UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Replacement of the Spiral Drain at the North End of the UBC Campus

TEAM 21

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Executive Summary

The spiral drain at the north end of UBC has been serving its purpose protecting the campus from erosion and flooding since 1930. As a participant of the UBC Seeds Program, our team has undertaken the design of a replacement facility.

The main concern with the existing spiral drain lies with incapability to handle upcoming 100-year and 200-year storm water levels. The final design will feature the capacity to withstand these two water level cases, which were calculated using the historical precipitation data for the local region. Other key objectives that our final design aims to achieve are minimizing its environmental impact, ensuring surrounding soil stability, and providing a minimal life-time cost.

Given consideration to constructability, innovation and environmental aspects, our group has chosen to provide a replacement for the spiral drain facility that features the use of an oil grit removal system in combination with a bio-retention system incorporated into an open culvert design to remove impurities from storm water before outputting to the ocean. Additionally, the design features turbines at the output point of the culvert which not only generate electricity to be returned to the power grid, but also reduce erosion by decreasing the flow at output.

Technical analysis on the various components involved with the implementation of this design has been performed. First of all, to minimize the risk of soil movement on the slope, soil nails are installed with the culvert to remediate and retain the unstable soil conditions. Soil nail capacity and resistance calculations have been performed for the arrangement of soil nails specified in the design. The hydraulic forces acting on the top part of the culvert are also calculated theoretically to help us determine our structure dimensions and layout. In addition, the concrete mixtures used for these culverts have been analyzed and optimized to ensure the sustainability of the culverts both economically and environmentally. When conducting the concrete mix design analysis, we have taken into consideration the strength, cost, ease of placement, durability, and environmental footprint of the materials and construction methods used to construct and place the culverts. The stability of the steel-reinforced concrete structure is checked with modelling under extreme loading cases to ensure that the structure does not fail. Furthermore, a detailed cost estimate, construction plan, and final design drawing has been prepared.

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1 Introduction

After serving the area for more than 80 years, the spiral drain that is located on the north side of the UBC campus is due for a replacement in the coming decade or two. Our team, tasked by the UBC SEEDS Sustainability Program, has designed a feasible plan for a new drainage system that will replace the existing spiral drain. Due to future climate change and increase in population around the area, the new design will not only act as a retrofit to the old design but to also meet new requirements as discussed in following sections.

The most important objective for the new drainage system is that it will accommodate 100 year and 200 year storm water flow adequately. According to UBC's Integrated Storm Management Plan (ISMP), the current spiral drain is only capable of handling a 120 year storm. Due to rising climate change concerns, the chance of a 1 in 200 year storm is becoming more and more likely to happen in this area. If one of these big storms does strike, the damage that the storm water could cause to the area due to inadequate drainage system could be catastrophic. Therefore, a new design that will replace the spiral drain needs to fully accommodate a 1 in 200 year storm. Furthermore, the design also needs to cause minimal negative impact both socially and environmentally. Additionally, the overall cost of the project also needs to be considered greatly. Of course, the structural strength, feasibility and life time of the design needs to meet basic design criteria set by BC or Vancouver building code. The drainage system that will be presented in the following report will not only sufficiently meet the above criteria, but also exceed the expectation of a normal drainage system in many other ways.

Member	Contributions
Allan Chen	Design CAD Drawing; Design SketchUp Model; Hiking Trail Option; Proofreading & Editing
Chris George	Draft Plan of Construction; Construction Schedule; Concrete Mix Design Proofreading & Editing
Herman Hehar	Concrete Reinforcement Design; Power Generating Option; Proofreading & Editing
Shivtaj Sivia	Soil Slope Analysis; Soil Nail Analysis & Design; Proofreading & Editing
Tom Qu	Seeds Title Page; Executive Summary; Hydraulic Analysis; Cost Estimate; Proofreading & Editing
Andrew Zhao	Letter of Transmittal; Components Description; Proofreading & Editing; Formatting & Submission

2 Project Issues & Constraints

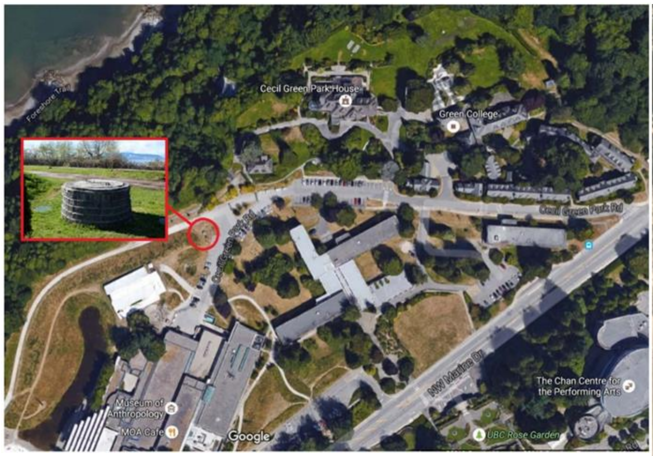

Figure 1 Overhead View of Spiral Drain

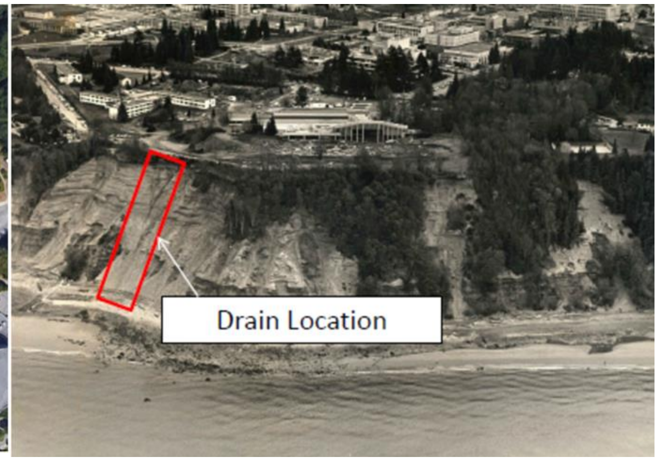

Figure 2 View of Spiral Drain from Cliff-side

The location of the project is as shown in the figures above. As the photos illustrate, one of the biggest challenges of this project is the site location and surrounding environment. When making decisions regarding which construction methods to use on the project, the site location plays a large factor. Excavation needs to be conducted with precision and care to maintain the stability of the cliff. In addition, since the area is highly populated with trees, foliage and wildlife, the design having minimal impact on the surrounding environment is a particularly important consideration.

The final design was developed to meet numerous geological, environmental, social and economic issues and constraints, all of which will be discussed in the following sections.

2.1 Geological Constraints

The sediments deposited on the point grey peninsula were laid down mainly by the process of glaciation and erosion by the sea. Furthermore, sediments like clay, silt and sand were also deposited by the Fraser River during the interglacial period. Most of the soil over the till surface is composed of sand, and beach gravel. Whereas the typical soil profile in the cliff on the UBC peninsula is composed of Capilano Sediment, Vashon Drift and Quandra Sand units. Each of these are explained as follows:

1) Quandra Sand Units:

   The sediments in this unit range from fine to coarse sand which intern is composed of feldspar, quartz and volcanic ash along with few silt and gravel interbeds. This sand unit ranges approximately from 0 m to 65 m above the sea level. The thick sand unit acts as the Upper Aquifer whereas the fine sand and silt unit at the base act as the Lower Aquifer.

2) Vashon Drift:

   This unit ranges approximately from 65 m to 68 m and is composed of sandy and loamy lodgment till.

3) Capilano Sediments:

   Beach gravels along with glaciomarine silt/clay are the main sediments found in this unit. It approximately ranges from 68 m to 69 m above the sea level.

Most of the precipitation falling on grey point peninsula either flows off the cliff, infiltrates into the ground, or gets intercepted up by the plants through the process of evapotranspiration. Furthermore, water seepage from the culvert into the ground could lead to pore-water pressure development around the culvert and can contribute to slope instability in the area. The presence of existing vertical dewatering wells on the site is capable of diverting the water from the Upper Aquifer to the Lower Aquifer, thus preventing the instability of the slope in the during construction and during operation.

2.2 Environmental Constraints

Environmental protection is one of the biggest issues to be considered for the construction phase of this project. It is of utmost priority to protect the wildlife habitat and ecosystem on the cliff and to ensure that disturbance to the environment during the construction process is minimized. In addition, ensuring contaminants from construction machinery do not discharge into the sewer is extremely important. This is because these contaminants can increase the turbidity of water and may contain pathogens. To protect the site of such contaminants, a settling tank will be temporarily installed to treat the contaminated water due to construction. In order to compensate for the deforestation on the site, part of our design includes the re-planting of the same quantity of trees as those removed during construction, at a suitable location on UBC campus. Another important aspect of construction to consider is the noise pollution and air pollution from the construction. These important issues have been addressed in our design and will be discussed in later sections in this report which focus on environmental impacts.

2.3 Social Constraints

Social concerns and constraints played a big role in design and construction of our storm water management system. Social constraints, issues that arise in social interaction, are divided into four main categories:

1. Government

2. Aboriginals
3. Residents in the vicinity of the drainage system
4. Citizens visiting the surrounding area

By taking into account the different groups of people mentioned above, we will be able to conduct our plans smoothly.

2.3.1 Government

Before we move on to the permit phase of the project, we need to send a project description to Canadian Environmental Assessment Agency. The CEA Agency will then determine if we need an EA report. The contents of the EA report will outline adverse effects to environmental, social, economic, health, heritage and First Nations values. Then feedback will be returned, which list how adverse effects can be avoided or mitigated.

After the detailed design for our project is complete, we will need to apply for government permits that will allow us to proceed to the construction phase. The reason that permits are important is because there are numerous laws and regulations that will restrict our building and constructing methods for the new drainage system. The most important of which are the permits which will be required from Metro Vancouver. Although located on UBC campus, the cliffs on which construction will take place is located on land which falls under the jurisdiction of Metro Vancouver. It is important to start the process of obtaining these permits as early as possible, as no construction can begin without these permits.

- Environmental Assessment

We are expecting to be required to complete an EA for the federal government because our design involves logging and excavation of the slope, and because work will be performed on Musqueam Territory. Once we file the report and get feedback from Federal or Provincial Agencies, we might be required to alter our design to accommodate the new guidelines that are being provided. After fulfilling the requirements given by the government, we will be able to proceed to the permitting stage.

- Development-Building Permitting

This new development of drainage system will need a development-building permit from the City of Vancouver. The development-building permit is a combined that city staff will evaluate if the site is needed. Applying for this permit before construction phase is essential.

- Logging Permit

Part of our preliminary design requires the removal of trees along the line of the drain path. Since we will be logging this path line, a tree removal permit will be required from the government. In our particular case, the requirement for tree removal is satisfying section 4.5 a) from the tree permit bylaw manual.

- Discharge Permit

The sole purpose of the drainage system is discharging storm water into the ocean which prompts the requirement for a discharge permit from Metro Vancouver. Sometimes the discharge permit can be a part of the building permit, which may make the permit process easier. Since we will not be purposefully discharging harmful substances, a standalone discharge permit will not be needed.

- Federal Acts and Regulations

When designing and constructing our new drainage system for UBC, we had to keep in mind two federal acts:

- Navigation and Protection Act
- Fisheries Act

Only once we've met the requirements of the federal acts can we then move to the developing stage, especially precautionary steps on preventing harmful substances discharged into the ocean.

- Crown Land Tenure

When we start constructing and when we finish constructing, the drainage development will be occupying crown land. Resulting from this occupation, an application for crown land tenure will be required. During the occupancy of crown land, all parts of the Land Act need to be satisfied.

2.3.2 Aboriginals

Because development land is in Musqueam Territory, it is very important members of the band are included in the design and development process. It is important to involve the Musqueam band as soon as possible to minimize the design changes we need to make later on. Our team is aware that we need to comply with First Nation demands after they have reviewed the new plans for the area, to avoid conflicts. Later in the design process, our team will be supplying a letter of engagement for the Aboriginal community to review. When dealing with aboriginal people like the Musqueams, we need to have a polite tone and acknowledge their ancestral traditions. Having an open mind is also essential for quick and hassle-free agreement with the Aboriginals. A final agreement needs be reached before any construction can commence.

2.3.3 Locals

In ensure to ensure residents in the area are informed, before construction begins we will be distributing flyers in a 1 km vicinity of the site. This will give enough preparation time for the residents to be ready for the possible inconveniences that our construction might bring to the area. Furthermore, the residents of the area will be affected by the construction noise from building the new drainage system in the area. To minimize this impact as much as possible, we have planned the best times to work on certain tasks in our scheduling section, as well as planned for alternative mitigation methods such as noise barriers, which will be discussed later on in the report.

2.3.4 Visitors to the surrounding area

Visitors of the area will also be informed beforehand by posters prior to the construction phase. Our team will provide information regarding closure to areas, such as the beach area around the downstream drainage pipe, ahead of time so there will not be any interference during construction phase.

3 Design Components

The bio-retention culvert design requires many key components for it to function properly. The breakdown of each major element is detailed as follows.

3.1 Stormceptor MAX

When the storm water first enters the drainage system, the runoff will flow through an oil and grit separation system called Stormceptor developed by Imbrium Systems. This filtration system will prevent oil, sediment, floatables and other pollutants from entering the water body below. Metro Vancouver discharge bylaws will be sufficiently met because of this separation system. Through a series of specially designed chambers, the flow of water is slowed while oil is captured by the initial tank. Particles will settle to the bottom container and filtered water will rise through the second tank. The treated water will then exit through the outlet pipe. Regular maintenance on cleaning the system is needed every 6 months for the first year to determine a rate of accumulation for oil and grit. After the first year, inspection will be performed yearly. Figure 2 shows a concept model of the Stormceptor for a better visualization for the component.

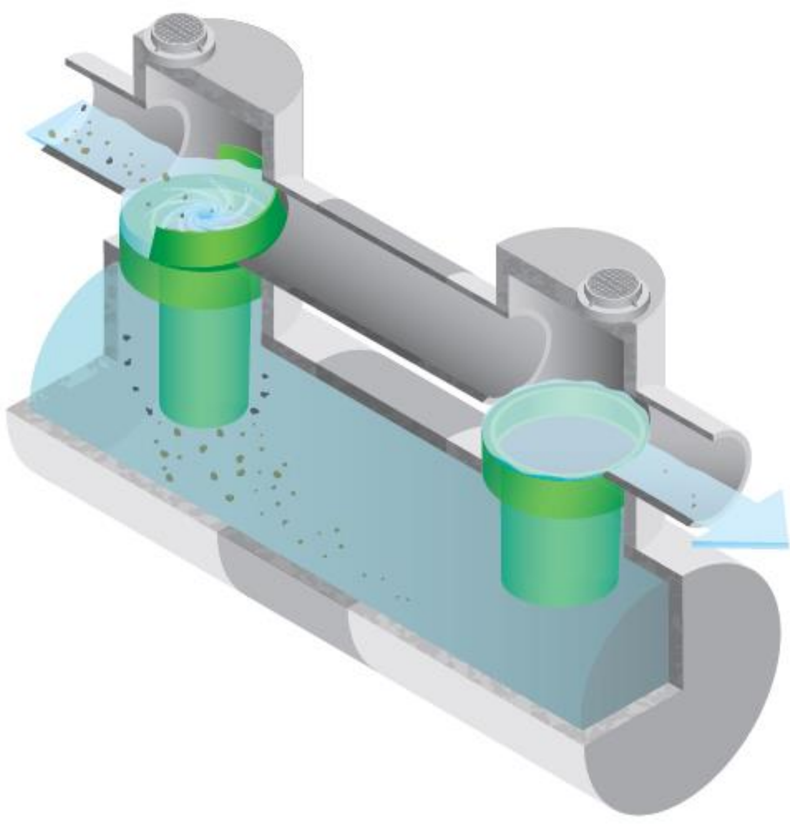

Figure 2 Stormceptor Max Illustration from Product Sheet

The model of Stormceptor used is the MAX model. The system will feature two 8 ft tall chambers and will be able to accommodate over 55000 liters of water. For Stormceptor MAX specifications, see **Appendix A**.

3.2 Bio-Retention Streambed

The effluent coming out of the Stormceptor will then enter the major functioning body of our design: the streambed. The stream bed will consist of soil and vegetation which will further filter the storm water as the water travels the length of the system. The effort and frequency of maintenance in this area of the drainage system will be very minimal as erosion will not be a major concern for the region. However, additional monitoring on wash away of the soils in this area needs to be conducted regularly; if needed, soil and vegetation will be replenished. Figure 3 illustrates upper portion of the streambed in detail.

Figure 3 Bio-Retention Stream Bed

Figure 4 Bio-retention Downstream

The bio-retention streambed will feature clay which not only will be more structurally stable than sand but also act as a very nice filtration system for the water passing through. On top of this clay layer will settle a layer of mulch which will provide a medium for biological growth, decomposition and absorption of heavy metals if presented. The Streambed is topped off with native and ornamental vegetation and a mixture of groundcover, grasses and shrubs is recommended to create a varied plant community which prevents susceptibility to insect and disease infestation. The landscaping of this part of the project will be provided by Sequoia Landscape Services. More plants and information regarding aquatic vegetation will be provided by Sequoia Landscape services as they are an expert in this field.

