Multi-purpose Building
and Overflow Parking
Detailed Design Report

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University of British Columbia

CIVL 446

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EXECUTIVE SUMMARY

Declining attendance revenues and general funding at the University of British Columbia Botanical Garden have severely limited the capabilities of the institution to undertake meaningful research in recent years. The collection's lack of renown and isolated position on campus have further contributed to the garden fading into near obscurity. Despite dwindling financial resources, UBC Botanical Garden officials have explored investment in new facilities on its grounds in order to increase the venue's visibility and attract more visitors—one such possible project is a multi-purpose building providing both improved research functionality and an additional revenue stream from offering food and lounge services to patrons and UBC students.

CIVL 446 Group 15 has been retained by the University of British Columbia Botanical Garden to provide a detailed design of an earth-retaining wall for a proposed multi-purpose building design concept, also provided by the same team. This report describes technical details of a recommended structural design along with relevant geotechnical analysis and construction management deliberations required to construct the wall. A brief summary of the overall conceptual building design is provided prior to the technical description and analyses, and concluding remarks and considerations are offered after the technical body.

The final design consists of a 184m long cantilever wall with Z-shaped sheet piles supported by anchors spaced at equal distances as required to balance all passive and active soil forces. Geotechnical limit states analyses establish factors of safety for a variety of most-probable failure modes including rotational, translational and global instability failure. Construction of the project is estimated to cost approximately $500 000, with the whole process lasting 73 days.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1 INTRODUCTION

1.1 Purpose

The purpose of this report is to complete a detailed design of the first stage of construction; site excavation and shoring. The report begins with a brief description of the multi-purpose building and underground parkade; discussing the building's features, including cross-sections and floor plans from a building information model (BIM). Details on the design of the retaining wall are presented afterwards. Firstly, a review of the geotechnical conditions at the site will be discussed and wall failure mechanisms will be analyzed. The structural components of the wall will be examined and defined as required by the geotechnical conditions. Finally, the construction management process required to install the retaining wall will be presented, including a cost analysis and construction schedule.

1.2 Background

The existing facilities at the UBC Botanical Gardens can only accommodate small functions indoors while large functions are at the mercy of the outside weather. Furthermore, functions are extremely limited due to the lack of parking at the gardens. The concept for the multi-purpose building spawned out of this need for a large space to encourage events all year round. Likewise, the parkade incorporated into the design of the multi-purpose building will meet the need of overflow parking required during these larger events.

1.3 Description

The multi-purpose building is designed to provide a space capable of many functions. As a focus of the UBC Botanical Gardens, the building will maintain its roots in providing research capabilities and office space for researchers and employees of the garden. In addition, the building will also permit large banquets including weddings, business parties and social gatherings to occur in the main hall. Meanwhile, the smaller lecture theatre will suit lectures, industry presentations and seminars. Additionally, the kitchen will serve quality food to guests during banquets and act as a classroom for a cooking class during other times. The inclusion of an underground parkade will accommodate the increased visitorship to the garden and relieve some of the strain on the garden's existing parking lot.

The multi-purpose building's practical uses are only one aspect of its design. The building's exterior is architecturally pleasing with a large glass facade facing SW Marine Drive and an intensive green roof that is perfectly integrated into the existing landscape. The astounding architecture is sure to promote the UBC Botanical Gardens while granting visitors to UBC a grand entrance when arriving from SW Marine Drive.

1.4 Scope

The scope of this report involves the detailed design of the building excavation in three engineering disciplines. These disciplines include:

- Geotechnical Analysis and Design
- Structural Analysis and Design
- BIM and Construction Management

A Building Information Model (BIM) is created for the entire multi-purpose building and underground garage to give insight on its appearance and location. The model includes architectural features, floor plans, and cross-sections. However, this high level model does not include mechanical, electrical, or plumbing systems as, at this stage, it is only intended to provide a visual representation of the project. These systems may be added later as the project develops.

Apart from the BIM model encompassing the entire building and underground parkade, this report solely regards the design of the structural excavation wall. This allows for an accurate and precise design for one entire aspect of the building. A suitable wall design is analyzed and detailed using the three components of engineering as described above.

Geotechnical services will most prominently consist of limit states analyses facilitating retaining wall design; safety extents in the face of most-probable causes of wall failure including sliding, toppling and global slope instability are considered. The design process also includes a desk study-level geotechnical investigation through the use of available research, and iterations of preliminary design considering a variety of earth retaining techniques. Slope stability of the building excavation is accounted for through the assignment of safe side slopes.

The scope of the structural aspect of the retaining wall design includes details on the type, size and spacing of every component. All structural failure modes for the wall are checked.

Construction Management consists of three main elements: a preliminary cost estimate, a project schedule, and a site management plan. First, the cost estimate is developed based on the structural design and RSMeans Database. Second, a construction schedule is developed based on the material quantity and productivity rates. A well-designed construction schedule will also include a critical path and individual task duration to provide close control of the project. Lastly, a site management plan is designed to provide effective on-site construction solutions.

All designs comply with the specifications outlined in regulatory documents including the National Building Code of Canada (NBCC), and the Canadian Standards Association (CSA) Wood, Steel, and Concrete design codes. In addition, the design adheres to any BC, Metro Vancouver, and UBC building regulations and guidelines.

2 MULTI-PURPOSE BUILDING

2.1 Overview

A conceptual design is proposed for the forthcoming multi-purpose building, a venue which will augment the botanical garden's capabilities as a scientific institution by providing a communal space supported by educational and research facilities. By virtue of its prominent location on the corner of SW Marine Drive and Stadium Road, the building will improve the visibility of the garden area and also serve as an additional more-accessible entry point into the garden. The venue will also be a secluded lounge retreat in itself for students, containing commercial food services and group study spaces to promote learning and community. Substantial open interior areas can be rented to external parties for evening or weekend events such that the facility creates additional revenues for the UBC Botanical Garden.

2.2 Features

The venue is designed to attract UBC students and other people to the botanical garden, and will serve educational and recreational functions for the student body while exhibiting a sustainable building design. A café area with a spacious, commercial-grade kitchen area will offer food services for guests to the building, and also provide a facility which can be used for healthy-cooking classes or to support laboratory activities of UBC Botanical Garden staff (Figure 1 and Figure 2). Much of the building interior itself is also dedicated lounge space littered with group study tables, couches and individual desks (Figure 3) such that the botanical garden can become an academic retreat for students who are either seeking solitude from the campus at large or simply desiring a well-lighted, comfortable location to congregate with fellow students. Within the lounge space is an entertainment station (Figure 4) for groups of building occupants to watch sports events or news together; the video equipment can also be used for educational purposes when required.

Figure 1: Café area with kitchen in background.

Figure 2: Commercial-grade kitchen used to serve café.

Figure 3: Open group study area with curtain wall backdrop.

Figure 4: Entertainment station lounge area.

The building will also provide administrative and research facilities for UBC Botanical Garden staff. A large, glass-walled laboratory facility in the northern region of the interior offers ample space for lab experiments and other contained activities. An adjoining refrigeration and incubation room contains appliances to facilitate sustenance of controlled environments or conditions for samples and specimens (Figure 5 and Figure 6). Office spaces and a fully-featured meeting room containing a video wall and kitchenette are also available adjacent to the lab area to serve other professional functions for UBC Botanical Garden staff (Figure 7 and Figure 8), and a lecture theatre in the southern reaches of the building provides an educational lecture facility for use by academics at the university or by outside speakers invited to the campus (Figure 9). Together with the industrial-grade kitchen, the lab, office and lecture theatre make the multi-purpose building well-equipped to serve practical functions in support of the UBC Botanical Garden's research goals.

Figure 5: Group study area with laboratory in background.

Figure 6: Incubation and refrigeration room adjoining library.

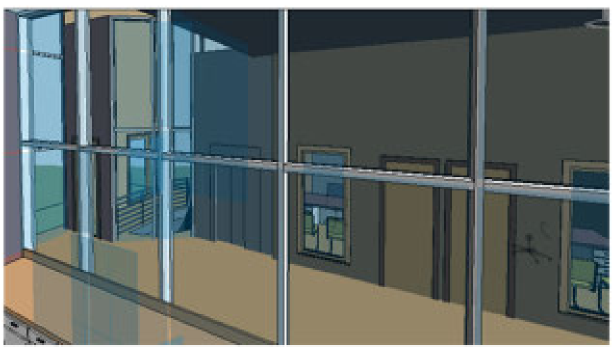

Figure 7: View of office corridor from inside laboratory.

Figure 8: Interior of meeting room.

