Design of Recreation Center at WPI

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.

Submitted By:

Benjamin Erle ________________

Jason Gray ________________

Charles Labbee ________________

To:

Project Advisor

Professor Tahar El-Korchi ________________

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Abstract

This project was to investigate various design methods for the new recreational facility for Worcester Polytechnic Institute (WPI). A floor plan was developed based on the need of recreational spaces and steel design of the building. Beams, columns and girders were designed throughout the four floors. The design included foundations for the building and the pool. This project also investigated design options to improve the “green” building design and obtain a silver LEED accreditation rating. Cost estimating was also conducted based on materials required for the building.

Authorship

1. INTRODUCTION .... Ben
2. BACKGROUND
    City of Worcester's Building Requirements .... Jason
    Structural Design .... Chuck, Ben, Jason
    LEED Certification .... Ben
3. METHODOLOGY
    Structural Layout .... Jason
    Structural Analysis & Design .... Ben, Chuck
4. STRUCTURAL ANALYSIS & DESIGN
    Building Footprint .... Jason
    Floor Systems .... Chuck
    Beams & Girders .... Ben, Chuck
    Columns .... Chuck
    Truss Design .... Chuck
    Foundation .... Chuck
    Retaining Wall/Sheet Piles .... Ben
5. COST ESTIMATING .... Jason

Capstone Design

The project focused on alternative designs to the new recreational facility which would be economically and environmentally sound. The design for the new recreation center takes into account several constraints listed by the ASCE commentary which were addressed by the analysis in the project.

Economic

In order to investigate total costs, the building used concrete, steel and glulam wood to see which one, or which combination of materials, would produce the most advantageous total project cost (via cost comparisons) as well as produce a safe building that would conform to required building and structural codes.

Environmental

The designs included sustainable and green engineering options which would increase the recreational center's level of LEED. These LEED alternatives were investigated and it was determined that the power generated through natural resources would cut down on greenhouse gas emissions and, as a result, would not contribute to climate change and would also save enormous amounts of money for WPI. When appropriate, recyclable materials were included in the design because these materials helped address the environmental constraint (recyclable steel as opposed to unrecyclable concrete).

Sustainability

The research on LEED helped address the sustainability aspect of the project. By adding a few "green" components (i.e. rainwater harvesting system and solar panels), the sustainable design of the building was enhanced.

Manufacturability/Constructability

The materials that were under consideration were primarily used to determine whether the final design was to use one material opposed to another or if the design must incorporate multiple materials. It was important to take into account all of the diverse loads that would be applied on the building and evaluate if the design would suffice. It was also important to take into consideration the different aspects of the various construction materials. This includes, but not limited to, costs and material availability.

Social

The vision of this project was to expand the availability of recreational activities for the always increasing WPI population. The current athletic facilities are outdated and are unable to sustain the aforementioned increasing WPI population. The objective of this project was to maximize open areas to alleviate time conflicts between different teams and clubs as well as provide a variety of opportunities for students and faculty to participate in leisurely activities.

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Acknowledgments

Our group would like to recognize all the people who aided in the completion of this project. First and foremost, the group would like to thank our advisor Professor Tahar El-Korchi for all his time spent reviewing our drafts, providing comments and all other efforts to improve the report. We would like to also thank Professor Tao for offering his geotechnical expertise for our design.

1. INTRODUCTION

WPI President, Dennis Berkey, has been an advocate for campus expansion. With increasing enrollment figures, a projected rise from 2,800 to 3,400 by the year 2015 according to his Vision Statement in January of 2007, he wants WPI to become a more close-knit campus.[1] Admission figures can be seen in Figure 1 below.

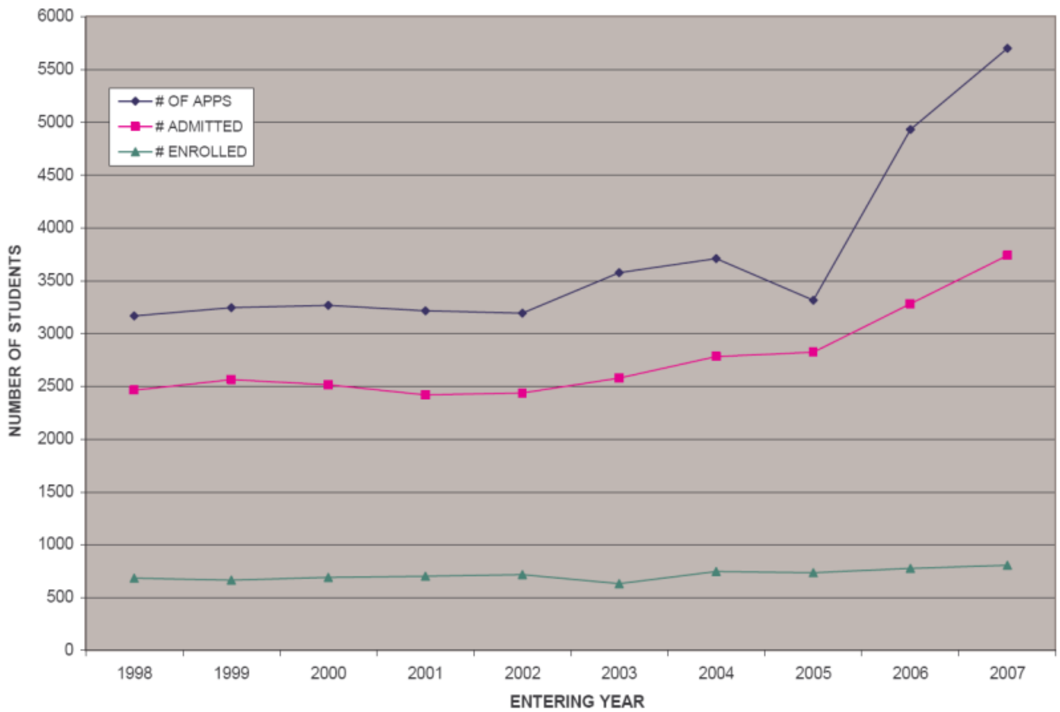

Figure 1: Undergraduate Admissions Data

(WPI Student Factbook)

One way he proposes on achieving this sense of community is through his revised 1999 Strategic Plan, which included a goal to develop campus facilities according to a plan that would support both academic and co-curricular needs, in which he explicitly stated that the new recreation facility will bring a great sense of enthusiasm to WPI.[2]

The current recreation centers, Harrington Auditorium and Alumni Gymnasium, are primarily used for varsity sports and, as a result, recreational use is limited during various times of the

[1] http://www.wpi.edu/Admin/President/vision.html
[2] http://www.wpi.edu/Admin/President/strategicplan.html

year. The proposed Recreation Center is to be constructed near the athletic fields as shown in Figure 2.

Figure 2: Site Sketch of Proposed Location of New Recreation Center

The yellow circles with dotted lines in the figure show the sun's path during the course of a day (going from right to left), the red dashed line are merely for reference and the solid yellow area is the proposed location for the new recreation center.

Due to overuse of these spaces, most of these facilities are run down and in great need of refurbishment or replacement. Harrington Gymnasium, built in 1968, is the only indoor athletic facility that has seen a face lift in recent years and is properly maintained.[3] Though the court has been replaced as of this year, it is the only open indoor space for teams like baseball, softball, volleyball and club sports like lacrosse, volleyball, dance, step and badminton. These teams have had to make use of every inch of Harrington Gymnasium and Alumni Gymnasium (built in 1916) [1], including foyer entrances to practice dance and step moves, baseball drills under the bleachers and a storage room used for batting cages. In addition, poor ventilation throughout the building, particularly in the weight room, further deters students.

[3] http//:www.wpi.edu

With all of these time conflicts and space restraints, many of the students who do not play a varsity sport are unable to participate in recreational sports in these buildings or use the work-out facility. WPI has tried to help these students by coming up with a plan to build an additional athletic facility.

Current indoor athletic facilities are not among the school's highlights nor do they help promote the school to prospective student athletes. The purpose of the project is to take the needs of WPI and develop a finished product that will be suitable for the growing student population. Our goal is to produce a building that will be LEED certified as well as contain state of the art facilities such as brand new basketball courts, an Olympic-size swimming pool, new squash and racquetball courts, an aerobics room, a yoga room, a new work-out facility complete with weightlifting machines and free weights, and a cardio room. With this new recreational facility, WPI plans to further promote extra-curricular activities, overall wellness and help balance their reputation between academics and athletics.

2. BACKGROUND

When beginning to design a building, there are a logical set of steps that must be taken. The first action that must be taken, after a preliminary design, is the acquisition of permits to see if the building type and location is even feasible. All regulations set by the state of Massachusetts and the city of Worcester must be followed throughout the entire project. A comprehensive review of these rules and regulations is necessary.

City of Worcester's Building Requirements

Every city in the country has a set of rules that specify the minimum acceptable level of safety for buildings. The main goal of building codes is to protect public health, safety and general welfare as they correspond to the construction and use of buildings such as the recreation center.[4]

The first necessary step to begin constructing the recreation center is by drawing plans (exterior and interior) to scale and showing the locations and dimensions of the lot that is to be built upon. All this information is required by the Code Commissioner (city officer designated by the City Manager). This administrator is part of the Zoning Ordinance in the City of Worcester. The Code Commissioner will then announce regulations that should be followed and subsequently file a copy of these rules with the City Clerk.[5, 6]

Once the Code Commissioner files the parameters with the City Clerk, the next step would be to acquire a building permit. A building permit gives its owner legal permission to start construction of a building project in accordance with the approved drawings and specifications provided for the recreation center. Building permits have to be obtained before any construction is done as they are needed to erect, construct, enlarge, alter, repair, improve or

[4] http://www.ci.worcester.ma.us/dpw/
[5] http://www.ci.worcester.ma.us/cco/clerk/ordinances/revisedordinances1996.pdf
[6] http://www.ci.worcester.ma.us/cco/clerk/ordinances/zoningord2607.pdf

demolish any building or structure. A fee is collected based on the size of the job and covers the cost of the application, the review, and the inspection process.[7]

The application for the building permit should include written consent from the owner, if not the applicant. The following must be included with the application:

- Off street parking and loading spaces.
- Plot plan of the land showing all the dimensions of the recreation center and the exact location of the existing buildings that may be altered (Harrington).
- A description of any proposed building, structure or addition.
- A statement explaining any proposed external alterations which increase the height or area of any existing building or structure.
- The number of locations and design of parking, loading spaces, signs and buffers where appropriate.
- Proof of recording of a land development plan for construction of any dwelling not on a separate lot of record.
- On-lot sewage disposal permit, where public water and sewer is not available.
- Public water/sewer – a letter from the Worcester Township Water/Sewer Operations for valid connection permits.
- Erosion and sedimentation control plan from the Worcester County Conservation District.
- Workers Compensation Insurance Coverage Information for the contractor.
- Workers Compensation Certificates for contractors.
- Storm water management plans in accordance with Section 329 of the Zoning Ordinance.[8]

A copy of the application for a building permit in the city of Worcester can be found in Appendix E.

[7] http://www.ci.worcester.ma.us/forms.html
[8] http://www.ci.worcester.ma.us/dpw/engineering/permit_manual.pdf

Once the contractor has been approved for a permit, he or she has legal permission to start construction. The Code Commissioner is available for whenever one would have any questions about issues with the project. The Code Commissioner should be seen as someone who will help make the project a problem-free event. Various permits are required for electrical, plumbing, heating and air-conditioning work and the contractor would be the one to go to in order to obtain these.[9]

On-site inspections will occur every now and then throughout the duration of the construction. The Code Commissioner will determine approximately how many inspections may be needed for the project. Usually, a one or two day notice is needed when requesting visits. They are required to make sure the work conforms to the permit, local codes and plans. It is important to acknowledge that the Code Commissioner will also help with questions or concerns regarding the project and to ward off potentially costly mistakes.[10]

The Code Official will provide documentation when construction on the recreation center is complete and code compliance is determined. Once this is done, the job is essentially finished and the community can be content knowing that the new facility met the safety standards required by the City of Worcester.[9]

Structural Design

When designing a multipurpose structure such as the Recreation Center, each room, hallway and activity must be analyzed to design the most effective and efficient facility. The list of spaces and their respective sizes are shown in Appendix D. The spaces are broken down into five categories; public areas, activity spaces, training & rehabilitation, administration/coaches and support spaces. These different spaces make the design of this building more challenging because there are no generic spaces, thus requiring greater attention to detail. The study the dead and live loads from these spaces are important for developing a floor plan.

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[9] http://www.ci.worcester.ma.us/isd/building_zoning/building/faq.htm
[10] http://www.ci.worcester.ma.us/isd/building_zoning/home.html

Dead loads are defined as the weight of materials of construction that are permanent to the building which include, floors, walls, finishes, roofs, stairways and stationary mechanical equipment. The majority of the dead loads were the weight of the steel or concrete. These loads were determined during the design where the amounts and weights of steel and concrete were determined. Once the weight of the building was determined, an accurate cost estimate was developed. Currently the cost of hot rolled structural steel is approximately $120 per ton and the cost of concrete, including the labor to make the forms, is $1,000 per yd^3.[11]

Live loads are "loads produced by the use and occupancy of the building or other structure and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load."[12] The recreation center "shall be designed and constructed to support safely the nominal loads in load combinations defined in 780 CMR without exceeding the appropriate specified allowable stresses for the materials of construction."[13] Snow, wind and earthquake loads are live loads that need to be taken into consideration. The values for these live loads for Worcester, MA can be found in the MSBC Table 1604.10:

- Ground Snow Load: 55 psf
- Basic Wind Speed: 100 MPH
- Earthquake Design Factors: S_s - 0.24 S_1 – 0.067

Other live loads are due to the occupancy of the building and are shown in Table 1.

Table 1: Minimum Live Loads from MSBC and ASCE 7

Occupancy	Uniform Load (PSF)	Concentrated (LB)
Corridors 1st floor	100	-
Corridor other than 1st floor	100	-
Corridors above	80	2000

[11] http://www.aisc.org
[12] MSBC 1602.0 p. 379
[13] MSBC 1602.0 p. 379

1st		
Elevator machine room	150	300
Gymnasium	100	-
Offices	50	2000
Lobbies 1st floor	100	-
Classroom	50	-
Stairs and Exits	100	-
Boiler Room	150	-
Fan Room	150	-
Restrooms	60	-

Sources: Massachusetts State Building Code, 2008
ASCE Minimum Design Loads for Buildings 7-95, 2000

Not all live loads can be found in the MSBC. These loads were to be "determined in accordance with a method approved by the building official."[14] ASCE standards were used to fill in the voids in Table 1 because the MSBC refers to ASCE 7 in many instances.

An example of the types of loads that was not included in ASCE 7 or the MSBC was green roof loads. The loads associated with green roofs were the weight of the soil and plant material. The weight of saturated plant modules ranges from 11-50 psf. The soils used were typically 20–40% lighter than normal fill. These loads were in addition to the typical snow loads for Worcester, MA.

Load Combinations

Once the loads can be identified, the appropriate load combinations need to utilized. Table 2 shows the load combinations used for LRFD design.

[14] MSBC-T-1607.2, p. 391

Table 2: LRFD Load Combinations

1.	1.4D
2.	1.2D + 1.6L + 0.5(Lr or S or R)
3.	1.2D + 1.6(Lr or S or R) + (0.5L or 0.8W)
4.	1.2D + 1.3W + 0.5L + 0.5(Lr or S or R)
5.	1.2D ± 1.0E + 0.5L + 0.2S
6.	0.9D ± (1.3W or 1.0E)

Source: Structural Steel Design – 4th Edition, McCormac, 2008

The following LRFD resistance factors in Table 3 that correlate to the above equations were found in Section 2-9 in the *AISC Steel Construction Manual – 13th Edition, 2006*:

Table 3: LRFD Resistance Factors

AISC-LRFD Resistance Factors

member	resistance factor	limit states
Tension	$\phi = 0.90$	yielding
	$\phi = 0.75$	fracture
Compression	$\phi = 0.85$	buckling or yielding
Beams	$\phi_b = 0.9$	bending
	$\phi_v = 0.9$	shear
Welds	same as for member actions	
Fasteners	$\phi = 0.75$	all

These equations and coefficients are used to adjust the loads to conservatively and safely design a structure.

Floor Systems

The project design group developed the four floor systems found in the new recreational center. Contributing dead and live loads were identified and taken into consideration for the rest of the structural design.

One of the first components to be analyzed is the flooring. The following types of concrete flooring will be designed for in our steel-framed building;

1. Concrete slabs supported with open-web steel joists
2. Concrete slab and steel beam composite floors
3. Steel-decking floors with concrete topping
4. Precast concrete slab floors

The simplest solution for designing the floor systems would be to provide a constant beam depth and varying the reinforcement along the span. Simple formwork can make construction time shorter, resulting in a recreational center that can be used by WPI students as soon as possible.

In the preliminary design stage, it is important to consider fire resistance. Building codes regulate the fire resistance of the various elements and assemblies of a building structure. Fire resistance must be considered when choosing a slab thickness. This is important in steel buildings because although the steel is incombustible, the strength is greatly reduced when heated to the extreme temperatures in a fire. Also, because steel conducts heat so well, it can spread heat to different sections of the building and setting adjacent materials ablaze. Concrete member thickness required for structural purposes usually provides at least a two-hour fire-resistance rating. Sufficient protection to the reinforcing steel is required to shield it from fire. Fire protective covers include, concrete, gypsum, mineral fiber sprays, special paints and other materials.[15] Worcester's building code must be consulted to ensure that minimum fire resistance requirements are met.

Before analyzing the floor system, it is important to assume preliminary member sizes. The slab and beam thickness are usually determined first to make sure that the building deflection requirements are met.

For solid, one-way slabs and beams that are not supporting or attached to partitions or other construction likely to be damaged by large deflections, it is necessary to determine the

[15] *Structural Steel Design – 4th Edition, McCormac, 2008*, p.614

minimum thickness (also referred to as *h*). For continuous one-way slabs and beams, determining the minimum thickness based on one-end continuous will satisfy deflection criteria for all spans. Deflections need not be computed when a thickness at least equal to the minimum is provided.

Deflection calculations for two-way slabs are complex, even when linear elastic behavior is assumed. The minimum requirements are shown in Figure 3. The figure shows the ratio of the flexural stiffness of a beam section to the flexural stiffness of a width of slab bounded laterally by centerlines of adjacent panels.

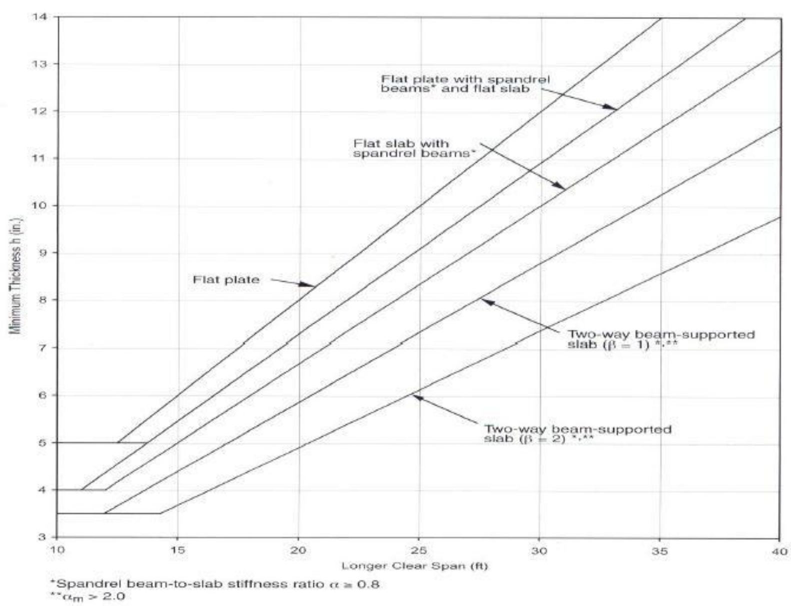

Figure 3: Minimum Thickness Requirements
(Structural Steel Design 4th Edition – McCormac, 2008)

In general, all members of frames or continuous construction must be designed for the maximum effects of factored loads using an elastic analysis. Even though numerous computer programs exist that can accomplish this task, the set of approximate coefficients can be used to determine moments and shear forces, provided the limitations in Figure 3 are satisfied. The coefficients in Figure 4 provide a quick and conservative way of determining design forces for beams and one-way slabs, and can be used to check output from a computer program.

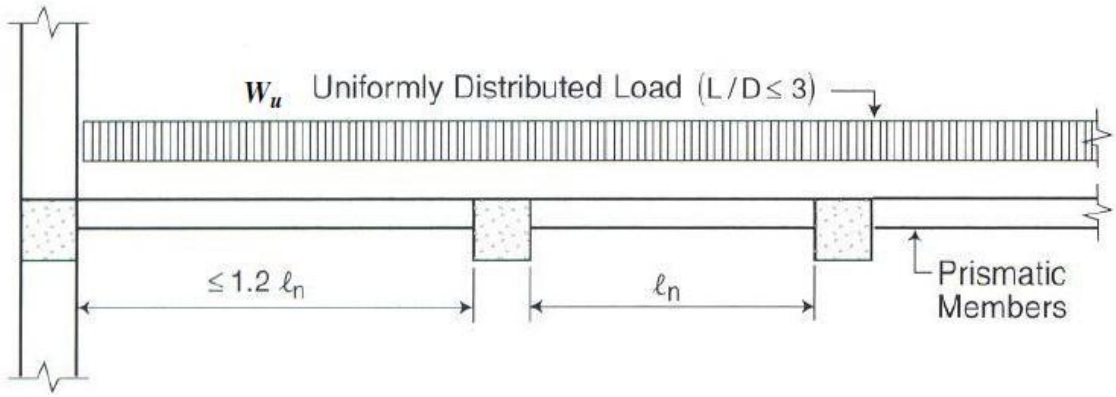

Figure 4: Conditions for Analysis

(Structural Steel Design 4th Edition – McCormac, 2008)

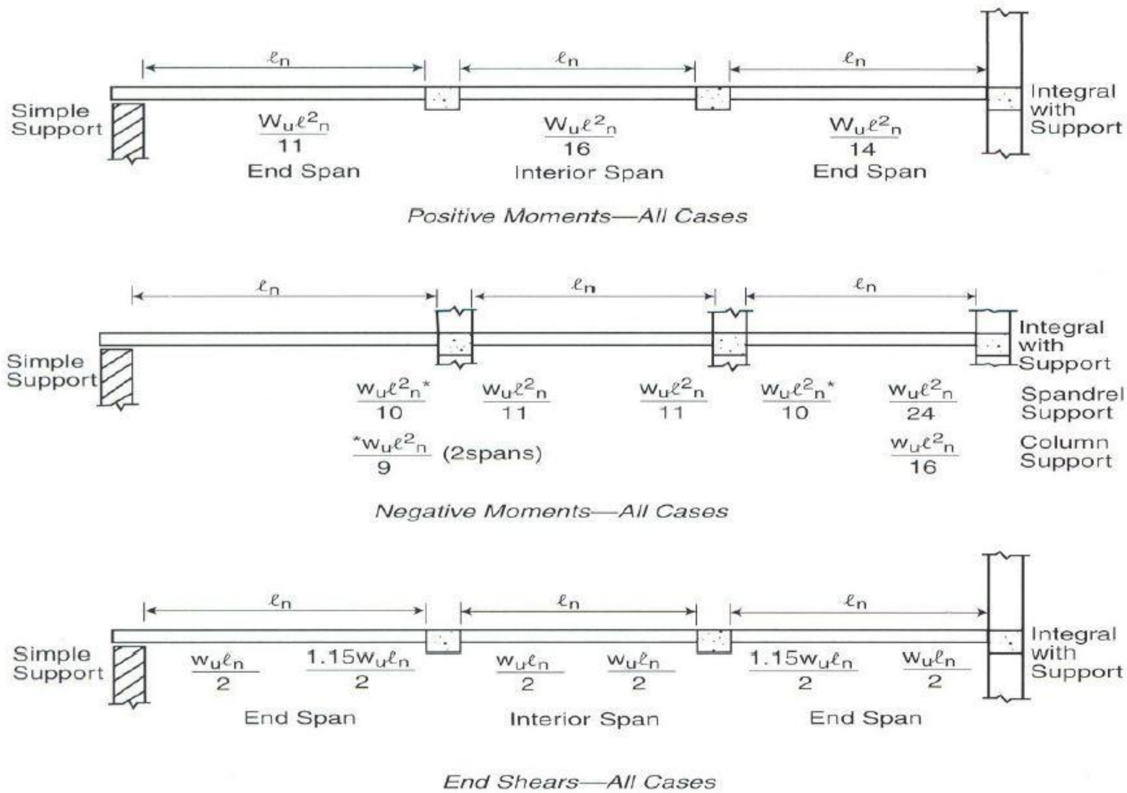

Figure 5: Analysis by Coefficients

(Structural Steel Design 4th Edition – McCormac, 2008)

Instead of an analysis procedure satisfying equilibrium and geometric compatibility, the Direct Design Method or the Equivalent Frame Method can be used to obtain design moments for two-way slab systems. If the conditions in Figure 5 of the Direct Design Method are met, then the total factored static moment for a span can be distributed as negative and positive moments in the column and middle strips.

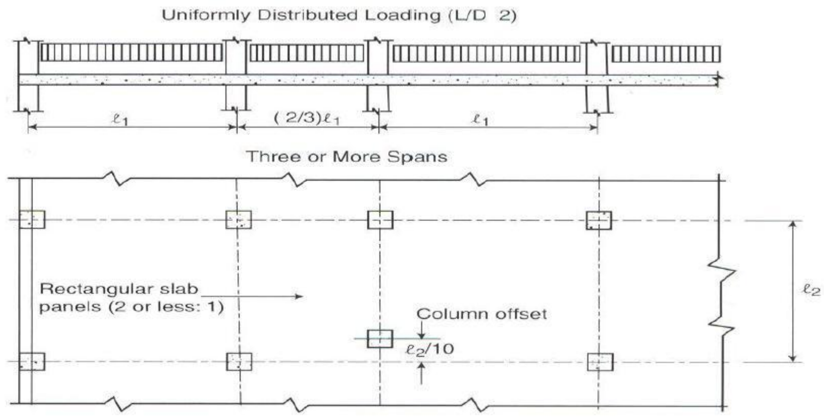

Figure 6: Conditions for Analysis

(Structural Steel Design 4th Edition – McCormac, 2008)

The required amount of flexural reinforcement is calculated using the design assumptions based on the factored moments from the analysis. In typical cases, beams, one-way slabs, and two-way slabs will be tension controlled sections, so that the strength reduction factor is equal to 0.9. For greater concrete strengths, the required flexural reinforcement must be greater than or equal to the minimum area of steel and less than or equal to the maximum area of steel.

For one-way slabs, the minimum flexural reinforcement in the direction of the span is the same as the minimum area of steel for shrinkage and temperature reinforcement. The maximum spacing is the lesser of the following: 3*h* or 18 inches.

For two-way slabs, the minimum reinforcement ratio in each direction is 0.0018 for Grade 60 reinforcement. In this case, the maximum spacing is 2*h* or 18 inches. A maximum reinforcement ratio for beams and slabs is not directly given in the *Building Code Requirements for Structural Concrete* and as a result, it requires that nonprestressed flexural members must be designed so that the net tensile strain in the extreme layer of longitudinal tension steel at nominal strength is greater than or equal to 0.004. This requirement limits the amount of flexural reinforcement that can be provided at a section.

Both one-way shear and two-way shear must be investigated in two-way floor systems. Design for one-way shear or wide beam shear consists of making sure the critical sections are located some distance from the front of the support as seen in Figure 7.

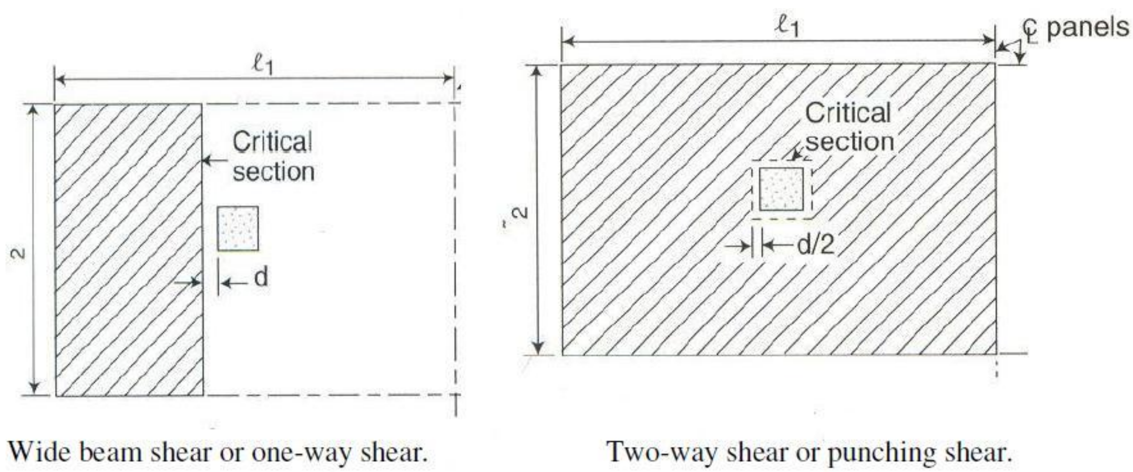

Figure 7: One/Two-Way Shear

(Structural Steel Design 4th Edition – McCormac, 2008)

Two-way or punching shear usually is more critical than one-way shear in slab systems supported directly on columns. As shown in Figure 7, the critical section for two-way action is at some distance from edges or corners of columns, concentrated loads, reaction areas, and changes in slab thickness, such as edges of column capitals or drop panels.

The moment transfer in the slab-column connections takes place by a combination of flexure and eccentricity of shear. The portion of total unbalanced moment transferred by flexure is a function of the critical section dimensions.

After floor sections, roof sections were to be designed. As mentioned before, the gymnasium was the main challenge. For long spans between columns, there were a few options; arches, trusses, rigid frames, box girders and built up I-girders. Truss members were designed in the building to support the long spans. The key component that needed to be decided by the group was the type of truss. The trusses were designed to carry additional loads (live load over the gymnasium) due to the green roof. All structural members have to be adequately designed for strength and other design criteria. However, sometimes, certain designs are more challenging because of the complex nature of codes and other constraints.

The types of connections in the building were determined through analysis at which point bolted or welded connections will be chosen depending on the strength requirements. This decision was important because the difference in cost of these two options could have been great. Welded connections were relatively expensive requiring certified welders, while bolts could be installed by skilled construction workers.

The concrete type we used for flooring and retaining walls is Portland Cement Type II because it is the generic structural concrete that can be exposed to soil and ground waters where sulfate concentrations are higher than normal. The concrete slab design was checked for two separate safety conditions: fire resistance rating and strength which can be defined as the following:

- Interior concrete – strength and density
- Exterior – strength and durability issues.

The concrete for the pool foundation will be watertight so none of the chlorinated water from the pool leaks through and corrodes the reinforced steel bars (reinforcing steel for the pool will be coated to help withstand chlorinated water also). In order to attain this watertight quality, the concrete mix must have a low water-cement ratio. There are several materials that can be used for the concrete; however, the most advantageous material to use would be fly ash. This is true because fly ash does not require much water for mixing which leads to less bleeding, or simply a better watertight pool foundation. This is an extremely vital part of the design.

The new recreational center's floor systems have design requirements of concrete floor systems with nonprestressed reinforcement. It is important to be aware of the fact that once the required flexure and shear reinforcement have been determined, the reinforcing bars must be developed according to the *Building Code Requirements for Structural Concrete*. The structural integrity conditions must be satisfied as well.

Foundation Design

The foundation of the building was the last part to design because the weight distribution of the structure had to be recorded before one could even begin. The foundation design depended not only on the weight of the structure but on the ground conditions and pressures. It had to be designed to handle loads while limiting settlement, heave and lateral movement to tolerable levels.[16] The type of cement that was used was Portland Type II for reasons specified above.

Designing a footing involved an analysis of the bearing pressure it will exert to the soil beneath it. Figure 8 was a depiction of the stresses applied to the soil under the footings.

[16] MSBC 780 CMR 1801.0, p.429

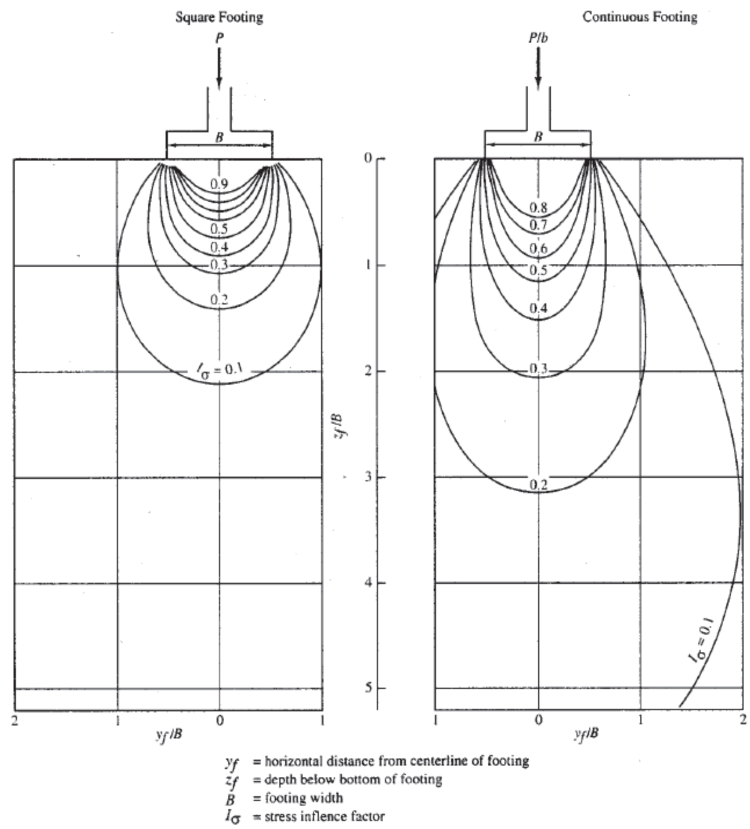

Figure 8: Induced Stresses Beneath Footings

(Foundation Design 2nd Edition – Coduto, 2001)

Footings had to be reinforced due to the flexural stresses. The flexure analysis was necessary to ensure the footings do not bend upward as seen in Figure 9.

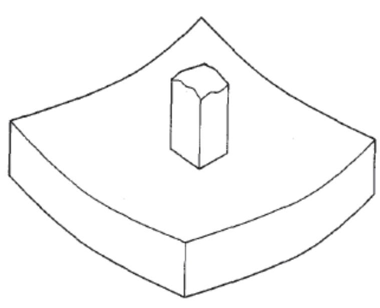

Figure 9: Spread Footing Bending

(Foundation Design 2nd Edition – Coduto, 2001)

To prevent the footings from bending steel reinforcement was used in both directions. The minimum required area of steel was found based on the bending moment. Once the area of the steel was known, reinforcing bars were chosen. The only other consideration for this design was the development lengths of the reinforcing bars. In almost all cases the original bar sizes needed to be changed to smaller bars to decrease the development length. Figure 10 is an example of a typical footing with reinforcement.

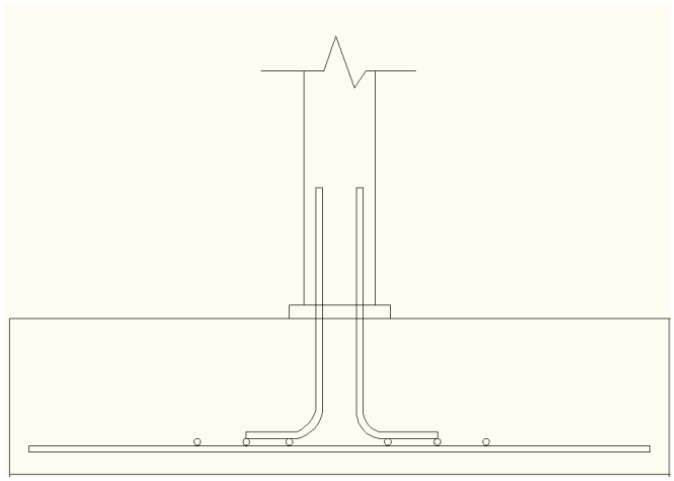

Figure 10: Typical Foundation and Reinforcement

Once the foundation was analyzed for vertical loads, horizontal and uplifting loads must be examined. A geotechnical report of the existing ground conditions may need to be obtained in order to determine whether or not the building would settle once constructed. Since the recreation center was to be built closely to other structures at WPI, there were sufficient geotechnical reports that will be used for the foundation design.

However, this was the only building at WPI that would be at the same elevation as the athletic fields, which have a high water table due to Salisbury Pond. This meant the foundation would have greater lateral pressures due to water and soil than other WPI buildings. The foundation on the side facing the quadrangle (eastern side) required the most resistance to lateral pressure because it was approximately 30 feet underground. Table 2 from the MSBC gives the allowable pressures for specific soil types used for design.

Table 4: Allowable Bearing Pressures for Foundation Materials

Material Class	Description	Notes	Consistency in Place	Allowable Net Bearing Pressure (tons/ft^2)
1a	Massive bedrock: Granite, diorite gabbro, basalt, gneiss	3	Hard, sound rock, minor jointing	100
1b	Quartzite, well cemented conglomerate	3	Hard, sound rock moderate jointing	60
2	Foliated bedrock: slate, schist	3	Medium hard rock, minor jointing	40
3	Sedimentary bedrock: cementation shale, siltstone, sandstone, limestone, dolomite, conglomerate	3,4	Soft rock, moderate jointing	20
4	Weakly cemented sedimentary bedrock: compaction shale or other similar rock in sound condition	3	Very Soft Rock	10
5	Weathered bedrock: any of the above except shale	3,5	Very Soft rock, weathered and/or major jointing and fracturing	8
6	Slightly cemented sand and/or gravel, glacial till (basal or lodgment), hardpan	7,8	Very dense	10
7	Gravel, widely graded sand and gravel; and granular ablation till	6,7,8	Very dense Dense Medium dense Loose Very loose	8 6 4 2 Note 11
8	Sands and non-plastic silty sands with little or no gravel (except for Class 9 materials)	6,7,8, 9	Dense Medium dense Loose Very loose	4 3 1 Note 11
9	Fine sand, silty fine sand, and non-plastic inorganic silt	6,7,9	Dense Medium dense Loose Very loose	3 2 1 Note 11
10	Inorganic sandy or silty clay, clayey sand, clayey silt, clay, or varved clay; low to high plasticity	5,6,10	Hard Stiff Medium Soft	4 2 1 Note 11
11	Organic soils: peat, organic silt, organic clay	11		Note 11

Source: Massachusetts Building Code, Table 1804.3, 2008

Retaining Wall

Retaining walls were necessary to help withstand lateral earth forces. Our building required the design of a retaining wall because the slope on the quadrangle side of the football field would be excavated and a retaining wall would be essential to hold the remaining soil back in place. There are three conditions, the at-rest, the passive and the active, that describe the retaining wall movements.

A typical retaining wall design is a cantilever retaining wall. A cantilever retaining wall must be designed to be externally stable in the following ways: it will not slide horizontally, it will not overturn, the resultant of the normal force that acts on the base the footing must be within the middle third of the footing, the foundation must not experience a bearing-capacity failure, it must not undergo a deep-seated shear failure and finally must not settle excessively.[17] However, cantilever retaining walls are only manageable for maximum wall heights between 10-14 feet.[18] Figure 11 depicts a typical design of a reinforced cantilever retaining wall. The dimensions included in the figure below are not applicable to the design and were included in an example problem done out in the *Foundation Design 2nd Edition – Coduto, 2001* textbook.

[17] Foundation Design 2nd Edition – Coduto, 2001
[18] Foundation Design 2nd Edition – Coduto, 2001

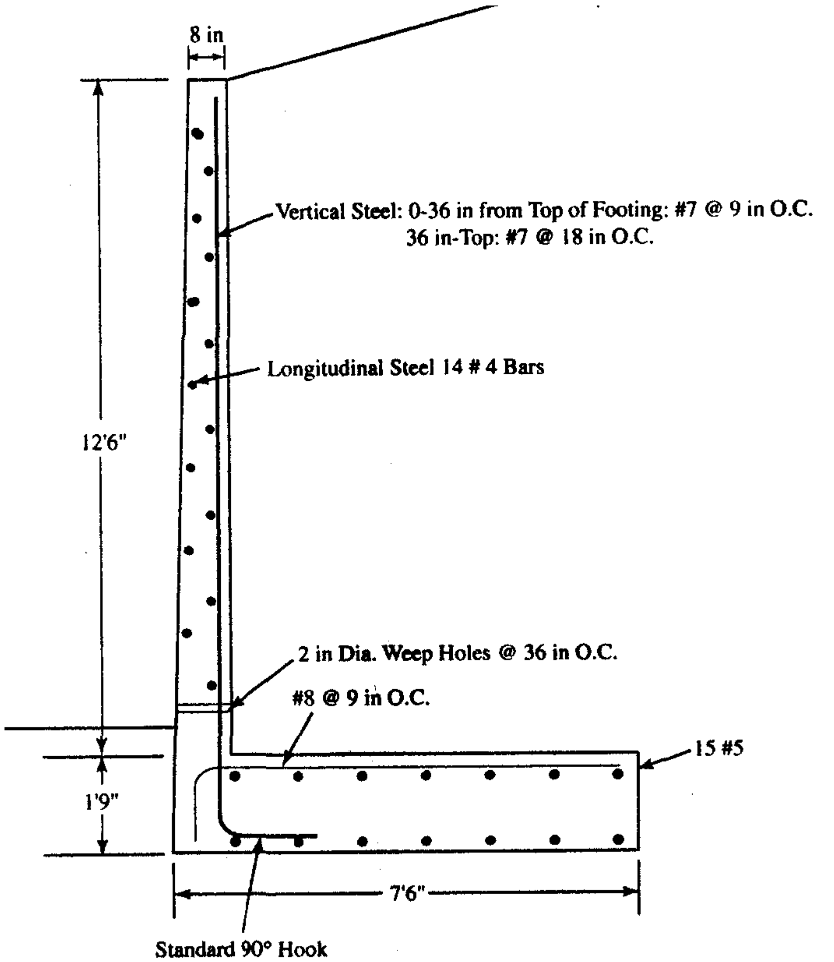

Figure 11: Typical Reinforced Cantilever Retaining Wall
(Foundation Design 2nd Edition – Coduto, 2001)

Retaining walls above that maximum height, stated above, become too large and uneconomical and designs for sheet-pile sections are necessary.

Sheet pile sections are rolled plate-steel structural members which are driven into the ground to form a wall and are used for construction excavation.[19] With the sheet-pile sections in place, we can include tie-backs and assume enough rigidity to leave it in place as the building is erected. Figure 12 below shows what a typical cantilever sheet pile wall looks like and how far it extends down below grade.

