

New WPI Sports & Recreation Center III: Construction Management and Constructability Analysis

A Major Qualifying Project

Submitted to the faculty of Worcester Polytechnic Institute

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Abstract

This project presents an alternative design to the earth-retaining structure to support lateral loading during construction of the foundation of the Worcester Polytechnic Institute new Sports and Recreation Center. The design was chosen based on soil profiles representing the earth surrounding the existing soil nail wall. Through the use of Building Information Modeling (BIM), we created a 3D model of the site to represent the existing conditions, mass excavation and total backfill of the different volumes of earth.

Acknowledgements

Our Major Qualifying Project team would like to thank all of the individuals that contributed to us during the duration of our project. Our team would especially like to thank our advisors, Professor Guillermo Salazar and Professor Mingjiang Tao for their help and guidance to completing the project. Our team would also like to thank the Gilbane team that was working on the WPI Sports & Recreation Center project, including Neil Benner, Melissa Hinton and Justin Gonsalves, for providing us with valuable information, including the architect's drawings, soil reports and production reports, and allowing us to attend owner meetings. Our team extends our gratitude to Menglin Wang for her knowledge and support regarding the BIM software used throughout the project. Lastly, we thank Sean O'Connor and the rest of the staff from WPI Network Operations for their assistance and guidance when touring the site.

Authorship Page

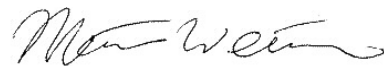
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Capstone Design Experiment Statement

The capstone design requirement of this Major Qualifying Project was met by developing an alternative design for the earth retaining structure of Worcester Polytechnic Institute's New Sports and Recreation Center located next to Morgan Hall's foundation. This retaining structure provides load carrying capabilities during the construction of the project and provides safety for workers from soil caving into the work site. The earth retaining structure that was used to support the excavation was a Soil Nail wall. This type of practice is common in the construction industry for projects where large retaining structures are necessary.

The design alternative for the earth retaining structure involved the investigation of advantages and disadvantages of different types of retaining structures. . The group also explored the load carrying capabilities of the different options for design of the wall. A soil profile analysis further followed concerning implementation times and effects on any surroundings such as other buildings and the environment to further investigate the design options of the retaining structures.

Along with this information the group collected expert advice from the designer of the current earth retaining structure and insight from observations of meetings between the contractors, project managers, and owners. From this we were able to determine best practices and techniques used in construction to help formulate the best and most realistic options for an alternative earth retaining structure. This strategy included exploring the constructability of different earth retaining structure designs; this enabled us to identify any unforeseen problems before the actual construction takes place.

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1. Introduction

Construction is an imperative part of our lives in society. Residential housing, commercial buildings and other infrastructure that surround us are all evidence of works that have undergone a form of construction. The work may be a new building, a renovation of an older building or the restoration of a historical site, but they all involve the same basic components found throughout the construction industry. There is a need for coordinated multitasking within all construction projects, especially those of a larger scale. A successful project will be completed through multiple phases that will overlap in order to minimize the total time it takes to complete the construction. Owners, designers, engineers, managers and general contractors must all coordinate their efforts with each other in order to complete a project on time and within approved costs.

A project in the construction industry is a temporary endeavor undertaken by a group of individuals and organizations in order to meet an owner's objectives and provide a well-constructed finished product. Each project requires project management in order to organize and plan the development of the project. With each new project come new ideas, unforeseen conditions and possible troubles. The purpose of project management is to minimize the possibilities for mistakes, delays, excess spending and to troubleshoot when necessary. Project Managers use "methods and tools to perform traditional management functions such as earned value analysis, scheduling, estimating, and now there is an increasing use of virtual construction and Building Information Modeling (BIM) to assist the managers in meeting the time, cost, and quality objectives of the project" (Moreau, 2010).

The use of BIM in project management is a relatively new, but extremely efficient concept. BIM computer programs, such as Civil 3D architecture and Revit, allow all stakeholders

in a construction project to view a computer animated model of the building to be gradually constructed in digital form. This allows all parties to gain a better visual understanding of how the project will evolve, thus facilitating alignment of expectations and better coordination to attain the owner's desired results. It also allows engineers and project managers to estimate costs and scheduling more efficiently, minimizing any potential future problems. A more extensive description of Building Information Modeling can be found in our BIM background section.

The WPI campus has seen many changes since its founding in 1865. Over the years, WPI has added the George C. Gordon Library, modern chemistry and biomedical facilities, an admissions building, a new student center and multiple residence halls. Aside from the construction of Harrington Auditorium and the new athletic field, WPI has not addressed its need for modern athletic accommodations, until now. The new 146,000 square-foot Sports and Recreation Center is currently being constructed on the west side of the campus, between Alumni Field, Morgan Hall and Harrington. The project, slated to be completed in August 2012, will feature a four-court 29,000-square-foot gymnasium, a natatorium, 11,000 square feet of fitness space, squash and racquetball courts, an indoor rowing tank, well-equipped locker rooms, offices for athletic department administrators and head and assistant coaches, and a glass-covered passageway that will connect Harrington Auditorium with the new Center and link the pedestrian path from west campus to the Quad. Designed by Cannon Designs, LLC, the construction of the project is being managed by Gilbane Construction, Inc.

A particularly noteworthy portion of the construction of WPI's Sports and Recreation Center was the excavation for the foundation of the building. Construction of the building calls for mass excavation ranging from the field level of WPI's Alumni Stadium and cutting into a large portion of the adjacent hill. The close proximity of Morgan Residential Hall and Harrington

Gymnasium as well as the depth of the excavation and the nature of the soil forced designers to use retention walls in order to safely excavate the soil which was to hold the new building's foundation.

The focus of the project was to investigate and analyze the challenges surrounding this complicated excavation process needed in the construction of the new Sports and Recreation Center. To complete this work we explored several different aspects which helped us gain a further understanding of the project and construction management in general. We first explored was the type of soil to be excavated. Using soil bearing reports, provided by Haley and Aldrich Geotechnical Company, we created a profile of the soil surrounding the construction site. This allowed us to anticipate the type and magnitude of the forces which would be acting on the wall and also helped in determining the proper selection of retaining wall methods. Next, alternative designs to the earth retaining structure were explored. By using the dimensions of the actual wall which was implemented, we created two alternative designs using different categories of retaining walls which could have theoretically been implemented. Next using Building Information Modeling technologies we created a 3D model of three multiple phases in the excavation of the project.

2. Background

In this chapter we will describe the new WPI Sports & Recreation center that is currently under construction. We will discuss all of the parties associated with the project including the owners, builders and architects and how the use of Building Information Modeling can be beneficial in modern day construction. In addition, we will explore Earth's pressure theories and multiple earth retaining structures that could be implemented in future projects.

2.1 New Sports & Recreation Center:

On October 30, 2009 the "WPI Board of Trustees voted unanimously towards the construction of the 140,000 square-foot Sports and Recreation Center" (WPI, 2009). The facility is currently being constructed on the west side of the WPI campus between Alumni Field, Morgan Hall and Harrington Gymnasium. It is planned to be completed by Gilbane Building Co. based out of Providence, RI, a real estate development and construction company. Designed by Cannon Design Inc., based in Boston, MA, the new facility will contain a four-court 29,000 square-foot gymnasium and an indoor three-lane jogging track will stretch the perimeter of the area. In addition, the facility will "feature a 25-meter competition swimming pool which will vary in depth, seating for 250 spectators, a lifeguard room, and storage and filtration areas" (WPI, 2009). Other specialized spaces include an indoor rowing tank, racquetball and squash courts, well-equipped locker rooms and a training and rehabilitation suite at field level. Aside from all of the athletic commodities, the new building will also contain a robot pit to accommodate for the Robotic competitions, in direct correlation with the new and growing Robotics major WPI offers. A corridor will connect the existing Harrington Auditorium to the new building, creating larger event space for career fairs, admissions open house, alumni events and conferences.

The new building will provide some beneficial changes for WPI athletics, for both varsity athletes and club and recreational athletes. The modern facility will be the first new athletic building on the WPI campus since the completion of Harrington Auditorium in 1967. Varsity athletes will “have a facility that matches their drive for excellence and allows them to reach their highest athletic potential.” The facility also provides recreational athletes with a place to grow and develop skills and fundamentals. “Essential and long overdue, the new Sports and Recreation center will at last bring WPI’s athletics facilities for women in line with those for men” (WPI, 2009). WPI currently has its highest enrollment of females and female athletes; however, the current facilities cannot adequately provide the space needed for all of the women’s sports offered by the school. The addition of the fitness center will allow for expansion of female locker rooms and training equipment.

Gilbane Building Company is the Construction Manager for the project which broke ground on May 16th, 2010, immediately following the spring 2010 Commencement and is scheduled to be completed in August 2012. Financed through “fundraising, debt, and use of accumulated operating surpluses”, the project is designed to meet LEED Certification standards from the U.S. Green Building Council (WPI, 2009). WPI firmly believes the ‘The Time is Now’ to build the highly anticipated Sports and Recreation Center. According to the official website, “the new Sports and Recreation Center will embody the distinctive WPI education while ushering in a new era of athletics and student achievement at the university” (WPI, 2009).

2.2 Construction Project Management

In the field of civil engineering, a construction project is the building of an infrastructure. The completion of a project may require attention and participation from a wide range of groups including financial organizations, governmental agencies, engineers, architects, lawyers,

insurance companies, contractors, manufacturers and building tradesmen (Sears, 2000). All of these facets to the project demand a strict management of resources. The success of the project is greatly impacted by the efficiency in which the leaders of a construction project work.

There are three main parties who participate on every project. These groups are the Owners, the Builders: Construction Project Managers (CPMs) or General Contractors (GCs) and the Designers:, Architects and Engineers. The owner is represented by a group of individuals or organizations who fund the project and articulate the ultimate use of the facility. The CPMs are hired by the owners to oversee construction of the project. Gilbane, the CM for this project, will direct, coordinate, budget and schedule all design and construction processes, including the selection, hiring, and oversight of subcontractors. They ensure the completion of the project meets the needs of the owners and is finished on time and within the estimated budget. The architects are the group who design the facility based on the owner's desires and requirements in accordance with building codes and professional practices. It is imperative that these three groups have constant communication and work together towards the goal of the project.

2.2.1 Owners

The owners of a project have particular interests in both the efficiency of the construction process and the final result. This is because it is this group who will be providing the resources and will be investing the large sums of money into the project's development. They also are beneficiaries of the final outcome of the project, and need to make sure that their requirements are met. Construction projects are tailored according to the needs and constraints of the owner, which is why communication between parties is so important. Final say on important decisions rests with the projects owners, since once again; they are the ones providing the funding.

The WPI Board of Trustees and President Dennis Berkey personify the owners of the Sports and Recreation center. Represented during construction by Worcester-based Cardinal Construction, they will work with Gilbane and Cannon Design in order to meet the specifications and necessities of the WPI Athletic department and Facilities department. The \$53.2 million project will be funded through WPI's endowment, tuition fees and private donations.

The individuals who speak on behalf of WPI during the development of this project are:

- Brent Arthaud, Cardinal
- Michael Andrews, Cardinal
- Dana Harmon, WPI Athletic Director
- Janet Richardson, WPI VP of Student Affairs
- Jeffrey Solomon, WPI CFO
- Alfredo DiMauro, Assistant VP for Facilities
- Ann McCarron, Associate Athletic Director
- Sean O'Connor, Assistant VP for Information Security and Networking

As depicted in Figure 1, below the role of the owner in the construction process is vital from the first idea to the completion of the structure. The first step for the owners is to develop a project scope with the designer. This scope will define the needs in which the outcome of the project will need to meet, whether it is an apartment building that will need to house 100 people or a four lane highway that needs to account for varying weather conditions. Owners will work with planners and engineers to assess the feasibility and options of such a project

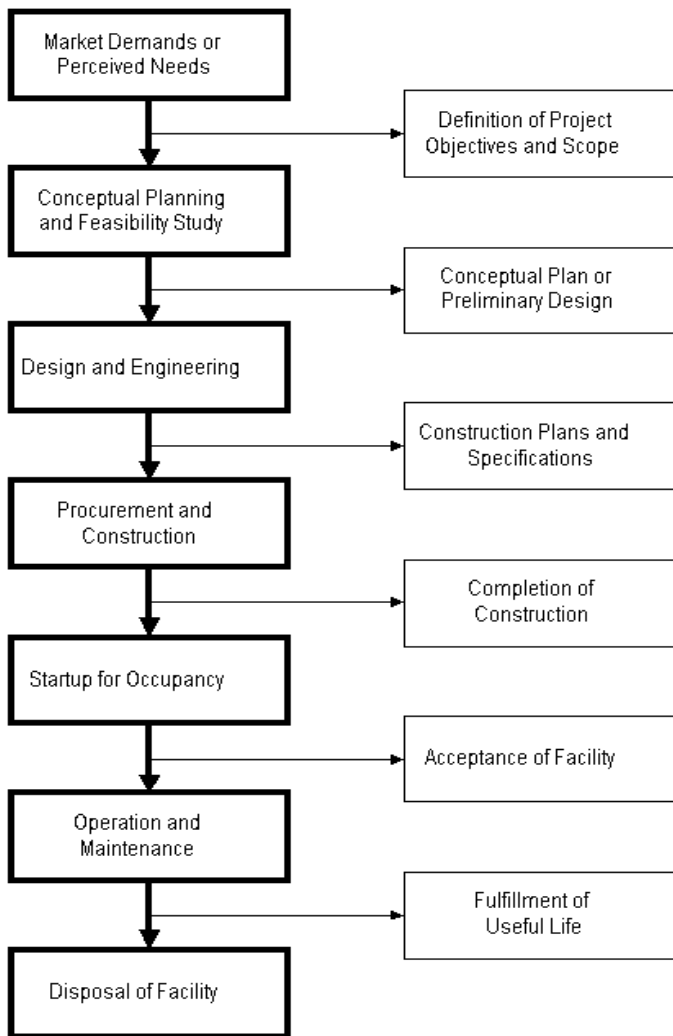


Figure 1: The Project Lifecycle of a Constructed Facility

Source: http://pmbok.ce.cmu.edu/01_The_Owners%27_Perspective.html

The size and type of the project as well as the project delivery method selected may affect the level of involvement of the owners. “Very often, the owner retains direct control of work in the planning and programming stages, but increasingly outside planners and financial experts are used as consultants because of the complexities of projects” (Hendrickson, 2008). This is not to say that the owners do not still make all final decisions but often the complexity of some projects are too great and an outside consultant work is required to help. Once a scope is defined designing of the project will commence. Again, owners must work closely with engineers and architects to ensure the design, documented in blue-prints, fits their goals.

Once a design is created the physical construction may begin. During this time owners should have already gotten their visions across to the designers and construction team. It is important for them to communicate to make sure that the project is proceeding in the direction the owners wish. During this time owners will also take special interest in ensuring the efficiency of the project so that it is being completed without wasting any time or money.

2.2.2 Architects

The main responsibility of the architect and other planning engineers is to create a design for the project. Boston-based Cannon Design is the lead designer for the new WPI Sports and Recreation Center. The architect will take the ideas, needs and constraints of the owners and through the Construction Documents provide the builder with the intent of the design (geometry and performance). The owners will work initially with the “design consultants” to create such a design. In the design phase, the architect has many rules and regulations which must be followed to ensure a safe and feasible design which captures the needs and restraints of the owners (Garnett, 2009). A building must be designed and built according to state, local and building codes in order to receive its certificate of occupancy.

First designers must work with the owners to create a conceptual design according to governmental requirements and ordinances. In addition, project risks must be assessed in this stage. Engineers and planners conduct technical and environmental studies, develop engineering criteria and conduct risk assessments in the planning stages of a design. Once these initial planning phases are complete architects can work with the owners to create detailed designs which can be handed over to the builders.