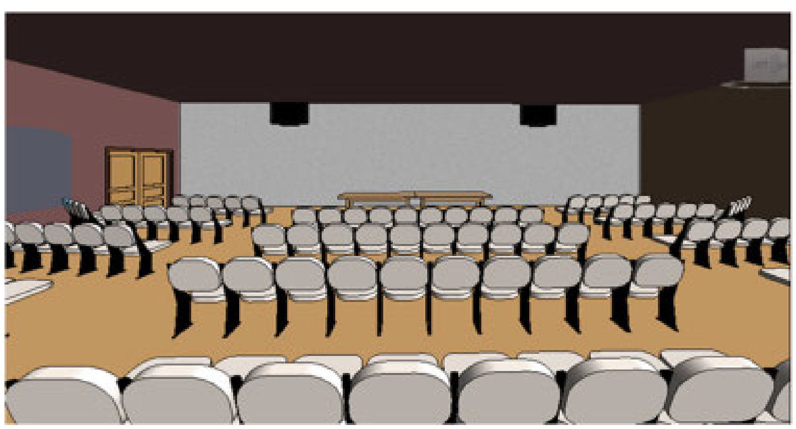

Figure 9: Interior view of lecture theatre.

Other features of the proposed facility include an underground parkade with space to accommodate 45 vehicles (Figure 10 and Figure 11), and an easily-accessible green roof which can act as a patio space (Figure 12). Availability of parking space at the botanical garden eliminates the former disincentive to guests exhibited by lack of vehicle storage space, possibly encouraging more patrons to attend and allowing for the possibility of group trips. The green roof serves an aesthetic function for the building in creating a facade of integration of the building with the adjacent hillside it is built into, while allowing for water retention to mitigate erosion and contamination and siltation of waterways. With its environmental utility, the green roof allows the building's design to abide by the UBC Botanical Garden's mission of sustainability and by the university commitment as a whole to green buildings.

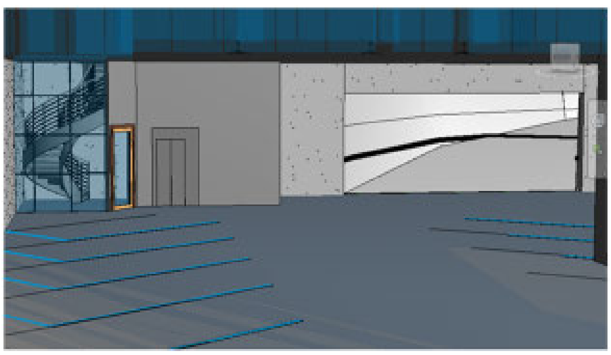

Figure 10: North side of parkade with entry ramp in view.

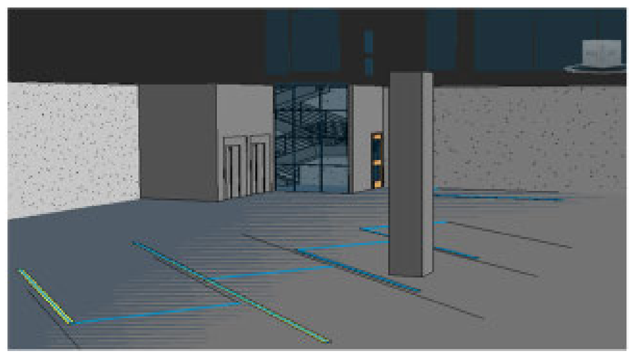

Figure 11: South side of parkade with stairwell and elevators.

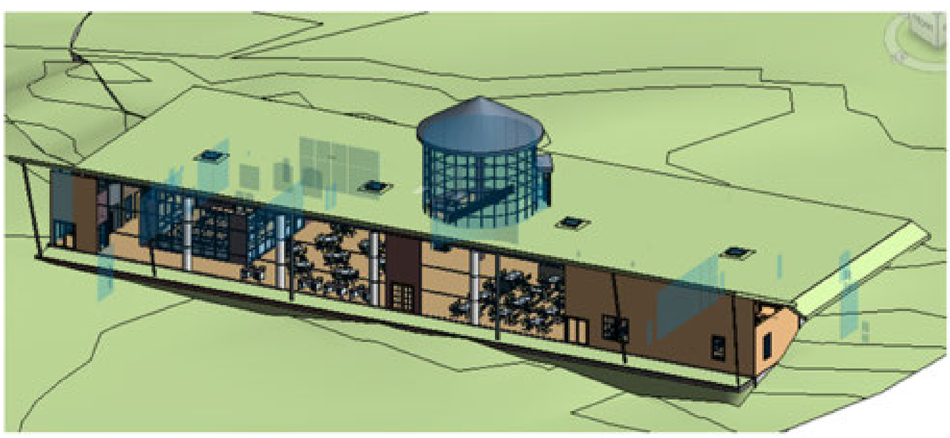

Figure 12: Isometric view of green roof and building situation into side hill.

3 GEOTECHNICAL ANALYSIS AND DESIGN

3.1 Soil Analysis

3.1.1 Description of Lower Mainland Soils

The soil conditions of Southwest BC varies as a function of its proximity to volcanic inclusions and to low-lying sediment beds, but is generally composed of alternating levels of sands, silts, and clays, topped with a layer of organic podzol soil and all underlaid with a layer of competent glacial till over granitic or basaltic bedrock.

The lower mainland varies significantly in its soil composition, ranging from exposed granitic bedrock of North Vancouver's mountains to the highly compressible fine soil of the Fraser Valley. Due to the significant variation in soil parameters from sites even 30m away, accurate parameters for friction angle, cohesion, undrained shear strength, unit weight, water table level and even the soil type are difficult to assess, but can be approximated using known excavation data from sites nearby. Despite the existence of geotechnical investigations for a number of buildings around UBC's campus, a specific pre-construction investigation must be performed for every new site to accurately determine subsurface conditions.

3.1.2 Assumptions of In-situ Soil Conditions

A number of assumptions are made for the soil conditions of the proposed building site. Using photos and geotechnical reports available on UBC's Connect site for CIVL 446, as well as from discussions with geotechnical engineering professor Dr. John Howie, a uniform composition of glacial till from 1m depth to the bottom of the proposed excavation, approximately 11 m below grade is assumed.

According to Dr. Howie, it is common to see glacial till very close to the surface. Such till can "support itself nearly vertically" due to the tremendous preloading stresses from a 2 km thick ice sheet overlying the deposit for thousands of years. Without knowing for sure, a retaining wall is designed in the case that the soil is not self-supporting.

The shear strength of the till is assumed to be 200 kPa. The glaciers of the Pacific Northwest deposited a till consisting primarily of granular, but also of fine sediments. Compared to the fine clayey and silty glacial deposits in Northern Europe, till deposits of the Pacific Northwest tend to have higher hydraulic conductivity, on the order of 1×10^{-3} m/day.

Pore pressure dissipation and water table level parameters are a major consideration for construction in areas of fine soils or fine stratum. To be conservative, calculations are performed on both saturated and unsaturated soil states. The justification for a saturated soil condition is the near-constant rain for much of the fall, winter and summer. Combined with fine grained layers of medium or low hydraulic conductivity, pore water pressure can develop in soils until the rate of water egress exceeds the rate of water ingress. During the summer however, long periods of dry weather produce a dry soil state with minimal or nonexistent pore water pressure. Because of the two distinct states, both soil conditions are investigated to ensure stability of the retaining wall.

3.2 Potential Geotechnical Failures

3.2.1 Rotational Failure

Lateral earth pressures acting on retaining walls tend to produce lateral forces that can result in toppling of the wall. The wall must balance active and passive earth pressures about the potential rotation point such that resisting moment exceeds driving moment. In a saturated soil, undrained shear strength (rather than effective stress) is used in the calculation of rotational stability. Detailed calculations for the factor of safety can be found in Appendix A.

Figure 13: Rotational failure of wall (Levees.org).

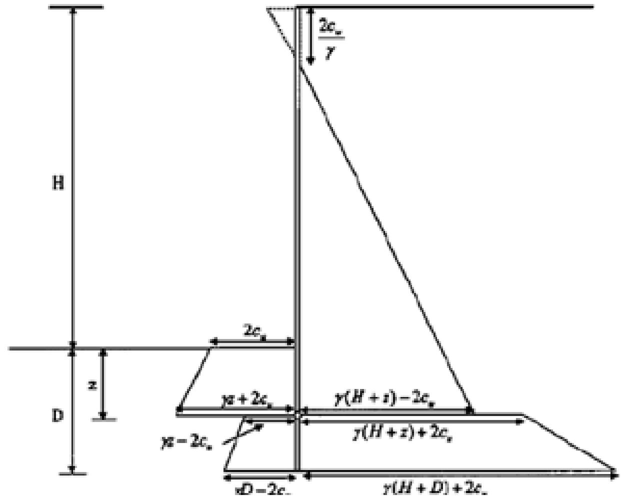

Figure 14: Rotational failure mechanism (Kumar et al.).