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[19] Foundation Design 2nd Edition – Coduto, 2001

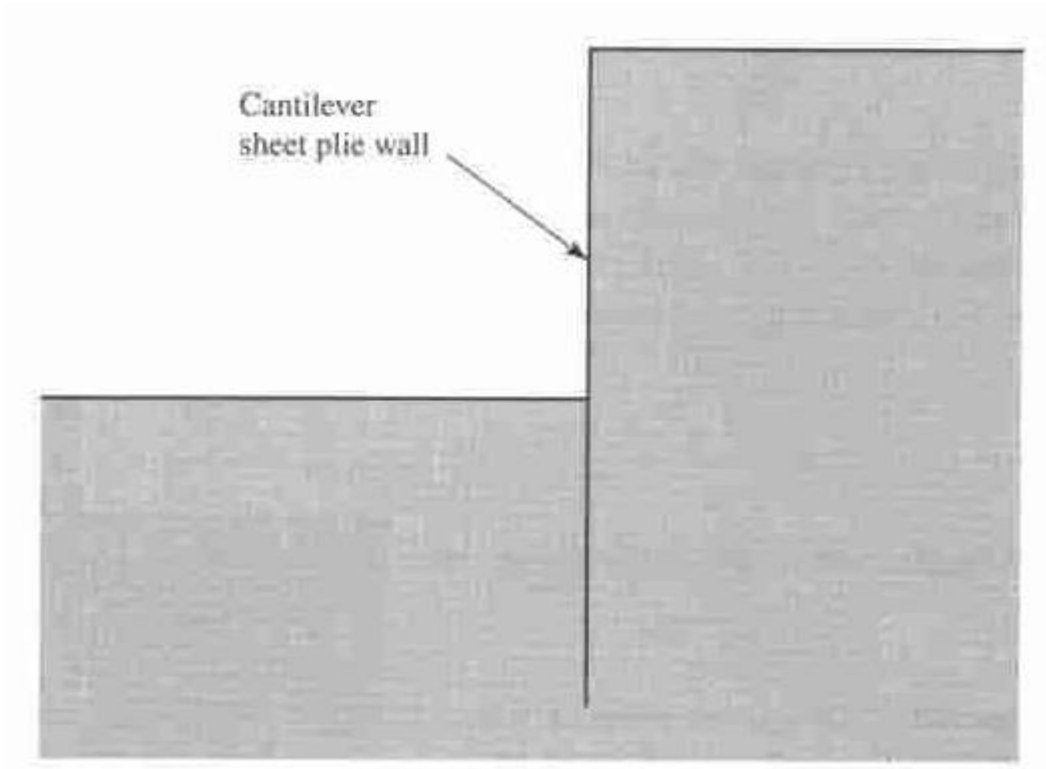

Figure 12: A typical cantilever sheet-pile section
(Foundation Design 2nd Edition – Coduto, 2001)

LEED Certification

The building was designed so that it can receive a silver accreditation from a LEED certified professional. According to their current checklist, which can be seen in Appendix C, a building must have at least 33 points in order for it to be considered silver. The points are distributed into six different categories:

1. Sustainable sites - 14 points
2. Water efficiency - 5 points
3. Energy and atmosphere - 17 points
4. Materials and resources - 13 points
5. Indoor environmental quality - 15 points
6. Innovation and design process -5 points

The plan was to obtain points from all the categories by focusing on using clean energy (i.e. solar power, wind turbine, etc.), recycling natural resources (rainwater harvesting) and materials used in construction in addition to using low-emitting materials (i.e. paints, carpets, adhesives/sealants, etc). By combining these aspects of the construction process, the 33 points necessary to receive silver were obtained.

Sustainable Sites

The project was able to obtain three points in the Sustainable Sites section of the LEED checklist for new construction. Two points came from SS Credit 4: Alternative Transportation, SS Credit 4.1 Public Transportation and SS Credit 4.2 Bicycle Storage & Changing Rooms. The requirement needed for SS Credit 4.1 was to have either campus or public routes in place by the end of construction.[20] This credit was easily obtained because there were a couple of public bus routes located within walking distance of the WPI campus and we already have the Gateway Shuttle, which could transport students and faculty from Gateway to the new recreation center. SS Credit 4.2 was challenging because the bicycle rack capacity had to be

[20] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097

calculated based on the maximum transient (visitors of the facility for less than 7 hours) loading.[19] The showers and changing rooms, however, were calculated using the number of full-time employees of WPI who will be working in the new recreation center. The final point earned in this section was SS Credit 7.2 Heat Island Effect - Roof. The requirement needed for the credit was to have 75% of the roof area covered by a collection of high albedo (reflection of sunlight) and vegetation.[19] Having a vegetated roof also helped obtain points in the Indoor Environmental Quality section of the LEED checklist for new construction which will be discussed later.

Water Efficiency

There were three different credit areas for water efficiency. WE Credit 1: Water Efficient Landscaping (2 points), WE Credit 2: Innovative Wastewater Technologies (1 point) and WE Credit 3: Water Use Reduction (2 points).[19] In order to achieve the two points awarded for Water Efficient Landscaping, documentation must be provided that supported the rainwater harvesting system, the landscape design and the extent of the supplemental temporary irrigation system.[19] A rainwater harvesting system would alleviate a decrease in the use of public water and thusly assist in reducing future costs for WPI. Rainfall on a 2,000 ft^2 roof can collect as much as 55,000 gallons per year.[21] The water recovered from a typical system could be used for several purposes including outdoor irrigation, cold water toilet flushing and clothes washing (those two subjected to local ordinances). WE Credit 2: Innovative Wastewater Technologies, can be achieved if more effective uses were designed for the rainwater harvesting techniques, as well as develop more economical waste treatment technologies which included adding a high-efficiency filtration system. WE Credit 3 was determined by calculating the amount of water used in a select few of the buildings fixtures including lavatories (public and private), showers (public and private) and faucets, but did not include water fountains or emergency showers. In order to determine the amount of water used on a typical day using a certain fixture (i.e. toilet) one must use the following calculation:

[21] http://www.rainwaterrecovery.com/harvesting.html

Public toilets = Total number of fixtures*Estimated daily usage*Flow rate(GPF)*Duration[22]

To achieve one point the water use must be reduced by at least 20% and to obtain both points water use must be reduced by at least 30%.

Energy and Atmosphere

There were six different credit areas in the Energy and Atmosphere section of the LEED checklist for new construction. EA Credit 1: Optimize Energy Performance, can achieve anywhere between 2 and 10 points depending on how well their energy performance was compared to a similar building without anything helping it optimize energy (between 14-42% better).[21] However, LEED had a prerequisite of minimum energy performance for all newly constructed buildings. One way on optimizing energy was the use of solar panels to the roof of the building. There were many advantages to solar energy, but one major disadvantage was the cost of installation, which was mainly due to the high cost of semi-conducting materials used in producing a panel. In order to figure out how many watts of solar power needed for 100% solar energy, this equation must be used:

100% Solar = [(Average Daily KWH usage) / (# of hours of full sunlight)] * 1.15

Each watt costs about $7 (if done by yourself) to $9 (if installed by a licensed professional), which included the costs of semi-conducting materials.[23] The advantages of solar panels, however, are endless. One reason was that solar power was a renewable resource which cuts down on the emissions of greenhouse gases. Another reason was the money it will end up saving for WPI. There are governmental financial incentives if a consumer adds solar panels, the recovery period after the initial investment can be almost immediate depending on how much electricity is actually used and the energy produced thereafter is free. There are three types of solar technologies currently being developed by the U.S. Department of Energy:

[22] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[23] http://www.solar-electric.com/solar_system_costs.htm

photovoltaic cells, concentrating solar power technologies and low temperature solar collectors.[24] These solar technologies are discussed later. Solar panels also contribute to earning points for EA Credit 2: On-Site Renewable Energy, which can give a maximum of three points depending on how much of the energy used is renewable (between 2.5% and 12.5%).[23] EA Credit 3: Enhanced Commissioning was easily obtainable if Canon Design has an engineer who was not responsible for designing or managing the project come and serve as an "independent commissioning authority."[25] Finally, EA Credit 6: Green Power was achieved when the managing company purchases Green Tags. However, the green power generated from solar panels was only credited for EA Credit 2.[23]

Photovoltaic Cells and Low Temperature Solar Cells

Photovoltaic cells were used to generate electricity that can: pump water, charge batteries, supply power to a utility grid and much more.[26] The electricity developed by the photovoltaic cells provided some of the lighting required for the building as well as provide the electricity needed for the pumping of water in sinks and water bubblers. The low temperature solar collectors were designed to harness the sun's energy, transform the radiation from the sun into heat which was transferred to water, solar fluid or air.[27] The heat provided by the solar collectors was used to heat the water in the pool and the water used in sinks.

Materials and Resources

Materials and resources used have seven different credit areas with which to earn LEED points. MR Credits 4-7 accounted for a maximum of six points. Credit 4: Recycled Content was achieved by using recycled materials, 10% earned one point and 20% earned two points.[28] Credit 5: Regional Materials was achieved when the materials used were extracted, processed and manufactured within our given region, 10% earns one point and 20% earns two points.[28] Credit 6: Rapidly Renewable Materials was achieved by using materials as defined by LEED,

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[24] http://www.energy.gov/energysources/solar.htm
[25] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[26] http://www.eere.energy.gov/solar/pv_use.html
[27] http://www.eere.energy.gov/solar/sh_basics_collectors.html
[28] http://www.usgbc.org/ShowFile.aspx?DocumentID=3998

which included: concrete, masonry, earthwork and furnishings.[29] In order to achieve Credit 6, the cost of the rapidly renewable materials must be at least 2.5 % of the total cost of the materials.[30] Finally, Credit 7: Certified Wood was achieved when the costs of the certified wood components used were at least 50% of the total new wood costs. A list of green materials that was used for the recreation center was found at *www.BuildingGreen.com*.

Indoor Environment Quality

There are 8 different credit areas that contribute to LEED points. EQ Credit 1: Carbon Dioxide (CO_2) Monitoring can be achieved by installing a permanent CO_2 monitoring system which monitors a mechanically ventilated system or a naturally ventilated system that was designed to maintain minimum ventilation requirements.[29] Credit 4: Low-Emitting Materials has four points that were easily obtainable by using any of the products that were LEED certified. The materials in the LEED checklist include adhesives and sealants, paints and coatings, carpet systems and composite wood and agrifiber products. These were the products that were planned to be used in the building to help obtain the maximum four points.

Flooring

For the weight room, aerobic room, locker rooms, trainer's room and the offices, using Prime Sports Flooring provided by Flexco Flooring was the plan. Using this flooring system, would give the building a point for a low-emitting material.

Adhesives

For the sealant and adhesives, products from Bostik were used. Bostik sold adhesive products used for concrete and for windows. Since the new fitness and aerobics rooms will be located in the circular section on the northern side of the building and will be glass curtain-wall, the sealant to help relieve heating costs was used.

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[29] http://www.buildinggreen.com/auth/productsByLeed.cfm?LEEDCreditID=28

[30] USGBC LEED Sample Credit Template NCv2.2

Paint

Eco-friendly paint supplies from local distributors like Sherwin-Williams were used. Their green products are extremely advantageous in assisting in LEED certifications which can help obtain three points: low emitting material (1 point), and design and verification of thermal comfort (2 points).[31]

Wood

Finally the composite wood used for furniture came from the company SierraPine. Their products can attain up to six accreditation points including two for using recycled content, two for using regional materials, one for being certified wood and one for not using formaldehyde.[32]

Credit 6: Controllability of Systems achieved two points, one for lighting and one for thermal comfort. In order to achieve the point for lighting, a control system was designed that provided comfort control for at least 50% of the occupants.[33]

Credit 7: Thermal Comfort also achieved two points, one for design and one for verification. When obtaining EQ Credit 7.1 (thermal comfort design), an explanation was provided about how the thermal comfort system would achieve the design criteria, which included minimum and maximum indoor space as well as the maximum indoor space humidity for all four seasons.[32] To acquire the second point for thermal comfort, a permanent monitoring system was installed that would validate the thermal comfort conditions of the project.[34] One way in which this was achieved was by using LEED certified building insulations as well as using Sherwin-Williams' E-barrier™. This product has low emissivity rating which reflects the sun's radiant energy during the summer keeping temperatures lower and contains the radiant energy in the building during the winter keeping it warm.[35]

[31] http://www.sherwin-williams.com/pro/green/index.jsp
[32] http://www.sierrapine.com/index.php?pid=20
[33] USGBC LEED Sample Credit Template NCv2.2
[34] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[35] http://www.sherwin-williams.com/pdf/products/ebarrier.pdf

EQ Credit 8 Daylight & Views had two points that were achieved. The first point was procured if 75% of the total space has sunlight. This was calculated using one of three options: glazing factor calculation, computer simulation and daylight measurements.[34] The second point obtained from EQ Credit 8 was if 90% of the regularly occupied space had views to the outside.[34] The plan on obtaining this point was to use glass curtain walls for most of the building to allow for outside views towards the current football and future soccer fields. Calculations were completed using the supporting calculator on the LEED site for new construction.

Innovation in Design Process

Innovation in Design has two areas that accounted for points. ID Credit 1 contained a maximum of four points (one point each) which were accrued when an original innovative credit was created that included a title, a statement of credit intent, a statement describing credit requirements and a statement that describes the approach to the credit.[29] The other area where the building gained a point was having the project signed off by a LEED accredited professional.

3. METHODOLOGY

Structural Layout

The drawings and layout of the new recreational center were developed using the AutoCAD software. This included the layout of the building, columns, beams, and girders. An alphanumeric grid was also outlined to reference columns as well as specific girders and beams. Bay designations were structured around the columns labeled in the alphanumeric grid to simplify identifications and layouts. Multiple elevation views were used to show the height of the building as well as slab elevations from different angles. AutoCAD was also used to determine dimensions of various columns, beams, and girders throughout the building.

The multiple-floored building was analyzed and columns, beams, and girders were structured around various recreational rooms such as the Olympic natatorium, the gymnasium, the squash and racquetball courts, and the rock climbing wall. Once the layout and dimensions were determined, design of the structural members followed.

Structural Analysis & Design

This section will describe the techniques and designs used to develop a structural layout of the recreation center. The textbook *Structural Steel Design – 4th Edition, McCormac, 2008* was used for design of the floor system, flexural members, axial members and base plates. The *Massachusetts State Building Code* was used to insure that the design was in compliance with all code regulations.

Load Combinations

Structural steel design is an area of knowledge of structural engineering used to design steel structures. There are currently two schools of thought in steel design. The oldest is the Allowable Strength Design (ASD) method. The second, and most recent, is the Load and Resistance Factor Design (LRFD) method.

The conditions for the LRFD comply with the prerequisites of the American Institute of Steel Construction (AISC) specifications for load combinations. The design corresponds with those requirements when the allowable strength of each structural member equals or exceeds the required strength determined on the basis of the LRFD load combinations. This can also be written as so:

$$R_u \leq \varphi R_n$$

R_u = required strength

R_n = nominal strength

ϕ = resistance factor

$\phi \cdot R_n$ = allowable strength

When calculating LRFD load combinations, the required strength, R_u, is determined from the load combinations seen in Table 2.

Tables 2-3 were used to determine the loads in pounds per square foot (psf). For each unique part of the new recreational center, dead and live loads were calculated. Examples of this can be seen in Table 5:

Table 5: Sample Use of Load Combinations

Load Combinations		
	1. Find Appropriate Loads	
	Dead (psf)	Live (psf)
a. Corridor	65	100
b. Offices/Classroom	65	50
	2. Find the Factored Applied Load	
Assume 8' Tributary Width		
Load Combination #	a. Wu (Lb/Ft)	b. Wu (Lb/Ft)
1	728	728
2	**1904**	**1264**
3	624	624
4	1024	824
5	1024	824
6	468	468

Once the loads and load combinations were calculated, it was time to apply these figures to the structural layout of the new recreational center. The design of the floor system was the first constituent to be explored.

Floor System

The first component to be analyzed was the floor system. The floor system was connected to the beams using shear connectors yielding a composite system. The design manual *Designing with Steel Form Deck, SDI, 2003* was used to obtain dimensions for the decking.

Once the decking was detailed, a manufacturer was referenced to select the actual product. The manufacturer also used provided design values and allowable loads for different types of decking and different slab types.

Composite Sections

Composite sections were designed for all floors of the Recreation Center. These composite sections were designed based on the loads and load combinations discussed above. This design encompasses flexure stresses, shear stresses and deflections.

Design of the composite beams started with finding the required area of steel for the W-shaped member based on the maximum factored moment ($\Phi_b M_n$) due to dead and live loads (flexure design). This maximum factored moment from the loads was used to compare to the strength ($\Phi_b M_{px}$) of W-shapes in Table 3-2 from the *AISC Steel Construction Manual, 2006*. Tables 5-8 summarize the design process of a composite section. Table 6 shows the steps taken to design the member before the strength of the slab could be considered.

Table 6: Spreadsheet Used for Flexure Design

Design for Flexure			
	1. Load Combination		2. Maximum Applied Moment
	W_u (Lb/ft)	W_u (Lb/in)	M_u (FT-LBS) $W*L^2/8$
a. Corridor	2856	238	142,800
b. Offices/Classroom	1896	158	94,800
c. Restrooms	2088	174	104,400
3. Choose Beam Size	**Beam Properties**		
Beam Size	Beam Weight	Beam Capacity	
AISC T.3-2	(LB/FT)	$\Phi_b M_{px}$ (FT-LBS)	
a. W10x33	33	**146,000**	
b. W12x26	26	**140,000**	
c. W12x26	26	**140,000**	

4. Check Against Weight (M_u)	**5. $\Phi_b M_{px}$ > M_u?**
(FT-LBS)	
a. 145,080	**Yes**
b. 96,360	**Yes**
c. 105,960	**Yes**

All examples shown in Table 6 are acceptable because the factored strength is greater than the applied moment. This process gives a preliminary section to further design for.

The next step in this design was to determine the strength of the composite section. This was important because the composition section is, in our case, about twice as strong as an independent floor system. Table 7 shows this design process.

Table 7: Spreadsheet Used for Composite Section Strength

Determining Strength of Composite Section				
	1. Determine Φ_b			
	h (in.)	h/t_w	$h/t_w < 3.76\sqrt{E/F_y f}$?	
a. Corridor	12.27	39.58	YES	
b. Offices/Classroom	10.84	47.13	YES	
c. Restrooms	10.84	47.13	YES	
2. Locate PNA		**3. Strength of Composite Section**		**4. $\Phi_b M_n > M_u$?**
a (in.)	a < t ?	M_n (in-K)	$\Phi_b M_n$ (FT-K)	
1.37	*Yes so PNA is in slab*	5223.32	**391.75**	**Yes**
0.94	*Yes so PNA is in slab*	3683.95	**276.30**	**Yes**
0.94	*Yes so PNA is in slab*	3683.95	**276.30**	**Yes**

The composite section was then checked for adequacy in shear. Shear design, like the flexure design, started with the load combinations in order to find the maximum shear force experienced by the section. After briefly calculating the web shear coefficient, the shear capacity was evaluated. From here, the applied shear could be compared to the shear capacity. The spreadsheet in Table 8 was used for this design.

Table 8: Spreadsheet Used for Shear Design

Design for Shear			
	1. Load Combination		2. Maximum Applied Shear
	W_u (Lb/ft)	W_u (Lb/in)	V_u (k)
a. Corridor	2901.6	241.8	**29**
b. Offices/Classroom	1927.2	160.6	**19.3**
c. Restrooms	2119.2	176.6	**21.2**

3. Web Shear Coefficient	4. Shear Capacity	5. $\Phi V_n > V_u$?
h/t_w	ΦV_n (kips)	
39.6	**131.13**	**Yes**
47.2	**84.18**	**Yes**
47.2	**84.18**	**Yes**

The last design check was for deflections. Table 9 is an example of deflections for floors using the equation L/240. For the roof, L/200 was the design equation utilized which enabled smaller sections to be used. These deflection calculations included the construction live loads (wet concrete).

Table 9: Spreadsheet Used for Deflection Checks

Deflections		
Members	**Member Properties**	
	E (psi)	$\mathbf{I_x}$ (in^4)
a. W10x33	$29x10^6$	171
b. W12x26	$29x10^6$	301
c. W12x26	$29x10^6$	301
1. Actual Deflection	**2. Allowable Deflection for Floors**	**3. Actual < Allowable?**
$5wL^4/384EI$ (in)	$L/240$ (in)	
1.54	**1.55**	**Yes**
1.38	**1.55**	**Yes**
1.52	**1.55**	**Yes**

Using these five spreadsheets, all of the composite sections for every floor and roof were designed. All of the designed sections and their locations are presented via AutoCAD drawings in Chapter 4.

Columns

The axially loaded members (columns) were designed using the LRFD approach. W-shaped members were selected and designed for axial loading members rather than built-up columns, composite columns or other different shapes. Table 4-1 from the *AISC Steel Construction Manual, 2006* was used to determine the available strength in axial compression based on the effective length (KL) with respect to the radius of gyration (r_y). Table 10 shows the spreadsheet used for column design.

Table 10: Spreadsheet Used for Column Design

Column Design			
1. Load Combination	**2. Area Req'd**	**3. Choose a Section**	**4. Effective Slenderness Ratio**
P_u (k) = 1.2D + 1.6L	$P_u / \varphi_c F_{cr}$	AISC T.1-1	$\frac{KL}{r_y}$
400	10.6	Try W12-50	79.6
5. $\Phi_c F_{cr}$ from AISC T.4-22	**6. Calculate $\Phi_c P_n$**	**7. $P_u < \Phi_c P_n$?**	
Ksi	$\Phi_c F_{cr} * A$ (k)		
28.35	413.91	**Yes**	

This process gave us W-shaped columns for all floors of the building and can be found in Chapter 4.

Base Plates

The next step in the design process was to consider how the columns would transfer their loads to the foundations. To do this column base plates had to be designed for.

A few properties of the footing had to be identified such as the type of foundation and its surface area. A basic analysis of the footing was completed to find these properties using the spreadsheet provided by the textbook, *Foundation Design 2nd Edition – Coduto, 2001*. The required base plate area was found from the factored load and area of the footing. Once a preliminary base plate area was calculated, the dimensions *m* and *n* were optimized to help find the dimensions for the entire base plate.

Finally, the bearing strength of the concrete was checked and the thickness of the plate could be determined. The base plates are detailed in Chapter 4 using AutoCAD drawings.

Truss Design

A truss system was designed for the long spans of the gymnasium and the natatorium instead of typical W-sections which would have been extremely deep and impractical. A study of the effectiveness of truss designs using RISA-2D was conducted to find which could most effectively carry the given loads. Structural analysis on three basic truss configurations was performed for uniform green roof and snow loads. The design of the truss also incorporated the use of different shapes within RISA-2D.

The truss was designed for the gymnasium and only had loads of the green roof combined with snow loads. The height of this truss determined how high the green roof would extend above the rest of the roof.

The second truss designed was slightly more complex because it was on the second floor and was required to carry uniform loads from the floor above as well as point loads from columns throughout its span. RISA-2D was used to render the truss designs.

Foundation

When designing the foundation for a structure, one must first consider the soil conditions which the building will transfer the loads to. For the foundation design, the geotechnical report prepared by Haley & Aldrich Inc. for WPI was used to obtain site information, soil characteristics and foundation design recommendations. The report also gave depths of the water table which was an important aspect to the foundation design.

Once the soil conditions were established, the bearing capacity design began. To simplify the design of the spread footings for the building, four broad categories of column loads were chosen. These four categories grouped every single column. *Foundation Design 2nd Edition – Coduto, 2001* was used for all design steps of the footings which was the selected foundation for the building.

Bearing capacity design was the first step to sizing the footings. Different areas of footings were chosen using the 'Bearing Capacity of Shallow Foundations' excel spreadsheet (provided with the *Foundation Design 2nd Edition – Coduto, 2001* textbook). This spreadsheet, based on the height of the water table, depth of footing, factor of safety, effective friction angle and the bearing capacity factors, computed the allowable column load per footing. These values were obtained from the geotechnical report and the *Foundation Design 2nd Edition – Coduto, 2001* textbook.

An important consideration in this process was the height of the water table. Figure 13 shows the three cases in the design of the bearing capacity. Based on the case, a specific equation was used.

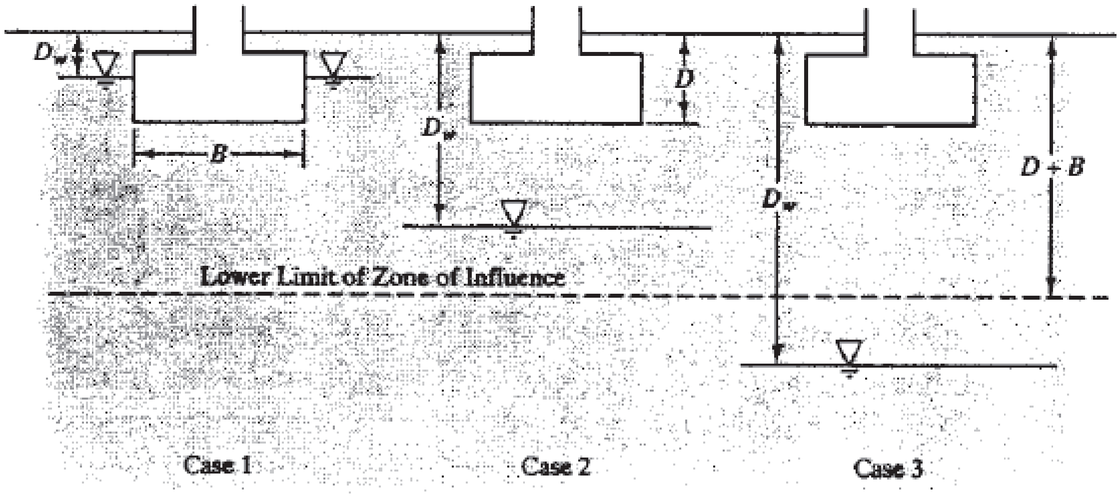

Figure 13: Three Groundwater Table Cases for Vertical Stress Analysis

The final result of finding the bearing pressure yielded the surface area of the footing. To obtain its thickness another step was required.

The thickness was calculated using a two-way shear analysis to ensure that the column, which would transfer its loads through a base plate, would not puncture the concrete. This simple calculation gave the overall thickness of the footing and the height of the reinforcing steel from the top.

Once we knew the volume of the footing, the reinforcing bars were selected. The required area of steel came from a flexural design (based on the bending moment the column would place on it). Reinforcement was chosen and detailed to ensure adequate cover and development lengths. These footings and their reinforcement were detailed using AutoCAD.

A settlement analysis was performed on the underlying soil of the building after the footings were designed. The analysis began with locating the height of the groundwater table based on the geotechnical report. The height of the water table is important because if it drops a significant amount below the footing the effective stress of the soil beneath the footings will increase greatly. This process would have caused catastrophic failure of the building. The reason this happens is because the pore water pressure will carry some of the load when it is relatively close or at the elevation of the footing. This will take stress away from the surrounding soil.

Retaining Wall/Sheet Piles

This section describes the design process of a cantilever retaining wall. Before one designs the dimensions of the retaining wall, they must first choose which of the previously stated conditions the retaining wall is following and use that as a basis for design.

In order to calculate the normal force of the soil pressure per unit length of wall, the following equation was used:

$$P_o/_b = \frac{\gamma * H^2 * K_o}{2}$$

where, H is the height of the wall, γ is the unit weight of the soil, and K_o is the coefficient of lateral earth pressure in the at-rest condition.[36]

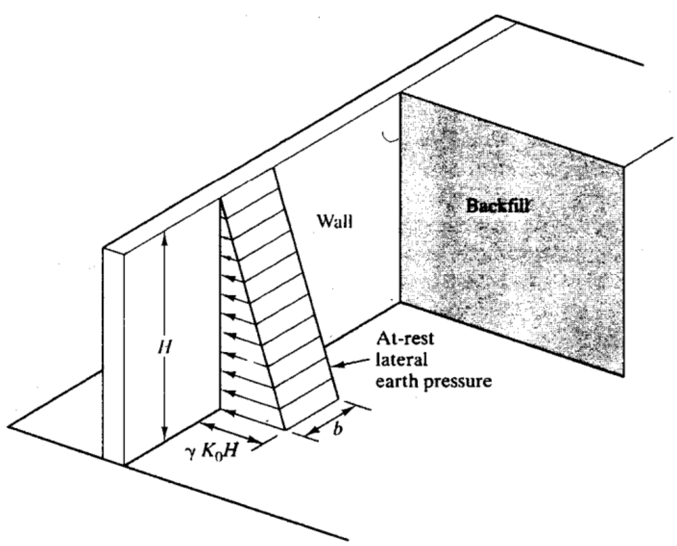

Figure 14: Normal Force Acting on a Cantilever Retaining Wall (Foundation Design 2nd Edition – Coduto, 2001)

Figure 14 depicts the lateral earth pressure in the at-rest condition.

[36] Foundation Design 2nd Edition – Coduto, 2001

Engineered retaining walls often use a method called the equivalent fluid method which uses a fluid unit weight of water, instead of K values to calculate the normal forces acting on the wall. The resulting force acting along the wall was the same as before and was calculated by the equation:

$$P_a/_b = \frac{G_h * H^2}{2}$$

where G_h is the horizontal equivalent fluid density.[37]

Another load that acts on the retaining wall is the surcharge load. Figure 15 depicts a typical uniform surcharge load as well as a point load. The surcharge loads extend as far horizontally as the approximate height of the wall.[37]

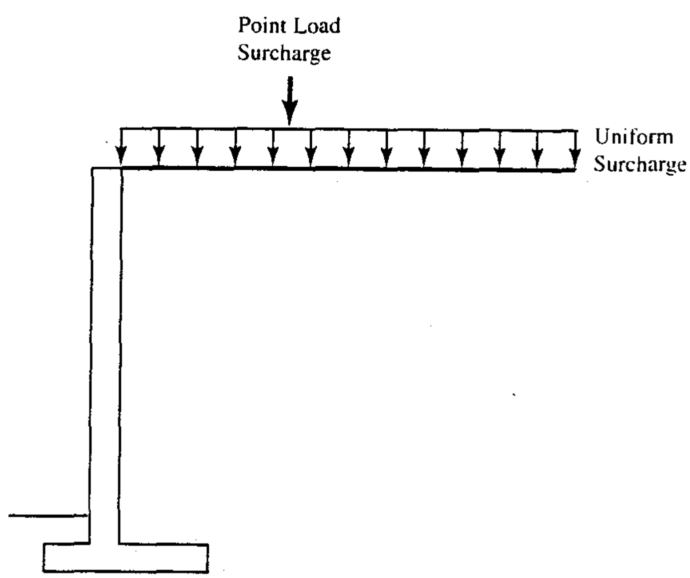

Figure 15: Surcharge Loads
(Foundation Design 2nd Edition – Coduto, 2001)

We calculate the surcharge load by using the equation:

$$\sigma = K * q$$

where sigma (σ) is the additional surcharge load, and q is the surcharge pressure.[37] The reason for this is because the report stated, "[f]or surcharges on building walls, the resulting lateral

[37] Foundation Design 2nd Edition – Coduto, 2001

load should be calculated based on a uniform lateral pressure equal to 0.5 times the vertical surcharge pressure acting on the backfilled side of the wall, applied over the full height of the wall."[38]

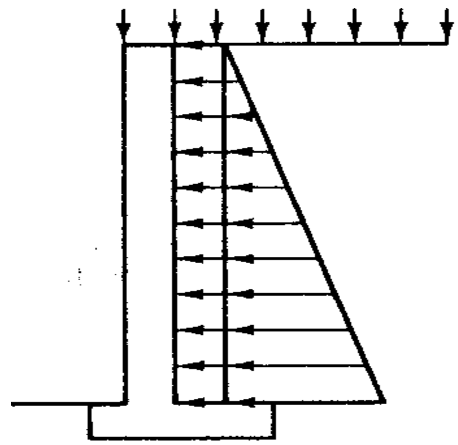

Figure 16: Loading Diagram with a Uniform Surcharge Load (Foundation Design 2nd Edition – Coduto, 2001)

Figure 16 shows the loadings the recreational center's retaining wall will experience due to the soil and distributed loads from the floors above.

Once those key components were calculated, the next step in the design process was to determine the preliminary dimensions of the retaining wall. The reinforcement ratio (R_n) was first determined by using the given data and using Table 10 below and was used to calculate key components for the wall dimensions as well as help determine bar sizes.

[38] Geotechnical Design Investigation, Haley & Aldrich, Inc. File No. 32597-001

Table 11: Reinforcement Ratios

TABLE 3.6.1 Balanced and Maximum Reinforcement Ratio ρ for Singly Reinforced Rectangular Beams

f_y		$f_c' = 3000$ psi, $\beta_1 = 0.85$	$f_c' = 3500$ psi, $\beta_1 = 0.85$	$f_c' = 4000$ psi, $\beta_1 = 0.85$	$f_c' = 5000$ psi, $\beta_1 = 0.80$	$f_c' = 6000$ psi, $\beta_1 = 0.75$
40,000 psi		$\rho_b = 0.0371$	$\rho_b = 0.0433$	$\rho_b = 0.0495$	$\rho_b = 0.0582$	$\rho_b = 0.0655$
	$\rho_{max} =$	$0.626\ \rho_b = 0.0232$	$0.626\ \rho_b = 0.0271$	$0.626\ \rho_b = 0.0310$	$0.626\ \rho_b = 0.0365$	$0.626\ \rho_b = 0.0410$
50,000 psi		$\rho_b = 0.0275$	$\rho_b = 0.0321$	$\rho_b = 0.0367$	$\rho_b = 0.0432$	$\rho_b = 0.0486$
	$\rho_{max} =$	$0.675\ \rho_b = 0.0186$	$0.675\ \rho_b = 0.0217$	$0.675\ \rho_b = 0.0248$	$0.675\ \rho_b = 0.0291$	$0.675\ \rho_b = 0.0328$
60,000 psi		$\rho_b = 0.0214$	$\rho_b = 0.0249$	$\rho_b = 0.0285$	$\rho_b = 0.0335$	$\rho_b = 0.0377$
	$\rho_{max} =$	$0.724\ \rho_b = 0.0155$	$0.724\ \rho_b = 0.0181$	$0.724\ \rho_b = 0.0206$	$0.724\ \rho_b = 0.0243$	$0.724\ \rho_b = 0.0273$
f_y		$f_c' = 20$ MPa, $\beta_1 = 0.85$	$f_c' = 25$ MPa, $\beta_1 = 0.85$	$f_c' = 30$ MPa, $\beta_1 = 0.85$	$f_c' = 35$ MPa, $\beta_1 = 0.81$	$f_c' = 40$ MPa, $\beta_1 = 0.77$
300 MPa		$\rho_b = 0.0321$	$\rho_b = 0.0401$	$\rho_b = 0.0482$	$\rho_b = 0.0536$	$\rho_b = 0.0582$
	$\rho_{max} =$	$0.643\ \rho_b = 0.0206$	$0.643\ \rho_b = 0.0258$	$0.643\ \rho_b = 0.0310$	$0.643\ \rho_b = 0.0344$	$0.643\ \rho_b = 0.0374$
350 MPa		$\rho_b = 0.0261$	$\rho_b = 0.0326$	$\rho_b = 0.0391$	$\rho_b = 0.0435$	$\rho_b = 0.0472$
	$\rho_{max} =$	$0.679\ \rho_b = 0.0177$	$0.679\ \rho_b = 0.0221$	$0.679\ \rho_b = 0.0266$	$0.679\ \rho_b = 0.0295$	$0.679\ \rho_b = 0.0321$
400 MPa		$\rho_b = 0.0217$	$\rho_b = 0.0271$	$\rho_b = 0.0325$	$\rho_b = 0.0361$	$\rho_b = 0.0393$
	$\rho_{max} =$	$0.714\ \rho_b = 0.0155$	$0.714\ \rho_b = 0.0193$	$0.714\ \rho_b = 0.0232$	$0.714\ \rho_b = 0.0258$	$0.714\ \rho_b = 0.0280$
f_y		$f_c' = 200$ kgf/cm^2, $\beta_1 = 0.85$	$f_c' = 240$ kgf/cm^2, $\beta_1 = 0.85$	$f_c' = 280$ kgf/cm^2, $\beta_1 = 0.85$	$f_c' = 320$ kgf/cm^2, $\beta_1 = 0.82$	$f_c' = 360$ kgf/cm^2, $\beta_1 = 0.79$
2800 kgf/cm^2		$\rho_b = 0.0357$	$\rho_b = 0.0429$	$\rho_b = 0.0500$	$\rho_b = 0.0551$	$\rho_b = 0.0598$
	$\rho_{max} =$	$0.619\ \rho_b = 0.0221$	$0.619\ \rho_b = 0.0265$	$0.619\ \rho_b = 0.0310$	$0.619\ \rho_b = 0.0341$	$0.619\ \rho_b = 0.0370$
3500 kgf/cm^2		$\rho_b = 0.0265$	$\rho_b = 0.0318$	$\rho_b = 0.0372$	$\rho_b = 0.0410$	$\rho_b = 0.0444$
	$\rho_{max} =$	$0.667\ \rho_b = 0.0177$	$0.667\ \rho_b = 0.0212$	$0.667\ \rho_b = 0.0248$	$0.667\ \rho_b = 0.0273$	$0.667\ \rho_b = 0.0296$
4200 kgf/cm^2		$\rho_b = 0.0206$	$\rho_b = 0.0248$	$\rho_b = 0.0289$	$\rho_b = 0.0319$	$\rho_b = 0.0345$
	$\rho_{max} =$	$0.714\ \rho_b = 0.0147$	$0.714\ \rho_b = 0.0177$	$0.714\ \rho_b = 0.0206$	$0.714\ \rho_b = 0.0228$	$0.714\ \rho_b = 0.0247$

Source: Reinforced Concrete Design 2nd Edition, Wang 2007

The following step was used to determine the height of the wall. An extra four feet below the bottom of the footing was provided for frost penetration.[39] Next, a uniform footing thickness based on the total height of the wall which is typically 7-10% of the total height was estimated. Subsequently, the base length based on the load distributions was determined. The base length is the length of the bottom on the stem plus the length of the heel. In order to perform that operation, the resultant forces acting on the wall were calculated. The moments about the point on the bottom of the footing directly below the inside part of the stem were summed after that. Once the equation was arranged, a length that consisted of the weight of the soil being equivalent to the pressures acting on the wall was concluded. After that distance was calculated, it was multiplied by 1.5 to obtain the desired base length. The stem thickness based on the bending moment was calculated with the equation:

$$M_y = \frac{P_1(y^2)}{2} + \frac{P_2(y^3)}{6}$$

where P_1 and P_2 are the resulting forces acting on the wall and y is the distance from the bottom corner of the footing to the force.

[39] Reinforced Concrete Design-7th Edition. Wang 2007

A factor of safety equal to 1.6 was put into the M_y equation to establish M_u. Once M_u was calculated, the required thickness (d) could be determined using the equation:

$$Req.d = \sqrt{\frac{M_u}{\phi * R_n * b}}$$

where M_u is the factored allowable moment capacity, ϕ is the resistance factor, R_n is the steel ratio calculated by the data previously computed and data in Table 11 and b is the unit length in inches.

To determine the total thickness, both 0.5 inches for the reinforcement bar radius and 2-3 inches for cover were added. The critical section for shear strength was checked and calculated by using the equation:

$$V_y = P_1(y) + \frac{1}{2}(P_2)(y^2)$$

Once that was calculated, V_y was multiplied by 1.6 (factor of safety) to obtain V_u (actual shear strength). The allowable shear strength (V_c) was then determined to see if the allowable was larger than the actual. The allowable shear strength was computed using the equation:

$$\phi * V_c = \phi * \left(2 * \sqrt{f'_c}\right) * b * d$$

where V_c is the factored shear capacity, f'_c is the compressive strength of the steel and d is the thickness in inches. If the allowable is greater than the actual then shear reinforcement is not required because it is in accordance with ACI-11.5.6.1.

After the thickness was determined, the decision was whether or not the retaining wall adhered to the factor of safety against overturning. Using the preliminary dimensions, the moments with respect to the heel were summed. Based on the summed moments and the gravitational forces applied by the soil and concrete, the retaining wall was checked to see if it was greater than the factor of safety, 2.

The next step was to determine whether the force was within the middle third of the base. In order to do this, the x-bar, which is the sum of the moments (i.e. the moments resulted from the weights of soil and concrete and the moment resulted from the soil acting horizontally), was to be divided by the sum of the weights. Next, 'e', which is just x-bar minus half of the base length, was calculated. It was determined whether the resulting force was in the middle-third by multiplying 'e' by 6 and dividing by the base length to see if it was less than or equal to 1. Once that was completed, it was important to verify that the maximum applied force was less than the allowable bearing capacity. This was confirmed using the equation:

$$R = \left({}^{1}/_{2} \right) * \rho_{max} * (b.l.)$$

where R is the summed resulting gravitational forces, ρ_{max} is the maximum allowable resultant force and b.l. is the base length. Once this was concluded the next step was to establish whether or not the recreational center's retaining wall was safe enough against sliding forces.

To validate the retaining wall's safety, the forces causing sliding (the forces from the soil acting horizontally) and the frictional force, calculated by μ*R where, μ is the coefficient of friction and R being the summed gravitational forces of the soil and concrete) were examined. Once those components were calculated, the frictional force was divided by the forces causing sliding to determine if it was greater than 1.5.

The design of the reinforcement of the wall was the subsequent stage in the analysis. The first component to find was the required area of steel by using the equation:

$$ {}^{A_{vf}}/_{b} = \frac{{}^{V_u}/_{b}}{\phi * f_y * \mu} $$

where A_{vf}/b is the required area of steel per unit length of wall, V_u/b is the actual shear strength per unit length of wall, f_y is the yielding strength of the steel and μ is the coefficient of friction. The flexural steel area was the next computation solved by using the equation:

$$ {}^{A_s}/_{b} = \left(\frac{f'_c * b}{1.176 * f_y} \right) (d - \sqrt{d^2 - \frac{2.353 * \left(\frac{M_u}{b} \right)}{\phi * f'_c * b}}) $$

where M_u/b is the actual moment capacity per unit length of wall and d is the required thickness. Then, the required area and the flexural steel area were added together to obtain the total required steel area. Once the total required area of steel was calculated, an analysis was done to determine which steel bar size to use and how far apart they would be placed based on the total required area of steel. Finally, the moments at the top and bottom of the stem were established. To determine this, the component, 'a' was computed via the following equation:

$$a = \frac{\rho d f_y}{0.85 f'_c}$$

where a is a constant used to determine the moment capacities at the top and bottom of the stem and ρ is the steel ratio to be used. Once this was analyzed, it was used in the moment equation:

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

where M_n is the factored moment capacity at the top and bottom of the stem and A_s is the area of steel. The moments at the top and bottom of the stem were compared to the actual moment. If they were larger at the top and bottom than the actual moment, then the reinforcement was designed well enough for the vertical steel. The required longitudinal steel was calculated using the equation:

$$A_s = .002 A_g$$

where A_s is the area of steel and A_g is the gross area of the concrete. Using this area, it was easy to conclude on which steel bar size to use and how many would be needed for the longitudinal direction in the stem.