While creating the design, architects keep track of a projected schedule and cost estimations of the project. The owners will use this information to help select and understand the variety of bids from construction companies that they may be receiving. Once a final design is created and construction begins the designers still hold a role in the project. Often time there are design changes that are necessary because of unforeseen stumbling blocks in the project. Also architects may need to work closely with the construction team in order to ensure their plans are carried out correctly and efficiently (Garnett, 2009).

The individuals who represent Cannon on this project during the construction phase are:

- Dominic Vecchione, Associate VP Construction Administration
- Lynne Deninger, AIA, LEED

In addition to the architects who designed the building, geotechnical engineers were hired in order to survey the land prior to the necessary excavation. Boston-based Haley & Aldrich performed soil boring and recorded soil reports for the owner, designer and builder. Some of the individuals representing Haley & Aldrich are:

- Alec D. Smith, PhD, P.E., Vice President
- Michael D Cararo, Staff Engineer
- Erin F. Wood, Senior Engineer

Since construction began, GZA Environmental has replaced H&A to act as the geo-consultants for the project. H&A were primarily responsible for the existing conditions of the soil prior to excavation.

2.2.3 Project Managers

Since the owners are the ones with final say on decisions regarding the project, it is in the best interest of all other parties that the owners get what they want. It the Construction Project Manger's primary responsibility to make sure that the project is completed fitting the scope, time frame and budget specified by the owners.

To help ensure the scope of the project is met the CPM must be in constant communication with the owners, engineers, contractors and manufacturers. If a desired aspect of the owners is not being met then this communication between all parties will help identify and fix the problem.

Time and money are two other vital aspects of the project that CPMs must control. An experienced CPM will create a realistic yet aspiring project schedule which is achievable and also makes the project owners pleased. The only way to accomplish this is with a project manager with knowledge and experience of each and every aspect of the construction process. A good CPM knows how long to expect their workers to complete each task, when a new aspect of the job can be started and what problems and delays can be expected along the way. By having a firm understanding of these things a CPM will best create a timely and feasible project schedule. Effectively managing their resources will help CPMs stay on budget. Knowing what prices to expect from contractors and manufacturers, how long to schedule for labor time of the different project elements and managing the project so it is done as efficiently as possible are all qualities that will make frugal but wise CPMs resulting in happy owners.

The managing of all aspects of this complex construction system is what sets aside construction project managers from other engineers. While extensive knowledge of the technical phases of a project is vital, just as important is the effective management and delegation of tasks by the CPM. As made apparent in this quote from the book *Engineers and Ivory Towers* by Hardy Cross it is ever more important for a project manager to possess social, economic and organizational skills in addition to his or her technical knowledge.

“It is customary to think of engineering as a part of a trilogy, pure science, applied science and engineering. It needs emphasis that this trilogy is only one of a triad of trilogies into which engineering fits. This first is pure science, applied science and engineering; the second is economic theory, finance and engineering; and the third is social relations, industrial relations and engineering. Many engineering problems are as closely allied to social problems as they are to pure science.” (Cross, 1952)

The following two figures help illustrate the important role a Project Manager plays in the entire construction process. Figure 2 shows the gap CPMs fill in communication between all parties in construction. In this diagram communication between the agency (owner) and the job specialists is bridged by the project manager. In the second diagram there is no project manager and one can see the added stress this would place on the owners.

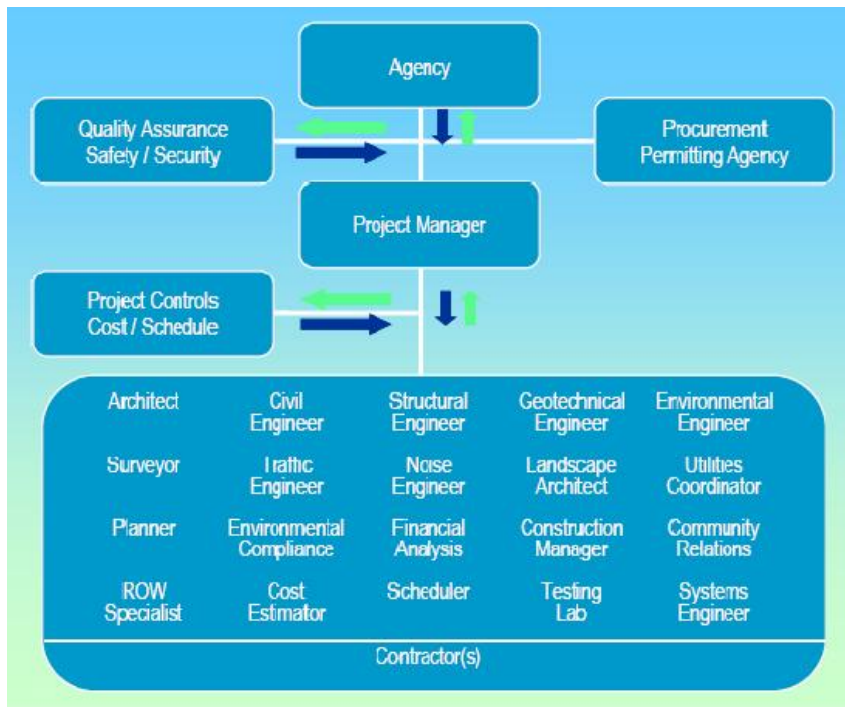


Figure 2: A project with a PM

Source: <http://www.fta.dot.gov/documents/FTA-CONSTRUCTION-PRJT-MGMT-HDBK2009.pdf>

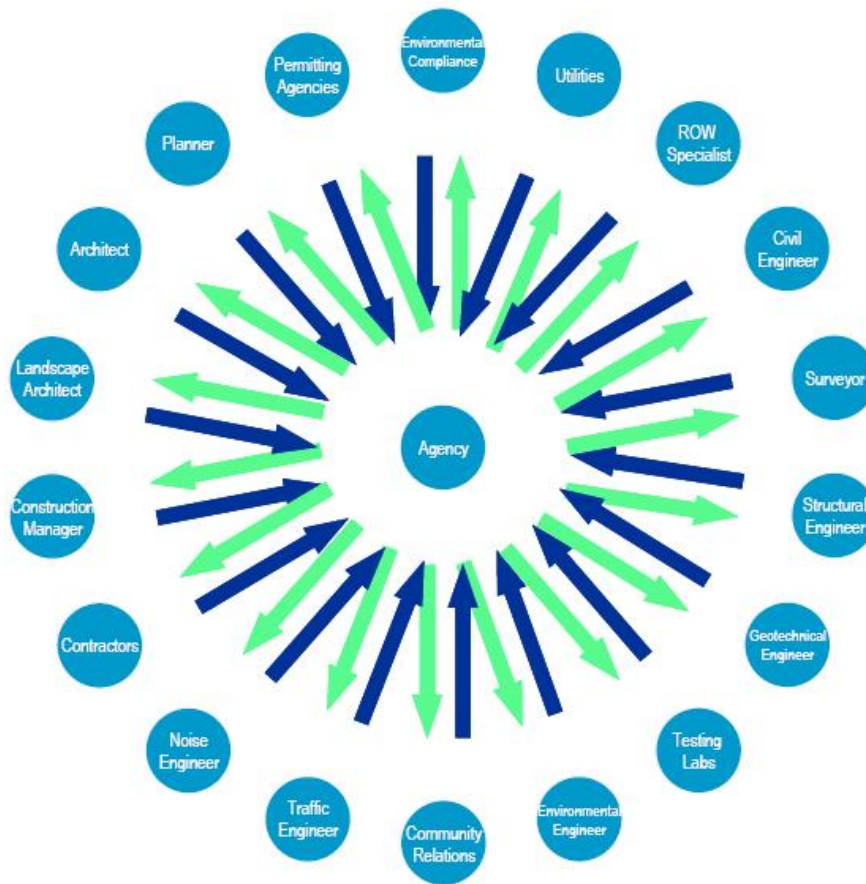


Figure 3: A project without a Project Manager

Source: <http://www.fta.dot.gov/documents/FTA-CONSTRUCTION-PRJT-MGMT-HDBK2009.pdf>

One final smaller yet equally important job the project manager must oversee is the overall safety of the project. For all projects safety is a top priority. Construction can be a dangerous endeavor if not practiced correctly. There are many concepts in which CPMs must enforce to ensure a safe overall construction site. Monitoring the job site to ensure procedures are being followed properly and the safety hazards are detected early and corrected is one important practice for a CPM. Another is securing a proper perimeter and being aware of public and private neighboring entities. The laws that regulate these best safety practices are state and federal Occupational Health and Safety Acts (OSHA). By following these regulations a CPM can help assure the safety of his or her job site. One final strategy a CPM may use is providing safety

education courses for workers and the public and by offering incentives for safe construction practices.

The main individuals working on this project from Gilbane are:

- William Kearney Jr., Project Executive
- Neil Benner, Senior Project Manager
- Melissa Hinton, Project Engineer
- Justin Gonsalves, Project Engineer

2.3 Building Information Modeling:

Building Information Modeling (BIM) is a relatively new concept in construction which allows architects, engineers and other construction professionals to work more efficiently with one another using consistent and coordinated digital information about a project. BIM allows these parties to better visualize the construction's phases and provides information such as time and scheduling to all aspects of the building (Autodesk, 2009). The use of BIM on WPI's new Sports and Recreation Center marks the first time BIM tools have been used on a WPI-owned project.

Utilizing three-dimensional, real-time, and parametric object oriented building software as a basic tool, BIM provides a means to monitor and predict project production. "BIM is an integrated process that vastly improves project understanding and allows for predictable outcomes" (Autodesk, 2009). This allows important design decisions to be made early on in the process. Using BIM, a team of engineers and architects can design a building using software to model the building's geometry, spatial relationships, geographic information, quantities and properties of building components.

Some of the amenities offered by BIM include the ability to gradually display the building construction progress integrating, cost analysis and scheduling. “Quantities and shared properties of materials can be extracted easily. Scopes of work can be isolated and defined and systems, assemblies and sequences can be shown in a relative scale with the entire facility” (Wikipedia, 2010). One of the greatest capabilities of BIM is the ability to model representations of the parts and pieces being used in the building, along with the structure of the building itself.

BIM can also be used for site analysis, as it was used in the WPI Sports and Recreation Center project. By using site elevations, locations of bodies of water, utilities and more, BIM can accurately depict the site of a potential project. This allows the engineers designing the project to have a realistic idea of the site without physically being at the location. Furthermore, BIM will allow these designing engineers to make virtual changes to the site, such as excavating a given amount of soil from a given area. Then this information can be efficiently shared with other parties, such as the project owner’s, to see if the desired outcomes are being portrayed.

2.4 Earth Retaining Structures

Earth retaining structures for excavations are designed to hold and resist pressure from the different soil types and to provide a safe working environment for ease construction. These structures are necessary when the construction site is located beneath the sub-grade, which is a surface of earth or rock that is leveled off to receive a foundation (Merriam-Webster, 2010). There are several different earth retaining structures that can be used during excavation; the design of these retaining structures is often made specifically to accommodate different factors such as sub-grade elevation, soil type, and specific project conditions. Aside from preventing banks of earth from slipping, retaining structures can also be used for decoration of the landscape. If the area where a retaining wall is needed is visible after construction is completed,

there are different techniques used to cover the existing wall. These techniques are discussed with landscape designers and the owners of the project. Another option for visible retaining walls is the removal of them if applicable. If the contractors decide that the retaining structure is unnecessary after the completion of the project, the owner has the option to remove it to improve the landscape of the area around the excavation site. Below is the description of some of commonly used earth retaining structures (Texas Department of Transportation, 2010).

2.4.1 Design Considerations for all Earth Retaining Structures

There are several factors to consider when constructing an earth retaining structure, serviceability is the first factor. Serviceability factor simply means that the installation of this wall should not affect the appearance or nearby use of surrounding buildings or structures. If this requirement is not met, then severe deformation can occur to the excavation area and also areas surrounding it. At WPI, the soil nail wall that is being considered for re-design within this project can be found in the heart of the school's campus. Serviceability is extremely important because the internal structures and areas around buildings could not be affected by excavation or else the project would be delayed due to needed improvements for damaged areas.

The durability of the earth retaining structures must also be considered during the design process. For the current soil nail wall that was used the main concern is the durability of soil nails, this will strike the interest of the environmental conditions in order to determine what type of material or protective measures must be taken to ensure that soil nails will remain strong and intact despite the weathering conditions. This can be determined by the soil aggressivity and corrosion protective measures. Soil aggressivity is, according to the English Dictionary, "the upper layer of earth in which plants grows, a black or dark brown material typically consisting of organic remains, clay, and rock particles" (Dictionary of English, 2010). For the designers of the

soil nail wall used for the New Sports and Recreation Center, the soil nails must have been able to withstand top-soil and medium-very dense glacial till. Once the soil nail wall is no longer needed, it may serve as an aesthetic to make the appeal of the area more welcoming or it may be covered with backfill from the remaining soil.

An important aspect for designing anything in the construction industry is economic considerations. For earth retaining structures, the economic considerations are geared towards material cost, construction methods, work requirements, build-ability or the level of difficulty of construction, corrosion protection requirements, and type of facing. When designing the soil nail wall at the New Sports and Recreation Center, all these factors must be considered, especially the level of difficulty of the construction as this is the factor that will fluctuate the most from project to project.

Lastly, the environmental factors must be considered when designing earth retaining structures. It is important to consider this because these systems may have an adverse effect on the surrounding ground ecosystem. Also induce nuisance, pollution during construction, and the visual impact to the existing environment must also be considered when discussing environmental considerations. The main goal for the designer when considering this factor is to minimize the impact on the environment. This is due to instances that cannot be avoided when discussing the environment around the construction area.

2.4.2 Conventional Earth Retaining Structure

The conventional earth retaining structure consists of driven sheet piling, lagging walls, and drilled soldier beams. This type of retention structure is commonly used in areas where the groundwater can be decreased by dewatering. If dewatering is not possible then sheet piling will

be implemented to undergo the hydrostatic pressure, which is the pressure of the water at rest due to the weight of the fluid located above it (More Trench, 2010).

2.4.3 Secant Pile Walls

Another type of earth retaining structure is secant pile walls. Secant pile walls can be used in different ways, as a temporary or permanent wall. The walls can have multiple functions as well such as support during construction and integral parts of the permanent foundation (More Trench, 2010). These walls are formed with steel rebar or beams and the intersection of reinforced concrete piles. This wall has more stiffness than the conventional excavation support and can be implemented on different types of lands including cobbles and boulders. The only disadvantages of using this retaining structure are the height restrictions as it has a relatively low vertical load tolerance, waterproofing is difficult, and the high cost of construction (Deep Excavation, 2010).

2.4.4 Tangent Pile Walls

Tangent pile walls are similar to the secant pile wall as the piles in both walls are constructed the same way and consist of rebar, beams, and concrete. The major difference between the two is the tangent pile overlaps each other and the secant piles are aligned so that they touch one another. One advantage of using this design of an earth retaining structure is the ease and quickness of construction. There is no need to drill to ensure proper lateral loading (More Trench, 2010).

2.4.5 Deep Soil Mixed Wall

The deep soil mixed wall is an earth retaining structure that is relatively new to the construction industry. The structure consists of creating a supporting structure by mixing in situ-

soils and a stabilizing agent (Rutherford, 2007). These designs for earth retaining structures are most effective in urban areas and areas with high groundwater tables; this is due to its unique design. Deep soil mixed walls are a make-up of columns which cause little disturbance to its surroundings, and also generate low vibration and noise pollution during construction. The columns that make-up the deep soil mixed walls consist of a mix between the soil and the stabilizing agent. Blades on a multi-auger rotary shaft are responsible for mixing the two to form the soil-cement columns. Every other column a wide flange H-beam or sheet pile is placed to help resist the bending within the earth retaining structure. This design is also known to be a faster excavation and construction than other earth retaining structures (Rutherford, 2007).