3.2.2 Translational Failure

Similar to the rotational failure of the wall resulting from excess overturning moments, a translational failure can result when lateral driving forces exceed resisting forces. In a saturated soil, undrained shear strength (rather than effective stress) is used in the calculation of translational stability. Detailed calculations for the factor of safety can be found in Appendix A.

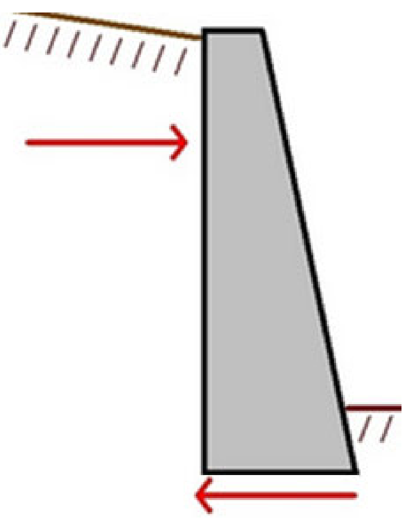

Figure 15: Sliding failure mechanism (Wikipedia.org).

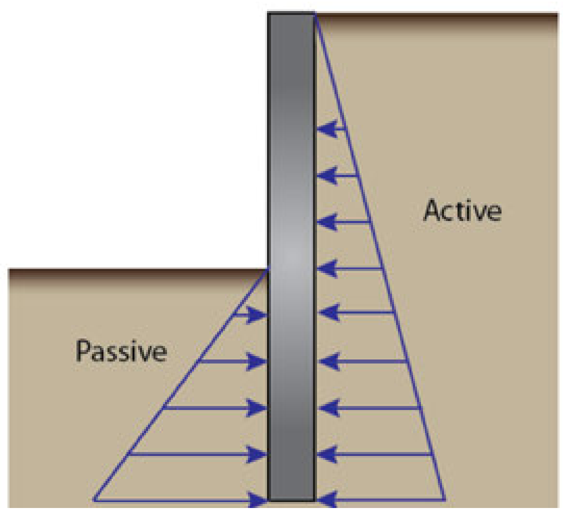

Figure 16: Active & passive earth pressures (Wikipedia.org).

3.2.3 Global Stability Failure

Circular slump failures are of particular concern to geotechnical engineers. These slides tend to be much larger in scale than translational or rotational wall failures, and are difficult to predict due to variability in the radius of rotation. To calculate for global stability (also known as deep-seated failure), the expected slide area is cut into slices and assessed piecewise.

Unlike the rotational and translational failures mentioned above, global stability is not determined by parameters of the retaining wall, but rather by parameters of the soil itself. The primary parameters are the unit weight and friction angle. Such soil failures are usually observed after periods of extended rainfall. The retained soil becomes saturated, and experiences an increase in pore water pressure which in turn reduces the effective stress in the soil. A left-ward shift in the Mohr-Coulomb failure envelope can result in exceedance of resisting forces, and cause the entire mass of soil to rotate, often without warning and in a catastrophic manner.

The soil conditions present at the gardens are some of the stiffest for geotechnical projects. The dense till lies near the surface and has a high friction angle and undrained shear strength. Dr. Howie even noted that some till soils can stand near-vertically without a lateral restraint. As a stark comparison to clays and silts which can experience failure on 30 degree slopes after heavy rains, the in-situ soil at the site does not have the tendency to fail globally.

Figure 17: Global stability failure mechanism (reviewcivilpe.com)

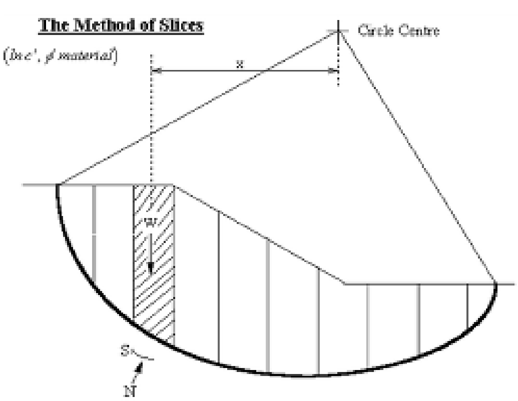

Figure 18: Method of slices (reviewcivilpe.com).

3.3 Justification for Sheet Pile Wall

Retaining walls are a common installation in urban construction, mining, civil infrastructure and other areas of civil engineering. There are many common designs including mechanically stabilized earth (MSE) walls, secant pile walls, soldier piles and lagging, shotcrete shoring, sheet pile walls and soil-mixed walls (SMW), all of which can be employed to restrain lateral earth pressure.

3.3.1 Secant Pile Wall

Secant piles (Figure 19) were considered, as they offer a strong, impermeable system. However, the high costs of drilling equipment, concrete and rebar cages makes the operation a very expensive consideration.

3.3.2 Mechanically stabilized earth (MSE)

Mechanically stabilized earth (MSE) walls (Figure 20) require a large quantity of excavation and backfill, thereby requiring significant tracts of garden area to be excavated. Despite their relatively low cost and high stability under differential settlements, the desire to maintain the garden in tact as much as possible was a drawback from this proposed method.

Figure 19: Secant pile wall (foundation-alliance.com).

Figure 20: Mechanically stabilized earth (MSE) wall (williamsae.com).

3.3.3 Soldier Piles and Lagging

Soldier piles and lagging (Figure 21) are another cost-effective retaining wall design. However, these require partial excavation on the back (retained) side to full depth in order to install the lagging. As the case with MSE wall construction, excavating the retained side of the wall would require tearing up a significant portion of the garden.

3.3.4 Shotcrete Shoring

Shotcrete shoring (Figure 22) is a viable method and commonly used soil retaining system around the lower mainland. The disadvantage is the high labour and material cost. Work must be completed in a series of 5m lifts, each requiring the installation of soil nails or stressed anchors. The result is a competent but expensive system typically implemented in large exposed faces such as those for high-rise foundations, or also for steeply cut slopes.

Figure 21: Soldier piles and lagging (hcgroup.ca).

Figure 22: Shotcrete shoring (plisystems.com).

3.3.5 Soil-Mixed Wall

Soil-mixed walls (SMW) (Figure 23) were not considered due to their primary use as a cut-off wall. The clay/soil/grout mix typically does not exceed 2 MPa and would thereby lack the factors of safety to restrain an 8m high wall of soil.

3.3.6 Sheet Piling

Sheet pile walls (Figure 24) were selected due to their proven effectiveness and speed/ease of installation. Unfortunately, due to the extremely compacted soil conditions expected onsite, the anchors required to maintain the equilibrium of the wall may be difficult to drill and grout into place. As a result, the construction method that will be utilised will entail excavating the land at the locations of anchors and anchor blocks for installation. Details on the construction method will be discussed in the section pertaining to construction management.

Figure 23: Soil mixing head on modified excavator (enr.construction.com).

Figure 24: Sheet pile wall (kshijita.com).

4 STRUCTURAL ANALYSIS AND DESIGN

A block anchored sheet pile cantilever wall has been chosen as the ideal design because it meets several parameters desirable for the purpose of the wall and existing site conditions. The system provides a balanced medium meeting all goals evenly. Although compact soil conditions on site present some challenges in regards to installation of sheet piles and anchors, their design and quality assurance are completed through proven techniques.

4.1 Sheet Pile Design

A cantilever sheet pile wall is used to resist the lateral loads from the retained soil, with active and passive soil pressures behind and in front of the wall respectively according to the State of California Department of Transportation's Trenching and Shoring Manual. These lateral loads are based on the existing soil properties with an internal friction angle of 35° and a saturated weight of 20.3 kN/m^3, which equals an effective weight of 10.5 kN/m^3 after subtracting the water pressure. In addition, a 10 kPa surcharge load is applied to account for the replaced topsoil and plants after construction. The net soil pressure distribution, due to active and passive soil pressure, as well as the surcharge load, is shown in Figure 25.

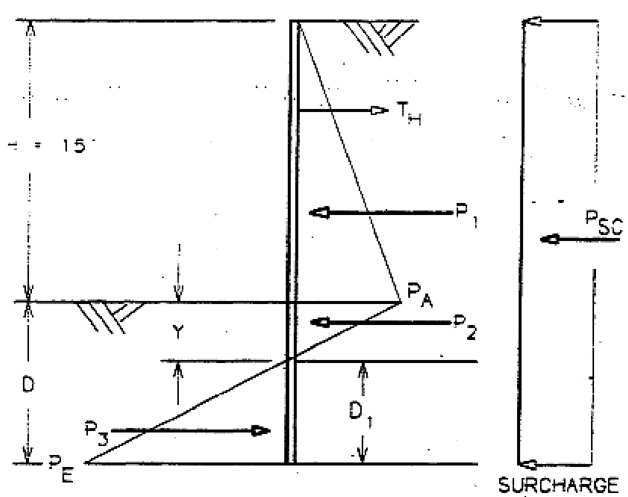

Figure 25: Net soil pressure distribution on retaining wall (State of California, DOT).