The first step in establishing the reinforcement for the footing would be to calculate the development length which was verified using the equation:

$$l_{dh} = {1200 * d_b}/{\sqrt{5000}}$$

where d_b is the diameter of the steel reinforcement bar and l_{dh} is the development length. It was necessary to add three inches to the l_{dh} to determine the minimum footing thickness. The answer to the minimum thickness was obtained using the shear forces. It was calculated via the weights of the soil per unit length and the footing per unit length. Those weights were summed and multiplied by a factor of safety (1.4). Subsequently, the factored shear strength per unit length ($\phi V_n/b$) was evaluated. The value of 'd' was determined by setting the minimum footing thickness and the factored shear strength equal to each other. Once 'd' was obtained, three inches and $d_b/2$ were added to get the required thickness. To design the reinforcement, the larger of the two thicknesses was used.

Next the controlling thickness was decided, the previously stated steps of figuring out the required area of steel per unit length of wall and comparing the maximum moment to the factored design moment went into evaluation. When this was calculated, it was concluded that a bar size and their spacing needed to be identified. The longitudinal steel was determined using the equation:

$$A_s = .0018 * A_g$$

where A_s is the area of steel and A_g is the gross area of the concrete. Finally, when this area of steel was established, bar sizes and quantities needed to be considered for effective reinforcement.

Pool Foundation

This section describes the method used to design a foundation for the Olympic-sized swimming pool. A foundation for this type of natatorium consists of four cantilever retaining walls around the perimeter and a mat foundation for the bottom of it.

The first step was to calculate the pressures on the retaining walls using two different scenarios.

Scenario 1: The groundwater table is at the surface of the pool. In this case, the pressure acting on the soil as a result from water ($\gamma \cdot H$) plus the pressure from the effective unit weight of the soil [$(\gamma_s - \gamma_w) \cdot K \cdot H$] was calculated.

Scenario 2: The groundwater table is located below the bottom of the pool. In this case, γ·K·H was evaluated using variables obtained in *Haley & Aldrich's Geotechnical Report*.

The design for the pool's foundation was based on the critical loadings. Once the result was obtained, the loading in the excel spreadsheet provided to us by the textbook was adjusted accordingly.

To calculate the pressures on the mat foundation from the water, the unit weight of water was multiplied by the height. Using the excel spreadsheet found in the textbook, the dimensions of the mat were analyzed and used to find the allowable pressure on the soil. For the unit weights of the soil, the maximum and minimum unit weights (109 $^{lb}/_{ft^3}$ without water and 46.6 $^{lb}/_{ft^3}$ with water) were used. Once the numbers were plugged into the spreadsheet, they were compared to the data obtained using the Vesic method.

4. STRUCTURAL ANALYSIS & DESIGN

Building Footprint

The program AutoCAD was used for the design process that was used to outline the alternate design for the new recreational center next to Harrington. Measurements for the length of the building were taken and then drawn up in AutoCAD. Figure 17 depicts the footprint that was drafted and used throughout the design process. It includes the circular part of the building where the fitness center is. It's also important to note that the outer wall is 2'-6" thick.

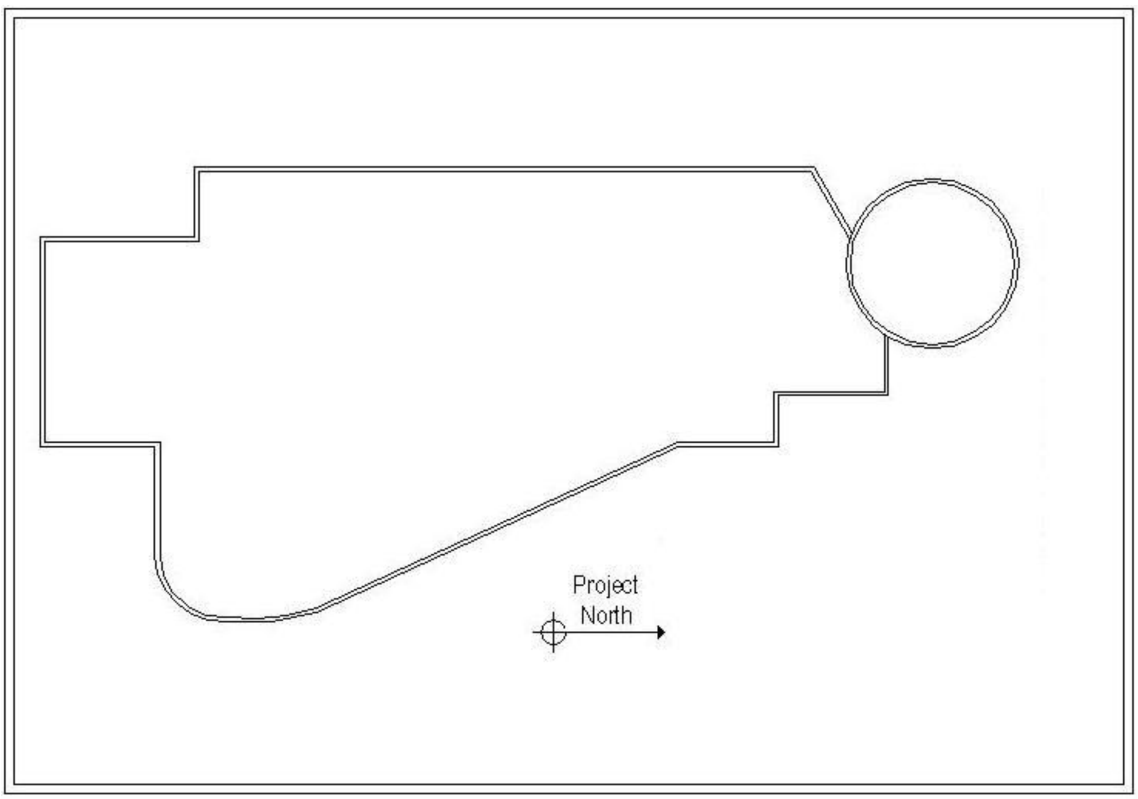

Figure 17: Building Footprint

Column Locations

Once the footprint had been sketched out, the next step was to design the girder, beam, and column layout for the building and fitness center. Figure 18 shows a standardized layout that would be applied to each of the floor systems. It was important to keep the spacing constant throughout the building. However, there were parts of the facility that had to be edited in order to keep in shape with the footprint. The fitness center in Figure 19 was designed to be completely symmetrical.

It also should be noted that there were differences amid the various floor systems due to certain recreational rooms such as the natatorium and gymnasium that are displayed a few figures down. The fitness center's layout remains constant for every floor.

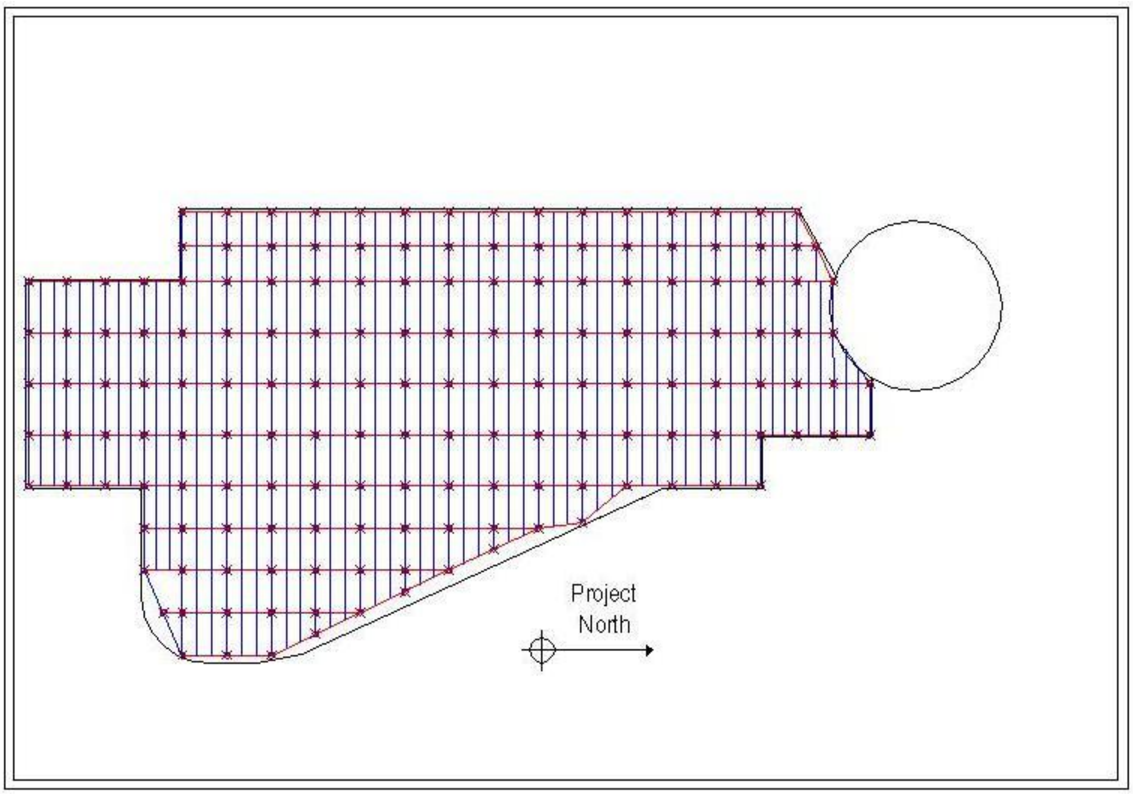

Figure 18: Girders, Beams, and Columns in the Building

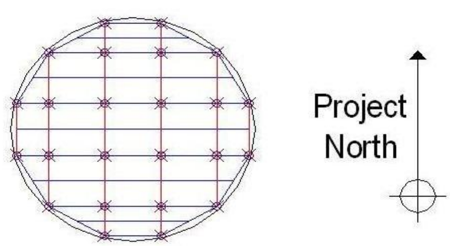

Figure 19: Girders, Beams, and Columns in the Fitness Center

Each floor has unique recreational rooms that serve different purposes. In the figures displayed below, columns can be viewed from each of their respective floors. Figure 20 represents the second floor. There is a large spacious area where the Olympic sized natatorium will be constructed. Girders and beams are above the indoor rowing tank north which is north of the natatorium.

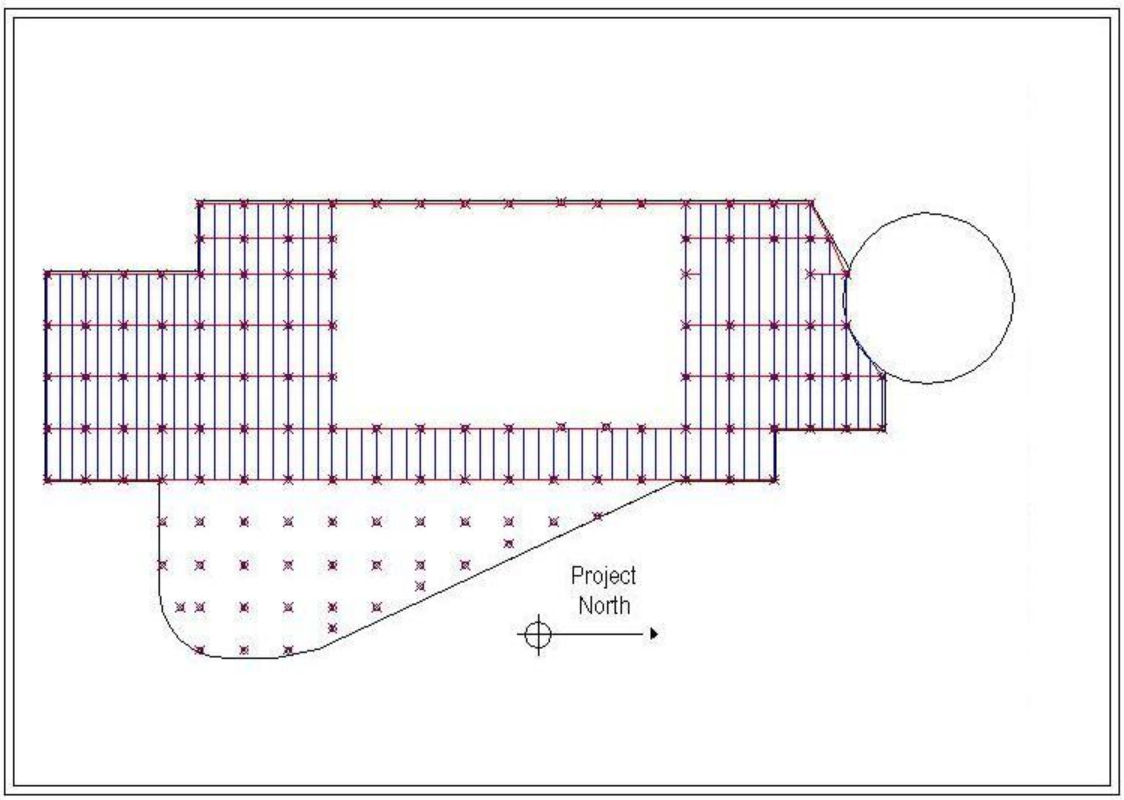

Figure 20: Second Floor Column Layout

In Figure 21, the third floor column layout can be seen. The beams, columns, and girders had to be adjusted for the squash and racquetball courts at the northern end of the building as well as the rock climbing wall at the southwestern part of the building. Beams and girders spread across the top of the natatorium.

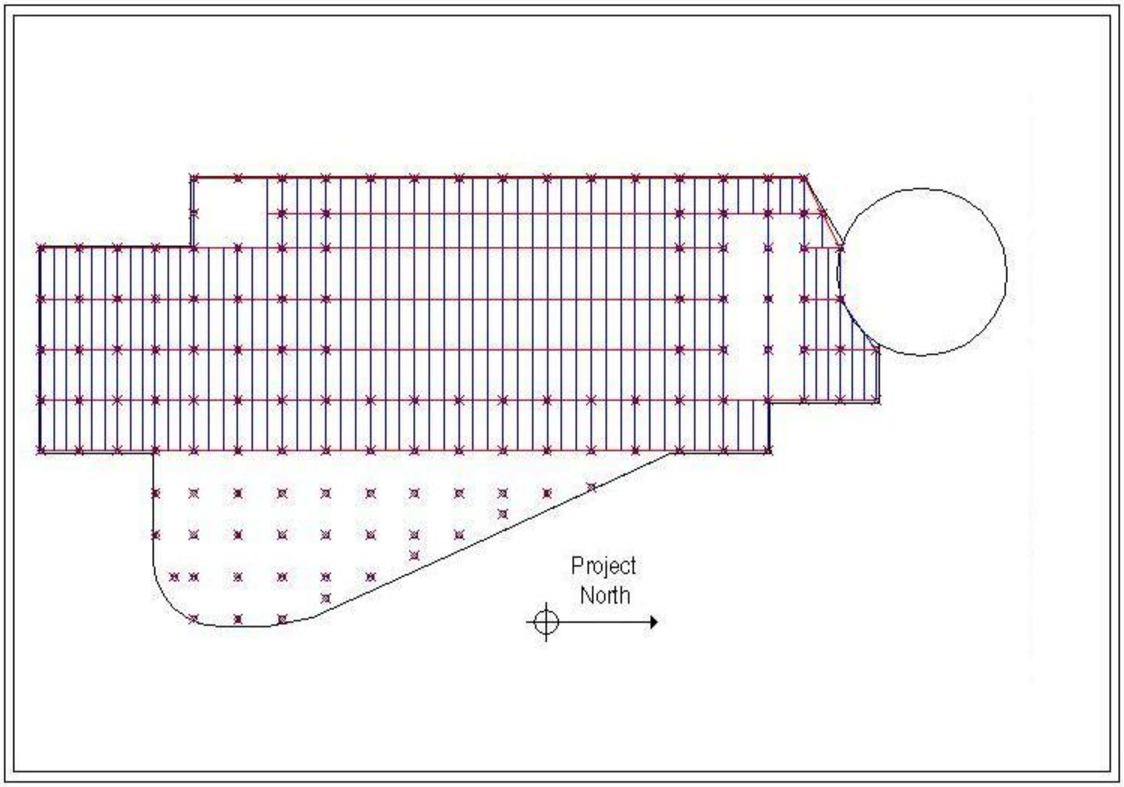

Figure 21: Third Floor Column Layout

The fourth floor column layout in Figure 22 has a large focus around the southern part of the building. That is where the gymnasium featuring basketball courts will be constructed. Beams and girders can be seen where the rock climbing wall and the squash and racquetball courts are.

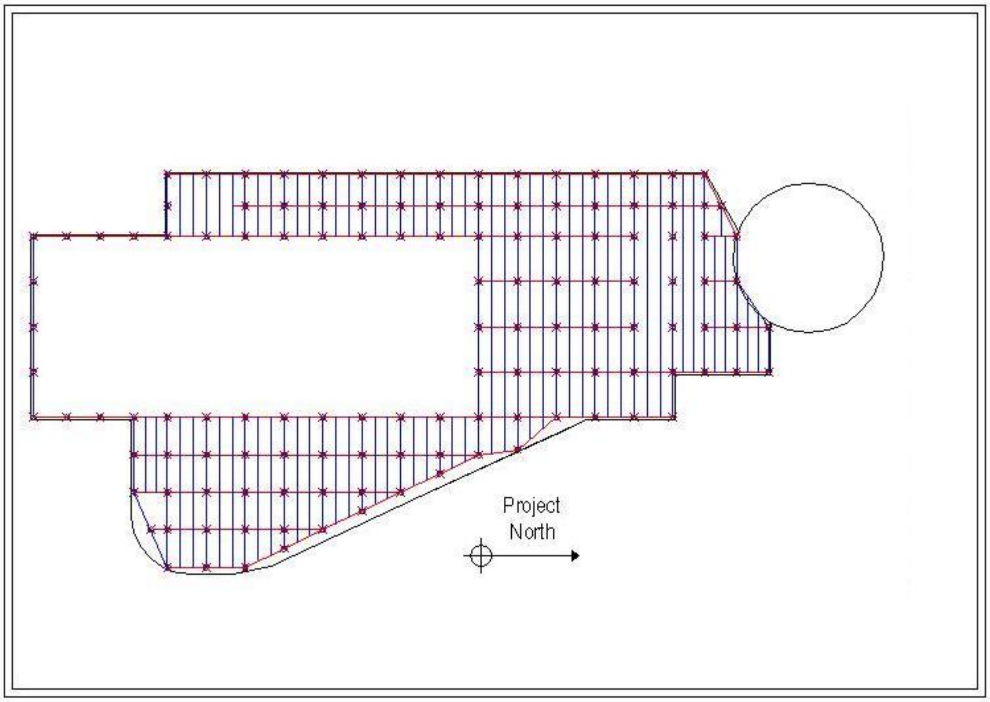

Figure 22: Fourth Floor Column Layout

Lastly, Figure 23 shows the roof column layout. The beams and girders above the gymnasium and indoor track are featured in the figure.

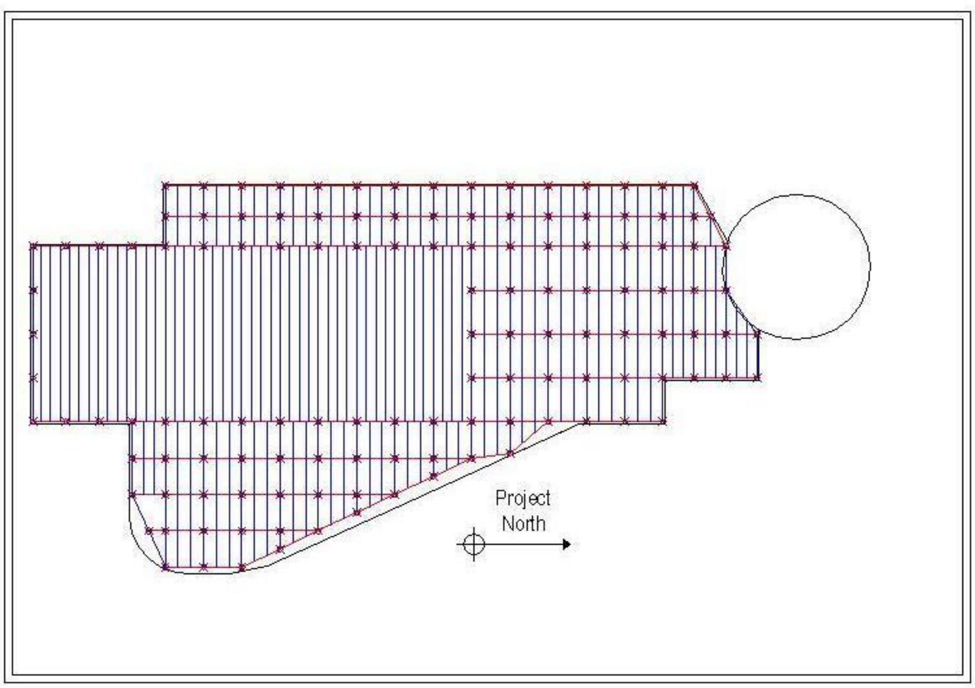

Figure 23: Roof Column Layout

Column Measurements & Alphanumeric Grids

Once the column layout was designed and structured per floor, the next step was to find measurements and create a system that would identify each individual column with ease. Below, Figure 24 shows the column measurements for the building while Figure 25 shows the column measurements for the fitness center. The dimensions shown in Figures 24 and 25 were obtained via AutoCAD. Take note of the repeating lengths and widths throughout the building as they come into play when creating bay designations.

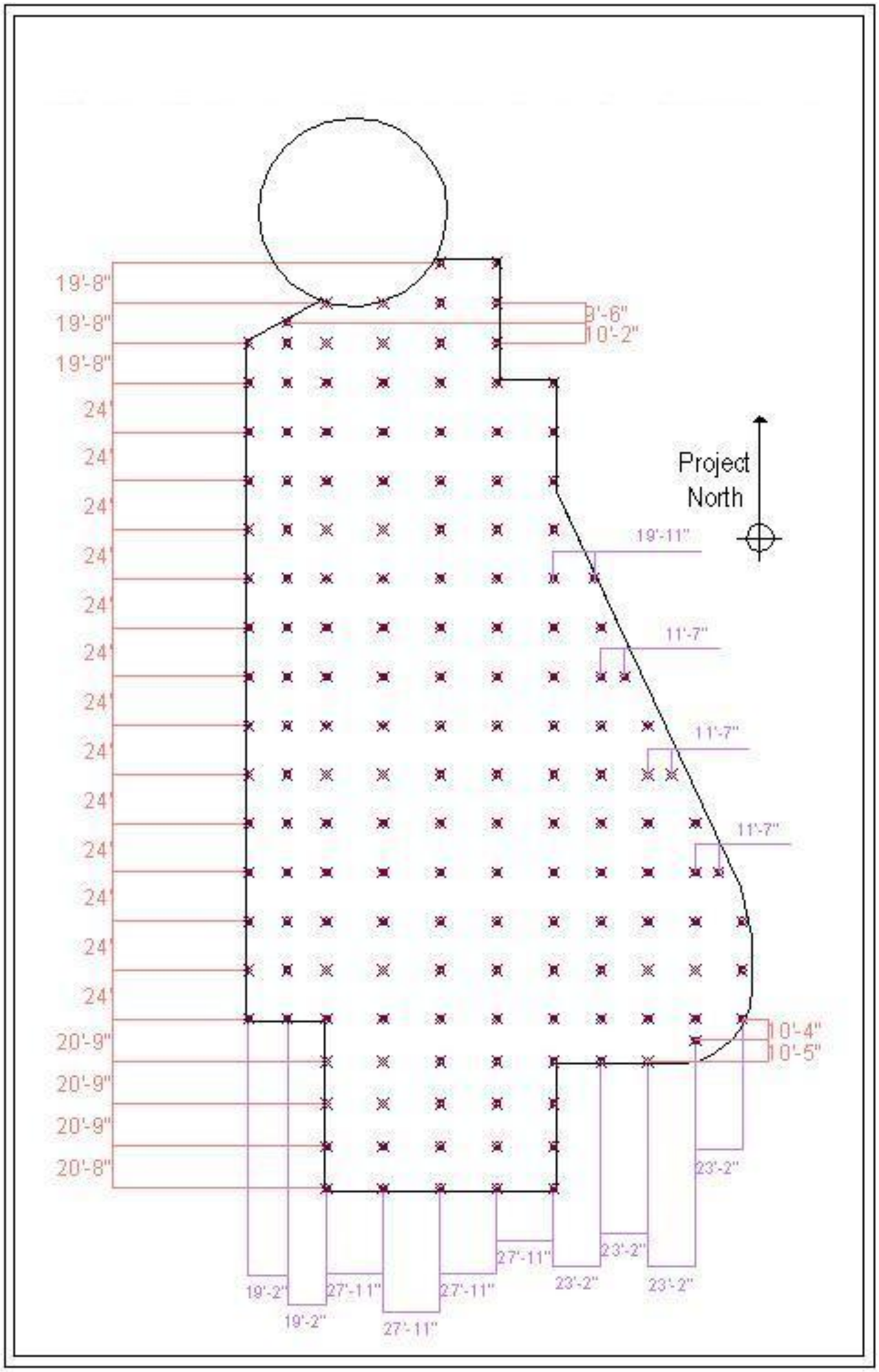

Figure 24: Building Column Measurements

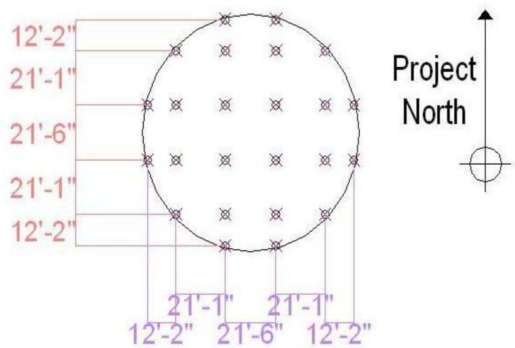

Figure 25: Fitness Center Column Measurements

Figures 26 and 27 present the alphanumeric grid for column locations for the building and fitness center respectively that was established in order to give each column a title. This system of column identification allowed for easy recognition of the column in question. The layout of the alphanumeric grid created the basic layout for a system of bay designations that will be covered later.

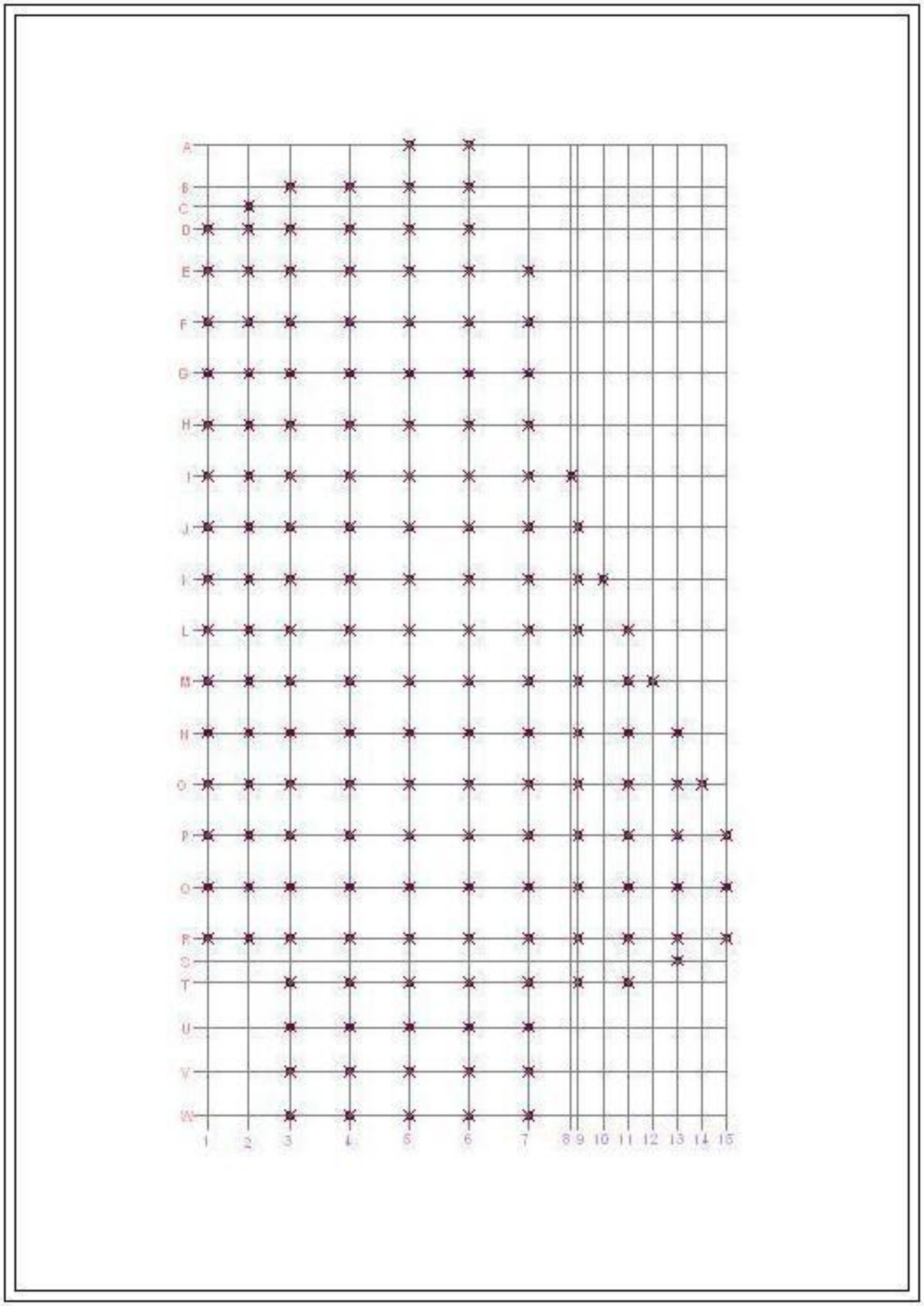

Figure 26: Alphanumeric Grid for Building Column Locations

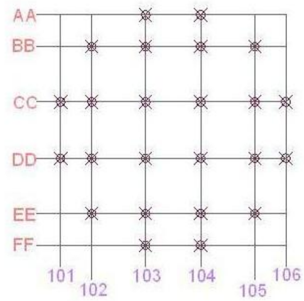

Figure 27: Alphanumeric Grid for Fitness Center Column Locations

Recreational Center Units

The recreational center is divided into three main types of units. Figures 28 and 29 outline these units for their respective areas. Each unit is composed of bay designations that are repeated often throughout the building. These units served as areas of focus for the design of the various flooring systems.

Each type of unit is repeated on floors one through four. All the units were divided based on column measurements. The building has different distances between columns but for design purposes we divided the athletic center into units to make certain areas easier to distinguish. The same goes for the fitness center.

Each individual unit shown in Figure 28 has symmetrical bays aside from the angled parts of the building. As a result, there are only a few unique areas that differ while the rest are simply repeated throughout. Figure 29 shows that units A and C are symmetrical while unit B serves as the middle ground for the fitness center.

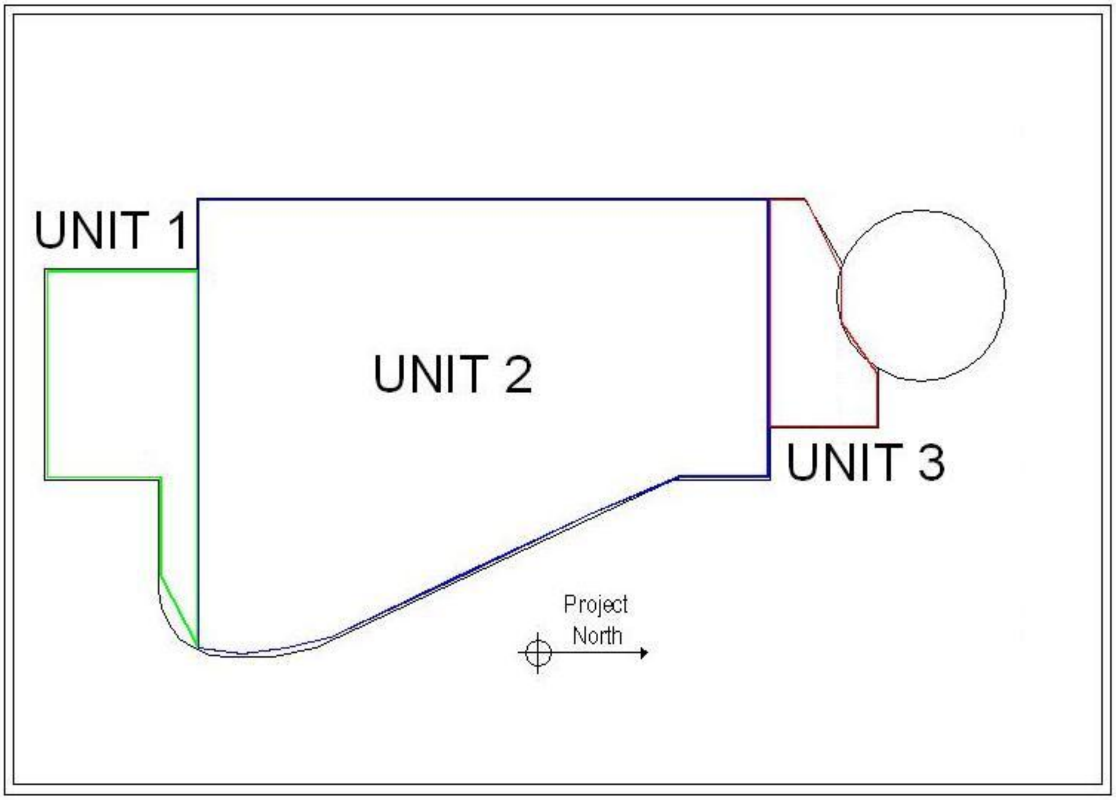

Figure 28: Athletic Center Units for the Building

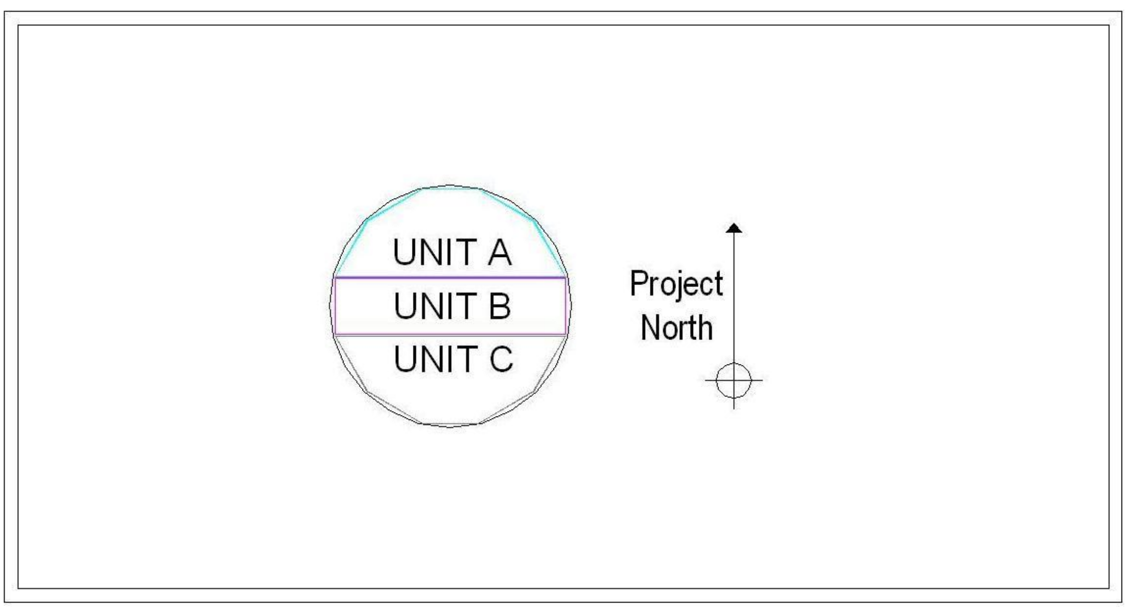

Figure 29: Athletic Center Units for the Fitness Center

Bay Designations

Bay designations were drafted based on the recreational center units, the column measurements, and the alphanumeric grid. Figures 30 and 31 contain bay designations that were used to specify areas of interest. It's important to take into account that a large majority of the bays repeat anywhere from three to 26 times.

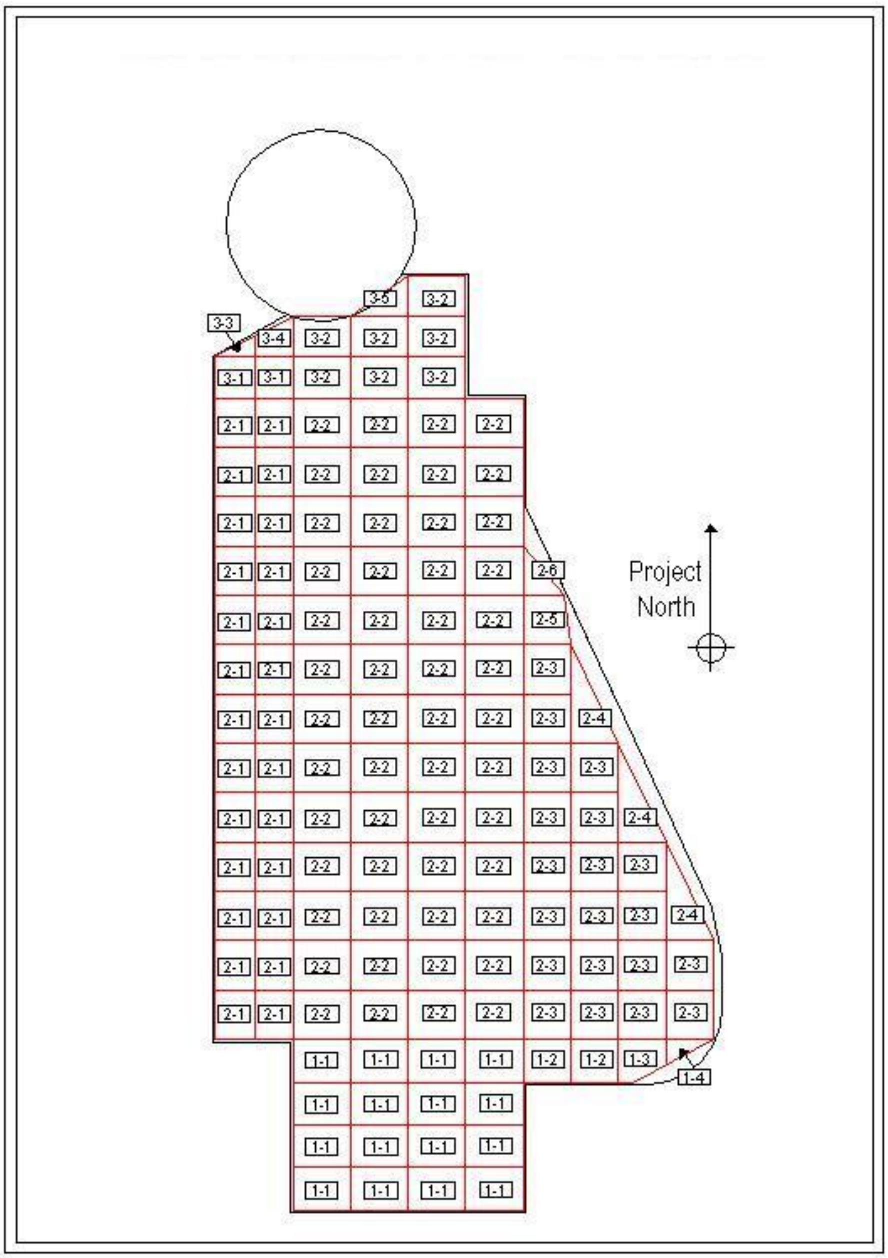

Figure 30: Bay Designations for the Building

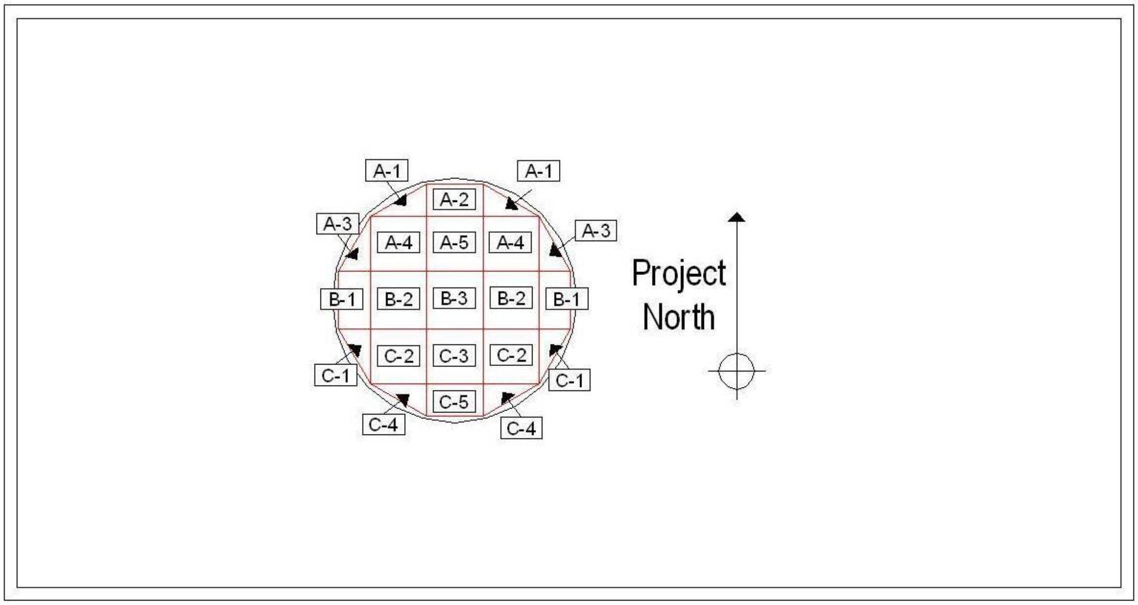

Figure 31: Bay Designations for the Fitness Center

Elevation Views

Due to the location of the new recreational center that will sit in the hill by the athletic fields, it was important to take into account its elevation as well as the slab elevations. Figure 32 shows the slab elevations and Figure 33 shows the building elevations, each from two different angles. Figure 32 shows the slab elevations in relation to sea level as well as the sequential floors while Figure 33 simply specifies the height of each floor from the ground up. The floor thickness usually defines what steel elevations of beams and girders will be.