2.4.6 Soil and Rock Anchors

Soil and rock anchors, another type of retaining earth structure, consists of vertical beams and pre-stressed bar. The beams are set into place into the earth past sub-grade, once this is completed the beams are connected by the bar and the void spaces are filled in with lumber. This ensures that the soil is not able to move because the lateral earth pressure is being resisted by the beams which are driven deep into the ground to provide sufficient stability for the structure (More Trench, 2010).

2.4.7 Rock Bolt Retaining Structure

When encountering ground which has a high density of rock in it, rock bolts are used as earth retaining structures during construction. This earth retaining structure can be mostly found in tunnel excavations and deeps open excavation which encounters poor, weathered rock (Deep Excavation, 2010). Rock bolts consist of grid patterns, where bolts are placed strategically. Once these locations are identified the exposed face of rock is then covered and anchored by wire

mesh. Some conditions require that ‘shotcrete’ be used as well with the wire mesh to help ensure stability and safety of the structure (More Trench, 2010).

2.4.8 Slurry Walls

Another earth retaining structure our group investigated is slurry walls.

“Slurry wall construction is the excavation below-grade through stabilizing slurry which supports the excavation walls and prevents caving and water intrusion and the replacement of slurry with purpose-designed backfill” (Baker, 2010).

There are two different types of slurry walls, the cut-off wall and the diaphragm wall. The cut-off wall is used when water control is needed for deep excavations as it ‘cuts-off’ curtains for dams and levees. This type of slurry wall also controls gas barriers for landfills and any contaminated groundwater located around the work site. Diaphragm slurry walls are the traditional retaining walls for heavy foundations and are a combination of retaining wall foundations and water control. In the tables below, it shows the steps of the slurry wall design and slurry wall quality control (Baker, 2010).

2.4.9 Soil-Nail Wall

The soil nail system is a complex way of providing a safe environment for any type of activity that is happening around the system. The main factor to account for when designing a soil nail wall is stability. The wall must surpass the state at which failures can form, in the ground or in the soil nail wall. Failure to provide stability can lead to severe damages and injuries due to a faulty wall. In order to design for stability, engineers analyze the modes of failure, in other words they must anticipate potential situations that could go wrong within the soil nail system. These are considered internal and external failures. Internal failures meaning the area within the soil nail ground. They may occur in either the active or passive zone. External

failure is referring to the surfaces outside the soil nail wall. This mostly concerns the face surface of the wall. The current yield strength of the soil nail wall constructed at WPI's New Sports and Recreation Center ranges from 13124.38 lbs/mm² to 15623.60 lbs/mm². This range has proven to provide enough stability to prevent any modes of failure.

2.5 Earth Pressure Theories

Before designing a retaining wall the amount of force which will be acting on that wall must be calculated. This force can be calculated using geotechnical earth pressure theories. Factors which must be considered in these calculations are the type and amount of wall movement, the shear strength and unit weight of the soil and also drainage and water table conditions. There are three types of earth pressures that will act against the retaining wall; area rest earth pressure, active earth pressure and passive earth pressure.

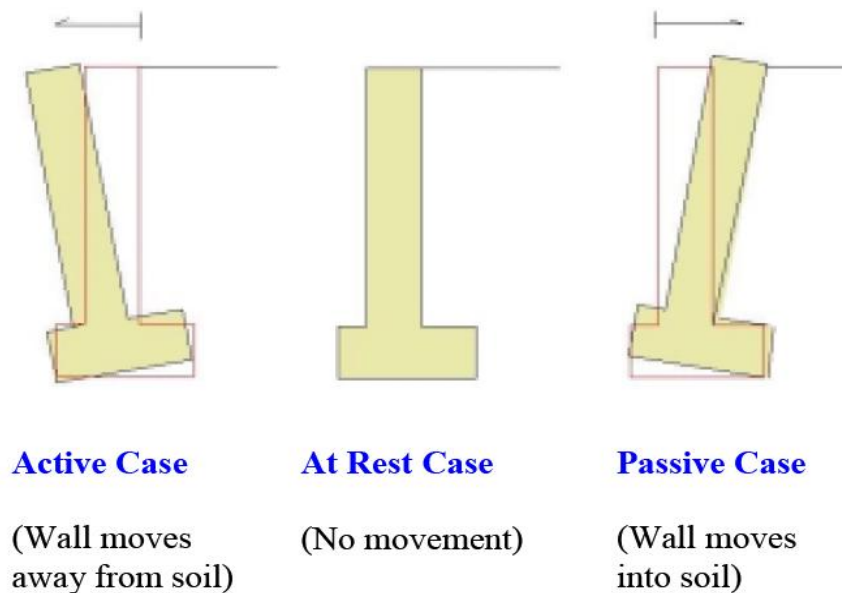


Figure 4: Wall movement

Source: <http://www.pdhcenter.com/courses/c155/c155content.pdf>

As shown in the figure above, the type of force being applied to the wall depends on the movement of the wall. In the case of active pressure the wall is moving away from the soil, causing the lateral pressure on the wall to decrease until the minimum active earth pressure force is obtained. In the Passive Case the opposite of this happens. The lateral force on the wall increases until the maximum earth pressure on the wall is reached.

When calculating the pressure on each of these types of walls, lateral earth pressure coefficients are used according to the types of wall movements. In general, the coefficients for Active, At Rest and Passive cases are designated as K_o , K_a and K_p , respectively. The corresponding equations for these coefficients for the simplest case (a vertical wall with level backfill) are as follows:

Equation 1: $K_o = 1 - \sin(\Phi)$

Equation 2: $K_a = \tan^2(45^\circ - (\Phi/2))$

Equation 3: $K_p = \tan^2(45^\circ + (\Phi/2))$

They are determined using different charts according to the angle of repose (Φ) of the soil, depicted in Table 1 below. The lateral earth pressure can be calculated by the vertical pressure multiplied by the appropriate coefficient.

Table 1: Earth pressure Rankine coefficient

ϕ (deg)	Rankine K_a	Rankine K_p
28	.361	2.77
30	.333	3.00
32	.307	3.26

Source: <http://www.pdhcenter.com/courses/c155/c155content.pdf>

There are several different theories that may be used to calculate the lateral earth pressures. Two commonly used theories are the Rankine and Coulomb Theories. The Rankine Theory assumes no friction between the wall and the backfilling soil, that lateral pressure is limited to vertical pressures and that the resulting force is parallel to the backfill surface. Coulombs' Theory is similar to Rankine's except that it accounts for the friction between the wall and backfilling soils, lateral pressure is not limited to the vertical wall and the resultant force is not always parallel to the backfill surface.

To calculate the total lateral earth pressure force one would take the lateral earth pressure at the bottom of the wall multiplied by the height of the wall times one half. This equation is generally portrayed as $P_a = (1/2)K_a \gamma H^2$, which uses unit weight, γ . This calculation is illustrated for both Coulomb's and Rankine's earth pressure theories in Figure 5 (<http://nirutkonkong1982.spaces.live.com/>).

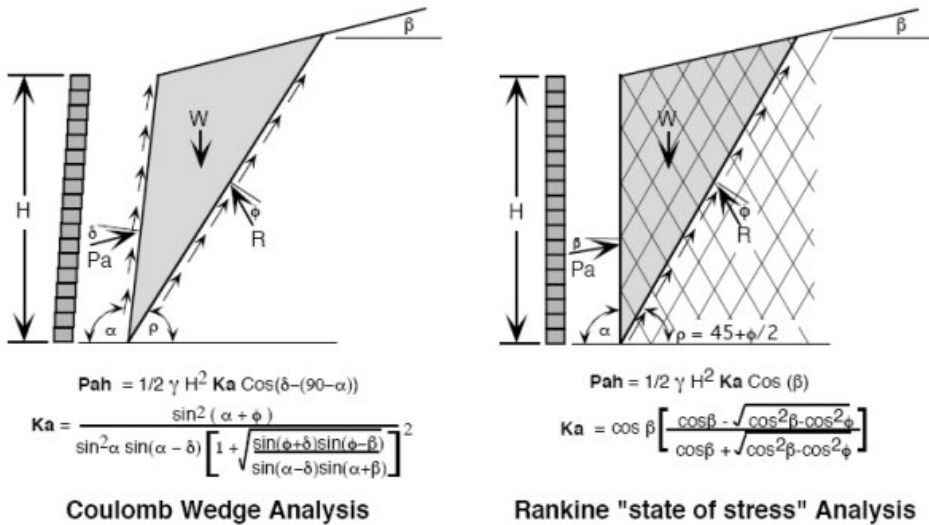


Figure 5: Earth pressure calculations comparison on retaining wall

There are several other forces that should be accounted for in designing a retaining structure. These forces are the surcharge load Earthquake load and water pressure. Surcharge loads are any additional loads that are being applied along the backfill surface. Examples of this

type of load may be building, traffic, embankment loads and other temporary loads. Earthquake loads should be accounted for according to AASHTO standards. Generally walls are designed to alleviate water pressure loads via weeping holes. For walls that are designed this way water pressure loads do not need to be accounted for. However some walls will not have the drainage feature in their design and will need to account for the additional lateral load associated with water pressure.

3. Building Information Modeling

In order to develop a 3D digital model of the site we used the computer software programs AutoCAD Civil 3D and Revit Architecture, both developed by Autodesk. AutoCAD Civil 3D was used in conjunction with Google Earth in order to create a surface and image in the program. Civil 3D imported the contour lines and elevations of the WPI campus along with satellite imagery to offer a visual point of reference. Using a navigation tool located in the upper right-hand corner of the Civil 3D screen, a user is able to explore the site from different angles and views. The navigation feature allows for a complete view of the plan and elevations of the WPI campus. Figure 6 shows a rotated view of the model in Civil 3D where layers are distinguishable.

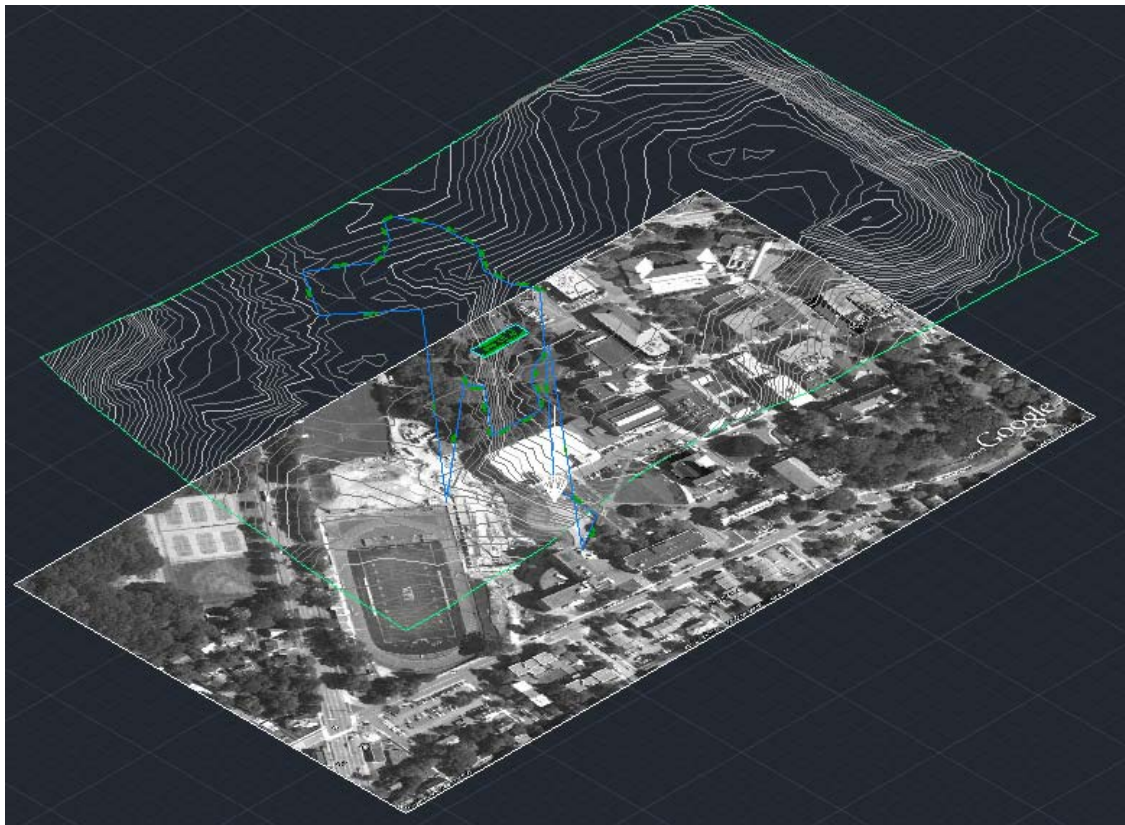


Figure 6: Site Model

The previous screen shot illustrates how the view can be rotated in order to see the contour lines of the geography and how they are laid over a satellite image. Civil 3D offered an easy alternative to calculate the area of the site and show how it affects the accessibility of the WPI campus. Figure 7 below shows an image of the current conditions of the site before construction began. Figure 8 shows an aerial view of the site during construction.