Two wall heights are chosen for the different elevations in the proposed excavation, with an exposed height of 8 m at the back (East) of the building and 4 m at the front (West). An assumption is made that the soil is fully saturated on both sides of the sheet piles. Although not likely to occur, this is the ultimate condition used in designing the wall. Detailed calculations, conforming to the CSA S16 Steel Design Code, showing the complete design of the sheet piles can be found in Appendix B.

The first step in designing the sheet pile wall is to determine the depth of embedment and the anchor forces. To determine these, the sheet pile wall is modelled as a simply supported beam with pinned connections at the base of the wall and at the anchor support. Since the depth of embedment and the anchor force are both unknown, both values need to be solved together as a system, such that equilibrium conditions are satisfied. Applying a factor of safety of 1.5, it is determined that an embedment depth of 2.7 m is sufficient for the 8 m wall, totalling to a 10.7 m height. Similarly, the 4 m wall requires an embedment depth of 1.3 m, totalling to a 5.3 m height. Corresponding anchor forces are 48 kN and 5.5 kN per metre of wall for each wall respectively.

The next step is to determine the maximum bending moment and maximum shear in the wall in order to size the steel members. For the 8 m wall, the maximum bending moment is determined to be 12 kNm with a maximum shear of 143 kN. Likewise, for the 4 m wall, the maximum bending moment is 3 kNm with a maximum shear of 50 kN. The taller 8 m wall is chosen as the governing case to select one size of sheet piles for the entire retaining wall for ease of construction. Based on the maximum bending moment of the 8 m wall, the elastic section modulus required is 77 cm^3, and based on the maximum shear, the cross-section area required is 21 cm^2. The AZ 17-700 sheet piles, with a steel grade of 350W, selected from Skyline Steel's data sheets meets both the required elastic section modulus and cross-sectional area, and is thus suitable for design. Figure 27 shows a cross-section view of the retaining wall with dimensions.

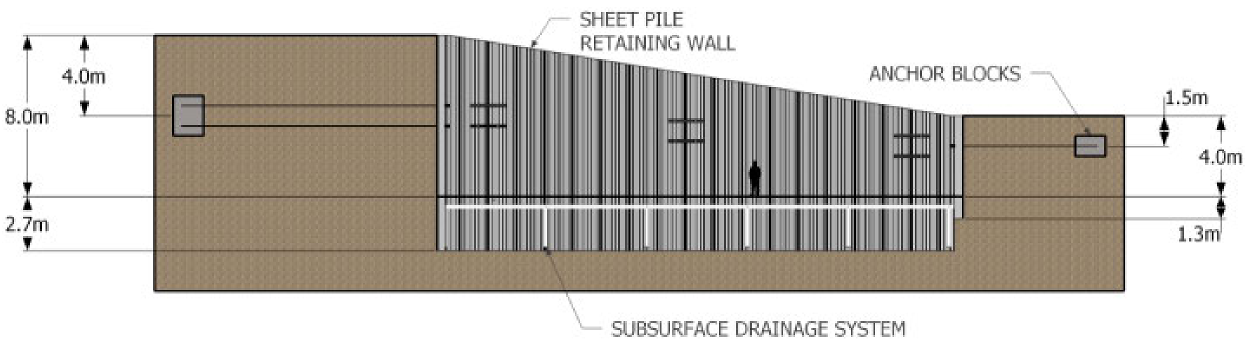

Figure 26:Cross-section view of the retaining wall showing dimensions.

Corrosion protection for the sheet pile wall is not required for this retaining wall. The sheet piles only lose less than 1.6 mm of thickness in a zone of high chloride attack after a 100 year service life (Wight, 2011). This tiny loss in the cross-section is negligible since the factor of safety for bending and shear are very high. If a service life of greater than 100 years is required, galvanizing or coating the sheet piles may extend the service life another 25 years.

4.2 Anchor Design

Anchors behind sheet piles are often used for lateral stability of the wall. The reason for implementing the anchors into this design is to relieve some lateral stress on the sheet piles and to maintain the wall's equilibrium. Furthermore, anchors are recommended for sheet pile walls exceeding 6.1 m (National Research Council, 2009).

The size of the anchors and anchor blocks used is determined according to lateral forces per metre length of the wall required to keep the wall in equilibrium. As previously mentioned, these forces are 48 kN and 5.5 kN per metre of wall for the 8 m and 4 m walls respectively.

The first step in the design is to size and space the anchor blocks required. The process to do this is an iterative process that requires initial sizing, calculating the pull-out capacity, and checking the spacing required between the blocks to allow for sufficient lateral force per metre length of wall. A major design consideration is spacing the blocks far away from each other to prevent deep excavations across the entire site. Although all the topsoil will be excavated, additional excavation due to closely spaced blocks will result in higher construction costs and durations. It was determined that a 10m space between all blocks was reasonable. To achieve this spacing, blocks of a 2 m x 2 m square front and a 1 m x 2 m square front for the 8 m and 4 m walls respectively have sufficient passive forces to overcome the active forces and provide the required pull-out resistance per metre of wall. Next, to determine the length of the anchor block, development length for equivalent rebar into concrete is checked according to Section 12.2.3 of the CSA A23.3 Concrete Design Code. It is important to note that this is a safe simplification as the actual anchor rod head has a much larger surface area than standard rebar, thus the anchor will be able to obtain full development at a much smaller length. Nevertheless, a length of 1.5m was determined after calculating a minimum value of 1.1 m. As a check, the vertical bearing capacity of the concrete block on the soil is calculated to far exceed the applied load of the concrete block according to Section 7.3.1.1 of *Budhu's Foundations and Earth Retaining Structures*. The distance the block is placed behind the sheet pile wall is calculated by again analyzing the passive and active forces. It is required that the blocks be far enough from the wall that they are clear of the wall's active zone and have sufficient space to develop a full passive zone. Summing these zone distances, design values of 12 m and 6 m are acceptable for the 8 m and 4 m wall respectively as the distance from the wall to the anchor blocks. The concrete anchor blocks are to be cast using concrete with a 28 day strength of 35 MPa. The plan view in Figure 27 shows the locations of all the anchor blocks.

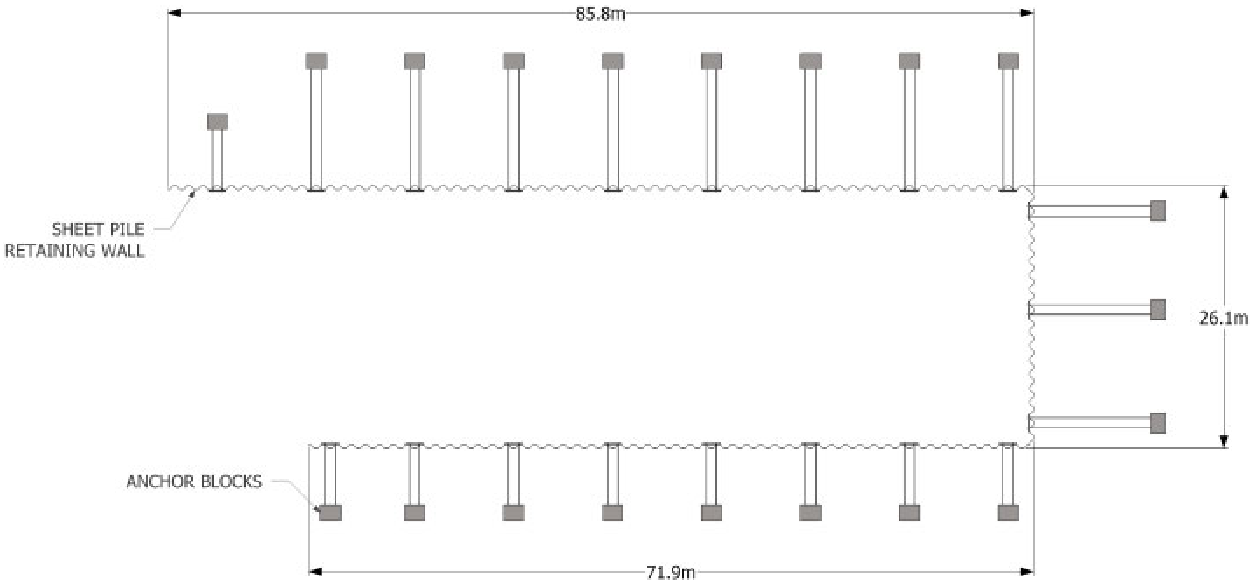

Figure 27: Plan view of the retaining wall showing location of anchor blocks.