3.3 Culvert

In case of a heavy rainfall and 1 in 200 year storms, the storm water from the bio-retention streambed will overflow and enter the culvert underneath. The discharge water will penetrate hydro sieves located on either side of the bio-retention streambed and fall into a culvert system below it. The purpose of the culvert is to properly handle and contain the surge in flows and will not be used frequently. Because of its functioning as a backup, maintenance will only be needed when a heavy storm happens in the area and that the culvert was handling storm water discharge. Figure 5 shows the inside of the culvert with extra storm water flow.

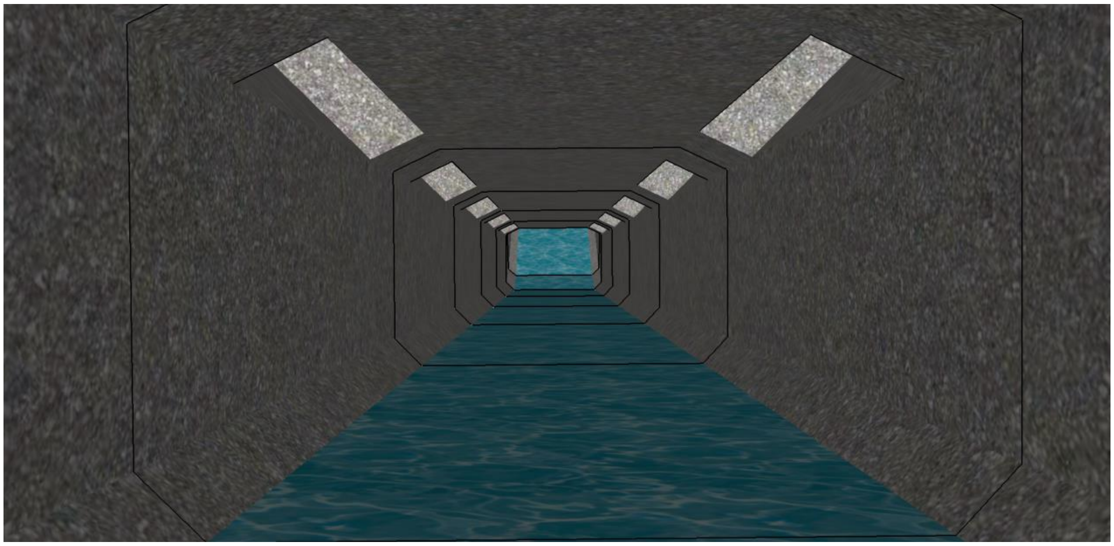

Figure 5 Culvert Interior

3.4 Soil Nail

Soil nails will be installed uniformly on the sides of the culvert to retain and remediate unstable soil conditions in the area. The functionality of the soil nail is to add more strength to the soil in the area to provide stability. A snippet of our layout drawing in Figure 6 below illustrates the soil nails tying the system together with the ground underneath.

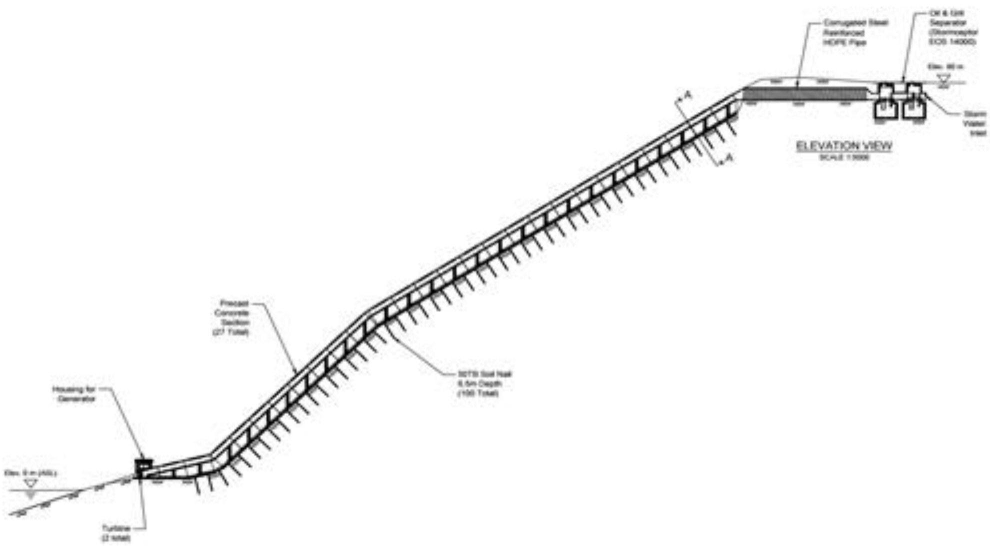

Figure 6 Profile View of Structure

4 Optional Design Component

The following design components are optional however are highly recommended by our team to be included with the final design.

4.1 Turbine

The turbine option in our bio-retention culvert design is an option that offsets the overall project lifetime cost. The turbine also helps to keep the water velocity from eroding the soil bank at the end of the culvert which may cause the structure to move due to shifting of soil. The turbine makes use of the gravity pulling the water from the stream bed down to spin the blades of the turbine to generate electricity; this electricity is then put back into the electrical grid all the while reducing velocity of water at output.

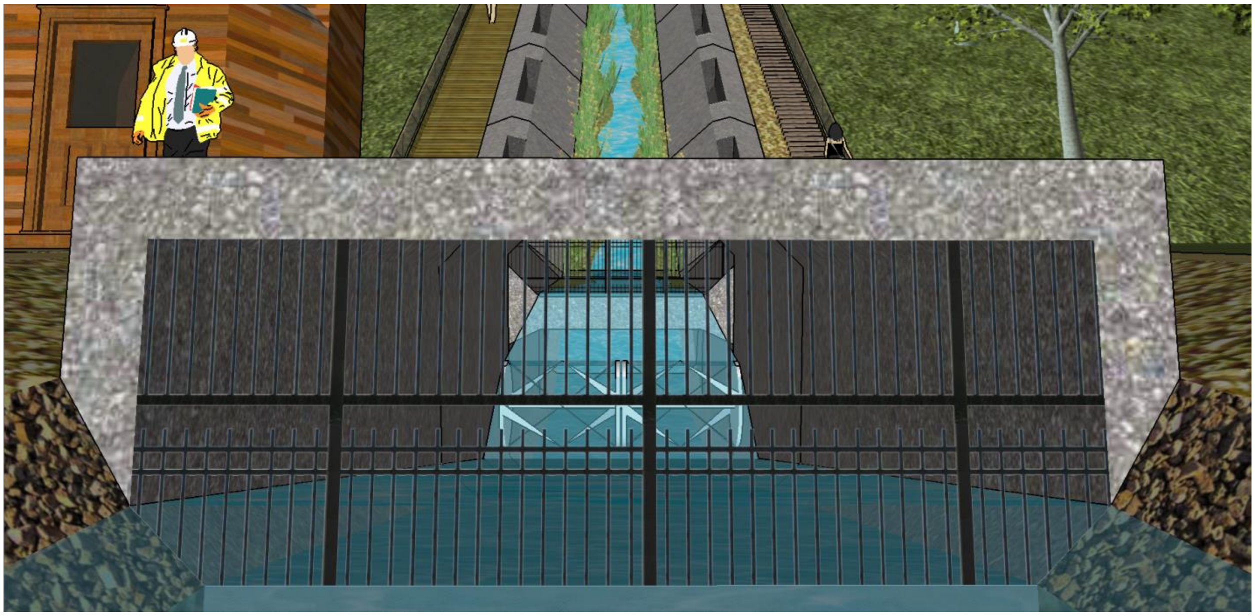

Figure 7 Turbine Option

The power generation aspect of the turbine is a worthwhile investment for the future. The turbine would produce energy that would be sold to the electrical grid to help offset the overall costs of the design. The turbine would produce an annual income of $81,750.00 as seen in **Appendix F**. That is larger number that overcomes the initial cost of the turbine the generator, electrical wiring, inverter and yearly maintenance and parts totaling $55,300.00. This leaves a total positive cash flow of $26,450.00 for the first year considering only power generating components. This income would increase for future years to provide an income of $81,750.00 with maintenance and parts cost of $27,700.00, providing revenue of $54,050.00.

It can be seen in Figure 7 that the turbine inside the culvert outlet will control the velocity of the water, thereby reducing erosion at the output as well as creating electrical energy. The turbine chosen is the Gorlov Helical Turbine. This turbine is specifically designed for open channel flow and free flowing water applications and used in rivers and streams. This design is perfect for large storms such as the 200 year storm this design is to handle. In the event of a 200 year storm, the culvert would be more than half full with storm water and the turbine will operate optimally without the aid of water flowing down from the streambed. Furthermore, this turbine has blades spaced wide enough that any larger particles coming in due to storm level flow would do minimal damage to the turbine.

4.2 Hiking Trail

As the construction process requires clearing of forest cover in a small vicinity of the installation area, rather than re-planting grass alongside the installed design or filling with gravels, the option of forming a path to hike down to the beach is preferred. The addition of this path will allow for quicker and more convenient access to Wreck Beach, which may increase the number of visitors to the beach and the vicinity of the UBC Campus.

Figure 8 Proposed Paths

As shown in Figure 8 above, there will be two proposed paths. While both have wooden handrails installed, one path will be more easily tread as opposed to the other. These paths, with a steep straight elevation change of 80m from the top of the slope to the beach, will allow tourists, locals and students to quickly traverse to the beach as compared to the many long winding trails to the east of the Cecil Green Park House.

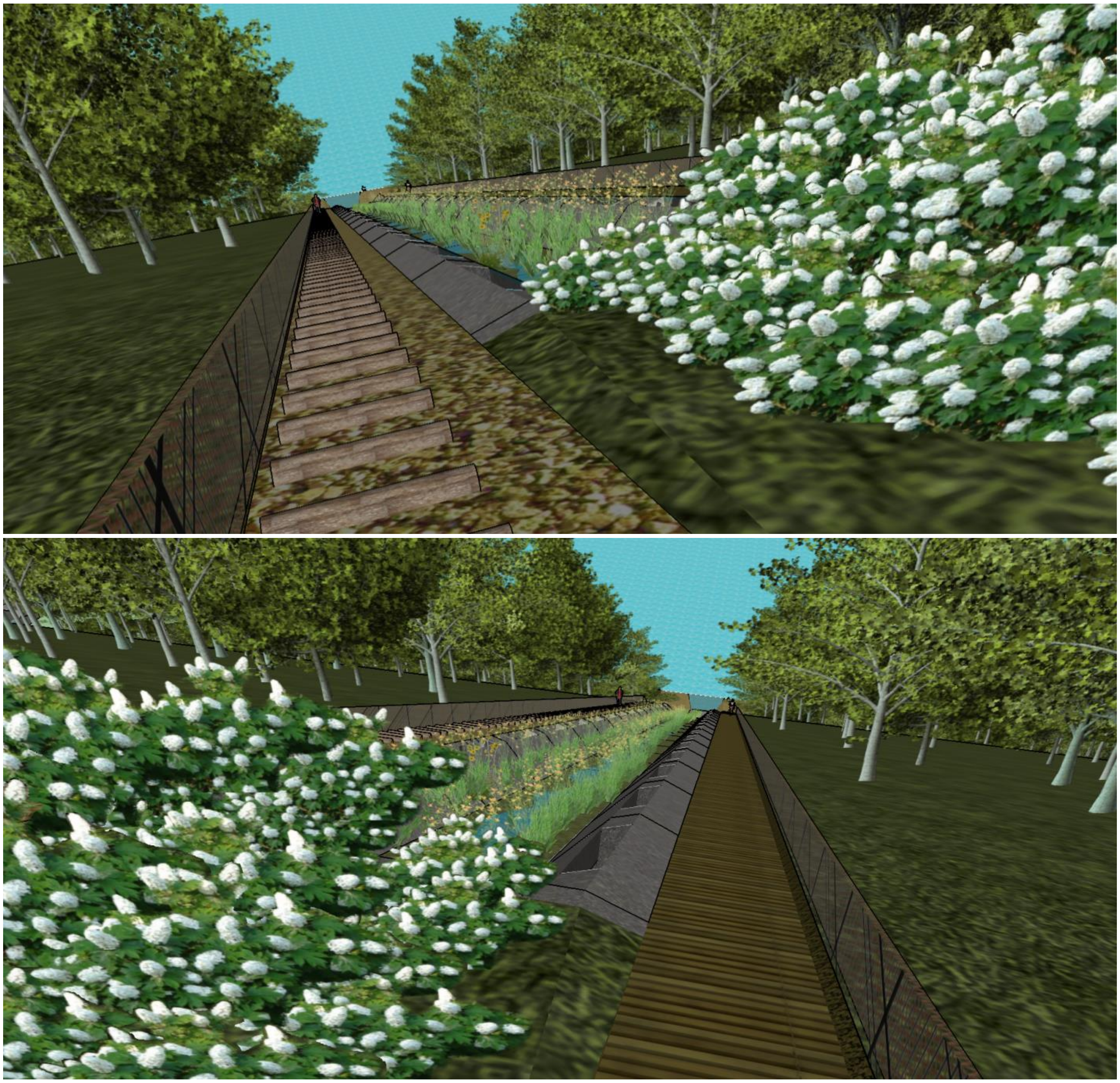

Figure 9 Left & Right Paths

The higher difficulty path on the left side is a wood mulch path with the addition of wooden steps as stable food holds; this path with fewer steps, requiring careful footing and ample dexterity, will take people to the beach quicker than the right side path. The right side path with a wooden staircase path containing level steps will allow passage to the beach for children to middle age adults that require more stable footing.

5 Design Criteria

Design criteria and technical considerations including storm water flow, hydraulic force acting on the structure, structural reinforcement, concrete mix, soil condition and soil nails are all required to be met. Refer to **Appendix I** for design drawing.

5.1 Storm Water Flow

One of the most important criteria involved in replacing the existing spiral drain is the capability of its replacement to handle 100-year and 200-year storm water levels. As such the new system was designed to handle both 100-year and 200-year storm water levels. In order to come up with the new design requirements, including determining the flow area, flow rate values for 100-year and 200-year storm water levels were calculated. To perform the calculations, the daily historic precipitation values were downloaded from the Government of Canada's Historical Climate Data page of the website. Next, three different approaches were taken to analyze the flow data and determine the maximum flow rates: the Gumbel Distribution method, Log Normal method and Log Pearson Methods. Refer to the Appendix A for the steps involved in the calculation of storm water values**.** The highest values obtained from the above mentioned three approaches were used to determine the dimensions of the replacement design. Table 1 below shows how the 100-year and 200-year storm values which were calculated.

Table 1 Calculated Values for 100-year and 200-year Storms

Gumbel Method			Log Normal Method			Log Pearson-3 Method		
T_r	K	Q(m^3/s)	T_r	K	Q(m^3/s)	T_r	K	Q(m^3/s)
2	-0.164	1.830	2	0	1.839	2	0.336	2.020
5	0.72	2.199	5	0.842	2.328	5	0.746	2.656
10	1.305	2.443	10	1.282	2.633	10	0.832	2.321
25	1.866	2.677	25	1.751	3.003	25	0.872	2.347
50	2.592	2.980	50	2.054	3.269	50	0.882	2.354
100	3.137	3.208	100	2.326	3.528	100	0.886	2.357
200	3.679	3.434	200	2.576	3.784	200	0.888	2.358

Since the Log Normal Method yields the highest storm water value i.e. $3.53\, {m^3}/{s}$ for 100-year and 3.78 ${m^3}/{s}$ for 200-year storm water level, the above mentioned values were used to figure out the required design capacity. See **Appendix B** for more information.

5.2 Hydraulic Force

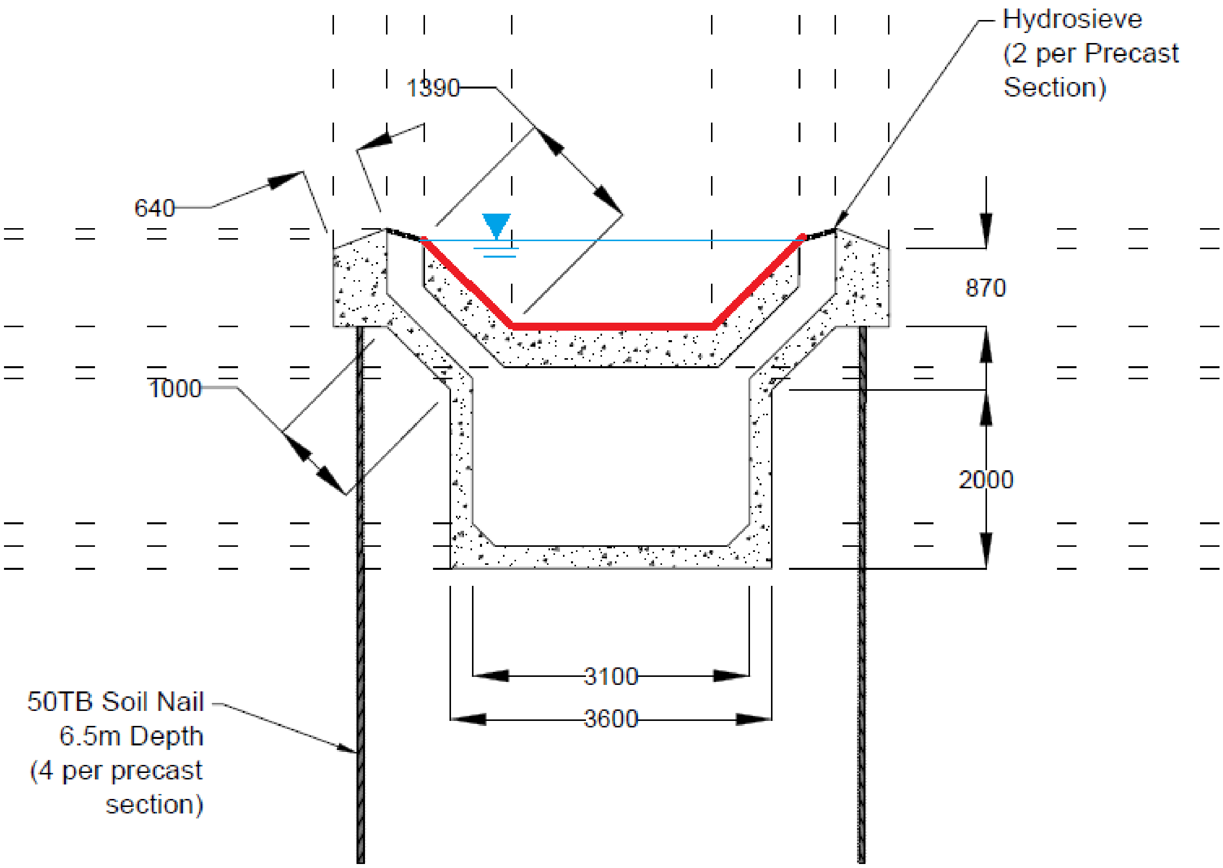

Figure 10 Concrete Structure

In our design, we considered the hydraulic forces acting on the structure during a 200 year storm condition. During a 200 year storm, the water will fill up the top trapezoid part of the culvert and the rest water will flow to the bottom rectangular section. However, only the hydraulic forces acting on the top trapezoid section highlighted in red are of concern as we designed the structure to balance these forces and any hydraulic forces acting on the bottom rectangular sections will be automatically balanced by the surrounding soil stress.