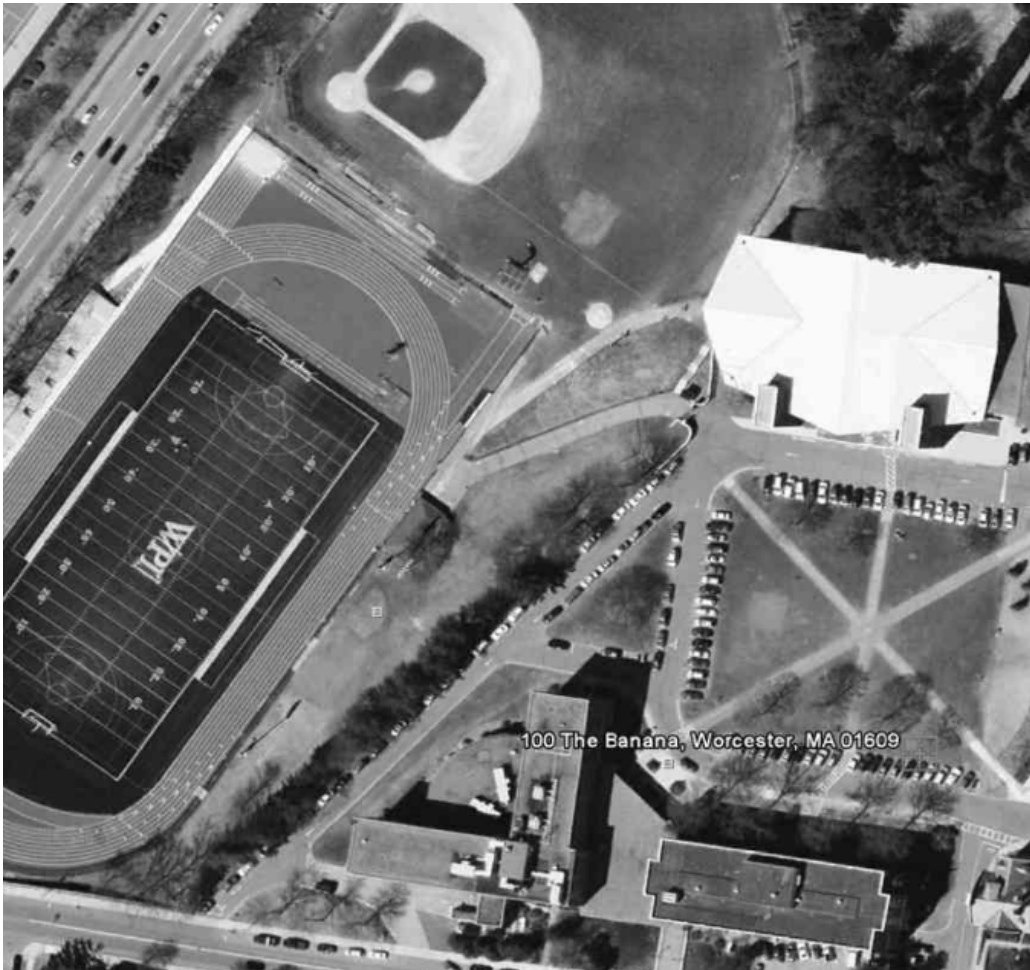


Figure 7: Existing Conditions

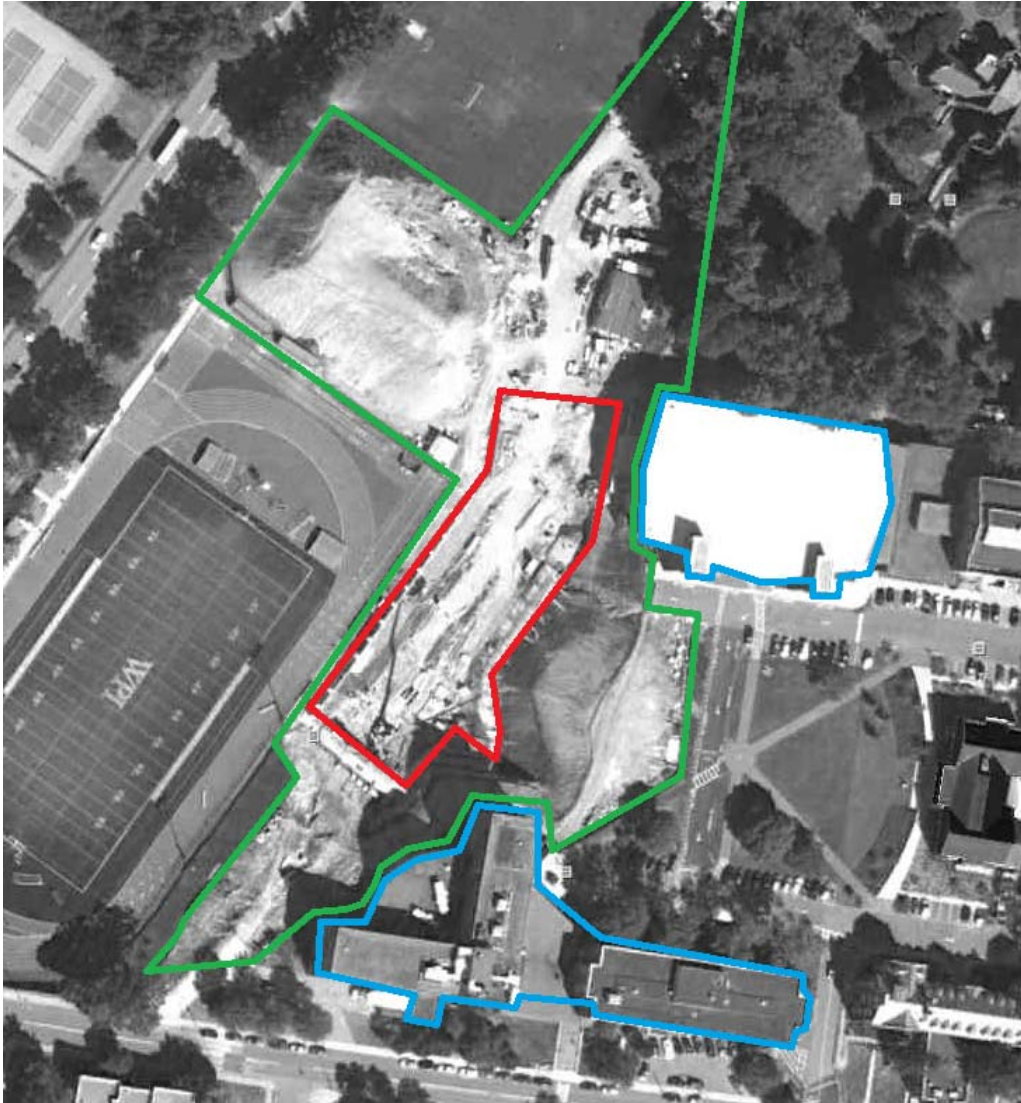


Figure 8: Site Plan

The green line delineates the construction site perimeter which runs almost 3,000 feet and covers nearly 5 acres of the WPI campus. The red outline shows the footprint of the new Sports and Recreation Center building and the blue lines show the footprint of the two surrounding the existing residential buildings, Morgan and Daniels' Hall, and Harrington Auditorium highlight their close proximity of the construction. The contractors created an access road which extends off the top of the photo (entrance from Salisbury Street) for all trucks, equipment and material deliveries. WPI has restricted the use of its quadrangle for construction purposes in order to

minimize student interactions and minimize disruptions on campus. There is another access road that runs from Institute Rd into the back of the building and between the field track and Morgan Hall and the baseball diamond is no longer in use since it has become the location to pile excavated earth. In addition to the WPI baseball field, approximately half of the excavated earth was hauled away to both fields in Paxton and St. Peter Marian High School to be used as fill there.

Revit Architecture was the other BIM program we used in order to quantify excavation volumes and place utilities such as, telecommunications, fiber optics, steam, water and sanitary sewers and electricity that will power the building. The program supports a feature that allows the user to import data from an external source (i.e. .dwg files) in order to edit massing and site elements within the file. We imported our Civil 3D file to a new Revit file and created a building pad to show the footprint of the new center at elevation 519'. Figure 9 provides an example of a cluster of spot elevations along their respective contour lines as well as the individual properties of a specified point.

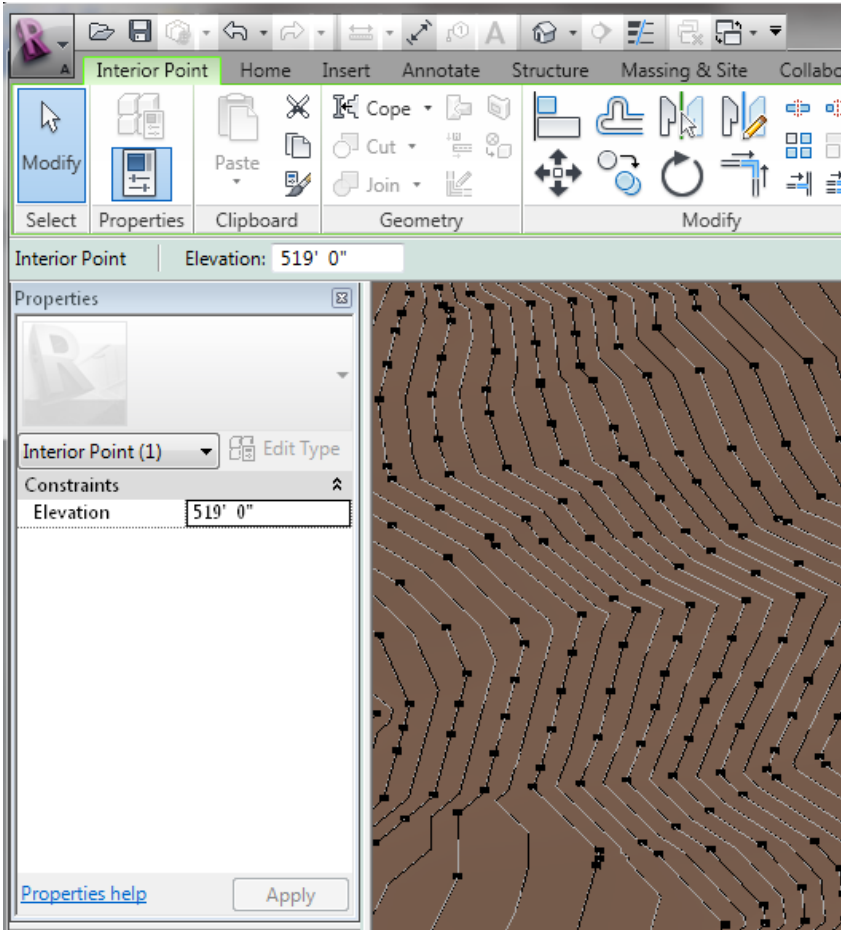


Figure 9: Spot elevation at 519'

The program was able to calculate the total volume of earth necessary to be removed, which would be placed in an excavation pile adjacent to the building. Using the area of the building pad as a reference, we created phases of the mass excavation and backfill in order to quantify the total volumes during each phase. We divided the entire process into three phases; existing conditions, mass excavation, and backfill after the building foundation and superstructure had been completed.

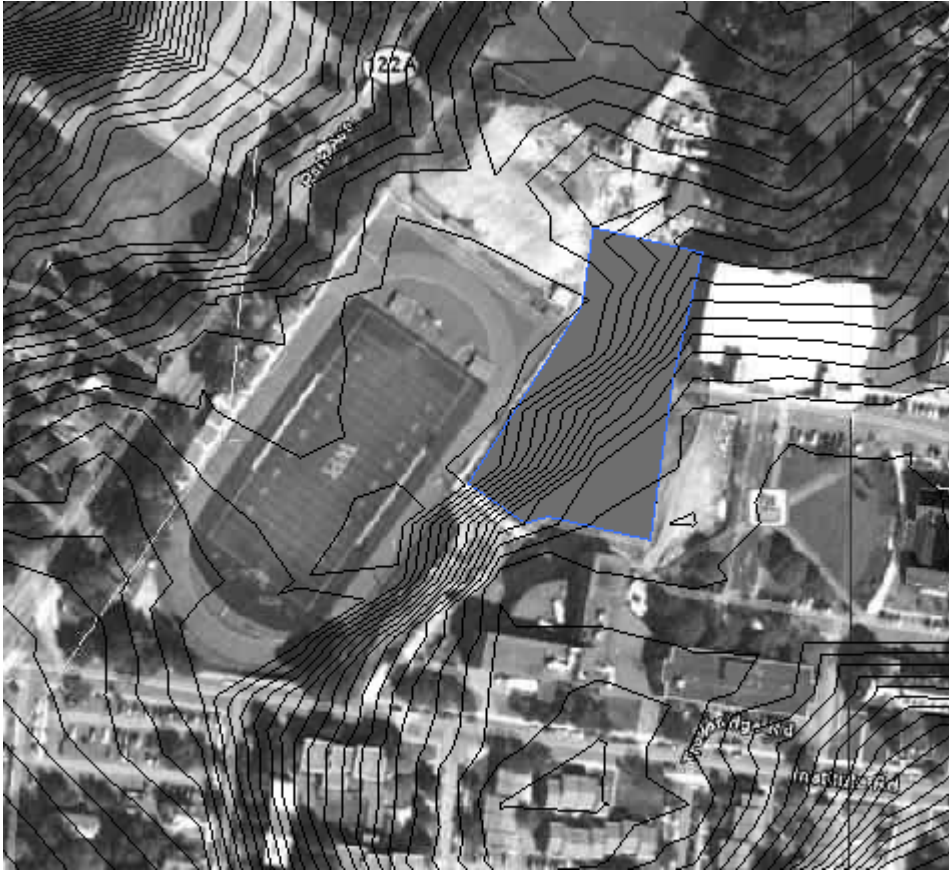


Figure 10: Building Pad in Revit along specified elevation 519'

The above screen shot, taken from Revit, clearly shows contour lines and elevations which were used to add the 3rd dimension to the site. The contour lines close in proximity represent a sharp change in elevation and the spaced lines represent a flatter area of the land. The building pad is the blue outline of where the mass excavation had taken place. Based on the area of the pad and the depth that needed to be reached, the volume of earth that was removed totaled 2,501,586 CF, approximately 92,000 cu. Yds. The earth excavated is a mixture of soil and glacial till which made it necessary to compensate for a swell factor by multiplying the volume by an additional 25%, resulting in just over 115,000 cu. Yds. Based off the computer model, the area surrounding the building after the superstructure had been erected would require 2,431,007 CF (90,000 cu. Yds) of backfill. Tables 2 and 3 display the cuts and fills performed by the computer,

resulting the net difference between the two processes. A complete tutorial of the modeling process can be found in Appendix F.

Table 2: Mass excavation phase

Topography Schedule					
Name	Surface Area	Projected Area	Cut	Fill	Net cut/fill
Existing surface	8564447 SF	8484818 SF	0.00 CF	0.00 CF	0.00 CF
Mass Excavation	8571261 SF	8484818 SF	2619784.40 CF	118198.33 CF	-2501586.07 CF

Table 3: Backfill phase

Topography Schedule					
Name	Surface Area	Projected Area	Cut	Fill	Net cut/fill
Mass Exc	8571261 SF	8484818 SF	0.00 CF	0.00 CF	0.00 CF
Backfill	8564447 SF	8484818 SF	79914.07 CF	2510921.70 CF	2431007.63 CF

The backfill phase of the project would require an additional 10% of the volume quantified by the computer model, accounting for the shrinkage factor when the machines would replace the earth. Bringing the total to less than 100,000 cubic yards, there would be a surplus of excavated soil that may be brought off site by dump trucks. The model generated in Revit did not account for unsuitable that may have been discovered during the mass excavation phase. In addition, these numbers appear to be higher when compared to the 60,000 cu Yds that Gilbane, Co. excavated in the summer of 2010 (Gilbane Co., 2010).

In our original scope of the project, we wanted to include the locations of the utilities entering the building; however, we found it difficult to edit topography in Revit while simultaneously placing pipes and conduits. We would like to see our model used in conjunction with another model that could show the elevations and locations of those same utilities within the site plan.

4. Soil Profiling

Before a design could be created it was first necessary to classify the type of soil that would be acting on the wall. Specific soil information was taken from Haley and Aldrich's Geotechnical Exploration Report of the WPI campus (Haley and Aldrich, 2008). Tests from this report were dated from 2003, 2006 and 2008. Because soil conditions have not changed over this relatively short period, tests from all dates could be used for our purposes. The geotechnical report consisted of soil boring reports taken from many locations surrounding the recreation center site along with short descriptions of findings and design considerations. The first step was to select borings that were relevant to the location of the walls. By using our knowledge of the location of the retention wall and Haley and Aldrich's soil bearing reports we were able to select three borings coinciding with the area where the retention wall was built adjacent to Morgan Hall. The location of all borings explored on WPI's campus and the borings we selected to analyze can be viewed in Appendix A – Boring Reports. These borings were explored to determine soil conditions for this section.

The type of test these specific reports used in exploration is known as Standard Penetration Testing or SPT. The test involves an instrument which is driven into the desired location of the boring. The amount of blows the hammer on the instrument needs to penetrate six inches helps measure the density of the soil. In this case tests were taken in increments of five or ten feet, depending on location. Also included in the report was a short description of the type of soil found at each depth. Using these two pieces of information we assigned general soil types to each depth. The soil types we found most appropriate to assign were low, medium and very dense topsoil and medium, medium-very and very dense glacial till. Using these soil types we

created a side view of each boring and aligned them with the other borings in that general location. By literally matching up soil types from boring to boring an estimate of the soil types in-between boring locations were found. With this, a cut of the earth at the retention wall site, with expected soil properties at given depths, took form. A diagram of this soil profile can be found in Appendix B.

From here it was next necessary to assign density and angle of repose values to each soil type. By adding the second and third SPT values an SPT-N value could be determined, which is the number used to correlate our desired values from the two following charts.