Once the size and spacing of the anchor blocks is determined, the anchors rods can be designed. With an anchor block spacing of 10m, the anchor consists of several rods spaced in groups. After initial calculations, it is determined that a group of four rods is reasonable for the 8 m wall, while a group of two is reasonable for the 4 m wall. These groupings allow for uniform spacing on the relevant block size and for ease of whaler installation as all sets will be identical. During product sourcing for anchor rods, DYWIDAG Systems International (DSI) was found offering a double-corrosion protected THREADBAR® that would work well in this application (DSI Canada). In addition to having the corrosion protection, which will prove vital in a long-term application, these rods can be ordered in up to 18.3 m lengths and are guaranteed to have a minimum tensile stress of 1034 MPa. Using this as the ultimate steel stress value, it is determined, according to Section 25.3.2.1 of the CSA S16 Steel Design Code, that the smallest size of DSI THREADBAR® easily meets the minimum strength required. Thus, the 26mm Diameter DSI THREADBAR® is chosen as the anchor rod for the retaining wall. A diagram from DSI Canada of the entire anchor system can be seen in Figure 28. In this design, C150 x 19 C-sections and

134 x 134 x 20 bearing plates will be used for the construction of the whalers. Detailed calculations showing the complete design of the anchors can be found in Appendix B.

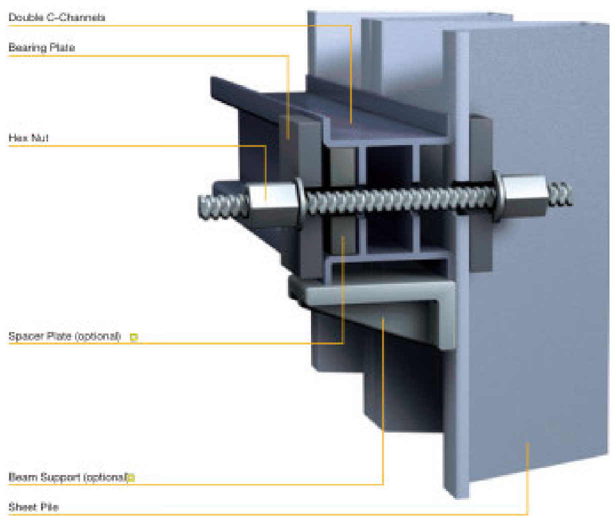

Figure 28: Schematic of the anchor system (DSI Canada).

5 CONSTRUCTION MANAGEMENT

The management team aim to develop an overall solution for the planning and controlling for the project, making sure the project is functionally and financially viable. The scope of construction management consists of three main elements: a preliminary cost estimate, a construction schedule, and a site management plan. First, at the estimated cost of $500 000, the estimate of the retaining sheet pile wall is developed to provide information to effectively control budget and funding. Second, the total construction time for the foundation wall is estimated to be 73 calendar days. Critical path and time phase for individual tasks are also estimated to effectively manage the construction process. Lastly, the construction site management plan illustrates the on-site operations of the construction. The following topics are covered under the site management section: site safety, equipment mobilization, and plate protection. The following sections will provide further detailed discussion of each element.

5.1 Preliminary Cost Estimate

A preliminary cost estimate is developed for the retaining sheet pile wall. The purpose of this section is to summarize the preliminary cost estimating process and to explain each component of the estimate. The estimate is developed based on the structural design (refer to Section 4). The intent of this estimate is to provide a preliminary cost information to confirm that the project is within budge.

5.1.1 Estimate Process

The estimation is developed by applying a unit cost method. The required quantity of each component is calculated based on the structural design. Afterwards, cost data (including material, labor, and equipment) are obtained from a construction estimation database - RSMeans. The cost data from the RSMeans database is automatically adjusted for the following factors:

- Time Factor (2014)
- Location Factor (Vancouver, BC)
- Currency Factor (Canadian Dollar)

Based on each component's quantity and unit cost, the following parameters are calculated for each component: labor-hour, duration, total bare cost, and cost with overhead and profit (O&P). The O&P included in the preliminary estimate is assumed to be 10% of the total bare cost. For further cost details, please refer to the cost worksheet in Appendix C.

5.1.2 Detailed Estimate

Each item of the preliminary cost estimate is calculated to feed into the structural design and RSMeans Database. Total cost consist of two main elements: the sheet pile wall and the anchor system. By having the cost divided into two parts, the sheet pile wall and anchor system can be evaluated independently. Specifically, the sheet pile wall and anchor system is estimated to cost CA$ 441 211 and CA$ 57 242 respectively. The preliminary estimate is summarized in Table 1. Refer to Appendix C for a complete estimate worksheet.

Table 1: Preliminary Cost Summary Table

Item #	Item	Unit	Quantity	Duration (Day)	Cost
1	Sheet Pile	ton	165.5	8	$ 374,380.34
2	Pile Driving Setup	Ea.	1.0	4	$ 24,490.63
3	Anchor Rod	ton	2.6	-	$ 8,471.90
4	Concrete Deadman	Ea.	20	2	$ 4,812.88
5	Steel Miscellaneous	ton	2.7	-	$ 1,616.87
6	Excavation	BCY	26401.6	14	$ 37,177.03
7	Backfill	BCY	9911.4	8	$ 42,764.04
8	Compaction	BCY	9911.4	4	$ 4,739.22
	Total			40	$ 498,452.90

5.2 Sequencing

A detailed construction schedule has been provided in Appendix D. The purpose of this schedule is to provide a safe and efficient sequence to which the works should be carried out.

5.2.1 Site Preparation

Due to the nature of this project's method of construction, it is deemed necessary that all flora be relocated off site to be preserved. The construction area, as marked by the fenced perimeter (Figure 29), will also be excavated of its podzol layer above the till in order for construction to commence. The construction area will then be restricted from public access by means of signage and fences around the construction site.

5.2.2 Sheet Pile Installation

In order to install the sheet piles, predrilling must be used due to the high strength of the soil medium. With the use of a drilling set-up, cylindrical sections will be drill-excavated along the intended position of the sheet pile. Sheet pile installation will be integrated with the pre-drilling process; extensive pre-drilling without any retention will result in collapse of the excavated area, hence sheet piles will be put in place after every 1 meter of pre-drilling.

5.2.3 Excavation and Anchor Installation

Since anchor blocks will be cast in place, the excavation phase will consist of three layers. Setting the elevation datum as the top of the 10.7 m sheet piles of the back wall, the first layer of excavation is the soil above the elevation to the first layer of anchors, namely from 0 m to 5 m below grade. Furthermore, the excavation will also include excavating soil above where the anchors are to be placed, namely on the exterior side of the sheet pile perimeter.

Upon finishing the first layer of excavation, the first layer of anchors may be installed. With reference to a schematic provided for the anchor setup, the anchor rods shall be installed first, while the concrete anchor blocks will be cast in-place on the other end of the anchor rod length to the specified dimensions. These concrete blocks will then be cured for a period of seven days. Provided the concrete anchor blocks have reached an acceptable strength, it is sequentially reasonable to backfill the anchors blocks before further excavating the interior of the sheet piles, since these anchors will only work when they are encased within the soil. The second layer of excavation-anchor installation-backfill (5m-6m exterior and interior) will proceed in a similar manner, followed by a third and final layer of excavation (6 m – 8 m interior)

To construct the underground parkade access ramp, a gradual ramp excavation will be completed to provide a slope of approximately 4:25. Since excavation has to be done in several stages and layers, the excavation of such a ramp will also have to be done correspondingly.

5.3 Construction Site Management

The construction site (Figure 29) includes site offices, visitor parking, laydown areas for construction vehicles, two entrances, and an easy mobilization route around the entire site. The two entrances will provide site access to the workers during operation hours only. Mobilization route will be two-way to maintain efficiency of traffic. Construction equipment will be left on site at all times until project finishes, while vehicles will be allowed access during work hours.