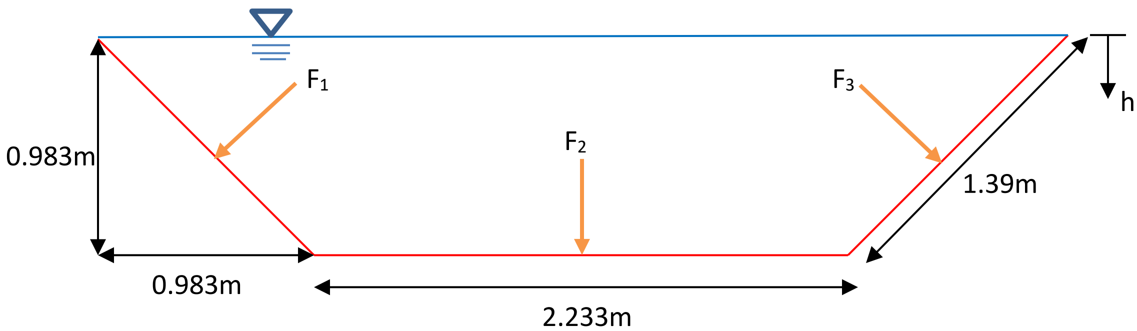

Figure 11 Stress Diagram

Calculation of F_1:

$$F_1 = \int_0^{0.983} \rho g h * w * dh = \int_0^{0.983} 1000 * 9.81 * h * (0.983 - h) * dh$$

$$F_1 = 9810 * \int_0^{0.983} (0.983h - h^2) dh = 9810 * 0.158 = 1553\ KN$$

Calculation of F_3:

Same way as to F_1 and is calculated to be F_3 = 1553 KN

Calculation of F_2:

$$F_2 = \int_0^{0.983} \rho g h * w * dh = \int_0^{0.983} 1000 * 9.81 * h * 2.233 * dh$$

$$F_2 = 21905.7 * \int_0^{0.983} h * dh = 21905.7 * 0.483 = 10584\ KN$$

Therefore, the total forces acting on the trapezoid section is $F_{total} = F_1 + F_2 + F_3$ = 13690 KN

5.3 Concrete Structural Reinforcement Design

To design the concrete culvert reinforcement, we used Canadian Standards Association (CSA) A23.3 and the textbook Reinforced Concrete Design: A Practical Approach. Our design had two sections that had to be designed for reinforcement due to loading on the structure from soil, self-weight and water pressure. Two typical culvert sections designed were designed; we considered the structure as separate sections and designed for these sections using the above-mentioned references as texts. The design was separate into Top Slab, Bottom Slab, Wall and Angled Wall as labelled in the images below.

Typical Section 1 (A0, A3, A4, A5 on drawing)

This typical section is the culvert section most common to this design. It is the main section of design running from the top of the hill to the bottom of the hill. In this section, the bottom slabs is designed to take self-weight load of the walls and water load in the culvert. The top slab in this section takes water load, self-weight and soil load. The angled walls and walls in this section are designed to take soil loads only because the worst-case scenario is when no water pressure is opposing the soil pressure.

Table 2 Section 1 Loads, Shear and Bending Moment

	Bottom Slab	Top Slab	Walls	Angled Walls
Loads (kPa)	Water load- 19.62 Wall self weight- 134.4	Water load- 7.68 Soil load-240 Self Weight-120	Soil Load- 444.41	Soil Load- 444.41
Shear (kN)	355.37	1153.80	400.0	222.21
Bending Moment (kNm)	319.83	1442.26	135.0	41.66

Typical Section 2 (A1, A2 on drawing)

This section was used at the output of the design. This section had to be designed to hold the turbine and water pressure that is due to section size changing to a smaller size. In this section, as same as the other typical section, has bottom slabs designed to take the self-weight, load of the walls and load of water pressure in the culvert. The top slab in takes no load in design but was reinforced for flexure and water pressure due to section size change. The angled walls and vertical walls, as with the other typical section, are designed to take soils loads only for the worst-case scenario when no water pressure is opposing the soil pressure.

Table 3 Section 2 Loads, Shear and Bending Moment

	Bottom Slab	Top Slab	Walls	Angled Walls
Loads (kPa)	Water load-19.62 Wall self weight-134.4	Self Weight-120	Soil Load-444.41	Soil Load-444.41
Shear (kN)	355.37	375	400.0	222.21
Bending Moment (kNm)	319.83	468.75	135.0	41.66

To design for these values in each section we looked at the factored shear and bending moment values. Then we based the rebar sizing, stirrup sizing and temperature reinforcement sizing based on the factored loads. The larger the loads the larger sized bar sizing used. To design the rebar, we also had to use a rebar cover of 60 mm to mitigate the environmental conditions and chlorides in the soils. We used rebar sizes of 25M up to 55M. With trial and error to find the best solution for each section, we found the most cost effective solutions. **See Appendix C** for more information.

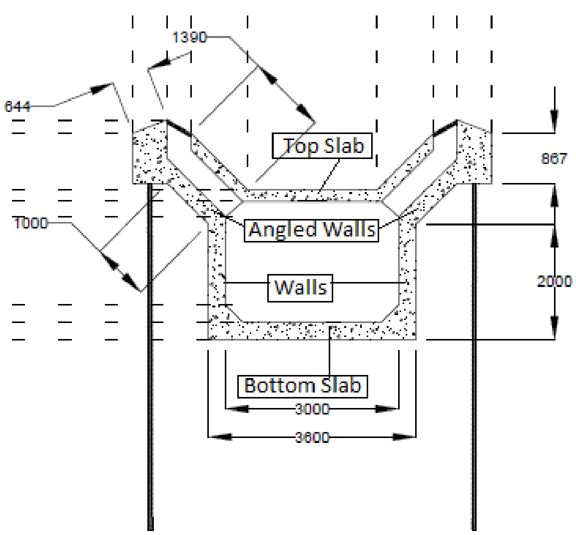

Figure 12 Typical Section 1 (A0, A3, A4, A5)

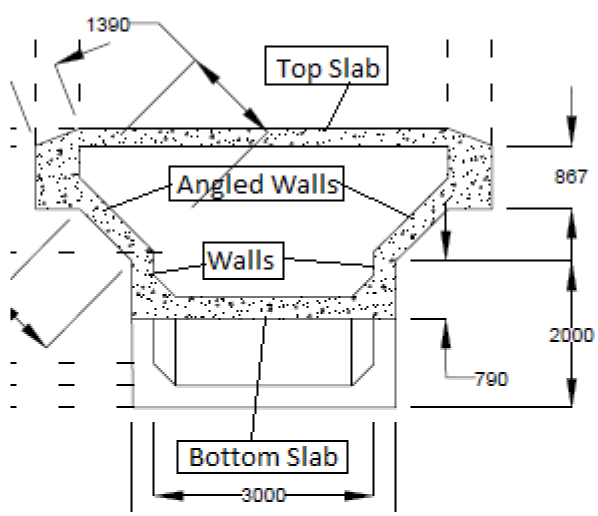

Figure 13Typical Section 2 (A1, A2)

5.4 Concrete Mix Design

Since the main feature of our team's design is a concrete culvert, it is important to ensure the highest level of quality of our concrete mix design. There are many parameters which can be used to determine the success of a concrete mix design, however, two parameters were chosen by our team to be the most significant and carried the most weight in our design analysis. The two key design parameters our team chose were:

- Strength
- Durability

Strength is obviously important as the structure needs to be able to bear the loads which will be imposed on it. Durability on the other hand, is of equal importance because in order for our design to be a success, it needs to have a reasonable service life with minimal repairs required. For these reasons, our team focused on designing a high strength, high performance concrete.

The full calculations for the concrete mix design can be found in **Appendix D**. All calculations made were in accordance with CSA and ACI mix design standards. A summary table of our final mix design can be found below.

Table 4 Concrete Mix Design Summary

CONCRETE MIX DESIGN SUMMARY TABLE	
w/c ratio	0.30
Water	202 kg/m^3 concrete
Cement	673 kg/m^3 concrete
Coarse Aggregate	703.8 kg/m^3 concrete
Fine Aggregate	704.8 kg/m^3 concrete
Admixtures	Superplasticizer, Air-entraining Admixture
SCMS	Silica Fume (~5% by weight)

5.5 Soil Nail Design

The soil profile on the cliff ranges from 80 – 100 m-ASL. The lateral pressure exerted by the soil also needs to be incorporated while designing the culvert. Furthermore, the water table profile on the cliff changes from 21 – 26 m ASL. Since the soil profile changes throughout the cliff, each layer of the soil in the cliff exhibits different properties such as density, friction angle and undrained shear strength. Using the above-mentioned soil properties, the vertical effective stress was calculated by subtracting the pore water pressure form the vertical stress. Since the friction angle for each layer of soil ranges from 28° - 33°, a friction angle of 30° was used to calculate the active lateral effective stress exerted by the soil.

In order to enhance the stability of the cliff slope, soil nails are used in the culvert design. The soil nails work together in tension and provide bending resistance to slope of the cliff thus create a self-supporting earth mass. A model of the design was created using GEO-SLOPE software to analysis different failure planes along the cliff. The Morgenstern-Price method was used to describe the failure plane type using the limit equilibrium approach (SLOPE/W).

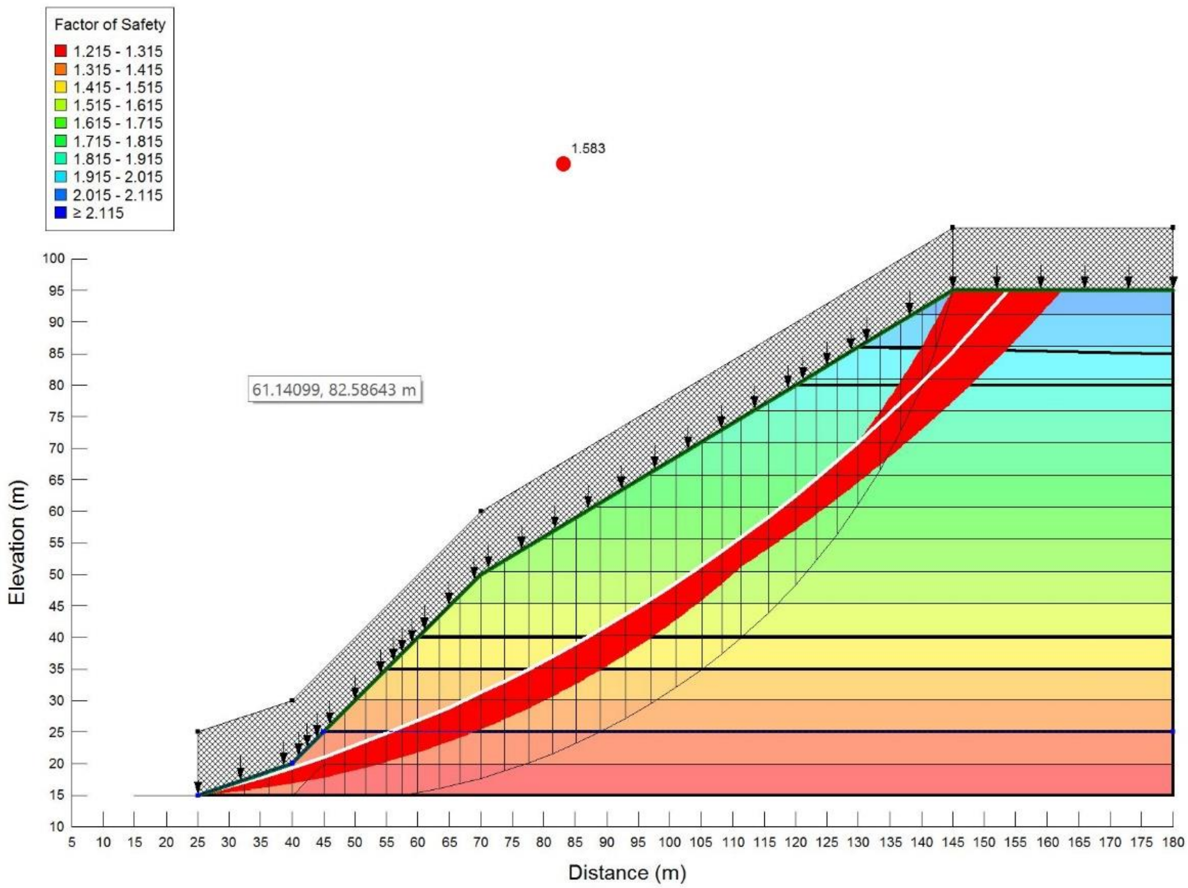

Figure 12 Slope Failure Plane on the Cliff

Soil nail reinforcement was then added to model on the GEO-SLOPE software. The nominal diameter of the soil nail was chosen to be 40 mm with the tensile strength of 660 MPa, and pullout resistance of 150 MPa was used as per the soil nail properties described in the DYWIDAG-SYSTEMS INTERNATIONAL handout. Upon the analyzing the soil failure plane generated by the GEO-SLOPE software, typical soil nail length required for the new design was approximated to be in the range of 22-40 m. The figure 15 below shows the failure plane generated by the GEO-SLOPE software on the cliff.

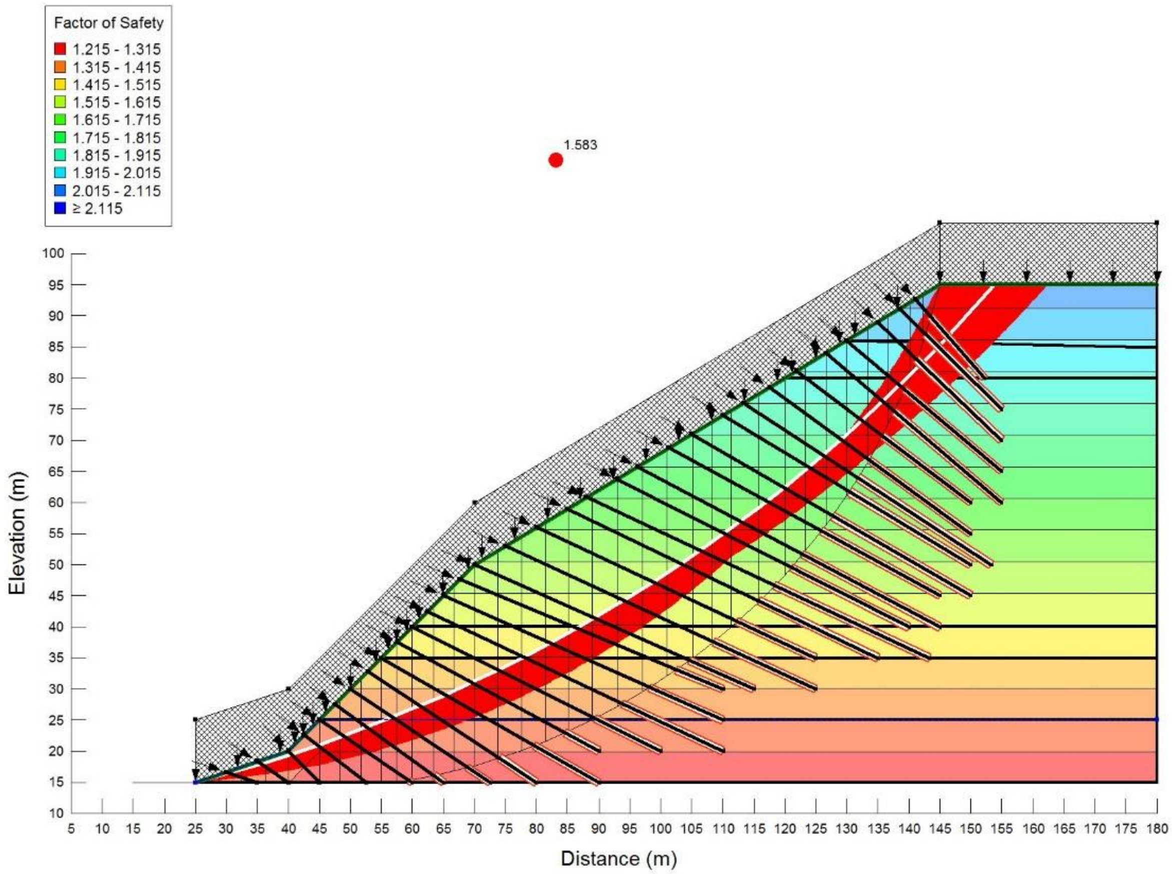

Figure 13 Slope Failure Plane with Soil Nails

The above figure 15 shows an approximate range of the soil nail length required on the cliff. The GEO-SLOPE software resulted in a factor of safety of 1.583. As the factor of safety is greater than 1, this shows that the soil nails will adequately support the system under the given soil conditions. Refer to **Appendix E** for slope and soil nail details used in the model and the results generated by the GEO-SLOPE software.