Table 4: Boring Results

	In-Situ Test Results	Relative Density	ϕ' (degrees)	
			(a) ⁽³⁾	(b) ⁽⁴⁾
SPT N-Value ⁽¹⁾ (blows/300 mm or blows/ft)	0 to 4	Very Loose	< 28	< 30
	4 to 10	Loose	28 to 30	30 to 35
	10 to 30	Medium	30 to 36	35 to 40
	30 to 50	Dense	36 to 41	40 to 45
	> 50	Very Dense	> 41	> 45
Normalized CPT cone bearing resistance (q_c/P_a) ^{(2), (4)}	< 20	Very Loose	< 30	
	20 to 40	Loose	30 to 35	
	40 to 120	Medium	35 to 40	
	120 to 200	Dense	40 to 45	
	> 200	Very Dense	> 45	

- Notes: (1) SPT N-values are field, uncorrected values.
(2) P_a is the normal atmospheric pressure = 1 atm ~ 100 kN/m² ~ 1 tsf.
(3) Range in column (a) from Peck, Hanson, and Thornburn (1974).
(4) Ranges in column (b) and for CPT are from Meyerhof (1956).

Table 5: SPT Values

SPT Penetration, N-Value (blows/ foot)	γ (lb/ft³)
0 - 4	70 - 100
4 - 10	90 - 115
10 - 30	110 - 130
30 - 50	110 - 140
>50	130 - 150

We found that the majority of soil we were looking at could be classified as very-dense glacial till and in general had N-values that were at or greater than 50. Therefore we determined the angle of repose value of the soil to be 45 degrees and the density of the soil to be 140 pcf. These figures were next used in the actual design of our retention walls.

5. Alternative Retention Wall Designs

A portion of this project, and our capstone design experience, was to compare and contrast alternative designs to the soil-nail retention wall used at the WPI Sports and Recreation Center. To complete this task we found it necessary to first analyze the soil profile of the areas where retention walls were built. In our background research we compared different types of methods commonly used in retention wall design. From this investigation we selected several retention wall techniques that seemed logical for this project. Once appropriate methods were selected, we proceeded in creating alternative and hypothetical designs for the wall.

5.1 Retention Wall Selection

From our background research we gained substantial knowledge of the different methods commonly used in retention wall design. We found that in general some walls were known to be more effective or less effective in particular situations. For example some types of walls are better against a groundwater table, some are meant for quick construction, some are temporary while others are more permanent and some are good for residential areas. With these pros and cons in consideration and our knowledge of the WPI Sports and Recreation Center site we could then select which methods we would use in our alternative design.

We found that the soil-nail wall design that was actually used was a wise choice. Soil-nail walls are relatively quick, meant for temporary use, have a low environmental impact among other things. We chose two walls with similar characteristics. A soldier pile wall is known as one of the quickest constructed walls, and also cause little vibration and disturbance to the environment which was a plus with the project being on a college campus near dormitories.

Similarly, deep soil mixing walls are known to be fairly inexpensive, constructed fast and work well in urban areas.

5.2 Soldier Pile with Wood Lagging retention Wall Design

The first retention wall method we chose to design is the soldier pile wall with wood lagging. Necessary design elements that needed calculation were the underground forces acting on the soldier piles and their locations, earth pressure coefficients for underground forces, the embedment depths of the soldier piles, the maximum moment acting on the wall, and the minimum section modulus of the steel piles. A step by step procedure with our actual calculations can be found in both Appendixes B & C.

For some specifications of soldier pile walls there are no calculations necessary. The spacing between soldier piles has a suggested distance of about 5 ft. For spacing between wood laggings there is a maximum distance of one and one half inches. For this value we selected one half inch. Also the dimensions and location of the wall did not need to be calculated since they were the same as the original soil-nail wall that was constructed. An additional design consideration was the groundwater table that is present in the given area. Since the water table ranges along the top of where the wall was constructed dewatering is necessary and therefore no water table considerations were used in our calculations.

The retention wall we designed has two main heights, the lower of which (21 feet) accounts for the majority of the wall. The maximum height (31 feet) reaches a point on the left half of the structure and has a gradual slope declining to the main wall height. We can assume uniformity for the sloped portion of the wall and therefore must only make calculations for the maximum and minimum points. The embedment depth for the maximum wall height is 15 feet and is 10.5 feet for the minimum wall height. This means that all soldier piles constructed along

the maximum and sloped portions of the wall must have a minimum depth below subgrade of 15 feet and all soldier piles constructed along the minimum height must be 10.5 feet deep. We also found that steel beams with maximum allowable stress strength of 50,000 psi with dimensions S 10 X 25.4 must be used to safely hold the forces acting on the wall due to soil. This specific steel I beam is strong enough to hold the wall at its maximum height, the point where the most force will be felt. While a smaller sized beam could be used for lower heights we determined that a uniformed sized beam should be used for the entire wall. This was it ensures that no failing will occur once the wall is constructed; also it will be an easier build for contractors.

Below is a plane view image of the Soldier Pile retention wall which we designed. Included are given parameters such as the walls width and height. Calculated figures include embedment depths of the piles and an image of the type of steel which will be necessary to prevent the wall from failing.

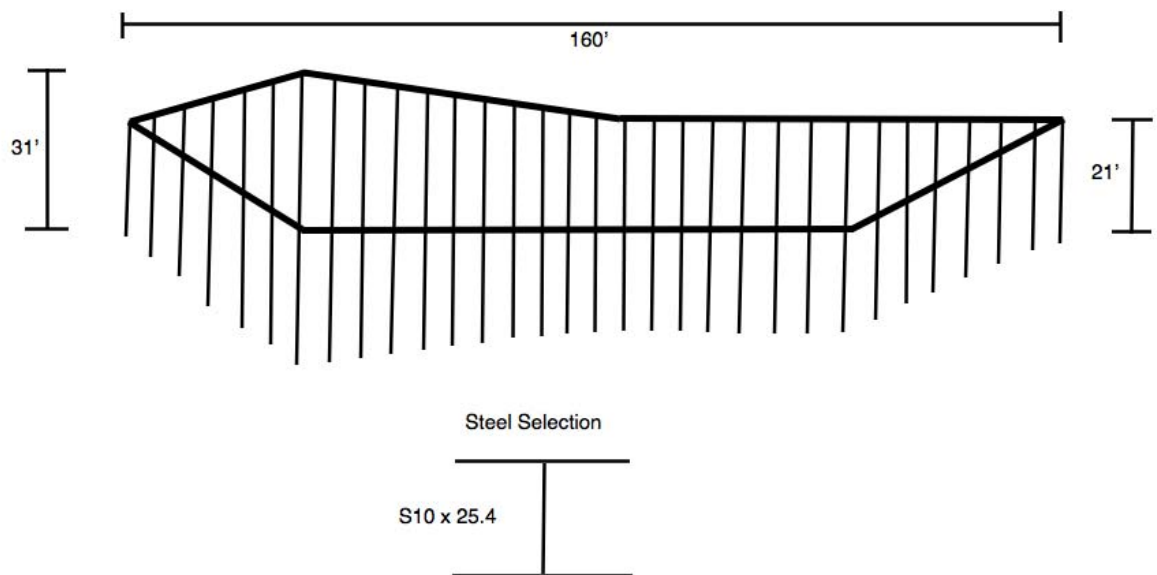


Figure 11: Soldier pile retention wall design

5.3 Deep Soil Mix Retention Wall Design

After considering all various types of earth retaining structures, one of the best alternative recommendation designs for the current earth retaining structure is the deep soil mixed wall. This wall is typically faster to construct than other earth retaining structures. The ease of installation and long design life that this type of structure maintains is the reason why we believed this design to be one of the more acceptable retaining structures for the location specialty of the current soil-nail system design. Also, the low impact on its environment during and after construction makes the deep soil mixed walls more practical in urban areas, such as the location of the Sports and Recreation center. The only detriment that this design offers is its uniqueness. Currently, this type of retaining structure is new to the construction industry, which means that there are no set universal design guidelines. Through other designs, engineers will be able to set failure parameters for this specific structure, until then we assumed that the deep soil mix wall is suitable for the size and location of the earth retaining structure. Below in Table 6 is the design process for deep soil mixed walls to better understand the thought process when considering the installation of a wall this type (Rutherford, 2007).

Table 6: A Design Process for DSM Walls

Design Process for DSM Walls
Initial feasibility assessment, dependent on site conditions and economics.
The type of retaining wall system is decided upon cost, site conditions, and required wall height.
Speed of construction and other project specific requirements.
External Stability Analysis
Repeatable Wall Section
Vertical Bearing Capacity

Once we decided to choose the deep soil mixed walls, we needed to learn about the components within the wall. A deep soil mixed wall contains the overlapping of soil-cement columns that are either installed using a multi-auger rotary shaft or a drilling tool. The columns have a 36 inch diameter and slightly overlap each other. This specialized equipment may increase the cost of the installation but significantly reduces construction time. Once the columns are in place, steel reinforcement is installed, this steel is usually either wide flange H-beams or sheet piles, and in this case we chose the wide H-beams. The H-beams are 4 feet on center apart from one another, this means that every other cement column will have an H-beam of steel. Figure 8 represents what the top of the deep soil wall will look like after complete installation.

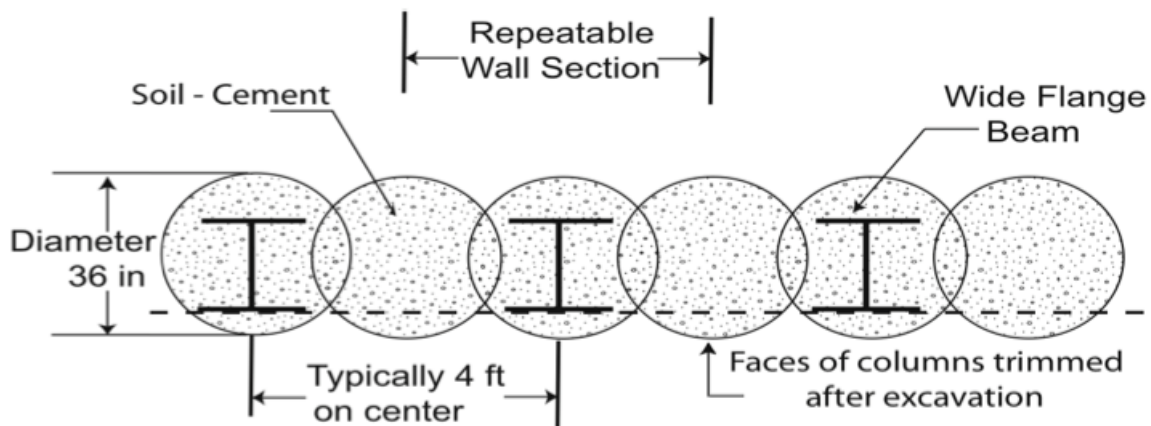


Figure 12: Deep soil mixed wall diagram

After an analysis of the makeup of deep soil mixed retaining structure, we then needed to analyze the components inside the structure. First we calculated the embedment depth of the flanges that are needed in the construction of the retaining structure. These embedment depths were consistent with the calculations of the embedment depth in soldier pile wall systems and

can be found in Appendix A. Once the embedment depths were found, we then conducted a shear resistance test for both values. The equation used was (Rutherford, 2007):

Where:

- 1) $V_{\max} = (p)(L_2)(b_w)$
 V_{\max} = Maximum Shear Resistance
 p = Maximum Earth Pressure
 L_2 = Clear Distance Between Flanges
 b_w = Vertical Height (two different values)

The shear resistance of a deep soil mixed wall with embedment of 15 feet and vertical height of 31 feet is 9589564.8 lbf, and the shear resistance of a deep soil mixed wall with embedment of 10.5 feet and vertical height of 21 feet is 6566767.2 plf. (See Appendix 8.2) Lastly we checked if a bending failure occurs using the equation (Rutherford, 2007):

Where:

- 2) L_2 is less than or equal to $D + h - 2e$
 L_2 = Clear Distance Between Flanges
 D = Depth of Columns
 h = Vertical Height
 e = (Vertical Height/100)

Both vertical heights will avoid bending failure making this type of earth retaining structure design possible to recommend as an alternative to the current soil-nail retaining system currently being used.

Lastly, we found what type of steel beam with a maximum allowable stress of 50,000 psi and section modulus of 1.11. The type of steel beam used for the deep soil mixed retaining structure is S8 x 23, these calculations can be found in Appendix B.

6. Conclusions and Recommendations

The success of a construction project depends greatly on the efficiency in which a Project Manager is able to manage a project. This management involves maximizing productivity of workers, proper scheduling and cost analysis. It also means good communication between all parties. Building Information Modeling provides a means to reduce the amount of work and possibly stressed produced on a construction job. The modeling and scheduling capabilities provide a means to track multiple aspects of a project at once while offering an aesthetically pleasing alternative to large scale plans and drawings.

In our project, we utilized BIM in order to determine estimated excavation volumes in comparison to actual volumes. Originally, we had planned to compare volumes, cost and duration of the excavation, however; we were unable to quantify all three variables due to both time and logistical constraints. From the excavation we were able to model using Revit; we found that the program was very sophisticated for what seemed to be a simple task. The program was able to calculate the amount of earth moved from the existing conditions to both the WPI and surrounding fields.

For future students who wish to partake in Building Information Modeling-related projects, we recommend a stronger background in the program before completely committing to multiple objectives. When used correctly and efficiently, both Civil 3D and Revit provide tremendous resources to both students and professional working in the construction industry. In addition, any analysis regarding scheduling, labor and cost would benefit the students, WPI and a potential sponsoring agency. We believe that there are other sources of computer software that could be even more beneficial for a project similar to this. After browsing the Internet we stumbled across two programs that specialize in site work and earthwork. The first, Trimble

Paydirt® Software is an estimating software for earthwork and material takeoff; and the second, InSite SiteWork Earthwork and Utility Estimating Software provides excavation and utilities takeoff from PDF and CAD files.

Our intent in designing alternative retention walls to be used in the excavation of WPI's Sports and Recreation Center was to explore the feasibility of alternative design methods and their effectiveness. Our goal was to take into consideration the wall's impact on its surrounding environment, ease and efficiency of construction and also to ensure an adequate design. In other words we needed to make sure the wall would have the capability to withstand the earth's forces while also being efficient and safe for construction within the scope of the project.

The two designs that we felt best met these criteria were the Soldier Pile and Deep Soil Mixed retention wall designs. We found that these two designs were fast paced and had little effect on the surrounding environment compared to other options that we studied. We calculated embedment depths and proper steel selection of H flange beams. In doing this we were able to complete the proper procedures necessary to ensure our designs would be able to withstand failure. An additional aspect that we would have liked to have covered was economic implications of constructing these designs. However due to time constraints and lack of knowledge of economic factors we were unable to complete this task.

In comparison of our two alternative designs and the implemented Soil-Nail retention wall, we conclude that the Soil-Nail wall was the best option. The Soil-Nail wall has all of the factors we identified as important in our two designs and also was designed in accordance to prevent failure. However in hindsight, a major obstacle of our designs would be the location of bedrock at the Sports and Recreation Center site. Since our designs would include driving steel deep into the soil at base level of excavation, they would have to penetrate this bedrock layer. In

order to do this, blasting or other drilling techniques would be necessary. This would increase the cost and time of the project, thus decreasing its efficiency. For future students completing a similar MQP we recommend seeking alternative retention wall designs where drilling into this surface would not be necessary. We would also recommend assessing the economic impacts as we were unable to cover this in our report.