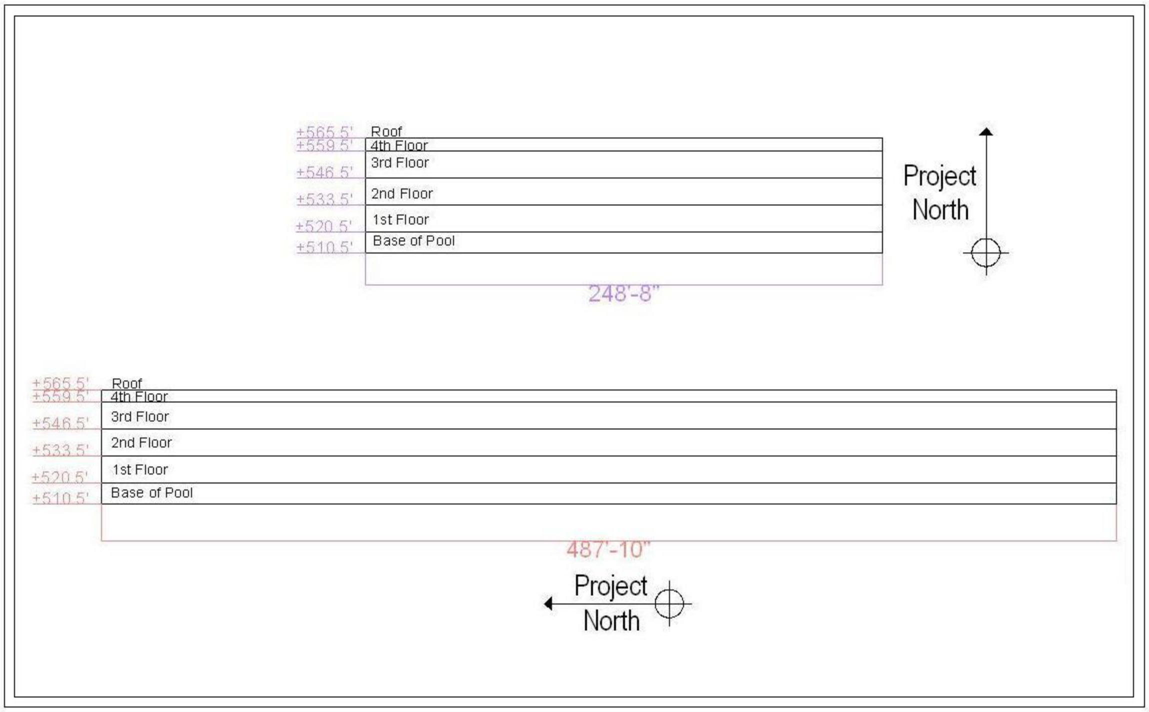

Figure 32: Slab Elevations

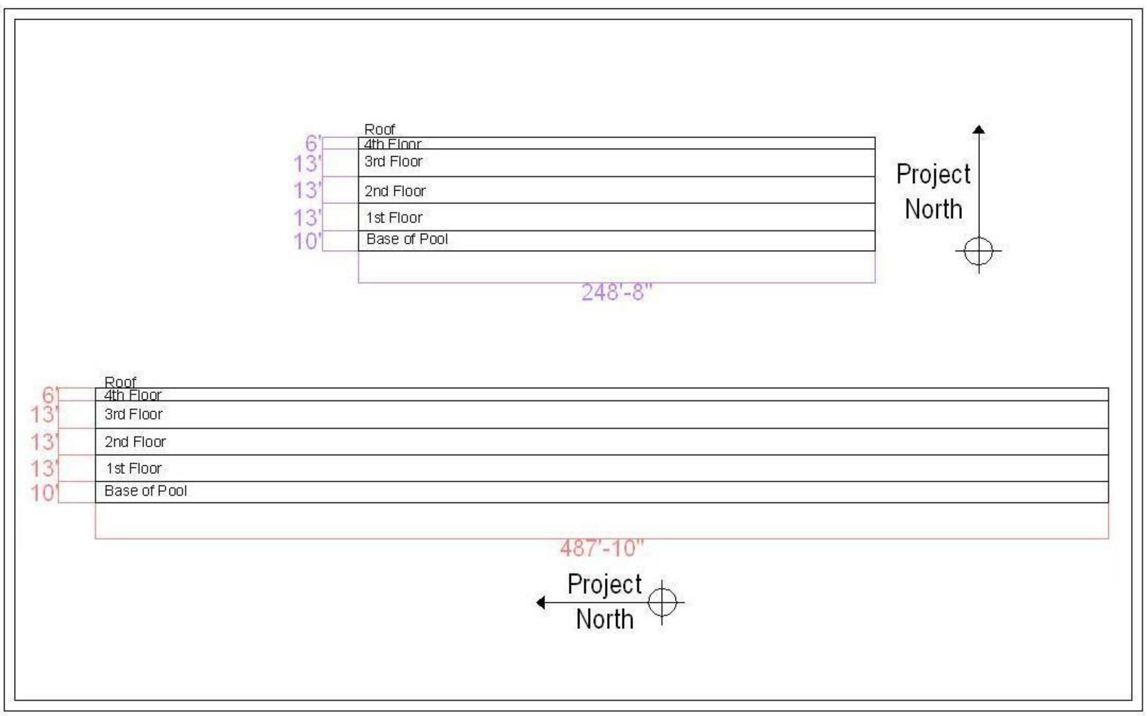

Figure 33: Floor Heights

Column height varies throughout the building. Figure 34 displays this using the elevations from Figures 32 and 33. The empty space to the left of the bottom diagram should be discounted as that refers to the circular fitness center at the northern end of the building. This outline helps show where the pieces fit and puts them into perspective

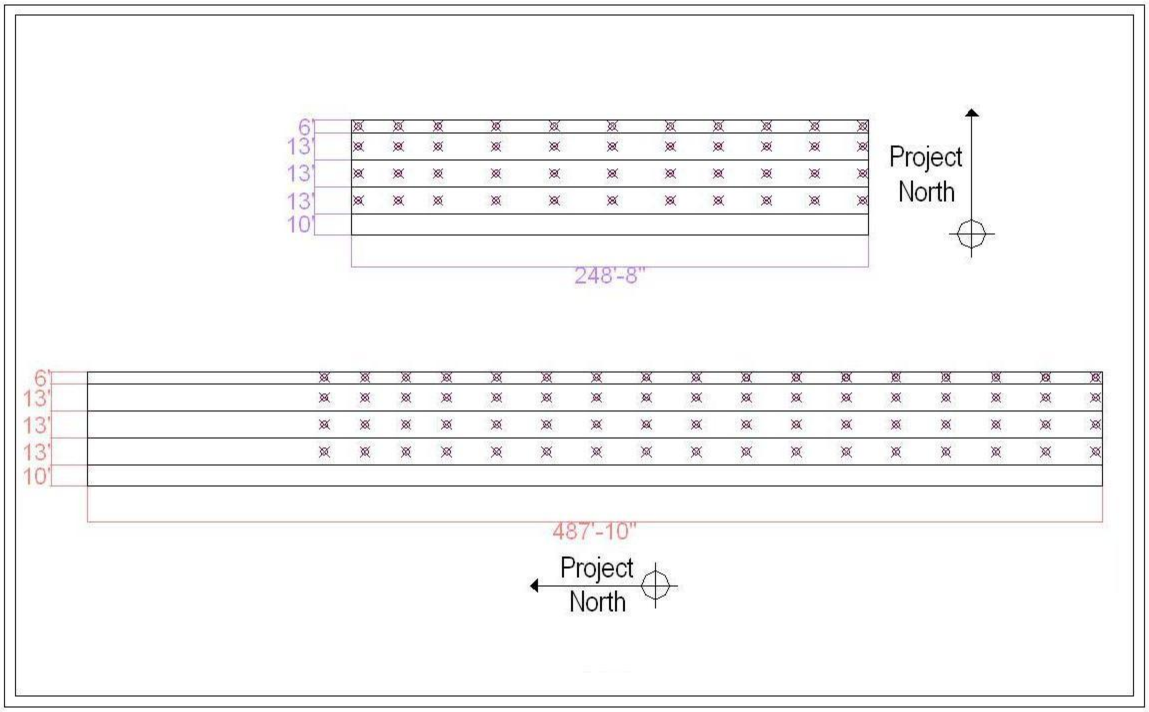

Figure 34: Building Elevations with Columns

3D Views

The program Revit Building was used in order to produce a 3D visual of what the new recreational center would look like. The 3D visual used the same dimensions as the 2D design. The topography and elevations were taken into account when creating the model. Below, Figures 35-38 feature the building from different angles so as to get an idea of what the final design should look like.

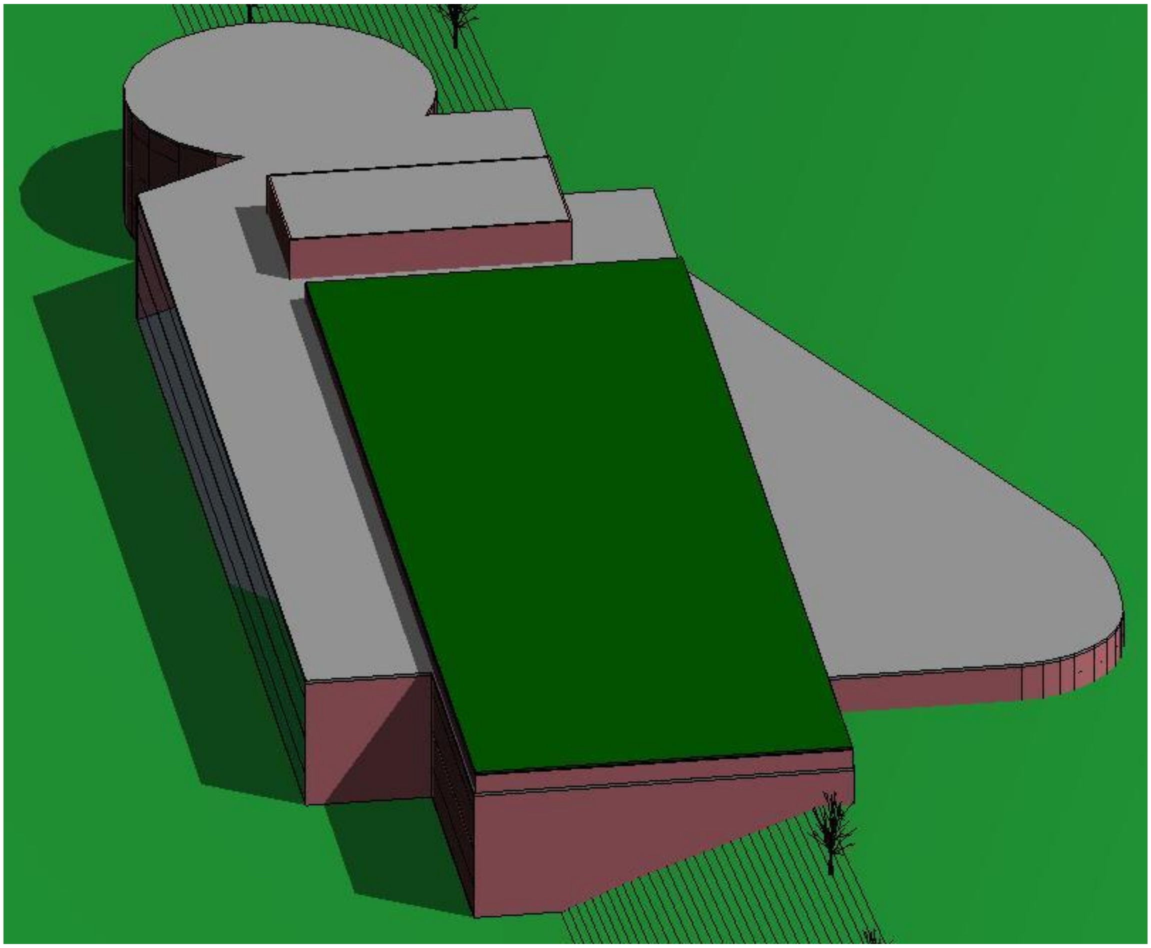

Figure 35: South Side of Building

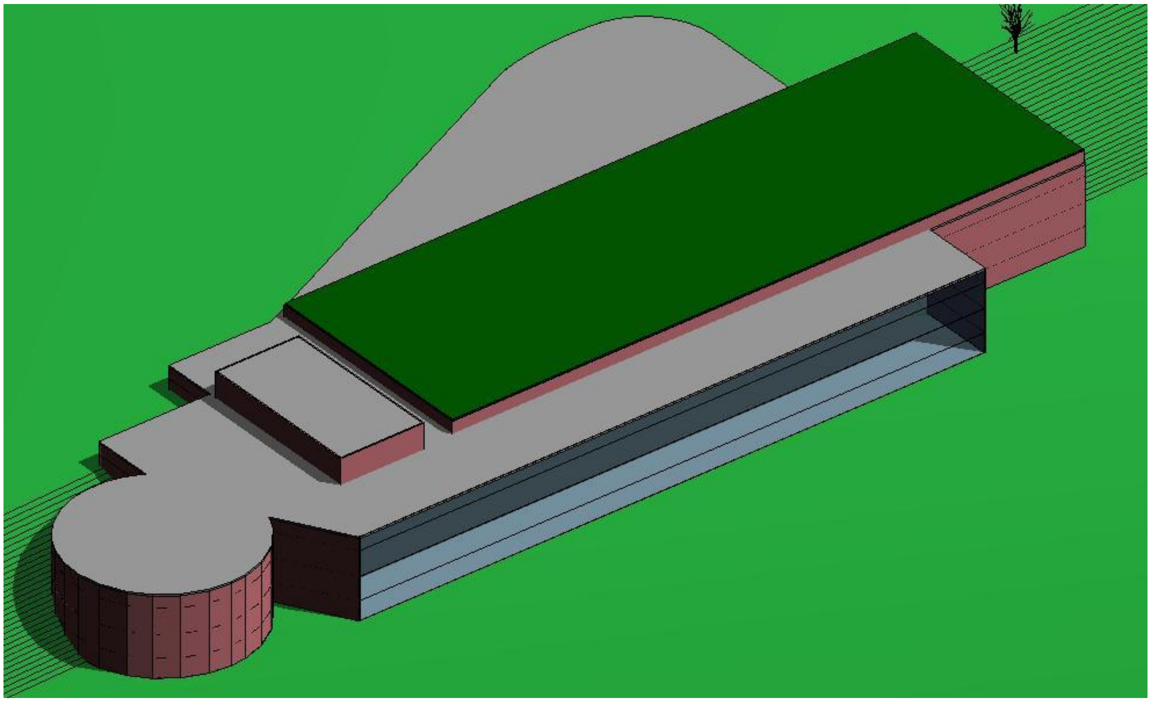

Figure 36: West Side of Building

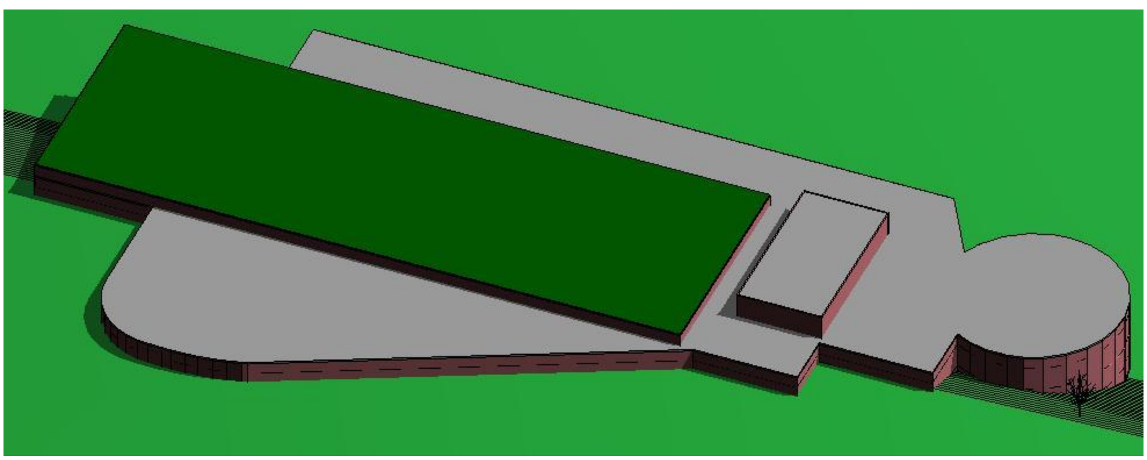

Figure 37: East Side of Building

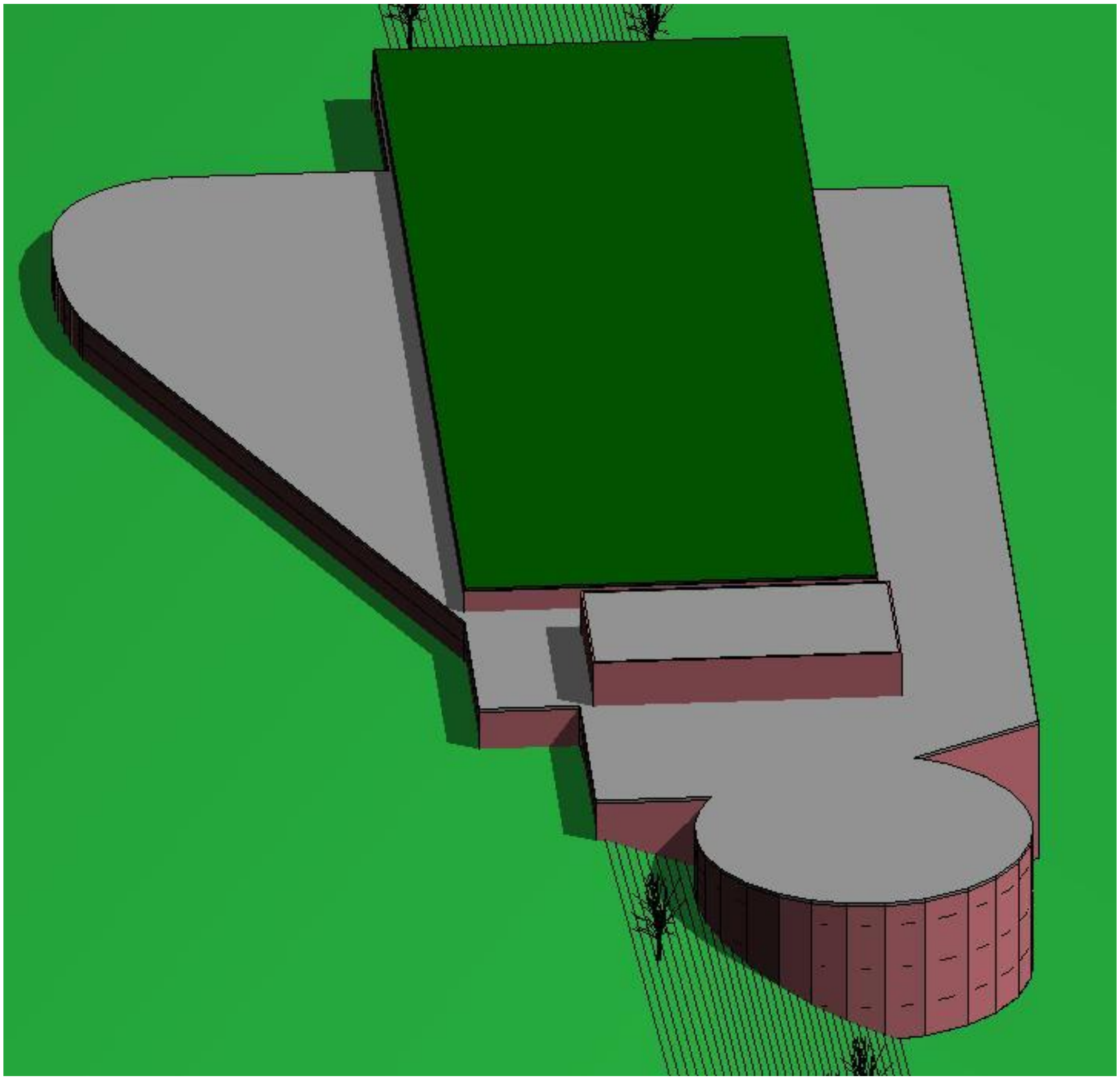

Figure 38: North Side of Building

Summary

In this section, the building footprint was defined and column locations were detailed. Measurements of columns, beams, and girders were taken and alphanumeric grids were sketched. The building and fitness center were divided into units and were assigned bay designations based on their unit number and the lengths of beams between columns. Lastly, top-of-slab and building elevations were determined. Once these structural members were located and identified, it was time to design the four floors for the recreational center.

Identifying Loads

The first step in designing a floor system and structural members is to indentify the gravity loads. Different zones throughout the building were identified. This was particularly important for the roof where snow drifts were calculated. The magnitudes and lengths of the snow drifts were calculated based on a ground snow load of 55 lb/ft^2. The different load zones are shown in Figure 39 below.

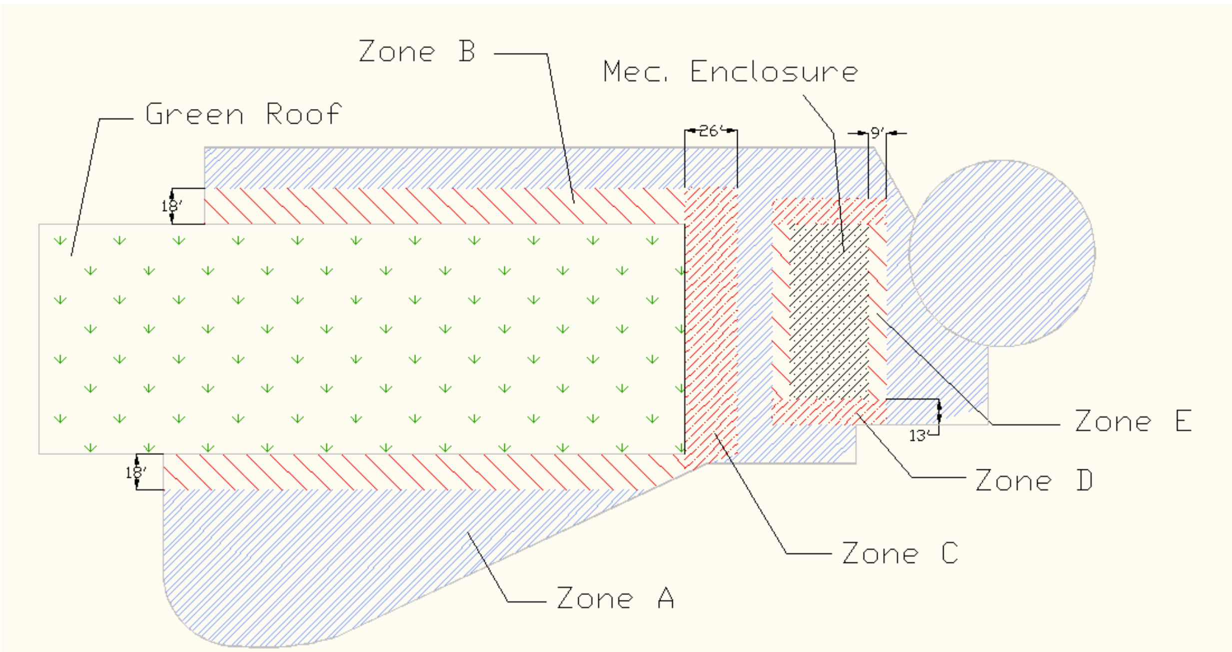

Figure 39: Diagram of Loads on Roof

Table 12 lists these zones along with their respective loads.

Table 12: Design Loads for the Roof

Zone A	43 psf
Zone B	91 psf
Zone C	113 psf
Zone D	78 psf
Zone E	67 psf
Green Roof	95 psf
Mec. Enclosure	120 psf

The same approach was used for the interior floors of the building. Based on the floor plan, different zones were designated to simplify the design process. Table 13 shows the different types of loading zones that were used.

Table 13: Design Loads for Floors

Corridor	238 psf
Offices/Classroom	158 psf
Gymnasium/Racquetball/Squash	262 psf
Rest Rooms	174 psf

Based on the general floor plan developed, different sections of the building could be appropriately designed using these loads.

Floor Systems

The recreation center was chosen to have steel form deck with a cast-in place concrete slab. This composite system was chosen because of its resistance to live loads, stiffness (smaller deflections), capability to handle overloads, required smaller slabs and beam depths (which reduce floor heights and material costs). This composite system increases strength due to the fact that the compression normally exerted on the top flange of the beam will be carried by the concrete and allow the steel to carry mainly tensile stresses. Shoring will not be used throughout construction; therefore the members were also designed for live load construction.

The slab thickness was the first consideration for the floor system. Table 14 attained from *Designing with Steel Form Deck, SDI, 2003* was used to determine the slab thickness. According to the *Massachusetts State Building Codes* the minimum thickness of the composite systems for fire-resistance had to be for no less than two hours.

Table 14: Hourly Resistance of Slabs

Concrete Aggregate Type	Minimum eqivalent thickness (inches)* for fireresistance rating (hours)				
	1 hr.	1½ hrs.	2 hrs.	3 hrs.	4 hrs.
Siliceous	3.5	4.3	5.0	6.2	7.0
Carbonate	3.2	4.0	4.6	5.7	6.6
Sand-lightweight	2.7	3.3	3.8	4.6	5.4
Lightweight	2.5	3.1	3.6	4.4	5.1

Although more expensive, the aggregate type chosen for the slab was sand-lightweight. This lightweight aggregate helped minimize floor thicknesses throughout the building. For this type of aggregate the minimum equivalent thickness is 3.8”. This number was rounded up to achieve a slab thickness of 4”.

Following the design of the slab, the shape and dimensions of the steel form decking was chosen. The Steel Deck Institute was referenced on this design. Actual products were selected from Commercial Siding and Maintenance (CSM), a company steel form deck manufacturer. This manufacturer provided design values such as the moment of inertia, area of steel, strength of steel and self weight. Tables presented for composite metal decks supplied the allowable superimposed live loads using studs. These loads could be compared to the design as a check. Table 15 shows this table from CSM that was used.

Table 15: Properties of 1.5 SB Lightweight Composite Metal Decking

							Superimposed Live Loads - psf: Studs @ 1'-0" O.C.											
D, Wc, Ac	Gage	Single Span	Double Span	Triple Span	Stud Factors		Span - Feet and Inches											
					2' o.c.	3' o.c.	6'-0"	6'-6"	7'-0"	7'-6"	8'-0"	8'-6"	9'-0"	9'-6"	10'-0"	10'-6"	11'-0"	11'-6"
4" 28.8 psf 20.6 in²	22	6'-3"	8'-5"	8'-6"	0.87	0.80	400	400	372	303	249	208	175	149	128	110	96	84
	20	7'-4"	9'-8"	9'-11"	0.83	0.78	400	400	400	328	270	225	190	161	138	120	104	91
	18	7'-9"	10'-1"	10'-5"	0.81	0.76	400	400	400	371	306	255	215	183	157	135	118	103
	16	9'-1"	11'-3"	11'-8"	0.78	0.74	400	400	400	400	339	283	238	202	174	150	130	114
4-1/2" 33.6 psf 24.8 in²	22	6'-0"	8'-0"	8'-1"	0.88	0.81	400	400	400	400	356	296	250	212	182	157	137	120
	20	6'-11"	9'-3"	9'-5"	0.84	0.79	400	400	400	400	385	321	270	230	197	170	148	130
	18	7'-4"	9'-7"	9'-11"	0.82	0.77	400	400	400	400	400	362	305	259	222	192	167	146
	16	8'-7"	10'-9"	11'-2"	0.79	0.75	400	400	400	400	400	400	338	287	246	213	185	162
4-3/4" 36.0 psf 27.0 in²	22	5'-10"	7'-10"	7'-11"	0.88	0.82	400	400	400	400	400	349	294	250	214	185	161	141
	20	6'-9"	9'-1"	9'-2"	0.85	0.80	400	400	400	400	400	377	318	270	232	200	174	152
	18	7'-2"	9'-5"	9'-9"	0.83	0.78	400	400	400	400	400	400	358	305	261	226	196	172
	16	8'-4"	10'-6"	10'-11"	0.80	0.76	400	400	400	400	400	400	396	337	289	249	217	190
5" 38.4 psf 34.1 in²	22	5'-8"	7'-8"	7'-9"	0.88	0.83	400	400	400	400	400	400	343	291	250	216	188	164
	20	6'-7"	8'-10"	9'-0"	0.85	0.81	400	400	400	400	400	400	370	315	270	233	203	178
	18	7'-0"	9'-3"	9'-6"	0.83	0.79	400	400	400	400	400	400	400	355	304	263	228	200
	16	8'-2"	10'-4"	10'-8"	0.80	0.77	400	400	400	400	400	400	400	392	336	290	252	221
5-3/4" 45.6 psf 36.7 in²	22	5'-4"	7'-3"	7'-4"	0.90	0.84	400	400	400	400	400	400	400	380	339	305	274	248
	20	6'-2"	8'-4"	8'-6"	0.87	0.82	400	400	400	400	400	400	400	400	400	353	307	269
	18	6'-7"	8'-8"	9'-0"	0.85	0.80	400	400	400	400	400	400	400	400	400	390	345	202
	16	7'-8"	9'-9"	10'-1"	0.82	0.78	400	400	400	400	400	400	400	400	400	400	381	333

Source: Commercial Siding and Maintenance, 2009

Based on Table 13, decking was designed for the roof and for floors 2-4. 22-gage 1.5 SB lightweight composite decking and 20-gage 1.5 SB lightweight composite decking was used for the roof and interior floor respectively. This decking was chosen for triple spans and a maximum 8’ span. The decking used for the roof and interior floors is shown in Figure 40.

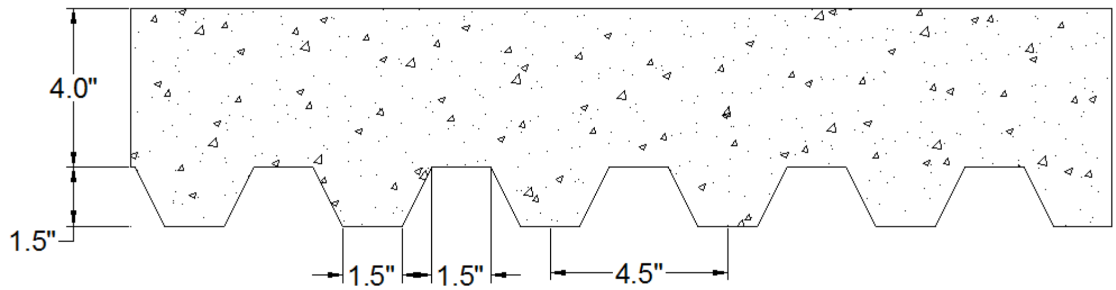

Figure 40: 1.5" Steel Form Deck

Beams & Girders

These beams and girders were determined using RISA-2D and the loading zones identified earlier. All of the beams and girders were W12 sections and the numbers on the figures designate the beam weight of each particular girder or area. Also, if there are two areas which have differently sized beams the outer edge of the area will use the larger of the two beam sizes for conservative design purposes.

The sizes of the beams based on a composite system are relatively small compared to design of floor and beams independently. This allowed greater ceiling heights and saved on material costs. The Figures 41-54 display the increased beam and girder sizes that safely and effectively withstand the critical loading and abide by the deflection limit.

The only problem encountered with the composite sections was the construction live load deflection test. All beams and girders failed the deflection limit of L/240 for floors and L/200 for the roof. Beam sizes were increased to increase the shear capacity and then re-checked. In doing this, it ensures that shoring will not be required during construction, further reducing the cost of construction.

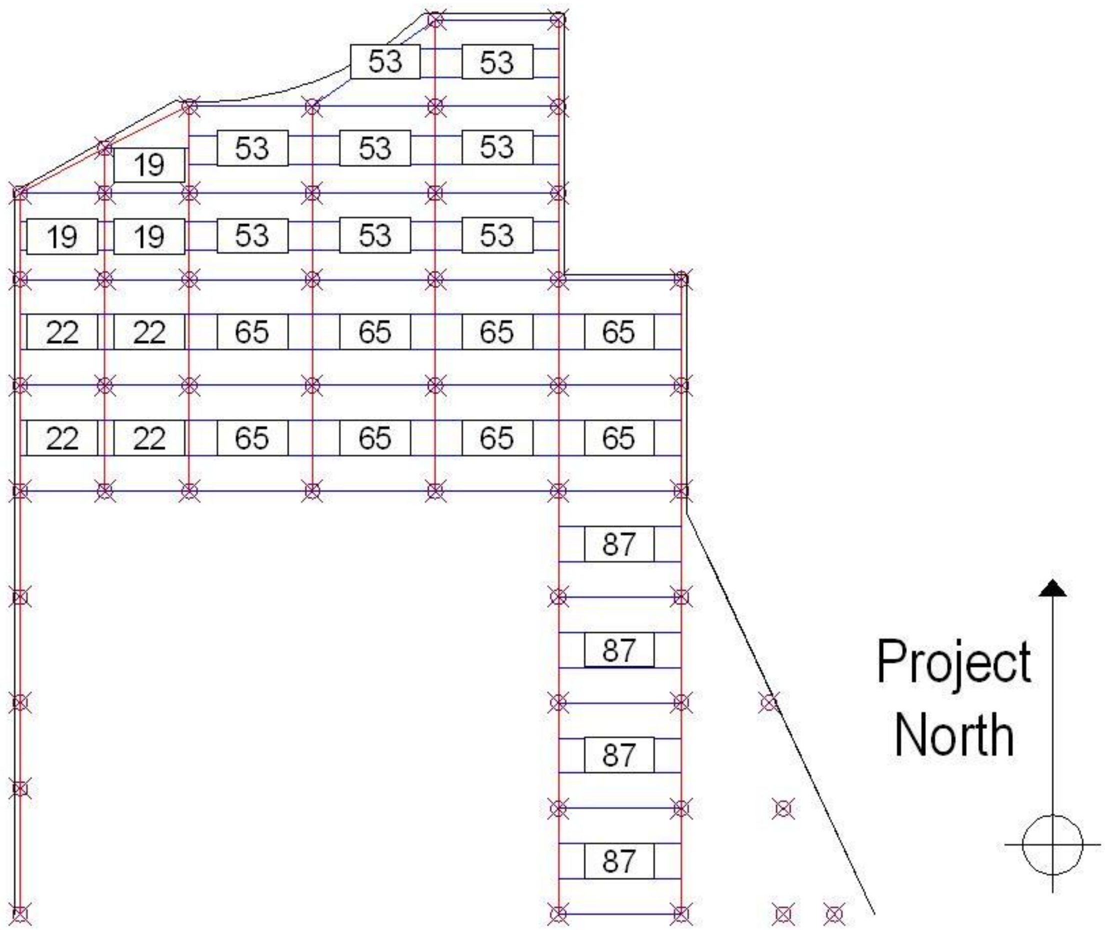

Figure 41: 2nd Floor Beam Selection (North End)

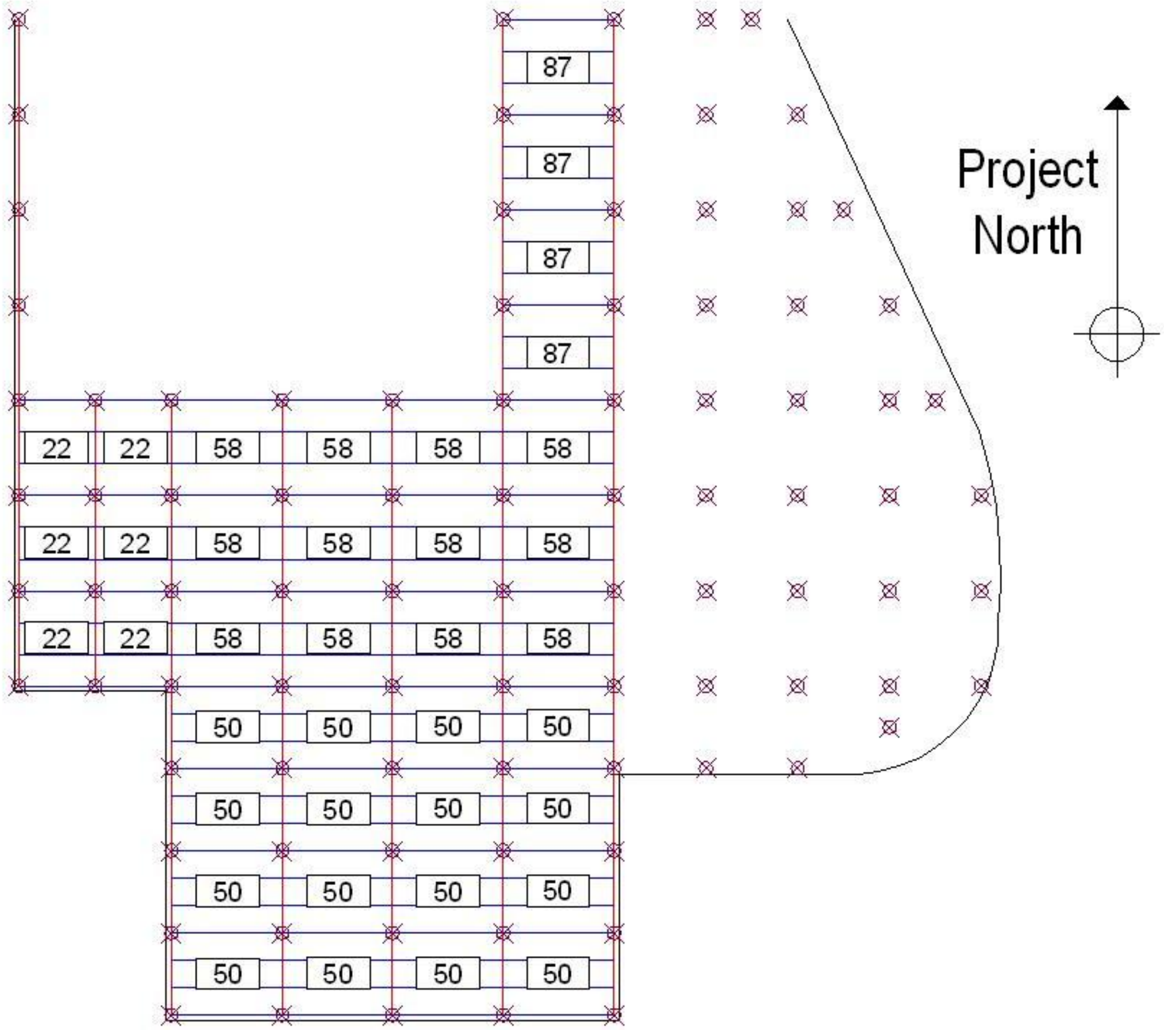

Figure 42: 2nd Floor Beam Selection (South End)

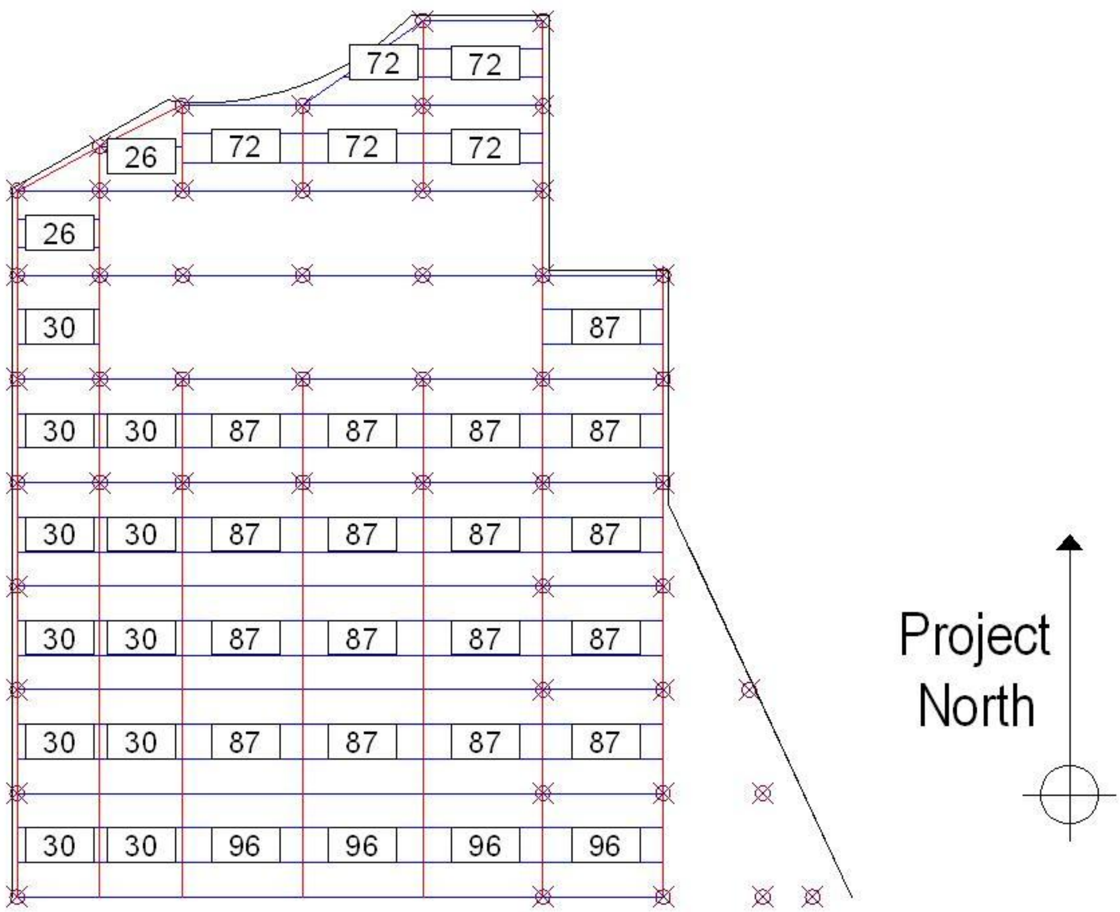

Figure 43: 3rd Floor Beam Selection (North End)