6 Project Planning

As the construction process will take place upon the sloped surface of the cliff, careful planning is required to prevent hazards and delays to construction.

6.1 Schedule

Construction is expected to begin on May 1, 2017, and is expected to last 174 days, with the project completion date being late December 2017. Construction is scheduled to only take place during standard working hours on week days. The full construction schedule detailing construction activities and durations for these activities can be found in **Appendix G**. Below is the general work breakdown structure for the project. Note that some activities have additional details or explanations below them.

Start-up:

- Site Setup (site trailers, safety station etc.)
  - Site trailers for foreman and site workers to complete paperwork and to eat lunch in will be required. Other necessary things for site are portable toilets, a safety trailer, material storage, and disposal bins. In addition, construction fencing and signage will need to be set up.
- Start-up meetings with client
- Trades initiation & site safety orientations
- Material Procurement
  - This includes the procurement of all of the pre-cast concrete culverts required as well as the generator and power cables for the design.
- Equipment mobilization
- Permit Applications and acquiring

Logging:

- Tree Marking
  - Trees which will need to be cut will get marked prior to cutting.
- Equipment setup
- Tree cutting
- Stockpiling trees

    - After trees are cut down they will be piled at the top of the cliff to eventually be taken off site via logging truck.
- Log/material removal

Excavation:

- Surveying & staking
- Excavation
- Removal of excess soil
- Compaction
    - Once the require volume of soil has been removed, the underlying soil will need to be compacted to ensure the proper strength of the soil to bear the weight of the concrete culverts.
- Slope finishing
    - This includes finishing touches to the surface to get it ready for the placement of the concrete culverts.
- QA/QC

Precast Section Installation:

- Surveying & staking
- Crane Pad installation
    - Some areas on the cliff side will need temporary structures installed for the crane.
- Drilling Holes
    - Before soil anchors/nails can be installed the holes for them to be inserted into need to be drilled.
    - Due to the slope, two platforms will be needed for drilling; from one platform the rig will drill within it's radius before being lifted to the second platform to drill from.
    - The first platform will then be lifted and secured to the next spot for the rig to drill; this process will continue until all soil nail holes are complete
- Soil nail installation
    - Once the soil nail holes have been drilled, long steel soil rods/anchors will be driven into the soil.
- Grouting
    - After the soil nails are inserted into place, they need to be grouted to keep them in place and to ensure their strength.

- Lowering pre-cast sections into place with crane
  - The concrete pre-cast culverts will have pre-drilled holes which will line up with the soil anchors sticking out of the ground. This is so that once the culverts are lowered onto the anchors; they will be fixed in their correct position. The culverts will then be fastened to the anchors to ensure they stay in place.
- QA/QC

Generator Installation

- Install Generator & connector cables
- QA/QC
- Backfill

Tie-in System:

- Surveying & staking
- New pipe installation
  - New pipes will need to be laid which will eventually tie into the existing storm water system.
- Oil/grit separator installation
  - This will be used to ensure that the water flowing in the culverts and being discharged into the ocean is free of oil, grease and grit.
- Connect new pipe to existing system

Trail/Bio-retention Garden Construction:

- Surveying & staking
- Compaction
- Geotextile installation
  - Geotextile fabric will be installed on the subgrade to stabilize the soil further, and to promote proper drainage.
- Gravel/course aggregate installation
  - Rather than pouring concrete for the hiking trail included in our design, which does not allow for draining of water and is environmentally unfriendly due to the production of CO_2 in concrete production, the hiking trail will be constructed out of dirt and aggregate.
- Surface finishing
- Fencing + Hand railing installation

- To ensure the hiking trail is safe and to protect the bio-retention stream , fencing will be installed to separate the hiking trail from the bio-retention stream.

- Signage installation
  - Part of our design incorporates educational billboards along the hiking trail to inform trail-goers on important environmental issues and about BC ecology.
- Landscaping

<u>Commissioning & Testing</u>

- Generator/ Electrical system
- Water systems
- City inspections

6.2 Area of Construction

The area designated for construction will be as shown in the following illustration. The yellow area is the general area which will be fenced off for construction. The blue rectangle shows the location where our design is to be located. The red circle indicates the area where trailers, supplies and machines will be stored during and at the end of construction shifts.

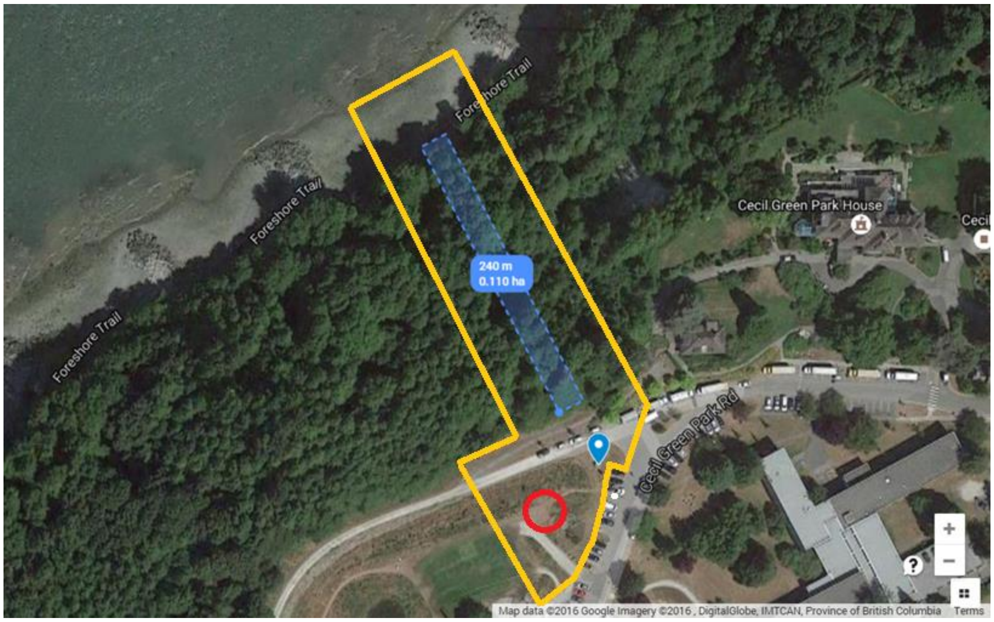

Figure 14 Area of Construction

6.3 Sub-Trade Selection

Our team has chosen to out-source the majority of the project's work to sub-trades, and as such it was extremely important to carefully consider the sub-trades being used for the project. When considering which trades to work with, we chose to look for trades which had experience with similar projects on the lower mainland, and preferably with experience working at UBC. With consideration to the above factors, we have created a preliminary table containing the sub-trades to be used for the project:

Table 5 Sub-Trade Selection

Scope of Work	Sub-Trade Selected
Precast Concrete Culverts	Architectural Precast Structures
Excavation	Matcon Civil Constructors Inc.
Landscaping	Sequoia Landscape Services

6.4 Impacts of Material & Construction

The environmental impacts of the materials that are used in the design are of important consequence to the environment, and as such the concrete stream bed, culverts, turbines and generator used for the implementation will be briefly discussed.

a. Concrete Culverts

Out of the construction materials, the pre-cast concrete structures have the biggest adverse effect of on the environment. This is in part due to the fact that the concrete culverts are the largest component of the design, but in addition concrete itself has very harmful environmental effects, as every 1kg of concrete produces 1kg of CO_2.

i. Cement

The cement used to construct the culverts in our design generates a lot of CO_2 during production. This is an important issue to keep in mind as we want to keep the project's carbon footprint as small as possible. Cement production also results in the release of SO_2, which is a negative environmental impact as this can causes air acidification and lead to acid rain, which is harmful to most living organisms. Another danger of cement during the construction the concrete sections is the floating particles of cement dust can be harmful to living organisms in the area. Cement is also known to be very energy intensive and the energy required to produce cement is very large.

ii. Rebar

The concrete structure has rebar which is made of steel. The fabrication of steel is a very energy intensive process as well and requires the use of coal to heat furnaces. The coal produces a large amount of CO_2 and SO_2 gasses that pollute the air as stated in the paragraph above.

iii. Additives

The use of additives in concrete is useful in giving the concrete different properties such as strength as well as increased resistance to water and chemicals. The problem, however, is that these additives can be toxic to the environment.

b. Turbine and Generator

The construction of the turbine is of more minor concern than the concrete sections. The biggest effect on the environment is that the components cannot be sourced locally and will need to be transported from another country. The CO_2 released during the shipping process will produce air pollution. The turbine is made of stainless steel which is fabricated at steel mills, which produce amounts of CO_2 and SO_2 which are of great concern to the environment. Another material within the generator is electrical steel which is needed to build the internal components of the generator. These steels include silicon which is dangerous to human health because the particles are very fine and can be easily ingested without proper precautions. Electrical steels are specially made and as such are also needed to be shipped in which leads to the generator resulting in pollution for the environment.

When installing the design, the largest concerns to the environment are:

- CO_2 production from the machinery used in construction
- The removal of trees required to implement our design

The usage of large machinery produces large amounts of CO_2 and SO_2 gases that are harmful to the environment. In addition, these machines on the cliff will be harmful to the surrounding ecosystem, disturbing the wildlife in the area.

The removal of trees is a big concern because the trees convert the carbon dioxide in the atmosphere and when these trees are removed there is loss in the ability to covert the carbon dioxide to oxygen. However as long as the logged trees are not burned or decomposed, they will continue to act as heat sinks. The trees are also home to many wildlife species, so the removal of trees will result of some movement of wildlife in the area. In order to compensate for the amount of trees we will need to remove during construction, our team will be planting at least an equivalent amount of trees in a suitable location. In addition, the lumber generated by the trees which are logged during construction can be used for future projects at UBC.

6.5 Construction Impact Mitigation Plan

Our team has made an effort to ensure the negative impacts of construction have been addressed and mitigated. Throughout the project, we will strive to ensure noise pollution, energy use, air pollution, and water system contaminants are kept to a minimum. Below is a list outlining the main mitigation measure our team will use to ensure the negative impacts of construction are kept to a minimum.

1. Adequate construction barriers, signage, and lighting must always be present on site to ensure the safety of the workers and the public
2. All construction workers on site must have adequate safety training prior to beginning of construction
3. Work will take place during daylight hours to ensure noise pollution is kept to a minimum
4. Drain/filter covers and grates will be installed prior to construction to ensure construction debris and dust does not enter the storm water system
5. Construction vehicles will be periodically sprayed down to ensure there is no excess dust build up
6. Government approval must be obtained prior to any road closures; Local police, ambulance, and fire departments must be given notification regarding any road closures
7. Any safety incidents or near-misses must be reported immediately so the proper procedures can be taken to identify and correct the problem causing the issue
8. Quality control and assessment guidelines will be strictly enforced and any work defect will be reported immediately

9. As per city of Vancouver's by-laws, work can only be between the hours of 7:30am and 5pm, Monday to Saturday (although the schedule does not schedule work for Saturday).
10. Site housekeeping will be strictly enforced; Site clean-up will take place daily, and any garbage or other disposal material will be placed in their appropriate bin located on site
11. All loose fine particulate matter will be covered up at the end of each day to avoid excess dust.
12. Impermeable surfaces and site entrances will be sprayed down periodically to avoid a build-up of dust/debris.
13. For each tree logged for the purpose of this project, the same number of trees will be planted in the vicinity over 5 years post construction.

6.6 Environmental Plan

Within the vicinity of the worksite, there are numerous amounts of negative impacting accidents that could happen (e.g. spillage.) To account for these potential environmental hazards, our group will be using geo-membrane liners to seal off the most vulnerable areas. The areas that need to be contained are in the vicinity of:

- Construction machinery
- Storage trailers
- Fuel Tanks
- Downstream beach

A recommended containment provider is Nilex. This company has been a pioneer of the field, therefore will provide maximum safety to our surrounding ecosystems.

6.7 Tree Protection

When working on the hillside constructing the drainage system, even after logging the needed path, the construction team will still be in close proximity to trees. To protect the trees from possible harm, we will be installing tree protection fences. The tree protection zone will be measured and calculated by the surveying team before the installation of the fences happen to ensure that all of the trees are adequately safe guarded.

7 Project Cost

The project cost at this final design stage of the project is estimated as a Class B, where the cost estimation is based on our final detailed design drawings and up-to-date market investigation. Since our project contains two optional design components: the power generating turbine and the hiking trial, the project costs have been estimated under two different situations where the optional components are considered and ignored, respectively.

The table on the following page, Table 6, details the project costs breakdown with power generating turbine and hiking trial considered during construction.

Table 6 Project Cost with Optional Design Components

FINAL DESIGN COST ESTIMATE (CLASS B)						
CATEGORY	ITEM #	DESCRIPTION	UNIT	QUANTITY	RATE	COST
Materials	M1	Stormceptor Max[1]	1	1 unit	$ 130,000 /unit	$ 130,000
	M2	Precast Concrete[2]	27	20 m^3	$ 300 /m^3	$ 162,000
	M3	50 mm OD Soil Nail Anchor Bolt[3]	100	6.5 m	$ 5 /m	$ 3,250
	M4	Streambed Gravel/Soils[4]	320	1 yd^3	$ 15 /yd^3	$ 4,800
	M5	Streambed Vegetation[5]	1	405 yd^2	$ 30 /yd^2	$ 12,150
	M6	Corrugated Steel Reinforced HDPE Pipe[6]	1	20 m	$ 65 /m	$ 1,300
	M7	Turbine (optional)[7]	2	1 unit	$ 6,000 /unit	$ 12,000
	M8	Generator (optional)[8]	1	1 unit	$ 900 /unit	$ 900
	M9	Power Cable (optional)[9]	2	200 m	$ 15 /m	$ 6,000
	M10	Inverter (optional)[10]	1	1 unit	$ 8,800 /unit	$ 8,800
	M11	20M Rebar[11]	2.8	1 tonne	$ 1,763 /tonne	$ 4,932
	M12	25M Rebar[12]	24.5	1 tonne	$ 1,763 /tonne	$ 43,195
	M13	30M Rebar[13]	6.9	1 tonne	$ 1,764 /tonne	$ 12,097
	M14	35M Rebar[14]	4.6	1 tonne	$ 1,763 /tonne	$ 8,096
	M15	45M Rebar[15]	46.3	1 tonne	$ 1,763 /tonne	$ 81,667
	M16	50MPa Concrete[16]	673	1 m^3	$ 236 /m^3	$ 158,828
	M17	40mm Diameter Soil Nail[17]	1186	1 m	$ 21 /m	$ 24,906
Construction	C1	Logging[11]	130	1 tree	$ 350 /tree	$ 45,500
	C2	Excavation[12]	1	15700 yd^3	$ 120 /yd^3	$ 1,884,000
	C3	Grading[13]	1	810 yd^2	$ 2 /yd^2	$ 1,215
	C4	Drilling[14]	100	6.5 m	$ 150 /m	$ 97,500
	C5	Grouting[2]	100	0.0184 m^3	$ 300 /m^3	$ 551
	C6	Crane Operation[15]	1	100 hr	$ 340 /hr	$ 34,000
	C7	Geotextile Installation[13]	1	41 ft	$ 30 /ft	$ 1,234
	C8	Landscaping[16]	1	405 ft^2	$ 15 /ft^2	$ 6,075
	C9	Trail Signage Installation (optional)[17]	20	1 ft^2	$ 15 /ft^2	$ 300
	C10	Trail Fences, Handlebar, Steps Installation (optional)[18]	2	450 ft	$ 15 /ft	$ 13,500
Project Management	P1	Construction Superintendent[19]	1	8000 hr	$ 40 /hr	$ 320,000
	P2	Skilled Labor[19]	10	800 hr	$ 18 /hr	$ 144,000
	P3	Electrician[19]	1	40 hr	$ 30 /hr	$ 1,200
	P4	Land Surveyor[19]	2	20 hr	$ 24 /hr	$ 960
	P5	Project Manager (Class E4)[20]	1	288 hr	$ 195 /hr	$ 56,160
	P6	Project Engineer (Class E3)[20]	1	960 hr	$ 159 /hr	$ 152,640
	P7	Field Engineer (Class E1)[20]	1	960 hr	$ 121 /hr	$ 116,160
Miscellaneous	MSC	Tree Removal Permit[21]	113	1 tree	$ 190 /tree	$ 21,470
Contingency	CNT	Estimated @ 20% of Implementation Cost				$ 714,277
INITIAL IMPLEMENTATION TOTAL						$ 4,285,665
Operation & Maintenance (Assume 100 yr Service Life)	OM1	Gardener[19]	2	100 yr	$ 35,360 /yr	$ 7,072,000
	OM2	Maintenance Worker[19]	2	100 yr	$ 39,520 /yr	$ 7,904,000
	OM3	Sediment Removal[13]	1	100 yr	$ 500 /yr	$ 50,000
	OM4	Turbine and Generator Parts (5% Installation Cost) (optional)[22]	1	100 yr	$ 27,700 /yr	$ 2,770,000
	OM5	Power Generation Revenue (optional)	1	100 yr	-$ 81,750 /yr	-$ 8,175,000
SERVICE LIFE TOTAL						$ 13,906,665
Consultation Fee	CF1	Professional Service charge				$ 18,443
	CF2	Disbursement Charge				$ 1,820,708
CONSULTATION FEE TOTAL						$ 1,839,150
PROJECT OVERALL COST						$ 15,745,815

The estimated final project implementation cost comes down to approximately $4,290,000 with an approximate cumulative total of $13,900,000 over an estimated duration of a 100 year service life[19]. As shown on the table, the power generated by the turbine offsets approximately $8,175,000 by contributing power back into the grid, allowing for a reasonable return on investments made during the service life of the facility. The total consultation fee is estimated to be $1,840,000 for this project and a more detailed breakdown on the consultation fee is placed in the **Appendix H**. Therefore, the overall project cost is calculated to be around $15,750,000 if we include the optional components.