References

1. "About Earned Value Analysis - Project - Microsoft Office." *Office - Microsoft Office*. Web. 14 Oct. 2010. <<http://office.microsoft.com/en-gb/project-help/about-earned-value-analysis-HP001034258.aspx>>.
2. "About Earned Value Analysis-Project-Microsoft Office." Office-Microsoft Office. Web. 20 Sept. 2010. <<http://office.microsoft.com/en-gb/project-help/about-earned-value-analysis-HP001034258.aspx>>.
3. "Autodesk - Building Information Modeling - About BIM." *Autodesk - 3D Design & Engineering Software for Architecture, Manufacturing, and Entertainment*. N.p., n.d. Web. 20 Sept. 2010. <<http://usa.autodesk.com/company/building-information-modeling/experience-bim>>.
4. "Building Information Modeling - Wikipedia, the free encyclopedia." *Wikipedia, the free encyclopedia*. N.p., n.d. Web. 20 Sept. 2010. <http://en.wikipedia.org/wiki/Building_Information_Modeling#cite_ref-0>
5. Clough, Richard Hudson., Glenn A. Sears, and S. Keoki. Sears. *Construction Project Management*. New York: Wiley, 2000. Print.
6. Concrete Network. <<http://concretenetwork.com>>.
7. Gannett Fleming, Inc. *Construction Project Management Handbook*. Rep. Mill Valley, California, September, 2009. Print.
8. "Hayward Baker - Grouting, Ground Improvement, Structural Support and Earth Retention Specialists." *Hayward Baker; A Keller Company*. Web. 14 Oct. 2010. <http://www.haywardbaker.com/services/slurry_trench.htm>.
9. Hendrickson, Chris. "Project Management for Construction." *Project Management for Construction*. Summer 2008. Web. 04 Oct. 2010. <<http://pmbok.ce.cmu.edu/>>
10. Nagrecha, Suketu. "An introduction to Earned Value Analysis". March 16, 2002. <http://www.pmiglc.org/COMM/Articles/0410_nagrecha_eva-3.pdf>

11. "NRDC: Building Green - LEED Certification Information." *NRDC: Natural Resources Defense Council - The Earth's Best Defense*. Web. 13 Oct. 2010. <<http://www.nrdc.org/buildinggreen/leed.asp>>.

12. "A New Center for Excellence." *A New Center for Excellence*. N.p., n.d. Web. 19 Sept. 2010. <<http://sportsandrecreation.wpi.edu/project>>.

13. Merriam-Webster Online. Web. 20 Sept. 2010. <<http://www.merriam-webster.com/>>.

14. "Rembco - Soil Nail Wall." Rembco - Soil Nailing Rock Anchors Chemical Compaction Grouting Micropiles Sinkhole. Web. 04 Oct. 2010. <http://www.rembco.com/soil_nail_wall.html>.
15. Rutherford C.J., Biscontin G., Koutsoftas D., Briaud J.L. (2007). Design Process of Deep Soil Mixed Walls for Excavation Support. *International Journal of Geoenvironmental Case Histories*, <http://casehistories.geoengineer.org> , Vol.1, Issue 2, p.56-72

16. "Secant Pile Walls - Tangent Pile Walls - Soldier Piles." *Deep Excavation - Deep Excavations - Deep Excavation - Deep Excavations*. Web. 03 Oct. 2010. <http://www.deepexcavation.com/secant_pile_walls.htm>.

17. "Soil Aggressivity - WordReference.com Dictionary of English." *English to French, Italian, German & Spanish Dictionary - WordReference.com*. Web. 15 Dec. 2010. <http://www.wordreference.com/definition/soil_aggressivity>.

18. "Structural Earth Retention / Excavation Support Methods Conventional Excavation Support Secant Pile Walls Tangent Pile Walls Soil Nailing Soil and Rock Anchors Rock Bolts| Services | Moretrench." *Moretrench | Construction and Geotechnical Services*. Web. 04 Oct. 2010. <http://www.moretrench.com/services_article.php?Structural-Earth-Retention-Excavation-Support-Methods-23>.

19. "Sub-grade - Definition and More from the Free Merriam-Webster Dictionary." *Merriam-Webster Online*. Web. 04 Oct. 2010. <<http://www.merriam-webster.com/dictionary/sub-grade>>.

20. "WPI Trustees Vote to Proceed with Sports and Recreation Center - WPI." *Worcester Polytechnic Institute (WPI)*. N.p., n.d. Web. 19 Sept. 2010. <http://www.wpi.edu/news/20090/rec-plans.html>

Appendices

- A. Boring Reports
- B. Soil Profile
- C. Retention Wall Embedment Depth
- D. Retention Wall Steel Selection
- E. Deep Soil Mixed Walls
- F. Building Information Modeling

A. Boring Reports

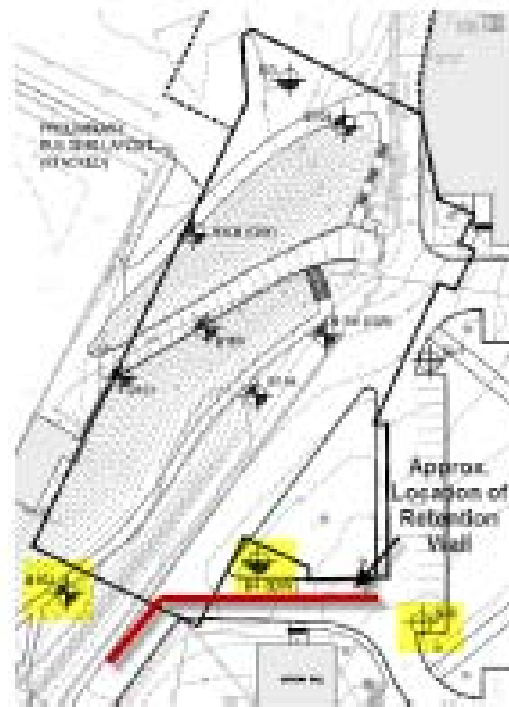


Figure 1: Boring Report locations

The above image is an aerial view of WPI's Sports and Recreation Center's location. In red is the approximate location of where the retention wall was constructed. Spread throughout the image are different boring holes which Haley and Aldrich tested. Highlighted are the three borings which we chose to look at specifically, B102, B4 and B6, in order to gain an understanding of the soil surrounding the retention wall.

B. Soil Profile

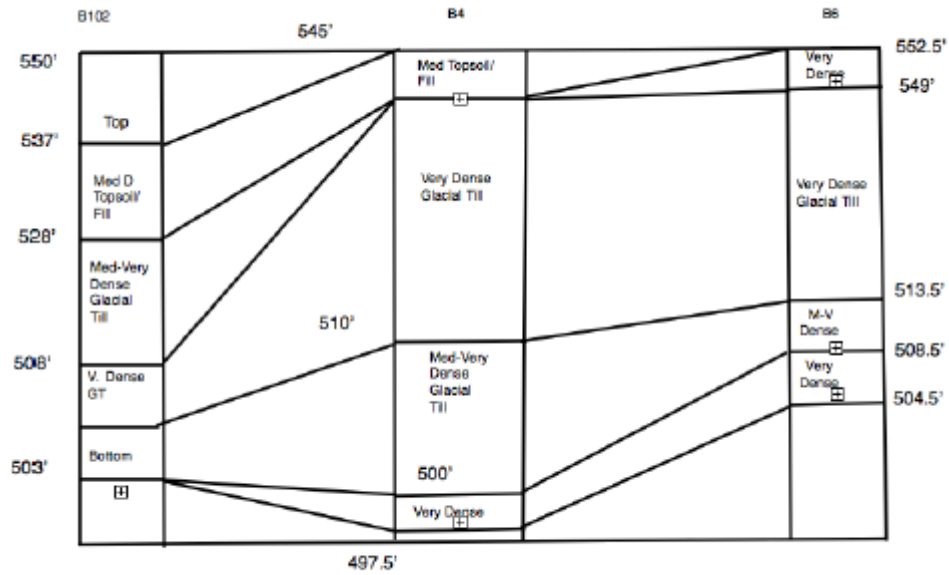


Figure 1: Soil Profile section

This image is a cross-section view of the different layers of soil found based on the three selected borings, B102, B4 and B6. The image includes heights where expected changes in soil classifications occur along with the soil classifications themselves. Not that the majority of the soil where the retention wall would be implemented is classified as “very-dense glacial till”.

C. Retention Wall Embedment Depth Procedure and Calculations

One potential alternative design for the earth retaining structure built to support the excavation efforts done for the New WPI Sports and Recreation Center is to implement a sheet pile structure. The first necessary calculation to make for this design is to find the depth the piles must penetrate the soil at the subgrade level, also known as embedment depth. We completed this calculation by following the step by step procedure found in Braja Das's *Principles of Foundation Engineering*.

The maximum and minimum wall heights were used in these calculations in order to get the maximum and minimum pile depths. These heights are 31 and 21 feet respectively. From our soil profiling work we already concluded that the soil's density is 140 pcf with an angle of repose of 45 degrees. Note that the following paragraphs include a description of the step by step procedure with the empirical equations used and the results we found from each equation. A hand written step by step procedure follows which includes the equations with the numbers that were inserted into each variable and also the results calculated at each step.

The first step in finding the embedment depth of the sheet piles is to calculate the active and passive pressure coefficients K_a and K_p . Equations 1 and 2 were used to determine these numbers. By using an angle of repose of 45 degrees these calculations were determined to be 0.172 and 5.83 respectfully. At several points throughout this procedure calculations call for the passive coefficient minus the active coefficient so at this point we can define $K_a - K_p = 5.66$.

$$1) K_a = \tan^2(45 - \phi/2) = 0.172$$

$$2) K_p = \tan^2(45 + \phi/2) = 5.83$$

Next we determine the active pressure at depth L (subgrade level). Since we are looking at two different wall heights separate calculations were needed. For wall height 31 ft. this

number was found to be 746.48 lb/ft² and for a wall height of 21 ft., 505.68 lb/ft². Equation 3 was used.

$$3) P_2 = yLK_a$$

Using this figure we next calculated L_3 . This point represents a depth below the subgrade where there is no shear force acting on the soldier pile. Equation 4 was used and L_3 was found to be 0.94 ft. for the 31 foot wall and 0.638 ft. for the 21 foot wall.

$$4) L_3 = p_2 / (y(K_a - K_p))$$

It is now possible to find the summation of the horizontal forces acting on the wall. This is done by finding the area of the triangular pressure diagram we would have using p_2 . Equation 5 was used for this calculation and found to be 11922.03 lb/ft. and 5470.95 lb/ft. for the 31 and 21 foot wall sections respectively.

$$5) P = .5p_2L + .5p_2L_3$$

The location of this force is also an important design consideration. We know that the resultant force of a pressure distribution diagram in the form of a triangle will occur one third from the base of the triangle. With that knowledge we can find the distance from P to the point A by adding L_3 and 1/3 of L. Equation 6 was used in this calculation and determined to be 11.28 ft. and 7.64 ft. for the 31 and 21 foot sections.

$$6) z = L_3 + L/3$$

Several additional underground forces needed to be calculated. We named these forces p_3 , p_4 and p_5 and they represent active pressures at different depths beneath the subgrade. Equations 7, 8 and 9 were used for these calculations. For the 31 foot wall these forces are 11093.6 lb/ft., 37142.24 lb/ft. and 26048.64 lb/ft. respectively. For the 21 foot wall section these forces are 7527.8 lb/ft., 25173.55 lb/ft. and 17645.75 lb/ft. respectively. Note that p_3 and p_4 require length L_4 which will be calculated shortly.

$$7) P_3 = L_4(K_p - K_a)y$$

$$8) P_4 = p_5 + yL_4(K_p - K_a)$$

$$9) P_5 = yLK_p + yL_3(K_p - K_a)$$

Our goal here is to find L_4 by summing the moments about the bottom of the wall. To complete this, the sum of the areas at each acting force must be obtained. We called these areas A_1 , A_2 , A_3 and A_4 and their corresponding calculations are as depicted in Equations 10 through 13. For a wall height of 31 feet these calculations were 32.87, 120.36, 5004.1 and 3479.39 respectively. For a height of 21 feet the areas were 22.27, 55.23, 1555.31 and 7236.71 respectively.

$$10) A_1 = p_5 / (y(K_p - K_a))$$

$$11) A_2 = 8P / (y(K_p - K_a))$$

$$12) A_3 = 6P[2zy(K_p - K_a) + p_5] / y^2(K_p - K_a)^2$$

$$13) A_4 = P(6zp_5 + 4P) / y^2(K_p - K_a)^2$$

It is now possible to determine our final length, L_4 , which represents the distance between point "A" and the bottom of the necessary depth of the soldier piles. This formula can be found in Equation 14. We determined L_4 to be 14 ft. for the 31 foot section and 9.5 feet for the 21 foot section. This equation involved solving a function to the fourth degree, so a guess a check approach was taken.

$$14) L_4^4 + A_1L_4^3 - A_2L_4^2 - A_3L_4 - A_4 = 0$$

Once we know L_4 our designated depth can be determined. Since L_4 represents the distance from point A to the necessary embedment depth, and L_3 represents the distance from point A to the subgrade, we can find the total distance by adding these two figures together (Equation 15). For a wall height of 31 feet the required Depth (D) is approximately 15 feet. For a wall height of 21 feet that depth is 10.5 feet.

$$15) D=L_3+L_4$$

The total depth the piles would have to penetrate for the weight of the wall to not overturn the wall is equal to this D value. By adding the length above ground, or our L values, with their corresponding D values the total length of each pile can be found. Piles at height 31 feet have an additional 15 feet submerged in soil, making them 46 feet long as depicted in figure 13.

Soldier Pile Retention Wall Design Analysis

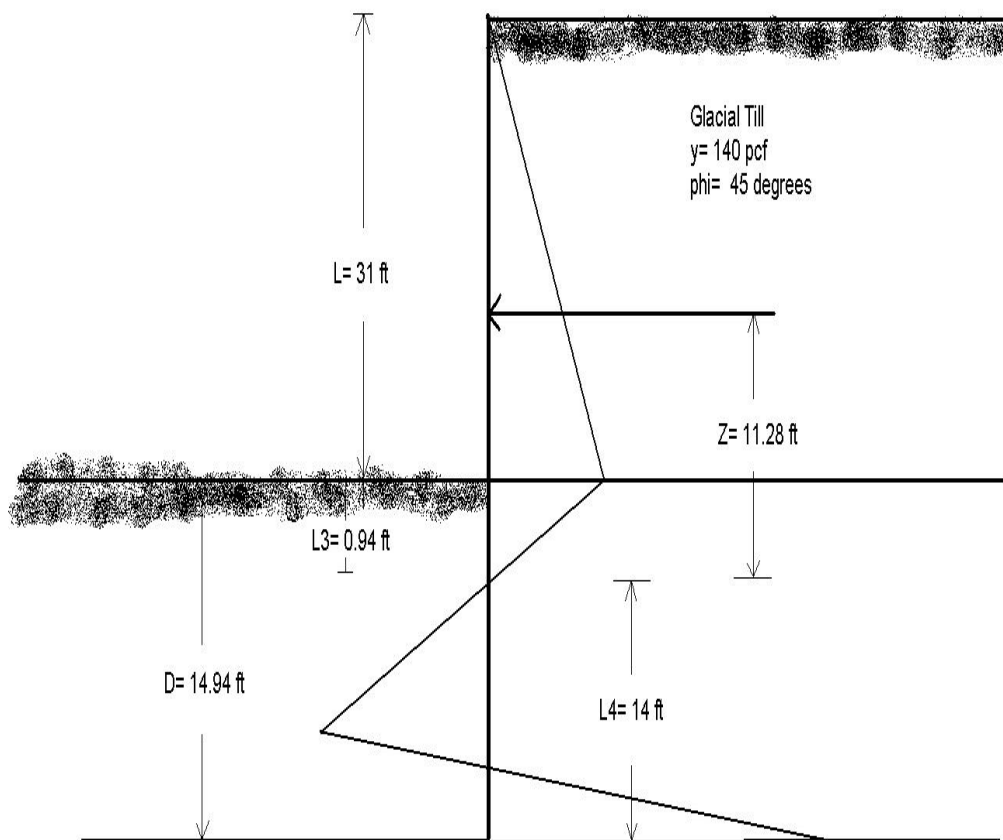


Figure 1: Embedment Depth Analysis 31' Section

Similarly the 21 foot height portion of the wall would need an additional 10.5 feet underground and therefore be 31.5 feet long. These depths are depicted in figure 14.