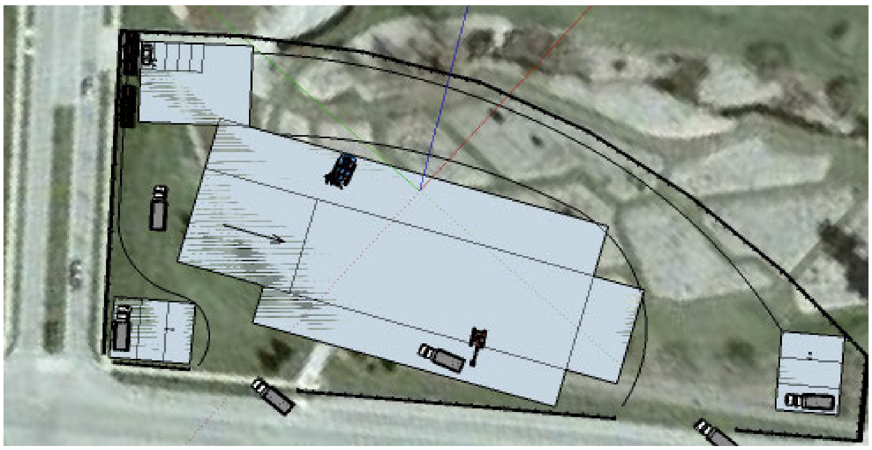

Figure 29: Construction site layout.

6 CONCLUSIONS & RECOMMENDATIONS

The existing conditions at the site were estimated according to available data found from geological testing completed in near-by locations. With these soil parameters, an anchored sheet pile wall of 184 m length was designed in detail. It is strongly recommended that site investigations to determine the exact soil characteristics are completed. This will confirm the applicability of the retaining wall design presented in this report.

As mentioned, another possible retaining wall design that may have potential at this site is essentially no wall at all. Studies of subglacial tills in England that have similar characteristics to that found at UBC Campus have found an average undrained shear strength of 185 kPa (Clarke and Hughes et al., 2008). Since the fabric and composition can vary greatly depending on exact glacial conditions, an undrained shear strength of 200 kPa was estimated for this site based on near-by soil investigations and guidance from Dr. Howie. Although only a temporary approach, a self-standing wall could have been achieve with minimal cost and time. While a self-supporting 8m tall wall is ambitious, a shotcrete wall with simple anchors or nails may be very reasonable in a soil of this strength. However, as previously described, these shotcrete walls entail extensive work and is only sufficient temporarily. Therefore, the current best design for an excavation of this scale in the soil conditions as estimated is an anchored cantilever wall.

7 REFERENCES

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APPENDIX A: GEOTECHNICAL DESIGN CALCLUATIONS

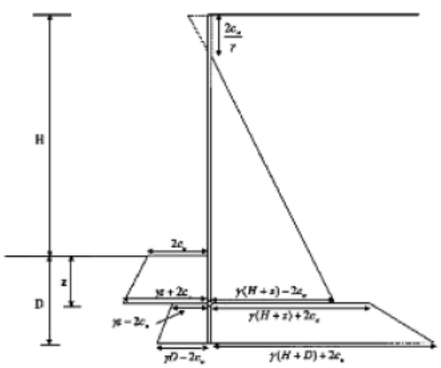
Calculation for passive and active lateral earth pressure coefficients:

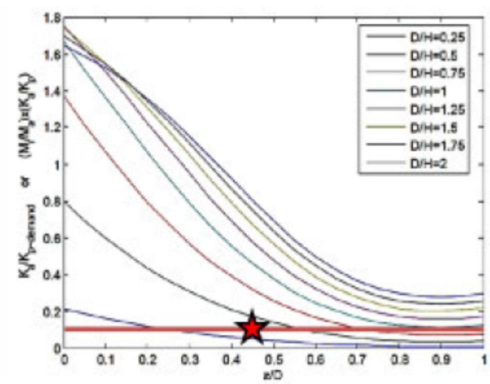
$$K_a = \frac{1-\sin\theta}{1+\sin\theta} = \frac{1-sin35}{1+sin35} = 0.27$$

$$K_p = \frac{1+\sin\theta}{1-\sin\theta} = \frac{1+sin35}{1-sin35} = 3.7$$

Rotational Failure – Total Stress Analysis

With an embedment depth (D) of 2.7m and a height (h) of 8m, the pile wall has a low h/D ratio, making it a potential risk for a rotational failure.





$$\frac{K_a}{K_p} = \frac{0.27}{3.7} = 0.1$$

$$\frac{D}{H} = \frac{2.7m}{8m} = 0.34$$

Therefore, per chart,

z/D=0.45

Pivot pt,z =0.45(2.7m)

=1.2m below surface

$$M_{driving} = \frac{1}{6}[\gamma(H+z)-2c_u]\left[H+z-\frac{2c_u}{\gamma}\right]^2 + \frac{1}{2}(\gamma z - 2c_u)(D-z)^2 + \frac{1}{3}\gamma(D-z)^3$$

$$M_{driving} = \frac{1}{6}[20.3(8+1.2)-2*200]\left[8+1.2-\frac{2*200}{20.3}\right]^2 + \frac{1}{2}(20.3*1.2-2*200)(2.7-1.2)^2 + \frac{1}{3}*20.3(2.7-1.2)^3$$

$M_{driving} = -4300kNm$ (indicates force required to mobilize soil)

$$M_{resisting} = \frac{1}{2}[\gamma(H+z)+2c_u](D-z)^2 + \frac{1}{3}\gamma(D-z)^3 + c_u z^2 + \frac{1}{6}\gamma z^3$$

$$M_{resisting} = \frac{1}{2}[20.3*9.2+400](1.5)^2 + \frac{1}{3}20.3(1.5)^3 + 200*1.2^2 + \frac{1}{6}20.3*1.2^3$$

$$M_{resisting} = 977kNm$$

$Factor\ of\ Safety_{rotation} = \frac{M_{resisting}}{M_{driving}} < 1$ – Hence anchors are required

Rotational Failure – Effective Stress Analysis

$$M_{driving} = K_a\gamma\left[\frac{(H+z)^3}{6} + \frac{z(D-z)^2}{2} + \frac{(D-z)^3}{3}\right]$$
$$M_{driving} = 0.27 * 20.3\ \left[\frac{(8+1.2)^3}{6} + \frac{1.2(2.7-1.2)^2}{2} + \frac{(2.7-1.2)^3}{3}\right]$$
$$M_{driving} = 725\ kNm$$
$$M_{resisting} = K_p\gamma\left[\frac{(H+z)(D-z)^2}{2} + \frac{(D-z)^3}{3} + \frac{z^3}{6}\right]$$
$$M_{driving} = 3.7 * 20.3\ \left[\frac{(8+1.2)(2.7-1.2)^2}{2} + \frac{(2.7-1.2)^3}{3} + \frac{(1.2)^3}{6}\right]$$
$$M_{driving} = 884\ kNm$$

$$Factor\ of\ Safety_{rotation} = \frac{M_{resisting}}{M_{driving}} = \frac{725}{884} < 1 - \text{Hence anchors are required}$$

Translational Failure – Total Stress Analysis

$$F_{resisting} = \frac{1}{2}[\gamma D^2 + 2c_u D]$$
$$F_{resisting} = \frac{1}{2}[20.3 * 2.7^2 + 2 * 200 * 2.7]$$
$$F_{resisting} = 614\ kN$$
$$F_{driving} = \frac{1}{2}[\gamma(H+D) - 2c_u]$$
$$F_{driving} = \frac{1}{2}[20.3(8+2.7) - 2 * 200]$$
$$F_{driving} = -91.4kN \quad \text{This is negative due to strong soil cohesion}$$

$$Factor\ of\ Safety_{sliding} = \frac{F_{resisting}}{F_{driving}} < 1 - \text{Hence anchors are required}$$

Translational Failure – Effective Stress Analysis

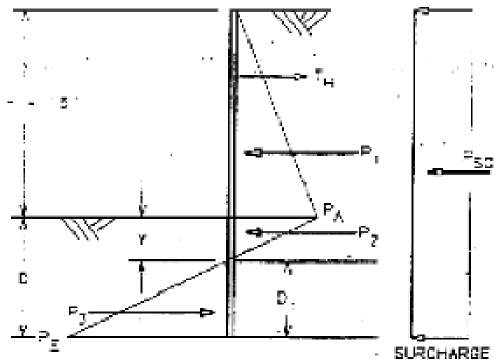
$$F_{resisting} = \frac{1}{2}K_p[(\gamma - \gamma_w)D^2] + \frac{1}{2}\gamma_w D^2$$
$$F_{resisting} = \frac{1}{2} * 3.7[(20.3 - 9.8) * 2.7^2] + \frac{1}{2} * 9.8 * 2.7^2$$
$$F_{resisting} = 177\ kN$$
$$F_{driving} = \frac{1}{2}K_a[(\gamma - \gamma_w)(H+D)^2] + \frac{1}{2}\gamma_w(H+D)^2$$
$$F_{driving} = \frac{1}{2} * 0.27[(20.3 - 9.8)(8+2.7)^2] + \frac{1}{2}9.8(8+2.7)^2$$
$$F_{driving} = 723\ kN$$

$$Factor\ of\ Safety_{sliding} = \frac{F_{resisting}}{F_{driving}} = \frac{177}{723} < 1 - \text{Hence anchors are required}$$