The cost breakdown for the other case where two optional design components are ignored during construction is shown in the following table, Table 7.

Table 7 Project Cost without Optional Design Components

FINAL DESIGN COST ESTIMATE (CLASS B)							
CATEGORY	ITEM #	DESCRIPTION	UNIT	QUANTITY	RATE		COST
Materials	M1	Stormceptor Max[1]	1	1 unit	$ 130,000	/unit	$ 130,000
	M2	Precast Concrete[2]	27	20 m^3	$ 300	/m^3	$ 162,000
	M3	50 mm OD Soil Nail Anchor Bolt[3]	100	6.5 m	$ 5	/m	$ 3,250
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	M5	Streambed Vegetation[5]	1	405 yd^2	$ 30	/yd^2	$ 12,150
	M6	Corrugated Steel Reinforced HDPE Pipe[6]	1	20 m	$ 65	/m	$ 1,300
	M7	20M Rebar[7]	2.8	1 tonne	$ 1,763	/tonne	$ 4,932
	M8	25M Rebar[8]	24.5	1 tonne	$ 1,763	/tonne	$ 43,195
	M9	30M Rebar[9]	6.9	1 tonne	$ 1,764	/tonne	$ 12,097
	M10	35M Rebar[10]	4.6	1 tonne	$ 1,763	/tonne	$ 8,096
	M11	45M Rebar[11]	46.3	1 tonne	$ 1,763	/tonne	$ 81,667
	M12	50MPa Concrete[12]	673	1 m^3	$ 236	/m^3	$ 158,828
	M13	40mm Diameter Soil Nail[13]	1186	1 m	$ 21	/m	$ 24,906
Construction	C1	Logging[11]	130	1 tree	$ 350	/tree	$ 45,500
	C2	Excavation[12]	1	15700 yd^3	$ 120	/yd^3	$ 1,884,000
	C3	Grading[13]	1	810 yd^2	$ 2	/yd^2	$ 1,215
	C4	Drilling[14]	100	6.5 m	$ 150	/m	$ 97,500
	C5	Grouting[2]	100	0.0184 m^3	$ 300	/m^3	$ 551
	C6	Crane Operation[15]	1	100 hr	$ 340	/hr	$ 34,000
	C7	Geotextile Installation[13]	1	41 ft	$ 30	/ft	$ 1,234
	C8	Landscaping[16]	1	405 ft^2	$ 15	/ft^2	$ 6,075
Project Management	P1	Construction Superintendent[19]	1	8000 hr	$ 40	/hr	$ 320,000
	P2	Skilled Labor[19]	10	800 hr	$ 18	/hr	$ 144,000
	P3	Electrician[19]	1	40 hr	$ 30	/hr	$ 1,200
	P4	Land Surveyor[19]	2	20 hr	$ 24	/hr	$ 960
	P5	Project Manager (Class E4)[20]	1	288 hr	$ 195	/hr	$ 56,160
	P6	Project Engineer (Class E3)[20]	1	960 hr	$ 159	/hr	$ 152,640
	P7	Field Engineer (Class E1)[20]	1	960 hr	$ 121	/hr	$ 116,160
Miscellaneous	MSC	Tree Removal Permit[21]	113	1 tree	$ 190	/tree	$ 21,470
Contingency	CNT	Estimated @ 20% of Implementation Cost					$ 705,977
INITIAL IMPLEMENTATION TOTAL							$ 4,235,865
Operation & Maintenance (Assume 100 yr Service Life)	OM1	Gardener[19]	2	100 yr	$ 35,360	/yr	$ 7,072,000
	OM2	Maintenance Worker[19]	2	100 yr	$ 39,520	/yr	$ 7,904,000
	OM3	Sediment Removal[13]	1	100 yr	$ 500	/yr	$ 50,000
SERVICE LIFE TOTAL							$ 19,261,865
Consultation Fee	CF1	Professional Service charge					$ 18,443
	CF2	Disbursement Charge					$ 2,351,248
CONSULTATION FEE TOTAL							$ 2,369,690
PROJECT OVERALL COST							$ 21,631,555

The estimated final project implementation cost comes down to approximately $4,240,000 which is lower than the previous case. However, the cumulative total over the 100-year service life is approximately 19,260,000 and is way greater than the previous value. This is because the power generation revenue is taken away if turbine is not installed, and thus there will be a higher net project cost in the long term. The overall project cost for this case where optional components are ignored is calculated to be approximately $21,630,000.

As such, it is recommended that the optional design component, the power generating turbine, be installed as it provides a significant offset on the net project cost in the long term. While the hiking trail does not generate income, this optional component at an insignificant cost of $13,800 compared to the overall total, is recommended to be installed. The trail serves as a quick access route for maintenance personnel to various points of the system and to the generator housing by the design outlet and more importantly the shore of Wreck Beach for the benefit of tourists, residents and locals.

8 Conclusion and Recommendations

After extensive analysis of different aspects of the bio-retention system, the project is finally ready to move onto the next phase. Through these studies, the bio-retention system was found to be a feasible and efficient design.

The water cement ratio that is recommended for use in majority of culvert sections is 0.3 with the addition of super plasticizers to increase workability and air entraining admixture to increase protection against freeze-thaw. The soil nail was chosen to have a 40mm nominal diameter, tensile strength of 660MPA and a pull resistance of 150 MPA.

The construction of the drainage system is expected to begin on May 1, 2017, and is expected to last 174 days, with the project completion date being late December 2017.

The final updated cost is estimated as Class B which is based on our final detailed design drawings and up-to-date market investigation. The estimated final project implementation cost comes down to approximately $4,290,000 with an approximate cumulative total of $13,900,000 over an estimated duration of a 100 year service life[19]. As shown on the table, the power generated by the turbine offsets approximately $8,175,000 by contributing power back into the grid, allowing for a reasonable return on investments made during the service life of the facility.

The construction materials of this design, such as concrete and steel, as well as the heavy machineries that will be operating on site will have adverse effects on the environment and living organism. Therefore, it is advised that all machineries to be used at a minimal amount wherever is possible to reduce these negative effects. Moreover it is recommended that geo-membrane liners be used to seal off the most vulnerable area in vicinity from being negatively impacted by any accidents that could occur in the construction zone.

Endnotes

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APPENDICES

Appendix A - Stormceptor MAX Specifications

STANDARD SPECIFICATION FOR

"OIL GRIT SEPARATOR" (OGS) STORMWATER QUALITY TREAMENT DEVICE FOR LARGE DRAINGE AREAS

PART 1 – GENERAL

1.1 WORK INCLUDED

This section specifies requirements for selecting, designing, maintaining, and constructing an underground, modular Oil Grit Separator (OGS) device for stormwater quality treatment of large drainage areas. Work includes supply and installation of concrete bases, precast sections, and the appropriate precast section with all internal components completely and correctly installed within the OGS device, water tight seals prior to arrival to the project site.

1.2 REFERENCE STANDARDS

1.2.1 For Canadian projects only, the following reference standards apply:

Canadian Standards Association

CAN/CSA-A257.3-M92: Joints for Circular Concrete Sewer and Culvert Pipe, Manhole Sections, and Fittings Using Rubber Gaskets

CAN/CSA-A257.4-M92: Precast Reinforced Circular Concrete Manhole Sections, Catch Basins, and Fittings

CAN/CSA-S6-00: Canadian Highway Bridge Design Code

1.2.2 For ALL projects, the following reference standards apply:

ASTM D-4097: Contact Molded Glass Fiber Reinforced Chemical Resistant Tanks

ASTM C 478: Specification for Precast Reinforced Concrete Manhole Sections

ASTM C 443: Specification for Joints for Concrete Pipe and Manholes, Using Rubber Gaskets

ASTM D2563: Standard Practice for Classification of Visual Defects in Reinforced Plastics

ASTM D2584: Test Method for Ignition Loss of Cured Reinforced Plastics

1.3 SHOP DRAWINGS

1.3.1 Shop drawings shall be submitted upon request with each order to the contractor then forwarded to the Engineer of Record for review and acceptance. Shop drawings shall detail the precast concrete components and all OGS internal components prior to shipment, including the sequence for installation.

1.3.2 Unless directed otherwise by the Engineer of Record, OGS product substitutions submitted within 10 days prior to project bid shall not be accepted. All substitutions submitted shall be based on the exact same Performance and Design criteria detailed in Section 3, subject to review and approval by the Engineer of Record. Any and all changes to project cost estimates, bonding amounts, plan check fees for revision of approved documents, or design impacts due to regulatory requirements as a result of a product substitution shall be coordinated by the Contractor with the Engineer of Record.

1.4 HANDLING AND STORAGE

Prevent damage to materials during storage and handling.

1.4.1 Internal OGS device materials supplied by the Manufacturer for connection to the precast concrete shall be pre-fabricated and bolted to the precast and watertight sealed to the precast surface prior to delivery to the project site to ensure Manufacturer's internal assembly process and quality control processes are fully adhered to, and to prevent damage to the materials on site. Internal OGS materials shall not be installed, bolted or sealed at the job site. No exceptions will be accepted.

1.4.2 Follow all instructions including the sequence for installation in the shop drawings during installation.

PART 2 – PRODUCTS

2.1 GENERAL

2.1.1 The OGS inlet and outlet chambers shall be circular and vertically-oriented cylindrical precast concrete structures. The OGS's settling chamber shall be either a horizontally-oriented cylindrical precast concrete structure or a box-shaped precast concrete structure. The bypass shall be a horizontally-oriented cylindrical or box-shaped precast concrete structure of the same dimension as the inlet or outlet conveyance network, connecting between both the inlet and outlet chambers.

2.1.2 The OGS inlet and outlet chambers shall each include a fiberglass insert bolted and sealed watertight inside the vertically-oriented cylindrical precast concrete structure. The fiberglass inserts shall be installed inside their respective precast concrete risers prior to delivery to the project site. The fiberglass inserts shall provide a double-wall lining of 18 inches (450 mm) for oil storage and retention as a secondary containment system within the OGS.

2.1.3 The OGS shall be allowed to be specified as a bend structure in the stormwater drainage system.

2.2 PRECAST CONCRETE SECTIONS

All precast concrete components shall be designed and manufactured to meet highway loading conditions per State/Provincial or local requirements.

2.3 GASKETS

2.3.1 For round structures:Only profile neoprene or nitrile rubber gaskets that are oil

resistant in will be accepted. For Canadian projects only, gaskets shall be in accordance to CSA A257.3-M92. Mastic sealants, butyl tape/rope or Conseal CS-101 alone are not

acceptable gasket materials

2.3.2 For box structures: Gaskets shall meet all national and municipal specifications. Ensuring water tightness is the responsibility of the contractor.

2.4 JOINTS

The concrete joints shall be water-tight and meet the design criteria according to ASTM C-990, as well as all national and municipal specifications. For projects where joints require gaskets, the concrete joints shall be water-tight, and oil resistant and meet the design criteria according to ASTM C-443. Mastic sealants or butyl tape/rope alone are not an acceptable alternatives. Ensuring that the joints are watertight is the responsibility of the contractor.

2.5 FRAMES AND COVERS

Frame and covers shall be manufactured in accordance with per State/Provincial or local requirements, and for inspection and maintenance access purposes shall be at least 24 inch (600 mm) in diameter. A minimum one cover shall be clearly embossed with OGS manufacturer's product name to properly identify this asset's purpose is for stormwater quality treatment.

2.6 PRECAST CONCRETE

All precast concrete components shall conform to the appropriate CSA or ASTM specifications.

2.7 FIBERGLASS

The fiberglass portion of the OGS water treatment device shall be constructed in accordance with the following ASTM D-4097 standard, and shall be installed, bolted and watertight sealed prior to arrival to the project site.

2.8 LADDERS

Ladder rungs to be provided upon request per State/Provincial or local requirements.

2.9 INSPECTION

All precast concrete sections shall be level at the designated slope per the shop drawings, and inspected to ensure dimensions, appearance, integrity of internal components, and quality of the product meets State/Provincial or local specifications and associated standards.

PART 3 – PERFORMANCE & DESIGN

3.1 GENERAL

The OGS stormwater quality treatment device shall be designed to treat drainage areas greater than 8 impervious acres (3.25 ha) and remove oil and sediment from stormwater runoff during frequent wet weather events, and retain these pollutants during less frequent high flow wet weather events within the OGS lower chamber for later removal during maintenance.

3.2 RUNOFF VOLUME

The OGS device shall be engineered, designed and sized to treat a minimum of 90 percent of the annual runoff volume using a widely accepted continuous simulation runoff model using historical rainfall data which includes antecedent conditions as well as rainfall periods. Rainfall data sets should be comprised of a minimum of 15-years of rainfall data or a longer continuous period if available for a given location, but in all cases at least a minimum of 5-years continuous rainfall.

3.3 TOTAL SUSPENDED SOLIDS (TSS)

The OGS device shall be capable of removing the Engineer-specified total suspended solids (TSS) load, without scouring previously captured pollutants.

3.4 SIZING METHODOLOGY

The OGS device shall be engineered, designed and sized to treat a minimum of 90 percent of the annual runoff volume using a widely accepted continuous simulation runoff model using historical rainfall data which includes antecedent conditions as well as rainfall periods. Rainfall data sets should be comprised of a minimum of 15-years of rainfall data or a longer continuous period if available for a given location, but in all cases at least a minimum of 5-years continuous rainfall. The Peclet Number and volumetric scaling are not approved methods for modeling or calculating TSS removal, sizing, or scaling of OGS devices.

3.5 PARTICLE SIZE DISTRIBUTION (PSD) FOR SIZING

The OGS device shall typically be sized to remove the Engineer-specified sediment (TSS) load using the particle size distribution (PSD) shown in Table 3.5, in addition to adhering to sections 3.2 and 3.4 of this specification. The Engineer may specify an alternative PSD to determine OGS sizing for sediment (TSS) load removal and meet water quality objectives.

Table 3.5 – Particle Size Distribution		
Particle Size Distribution to be used to size OGS		
Particle Diameter (Micron)	**% by Mass of All Particles**	**Specific Gravity**
1000	5%	2.65
500	5%	2.65
250	15%	2.65
150	15%	2.65
100	10%	2.65
75	5%	2.65
50	10%	2.65
20	15%	2.65
8	10%	2.65
5	5%	2.65
2	5%	2.65

3.6 BYPASS DESIGN

OGS devices for larger drainage areas shall incorporate a bypass as a horizontally-oriented cylindrical or box-shaped precast concrete structure of the same dimension as the inlet or outlet conveyance network, and shall connect both the inlet and outlet chambers to the inlet and outlet conveyance network, thereby eliminating the requirement for an upstream bypass manhole and downstream junction manhole for management of less frequent high flow wet weather events and prevention of the washout of previously captured pollutants.

3.7 SEDIMENT STORAGE CAPACITY

Manufacturer's sediment storage capacity guidelines for the OGS stormwater quality treatment device shall be confirmed by the Engineer to have adequate minimum storage and comply with Section 3.6.1.1 for the anticipated annual sediment (TSS) loadings. Sediment loadings shall be determined by land-use and defined as a minimum of 450 kg (992 lb) of sediment (TSS) per impervious hectare of drainage area per year, or greater as noted in the Table 3.7 below. The OGS device's sediment storage capacity shall be specified as to not require maintenance (sediment removal) more frequently than once per year.

TABLE 3.7 - Typical Urban Areas and Pollutant Yields (Sediment) (Burton and Pitt, 2002)

Pollutant	Sediment Pollutant Load by Land Use (kg/ha/year)							
	Commercial	Parking Lot	Residential Density			Highways	Industrial	Shopping Centers
			High	Med.	Low			
TSS	1000	400	400	250	10	880	500	440

Source: U.S. EPA Stormwater Best Management Practice Design Guide, Volume 1, Appendix D, Table D-1

NOTE: to determine volume of adequate sediment storage capacity a bulk density of 1602 kg/m^3 (100 lbs/ft^3) shall be applied.