Soldier Pile Retention Wall Analysis

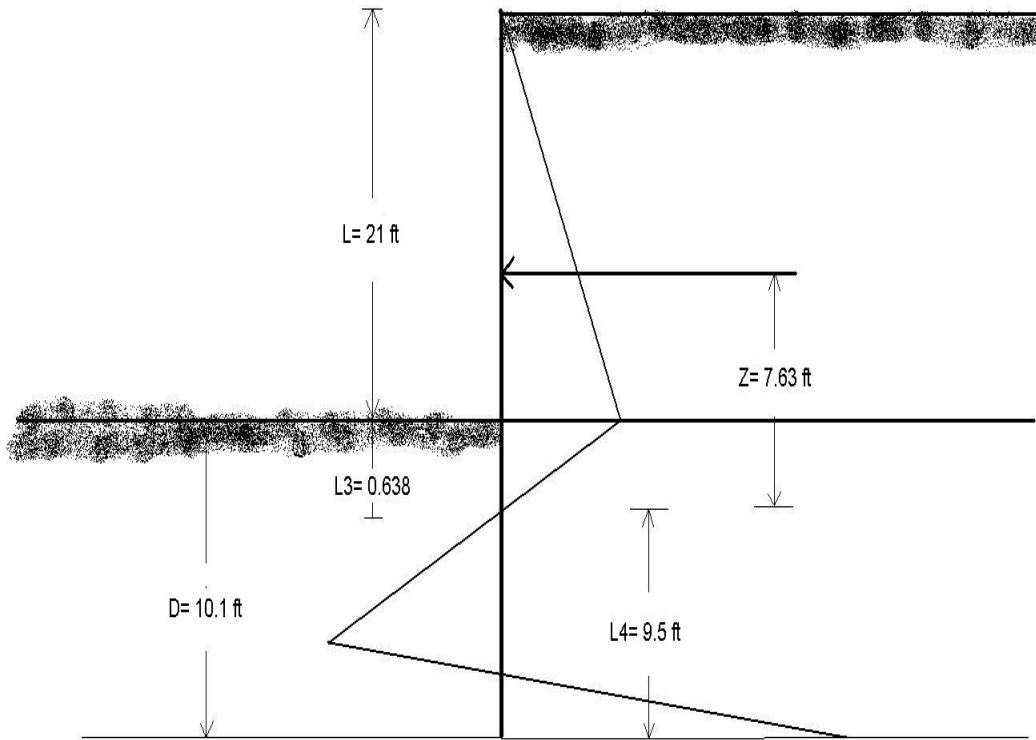


Figure 2: Embedment Depth Analysis 21' Section

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2/15/11

Retention Wall Embedment Depth Calculations

Sec A) Given: Wall height = 31' ^{soil density} PCF = 140 ϕ (angle of repose) = 45°

$$- K_a = \tan^2\left(45 - \frac{\phi}{2}\right) = \tan^2(45 - 22.5) = \underline{.172}$$

$$- K_p = \tan^2\left(45 + \frac{\phi}{2}\right) = \tan^2(45 + 22.5) = \underline{5.83}$$

$$K_p - K_a = \underline{5.66}$$

$$\begin{aligned} - P_2 &= \gamma L K_a \\ &= 140(31) \cdot .172 \\ &= \underline{746.48 \text{ lb/ft}^2} \end{aligned}$$

$$- L_3 = \frac{P_2}{\gamma(K_p - K_a)} = \frac{746.48}{140(5.66)} = \underline{.942 \text{ ft}}$$

$$- P = \frac{1}{2} P_2 L + \frac{1}{2} P_2 L_3$$

$$= \frac{1}{2} (746.48) 31 + \frac{1}{2} (746.48) \cdot 942$$

$$= 11570.44 + 351.6 = \underline{11922.03} \text{ lb/ft}$$

$$- P_s = \gamma L K_p + \gamma L_3 (K_p - K_s)$$

$$= 140(31) 5.87 + 140(-942)(5.66)$$

$$= \underline{26048.64} \text{ lb/ft}$$

$$- A_1 = \frac{P_s}{\gamma (K_p - K_s)} = \frac{26048.64}{140(5.66)} = \underline{32.87}$$

$$- A_2 = \frac{8P}{\gamma (K_p - K_s)} = \frac{8(11922.03)}{140(5.66)} = \underline{120.36}$$

$$- \bar{z} = L_3 + \frac{L}{3} = -942 + \frac{31}{3} = \underline{11.28} \text{ ft}$$

1

Retention Wall Embedment Depth Calculations

$$\begin{aligned} - A_3 &= \frac{6P[2\bar{z}_y(K_p - K_s) + P_s]}{\gamma^2(K_p - K_s)^2} \\ &= \frac{6(11922.03)[2(11.28)(140)(5.66) + 26048.64]}{140^2(5.66)^2} \\ &= \frac{71532.18[43925.184]}{627897.76} = \underline{5004.1} \end{aligned}$$

$$\begin{aligned} - A_4 &= \frac{P[6\bar{z}P_s + 4P]}{\gamma^2(K_p - K_s)^2} \\ &= \frac{11922.03[6(11.28)(26048.64) + 4(11922.03)]}{140^2(5.66)^2} \\ &= \frac{11922.03(1810660.075)}{627897.76} = \underline{34379.39} \end{aligned}$$

$$- L_4^4 + A_1 L_4^3 - A_2 L_4^2 - A_3 L_4 - A_4 = 0$$

$$L_4 = 14$$

$$0 = (14)^4 + 32.87(14)^3 - 120.36(14)^2 - 5004.1(14) - 34379.28$$

$$= ~~30446~~ = 587.93$$

Use 14 ft.

$$- D = L_3 + L_4 = 14 + .942 \\ \approx 15 \text{ ft}$$



Retention Wall Embedment Depth Calculations

$$\begin{aligned} - P_3 &= L_4 (K_p - K_a) \gamma \\ &= 14 (5.66) 140 \\ &= 11093.6 \text{ lb/ft} \end{aligned}$$

$$\begin{aligned} - P_4 &= P_3 + \gamma L_4 (K_p - K_a) \\ &= 26048.64 + 11093.6 \\ &= 37142.24 \text{ lb/ft} \end{aligned}$$

$$- z' = \sqrt{\frac{2P}{(K_p - K_a) \gamma}} = \sqrt{\frac{2(11922.03)}{(5.66) 140}} = 5.49'$$

$$\begin{aligned} - M_{max} &= P(\bar{z} + z') - \left[\frac{1}{2} \gamma z'^2 (K_p - K_a) \right] \frac{z'}{3} \\ &= 11922.03(17.22) - \left[\frac{1}{2} (140) (5.49)^2 (5.66) \right] \frac{5.49}{3} \\ &= 205297.36 - 23227.28 \\ &= 182070.0766 \text{ lb ft/ft} \end{aligned}$$

$$- S = \frac{M_{max}}{\sigma_{all}}$$

* assume σ_{all} for steel = 50,000 psi

3

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2/15/11

Retention Wall Embedment Depth Calculations

Sec B) Given \rightarrow Wall height = 21'

Soil density = $\gamma = 140$ pcf

ϕ : angle of repose = 45°

$$- K_a = \tan^2\left(45 - \frac{\phi}{2}\right) = \tan^2(45 - 22.5) = .172$$

$$- K_p = \tan^2\left(45 + \frac{\phi}{2}\right) = \tan^2(45 + 22.5) = 5.83$$

$$K_p = K_a = 5.66$$

$$- P_2 = \gamma L K_a$$

$$= 140(21) \cdot .172$$

$$= 505.68 \text{ lb/ft}^2$$

$$- L_2 = \frac{P_2}{\gamma(K_p - K_a)} = \frac{505.68}{140(5.66)} = .638$$

$$\begin{aligned}
 - P &= \frac{1}{2} (\cancel{746.68}) \cdot 21 + \frac{1}{2} (\cancel{746.68}) \\
 &= \frac{1}{2} P_2 L + \frac{1}{2} P_2 L_3 \\
 &= \frac{1}{2} (505.68) 21 + \frac{1}{2} (505.68) \cdot 638 \\
 &= 5309.64 + 161.31 = 5470.95 \quad \text{lb/ft}
 \end{aligned}$$

$$\begin{aligned}
 - P_5 &= \gamma L k_p + \gamma L_3 (k_p - k_s) \\
 &= 140 (21) 5.83 + 140 (.638) (5.66) \\
 &= 17645.75 \quad \text{lb/ft}
 \end{aligned}$$

$$- \bar{z} = L_3 + \frac{L}{3} = .638 + \frac{21}{3} = 7.638 \quad \text{ft}$$

5

Retention Wall Embedment Depth Calculations

$$- A_1 = \frac{P_5}{\gamma (K_p - K_a)} = \frac{17645.75}{140 (5.66)} = 22.27$$

$$- A_2 = \frac{8P}{\gamma (K_p - K_a)} = \frac{8(5470.95)}{140 (5.66)} = 55.23$$

$$\begin{aligned}
 - A_3 &= \frac{6P [2\bar{z} \gamma (K_p - K_a) + P_5]}{\gamma^2 (K_p - K_a)^2} \\
 &= \frac{6(5470.95) [2(7.638) 140 (5.66) + 17645.75]}{140^2 (5.66)^2} \\
 &= \frac{32825.7 (29750.45)}{627897.76} \\
 &= 1555.31
 \end{aligned}$$

$$\begin{aligned}
 - A_4 &= \frac{P [6\bar{z} P_5 + 4P]}{\gamma^2 (K_p - K_a)^2} \\
 &= \frac{5470.95 (6(7.638) 17645.75 + 4(5470.95))}{140^2 (5.66)^2}
 \end{aligned}$$

$$= 7236.712$$

$$-L_4^4 + A_1 L_4^3 + A_2 L_4^2 - A_3 L_4 - A_4 = 0$$

$$L_4 = 9.5$$

$$(9.5)^4 + 22.27(9.5)^3 - 55.23(9.5)^2 - 1555.31(9.5) - 7236.12 = 242$$

Use 9.5 ft

$$D = L_3 + L_4 = .638 + 9.5 = 10.14$$

$$\approx 10.5 \text{ ft}$$

6

Retention Well Embedment Depth Calculations

$$\begin{aligned} - P_3 &= L_4 (K_p - K_u) \gamma \\ &= 9.5 (5.66) 140 \\ &= 7527.8 \end{aligned}$$

$$\begin{aligned} - P_4 &= P_3 + \gamma L_4 (5.66) \\ &= 17645.75 + 7527.8 \\ &= 25173.55 \end{aligned}$$

$$\begin{aligned} - z' &= \sqrt{\frac{2P}{(K_p - K_u) \gamma}} = \sqrt{\frac{2(5470.95)}{(5.66) 140}} \\ &= 3.72 \text{ ft} \end{aligned}$$

$$\begin{aligned} - M_{\max} &= P(\bar{z} + z') - \left[\frac{1}{2} \gamma z'^2 (K_p - K_u) \right] \frac{z'}{3} \\ &= 5470.95 (7.638 + 3.72) - \left(\frac{1}{2} (140) 3.7^2 (5.66) \right) \frac{3.72}{3} \\ &= 17150 - 1775 \end{aligned}$$

$$= 62130 - 6120.1$$

$$= 55424.28$$

$$- S = \frac{M_{max}}{\sigma_{all}}$$

Given σ_{all} for steel = 50,000 psi

7

D. Retention Wall Steel Selection Procedure and Calculations

First we will determine the steel I beam classification necessary to support our designed Soldier Pile Wall. We first must calculate the maximum bending moment of the beams. With this we will know the required sectional modulus of the sheet piles required per unit length of the structure. We know that this point will coincide with the point we determined to have zero shear. To determine this point we use Equation 16. This point was found to be 5.49 feet and 3.72 feet for walls heights 31 and 21 feet respectively.

$$16) z' = [2P / (K_p - K_a) y]^{sq rt}$$

After finding the location of this point we can now use the rest of our calculations to sum the moment at this area. This calculation is depicted in Equation 17. The maximum bending moment for the 31 foot wall is 182070.08 lb*ft./ft. The max bending moment for the 21 foot section was found to be 55424.28 lb*ft./ft.

$$17) M_{max} = P(z+z') - [.5yz'^2(K_p - K_a)](1/3)z'$$

The required section modulus is found using equation 18. We assumed the allowable stress (σ_{all}) of steel to be 50,000 psi (http://www.skylinesteel.com/assets/Bulletins/MaterialTruth_TB_Web.pdf). With this assumption we then calculated the section modulus (S) for each wall height. The 31 foot section was determined to have a section modulus of 3.64 per horizontal foot of wall and the 21 foot wall has a modulus of 1.11 per horizontal foot.

$$18) S = M_{max} / \sigma_{all}$$

We selected the piles to be driven 5 ft. on center, that is to say the wall will have piles in 5 foot intervals. This is necessary to note at this point in our calculations since the section modulus we determined is in unit length of the wall. We must multiply S by 5 ft. since each pile

will need to hold 5 times what we have calculated. Our final section modulus for the 31 foot section is 18.2 and 5.55 for the 21 foot section. By coordinating those calculated figures to the following table we were next able to select the dimensions of our steel beams. The section modulus we determined is the minimum amount the beam must be designed to support. Therefore the value we select should be larger than this number. In this table, W_x is the corresponding value since we are determining the modulus in the stronger direction of the beam. For the 31 foot section the next greatest W_x value after 18.2 is 24.7. This corresponds to beam S 10 X 24.5. For the 21 foot section the value greater than 5.55 corresponds to beam S 5 X 14.5.

