"			
Horizontal Reinforcement	=	0.2	in^2
at bond beams			
or at least 2 longitudinal wires of W1.7			
*see plan for bar sizes and spacing			

Appendix O - *List of E-Files*

Analysis

Truss

Truss Analysis Summary

Truss Member Stresses Forces

Gravity Load Analysis

Level 4 framing – wood beams

Level 4 framing – steel girders

Framing Level 3

Wind Analysis

Building Wind

MECA Wind

Seismic Analysis

Seismic

Finite Element End Wall

MECA Seismic

Pool Slab

Pool Slab Design

Sources for pool slab

BIM Models

New Structural Model

Existing

Navisworks Model

Original Sources

Original Drawings – Alumni, 1914

Original Specs

Construction

Site Logistics

Site Plan

Primavera Schedule

Estimate

Photos

Alumni Tour #1

Site Tour