3.8 PETROLEUM HYDROCARBON CAPTURE AND STORAGE

3.8.1 The OGS device internal hydrocarbon storage area shall include a minimum of 16 inches (405 mm) of double wall containment for the full circumference of the device to provide safe oil and other hydrocarbon material storage and ground water protection.

3.8.2 Petroleum hydrocarbon storage capacity of solely the double wall containment area of the OGS device shall be a minimum of 600 gallons (2,270 Liters), or more as specified within this area. The total petroleum hydrocarbon storage capacity of this OGS device shall be greater than 600 gallons (2,270 Liters) in all cases, and this value shall be specified in all submittals, the shop drawings as a critical performance and design parameter.

PART 4 – INSPECTION & MAINTENENACE

The OGS manufacturer shall provide an Owner's Manual upon request.

4.1 A Quality Assurance Plan that provides inspection and maintenance for up to 5 years shall be included with the OGS stormwater quality device, and written into the Environmental Compliance Approval (ECA) or the appropriate State/Provincial or local approval document.

4.2 Inspection of the OGS device, which includes determination of sediment depth and presence of petroleum hydrocarbons in the lower chamber, shall be easily conducted from finished grade through a Frame and Cover of at least 24 inch (600 mm) in diameter, at a minimum through both the OGS vertically-oriented cylindrical inlet and outlet chambers, and their respective Oil Inspection Ports.

4.3 Pollutant removal from the OGS's lower chamber shall be conducted as a periodic maintenance practice using a standard maintenance truck and vacuum apparatus, and shall be easily conducted from finished grade through a Frame and Cover of at least 24 inch (600 mm) in diameter, at a minimum through both the OGS vertically-oriented cylindrical inlet and outlet chambers, and their respective Oil Inspection Ports.

4.4 No confined space for annual inspections or normal operation shall be required.

PART 5 – EXECUTION

5.1 <u>PRECAST CONCRETE INSTALLATION</u>

The installation of the precast concrete OGS device shall conform to highway, State/Provincial, or local specifications for the construction of manholes. Selected sections of a general specification that are applicable are summarized below.

5.2 <u>EXCAVATION</u>

5.2.1 Excavation for the installation of the OGS stormwater quality treatment device shall conform to highway, State/Provincial or local specifications. Topsoil that is removed during the excavation for the OGS stormwater quality treatment device shall be stockpiled in designated areas and not be mixed with subsoil or other materials. Topsoil stockpiles and the general site preparation for the installation of the OGS water quality device shall conform to highway, State/Provincial or local specifications.

5.2.2 The OGS device shall not be installed on frozen ground. Excavation shall extend a minimum of 12 inch (300 mm) from the precast concrete surfaces plus an allowance for shoring and bracing where required. If the bottom of the excavation provides an unsuitable foundation additional excavation may be required.

5.2.3 In areas with a high water table, continuous dewatering shall be provided to ensure that the excavation is stable and free of water.

5.3 BACKFILLING

Backfill material shall conform to highway, State/Provincial or local specifications. Backfill material shall be placed in uniform layers not exceeding 12 inches (300 mm) in depth and compacted to highway, State/Provincial or local specifications.

5.4 OGS WATER QUALITY DEVICE CONSTRUCTION SEQUENCE

5.4.1 The precast concrete OGS water quality device is installed and leveled in sections in the following sequence:

- aggregate base
- lower horizontal-oriented chamber section(s)
- transition slab (if required)
- inlet and outlet vertical riser upper chamber sections w/ pre-installed fiberglass inserts
- upper riser section(s) (as required)
- connect inlet and outlet pipes
- riser section and/or transition slab (if required)
- maintenance riser section(s) (if required)
- frame and access cover

5.4.2 The precast concrete base shall be placed level or at the designated slope per the shop drawings at the specified grade. The entire base shall be in contact with the underlying compacted granular material. Subsequent sections, complete with oil resistant, water tight joint seals, shall be installed in accordance with the precast concrete manufacturer's recommendations.

5.4.3 Adjustment of the OGS stormwater quality treatment device can be performed by lifting the upper sections free of the excavated area, re-leveling the base, and re-installing the sections. Damaged sections and gaskets shall be repaired or replaced as necessary. Once the OGS stormwater quality treatment device has been constructed, any lift holes must be plugged with mortar.

5.5 DROP PIPE, RISER PIPE, AND OIL PORT

Once the OGS vertically-oriented cylindrical inlet and outlet chambers have been set on the lower chamber, the inlet fiberglass drop pipe and oil ports must be attached to the inlet fiberglass insert, the outlet riser and oil port must be attached to the outlet fiberglass insert. Installation instructions and required materials shall be provided by the OGS manufacturer.

5.6 INLET AND OUTLET PIPES

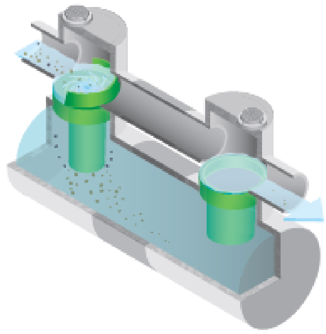
Inlet and outlet pipes shall be securely set into the upper chamber using grout or approved pipe seals (flexible boot connections, where applicable) so that the conveyance network and OGS structure is watertight. Non-secure inlets and outlets will result in improper performance.

5.7 FRAME AND COVER OR FRAME AND GRATE INSTALLATION

Precast concrete adjustment units shall be installed to set the frame and cover at the required elevation. The adjustment units shall be laid in a full bed of mortar with successive units being joined using sealant recommended by the manufacturer. Frames for the cover should be set in a full bed of mortar at the elevation specified.

Stormceptor® MAX

One system for your large stormwater capacity needs



The Stormceptor MAX responds to the needs of large-scale industrial, urban and residential areas which may require a single stormwater management device. It provides stormwater quality treatment for areas 20 to 100+ acres and industrial spill volume capture of 15,000+ gallons.

One Stormceptor MAX can provide protection for an entire neighbourhood, a full-scale industrial plant, urban redevelopments or other large developments.

Unique, comprehensive site coverage

- Increased sedimentation chamber extends horizontally rather than vertically
- Non-turbulent treatment environment allows oil to rise and sediment to settle
- Spill protection in dry and wet conditions
- Patented scour prevention technology contains captured pollutants for secure storage and easy removal
- Ideal for industrial, urban or residential sites with established infrastructure

Design flexibility

- Modular and expandable, depending on the site's size and water quality objective
- System can be constructed of different materials
- May be used as part of a stormwater treatment train, complimenting BMPs such as ponds or swales

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- Industry-leading continuous simulation modeling software uses site conditions to project the frequency and intensity of runoff to determine the best system for your

It's still a Stormceptor

- Continuous positive treatment of total suspended solids (TSS) in stormwater runoff year-round, regardless of flow rate
- Industry-leading reputation for efficiency and reliability

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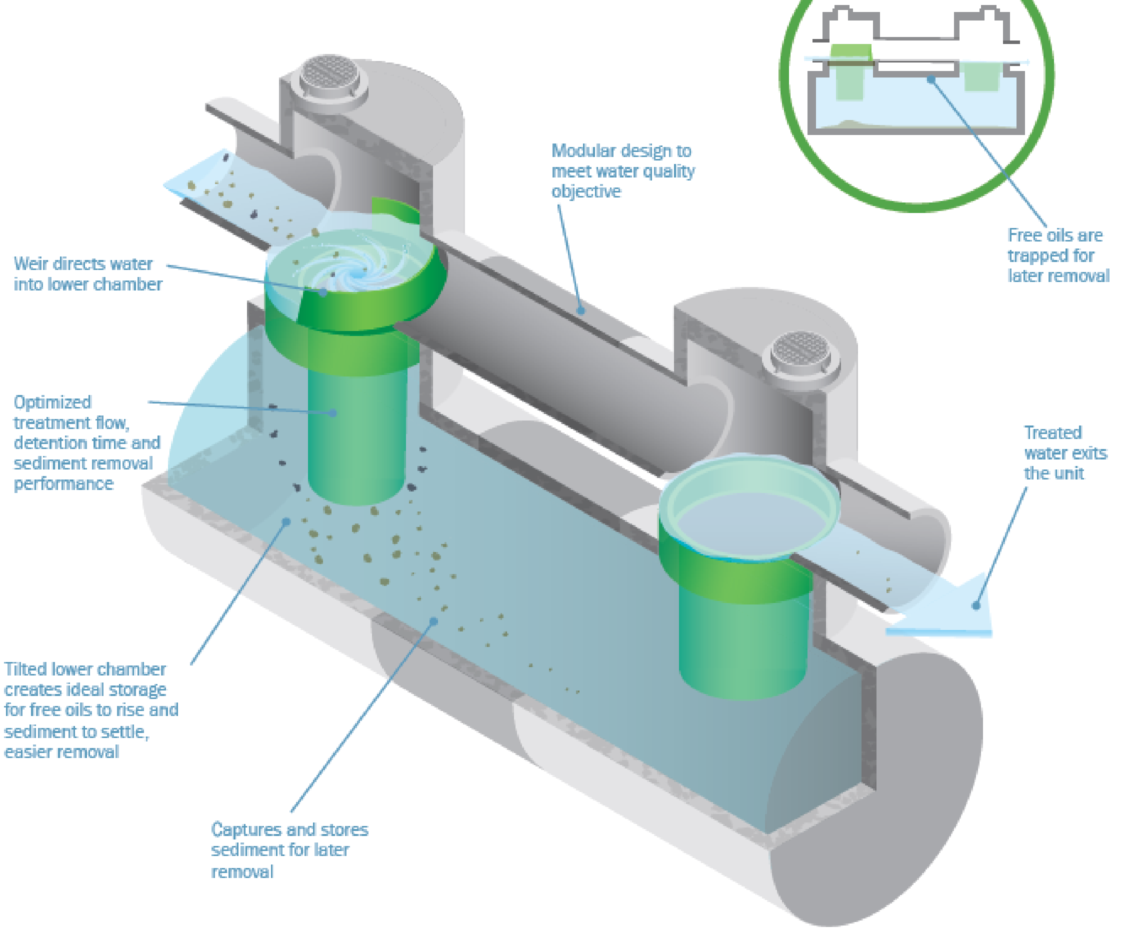
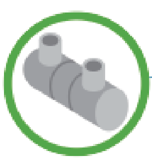
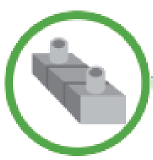




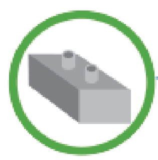
Pre-Cast Pipe Construction

Reliable and easy to install



Pre-Cast Box Construction

Larger volume-to-length ratio allows for treatment in a smaller footprint



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Appendix B - Storm Water Calculation

Year	Total Precip (mm/s)	Q(m^3/s)	Sorted Q (m^3/s)	Rank	Q(m^3/s)	Log(Q)
1957	0.000144946	0.58558179	2.493515432	1	2.493515432	0.39681206
1958	0.000494213	1.99662037	2.473720679	2	2.473720679	0.39335066
1959	0.000498997	2.015947531	2.407322531	3	2.407322531	0.381534281
1960	0.000466628	1.885177469	2.397035494	4	2.397035494	0.379674465
1961	0.000617207	2.493515432	2.392359568	5	2.392359568	0.378826454
1962	0.000484606	1.957810185	2.381604938	6	2.381604938	0.376869722
1963	0.000459452	1.856186728	2.310530864	7	2.310530864	0.363711774
1964	0.00047689	1.926637346	2.271253086	8	2.271253086	0.35626553
1965	0.000437307	1.766720679	2.23166358	9	2.23166358	0.348628726
1966	0.000495062	2.000049383	2.221532407	10	2.221532407	0.346652653
1967	0.000520293	2.101984568	2.163862654	11	2.163862654	0.335229692
1968	0.000592168	2.392359568	2.101984568	12	2.101984568	0.322629523
1969	0.000380633	1.537756173	2.048523148	13	2.048523148	0.311440876
1970	0.000380633	1.537756173	2.025455247	14	2.025455247	0.306522652
1971	0.000589506	2.381604938	2.015947531	15	2.015947531	0.304479225
1972	0.00053561	2.163862654	2.009557099	16	2.009557099	0.303100351
1973	0.000454514	1.836236111	2.000049383	17	2.000049383	0.301040719
1974	0.000562191	2.271253086	1.99662037	18	1.99662037	0.300295498
1975	0.000549884	2.221532407	1.993658951	19	1.993658951	0.299650867
1976	0.000445062	1.798049383	1.983371914	20	1.983371914	0.297404159
1977	0.000420679	1.69954321	1.957810185	21	1.957810185	0.291770584
1978	0.000410108	1.65683642	1.926637346	22	1.926637346	0.284799974
1979	0.000408295	1.649510802	1.898425926	23	1.898425926	0.278393656
1980	0.000552392	2.23166358	1.885177469	24	1.885177469	0.275352241
1981	0.000593326	2.397035494	1.856186728	25	1.856186728	0.268621663
1982	0.000497415	2.009557099	1.836236111	26	1.836236111	0.263928524
1983	0.000612307	2.473720679	1.798049383	27	1.798049383	0.254801615
1984	0.000595872	2.407322531	1.766720679	28	1.766720679	0.247167892
1985	0.00035598	1.438158951	1.69954321	29	1.69954321	0.230332211
1986	0.00050706	2.048523148	1.65683642	30	1.65683642	0.219279632
1987	0.000380903	1.538847222	1.649510802	31	1.649510802	0.217355164
1988	0.00049348	1.993658951	1.538847222	32	1.538847222	0.187195505
1989	0.000469907	1.898425926	1.537756173	33	1.537756173	0.186887479
1990	0.000571914	2.310530864	1.537756173	34	1.537756173	0.186887479
1991	0.000490934	1.983371914	1.484762346	35	1.484762346	0.171656945
1992	0.00050135	2.025455247	1.438158951	36	1.438158951	0.157806889
1993	0.000278356	1.124560185	1.124560185	37	1.124560185	0.050982703
1994	0.000367515	1.484762346	0.937834877	38	0.937834877	-0.027873621
1995	0.000232137	0.937834877	0.58558179	39	0.58558179	-0.232412437

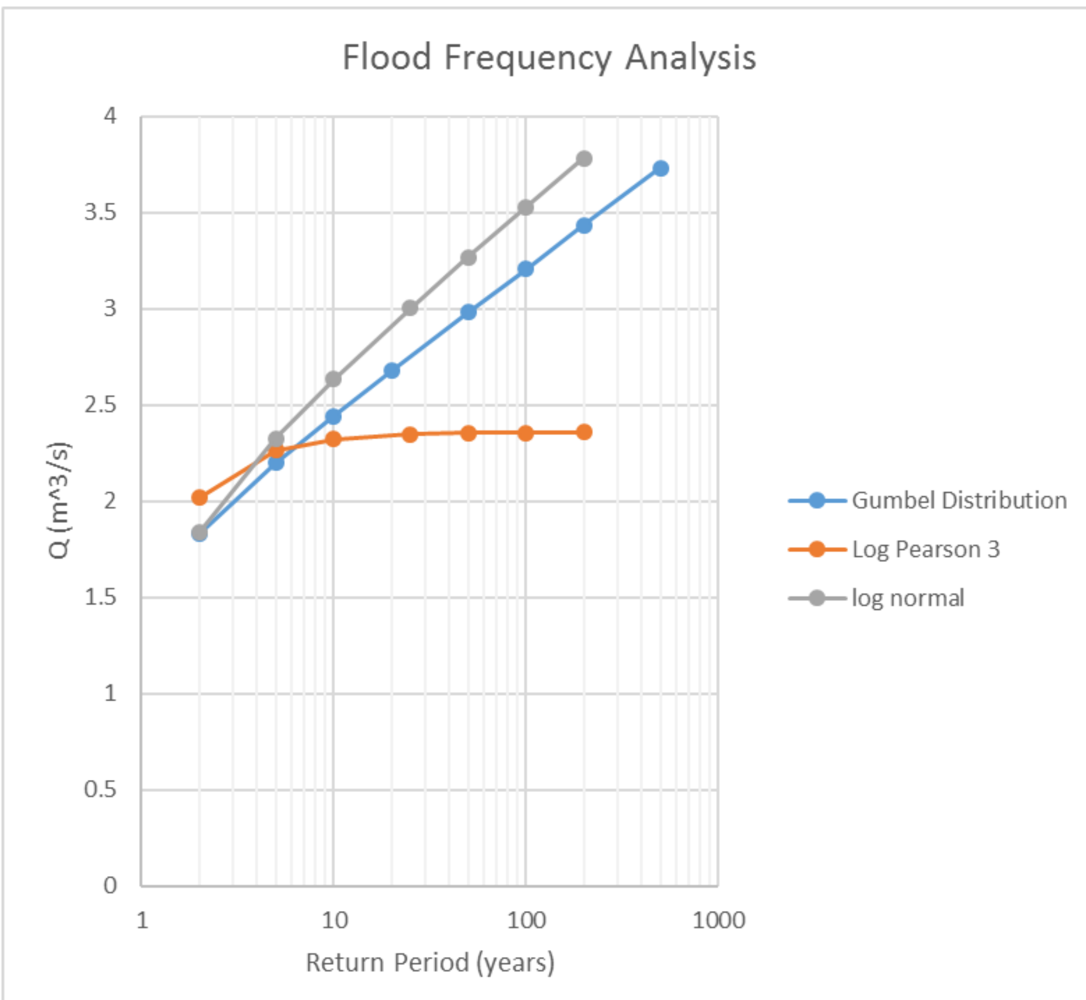
	Q	LogQ
Mean	1.898358	0.26453985
StDev	0.417461	0.12167334
Skew		-2.2589344