Table 1: Steel size selection

Designation	Dimensions					Static Parameters			
	Depth h (in)	Width w (in)	Web Thickness s (in)	Sectional Area (in ²)	Weight (lb/ft)	Moment of Inertia		Section Modulus	
Imperial (in x lb/ft)						I_x (in ⁴)	I_y (in ⁴)	W_x (in ³)	W_y (in ³)
S 10 x 35	10	4.944	0.594	10.3	35	147	8.36	29.4	3.38
S 10 x 25.4	10	4.661	0.311	7.46	25.4	124	6.79	24.7	2.91
S 8 x 23	8	4.171	0.441	6.77	23	6409	4.31	16.2	2.07
S 8 x 18.4	8	4.001	0.271	5.41	18.4	57.6	3.73	14.4	1.86
S 7 x 20	7	3.860	0.450	5.88	20	42.4	3.17	12.1	1.64
S 7 x 15.3	7	3.662	0.252	4.5	15.3	36.7	2.64	10.5	1.44
S 6 x 17.25	6	3.565	0.465	5.07	17.25	26.3	2.31	8.77	1.30
S 6 x 12.5	6	3.332	0.232	3.67	12.5	22.1	1.82	7.37	1.09
S 5 x 14.75	5	3.284	0.494	4.34	14.75	15.2	1.67	6.09	1.01
S 5 x 10	5	3.004	0.214	2.94	10	12.3	1.22	4.92	0.81

Source: http://www.engineeringtoolbox.com/american-standard-beams-d_1320.html

Retention Wall ~~Estimate~~ Steel Selection (P.4) Calculations

$$- S = \frac{M_{max}}{\sigma_{all}} = \frac{182070.08}{50,000} = 3.64 \text{ per unit length}$$

Soldier Piles 5 ft o.c.

$$3.64 \times 5 = 18.2$$

$$S 8 \times 23 \text{ steel} \Rightarrow S = 16.2$$

$$S 10 \times 28.4 \text{ steel} \Rightarrow S = 24.7 \star$$

Deep Soil Mixed Steel Selection

Flanges 4' o.c.

$$3.64 \times 4 = 14.56$$

$$S 8 \times 23 \quad S = 16.2$$

Retention Wall Steel Selection Calculations

$$-S = \frac{M_{max}}{S_{all}} = \frac{55424.28}{50000} = 1.11 \text{ per unit length}$$

Piles 5 ft o.c.

$$1.11 \times 5 = 5.55$$

$$S8 \times 14.75 \rightarrow S = 6.09 \quad \star$$

Deep Soil Mixed Steel Selection

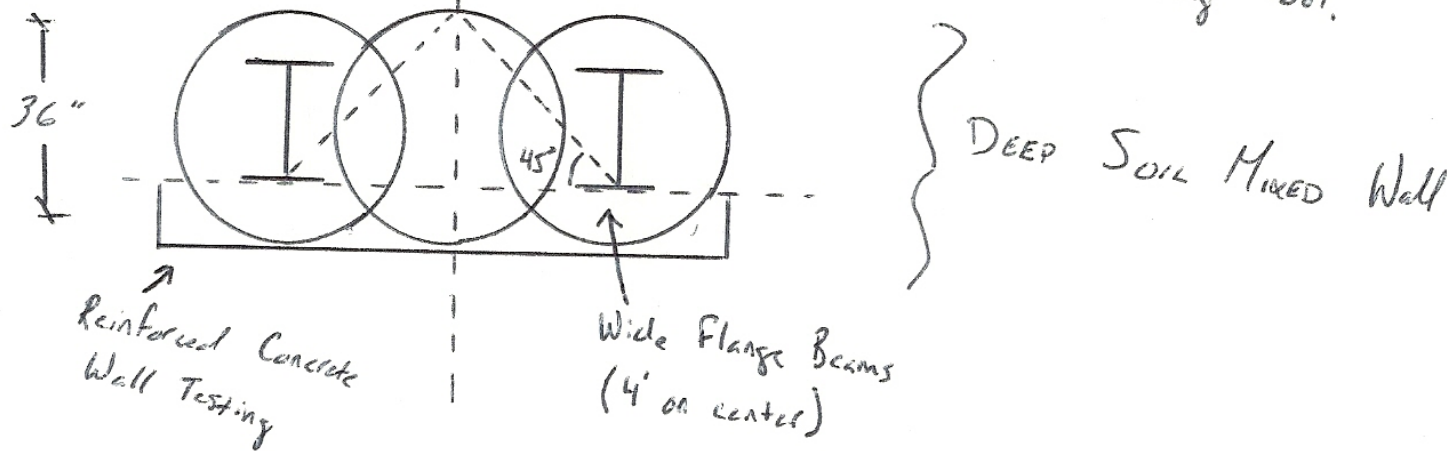
Flanges 4' o.c.

$$1.11 \times 4 = 4.44$$

$$\underline{S5 \times 10.0} \quad \star \quad S = 4.92$$

E. Deep Soil Mix Retention Wall Calculations

- Involves constructing a support wall by mixing in "situ-soils" with a stabilizing agent.
- Good for Urban Areas, w/ high groundwater tables since the placement of Deep Soil Mixed (DSM) columns causes little disturbance to the surroundings and generates low vibration and noise pollution.
- Due to its recent exposure to the construction industry, there are no standardized set design guidelines available.
- The most common method of DSM in excavations involves overlapping soil-cement columns that are either installed using a multi-ruger rotary shaft or a drilling tool.



SHEAR RESISTANCE of DSM: this is used to describe the magnitude of the shear stresses that the soil can sustain. This is being investigated in ...

Bending Failure test.

0. ... in order to later on conduct a

$$\text{Shear Resistance} = V_{\max} = p \cdot L_d \cdot b_w$$

$$V_{\max} = (52117.2 \text{ pif})(4')(46 \text{ ft and } 31.5 \text{ ft})$$

$$p = \text{Max earth pressure} = 52117.2 \text{ pif}$$

$$V_{\max} = 9589564.8 \text{ pif @ Vert. Height } 46'$$

$$L_d = \text{clear distance between flanges} = 4 \text{ ft}$$

$$\underline{\underline{6566767.2 \text{ pif @ Vert. Height } 31.5'}}$$

$$b_w = \text{vertical height} = 46 \text{ ft and } 31.5 \text{ ft}$$



← d Heights will be test because the vertical height of the wall is not consistent

Bending Failure Test of DSM: This test is done to make sure the design of the DSM will resist shear stresses sustained by the soil in order to avoid design failure.

$$L_d \leq D + h - 2e$$

L_d = clear distance between flanges = 4'

D = depth of columns = 36" or 3'

h = vertical height = 46 ft ^{→ 31 ft} and 31.5 ft ^{→ 21'}

e = vertical height / 100

For embankment depth of 15' and vertical height 31'

$$4' \leq 3' + 31' - (2(31/100))$$

$$4' \leq 33.38'$$

✓ It will avoid bending failure!

For embankment depth of 10.5' and vertical height 21'

$$4' \leq 3' + 21' - (2 \tan(20^\circ/2))$$

$$4' \leq 23.58'$$

✓ It will avoid bending failure!

F. BIM Tutorial

This “how to” approach is meant to follow the tutorial on the process of using Google Earth to capture a satellite image and use both GPS and surveying techniques to create a topographic surface.

Step 1:

After importing the picture into Revit, a building pad was created on top of the satellite image to act as a building footprint in order to determine the position and area of the building.

Figure 1 offers a visual aid of the building pad built adjacent to Alumni Field, WPI.

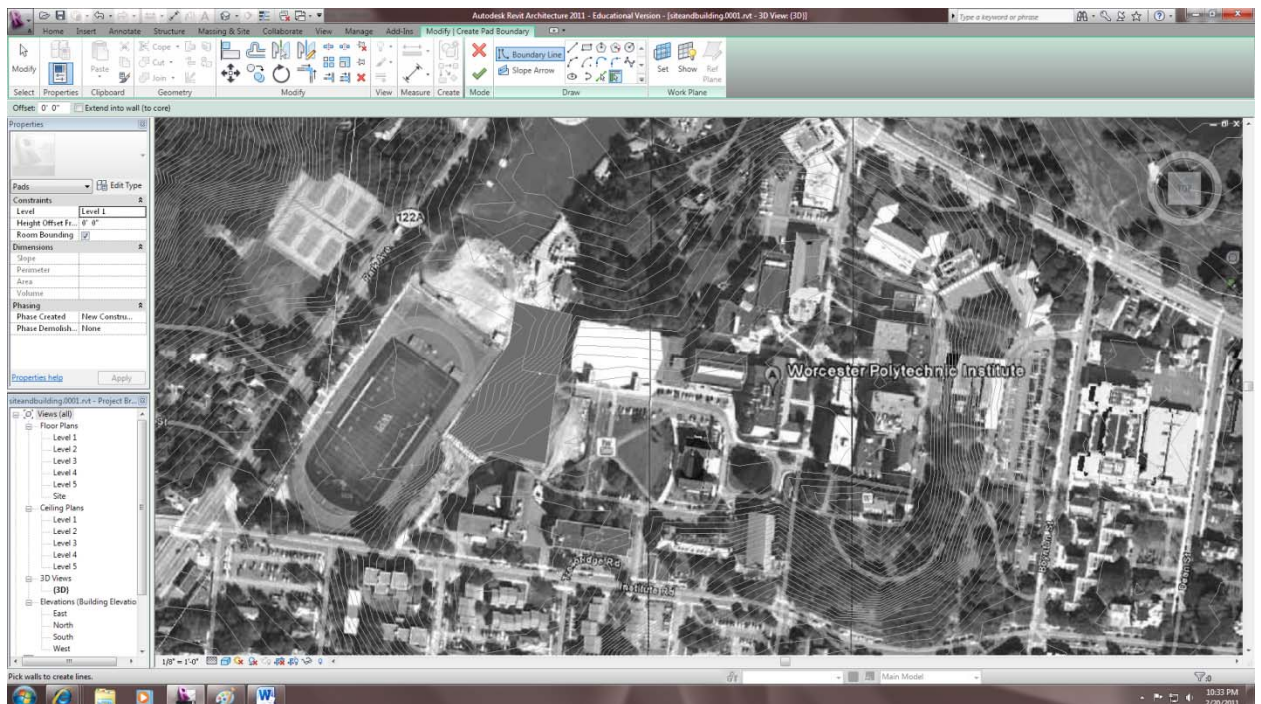


Figure 1. Building pad function in Revit

Step 2:

After the toposurface had been created using the technique in the previous tutorial, the properties were changed accordingly. The first surface was renamed to “Existing surface” and the phasing had changed to “Existing”.

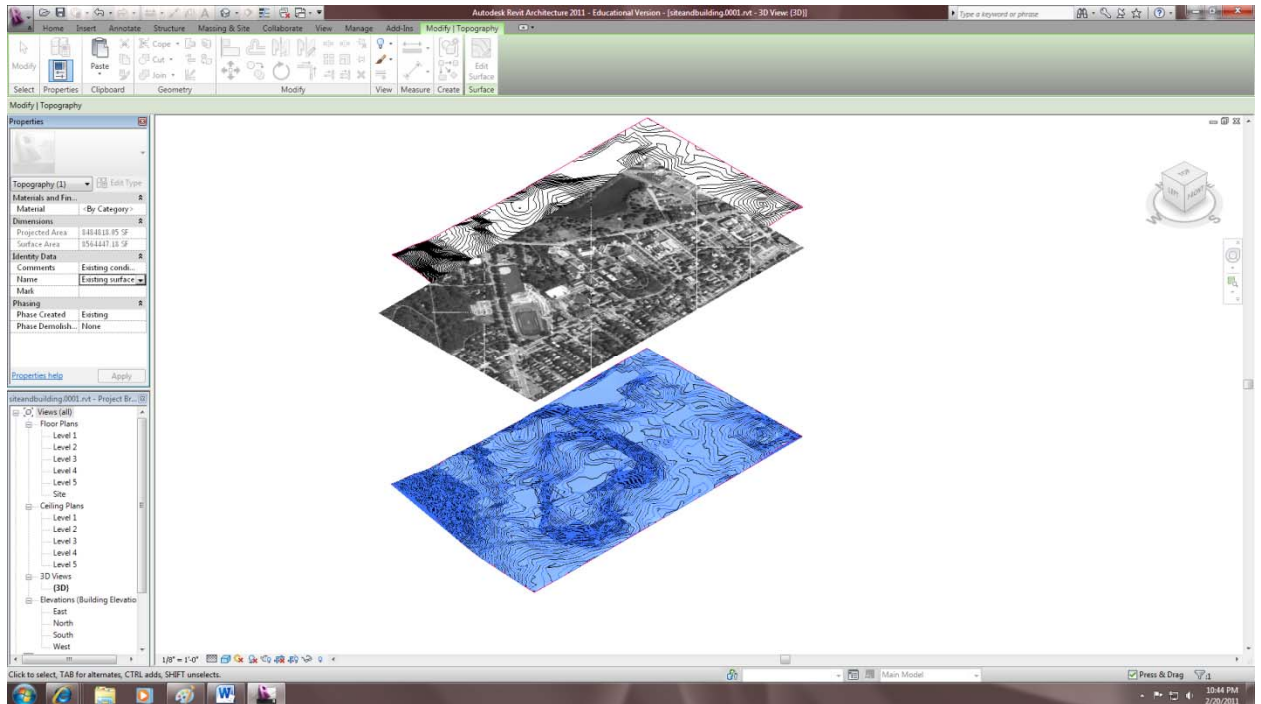


Figure 2. Editing surface properties in Revit

Step 3:

This next step is the most tedious step in the modeling process. The surface had to be modified accordingly in order to match the depths of the mass excavation. In the edit mode for topographic surfaces each point can be modified accordingly to match new conditions. The lowest point in the building (excluding the pool) called for an elevation of 519' and the elevation for the WPI quadrangle is 550'.

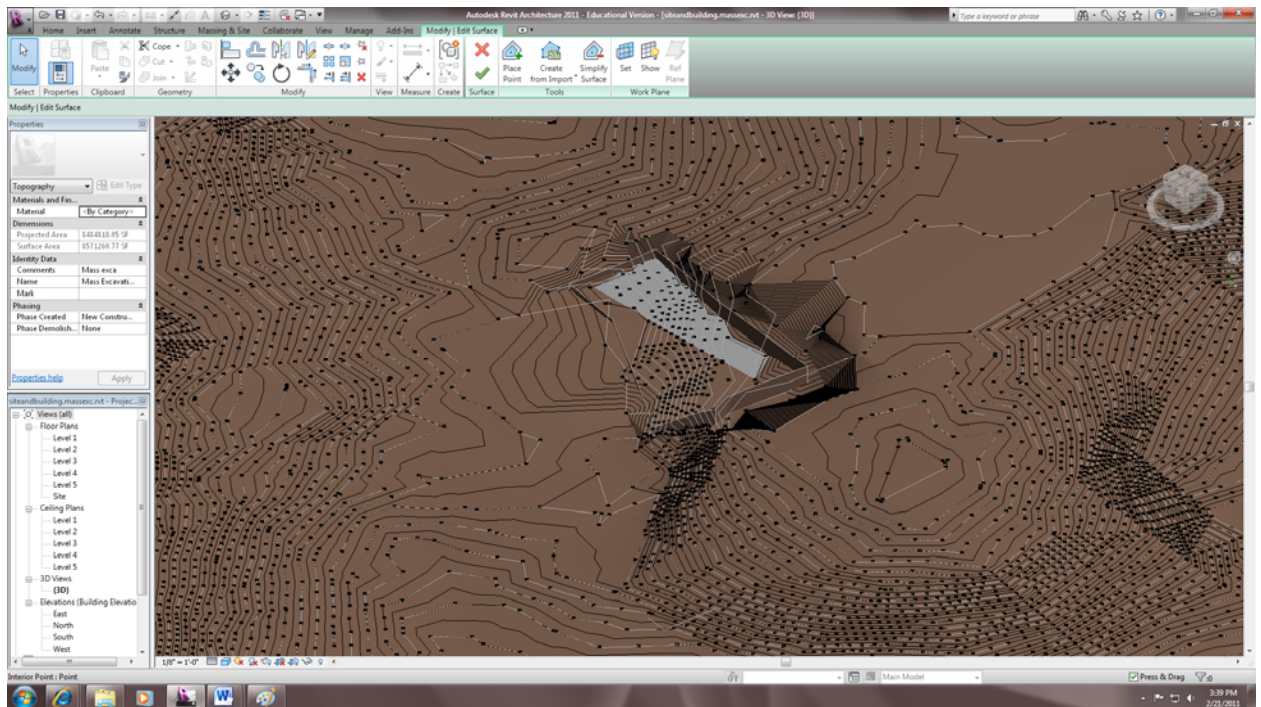


Figure 3. Individual points on the surface can be altered to represent different surface areas

Step 4:

After redefining elevations for certain points in the model, a schedule was created in Revit to calculate the volumes of excavation. In the 'View' tab on the banner in Revit, select

‘Schedule’ and create new. A topographic schedule was chosen and the two phases, Existing conditions and Mass excavation, were compared in regards to area, cut, fill and net cut/fill. The schedule reads similar to Figure 4.

Topography Schedule					
Name	Surface Area	Projected Area	Cut	Fill	Net cut/fill
Existing surface	8564447 SF	8484818 SF	0.00 CF	0.00 CF	0.00 CF
Mass Excavation	8571261 SF	8484818 SF	2619784.40 CF	118198.33 CF	-2501586.07 CF

Figure 4. Topography schedule in Revit

Step 5:

The process of altering the toposurface was repeated once more in order to find the correct volume of earth for the backfill and if the excavated earth would be enough. Figure 5 shows the final backfill numbers.

Topography Schedule					
Name	Surface Area	Projected Area	Cut	Fill	Net cut/fill
Mass Exc	8571261 SF	8484818 SF	0.00 CF	0.00 CF	0.00 CF
Backfill	8564447 SF	8484818 SF	79914.07 CF	2510921.70 CF	2431007.63 CF

Figure 5. Second topography schedule for cut/fill volumes