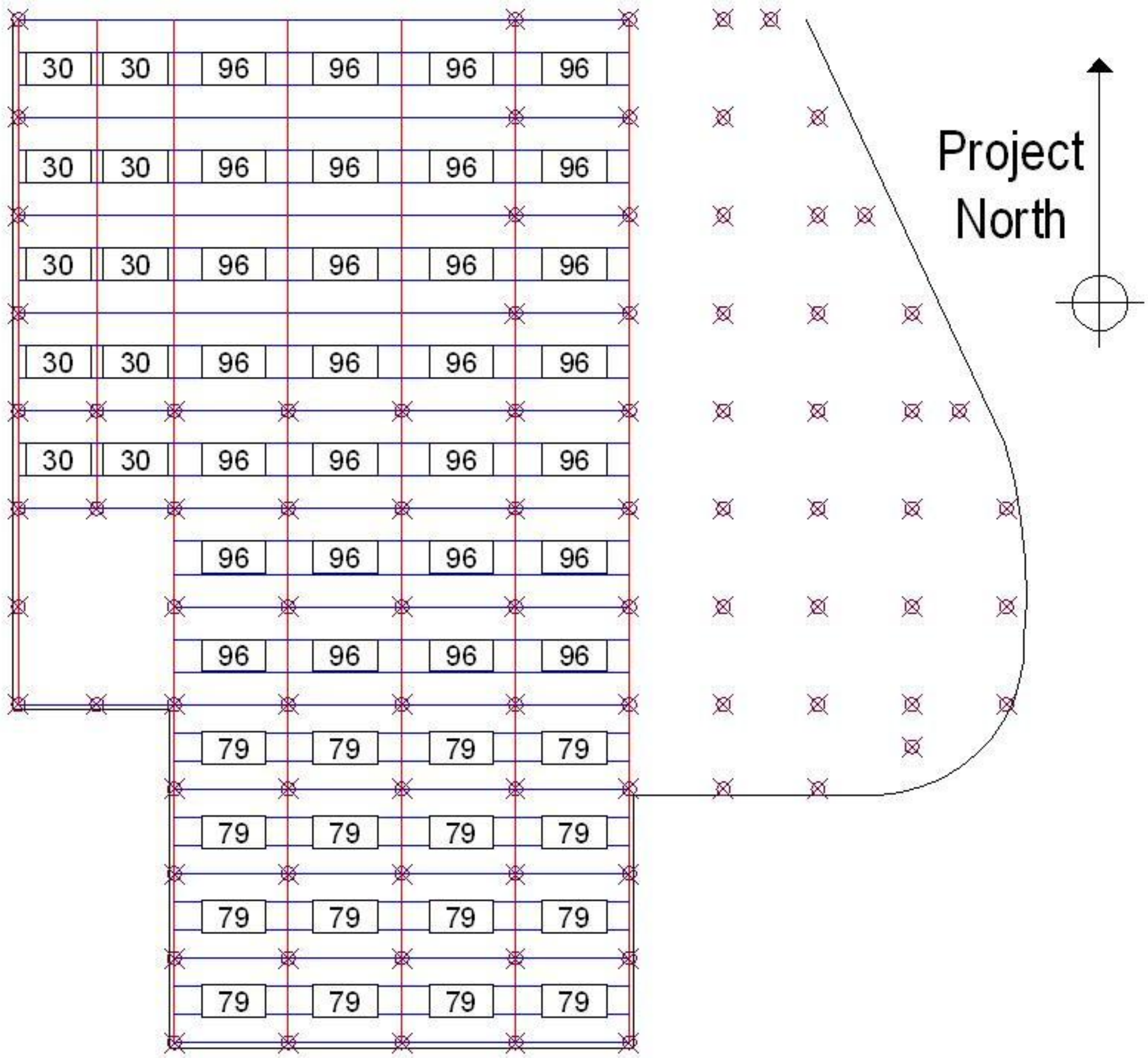

Figure 44: 3rd Floor Beam Selection (South End)

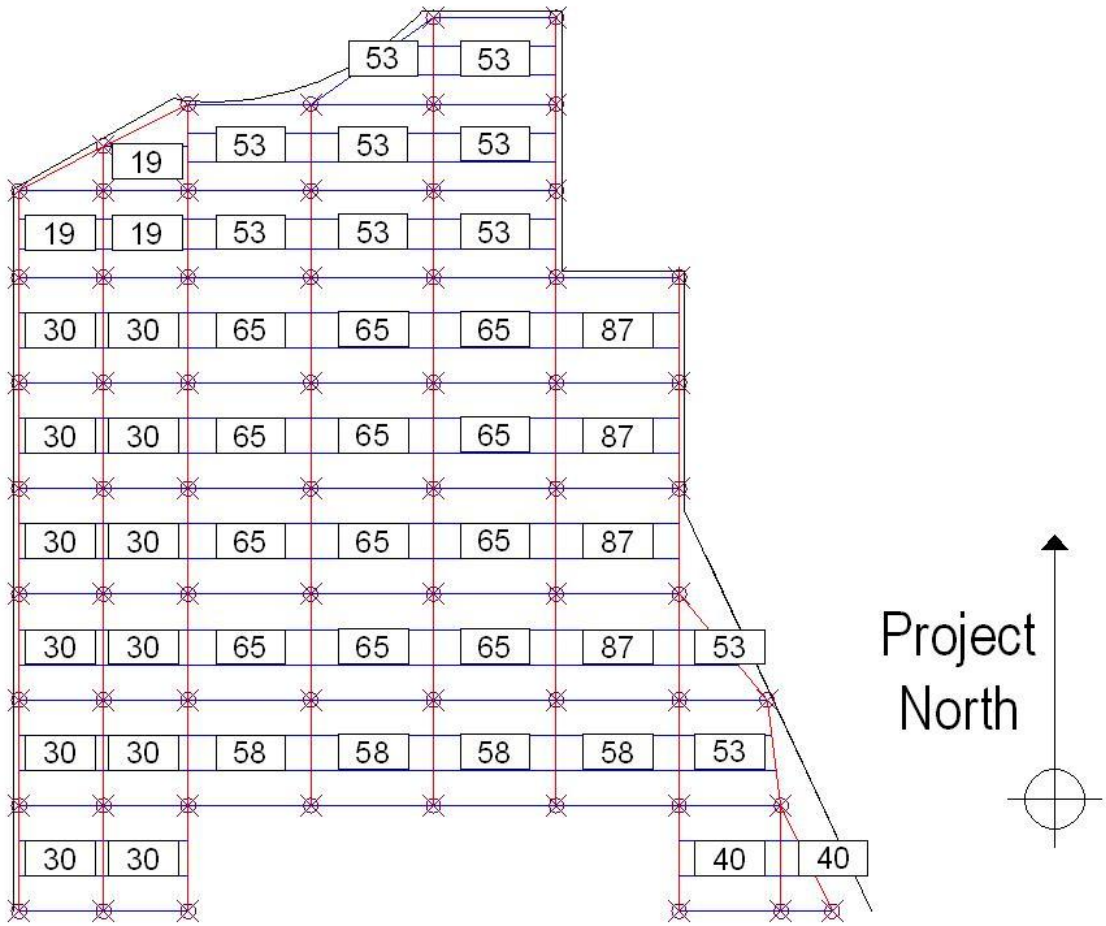

Figure 45: 4th Floor Beam Selection (North End)

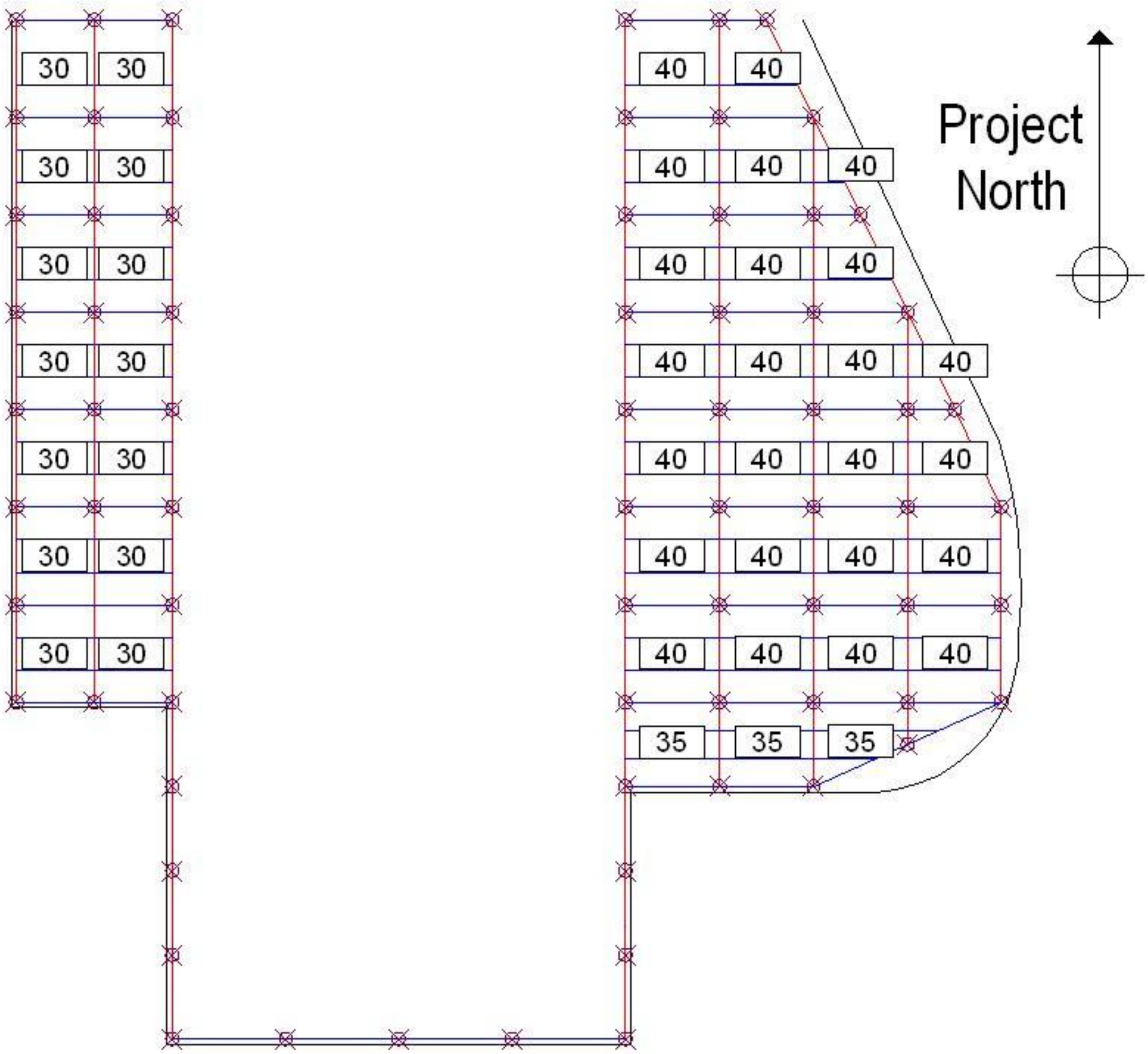

Figure 46: 4th Floor Beam Selection (South End)

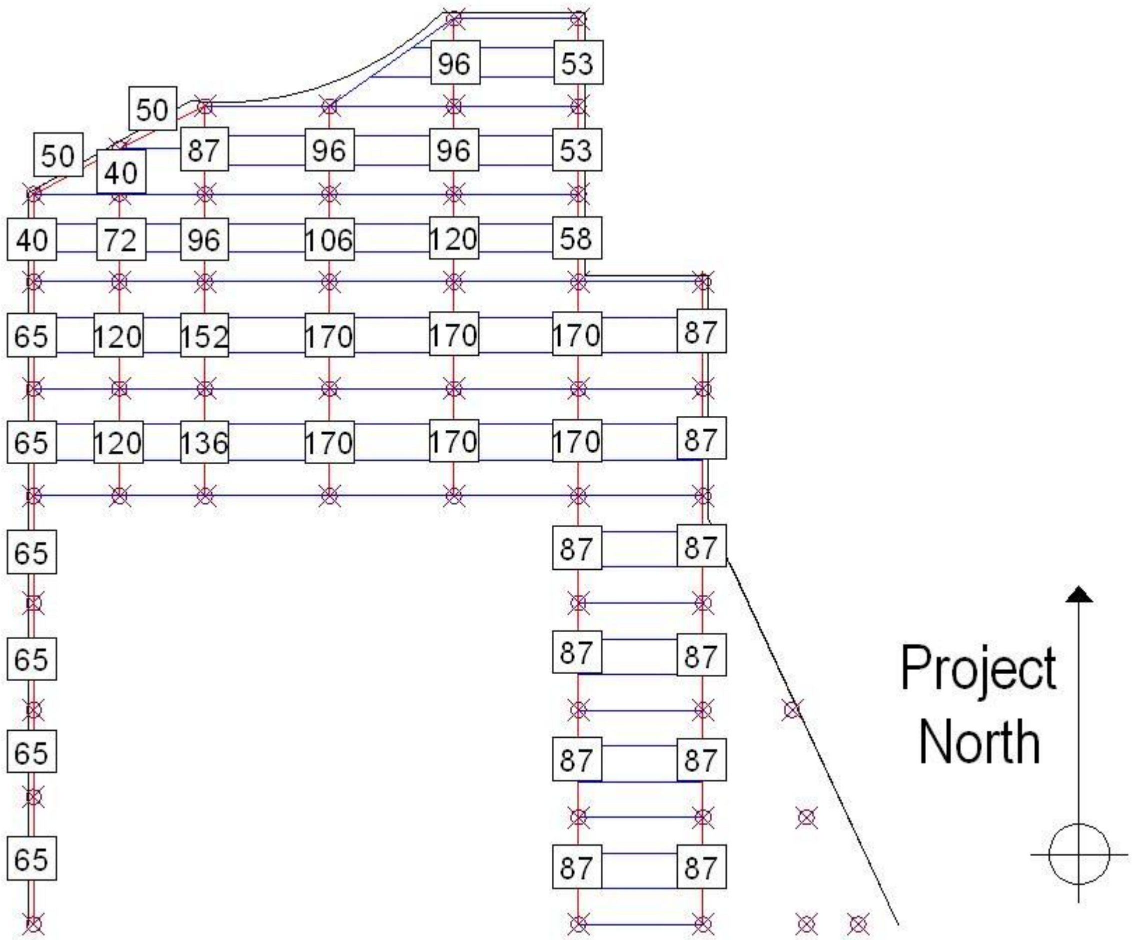

Figure 47: 2nd Floor Girder Selection (North End)

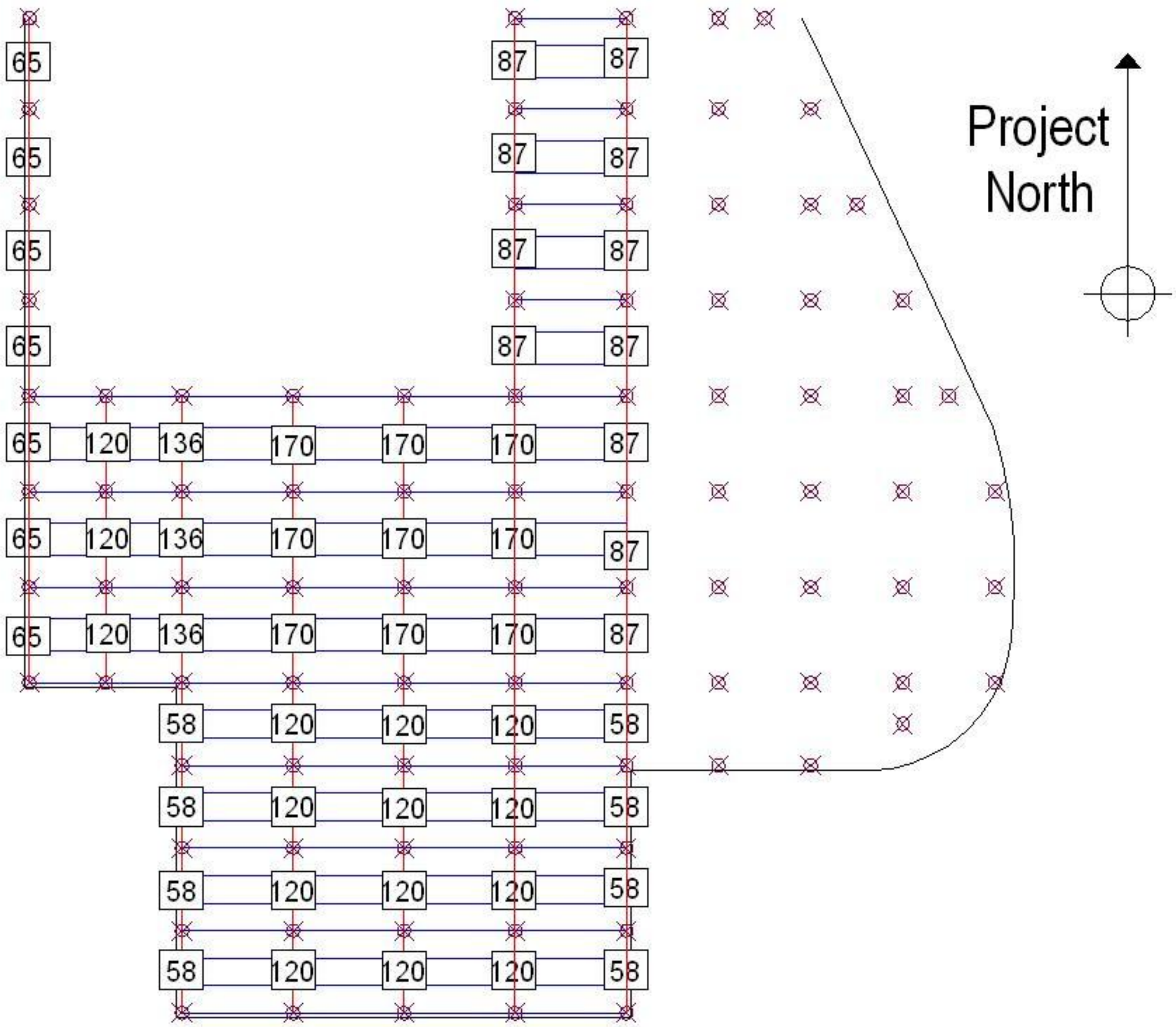

Figure 48: 2nd Floor Girder Selection (South End)

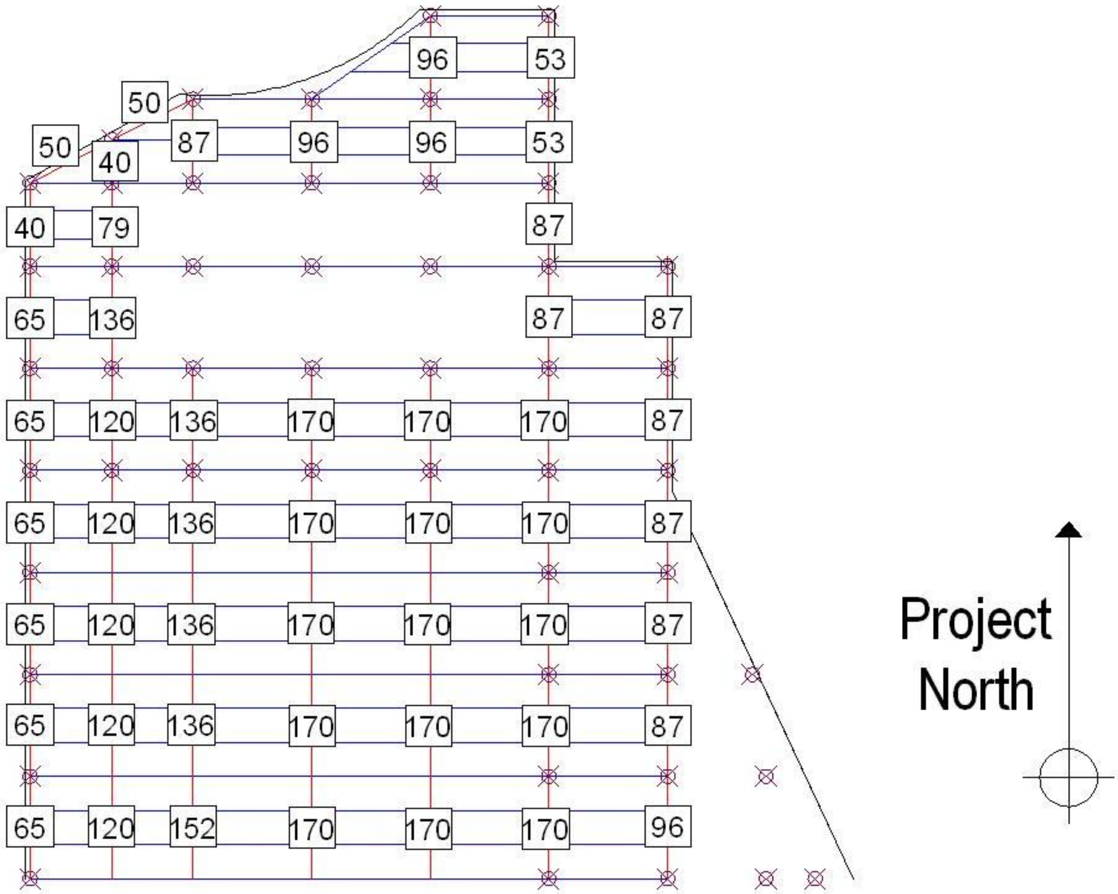

Figure 49: 3rd Floor Girder Selection (North End)

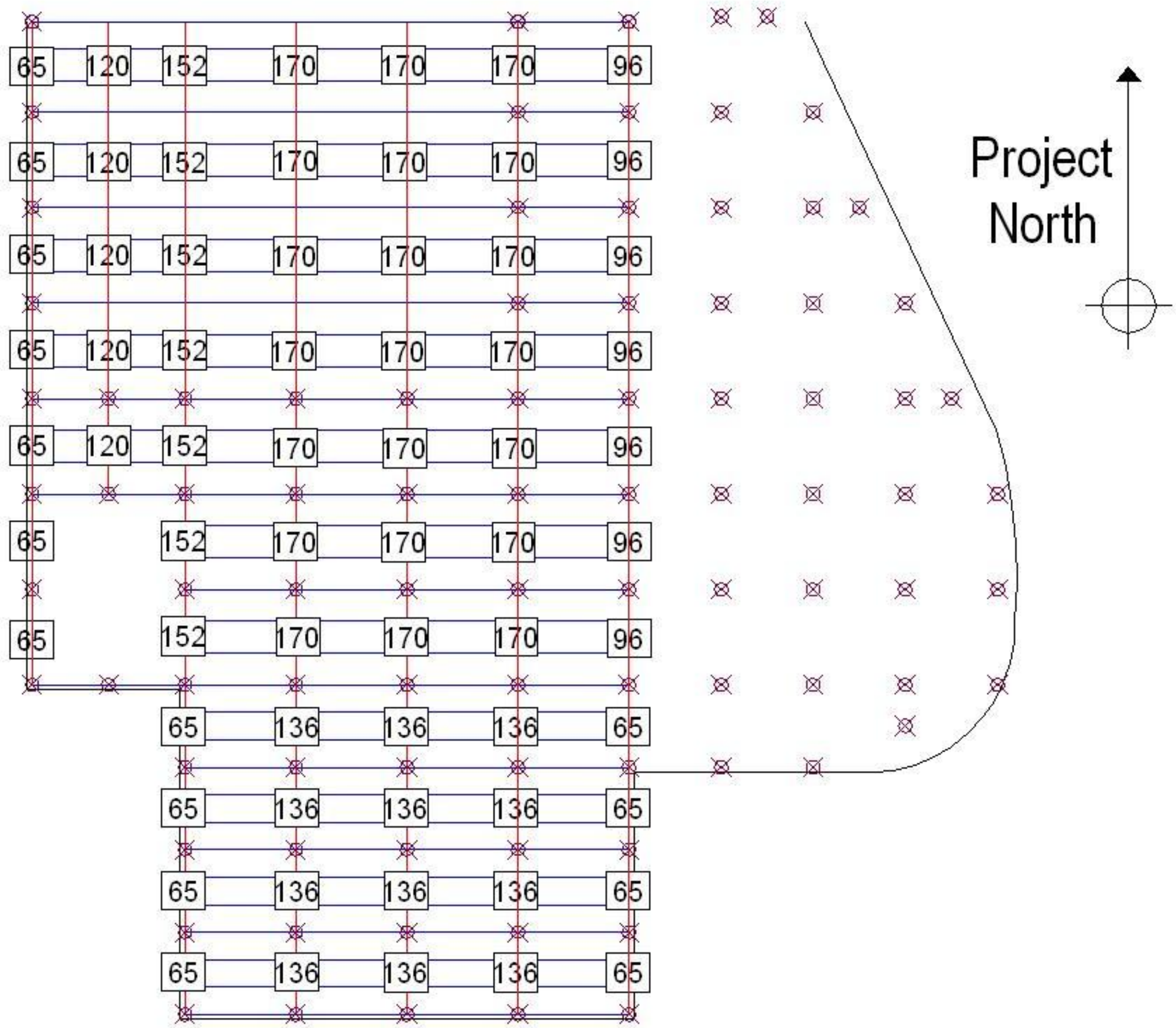

Figure 50: 3rd Floor Girder Selection (South End)

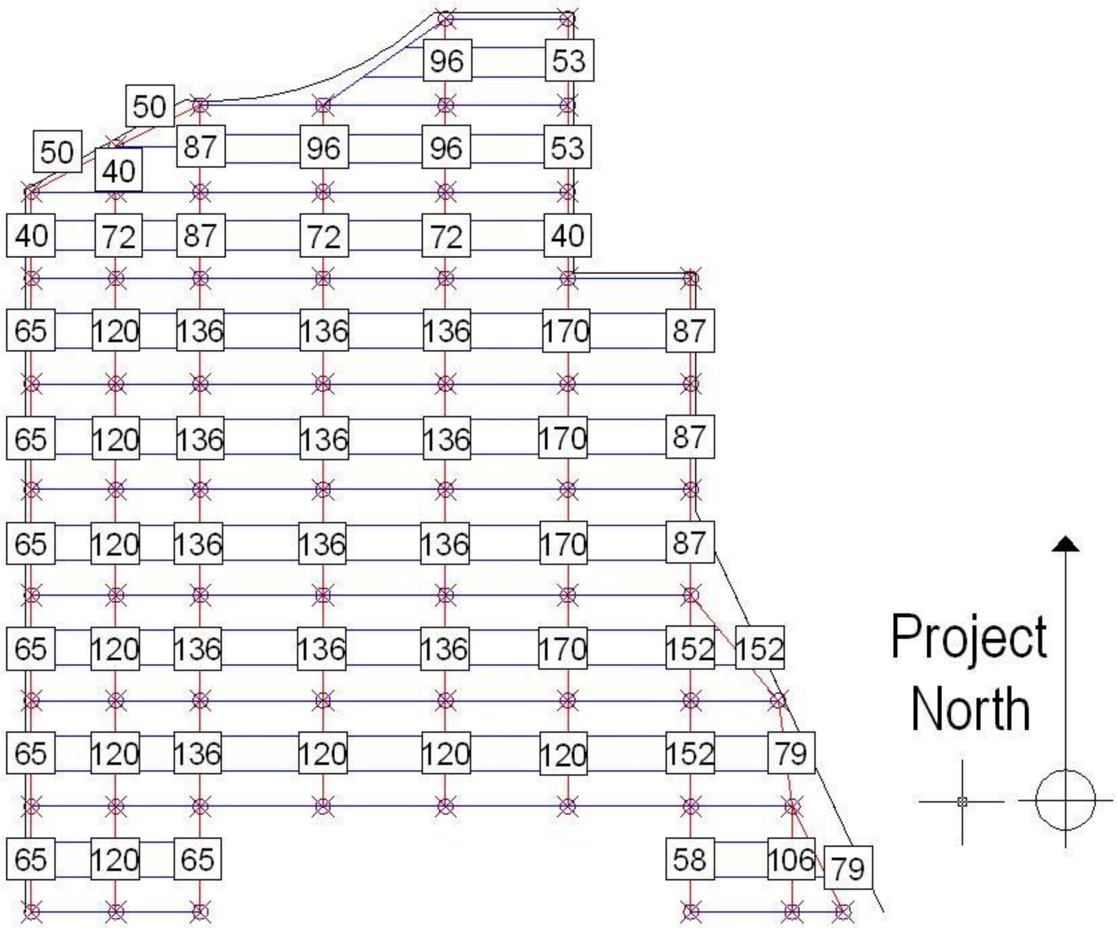

Figure 51: 4th Floor Girder Selection (North End)

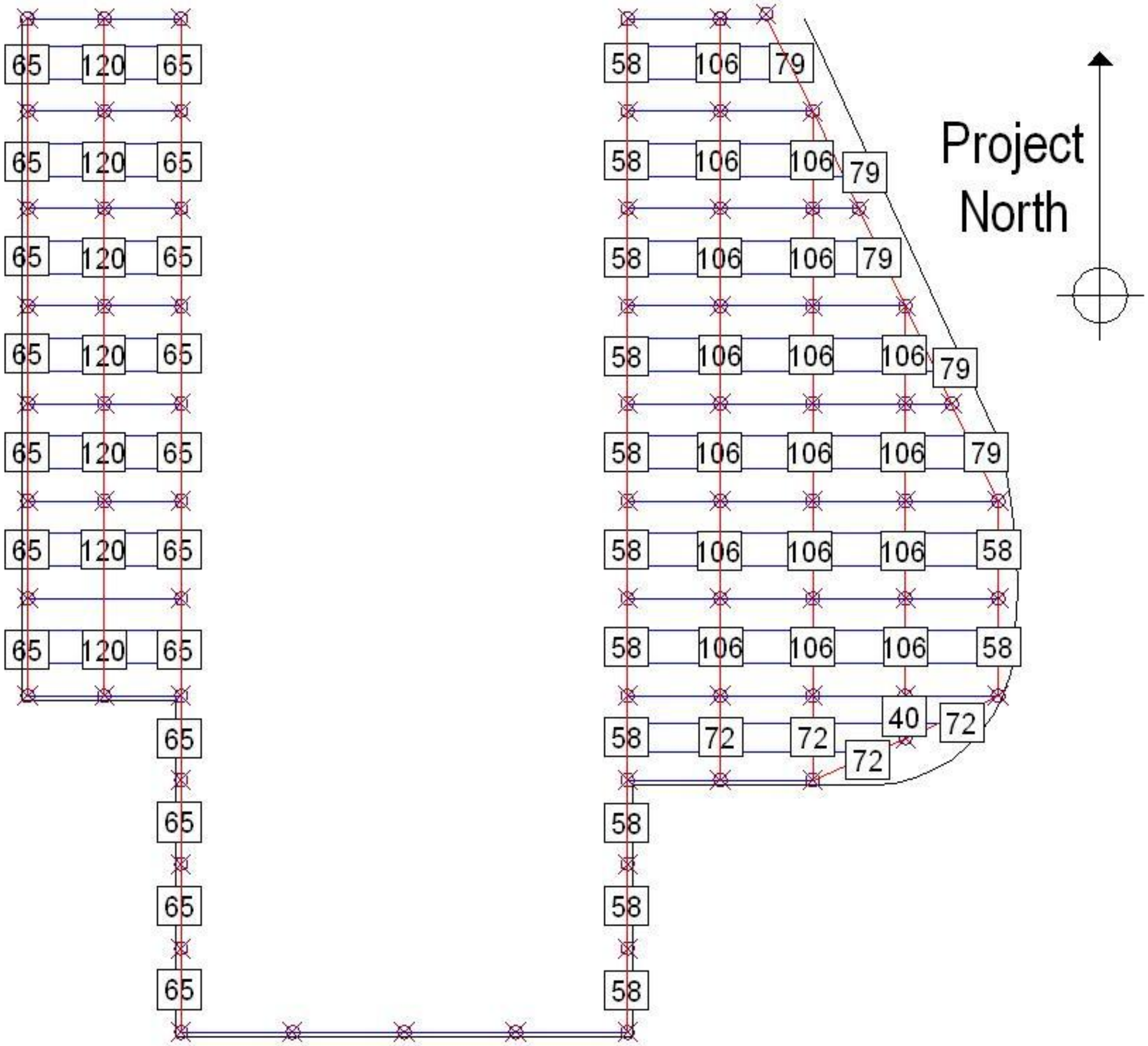

Figure 52: 4th Floor Girder Selection (South End)

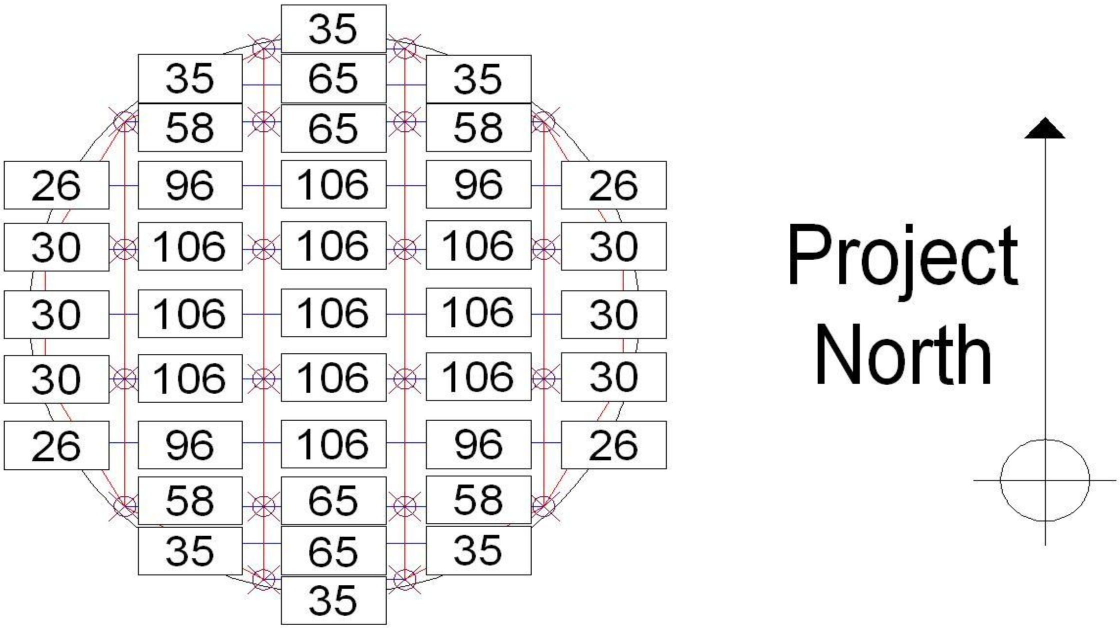

Figure 53: Fitness Center Beams

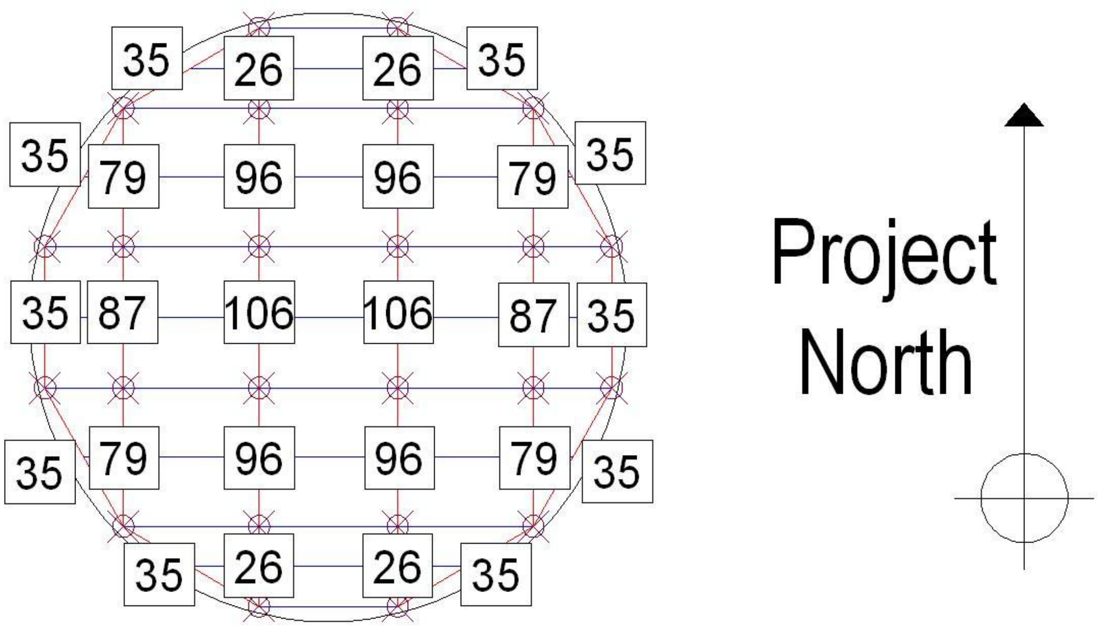

Figure 54: Fitness Center Girders

Columns

The columns used in the recreation center were all designed to be W-shaped members. Built-up columns were not necessary based on the calculated loads. For each section of the building a different column calculation was required.

Because the beams and girders all had depths of 12" the columns had to have depths of at least 12" so that the width of the flange fits into the space between the flanges. Based on Table 4-1 in the *AISC Steel Construction Manual, 2006*, the minimum size available for W12 shapes is a W12x40 which is adequate for most of the column loads.

Figures 55-58 below show the column selections for all four floors of the building.