Area	4040000	m^2

Log Pearson-3 Method							
Skew Coefficient/Tr	2	5	10	25	50	100	200
-2.2	0.33	0.752	0.844	0.888	0.9	0.905	0.907
-2.3	0.341	0.739	0.819	0.855	0.864	0.867	0.869

Log Normal Method							
Skew Coefficient/Tr	2	5	10	25	50	100	200
0	0	0.842	1.282	1.751	2.054	2.326	2.576

	Gumbel	LN	LP|||
K100	3.14	2.326	0.886
Q100	3.209186	**3.52819061**	2.356906894
K200	3.679	2.576	0.888
Q200	3.434197	**3.7841677**	2.358227902



Sample Calculations

1) Calculating the average flow rate

$$Q_{mean} = \frac{Q_1 + Q_2 + \cdots + Q_n}{N}$$

$$Q_{mean} = 1.898358 \ {}^{m^3}/_{s}$$

$$Log\ Q_{mean} = 0.26453985 \ {}^{m^3}/_{s}$$

2) Calculating the standard deviation for the flow rates

$$s = \sqrt{\frac{1}{N-1} \sum_{i=1}^{N} (x_i - \overline{x})^2},$$

$$S_Q = 0.417461$$

$$S_{Log\ Q} = 0.12167334$$

3) Calculating the skew coefficient for the flow rates

$$\frac{n}{(n-1)(n-2)} \sum \left(\frac{x_j - \bar{x}}{s} \right)^3$$

$$Skew_{Log\ Q} = -2.25893$$

4) Calculating 100 & 200-year storm water levels

Gumbel distribution:

$$T_{100} = Q_{mean} + s_Q * K_{100}$$

$$T_{100} = 1.898358 + 0.317461 * 3.14$$

$$T_{100} = 3.207335 \, {}^{m^3}/_{s}$$

$$T_{200} = 1.898358 + 0.317461 * 3.679$$

$$T_{200} = 3.434197\, {m^3}/{s}$$

Log Normal:

$$T_{100} = Log\ Q_{mean} + s_{\log Q} * K_{100}$$

$$T_{100} = 0.26453985 + 0.12167334 * 2.326$$

$$T_{100} = 3.528190\, {m^3}/{s}$$

$$T_{200} = 0.26453985 + 0.12167334 * 2.576$$

$$T_{200} = 3.784167\, {m^3}/{s}$$

Log Pearson-3:

$$T_{100} = Log\ Q_{mean} + s_{\log Q} * K_{100}$$

$$T_{100} = 0.26453985 + 0.12167334 * 0.886$$

$$T_{100} = 2.356906\, {m^3}/{s}$$

$$T_{200} = 0.26453985 + 0.12167334 * 0.888$$

$$T_{200} = 2.3582279\, {m^3}/{s}$$

Appendix C - Structural Design Calculations

A0-Sample Calculation- Bottom Slab

$$DL = \gamma * h * 2\ walls \ \rightarrow DL = 24\frac{kN}{m^2} * 2.8\ m * 2\ walls \rightarrow DL = 134.4\ kPa$$

$$LL = \rho * g * h \ \rightarrow LL = 1000\ \frac{kg}{m^3} * 9.81\ \frac{m}{s^2} * 2\ m \ \rightarrow LL = 19.62\ kPa$$

$$W_f = 1.25DL + 1.5LL \ \rightarrow W_f = 1.25(134.4) + 1.5(19.62) \rightarrow \ W_f = 197.43\ kPa$$

$$Take\ width\ one\ for\ slab \ \rightarrow W_f = 197.43\ \frac{kN}{m^2} * 1m \ \rightarrow \ W_f = 197.43\ \frac{kN}{m}$$

$$M_f = \frac{w * l^2}{8} \rightarrow M_f = \frac{197.43 * 3.6^2}{8} \ \rightarrow M_f = 319.84\ kNm$$

$$V_f = \frac{w * l}{2} \rightarrow M_f = \frac{197.43 * 3.6}{2} \ \rightarrow V_f = 355.37\ kN$$

Design for Flexure and Axial Loads

$$l_n = l \rightarrow ln = 3600\ mm$$

$$h = \frac{l_n}{20} \rightarrow h = 200\ mm$$

$$d = h - cover - \frac{d_b}{2} \rightarrow d = 200 - 60 - \frac{45}{2} \ \rightarrow d = 120\ mm$$

$$A_s = 0.0015 * f_c' * b\left(d - \sqrt{d^2 - \frac{3.85 * M_r}{f_c{}' * b}}\right) \rightarrow$$

$$A_s = 0.0015 * 50 * 1000\left(120 - \sqrt{120^2 - \frac{3.85 * (319.84e6)}{50 * 1000}}\right) \rightarrow$$

$$A_s = -ve\ number\ under\ square\ root\ so\ have\ to\ change\ h\ so\ use\ h = 260\ mm$$

$$d = h - cover - \frac{d_b}{2} \rightarrow d = 250 - 60 - \frac{45}{2} \ \rightarrow d = 180\ mm$$

$$A_s = 0.0015 * 50 * 1000\left(180 - \sqrt{180^2 - \frac{3.85 * (319.84e6)}{50 * 1000}}\right) \rightarrow \ A_s = 6887.83\frac{mm^2}{m}$$

$$s = \frac{A_b * 1000}{A_s} \ \rightarrow s = \frac{1500 * 1000}{7847.626} \ \rightarrow s = 215mm$$

$$A_s = \frac{A_b * 1000}{s} \rightarrow A_s = \frac{1500 * 1000}{190} \rightarrow A_s = 6976.75 > 7847.626 \frac{mm^2}{m} \; so\ ok$$

$$\rho = \frac{A_s}{b * d} \leq \frac{f_c'}{1100} \rightarrow \rho = \frac{7894.737}{1000 * 170} \leq \frac{50}{1100} \rightarrow \rho = 0.03876 \leq 0.45455$$

$$A_g = b * h > A_{smin} = 0.002 * A_g \rightarrow A_g = 1000 * 250 > A_{smin} = 0.002 * 250 * 1000$$

$$A_g = 260{,}000\ mm^2/m > A_{smin} = 520\ mm^2/m$$

$$S_{max} = 500mm, 3 * h \rightarrow S_{max} = 500mm, 3 * 250 = 500mm \rightarrow S_{max} = 500mm > s = 215\ mm$$

$$a = \frac{\emptyset_s * f_y * A_s}{\alpha_1 * \emptyset_c * f_c' * b} \rightarrow a = \frac{0.85 * 400 * 7847.626}{0.8 * 0.65 * 50 * 1000} \rightarrow a = 91.234\ mm$$

$$M_r = \emptyset_s * f_y * A_s * \left(d - \frac{a}{2}\right) \rightarrow M_r = 320.7686\ \frac{kN}{m}/m > M_f = 319.84 \frac{kN}{m}/m$$

$$d_c = (h - d) \rightarrow d_c = (250 - 170) \rightarrow d_c = 80$$

$$z = 0.6 * f_y * \sqrt[3]{d_c * (s * 2 *} d_c) < 25{,}000 \frac{N}{mm} \rightarrow$$

$$z = 0.6 * 400 * \sqrt[3]{80 * (190 * 2 *} 80) \rightarrow z = 33{,}632.62\ \frac{N}{mm} < 25{,}000\ \frac{N}{mm} \rightarrow$$

$Ok\ because\ CSA\ A23.3 - 04, 10.6.1\ says,$"$Note$: It is possible that the requirements of this Clause will not be sufficient for structures subject to very aggressive exposure or designed to be watertight.". This structure is exposed to very aggressive conditions due to being in the environment and is also supposed to be watertight structure as well.

<u>Design- 45M@215mm</u>

Design for Shrinkage and Temperature Reinforcement

$$A_{smin} = 0.002 * A_g \rightarrow A_{smin} = 0.002 * 250 * 1000 \rightarrow A_{smin} = 520 \frac{mm^2}{m}$$

$$S_{max} = 500mm, 5 * h \rightarrow S_{max} = 500mm$$

$$s = \frac{A_b * 1000}{A_s} \rightarrow s = \frac{500 * 1000}{520} \rightarrow s = 900mm\ but\ \max size\ is\ s = 500\ mm$$

$$A_s = \frac{A_b * 1000}{s} > A_{smin} \rightarrow A_s = \frac{500 * 1000}{500} \rightarrow A_s = 1000 > 500 \frac{mm^2}{m} \; so\ ok$$

<u>Design- 25M@500mm</u>

Design for Shear

$$d = h - cover - \frac{d_b}{2} \rightarrow d = 250 - 60 - \frac{45}{2} \rightarrow d = 180\ mm$$

$$d_v = d * 0.9, h * 0.72 \rightarrow d_v = 170 * 0.9, 250 * 0.72 \rightarrow \ d_v = 190mm$$

$$\beta = \frac{230}{1000 + 180} \rightarrow \beta = 0.193277$$

$$V_c = \emptyset_c * \beta * \lambda * \sqrt{f_c'} * d_v * b \ \rightarrow V_c = 0.65 * 1 * 0.194915 * \sqrt{50} * 180 * 1000 \ \rightarrow V_c = 168.7846\ kN$$

$$Shear\ force\ needed\ due\ to\ V_c < V_f$$

$$V_s = V_f - V_c \rightarrow \ V_s = 186.5894\ kN$$

$$s = \frac{\emptyset_s * A_v * f_y * d_v * cot\theta}{V_s} \rightarrow s = \frac{0.85 * 2 * 700 * 400 * 180 * \cot(35)}{194.1177} \rightarrow s = 693.1219\ mm$$

$$S_{max} = 600mm, 0.7 * d_v, \frac{A_v * f_y *}{0.06 * \sqrt{f_c'} * b} \rightarrow \ S_{max} = 690\ mm < s = 693.1219mm$$

$$V_s = \frac{\emptyset_s * A_v * f_y * d_v * cot\theta}{s} \rightarrow \ V_s = \frac{0.85 * 2 * 700 * 400 * 180 * \cot(35)}{125} \rightarrow V_s = 187.4336\ kN$$

$$V_r = V_s + V_c \ \rightarrow V_r = 356.2182\ kN > V_f = 355.37kN$$

<u>Design 30M@690mm</u>

A1-Sample Calculation- Straight Wall

$$LL = 444.41\ kPa\ given\ by\ Shivtaj\ who\ did\ soil\ pressure\ analysis$$

$$W_f = 1.5LL \ \rightarrow W_f = 1.5(444.41\ ) \rightarrow \ W_f = 666.615\ kPa$$

$$W_f = \frac{W_f}{2} \rightarrow \ W_f = \frac{666.615}{2} \rightarrow \ W_f = 333.075\ kPa$$

$$Take\ width\ one\ for\ slab \ \rightarrow W_f = 333.075\ \frac{kN}{m^2} * 1m \ \rightarrow \ W_f = 333.075\ \frac{kN}{m}$$

$$M_f = \frac{w * l^2}{8} \rightarrow M_f = \frac{333.075 * 1.8^2}{8} \rightarrow M_f = 134.9895\ kNm/m$$

$$V_f = \frac{w * l}{2} \rightarrow M_f = \frac{333.075 * 1.8}{3} \rightarrow V_f = 399.969\ kN/m$$

Design for Flexure and Axial Loads

$$t = \frac{h_u}{25}, 190\ mm\ \rightarrow t = \frac{1800}{25}, 190\ mm\ \rightarrow t = 200mm$$

$$d = t - cover - \frac{d_b}{2} \rightarrow d = 200 - 20 - \frac{25}{2} \rightarrow d = 170\ mm$$

$$A_s = 0.0015 * f_c' * b\left(d - \sqrt{d^2 - \frac{3.85 * M_r}{f_c{}' * b}}\right) \rightarrow$$

$$A_s = 0.0015 * 50 * 1000\left(170 - \sqrt{170^2 - \frac{3.85 * (134.9896e6)}{50 * 1000}}\right) \rightarrow A_s = 2547.297 \frac{mm^2}{m}$$

$$s = \frac{A_b * 1000}{A_s} \rightarrow s = \frac{500 * 1000}{72547.297} \rightarrow s = 150mm$$

$$S_{max} = 500mm, 3 * t\ \rightarrow S_{max} = 500mm > s = 150mm$$

$$\rho = \frac{A_s}{b * d} \leq \frac{f_c'}{1100} \rightarrow \rho = \frac{2547.297}{1000 * 170} \leq \frac{50}{1100} \rightarrow \rho = 0.014984 \leq 0.45455$$

$$A_s > A_{vmin} = 0.0015 * A_g \rightarrow A_s = 2547.297 \frac{mm^2}{m} > A_{vmin} = 0.002 * 200 * 1000$$

$$A_g = 2547.297 \frac{mm^2}{m} > A_{vmin} = 300\ \frac{mm^2}{m}$$

<u>Design 25M@150mm</u>

Design for Shear

$$d_v = d * 0.9, h * 0.72 \rightarrow d_v = 170 * 0.9, 200 * 0.72\ \rightarrow\ d_v = 153mm$$

$$\beta = \frac{230}{1000 + 153} \rightarrow \beta = 0.19948$$

$$V_c = \emptyset_c * \beta * \lambda * \sqrt{f_c'} * d_v * b\ \rightarrow V_c = 0.65 * 1 * 0.19948 * \sqrt{50} * 153 * 1000\ \rightarrow V_c = 140.2776\ kN$$

$$Shear\ force\ needed\ due\ to\ V_c < V_f$$

$$V_s = V_f - V_c \rightarrow\ V_s = 259.6914\ kN$$

$$s = \frac{\emptyset_s * A_v * f_y * d_v * cot\theta}{V_s} \rightarrow s = \frac{0.85 * 2 * 500 * 400 * 153 * \cot(35)}{259.6914} \rightarrow s = 285\ mm$$

$$S_{max} = 600mm, 0.7 * d_v, \frac{A_v * f_y *}{0.06 * \sqrt{f_c'} * b} \rightarrow\ S_{max} = 105\ mm < s = 285\ mm$$

$$V_s = \frac{\emptyset_s * A_v * f_y * d_v * cot\theta}{s} \rightarrow V_s = \frac{0.85 * 2 * 500 * 400 * 153 * \cot(35)}{105} \rightarrow V_s = 708.4629\ kN$$

$$V_r = V_s + V_c \rightarrow V_r = 848.7405\ kN > V_f = 399.969kN$$

Design 25M@105mm

A0, A3, A4, A5 Structural Culvert Design

Culvert Walls

Length of Wall (m)	1.8
Cover (mm)	20
Vertical Reinforcement Bar diameter (mm)	25
Vertical Reinforcement Bar area (mm^2)	500
Horizontal reinforcemen bar diameter (mm)	25
Horizontal bar area (mm^2)	500
Unit Strip length (mm)	1000
Compressive Strength- f'c (Mpa)	50
Max Soil Pressure (kPa)	444.41
Factored Load (kPa)	666.615
Factored Bending Moment (kN/m)	333.3075
Max Bending Moment (kNm/m)	134.9895
Factored Shear (kN/m)	399.969
Design for combined effect of flexure and axial loads	
Wall Thickness (mm)	200
Effective Depth (mm)	170
Area of Tension reinforcement ((mm^2)/m)	2547.297
spacing of vertical reinforcement (mm)	150
max spacing allowed (mm)	150
Max tension reinforcement requirement satisfied	Ok
Gross cross-sectional area (mm^2)	200000
Minimum area required (mm^2)	300
Is minimum area required ok	Ok
Design for shear	
Effective shear depth (mm)	153
β	0.19948
Shear strength concrete (kN/m)	140.2776
Is shear reinforcement needed	Yes
Shear strength of steel needed (kN/m)	259.6914
spacing of horizontal reinforcement (mm)	285
max horizontal reinforcement spacing (mm)	105
Shear capacity of horizontal reinforcement	708.4629
Factored shear resistance (kN/m)	848.7405
Is shear resistance ok	Ok
Is shear resistance less than max permitted shear resistance	Ok

Culvert Angled Walls

Length of Wall (m)	1
Cover (mm)	20
Vertical Reinforcement Bar diameter (mm)	25
Vertical Reinforcement Bar area (mm^2)	500
Horizontal reinforcemen bar diameter (mm)	25
Horizontal bar area (mm^2)	500
Unit Strip length (mm)	1000
Compressive Strength- f'c (Mpa)	50
Max Soil Pressure (kPa)	444.41
Factored Load (kPa)	666.615
Factored Bending Moment (kPa)	333.3075
Max Bending Moment (kNm/m)	41.66344
Factored Shear (kN/m)	222.205
Design for combined effect of flexure and axial loads	
Wall Thickness (mm)	200
Effective Depth (mm)	170
Area of Tension reinforcement ((mm^2)/m)	728.4767
spacing of vertical reinforcement (mm)	650
max spacing allowed (mm)	500
Max tension reinforcement requirement satisfied	Ok
Gross cross-sectional area (mm^2)	200000
Minimum area required (mm^2)	300
Is minimum area required ok	Ok
Design for shear	
Effective shear depth (mm)	150
β	0.2
Shear strength concrete (kN/m)	137.8858
Is shear reinforcement needed	Yes
Shear strength of steel needed (kN/m)	84.31918
spacing of horizontal reinforcement (mm)	850
max horizontal reinforcement spacing (mm)	105
Shear capacity of horizontal reinforcement	694.5714
Factored shear resistance (kN/m)	832.4573
Is shear resistance ok	Ok
Is shear resistance less than max permitted shear resistance	Ok