APPENDIX B: STRUCTURAL DESIGN CALCULATIONS

	COURSE CIVL 446	NAME JW / JM
	PROJECT UBC BOTANICAL GARDENS - MULTI-PURPOSE BUILDING	STUDENT # 22198097 / 73186090
	SUBJECT RETAINING WALL DESIGN	DATE 2014 APR 02

DESCRIPTION NOTES



INPUTS NOTES

Yield strength of steel	fy	=			350 MPa	
Ultimate strength of steel	fu	=			1030 MPa	From Dywidag Product Sheet
Modulus of steel	Es	=			200000 MPa	
Resistanace factor of steel	ϕs	=			0.9	
Resistanace factor of anchor	ϕar	=			0.67	
Exposed height of wall	H	=			8.0 m	
Depth of anchor	Da	=			4.0 m	
Internal friction angle	ϕ'	=			35 °	
Weight of podzol	γpod	=			10.0 kN/m^3	
Saturated weight of till	γsat	=			20.3 kN/m^3	
Unit weight of water	γw	=			9.8 kN/m^3	
Effective Weight of Soil	γ'	=	γsat - γw	=	10.5 kN/m^3	
Dry Weight of Soil	γdry	=			16.7 kN/m^3	
Surcharge load due to podzol	q	=	γpod * 1	=	10.0 kPa	
Factor of safety for wall height	FOS	=			1.5	

	COURSE CIVL 446	NAME JW / JM
	PROJECT UBC BOTANICAL GARDENS - MULTI-PURPOSE BUILDING	STUDENT # 22198097 / 73186090
	SUBJECT RETAINING WALL DESIGN	DATE 2014 APR 02

SHEET PILE DESIGN — NOTES

Passive earth pressure coefficient	kp	=	(1 + SIN(RADIANS(ϕ'))) / (1 - SIN(RADIANS(ϕ')))	=	3.69	
Active earth pressure coefficient	ka	=	(1 - SIN(RADIANS(ϕ'))) / (1 + SIN(RADIANS(ϕ')))	=	0.271	
Pressure at dredge line	Pa	=	ka * γ' * H	=	22.8 kN/m/m	
Pressure at base of wall	Pb	=	(kp - ka) * γ' * D2	=	41.3 kN/m/m	
Point of zero load	D1	=	Pa / ((kp - ka) * γ')	=	0.63 m	
Point of zero load to base of embedment	D2	=			1.1 m	
Pressure force from surcharge	Psc	=	ka * q * (H + D1 + D2)	=	26.5 kN/m	
Pressure force 1	P1	=	1/2 * Pa * H	=	91.1 kN/m	
Pressure force 2	P2	=	1/2 * Pa * D1	=	7.2 kN/m	
Pressure force 3	P3	=	1/2 * Pb * D2	=	23.7 kN/m	
Anchor force (unfactored)	Ta	=			48.0 kN/m	
Sum horizontal forces	ΣFx	=	Ta - P1 - P2 + P3 + Psc	=	0 kN/m	
Sum moments about O	ΣMo	=	P1 * (2/3 * H) + P2 * (H + 1/3 * D1) - P3 * (H + D1 + 2/3 * D2) -	=	0 kNm/m	
Solve for Ta and D2 so ΣFx and ΣMo = 0			ΣFx - ΣMo	=	0	
Depth of penetration	D	=	FOS * (D1 + D2)	=	2.7 m	
Total wall height	T	=	H + D	=	10.7 m	
Solve for x so ΣV = 0	ΣV	=	1/2 * ka * γ' * x1^2 + ka * q * x1 - Ta	=	0	
Point of zero shear (max moment)	x1	=			4.9 m	
Maximum moment	Mmax	=	(1/2 * ka * γ' * x1^2) * (x1/3) - Ta * (x1 - Da)	=	12.1 kNm/m	
Elastic section modulus required	Sreq	=	ABS(Mmax / (ϕs * (0.5 * fy)) * 1000^2 / 10^3)	=	77 cm^3/m	0.5 from EM_1100-2...pdf
Point of max shear	x2	=	T	=	10.7 m	
Maximum shear	Vmax	=	1/2 * ka * γ' * x2^2 + ka * q * x2 - Ta - IF(x1 > H, 1/2 * kp * γ' *	=	143.0 kN/m	
Section area required	Areq	=	ABS(Vmax / (ϕs * 0.33 * (0.66 * fy)) * 1000 / 10^2)	=	20.9 cm^2/m	0.33 from EM_1100-2...pdf

→ Select Skyline Sheet Piles AZ 17-700

Elastic section modulus	Ss	=			1730 cm^3/m	
Moment of inertia	Is	=			36230 cm^4/m	
Section area	As	=			133.0 cm^2/m	
Check moment reduction	ρ	=	(T * 1000)^4 / (Es * Is * 10^4) * 0.006895	=	1.2 in^2/lb	
From Figure 9-15 in TrenchingandShoring.pdf	Rm	=			1.0	
→ No moment reduction						
Factor of safety for bending	FOSM	=	(ϕs * Ss * (0.5 * fy)) / 1000 / Mmax	=	22.5	
Factor of safety for shear	FOSV	=	(ϕs * As * 0.33 * (0.66 * fy)) / 10 / Vmax	=	6.4	

	COURSE **CIVL 446**	NAME **JW / JM**
	PROJECT **UBC BOTANICAL GARDENS - MULTI-PURPOSE BUILDING**	STUDENT # **22198097 / 73186090**
	SUBJECT **RETAINING WALL DESIGN**	DATE **2014 APR 02**

ANCHOR DESIGN — NOTES

						Notes
Height of Block	Hb	=		=	2.0 m	
Width of Block	Bb	=		=	2.0 m	
Distance Anchor below Surface	ha	=		=	4.0 m	
Force due to Acitve Pressue on Block Face	Pa_block	=	Hb*Bb*γdry*ha*ka	=	72.4 kN/m	
Force due to Passive Pressure on Block Face	Pp_block	=	Hb*Bb*γdry*ha*kp	=	986.0 kN/m	
Pullout Capacity	Fa	=	Pp_block-Pa_block	=	913.6 kN/m	
Pullout Capacity > Anchor Force			if(Fa>Ta,"Good","Bad")	=	Good	
Min Distance From Wall to Anchor	Dwa	=	(H+1.3*D/tan((radians(45+ϕ'/2))))	=	9.8 m	
Design Distance From Wall to Anchor	Danch	=		=	12.0 m	
Max Distance between Plates Centres	Dmax_p	=	Fa/Ta	=	19.0 m	
Design Distance Between Plate Centres	Dp	=			10 m	
Number of Anchors Per Plate	Nc	=			4	
Force on Each Anchor	Fc	=	Dp*Ta/Nc	=	120 kN	
Each Min Tension Rod Area	Ag	=	Fc*1000/(ϕar*fu*.85)	=	204.69 mm2	HSC 25.3.2.1
Each Min Tie Rod Diameter	Tdm	=	sqrt(Ag*4/pi())	=	16.14372427	
THREADBAR Designation to use	Bar	=			26 mm	See Table below

DYWIDAG Grade 150 (ASTM A722) THREADBAR®

THREADBAR® Designation		Maximum THREADBAR® Diameter		Ultimate Stress (fu)		Cross Section Area (As)		Ultimate Load (fu*As)		Nominal Weight	
[in]	[mm]	[in]	[mm]	[ksi]	[MPa]	[in²]	[mm²]	[kips]	[kN]	[lbs/ft]	[kg/m]
1"	26	1.20	31	150	1,034	0.85	548	127.5	567	3.01	4.48
1 1/4 "	32	1.44	36	150	1,034	1.25	806	187.5	834	4.39	6.53
1 3/8 "	36	1.63	41	150	1,034	1.58	1,019	237.0	1,054	5.56	8.27
* 1 3/4 "	46	2.01	51	155	1,069	2.58	1,664	400.0	1,779	9.22	13.72
* 2 1/2"	66	2.79	71	150	1,034	5.16	3,355	774.0	3,443	18.20	26.36
* 3"	75	3.15	80	150	1,034	6.85	4,419	1,027.0	4,568	24.09	35.85

Anchor Block Design

Simplified Model for Development Length

Clear cover > Dia Bar?					Yes	
Clear Bar Spacing >1.4 Dia Bar?					Yes	
					Use Simplified Method	
Strength of Concrete	fc'	=			35 Mpa	
Bar Location Factor	k1	=			1.3	Will Have >300mm below
Coating Factoe	k2	=			1.2	has corrosion protection
Concrete Density Factor	k3	=			1	Normal Density Concrete
Bar Size Facto	k4	=			1	>20M Bar
Min Development Length	ld	=	.45*k1*k2*k3*k4*fy*Bar/sqrt(fc')	=	1080 mm	
Length Of Block	Bdep	=			1500 mm	