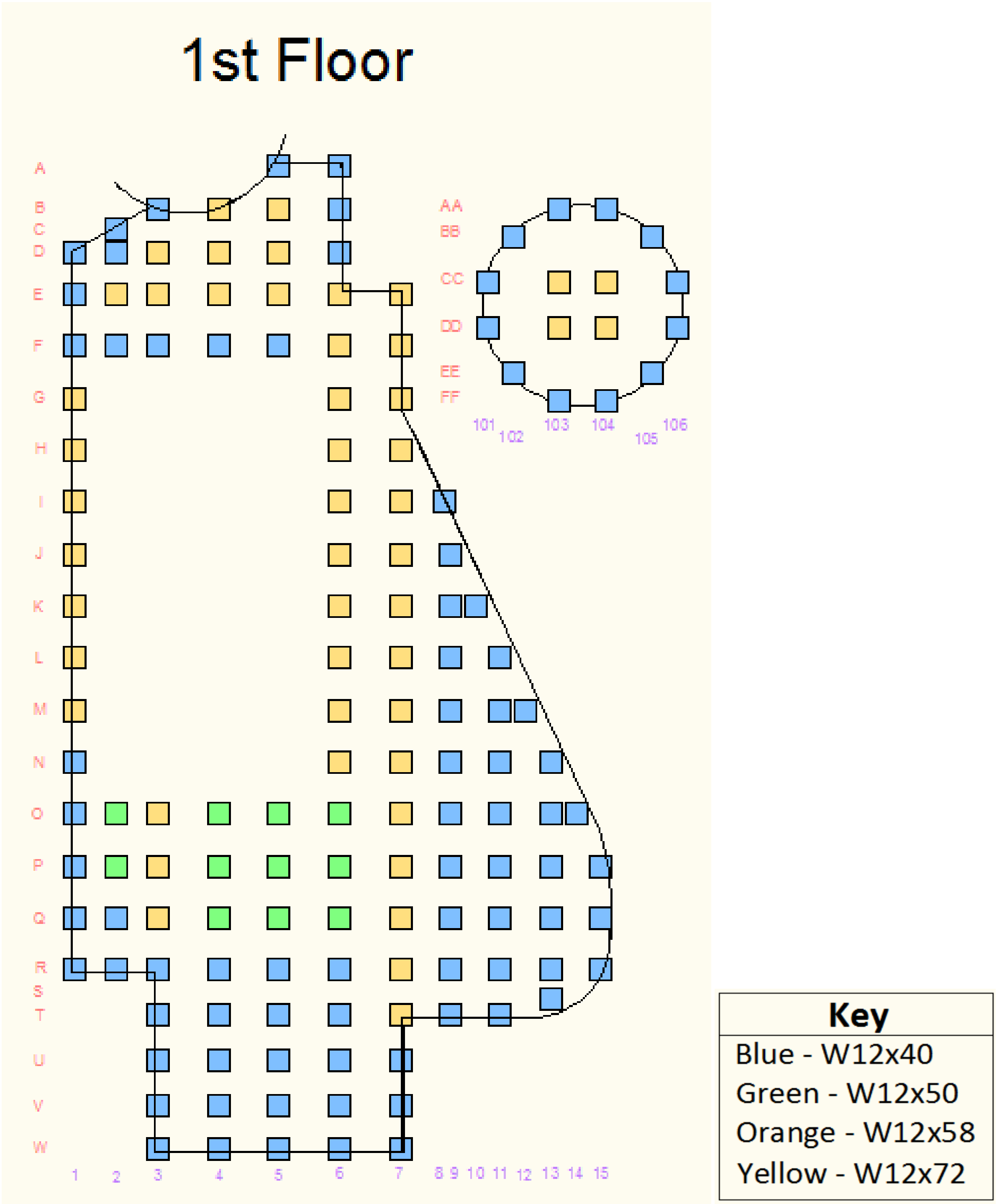

Figure 55: 1st Floor Column Selection

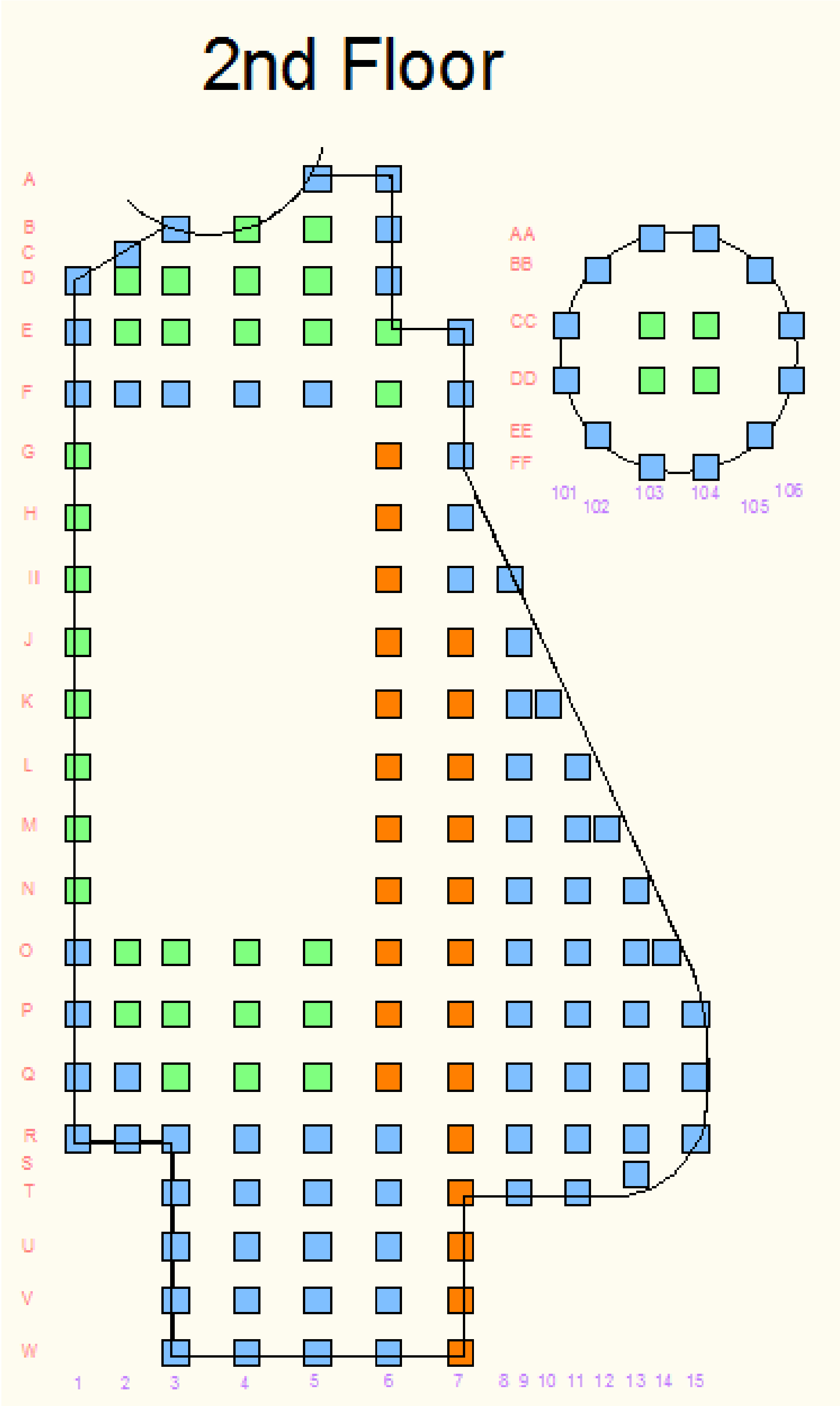

Figure 56: 2nd Floor Column Selection

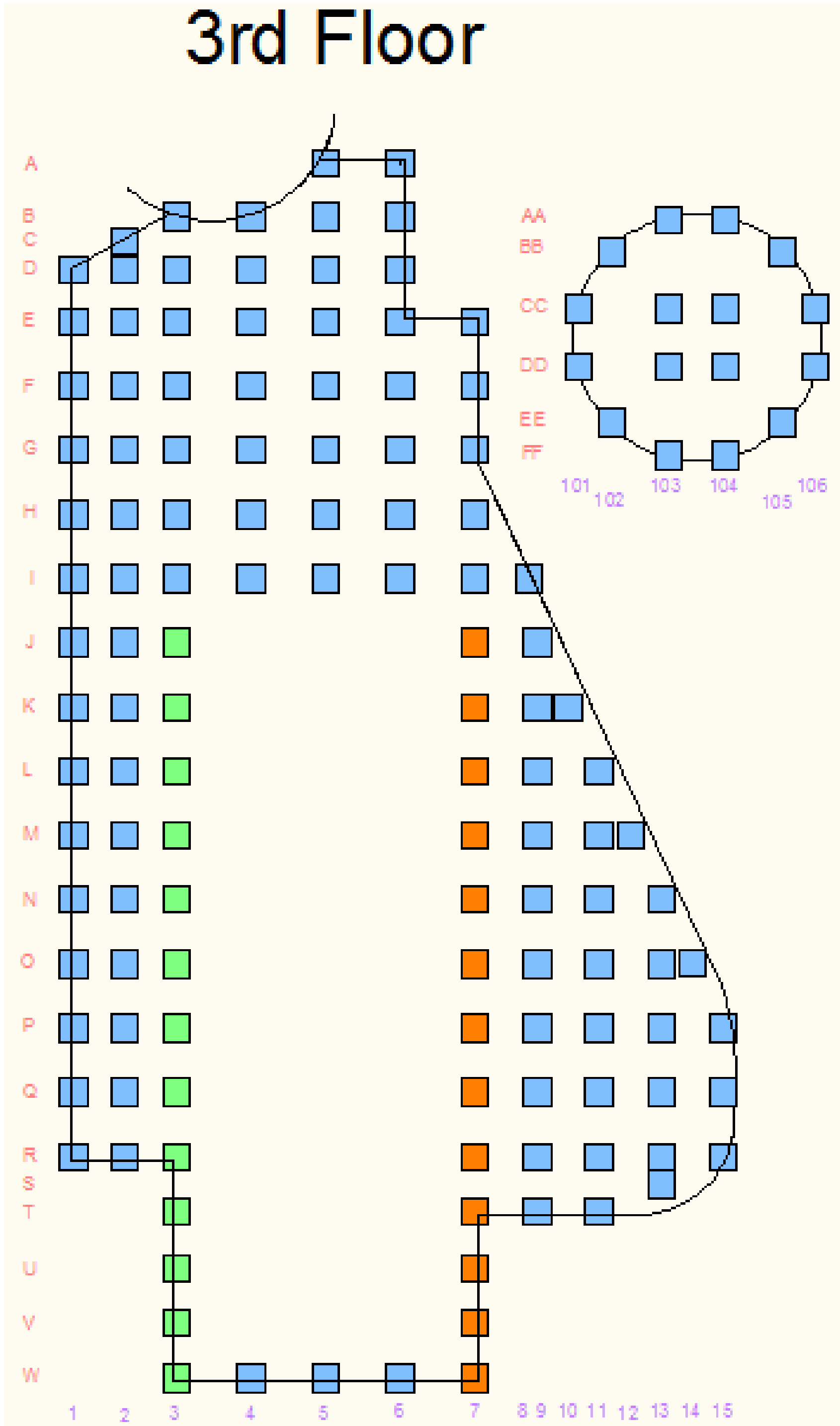

Figure 57: 3rd Floor Column Selection

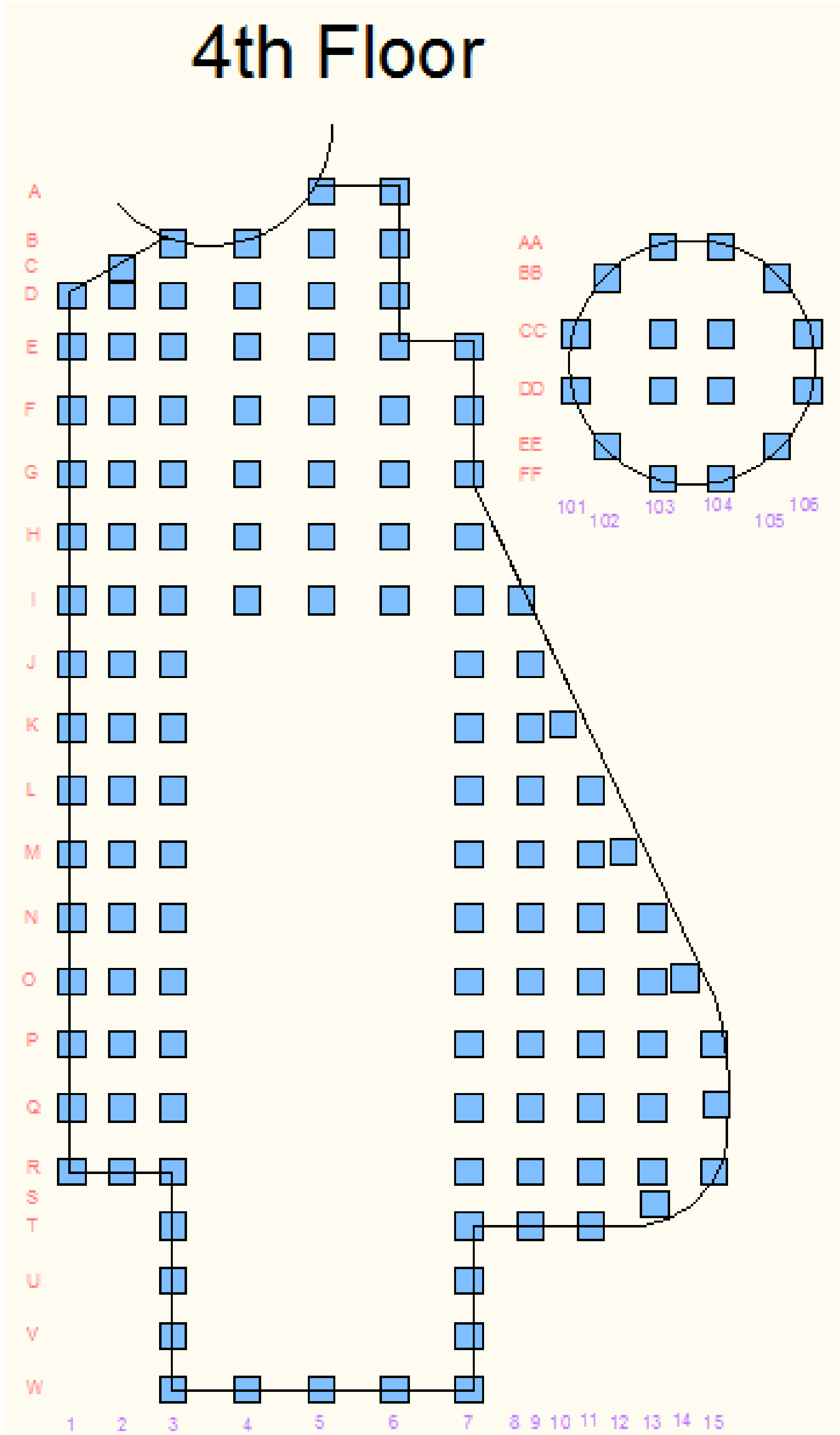

Figure 58: 4th Floor Column Selection

Table 16 shows the four types of columns and where they were used in the building.

Table 16: Selected Steel Columns for Floors 1-4

Steel Columns for Floors 1 - 4					
Member	1st Floor	2nd Floor	3rd Floor	4th Floor	Totals
W12x40	**57**	**59**	**128**	**154**	**398**
W12x50	**42**	**43**	**13**	**-**	**98**
W12x58	**-**	**25**	**13**	**-**	**38**
W12x72	**28**	**-**	**-**	**-**	**28**

Base Plates

The base plates' cross sections used are detailed above in Figures 55-58 in the foundation section. There were four different plates that were designed for the four types of columns. For column sizes ranging from W12-40 to W12-58, a base plate of 13" by 13" was required (note: this is not the same as 169 in^2). And since the W12-72 columns required a 16" square base plate, all base plates were made the same size (256 in^2). This was possible due to the fact that all columns had a depth of 12" and approximately the same flange width (b_f). Figure 59 shows the dimensioning for all the base plates used.

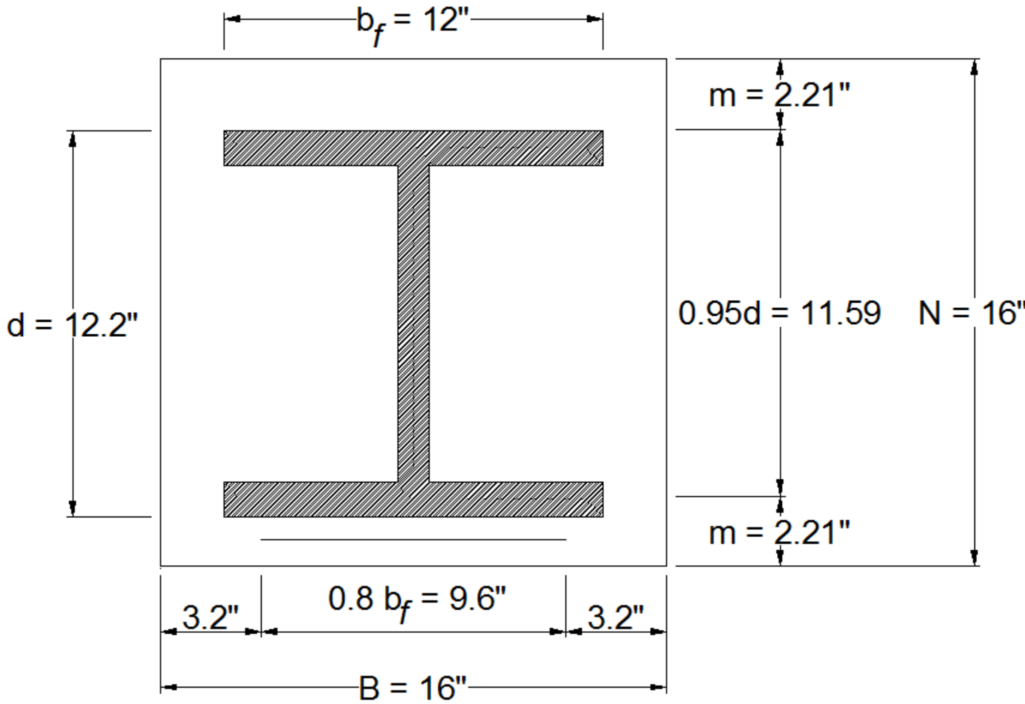

Figure 59: Base Plates for All Columns

Truss Design

There were two different truss designs completed for the recreation center. One set of trusses was used to support the ceiling of the gymnasium, the other for the natatorium. Before they were designed for explicitly, an analysis of the most effective truss configurations was conducted. Figures 60-61 are rendered images of the trusses from RISA-2D that were analyzed.

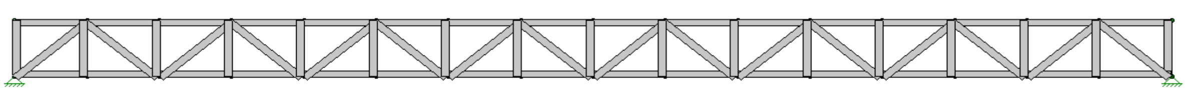

Figure 60: Deck Warren Truss

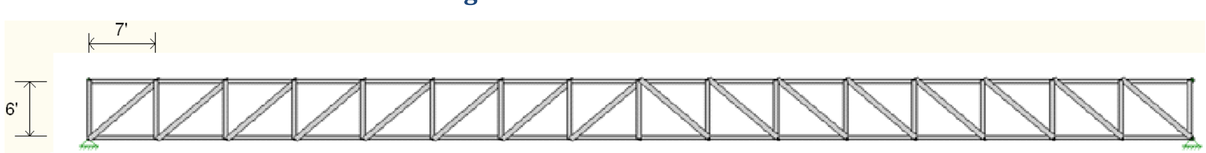

Figure 61: Deck Howe Truss

Deflection tests of all three designs were performed with RISA-2D using identical loads and members. Angles, double angles, W-shapes, circular/rectangular hollow sections and T-shapes were among the tested shapes for both of the trusses. The controlling design in these analyses was the deflection. Truss Configuration III was chosen after analysis showed it deflected the least under a uniform load it would be required to carry. The results from the bottom member of Truss Design III using the same size double angle are shown in Appendix B.

The trusses for the gymnasium were designed based on the uniform green roof and snow loads they would experience. The trusses use LL8x8x6 double angles exclusively and are spaced 6' center-to-center. Deflection allowance for the truss is L/240 (5.59") and the actual deflection was found to be 1.8". Figure 62 shows the deflected shape and supporting reactions of the chosen truss for the gymnasium.

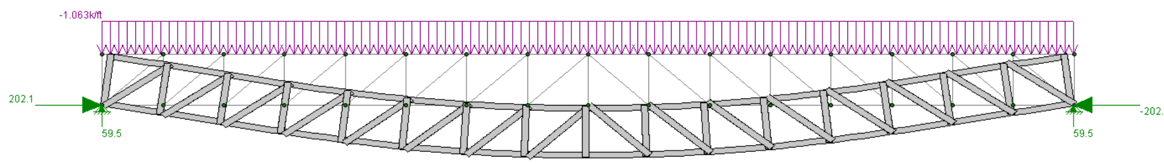

Figure 62: Deflected Truss under Green Roof Loads

The trusses used for the natatorium required their own RISA-2D analysis as well. These trusses carried not only uniform loads but point loads as well from the columns. A rendered image of the truss can be seen in Figure 63.

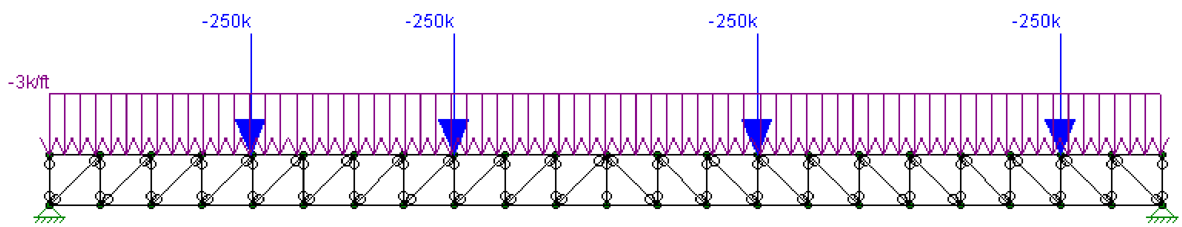

Figure 63: Truss for Natatorium with Applied Loads

These trusses are spaced at 4' on-center and are composed of LL8x8x18 double angles exclusively.

Foundation

The final foundation for the recreation center was chosen to be square spread footings. Other foundation design options included continuous footings, combined footings and a mat foundation. A foundation based on the applied load and other design and construction constraints was to be designed. The spread footings were also chosen over a mat foundation after a simple analysis showed the area of the footings would not exceed 50% of the total foundation area.

Since it would be impractical to design a unique footing for all 562 columns, the columns were placed in four groups based on a range of loads. This simplified the footing design to only four footing sizes without being over-conservative. These four types of footings were designed to handle the following loads seen in Table 17.

Table 17: Applied Loads to Footings

Footing	Column Load (kips)
Type I	0-100
Type II	100-200
Type III	200-410
Type IV	410-700

For the design of bearing capacity and the settlement, the geotechnical report by Haley & Aldrich, Inc. was used. The boring logs showed that there was a mix of soils classified as glacial till throughout the site that extends to a minimum of 30 ft. The report also showed the groundwater table at approximately 4-6' below the proposed elevation of the basement. Other information used from this report includes recommendation on settlement, excavation, filling/backfilling and dewatering.

Based on the depth of the groundwater table and recommendations in the geotechnical report, dewatering will have to be used during construction in order to temporarily lower the groundwater table. The height of the groundwater table required an adjustment to the effective vertical stress by changing the density of the soil beneath the footings. The following equation is how the density was adjusted in order to change the effective vertical stress.

$$\gamma' = \gamma - \gamma_w$$

When designing the footings for bearing pressure on the soil, several input values were required. Table 18 illustrates these values.

Table 18: Values Used in Terzaghi Method

Specific Weight – γ	109 lb/ft^3
Effective Friction Angle – ϕ’	10
Undrained Shear Strength – c	2000 lb/ft^2
Factor of Safety	3
N_c	17.69
N_q	7.44

As shown in Table 18, the effective friction angle used (10°) was considerably conservative based on the uncertainty of the glacial till. All other values used from the table are typical of sandy gravel.

Figures 64-67 show the dimensions and reinforcement for the four types of footings used as well as the cross-section of the base plates. As mentioned previously, all footings are square. All figures were drawn to scale in AutoCAD and scaled appropriately into this report to give the reader perspective.

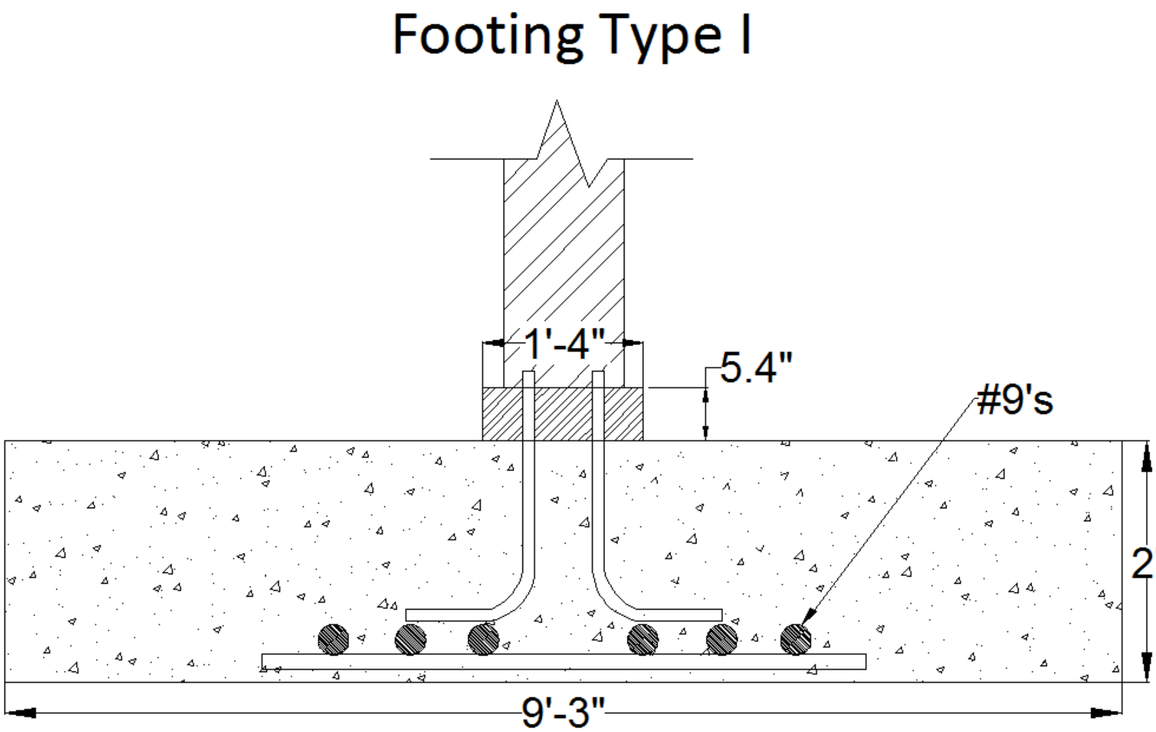

Figure 64: Footing Type I Details

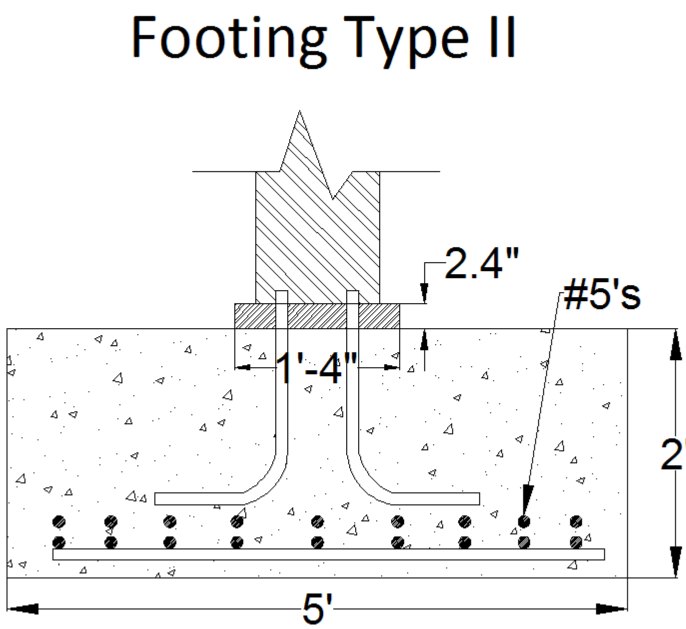

Figure 65: Footing Type II Details

Footing Type III

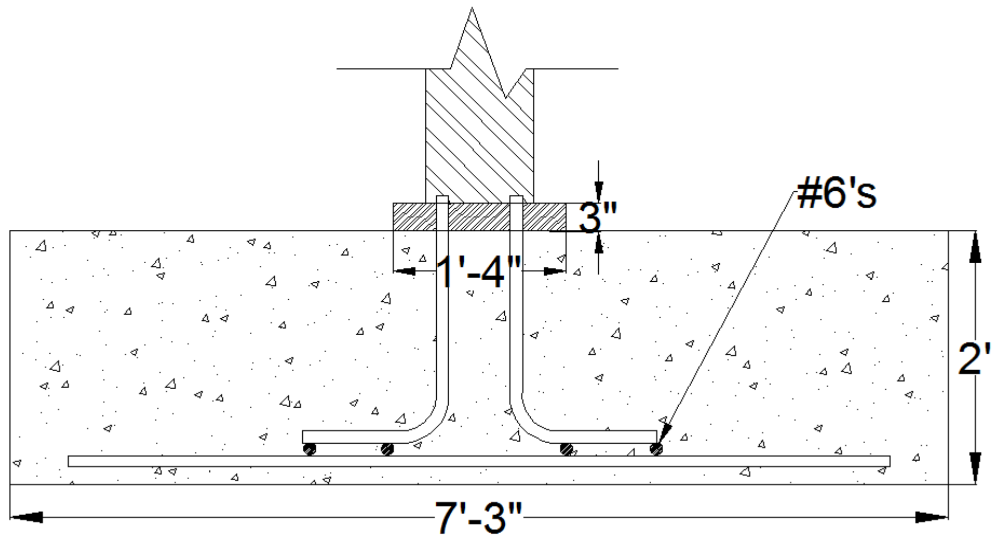

Figure 66: Footing Type III Details

Footing Type IV

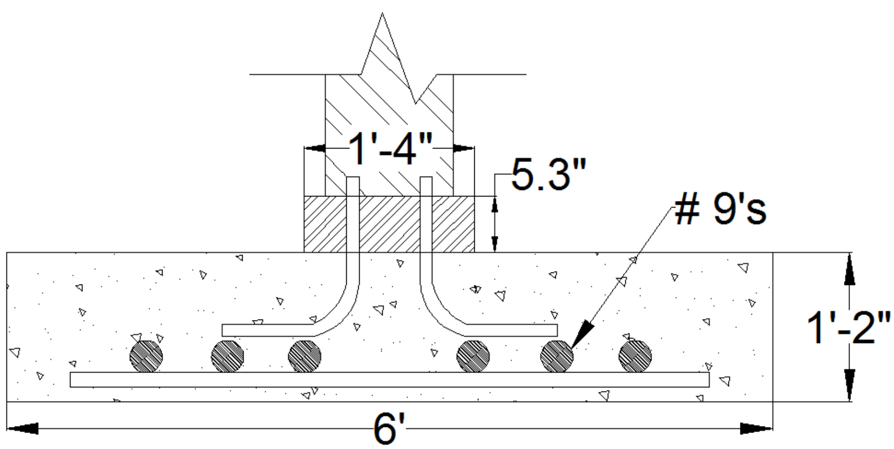

Figure 67: Footing Type IV Details

A settlement analysis was performed on the soil after the footings were designed. Settlement on the footings was no more than a ½". Haley & Aldrich, Inc. states in the geotechnical report that they predict settlement will not exceed ¾" which confirms the analysis. This assumption in the geotechnical report was based on recommended bearing pressures similar to what was designed for. This was important for the recreation center because the groundwater table was found to be at or above the elevation of the footings.

Retaining Wall/Sheet Piles

The elevation difference between the quadrangle and the football field was 26 feet. This height made it impractical to design a cantilever retaining wall because it would lead to extremely large dimensions. Preliminary designs estimated the thickness of the wall to be more than 8 feet. When the dimensions of the retaining wall became that large, the design and constructability for such a wall was economically unfavorable. Due to this constraint, a sheet pile wall was chosen.

The sheet pile section is 50 feet tall with tiebacks at 5' on-center and will penetrate the bedrock. Due to this constraint, the bedrock must be blown up and the rocks must be removed for the completion of the sheet pile construction. The Rowe's reduction number calculated was much bigger than the ones that are listed, so after careful consideration, the largest sized steel section AZ48 sections with ASTM A328 steel was chosen. The data was listed in a table given by the Skyline Steel Corporation in the *Foundation Design 2^nd^ Edition – Coduto, 2001* textbook. The calculations can be seen in Appendix B.

Pool Foundation

The pool foundation was difficult to design due to the bearing capacity limitations as well as satisfying all the necessary design requirements. For example, the base length had to be increased from 6 feet to 10 feet to help satisfy the overturning moment. Although, it may have been possible to include part of the mat as the "toe" of the footing, it was decided to be more conservative and design the cantilever retaining walls and the mat foundation separately.

Figure 68 shows the final dimensions of the pool foundation as well as the reinforcement bars and their locations. The retaining wall dimensions are congruent both in terms of dimensions as well as the reinforcement steel.

Since the mat foundation and the cantilever retaining walls are designed separately, the retaining walls and the mat had to be sealed together properly with no leakage and be able to be deformed in case the wall settles or is moved.

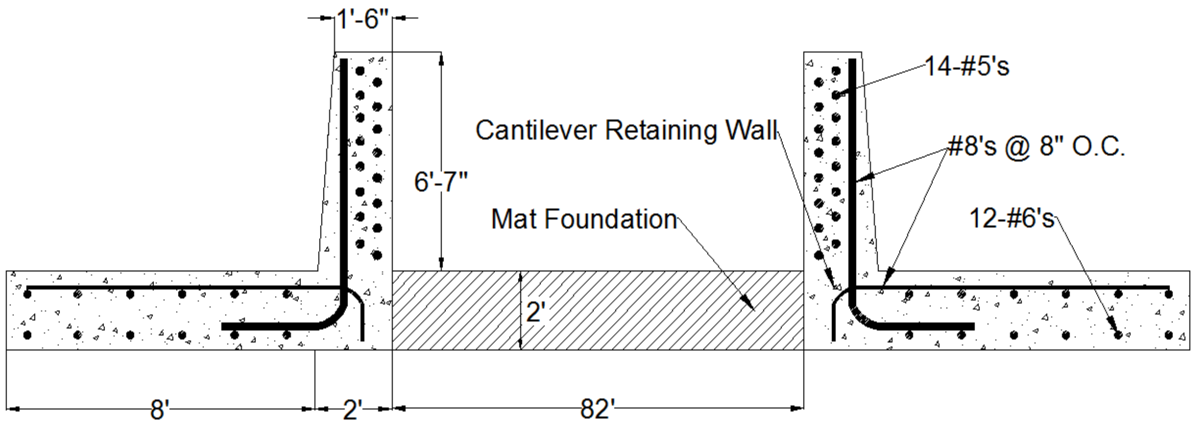

Figure 68: Pool Foundation Dimension

5. COST ESTIMATING

Cost estimation is the calculated cost of materials and labor necessary for the completion of a building. Since an estimate is made prior to construction, it is important to note that this is never the actual cost. The higher skilled cost estimators can provide a price that will be close to the final cost. Good cost estimators use proper estimating methods and can visualize the project as it would be completed.

When looking at the four floors in the new recreational center, the structural elements of the building were examined for cost estimation. This included all the materials and labor to needed for the construction of the building. When the estimator looks at the various materials from the plans and specifications on quantity sheets, they take note of their size, weight, volume, etc. and are able to make estimations. Also, when preparing labor estimates, the estimator needs to look at wages, vacations, variations in working conditions, and the labor needed for different kinds of work.

The national average prices listed in the *RSMeans Building Construction Cost Data 2008* were used to provide location indices relative to Massachusetts. These location indices are based on the national cost (its index is 100). In order to get costs representative of the state the recreational center would be built in, the national averages were adjusted in order to show relative costs.

In Massachusetts, the material cost for metals is 93.4% and the labor cost is 123.3% of the national average that was listed in *RSMeans Building Construction Cost Data 2008*. The weighted average for a standard construction project depends on the costs for each division and the national average indices. Table 19 displayed the Massachusetts location indices when compared to the national average indices.

Table 19: Location Indices

Division	Massachusetts Location Indices		
	Materials	Installation	Total
Contractor Equipment	-	100.6	100.6
Site & Infrastructure, Demolition	83.7	104.2	98.0
Concrete Forming & Accessories	99.0	129.5	125.3
Concrete Reinforcing	102.0	146.8	123.6
Cast-in-Place Concrete	90.4	143.4	110.0
Concrete	101.0	136.6	117.5
Masonry	96.4	144.1	124.9
Metals	93.4	123.3	102.1
Wood, Plastics, & Composites	100.4	131.3	117.0
Thermal & Moisture Protection	99.5	135.2	113.5
Openings	105.3	133.7	112.3
Plaster & Gypsum Board	105.1	131.3	121.3
Ceilings & Acoustic Treatment	96.2	131.3	117.8
Flooring	96.3	163.7	114.6
Wall Finishes & Painting/Coating	91.6	132.4	116.1
Finishes	99.6	137.2	119.2
Covers	100.0	102.4	100.5
Fire Suppression, Plumbing & HVAC	100.1	107.2	103.1
Electrical, Communications & Utilities	98.1	98.5	98.3
Weighted Average	98.7	120.8	108.1

The cost of steel was obtained from *RSMeans Building Construction Cost Data* 2008 and was estimated to be $2500 per ton and $3 per stud. Also, joists were $7.25 per foot of length.

Table 20 shows the cost of the steel members listed in Table 16 and the totals based on the amount of columns throughout the building.

Table 20: Cost of Selected Steel Columns for Floors 1-4

Steel Column Cost for Floors 1 - 4			
Member	Individual Cost	Total Columns	Total Cost
W12x40	**$800**	**398**	**$318,400**
W12x50	**$1000**	**98**	**$98,000**
W12x58	**$1160**	**38**	**$44,080**
W12x72	**$1440**	**28**	**$40,320**
			$500,800

Table 21 presents the substructure and superstructure costs calculated after taking into account the location indices listed in Table 19. The difference between a substructure and a superstructure has to do with construction in relation to the ground level. Any structures that are done below the ground level are considered substructures. That could range from a simple foundation to a basement floor or, in this case, the foundation of the Olympic-sized pool. Superstructures are those portions of a building or structure that are visible from the ground level up. This could refer to anything from a simple residential house to a multi-story building or a gymnasium/recreational center.

Table 21: Substructure/Superstructure Costs

Substructure/Superstructure Costs (ft^2)	
Building System	Cost per ft^2 of building
Substructure	**$1.98**
Superstructure	**$18.70**

The footings would be cast directly against the earth with no forming or finishing required. The costs assume the top of the foundation will be at finished grade. For scheduling purposes, it was estimated that a crew of three could lay out, excavate, place and tie the reinforcing steel and place 13 CY of concrete in an 8-hour day. Table 222 shows the costs of the different footing types as well as the total amount.

Table 22: Footing Cost

Footing Cost for Types I-IV			
Footing Type	Individual Cost	Total Footings	Total Cost
Type I	**$133.86**	**398**	**$53,276**
Type II	**$92.32**	**98**	**$9,047**
Type III	**$170.78**	**38**	**$6,489**
Type IV	**$64.62**	**28**	**$1,809**
			$70,621

Table 23 displays the square foot areas for the different floors of the building and the total area. The costs listed in Table 22 were calculated and the results based on the building area as well as the grand total can be seen in the below table.

Table 23: Building Area for Floors 1-4

Building Area for All Floors (ft^2)				
1st Floor	2nd Floor	3rd Floor	4th Floor	Totals
70,484 **$1,423,075**	**70,484** **$1,423,075**	**94,359** **$1,905,113**	**94,359** **$1,905,113**	**329,686** **$6,656,377**

The recreational center is using standard bricks that are 3-3/4” wide x 2-1/4” high x 8” long. The brick wall was built to be a triple wythe, cavity filled, 12" thick wall. Typical costs for smooth red clay brick walls laid in running bond with 3/8" concave joints included the bricks, mortar for bricks and cavities, typical ladder type reinforcing, wall ties and normal waste. Table 24 presents the total area of the brick wall as well as its cost.

Table 24: Brick Masonry

Brick Masonry for Building		
Brick Wall (ft^2)	Cost per ft^2 of wall	Cost of brick wall
69,500	**$32.85**	**$2,283,075**

The glass curtain wall was another factor that had to be looked at when estimating the cost of this project. They are designed to resist air and water infiltration, wind forces acting on the building, seismic forces, and its own dead load forces. Also, they are known to span multiple floors and take into consideration design requirements such as thermal expansion and contraction, building sway and movement, water diversion, and thermal efficiency for cost-effective heating, cooling, and lighting in the building.

Table 25 shows the area and cost of the glass curtain wall used in the new recreational center. Heavy duty float glass was the structural sealant curtain wall system used. It was built with a steel frame.

Table 25: Glass Curtain Wall

Glass Curtain Wall for Building		
Glass curtain wall (ft^2)	Cost per ft^2 of wall	Cost of glass curtain wall
7,500	**$39.60**	**$297,000**

These cost estimates as well as the square foot estimates for the floors were used as tools to understand where the design of the new recreational center was headed. We evaluated the material costs of steel, brick and glass to make the most cost effective decisions. These approximations were based around maximizing the space available provided in the AutoCAD drawings, minimizing the environmental impact and maintain the needs of Worcester Polytechnic Institute through cost effective and constructible means.

References

AISC | news. Retrieved 10/8/2008, 2008, from http://www.aisc.org/Template.cfm?Section=News&template=/PressRelease/PressReleaseDisplay.cfm&PressReleaseID=50114&PressReleaseCategoryID=1&ShowArchives=0

AISC | news. Retrieved 10/9/2008, 2008, from http://www.aisc.org/Template.cfm?Section=News&template=/PressRelease/PressReleaseDisplay.cfm&PressReleaseID=50114&PressReleaseCategoryID=1&ShowArchives=0

ASCE design loads on structures during construction(2002). (SEI/ASCE 37-02 ed.)

ASCE minimum design loads for buildings and other structures(2000). (Revision of ANSI/ASCE 7-95 ed.)

ASD vs LRFD. Retrieved 10/9/2008, 2008, from http://www.bgstructuralengineering.com/BGDesign/BGDesign05.htm

Bostik - durabound, hydroment, never-seez product catalogs. Retrieved 10/15/2008, 2008, from http://www.bostik-us.com/productCatalogs/index.asp?fa=productCatalogs

BuildingGreen.com - LEED® MR credit 6. Retrieved 10/15/2008, 2008, from http://www.buildinggreen.com/auth/productsByLeed.cfm?LEEDCreditID=28

Christopher Babbitt. (2008). RSMeans Building Construction Cost Data 2008 (66th ed.)

City of worcester permits and various forms. Retrieved 9/22/2008, 2008, from http://www.ci.worcester.ma.us/dpw/

Department of energy - solar. Retrieved 10/15/2008, 2008, from http://www.energy.gov/energysources/solar.htm

Discover solar energy ADVANTAGES DISADVANTAGES | PROS and CONS of solar energy. Retrieved 9/22/2008, 2008, from http://www.facts-about-solar-energy.com/solar-energy-advantages-disadvantages.html

Donald P. Coduto. (2001). *Foundation design: Principles and practices* (Second ed.)

DSIRE: Incentives by state: Incentives in massachusetts. Retrieved 10/15/2008, 2008, from http://www.dsireusa.org/library/includes/map2.cfm?CurrentPageID=1&State=MA&RE=1&EE=1

Flexco. Retrieved 10/15/2008, 2008, from http://www.flexcofloors.com/rubber_primesports.asp

Get-A-Quote: Online Construction Costs for Contractors. Retrieved 3/16/2009, 2009, from http://www.get-a-quote.net/default.htm

Green solutions - sherwin-williams. Retrieved 10/15/2008, 2008, from http://www.sherwin-williams.com/pro/green/index.jsp

Jack C. McCormac. (2008). *Structural steel design, 4th edition* Person Education, Inc.

List of low emitting materials table. Retrieved 10/15/2008, 2008, from http://www.chps.net/manual/lem_table.htm

Office of Enrollment Management. (2007). *WPI student fact book*. WPI:

Physical fitness (exercise room) | whole building design guide. Retrieved 9/30/2008, 2008, from http://www.wbdg.org/design/physical_fit.php

Rainwater recovery inc. Retrieved 9/22/2008, 2008, from http://www.rainwaterrecovery.com/

SierraPine - composite solutions. Retrieved 10/15/2008, 2008, from http://www.sierrapine.com/index.php?pid=20

Solar energy technologies program: PV in use: Getting the job done with solar electricity. Retrieved 10/15/2008, 2008, from http://www1.eere.energy.gov/solar/pv_use.html

Solar energy technologies program: Solar collectors. Retrieved 10/15/2008, 2008, from http://www1.eere.energy.gov/solar/sh_basics_collectors.html

Solar energy technologies program: Solar heating. Retrieved 10/15/2008, 2008, from http://www1.eere.energy.gov/solar/solar_heating.html

Solar system costs. Retrieved 10/15/2008, 2008, from http://www.solar-electric.com/solar_system_costs.htm

The Massachusetts State Building Code State Board of Building Regulations & Standards, (2008).

Thermal comfort - sherwin-williams. Retrieved 10/15/2008, 2008, from http://www.sherwin-williams.com/pro/green/thermal_comfort/

USGBC: LEED for new construction. Retrieved 9/23/2008, 2008, from http://www.usgbc.org/DisplayPage.aspx?CMSPageID=220

USGBC: LEED online - sample credit templates. Retrieved 10/15/2008, 2008, from http://www.usgbc.org/DisplayPage.aspx?CMSPageID=1447

WBDG - the whole building design guide. Retrieved 10/6/2008, 2008, from http://www.wbdg.org/

Appendix A: MQP Proposal

1. Introduction

WPI President, Dennis Berkey, has been an advocate for campus expansion. With increasing enrollment figures, a rise from 2,800 to 3,400 by the year 2015 according to his Vision Statement in January of 2007, he wants WPI to become a more close-knit campus.[40] Admission figures can be seen in Figure 1.1 below.

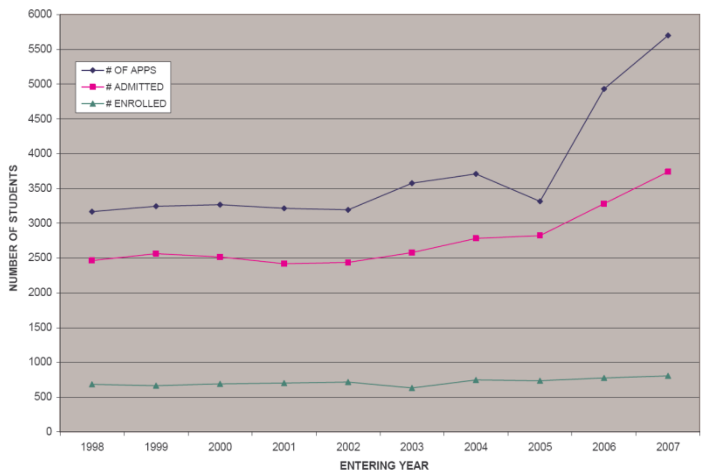

Figure 1.1: Undergraduate Admissions Data
Source: WPI Student Factbook

One way he proposes on achieving this sense of community is through his revised 1999 Strategic Plan, which includes a goal to develop campus facilities according to a plan that would support both academic and co-curricular needs, which he explicitly states that the new recreation facility will bring a great sense of enthusiasm to WPI.[41]

The current recreation centers, Harrington Auditorium and Alumni Gymnasium, are primarily used for varsity sports and, as a result, recreational use is limited during various times of the year. The proposed Recreation Center is to be constructed near the athletic fields as shown in Figure 1.2.

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[40] http://www.wpi.edu/Admin/President/vision.html
[41] http://www.wpi.edu/Admin/President/strategicplan.html

Figure 1.2: Site Sketch of Proposed Location of New Recreation Center

The yellow circles with dotted lines in the figure show the sun's path during the course of a day (going from right to left), the red dashed line are merely for reference and the solid yellow area is the proposed location for the new recreation center.

Due to overuse of these spaces, most of these facilities are run down and in great need of refurbishment or replacement. Harrington Gym, built in 1968, is the only indoor athletic facility that has seen a face lift in recent years and is properly maintained.[42] Though the court has been replaced as of this year, it is the only open space for teams like baseball, softball, volleyball and club sports like lacrosse, volleyball, dance, step and badminton. These teams have had to make use of every inch of Harrington Gymnasium and Alumni Gymnasium (built in 1916) [1], including foyer entrances to practice dance and step moves, baseball drills under the bleachers and a storage room used for batting cages. In addition, poor ventilation throughout the building, particularly in the weight room further deters students.

With all of these time conflicts and space restraints, many of the students who do not play a varsity sport are unable to play recreational sports in these buildings or use the work-out facility. WPI has tried to help these students by coming up with a plan to build an additional athletic facility.

[42] http//:www.wpi.edu

Current indoor athletic facilities are not among the school's highlights nor do they help promote the school to prospective student athletes. The purpose of our project is to take the needs of WPI and develop a finished product that will be suitable for the growing student population. Our goal is to produce a building that will be LEED certified as well as contain state of the art facilities such as brand new basketball courts, an Olympic-size swimming pool, new squash and racquetball courts, an aerobics room, a yoga room, a new work-out facility complete with weightlifting machines and free weights, and a cardio room complete with several different cardio machines. With this new recreational facility, WPI plans to further promote extra-curricular activities, overall wellness and help balance their reputation between academics and athletics.

1.1 Capstone Design

Our project focused on alternative designs to the new recreational facility which would be economically as well as environmentally sound. The design for the new recreation center takes into account several constraints listed by the ASCE commentary which are addressed by the analysis in the project.

Economic

In order to investigate total costs, we designed the building using concrete, steel and glulam wood to see which one, or which combination of materials, would produce the most advantageous total project cost as well as produce a safe building that would abide by various structural codes.

Environmental

Our designs included LEED options which would increase our level of LEED. We also investigated these LEED alternatives and determined that the power generated through natural resources would cut down on greenhouse gas emissions and, as a result, would not contribute to climate change and would also save enormous amounts of money for WPI. The materials used also helped address the environmental constraint because we would be using recyclable steel as opposed to unrecyclable concrete.

Sustainability

Our research on LEED helped us address the sustainability aspect of our project. By adding a few "green" components (i.e. rainwater harvesting system and solar panels) we can help raise the sustainability of the building.

Manufacturability/Constructability

The materials that were under consideration were primarily used to determine whether the final design was to use one material or another or if the design must incorporate multiple materials. We also had to take into account all of the diverse loads that would be applied on the building and evaluate if the design would suffice.

Social

The project itself will address the social constraints which include a lack of recreational space for both Varsity athletes and the general student body. This project will give the students who do not participate in Varsity athletics a greater opportunity to participate in various recreational activities.

2. BACKGROUND

To begin designing a building anywhere, there are a logical set of steps that must be taken. The first action that must be taken, after a preliminary design, is the acquisition of permits to see if the building type and location is even feasible. All regulations set by the state of Massachusetts and the city of Worcester must be followed throughout the entire project. A comprehensive review of these rules and regulations is necessary.

2.1 City of Worcester's Building Requirements

Every city in the country has a set of rules that specify the minimum acceptable level of safety for buildings. The main goal of building codes is to protect public health, safety and general welfare as they correspond to the construction and use of buildings such as the recreation center.[43]

The first necessary step to begin constructing the recreation center is by drawing plans (exterior and interior) to scale and showing the locations and dimensions of the lot that is to be built upon. In this case, it is an extension of an existing building. All this information is required by the Code Commissioner (city officer designated by the City Manager). This administrator is part of the Zoning Ordinance in the City of Worcester. The Code Commissioner will then announce regulations that should be followed and subsequently file a copy of these rules with the City Clerk.[44, 45]

Once the Code Commissioner files the parameters with the City Clerk, the next step would be to acquire a building permit. A building permit gives its owner legal permission to start construction of a building project in accordance with the approved drawings and specifications provided for the recreation center. Building permits have to be obtained before any construction is done as they are needed to erect, construct, enlarge, alter, repair, improve or

[43] http://www.ci.worcester.ma.us/dpw/
[44] http://www.ci.worcester.ma.us/cco/clerk/ordinances/revisedordinances1996.pdf
[45] http://www.ci.worcester.ma.us/cco/clerk/ordinances/zoningord2607.pdf

demolish any building or structure. A fee is collected based on the size of the job and covers the cost of the application, the review, and the inspection process.[46]

The application for the building permit should include written consent from the owner if not the applicant. The following must be included with the application:

- Off street parking and loading spaces.
- Plot plan of the land showing all the dimensions of the recreation center and the exact location of the existing buildings that may be altered (Harrington).
- A description of any proposed building, structure or addition. The recreation center is essentially an addition to Harrington.
- A statement explaining any proposed external alterations which increase the height or area of any existing building or structure.
- The number of locations and design of parking, loading spaces, signs and buffers where appropriate.
- Proof of recording of a land development plan for construction of any welling not on a separate lot of record.
- On-lot sewage disposal permit, where public water and sewer is not available.
- Public water/sewer – a letter from the Worcester Township Water/Sewer Operations for valid connection permits.
- Erosion and sedimentation control plan from the Worcester County Conservation District.
- Workers Compensation Insurance Coverage Information for the contractor.
- Workers Compensation Certificates for contractors.
- Storm water management plans in accordance with Section 329 of the Zoning Ordinance.[47]

Once the contractor has been approved for a permit, he or she has legal permission to start construction. The Code Commissioner is available for whenever one would have any questions

[46] http://www.ci.worcester.ma.us/forms.html
[47] http://www.ci.worcester.ma.us/dpw/engineering/permit_manual.pdf

about issues with the project. The Code Commissioner should be seen as someone who will help make the project a problem-free event. Various permits are required for electrical, plumbing, heating and air-conditioning work and he or she would be the one to go to in order to obtain these.[48]

On-site inspections will occur every now and then throughout the duration of the construction. The Code Commissioner will determine approximately how many inspections may be needed for the project. Usually, a one or two day notice is needed when requesting visits. They are required to make sure the work conforms to the permit, local codes and plans. It is important to acknowledge that the Code Commissioner will also help with questions or concerns regarding the project and to ward off potentially costly mistakes.[49]

The Code Official will provide documentation when construction on the recreation center is complete and code compliance is determined. Once this is done, the job is essentially finished and the community can be content knowing that the new facility met the safety standards required by the City of Worcester.[9]

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[48] http://www.ci.worcester.ma.us/isd/building_zoning/building/faq.htm
[49] http://www.ci.worcester.ma.us/isd/building_zoning/home.html

2.2 Design

For the design a multipurpose structure such as the Recreation Center, each room, hallway and activity must be analyzed to design the most effective facility. The list of spaces and their respectable sizes are shown in Appendix D. The spaces are broken down into five categories; public areas, activity spaces, training & rehabilitation, administration/coaches and support spaces. These different spaces make the design of this building more challenging because there are no generic spaces, thus requiring greater attention to detail. The study of these spaces is important before developing a floor plan.

2.2.1 Public Spaces

Public spaces will be the first thing visitors see when entering the main entrance from the quadrangle. For this reason, extra emphasis is necessary to provide a good first impression.

This area will have to be aesthetically appealing which deals more with the decor, light placements and furniture. However, there will be a few long spans of ceiling as shown in Figure 2.3. Overall, these sections will not be structurally challenging.

Figure 2.3: Example Reception Area

2.2.2 Activity Spaces

Activity spaces are the focus of this building and therefore require the most concentration. Each room must be specialized to fit the needs of that activity in order to attract students. A misrepresented space could result in misuse or lack of use by the student body. Every activity and sport deserves to have the most up to date equipment and spaces as economically feasible.

Four Court Gymnasium

The proposed four court gymnasium is undoubtedly one of the most anticipated spaces the recreation center plans to provide. Currently, there are two multipurpose courts on campus with approximately ten Varsity teams, club teams and intramurals using the courts for practice and competitions. By adding four more courts it will leave Harrington Gymnasium to be used only by varsity sports. This will allow teams to practice more frequently and at convenient times which in turn will improve WPI Athletics.

The four court gymnasium will have the capacity for several sport events including, basketball, badminton, baseball, softball, volleyball, wrestling and lacrosse. To be able to support all of the different varieties of sports, a vinyl curtain option will be installed that separates all four courts.

The design challenges associated with this space are the long spans that will be at least the length of a basketball court (94 feet). The design loads for the gymnasium will be 100 lb/ft^2 which will not pose a serious problem. The group will have to decide how to support the long spans; a truss member was used as seen in Figure 2.4.

Figure 2.4: Indoor Multipurpose Courts
UMaine, 2008

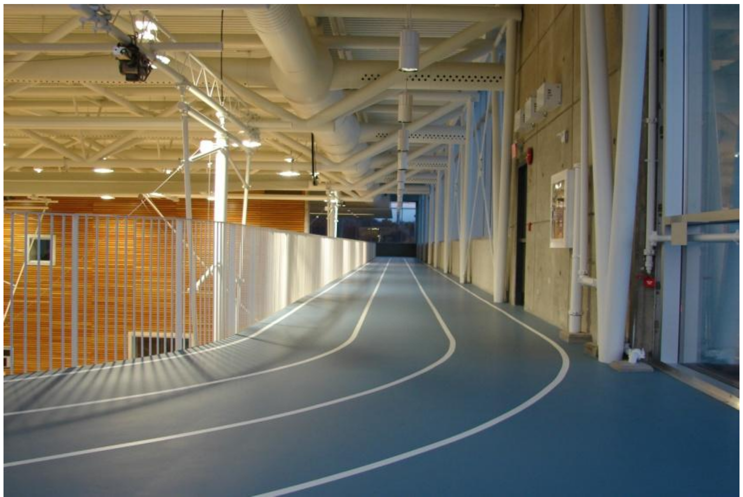
Tennis Court

Due to the overwhelming amount of extra space in the recreation center, an indoor tennis court was added on the end of the four court gymnasium. The tennis court, like the basketball courts will have a moveable curtain to impede stray balls. Figure 2.5 shows a partitioned indoor tennis court, like what will be seen in the recreation center.

Figure 2.5: Indoor Tennis Court
Western Tennis and Fitness Club

Jogging Track

The jogging track to be installed with the new facility will be a minor, however important feature. Currently, there is a small jogging track above Alumni Gymnasium. This track can only handle at most six people running in-sync. The new track will be 5,280 feet (1/8 mile) and have three lanes of traffic that will allow sprinters and walkers to co-exist. This will also



take some traffic away from Harrington Auditorium where walkers and joggers use the upper tier as a track for which it was not intended. This space will have relatively small loads and will not pose a design challenge. Figure 2.6 shows what the track will look like above the four court gymnasium.

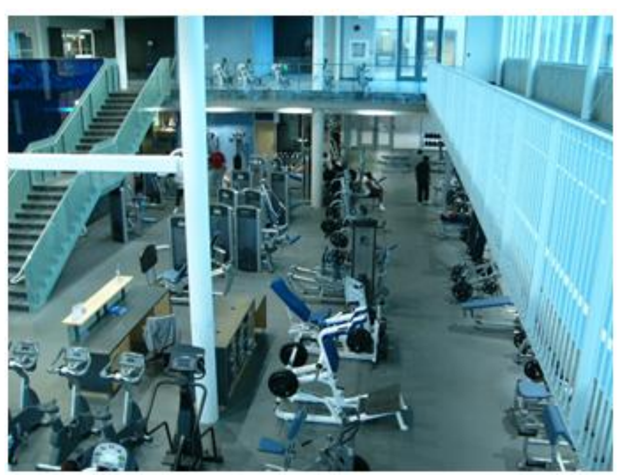
Figure 2.6: Indoor Track Overlooking Courts

UTM, 2008

Fitness Center

The fitness center is one of the many upgrades that will be appreciated by the students of WPI. The fitness center in the basement of Alumni Gymnasium can occasionally get crowded enough to deter students from exercising all together. Poor ventilation makes breathing conditions difficult and weights/surfaces slick which can produce a dangerous environment for workouts. This is also sometimes the result of poor cleaning and the overall lack of attention this area receives. The new fitness center will have to model current private gyms, equipped with new weights, nautilus machines, sweat towels, air filtration/circulation and separation between cardio and weightlifting sections. These are all concerns that will be addressed in the design of the new fitness center.

As far as structural design is concerned, this area of the recreation center will have unique loads due to free weights and nautilus machines. A typical live load for exercise or weight room is 150 lb/ft^2 which will make members in this area larger than in other areas of the building, making the fitness center one the most expensive spaces in terms of price per square



foot.50 The fitness center's multi-storied circular design will also be a challenge. The group will try and minimize the number of columns to maximize workout space on the first floor. Figure 2.7 below is an example of a two story fitness center that optimizes natural lighting and will be similar to what will be built.

Figure 2.7: Multi-Tiered Fitness Center

UTM, 2008

Natatorium

Of all the varsity sports at WPI, the men's and women's swimming teams are one of the few sports to not have a regulation size facility to host events. With this addition, it will attract a whole new environment surrounding men's and women's swimming. The main design challenge that is associated with this space is the large span ceiling, similar to the gymnasium. In Figure 2.8 below you can see an example of a long span ceiling that uses pre-stressed steel members instead of a truss design.

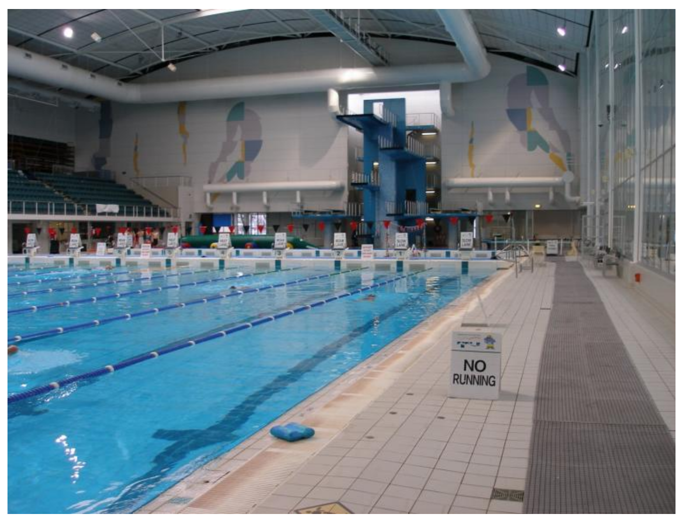


Figure 2.8: Olympic Sized Natatorium

Google, 2008

2.2.3 Training & Rehabilitation

Training and rehabilitation spaces are not structurally challenging to design. These

[50] WBDG - The Whole Building Design Guide

spaces will be located on the ground floor to facilitate easy access from the athletic fields and will not contribute significantly to the design of the foundation. The focus of the training and rehabilitation areas will be the furniture and equipment it will be supplied with. A hydrotherapy tub, training tables and ice machines are a few of the necessary pieces of equipment that trainers need to diagnose, treat and rehabilitate the athletes. Figure 2.9 shows a trainers room from Boston University which will be a model for WPI.

Figure 2.9: Training Room at Boston University

3. METHODOLOGY

This project is to help accommodate the students who attend WPI and are unable to participate in recreational activities due to time conflicts, over-crowded areas or any other inconvenience they may face. We are looking to construct a building that will be able to withstand the given loadings, maintaining minimal costs and achieving a LEED silver accreditation. To do this, a combination of design values for steel and concrete from the Massachusetts State Building Code (MSBC) and American Society of Civil Engineers (ASCE) manuals will be used. These texts contain specifications and design loads for the recreation center. Material and energy specifications will help us to design for a higher LEED certification. There are many factors and stresses to consider when designing a building. The loads that must be analyzed according to the MSBC can be categorized as dead and live loads. The building will be designed around the following basic floor plans.

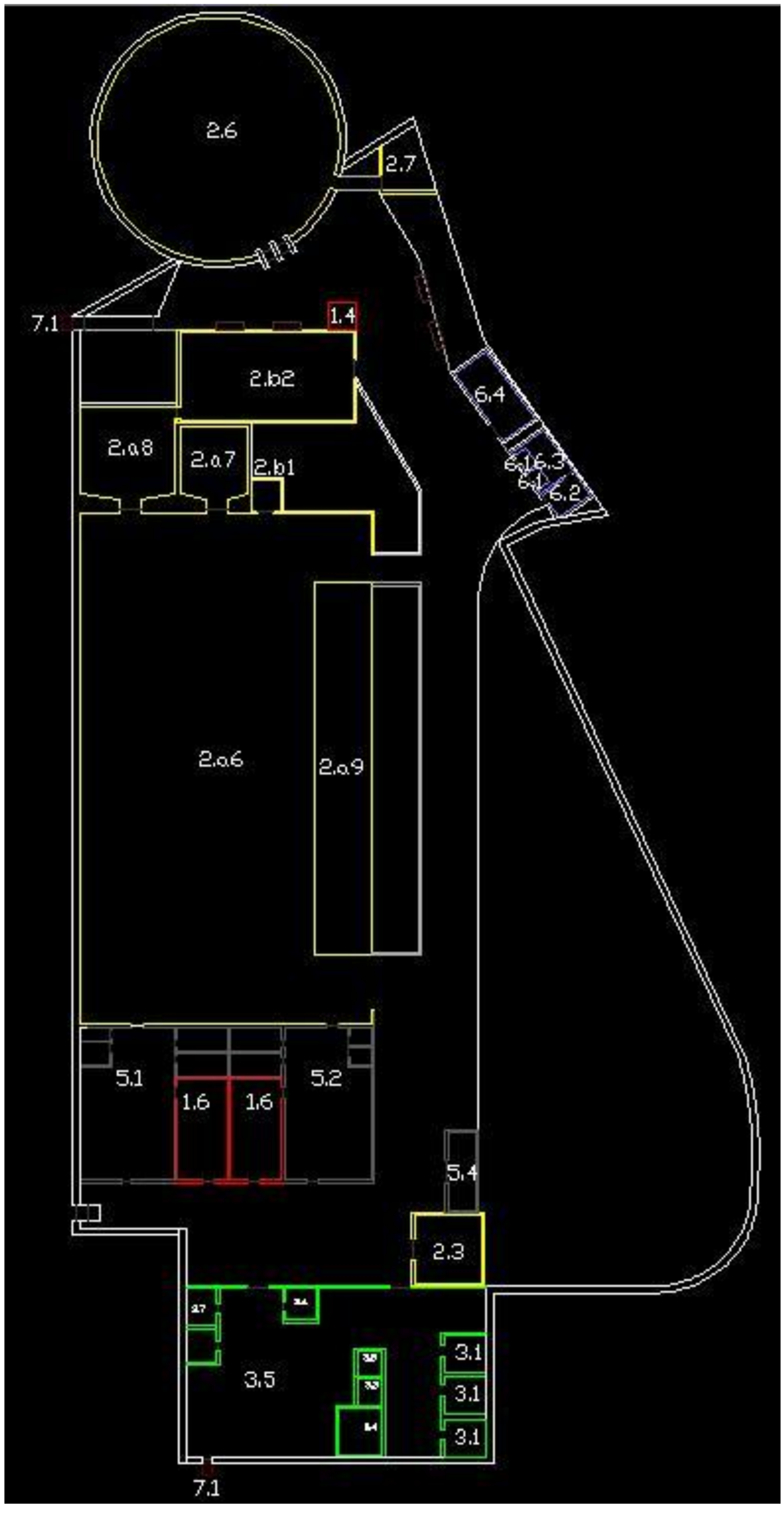


Figure 3.1: Floor Plan 1st Floor

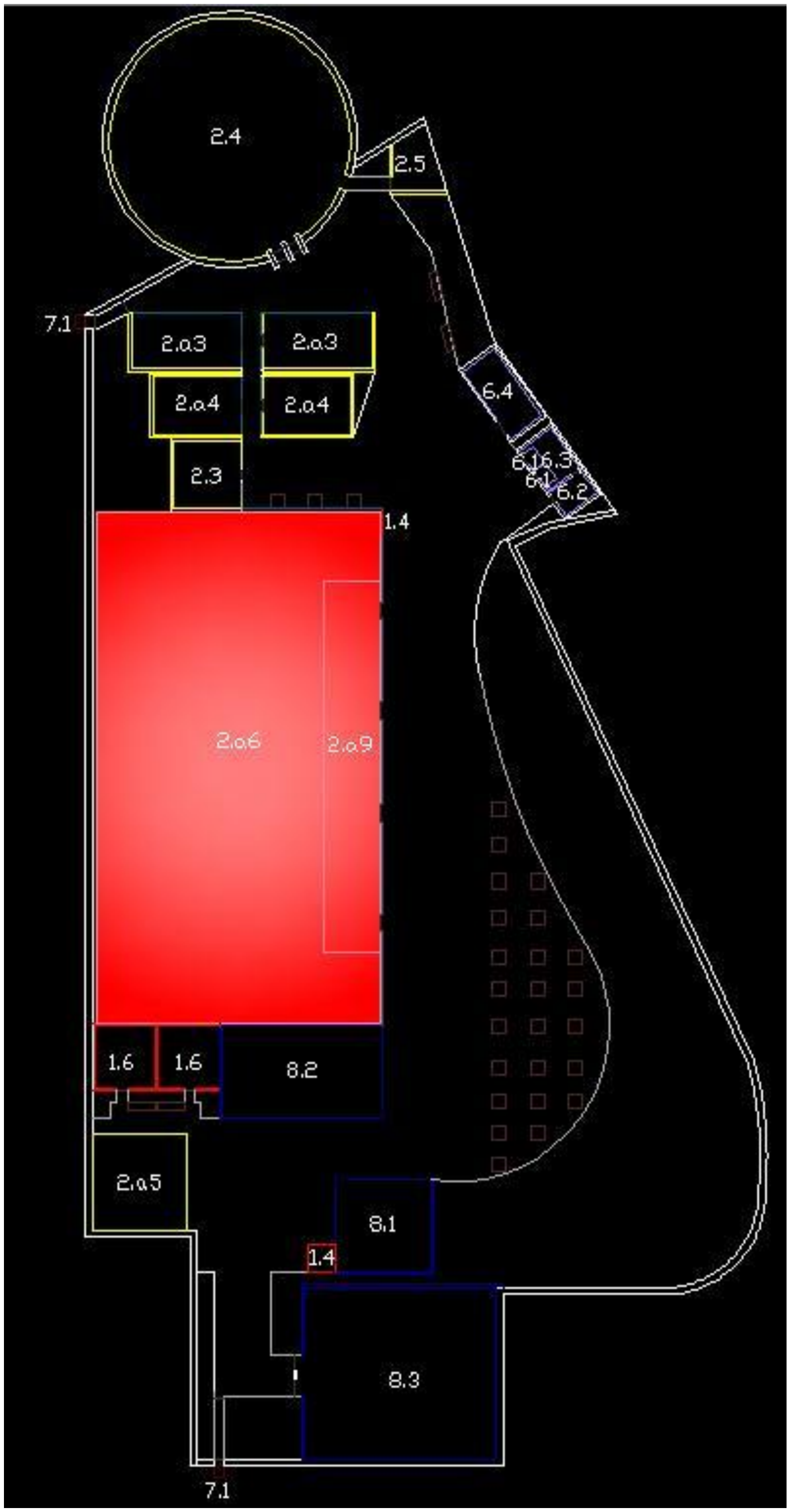


Figure 3.2: Floor Plan 2nd Floor

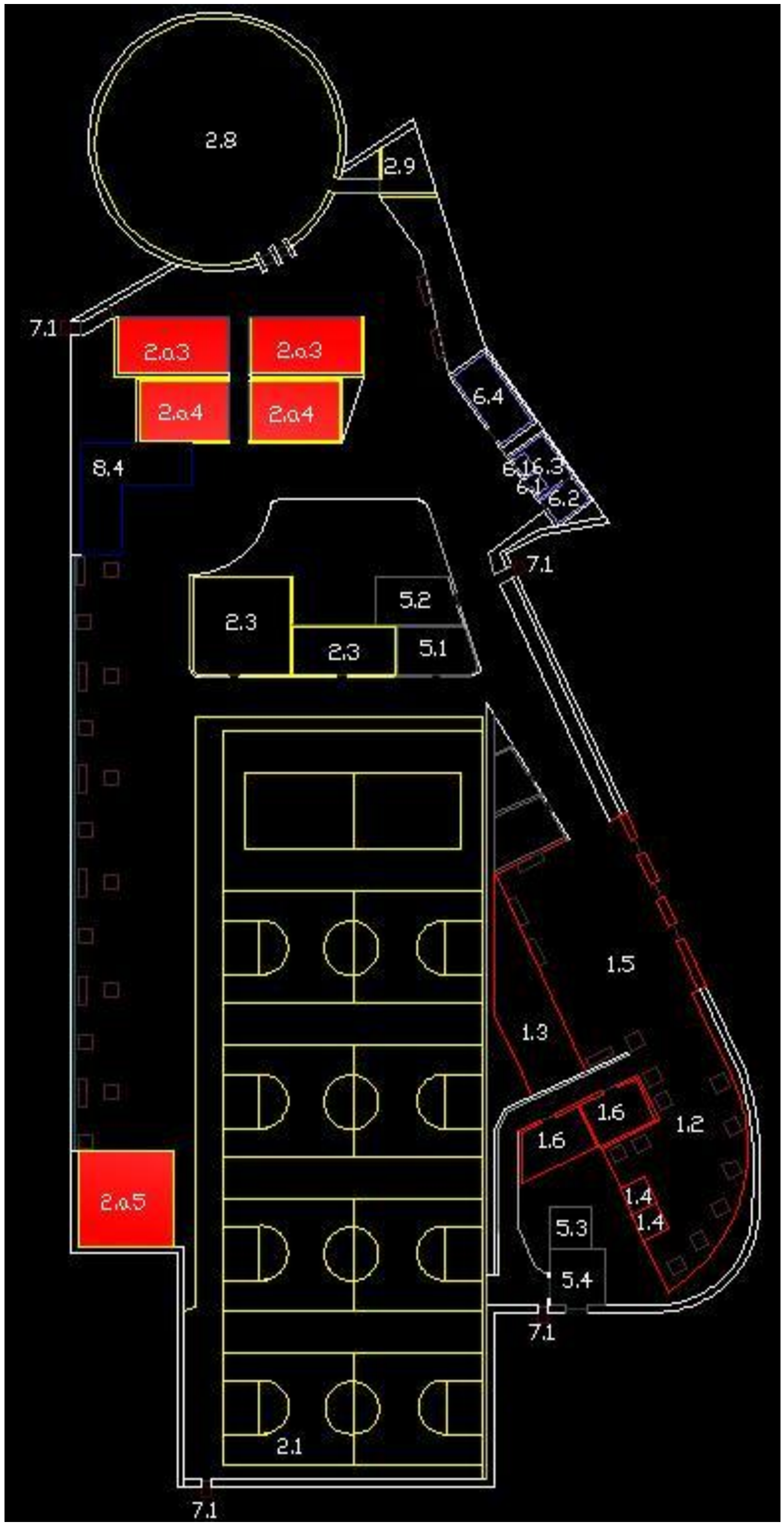


Figure 3.3: Floor Plan 3rd Floor

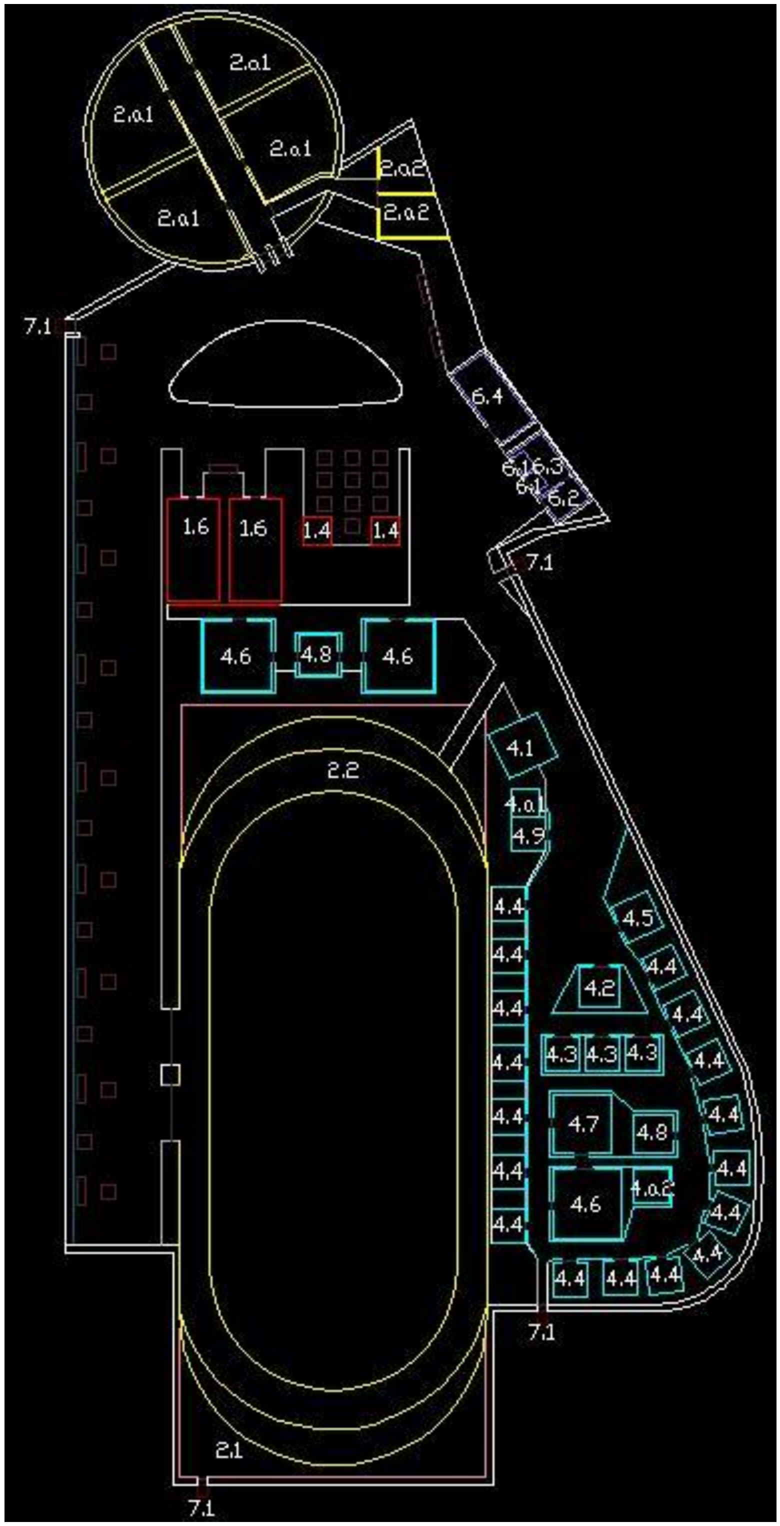


Figure 3.4: Floor Plan 4th Floor

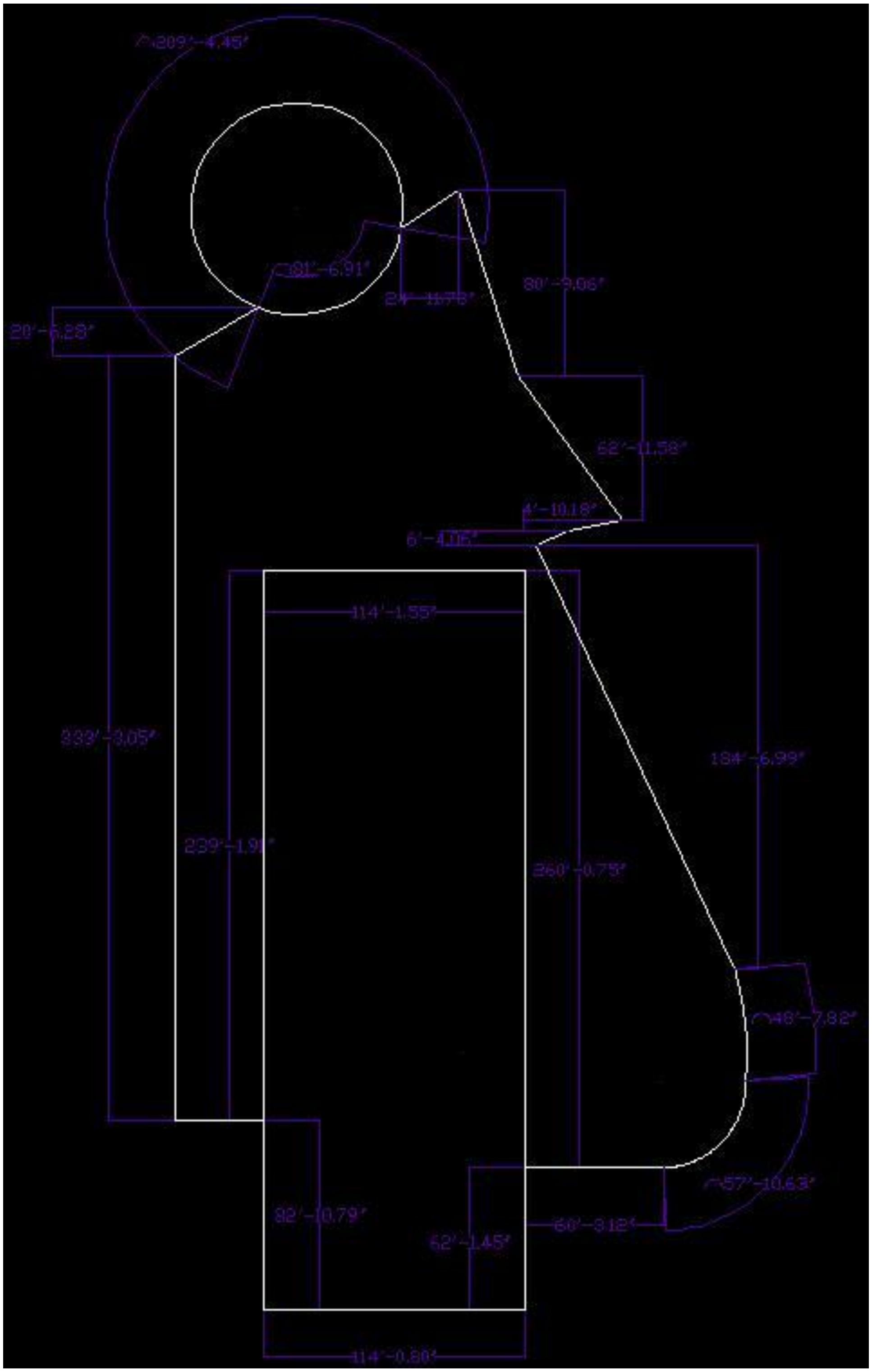


Figure 3.5: Floor Plan Roof

The rooms are numbered and full descriptions can be found in Appendix E. Using these floor plans the group will be able to design beams and columns for the building. This floor plan is subject to change; spaces are still empty and need to be better utilized. The group will continue to revise the floor plan in B term.

Dead loads are defined as the weight of materials of construction that are permanent to the building which include, floors, walls, finishes, roofs, stairways and stationary mechanical equipment. The majority of the dead loads will be the weight of the steel or concrete. These loads will be determined during the design in B term where the tonnage of steel and concrete will be decided. Once the weight of the building is determined, an accurate cost estimate can be developed. Currently the price of steel hot rolled structural is approximately $120 per ton and the cost of concrete, including the labor to make the forms, is $1,000 per yd^3.[51]

Live loads are "loads produced by the use and occupancy of the building or other structure and do not include construction or environmental loads such as wind load, snow load, rain load, earthquake load, flood load or dead load."[52] The recreation center "shall be designed and constructed to support safely the nominal loads in load combinations defined in 780 CMR without exceeding the appropriate specified allowable stresses for the materials of construction."[53] Snow, wind and earthquake loads are live loads that need to be taken into consideration. The values for Worcester, MA can be found in the MSBC Table 1604.10:

- Ground Snow Load: 55 psf
- Basic Wind Speed: 100 MPH
- Earthquake Design Factors: S_s - 0.24 S_1 – 0.067

Other live loads are due to the occupancy of the building and are shown in Table 3.1.

[51] http://www.aisc.org
[52] MSBC 1602.0 p. 379
[53] MSBC 1602.0 p. 379

Table 3.1: Minimum Live Loads from MSBC and ASCE 7

Occupancy	Uniform Load (PSF)	Concentrated (LB)
Corridors 1st floor	100	-
Corridor other than 1st floor	100	-
Corridors above 1st	80	2000
Elevator machine room	150	300
Gymnasium	100	-
Offices	50	2000
Lobbies 1st floor	100	-
Classroom	50	-
Stairs and Exits	100	-
Boiler Room	150	-
Fan Room	150	-
Restrooms	60	-

Sources: Massachusetts State Building Code, 2008
ASCE Minimum Design Loads for Buildings 7-95, 2000

Not all live loads can be found in the MSBC. These loads are supposed to be "determined in accordance with a method approved by the building official."[54] ASCE standards were used to fill in the blanks in Table 3.1 because the MSBC refers to ASCE 7 in many instances.

An example of the types of loads that are not included in ASCE 7 or the MSBC are green roof loads. The loads associated with green roofs are the weight of the soil and plant material. The weight of saturated plant modules ranges from 11-35+ psf. The soils used are typically 20–40% lighter than straight soil. These loads are in addition to the typical snow loads for Worcester, MA.

[54] MSBC-T-1607.2, p. 391

Several designs will be considered in the upcoming months where an analysis of stresses and loads will be completed. In addition to the basic structural design, foundations for both must be designed, along with retaining walls on the east, north and south sides of the building that will be underground.

3.1 Structural Design

Using the floor plans created by the group, design of the building will be completed with only slight alteration of these plans. If there is an area where it is structurally unfeasible to building, rooms may be rearranged to satisfy strength requirements. Identifying typical areas in this building will be difficult to do because the recreation center is not symmetrical.

For the structural design, ANSYS is the analysis software that will be used. For supporting manual calculations, there are two options: load and resistance factor design (LRFD) and allowable stress design (ASD). ASD compares actual and allowable stresses while LRFD compares required strength to actual strengths.[55] The group will need to decide which type of analysis will be performed where necessary for the steel design.

One of the first components to be analyzed is the flooring. The following types of concrete flooring will be designed for in our steel-framed building;

5. Concrete slabs supported with open-web steel joists
6. Concrete slab and steel beam composite floors
7. Steel-decking floors with concrete topping
8. Precast concrete slab floors

Concrete floor slabs are common for steel-frame buildings. They are strong and have excellent fire resistance and acoustic ratings. Fire resistance is important in steel buildings because although the steel is incombustible, the strength is greatly reduced when heated to the extreme temperatures in a fire. Also because steel conducts heat so well, it can spread heat to

[55] http://www.bgstructuralengineering.com/BGDesign/BGDesign05.htm

different sections of the building and setting adjacent materials ablaze. Fire protective covers include, concrete, gypsum, mineral fiber sprays, special paints and other materials.[56]

After floor sections, roof sections can be designed. As mentioned before, the gymnasium will be the main challenge. For long spans between columns, there are a few options; arches, trusses, rigid frames, box girders and built up I-girders. Truss members will be designed in this building to support the long spans. The key component that needs to be decided by the group is the type of truss. These trusses will have to be particularly strong because of the green roof live load that will only be over the gymnasium.

The types of connections in the building will have to be determined through analysis at which point bolted or welded connections will be chosen depending on the strength requirements. This decision will be important when the time comes because the different in cost of these two options can be great. Welded connections are relatively expensive requiring certified welders, while bolts can be installed by unskilled laborers.

The concrete type we plan on using for flooring and retaining walls is Portland Type II cement because it is the generic structural concrete that can be exposed to soil and ground waters where sulfate concentrations are higher than normal. The concrete slab design will be checked for two separate safety conditions; fire resistance rating and strength.

3.1.1 Foundation Design

The foundation of the building will be the last part to design because the weight distribution of the structure must be known to even begin this step. The foundation design depends not only on the weight of the structure but on the ground conditions and pressures. It must be designed to handle loads while limiting settlement, heave and lateral movement to tolerable levels.[57] The type of cement that will be used is Portland Type II for reasons specified above.

[56] *Structural Steel Design – 4th Edition, McCormac, 2008*, p.614
[57] MSBC 780 CMR 1801.0, p.429

Once the foundation is analyzed for vertical loads, horizontal and uplifting loads must be examined. A geotechnical report of the existing ground conditions may need to be obtained in order to determined whether or not the building will settle once constructed. If this report shows poor soil quality (composed of mostly clay, silt, sand or organic materials) this might warrant the use of piles or piers. Since the recreation center is to be built closely to other structures at WPI, there are sufficient geotechnical reports that will be used for the foundation design. However, this is only building at WPI that will be at the same elevation as the athletic fields, which have a high water table due to Salisbury Pond. This means the foundation will have greater lateral pressures due to water and soil than other WPI buildings. The foundation on the side facing the quadrangle (eastern side) will require the most resistance to lateral pressure because it will be approximately 30 feet underground. Borings and sampling will not be necessary until excavation because of the amount of earth that will be removed before the foundation in poured is so great the soil composition could easily change. Table 3.2 from the MSBC gives the allowable pressures for specific soil types that will be used for design.

Table 3.2: Allowable Bearing Pressures for Foundation Materials

Material Class	Description	Notes	Consistency in Place	Allowable Net Bearing Pressure (tons/ft^2)
1a	Massive bedrock: Granite, diorite gabbro, basalt, gneiss	3	Hard, sound rock, minor jointing	100
1b	Quartzite, well cemented conglomerate	3	Hard, sound rock moderate jointing	60
2	Foliated bedrock: slate, schist	3	Medium hard rock, minor jointing	40
3	Sedimentary bedrock: cementation shale, siltstone, sandstone, limestone, dolomite, conglomerate	3,4	Soft rock, moderate jointing	20
4	Weakly cemented sedimentary bedrock: compaction shale or other similar rock in sound condition	3	Very Soft Rock	10
5	Weathered bedrock: any of the above except shale	3,5	Very Soft rock, weathered and/or major jointing and fracturing	8
6	Slightly cemented sand and/or gravel, glacial till (basal or lodgment), hardpan	7,8	Very dense	10
7	Gravel, widely graded sand and gravel; and granular ablation till	6,7,8	Very dense Dense Medium dense Loose Very loose	8 6 4 2 Note 11
8	Sands and non-plastic silty sands with little or no gravel (except for Class 9 materials)	6,7,8,9	Dense Medium dense Loose Very loose	4 3 1 Note 11
9	Fine sand, silty fine sand, and non-plastic inorganic silt	6,7,9	Dense Medium dense Loose Very loose	3 2 1 Note 11
10	Inorganic sandy or silty clay, clayey sand, clayey silt, clay, or varved clay; low to high plasticity	5,6,10	Hard Stiff Medium Soft	4 2 1 Note 11
11	Organic soils: peat, organic silt, organic clay	11		Note 11

Source: Massachusetts Building Code, Table 1804.3, 2008

3.1.2 Retaining Wall Design

A retaining wall is required as part the overall building design. The east and south sides of the building will have floors underground. The east side first and second floors will be completely underground. It still needs to be determined how far underground the south side of the building will be based on the topographic information.

All sections of the building beneath ground level require a retaining wall. Not much has been researched on retaining walls in this term. In B term the group will become more learned on retaining walls and properly design them for the recreation center.

3.2 LEED Certification

We plan on designing the building so that it can receive a silver accreditation from a LEED certified professional. According to their current checklist, which can be seen in Appendix B, a building must have at least 33 points in order for it to be considered silver. The points are distributed into six different categories:

7. Sustainable sites - 14 points
8. Water efficiency - 5 points
9. Energy and atmosphere - 17 points
10. Materials and resources - 13 points
11. Indoor environmental quality - 15 points
12. Innovation and design process -5 points

Our plan is to obtain points from all the categories by focusing on using clean energy (i.e. solar power, wind turbine, etc.), recycling natural resources (rainwater harvesting) and materials used in construction in addition to using low-emitting materials (i.e. paints, carpets, adhesives/sealants, etc). By combining these aspects of the construction process, we will be able to obtain the 33 points necessary to receive silver.