Bearing Capacity of Block

Bottom of Block Depth	Df	=	Da+Hb/2	=	5 m	
Shape Factor 1	Sq	=	1+((Bdep/1000/Bb)*tan(radians(ϕ')))	=	1.5232	
Shape Factor 2	Sγ	=	1-0.4*(Bdep/1000/Df)	=	0.94	[illegible]
Depth Factor 1	dq	=	1+(2*tan(radians(ϕ'))*(1-sin(radians(ϕ')))^2)*1/tan(radians(Df/	=	17.1	
Depth Factor 2	dγ	=			1	
Groundwater level 1	wq	=	1/(1+γ'/γsat*(1-1/[illegible]))	=	0.61	Watertable 1m below surface for worst case scenario
Groundwater level 2	wγ	=	γ'/γsat	=	0.52	
Bearing Capacity Factor 1	Nq	=	exp(pi()*tan(radians(ϕ')))*(tan(radians(45+ϕ'/2)))^2	=	33.30	
Bearing Capacity Factor 2	Nγ	=	0.1054*exp(9.6*Radians(ϕ'))	=	37.13	Davis & Booker Rough Eqtn
Effective Bearing Capacity	qu	=	γdry*Df*(Nq-1)*Sq*dq*wq+0.5*γsat*(Bdep/1000)*Sγ*dγ*wγ	=	[illegible] kN/m2	
Allowable Bearing Capacity	qal	=	qu/1.5	=	[illegible] kN/m2	
Density of Concrete	ρconc	=			2400 kg/m3	
Weight of Anchor Block	qconc	=	ρconc*9.81*Hb/1000	=	47.088 kN/m2	
Enough Bearing Capacity for Concrete Block?			if(qconc<qal,"Good","Bad")	=	Good	

APPENDIX C: PRELIMINARY COST ESTIMATE WORKSHEET

Table 2: Total cost estimate of structural retaining wall of multi-purpose building.

Item #	Item	Unit	Quantity	Daily Output (Unit/day)	Unit Cost	Duration (Day)	Cost
1	Sheet Pile	ton	165.5	21.20	$ 2,261.63	8	$374,380.34
2	Pile Driving Setup	Ea.	1.0	0.27	$24,490.63	4	$ 24,490.63
3	Anchor Rod	ton	2.6	-	$ 3,010.80	-	$ 8,471.90
4	Concrete Deadman	Ea.	20	14	$ 240.64	2	$ 4,812.88
5	Steel Miscellaneous	ton	2.7	-	$ 607.95	-	$ 1,616.87
6	Excavation	BCY	26401.6	2000.00	$ 1.41	14	$ 37,177.03
7	Backfill	BCY	9911.4	1350.00	$ 4.31	8	$ 42,764.04
8	Compaction	BCY	9911.4	3000.00	$ 0.48	4	$ 4,739.22
	Total					40	$498,452.90

Table 3: Cost breakdown per item.

Item #	Item	RSMeans Line Number	Unit	Daily Output	Unit Cost	Comment
1	Sheet Pile Sheet piling, steel, 38 psf, 40' excavation, left in place, excludes wales	31 41 16 10 0900	ton	21.20	$ 2,261.63	
2	Pile Driving Setup Mobilization, set up and remove, rule of thumb: complete pile driving set up, large	31 06 60 15 1200	Ea.	0.27	$ 24,490.63	
3	Anchor Rod Sheet piling, steel, tie rod, upset, with turnbuckle, 1-3/4" to 4", excludes wales	31 41 16 10 3300	ton	-	$ 3,010.80	
4	Concrete Deadman Structural concrete, in place, 6' x 6' x 8", includes forms(4 uses), concrete (Portland cement Type I), placing and finishing	03 30 53 40 3570	Ea.	14.00	$ 240.64	
5	Steel Miscellaneous Sheet piling, wales, connections and struts, 2/3 salvage	31 41 16 10 2500	ton	-	$ 607.95	Walers, C-channels, Bearing Plates
6	Excavation Excavating, bulk bank measure, 3 C.Y. capacity = 250 C.Y./hour, shovel, excluding truck loading	31 23 16 42 3900	BCY	2000.00	$ 1.41	Parking & anchor installation
7	Backfill Backfill, structural, sand and gravel, 105 H.P. dozer, 50' haul, from existing stockpile, excludes compaction	31 23 23 14 3000	BCY	1350.00	$ 4.31	Reuse excavated soil
8	Compaction Compaction, riding, vibrating roller, 2 passes, 6" lifts	31 23 23 23 5000	BCY	3000.00	$ 0.48	Anchor installation

APPENDIX D: CONSTRUCTION SCHEDULE

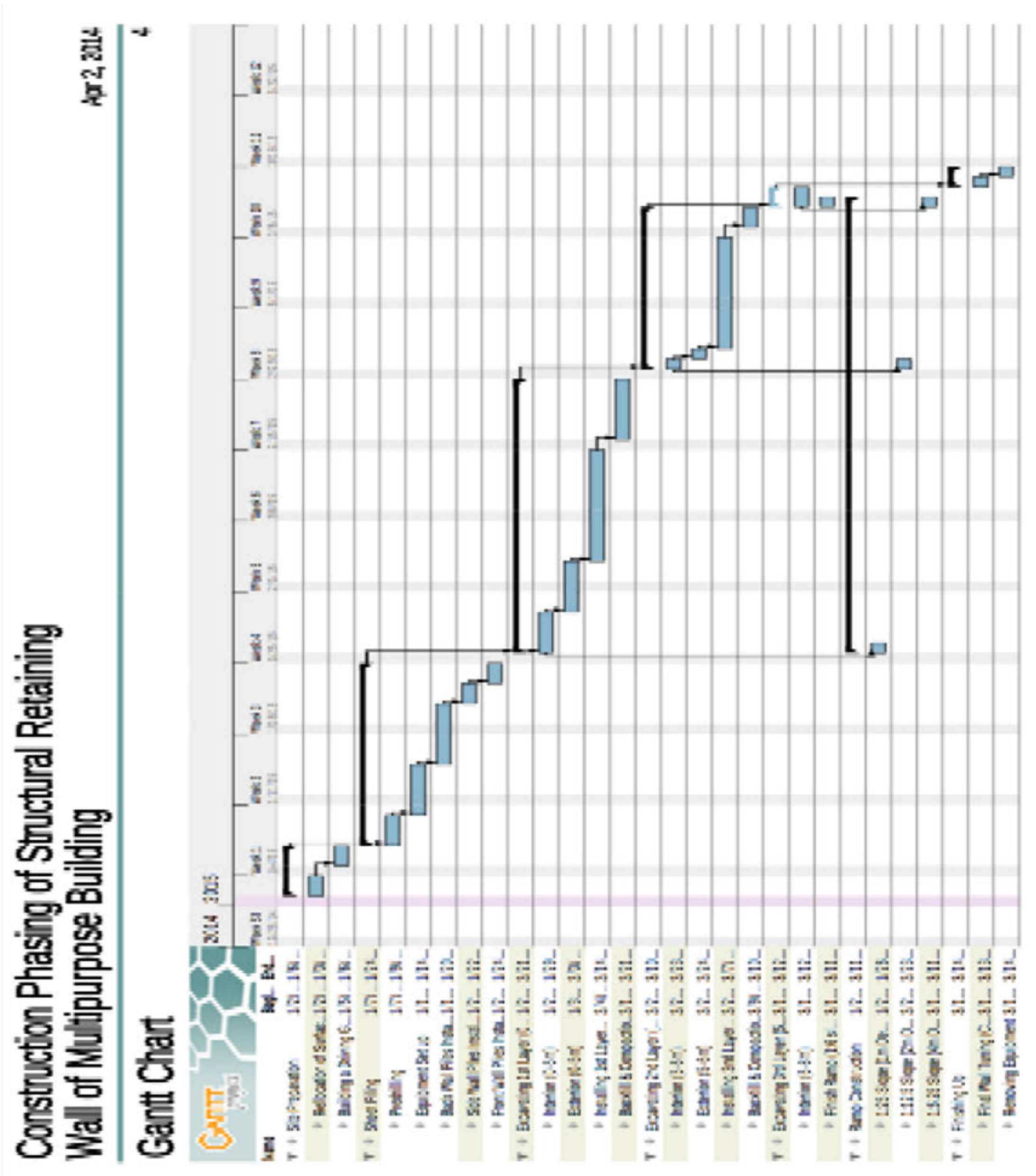


Figure 18: Construction phasing of structural retaining wall of multi-purpose building.