3.2.1 Sustainable Sites

Our project will be able to obtain three points in the Sustainable Sites section of the LEED checklist for new construction. Two points will come from SS Credit 4: Alternative Transportation, SS Credit 4.1 Public Transportation and SS Credit 4.2 Bicycle Storage & Changing Rooms. The requirement needed for SS Credit 4.1 is to have either campus or public routes in place by the end of construction.[58] This credit will be easily obtainable because there are a couple of public bus routes located within walking distance of the WPI campus and we already have the Gateway Shuttle, which could transport students and faculty from Gateway to the new recreation center. SS Credit 4.2 will be challenging because we have to calculate the bicycle rack capacity based on the maximum transient (visitors of the facility for less than 7 hours) loading.[19] The showers and changing rooms, however, can be calculated by using the number of full-time employees of WPI who will be working in the new recreation center. The final point we will earn in this section is SS Credit 7.2 Heat Island Effect - Roof. The requirement needed for this credit is to have 75% of the roof area covered by a collection of high albedo (reflection of sunlight) and vegetation.[19] Having a vegetated roof can also help obtain points in the Indoor Environmental Quality section of the LEED checklist for new construction, which will be discussed later.

3.2.2 Water Efficiency

There are three different credit areas for water efficiency. WE Credit 1: Water Efficient Landscaping (2 points), WE Credit 2: Innovative Wastewater Technologies (1 point) and WE Credit 3: Water Use Reduction (2 points).[19] In order to achieve the two points awarded for Water Efficient Landscaping, we must provide documentation that supports our rainwater harvesting system, our landscape design and the extent of the supplemental temporary irrigation system.[19] A rainwater harvesting system can help decrease the use of public water and thusly help in reducing future costs for WPI. Rainfall on a 2,000 ft^2 roof can collect as much as 55,000 gallons per year.[59] The water recovered from a typical system can be used for several purposes including outdoor irrigation, cold water toilet flushing and clothes washing (those two

[58] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[59] http://www.rainwaterrecovery.com/harvesting.html

subjected to local ordinances). WE Credit 2: Innovative Wastewater Technologies, can be achieved if we come up with more effective uses of the rainwater harvesting techniques, as well as develop more economical waste treatment technologies which includes adding a high-efficiency filtration system. WE Credit 3 can be determined by calculating the amount of water used in a select few of the buildings fixtures including lavatories (public and private), showers (public and private) and faucets, but does not include water fountains or emergency showers. In order to determine the amount of water used on a typical day using a certain fixture (i.e. toilet) you must use the following calculation:

Public toilets = Total number of fixtures*Estimated daily usage*Flow rate(GPF)*Duration[60]

To achieve one point we must reduce the water use by at least 20% and to obtain both points we must reduce water use by at least 30%.

3.2.3 Energy and Atmosphere

There are six different credit areas in the Energy and Atmosphere section of the LEED checklist for new construction. EA Credit 1: Optimize Energy Performance, can achieve anywhere between 2 and 10 points depending on how well their energy performance is compared to a similar building without anything helping it optimize energy (between 14-42% better).[21] However, LEED has a prerequisite of minimum energy performance for all newly constructed buildings. One way we plan on optimizing energy is the use of solar panels to the roof of the building. There are many advantages to solar energy, but one major disadvantage is the cost of installation, which is mainly due to the high cost of semi-conducting materials used in producing a panel. In order to figure out how many watts of solar power needed for 100% solar energy, you must follow this equation:

100% Solar = [(Average Daily KWH usage) / (# of hours of full sunlight)] * 1.15

[60] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097

Each watt costs about $7 (if done by yourself) to $9 (if installed by a licensed professional), which includes the costs of semi-conducting materials.[61] The advantages of solar panels, however, are endless. One reason is that solar power is a renewable resource which cuts down on the emissions of greenhouse gases. Another reason is the money they will end up saving for WPI. There are governmental financial incentives if a consumer adds solar panels, the recovery period after the initial investment can be almost immediate depending on how much electricity is actually used and the energy produced thereafter is free. There are three types of solar technologies currently being developed by the U.S. Department of Energy: photovoltaic cells, concentrating solar power technologies and low temperature solar collectors.[62] These solar technologies are discussed later. Solar panels will also contribute to helping us earn points for EA Credit 2: On-Site Renewable Energy, which can give a maximum of three points depending on how much of the energy used in renewable (between 2.5% and 12.5%).[23] EA Credit 3: Enhanced Commissioning will be easily obtainable if Canon Design has an engineer who was not responsible for designing or managing the project come and serve as an "independent commissioning authority."[63] Finally, EA Credit 6: Green Power can be achieved if the managing company purchases Green Tags. However, the green power generated from solar panels will only be credited for EA Credit 2.[23]

Photovoltaic Cells and Low Temperature Solar Cells

Photovoltaic cells are used to generate electricity that can: pump water, charge batteries, supply power to a utility grid and much more.[64] The electricity developed by the photovoltaic cells will provide some of the lighting required for the building as well as provide the electricity needed for the pumping of water in sinks and water bubblers. The low temperature solar collectors are designed to harness the sun's energy, transform the radiation from the sun into heat which will then be transferred to water, solar fluid or air.[65] The heat provided by the solar collectors will be used to heat the water in the pool and the water used in sinks.

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[61] http://www.solar-electric.com/solar_system_costs.htm
[62] http://www.energy.gov/energysources/solar.htm
[63] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[64] http://www1.eere.energy.gov/solar/pv_use.html
[65] http://www.eere.energy.gov/solar/sh_basics_collectors.html

3.2.4 Materials and Resources

Materials and resources used have seven different credit areas with which to earn LEED points. MR Credits 4-7 can account for a maximum of six points. Credit 4: Recycled Content can be achieved by using recycled materials, 10% earns one point and 20% earns two points.[66] Credit 5: Regional Materials can be achieved if the materials used are extracted, processed and manufactured within our given region, 10% earns one point and 20% earns two points.[26] Credit 6: Rapidly Renewable Materials can be achieved by using materials as defined by LEED, which includes: concrete, masonry, earthwork and furnishings.[67] In order to achieve Credit 6, the cost of the rapidly renewable materials must be at least 2.5 % of the total cost of the materials.[68] Finally, Credit 7: Certified Wood can be achieved if the costs of the certified wood components used are at least 50% of the total new wood costs. A list of green materials to use for the recreation center can be found at www.BuildingGreen.com.

3.2.5 Indoor Environment Quality

There are 8 different credit areas that contribute to LEED points. EQ Credit 1: Carbon Dioxide (CO_2) Monitoring can be achieved by installing a permanent CO_2 monitoring system which monitors a mechanically ventilated system or a naturally ventilated system that is designed to maintain minimum ventilation requirements.[29] Credit 4: Low-Emitting Materials has four points that are easily obtainable by using any of the products that are LEED certified. The materials included in the LEED checklist include adhesives and sealants, paints and coatings, carpet systems and composite wood and agrifiber products. These are the products we plan on using in our building to help us obtain the maximum four points.

Flooring

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[66] http://www.usgbc.org/ShowFile.aspx?DocumentID=3998

[67] http://www.buildinggreen.com/auth/productsByLeed.cfm?LEEDCreditID=28

[68] USGBC LEED Sample Credit Template NCv2.2

For the weight room, aerobic room, locker rooms, trainer's room and the offices, we plan on specifying on using Prime Sports Flooring provided by Flexco Flooring. Using this flooring system, we will be able to receive a point for a low-emitting material.

Adhesives

For the sealant and adhesives, we will use products from Bostik. Bostik sells adhesive products used for concrete and for windows. Since the new fitness and aerobics rooms will be located in the circular section on the northern side of the building will be glass curtain-wall, we will use the sealant to help relieve heating costs.

Paint

We are going to use eco-friendly paint supplies from local distributors like Sherwin-Williams. Their green products are extremely advantageous in assisting in LEED certifications which alone can help obtain three points: low emitting material (1 point), and design and verification of thermal comfort (2 points).[69]

Wood

Finally the composite wood we will use for furniture will come from the company SierraPine. Their products can attain up to six accreditation points including two for using recycled content, two for using regional materials, one for being certified wood and one for not using formaldehyde.[70]

Credit 6: Controllability of Systems can achieve two points, one for lighting and one for thermal comfort. In order to achieve the point for lighting we must design a control system that can provide comfort control for at least 50% of the occupants.[71]

Credit 7: Thermal Comfort can also achieve two points, one for design and one for verification. In order to obtain EQ Credit 7.1 (thermal comfort design), we must provide an explanation of

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[69] http://www.sherwin-williams.com/pro/green/index.jsp
[70] http://www.sierrapine.com/index.php?pid=20
[71] USGBC LEED Sample Credit Template NCv2.2

how the thermal comfort system will achieve the design criteria, which includes minimum and maximum indoor space as well as the maximum indoor space humidity for all four seasons.[32] To acquire the second point for thermal comfort, we must install a permanent monitoring system that will validate the thermal comfort conditions of the project.[72] One way in which we can achieve this thermal comfort is by using LEED certified building insulations as well as using Sherwin-Williams' E-barrier™. This product has low emissivity rating which reflects the sun's radiant energy during the summer keeping temperatures lower and contains the radiant energy in the building during the winter keeping it warm.[73]

EQ Credit 8 Daylight & Views has two points that can be achieved. The first point can be procured if 75% of the total space has sunlight. This can be calculated using one of three options: glazing factor calculation, computer simulation and daylight measurements.[34] The second point we can obtain from EQ Credit 8 is if 90% of the regularly occupied space has views to the outside.[34] We plan on obtaining this point by using glass curtain walls for most of the building to allow for outside views towards the current football and future soccer fields. Calculations are to be completed using the supporting calculator on the LEED site for new construction.

3.2.6 Innovation in Design Process

Innovation in Design has two areas that can account for points. ID Credit 1 contains a maximum of four points (one point each) which can only be accrued if we come up with our own innovative credit which must include a title, a statement of credit intent, a statement describing credit requirements and a statement that describes the approach to the credit.[29] The other area where the building can gain a point is having the project signed off by a LEED accredited professional.

[72] http://www.usgbc.org/ShowFile.aspx?DocumentID=1097
[73] http://www.sherwin-williams.com/pdf/products/ebarrier.pdf

Appendix B: Sample Calculations

Beam Design

Length – 20 ft
Tributary Width – 12 ft
Slab Thickness – 4 in

Load Combinations
Dead Load – 65 psf ; Live Load – 100 psf (Corridor)

$$2.\ U = 1.2D + 1.6L + 0.5S$$

$$U \cdot Trib.Width = \omega$$

$$\omega = 2856 \text{ Lb/FT}$$

Flexure Design

$$Max.Moment\ (M_u) = \frac{\omega \cdot L^2}{8} = 142{,}800\ FT \cdot Lbs$$

Select W Section AISC Table 3-2

Choose: W14x38; φ M_n = 231 FT-Kips
Recalculate max. Moment including the beam weight:

$$142{,}800\ FT \cdot Lbs + \frac{(1.2 \cdot 38\ Lb/FT) \cdot 20\ ft^2}{8} = 145{,}080\ FT \cdot Lbs$$

$$M_u < \varphi M_n \quad \textbf{OK CHECKS}$$

Composite Section Design
Locate the position of the neutral axis (a)

$$a = \frac{A_s \cdot F_y}{0.85 \cdot f'_c \cdot b_e} = 1.19\ in.$$

$$a < t$$

$$\therefore PNA\ is\ in\ the\ slab$$

$$\varphi M_n = \varphi M_p = \varphi \cdot A_s \cdot F_y \cdot \left(\frac{d}{2} + t - \frac{a}{2}\right) = 271{,}020\ FT \cdot Lbs$$

$$Revised\ \varphi M_n > M_u \quad \textbf{OK CHECKS}$$

Shear Design

$$Max.Shear\ (V_u) = \frac{\omega \cdot L}{2} = 28.56\ Kips$$

$$A_w = d \cdot t_w = 2.82\ in^2$$

$$\varphi V_n = 0.6 \cdot F_y \cdot C_v \cdot A_w = 84.65\ Kips$$

$$\varphi V_n > V_u \quad \textbf{OK CHECKS}$$

Deflection Check

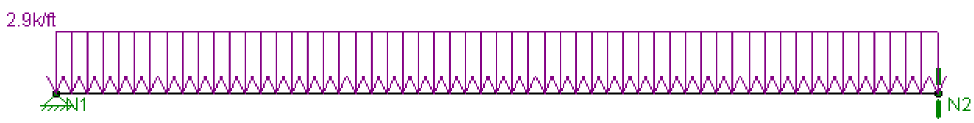
$$Max.Deflection = \frac{L}{240} = 1\ in$$

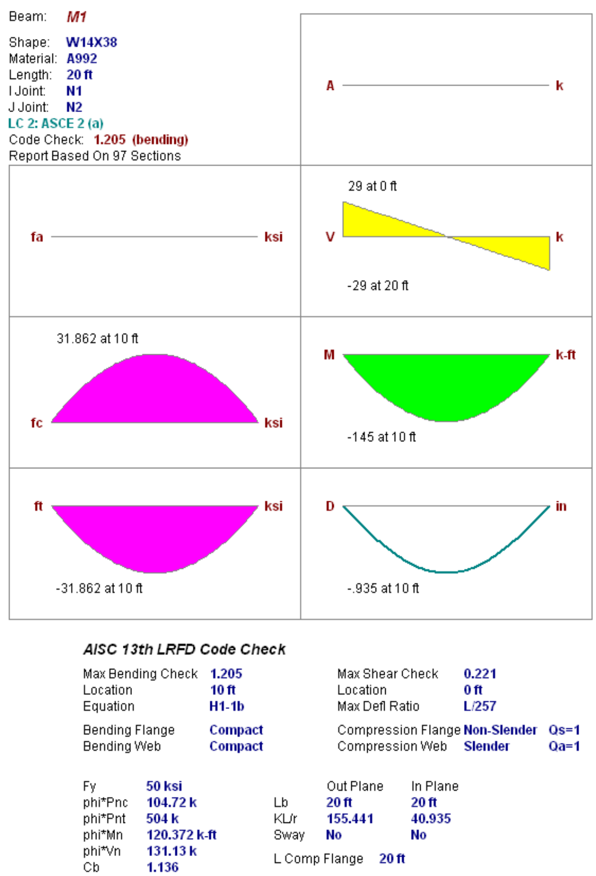
$$Actual\ Deflection = \frac{5 \cdot \omega \cdot L^4}{384 \cdot E \cdot I} = 0.94\ in$$

$0.936\ in < 1.0\ in$ **OK CHECKS**

USE W14x38

Check with RISA 2D





Column Design (LRFD)

Length – 13 ft
Tributary Area – 75 ft^2
F_y = 50 ksi

Load Combinations

Dead Load – 300 psf ; Live Load – 450 psf

$$P_D = 130{,}00\ lb$$

$$P_L = 210{,}000\ lb$$

$$2.\ \ U = 1.2D + 1.6L + 0.5S = 492\ kips$$

$$P_u = 492\ kips$$

Slenderness Ratio

$$Assume\ \frac{K\ L}{r} = 50$$

$$\therefore\ \varphi_c F_{cr} = 37.5\ ksi\ (T4 - 22)$$

Design of Axial Member

$$A\ Req'd = \frac{P_u}{\varphi_c F_{cr}} = 13.12\ in^2$$

Try W14 X 53: A = 15.6 in^2, r_y = 1.92 in

$$\frac{K \cdot L}{r_y} = 67.71$$

Find new $\varphi_c F_{cr}$ from Table.4-22

$$\varphi_c F_{cr} = 32.4\ for\ \frac{KL}{r} = 67$$

$$\varphi_c F_{cr} = 32.1\ for\ \frac{KL}{r} = 68$$

Interpolate between the two values.

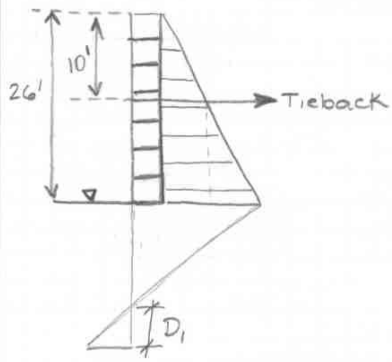
$$\varphi_c F_{cr} = 32.25\ ksi$$

New $\varphi_c F_{cr}$

$$\varphi_c \cdot P_n = \varphi_c F_{cr} \cdot A_g = 32.25 \cdot 15.6 = 503.1\ k\ \ \boldsymbol{OK}$$

Use W14 X 53

Calculations for Sheet Pile Walls and Tieback Anchors



$\sigma_{10} = (.5)(109)(10) = \underline{545\ psf}$
K γ L

$\sigma_{26} = (.5)(109)(26) = \underline{1417\ psf}$

@ z > 26:
$\sigma_{>26} = (109 - 62.4)(1.59 - .419) =$
$= \underline{54.6\ pcf}$

$\underline{\sigma = 0 \text{ @ } z = 26 + \frac{1417}{54.6} = 52'}$

$\tan^2(45 - \phi/2) = K_a$
$\tan^2(45 + \phi/2) = K_p$

Coefficient of friction:
$\tan \phi = 0.45$
$\phi = 24.2°$

Uniform surcharge load:
$\sigma = Kq$ $K = 0.5$
$q = 617$

$\underline{\sigma = 308.5\ plf}$

$K_a = \tan^2(45 - \frac{24.2}{2}) = 0.419$

$K_p/F = \tan^2(45 + \frac{24.2}{2})/1.5 = 1.59$

$$\Sigma M_{TB} = [(308.5)(10)(5)] + [(\tfrac{1}{2})(10)(545)(\tfrac{10}{3})] - [(853.5)(16)(8)] - [(\tfrac{1}{2})(16)(1417 - 853.5)(\tfrac{32}{3})] - [(\tfrac{1}{2})(1725.5)(26)(16 + \tfrac{26}{3})] + [(\tfrac{1}{2})(54.6)(D_1^2)(42 + \tfrac{D_1}{3})] = 0$$

$$0 = 15425 + 9083.3 - 109248 - 48085.3 - 553310.3 + 1146.6 D_1^2 + 9.1 D_1^3$$

$$0 = 9.1 D_1^3 + 1146.6 D_1^2 - 686135.3$$

$D_1 = 22.6'$ use $24'$

Use 50' long sheet pile with 24' embedment depth.

$\Sigma F_x = (\frac{1}{2})(10)(545) + (308.5)(10) + (853.5)(16) + (\frac{1}{2})(16)(563.5) + (\frac{1}{2})(1725.5)(26)$

$- (\frac{1}{2})(54.5)(22.6)^2 - P_{TB} = 0$

$2725 + 3085 + 13656 + 4508 + 22431.5 - 13918.21 = P_{TB}$

$P_{TB} = 32,488$ plf

If tie-backs are 5' O/C, load per anchor:

$(32488)(5) = 162,440$ lb/anchor

@ $z = 26'$ $V/b = 2725 + 3085 + 13656 + 4508 - 32488 = -8514$ plf

$V/b = 0$ @ depth z:

$(z-26)(1725.5) + (.5)(z-16)^2(109-62.4)(0.419) = 8514$

$1725.5z - 44863 + (.5)(z^2 - 32z + 256)(46.6)(.419) = 8514$

$1725.5z - 44863 + 9.76z^2 - 312z + 2498.56 = 8514$

$9.76z^2 + 1413.5z - 50878.44$

$$\frac{-1413.5 \pm \sqrt{(1413.5)^2 - (4)(9.76)(-50878.44)}}{2(9.76)}$$

$z = 30'$

@ $z = 30'$

$M/b = (2725)(30 - 6.67) + (3085)(30-5) + (13656)(30-10-8) - (32488)(30-10)$

$+ (4508)(30 - 10 - (\frac{2}{3} \times 16)) + (4)(54.6)(2) + (\frac{1}{2})(2)(54.6)(2.67)(109-62.4)(.419)$

$= 63,574.25 + 77125 + 163872 - 649760 + 42074.7 + 436.8 + 22772$

$M/b = -279,905.25$ use $279,906$ ft·lb/ft

Calculations for Sheet Pile Walls and Tieback Anchors

Try AZ 26 Sections, but see if we can use a smaller section:

$$I/b = (55{,}510\ cm^4/m)\left(\frac{1\ in}{2.54\ cm}\right)^4\left(\frac{1\ m}{3.281\ ft}\right) = 406.5\ in^4/ft$$

$$\log \frac{(26+24)^4}{(29{,}000{,}000)(406.5)} = -3.3 \quad \text{Per fig. 25.11: } m/m_{max} = 0.8$$

$$M/b = 0.8\ (227{,}417) = \underline{181{,}934\ ft\cdot lb/ft}$$

Able to use AZ 48 sections, but we must recalculate:

$$I/b = (115{,}670\ cm^4/m)\left(\frac{1\ in}{2.54\ cm}\right)^4\left(\frac{1\ m}{3.281\ ft}\right) = 847\ in^4/ft$$

$$\log \frac{(26+24)^4}{(29{,}000{,}000)(847)} = -3.6 \quad \text{Per fig. 25.11: } \underline{m/max = 0.8}$$

↳ same as above

Therefore, we should use AZ48 sections with ASTM A328 steel.

Appendix C: Summary of LEED Prerequisites and Credits for On-Campus Construction

Sustainable Sites	14 Possible Points	Rec. Center Target
Prerequisite 1: Erosion and Sedimentation Control	Required	X
Credit 1: Site Selection	1	1
Credit 2: Urban Redevelopment	1	
Credit 3: Brownfield Redevelopment	1	
Credit 4: Alternative Transportation	4	
Credit 5: Reduced Site Disturbance	2	
Credit 6: Stormwater Management	2	2
Credit 7: Reduced Heat Island Effect	2	2
Credit 8: Light Pollution Reduction	1	1
Water Efficiency	**5 Possible Points**	
Credit 1: Water Efficient Landscaping	2	2
Credit 2: Innovative Wastewater Technologies	1	1
Credit 3: Water Use Reduction	2	1
Energy and Atmosphere	**17 Possible Points**	
Prerequisite 1: Fundamental Building Systems Commissioning	Required	X
Prerequisite 2: Minimum Energy Performance	Required	X
Prerequisite 3: CFC Reduction in HVAC&R Equipment	Required	X
Credit 1: Optimize Energy Performance	10	1
Credit 2: Renewable Energy	3	1
Credit 3: Additional Commissioning	1	
Credit 4: Ozone Protection	1	
Credit 5: Measurement and Verification	1	
Credit 6: Green Power	1	1

Materials and Resources	**13 Possible Points**	
Prerequisite: Storage and Collection of Recyclables	Required	X
Credit 1: Building Reuse	3	
Credit 2: Construction Waste Management	2	2
Credit 3: Resource Reuse	2	2
Credit 4: Recycled Content	2	2
Credit 5: Local/Regional Materials	2	2
Credit 6: Rapidly Renewable Materials	1	1
Credit 7: Certified Wood	1	1
Indoor Environmental Quality	**15 Possible Points**	
Prerequisite 1: Minimum IAQ Performance	Required	X
Prerequisite 2: Environmental Tobacco Smoke (ETS) Control	Required	X
Credit 1: Carbon Dioxide (CO2) Monitoring	1	1
Credit 2: Ventilation Efficiency	1	1
Credit 3: Construction IAQ Management Plan	2	
Credit 4: Low-Emitting Materials	4	2
Credit 5: Indoor Chemical and Pollutant Source Control l	1	
Credit 6: Controllability of Systems	2	
Credit 7: Thermal Comfort	2	2
Credit 8: Day lighting and Views	2	2
Innovation and Accredited Professional Points	**5 Possible Points**	
Credit 1: Innovations in Design	4	
Credit 2: LEED Existing Building Accredited Professional	1	
TOTAL POINTS AVAILABLE	**69**	31

Appendix D: Room Data Sheet Summary

Table A-2: Basic Room Descriptions

Zone	Room Name	Room ID	Room Size (ft^2)
Public Area	Lobby	1.1	4,700
Public Area	Hall of Fame	1.2	500
Public Area	Reception Desk	1.3	450
Public Area	Vending Area	1.4	100
Public Area	Lounge	1.5	1,250
Public Area	Public Restrooms	1.6	2x300
Activity Spaces	4 Court Gymnasium	2.1	29,000
Activity Spaces	Jogging Track	2.2	8,400
Activity Spaces	Gym Storage	2.3	4x600
Activity Spaces	Fitness Center	2.4	10,000
Activity Spaces	Fitness Center Storage	2.5	300
Activity Spaces	Free Weights	2.6	5,000
Activity Spaces	Free Weights Storage	2.7	300
Activity Spaces	Group Exercise/Multipurpose	2.8	3x1,200
Activity Spaces	Group Exercise/Multipurpose Storage	2.9	400
Activity Spaces	Classroom	2.1	2x600
Activity Spaces	Classroom Storage	2.11	2x200
Activity Spaces	Racquetball/ Squash	2.12	3x840
Activity Spaces	Climbing Wall	2.13	1,200
Activity Spaces	Natatorium	2.14	19,100
Activity Spaces	Natatorium Storage	2.15	600
Activity Spaces	Pump Room/Pool Filtration	2.16	1,000
Activity Spaces	Natatorium Spectator Seating	2.17	2,800
Activity Spaces	Meet management/ lifeguard	2.18	120
Activity Spaces	Indoor Rowing Tank	2.19	2,000
Training & Rehabilitation	Office	3.1	2x180
Training & Rehabilitation	Exam Room	3.2	150
Training & Rehabilitation	Secure Storage	3.3	80
Training & Rehabilitation	Bulk Storage	3.4	250

Table A-2 Basic Room Descriptions Cont.

Training & Rehabilitation	Taping/Treatment/Rehabilitation	3.5	3,000
Training & Rehabilitation	Hydrotherapy	3.6	180
Training & Rehabilitation	Ice Machine	3.7	100
Training & Rehabilitation	Rest Room	3.8	80
Administration/Coaches	Reception/Secretarial	4.1	300
Administration/Coaches	Athletic Director	4.2	200
Administration/Coaches	Athletic Director Assistants	4.3	3x150
Administration/Coaches	Offices	4.4	18x150, 1x200
Administration/Coaches	Workroom	4.5	1x600, 1x450
Administration/Coaches	Video Editing Room	4.6	200
Administration/Coaches	Storage	4.7	150
Administration/Coaches	Secure Storage	4.8	100
Administration/Coaches	Rest Rooms	4.9	150
Support Spaces	Men's General/Pool Locker	5.1	1,000
Support Spaces	Woman's General/Pool Locker	5.2	1,000
Support Spaces	Storage & Collection	5.3	225
Support Spaces	Loading	5.4	400
			Total = 110,510 SF

Appendix E: City of Worcester Building Permit Application

Building & Zoning Approval Form

APPLICATION INFORMATION

ADDRESS ____

PROPOSED USE: ____

☐ EXISTING USE ☑ NEW USE ☐ CHANGE IN USE

STAMPED PLOT PLAN ATTACHED ☑ YES ☐ NO

DATE OF PLANNING BOARD APPROVAL _____ / _____ / ______

APPROVAL FORM ATTACHED? ☐ YES ☐ NO ☐ N/A

DATE OF ZONING BOARD APPROVAL _____ / ____ / ______

RECORDED APPROVAL FORM ATTACHED ☐ YES ☐ NO ☐ N/A

COPY OF PARKING LOT LICENSE PROVIDED ☐ YES ☐ NO ☐ N/A

PROPOSED OCCUPANCY RATING _________________PERSONS

SUBMITTED BY WPI________________ (Property Owner or Legal Representative)

OFFICE USE ONLY

ZONE ________
USE COMPLIANCE ☐ YES ☐ SPECIAL PERMIT ☐ PRE-EXISTING
SETBACK COMPLIANCE ☐ YES ☐ VARIANCE
PARKING COMPLIANCE ☐ YES ☐ VARIANCE ☐ SPECIAL PERMIT
APPROVED OCCUPANCY ________________ PERSONS
HISTORIC DEMOLITION COMPLIANCE ☐ YES ☐ NO ☐ N/A
FLOOD PLAIN COMPLIANCE ☐ YES ☐ N/A

APPROVED BY ______________________ DATE ____ / _____ / _____

The Commonwealth of Massachusetts

State Board of Building Regulations and Standards
Massachusetts State Building Code
780 CMR

City of Worcester

Application for a Building Permit

Address ______________________________

Application Entered By: ____________________ Application Date: ____________________

Plan Reviewed By: ____________________ Date: ____________________

Signature: ____________________ Date Issued: ____________________

Zone: ______________ **Proposed Use:** ____________________ **Census Tract:** ________

Lot Area:__________square feet **Frontage:**______________ Zoning Review: ______________ Zoning Officer

Front yard set back:________feet
Rear yard set back:________feet **Site Plan Approval:**________________
Side yard set back: ______feet **Parking Approval:**________________
Side yard set back: ______feet **ZBA Approval:**________________

Public Water: ______________ **Flood Zone:** ______________ **Sewer:** ______________

Owner of Record:____________________ **Phone Number:** ____________________
Address:____________________ **Cell Number:** ____________________
____________________ **Signature:**____________________

Engineer: ____________________ **Phone #:**______________ **Cell #:**______________
Architect: ____________________ **License Number:**____________________
Address:____________________
____________________ **Signature:**____________________

Licensed Construction Supervisor: **Phone #:**______________ **Cell#:**______________
____________________ **License Number:** ____________________
Address: ____________________
____________________ **Signature:**____________________

Home Improvement Contractor: **Phone #:**______________ **Cell#:**______________
____________________ **License Number:**____________________
Address: ____________________
____________________ **Signature:**____________________

City of Worcester

Page Two — Building Permit Application

Worker's Compensation Insurance Affidavit Submitted: ______________

Description of PROPOSED Work:____

____

____

Construction Type:______________ Floor Area: __________ square feet

Number of Stories: ______________ Use Group:____________

Office Use ONLY:

New Construction:________ Existing Building:__________ Alteration:________ Addition:____________

Repairs:______________ Accessory Bldg: __________ Demolition:________ Other:____________

Building Permit Fee: By Office Permanent Record Retention Fee: By Office Sprinkler Fee: By Office

Other Fee: By Office

Estimated Construction Cost: $________.00 Total Fee: $__________ Fee Received: ___/___/___

Received By:____________

Owner Authorization:

I, ________________________, as owner of the subject property hereby authorize

________________________, to act on my behalf in all matters relative to work authorized by this building permit.

____________________________________ ___/___/___

Signature of Owner — Date

***Owner/Authorized Agent Declaration*:**

I, ________________________ as Owner / Authorized Agent hereby declare that the statements and information on the foregoing application are true and accurate, to the best of my knowledge and belief.

Signed under the pains and penalties of perjury.

____

Print Name

____________________________________ ___/___/___

Signature of Owner / Authorized Agent — *Date*

Building Permit Number ____________

Street Address: ____

Do you intend to do interior work only? Yes: _______ No: _______

If Yes, you do not need to answer any of the questions below.

If No, please answer questions below.

****

If work includes exterior building activity and/or site work, please answer all the following questions.

1. Will any activity take place within 100 feet of a pond, lake, brook, stream, marsh or swamp? YES: _____ NO: _____
2. Does this property fill up with water after a rainstorm and hold it for a while? YES: _____ NO: _____
3. Will any activity take place within 100 feet of a storm drain component (catch basin, etc)? YES: _____ NO: _____
4. Is the property within a flood plain designated under the National Flood Insurance Program? YES: _____ NO: _____
5. Is this property steeply sloped? YES: _____ NO: _____
   (over 15% slope - pre or post construction)
   a. If no, will activity alter at least 10,000 square feet of land? YES: _____ NO: _____
   b. If yes, will activity alter at least 5,000 square feet of land? YES: _____ NO: _____

____

Signature

__________________________ __________________

Print Name — Telephone Number

IF YOU ANSWERED YES TO ANY OF THE ABOVE QUESTIONS, YOU MAY NEED APPROVAL FROM THE WORCESTER PLANNING BOARD OR CONSERVATION COMMISSION BEFORE YOU START WORK.

This is not a legal determination. If you have any doubts or questions, it is your responsibility to notify the office of Division of Land Use.

- -

For additional information regarding Local Wetlands Protection Ordinance and the Massachusetts Wetlands Protection act contact:

Department of Public Works
Engineering Division
20 East Worcester Street
Worcester, MA 01604
(508) 799-1454

Department of Inspectional Services
Worcester, Massachusetts

Building Unit

Joseph R. Mikielian
Commissioner

John R. Kelly
Acting Building Commissioner

Amanda M. Wilson, Director
Housing/Health Inspections

Building Permit # _______ 20___ will be issued subject to compliance with the requirements of the Commonwealth of Massachusetts State Building Code and the City of Worcester Zoning Ordinance.

Section 114.9 Posting of Permits:

A copy of the building permit provided by the Code Enforcement Division shall be kept in view and protected from the weather on the site of operations, open to public inspection during the entire time of prosecution of the work and until the certificate of occupancy shall have been issued. The building permit shall serve as an inspection record card to allow the building official conveniently to make entries thereon regarding inspection of the work.

Section 114.10 Notice of Start:

At lease twenty-four (24) hours notice of start of work under a building permit shall be given to the building official.

READ BEFORE SIGNING

Signature: ____

Print Name: ____

Address & Zip Code: ____

Telephone: ____

25 Meade Street, Worcester, MA 01610-2715 Phone: (508) 799-1198 Fax: (508) 799-8544 E-mail: inspections@ci.worcester.ma.us

Department of Inspectional Services
Worcester, Massachusetts

Building Unit

Joseph R. Mikielian
Commissioner

John R. Kelly
Acting Building Commissioner

Amanda M. Wilson, Director
Housing/Health Inspections

AFFIDAVIT

In accordance with Article 1 Section 111.5 of the Massachusetts State Building Code, I certify that all debris resulting from work associated with Building Permit # ______________
at property ____
Will be properly disposed of at:

____ ,
A licensed solid waste disposal facility as defined by MGL C 111 & 150 A.

____________________ Date

____________________ Signature of Permit Applicant

____________________ Print Name of Applicant

____________________ Firm Name (if any)

____________________ Address

The Code Enforcement Division acting under Chapter 8, Article 7 of the 1996 Worcester Revised Ordinances requires proof of disposal of debris generated as a result of this permit. The proof shall be a dated and signed receipt from the licensed disposal facility containing the following information:

A description of the debris, the weight and volume of the debris and the location of the disposal facility. The receipt must also have a signature of the owner/operator of the disposal facility.

Failure to comply with requirements of this ordinance will result in enforcement action by the City of Worcester.

25 Meade Street, Worcester, MA 01610-2715 Phone: (508) 799-1198 Fax: (508) 799-8544 E-mail: inspections@ci.worcester.ma.us

CONSTRUCTION CONTROL

PROJECT NUMBER: ____

PROJECT TITLE: ____

PROJECT LOCATION: ____

NAME OF BUILDING: ____

NATURE OF PROJECT: ____

In accordance with section 116.0 of the Massachusetts State Building Code, I,
______________________________ Registration No.________________________

Being a Registered Professional Engineer/Architect hereby certify that I have prepared or directly supervised the preparation of all design plans, computations and specification concerning:

___ENTIRE PROJECT ___ARCHITECTURAL ___STRUCTURAL

___MECHANICAL ___FIRE PROTECTION ___ELECTRICAL

___OTHER (SPECIFY)

For the above named project and that to the best of my knowledge, such plans, computations and specifications meet the provisions of the Massachusetts State Building Code, all acceptable engineering practices and all applicable laws and ordinances for the proposed use and occupancy. I further certify that I shall perform the necessary professional services and be present on the construction site on a regular periodic basis to determine that the work is proceeding in accordance with the documents approved for the building permit and shall be responsible for the following specified in Section 780 CMR 116.0, 6th edition of the Massachusetts State Building Code.

SEAL

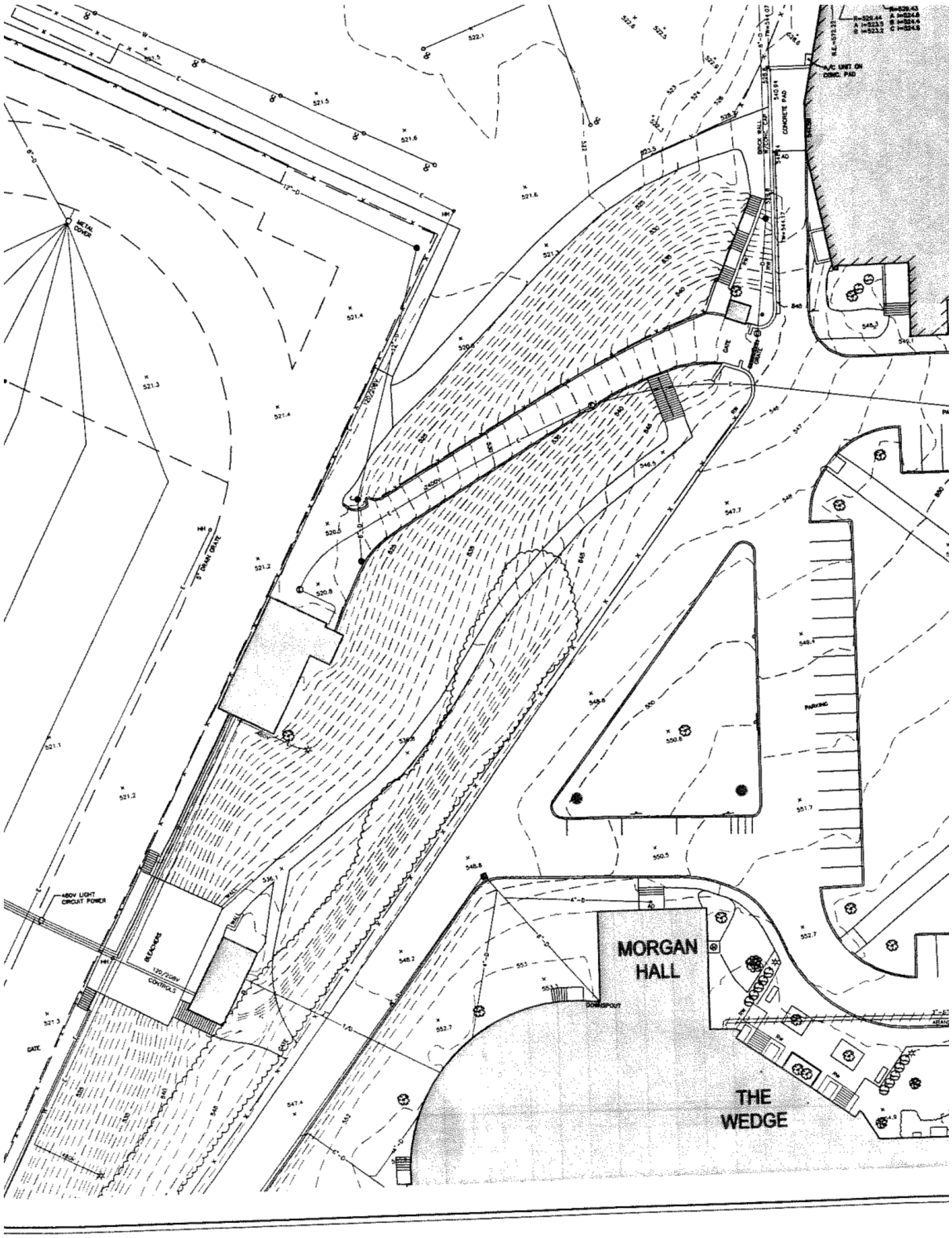
____
SIGNATURE

Subscribed and sworn to before me this _____ day of _______________2___

Notary public ______________________________

My Commission expires_______________

Appendix F: Topographical Map of Recreation Center Site



Appendix G: Floor Plan Room List

Zone	Room Name	Room ID	Floor
Public Area	Lobby	1.1	3
Public Area	Hall of Fame	1.2	3
Public Area	Reception Desk	1.3	3
Public Area	Vending Area	1.4	1,2,3,4
Public Area	Lounge	1.5	3
Public Area	Public Restrooms	1.6	1,2,3,4
Activity Spaces	4 Court Gymnasium	2.1	3
Activity Spaces	1/8 Mile Jogging Track	2.2	4
Activity Spaces	Gym Storage	2.3	1,2,3
Activity Spaces	Fitness Center	2.4	2
Activity Spaces	Fitness Center Storage	2.5	2
Activity Spaces	Free Weights	2.6	1
Activity Spaces	Free Weights Storage	2.7	1
Activity Spaces	Group Exercise/Multipurpose	2.8	3
Activity Spaces	Group Exercise/Multipurpose Storage	2.9	3
Activity Spaces	Classroom	2.a1	4
Activity Spaces	Classroom Storage	2.a2	4
Activity Spaces	Racquetball	2.a3	2
Activity Spaces	Squash	2.a4	2
Activity Spaces	Climbing Wall	2.a5	2
Activity Spaces	Natatorium	2.a6	1
Activity Spaces	Natatorium Storage	2.a7	1
Activity Spaces	Pump Room/Pool Filtration	2.a8	1
Activity Spaces	Natatorium Spectator Seating	2.a9	1
Activity Spaces	Meet Management/Lifeguard	2.b1	1
Activity Spaces	Indoor Rowing Tank	2.b2	1
Training & Rehabilitation	Office	3.1	1
Training & Rehabilitation	Exam Room	3.2	1
Training & Rehabilitation	Secure Storage	3.3	1
Training & Rehabilitation	Bulk Storage	3.4	1
Training & Rehabilitation	Taping/Treatment/Rehabilitation	3.5	1

Training & Rehabilitation	Hydrotherapy	3.6	1
Training & Rehabilitation	Ice Machine	3.7	1
Training & Rehabilitation	Rest Room	3.8	1
Administration/Coaches	Reception/Secretarial	4.1	4
Administration/Coaches	Athletic Director	4.2	4
Administration/Coaches	Athletic Director Assistants	4.3	4
Administration/Coaches	Smaller Offices	4.4	4
Administration/Coaches	Bigger Office	4.5	4
Administration/Coaches	Bigger Workroom	4.6	4
Administration/Coaches	Smaller Workroom	4.7	4
Administration/Coaches	Video Editing Room	4.8	4
Administration/Coaches	Storage	4.9	4
Administration/Coaches	Secure Storage	4.a1	4
Administration/Coaches	Rest Rooms	4.a2	4
Support Spaces	Men's General/Pool Locker	5.1	1,3
Support Spaces	Women's General/Pool Locker	5.2	1,3
Support Spaces	Storage And Collection	5.3	3
Support Spaces	Loading	5.4	3
Support Spaces	Boiler Room	5.5	1
Population Movement	Elevator	6.1	1,2,3,4
Population Movement	Elevator Mechanical Room	6.2	1,2,3,4
Population Movement	Elevator Shaft	6.3	1,2,3,4
Population Movement	Stairway	6.4	1,2,3,4
Safety	Fire Escape	7.1	1,2,3,4
Food & Shops	Little Concession Stand	8.1	2
Food & Shops	Big Concession Stand	8.2	2
Food & Shops	Athletic Shop	8.3	2
Food & Shops	Juice Bar	8.4	3
Seating	Bench	9.1	1,2,3,4
Seating	Table	9.2	1,2,3,4