<u>Culvert Top Slab</u>

Length of Slab (m)	5	
Cover (mm)	60	
Reinforcement Bar diameter (mm)	55	
Reinforcement Bar area (mm^2)	2500	
Stirrup bar diameter (mm)	25	
Stirrup bar area (mm^2)	500	
Unit Strip length (mm)	1000	
Compressive Strength- f'c (MPa)	50	
Soil Pressure and Self Weight (kPa)	360	
Water Pressure (kPa)	7.68123	
Factored Load (kPa)	461.521845	
Factored Uniform Load (kN/m)	461.521845	
Max Bending Moment (kNm/m)	1442.255766	
Factored Shear (kN/m)	1153.804613	
Design for combined effect of flexure and axial loads		
Slab thickness (mm)	250	
Effective slab depth (mm)	160	
Area of Tension reinforcement ((mm^2)/m)	#NUM!	
Is Area of Tension reinforcement ok	Not Ok	
Slab thickness (mm)	460	
Effective slab depth (mm)	370	
Area of Tension reinforcement ((mm^2)/m)	15692.41021	
spacing of reinforcement (mm)	150	
Tension Reinforcement ((mm^2)/m)	16666.66667	
Is Area of Tension reinforcement ok	Ok	
Is reinforcement spacing ok	Ok	
Is Max tension reinforcement requirement satisfied	Ok	
Gross cross-sectional area (mm^2)	460000	
Minimum area required (mm^2)	920	
Is minimum area required ok	Ok	
Max spacing allowed (mm)	150	
Depth of compression block (mm)	217.9487179	
Moment resistance (kNm/m)	1479.145299	
Is moment resistance ok	Ok	
Effective tension area per bar (mm^2)	27000	
z (N/mm)	32266.11418	
Is crack control paramenter ok	Not Ok	10.6.1- Note:

Design for shrinkage and temperature		
Minimum area required (mm^2)	920	
max bar spacing (mm)	500	
spacing of reinforcement (mm)	500	
Tension Reinforcement ((mm^2)/m)	5000	
Is crack control paramenter ok	Ok	
Design for shear		
Effective depth (mm)	370	
Effective shear depth (mm)	330	
β	0.172932331	
Shear strength concrete (kN/m)	262.2940831	
Is shear reinforcement needed	Yes	
Shear strength of steel needed (kN/m)	891.5105294	
spacing of stirrups (mm)	175	
max stirrup spacing (mm)	175	
Shear capacity of stirrups	916.8342857	
Factored shear resistance (kN/m)	1179.128369	
Is shear resistance ok	Ok	
Is shear resistance less than max permitted shear resistance	Ok	

Culvert Bottom Slab

Length of Slab (m)	3.6	
Cover (mm)	60	
Reinforcement Bar diameter (mm)	45	
Reinforcement Bar area (mm^2)	1500	
Stirrup bar diameter (mm)	30	
Stirrup bar area (mm^2)	700	
Unit Strip length (mm)	1000	
Compressive Strength- f'c (MPa)	50	
Concrete Pressure (kPa)	134.4	
Water Pressure (kPa)	19.62	
Factored Load (kPa)	197.43	
Factored Uniform Load (kN/m)	197.43	
Max Bending Moment (kNm/m)	319.8366	
Factored Shear (kN/m)	355.374	

Design for combined effect of flexure and axial loads		
Slab thickness (mm)	200	
Effective slab depth (mm)	120	
Area of Tension reinforcement ((mm^2)/m)	#NUM!	
Is Area of Tension reinforcement ok	Not Ok	
Slab thickness (mm)	260	
Effective slab depth (mm)	180	
Area of Tension reinforcement ((mm^2)/m)	6887.831	
spacing of reinforcement (mm)	215	
Tension Reinforcement ((mm^2)/m)	6976.744	
Is Area of Tension reinforcement ok	Ok	
Is reinforcement spacing ok	Ok	
Is Max tension reinforcement requirement satisfied	Ok	
Gross cross-sectional area (mm^2)	260000	
Minimum area required (mm^2)	520	
Is minimum area required ok	Ok	
Max spacing allowed (mm)	215	
Depth of compression block (mm)	91.23435	
Moment resistance (kNm/m)	320.7686	
Is moment resistance ok	Ok	
Effective tension area per bar (mm^2)	34400	
z (N/mm)	33632.62	
Is crack control paramenter ok	Not Ok	10.6.1- Note:
Design for shrinkage and temperature		
Minimum area required (mm^2)	520	
max bar spacing (mm)	500	
spacing of reinforcement (mm)	900	
Tension Reinforcement ((mm^2)/m)	1666.667	
Is crack control paramenter ok	Ok	
Design for shear		
Effective depth (mm)	180	
Effective shear depth (mm)	190	
β	0.193277	
Shear strength concrete (kN/m)	168.7846	
Is shear reinforcement needed	Yes	
Shear strength of steel needed (kN/m)	186.5894	
spacing of stirrups (mm)	693.1219	
max stirrup spacing (mm)	690	
Shear capacity of stirrups	187.4336	
Factored shear resistance (kN/m)	356.2182	
Is shear resistance ok	Ok	
Is shear resistance less than max permitted shear resistance	Ok	

A1, A2 Structural Culvert Design

Culvert Walls

Length (m)	1.8
Cover (mm)	20
Vertical Reinforcement Bar diameter (mm)	25
Vertical Reinforcement Bar area (mm^2)	500
Horizontal reinforcemen bar diameter (mm)	25
Horizontal bar area (mm^2)	500
Unit Strip length (mm)	1000
Compressive Strength- f'c (Mpa)	50
Max Soil Pressure (kPa)	444.41
Factored Load (kPa)	666.615
Factored Bending Moment (kPa)	333.3075
Max Bending Moment (kNm/m)	134.9895
Factored Shear (kN/m)	399.969
Design for combined effect of flexure and axial loads	
Wall Thickness (mm)	200
Effective Depth (mm)	170
Area of Tension reinforcement ((mm^2)/m)	2547.297
spacing of vertical reinforcement (mm)	150
max spacing allowed (mm)	150
Max tension reinforcement requirement satisfied	Ok
Gross cross-sectional area (mm^2)	200000
Minimum area required (mm^2)	300
Is minimum area required ok	Ok
Design for shear	
Effective shear depth (mm)	153
β	0.19948
Shear strength concrete (kN/m)	140.2776
Is shear reinforcement needed	Yes
Shear strength of steel needed (kN/m)	259.6914
spacing of horizontal reinforcement (mm)	285
max horizontal reinforcement spacing (mm)	105
Shear capacity of horizontal reinforcement	708.4629
Factored shear resistance (kN/m)	848.7405
Is shear resistance ok	Ok
Is shear resistance less than max permitted shear resistance	Ok

Culvert Angled Walls

Length of Wall (m)	1
Cover (mm)	20
Vertical Reinforcement Bar diameter (mm)	25
Vertical Reinforcement Bar area (mm^2)	500
Horizontal reinforcemen bar diameter (mm)	25
Horizontal bar area (mm^2)	500
Unit Strip length (mm)	1000
Compressive Strength- f'c (Mpa)	50
Max Soil Pressure (kPa)	444.41
Factored Load (kPa)	666.615
Factored Bending Moment (kPa)	333.3075
Max Bending Moment (kNm/m)	41.66344
Factored Shear (kN/m)	222.205
Design for combined effect of flexure and axial loads	
Wall Thickness (mm)	200
Effective Depth (mm)	170
Area of Tension reinforcement ((mm^2)/m)	728.4767
spacing of vertical reinforcement (mm)	650
max spacing allowed (mm)	500
Max tension reinforcement requirement satisfied	Ok
Gross cross-sectional area (mm^2)	200000
Minimum area required (mm^2)	300
Is minimum area required ok	Ok
Design for shear	
Effective shear depth (mm)	153
β	0.19948
Shear strength concrete (kN/m)	140.2776
Is shear reinforcement needed	Yes
Shear strength of steel needed (kN/m)	81.9274
spacing of horizontal reinforcement (mm)	905
max horizontal reinforcement spacing (mm)	105
Shear capacity of horizontal reinforcement	708.4629
Factored shear resistance (kN/m)	848.7405
Is shear resistance ok	Ok
Is shear resistance less than max permitted shear resistance	Ok

Culvert Top Slab

Length of Slab (m)	5	
Cover (mm)	60	
Reinforcement Bar diameter (mm)	45	
Reinforcement Bar area (mm^2)	1500	
Stirrup bar diameter (mm)	20	
Stirrup bar area (mm^2)	300	
Unit Strip length (mm)	1000	
Compressive Strength- f'c (MPa)	50	
Self Weight (kPa)	120	
Factored Load (kPa)	150	
Factored Uniform Load (kN/m)	150	
Max Bending Moment (kNm/m)	468.75	
Factored Shear (kN/m)	375	
Design for combined effect of flexure and axial loads		
Slab thickness (mm)	250	
Effective slab depth (mm)	170	
Area of Tension reinforcement ((mm^2)/m)	#NUM!	
Is Area of Tension reinforcement ok	Not Ok	
Slab thickness (mm)	310	
Effective slab depth (mm)	230	
Area of Tension reinforcement ((mm^2)/m)	7527.080878	
spacing of reinforcement (mm)	150	
Tension Reinforcement ((mm^2)/m)	10000	
Is Area of Tension reinforcement ok	Ok	
Is reinforcement spacing ok	Ok	
Is Max tension reinforcement requirement satisfied	Ok	
Gross cross-sectional area (mm^2)	310000	
Minimum area required (mm^2)	620	
Is minimum area required ok	Ok	
Max spacing allowed (mm)	150	
Depth of compression block (mm)	130.7692308	
Moment resistance (kNm/m)	559.6923077	
Is moment resistance ok	Ok	
Effective tension area per bar (mm^2)	24000	
z (N/mm)	29829.43206	
Is crack control paramenter ok	Not Ok	10.6.1- Note:

Design for shrinkage and temperature		
Minimum area required (mm^2)	620	
max bar spacing (mm)	500	
spacing of reinforcement (mm)	800	
Tension Reinforcement ((mm^2)/m)	1875	
Is crack control paramenter ok	Ok	
Design for shear		
Effective depth (mm)	230	
Effective shear depth (mm)	220	
β	0.18852459	
Shear strength concrete (kN/m)	190.6290331	
Is shear reinforcement needed	Yes	
Shear strength of steel needed (kN/m)	184.3709669	
spacing of stirrups (mm)	345	
max stirrup spacing (mm)	345	
Shear capacity of stirrups	186.0243478	
Factored shear resistance (kN/m)	376.6533809	
Is shear resistance ok	Ok	
Is shear resistance less than max permitted shear resistance	Ok	

Culvert Bottom Slab

Length of Slab (m)	3.6	
Cover (mm)	60	
Reinforcement Bar diameter (mm)	45	
Reinforcement Bar area (mm^2)	1500	
Stirrup bar diameter (mm)	30	
Stirrup bar area (mm^2)	700	
Unit Strip length (mm)	1000	
Compressive Strength- f'c (MPa)	50	
Concrete Pressure (kPa)	134.4	
Water Pressure (kPa)	19.62	
Factored Load (kPa)	197.43	
Factored Uniform Load (kN/m)	197.43	
Max Bending Moment (kNm/m)	319.8366	
Factored Shear (kN/m)	355.374	

Design for combined effect of flexure and axial loads		
Slab thickness (mm)	200	
Effective slab depth (mm)	120	
Area of Tension reinforcement ((mm^2)/m)	#NUM!	
Is Area of Tension reinforcement ok	Not Ok	
Slab thickness (mm)	260	
Effective slab depth (mm)	180	
Area of Tension reinforcement ((mm^2)/m)	6887.831473	
spacing of reinforcement (mm)	215	
Tension Reinforcement ((mm^2)/m)	6976.744186	
Is Area of Tension reinforcement ok	Ok	
Is reinforcement spacing ok	Ok	
Is Max tension reinforcement requirement satisfied	Ok	
Gross cross-sectional area (mm^2)	260000	
Minimum area required (mm^2)	520	
Is minimum area required ok	Ok	
Max spacing allowed (mm)	215	
Depth of compression block (mm)	91.23434705	
Moment resistance (kNm/m)	320.7685651	
Is moment resistance ok	Ok	
Effective tension area per bar (mm^2)	34400	
z (N/mm)	33632.62138	
Is crack control paramenter ok	Not Ok	10.6.1- Note:
Design for shrinkage and temperature		
Minimum area required (mm^2)	520	
max bar spacing (mm)	500	
spacing of reinforcement (mm)	2750	
Tension Reinforcement ((mm^2)/m)	545.4545455	
Is crack control paramenter ok	Ok	
Design for shear		
Effective depth (mm)	180	
Effective shear depth (mm)	190	
β	0.193277311	
Shear strength concrete (kN/m)	168.784606	
Is shear reinforcement needed	Yes	
Shear strength of steel needed (kN/m)	186.589394	
spacing of stirrups (mm)	693.1219254	
max stirrup spacing (mm)	690	
Shear capacity of stirrups	187.4336232	
Factored shear resistance (kN/m)	356.2182292	
Is shear resistance ok	Ok	
Is shear resistance less than max permitted shear resistance	Ok	

Rebar Quantity

Concrete weight (kg/m^3)	2400				
Rebar weights (kg/m)				cross-sectional ar	Rebar Density (kg/m^3)
10M Rebar	0.785			100	7850
15M Rebar	1.57			200	7850
20M Rebar	2.355			300	7850
25M Rebar	3.925			500	7850
30M Rebar	5.495			700	7850
35M Rebar	7.85			1000	7850
45M Rebar	11.775				
	LENGTH 1, m	Length 2, m	Total length, m	Total Weght, Kg	Total weight, Tonne
15M				0	0
20M	1188		1188	2797.74	2.79774
25M	5832	410.24	6242.24	24500.792	24.500792
30M	806.4	67.2	873.6	6857.76	6.85776
35M		390	390	4592.25	4.59225
45M	3744	190	3934	46322.85	46.32285

Soil Nail Quantity

Soil Nail Reinforcement No.	Length (m)	Soil Nail Reinforcement No.	Length (m)
1	16.8	17	55.0
2	23.0	18	49.2
3	27.6	19	45.9
4	32.6	20	49.2
5	37.2	21	52.6
6	35.2	22	44.7
7	40.1	23	36.9
8	47.6	24	40.3
9	51.8	25	32.5
10	46.6	26	27.1
11	49.7	27	21.5
12	55.1	28	18.0
13	52.7	29	12.6
14	61.1	30	7.1
15	55.5	31	6.0
16	49.7	32	5.3
Total Length (m)	682.2		

Appendix D - Concrete Mix Design Calculation

Concrete Mix Design

Target Strength: 50 MPa
Exposure: - freeze-thaw conditions
- saturated
- chlorides
- sulphides
MSA: 9.5mm

Step 1: Slump Target

↳ Use 100mm slump.

Step 2: Maximum Size Aggregate

↳ 9.5mm

Step 3: Mixing Water estimate

↳ Air entrained concrete (moderate exposure)

⇒ Water content = 202 kg/m³

↳ use 6% Air content.

Step 4: Selection of w/cm ratio

↳ Max w/cm ratio = 0.39

Additional Conditions

↳ structure wet continuously
↳ max w/cm = 0.45

Extra CSA Standards

↳ Class of exposure C-1
↳ Max w/cm = 0.40

Max w/cm = Min(0.39, 0.45, 0.40) = 0.39

⇒ Since we need HPC, use a lower w/cm ratio (HPC is between 0.2 - 0.35)

↳ Let's use 0.30

Step 5 : Calculation of Cement Content

$w/c = 0.30 = \frac{202}{\text{cement}}$

$\Rightarrow$ Cement Content = 673 Kg/m³

Step 6 : Coarse Aggregate Calculation

Assume : Fineness modulus = 2.8
Dry Rodded Density = 1.53 t/m³
Specific Gravity = 2.7

Volume of Coarse Aggregate

↳ 0.46

Weight of Coarse Aggregate
= 0.46 * 1.53 = 703.8 Kg/m³

Step 7 : Fine Aggregate Calculation

Cement Specific Gravity = 3.15

$V_{water} = 0.202$

$V_{cement} = \frac{673}{3150} = 0.214$

$V_{c\text{-}agg} = \frac{703.8}{2700} = 0.261$

$V_{air} = 0.06$

$V_{f\text{-}agg} = 1 - (0.202 + 0.214 + 0.261 + 0.06) = 0.263$

$M_{f\text{-}agg} = 0.263 \times 2680 = 704.8$ kg/m³

Step 8 - Correction for Moisture Content

Assume : fine Agg Moisture content = 1.3%
Capacity = 2%
Shortage = 0.7%

$\Rightarrow$ Extra water required = 0.007 × 704.8 = 4.93 Kg/m³

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DESIGN

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DATE

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Assume Coarse agg. Shortage = 0.2%

⇒ Extra water required = 0.002 × 703.8 = 1.41 Kg/m3

Final Mix Design (w/o additives)

Water : 202 kg/m3

Cement : 673 kg/m3

F-Agg : 704.8 kg/m3

C-Agg : 703.8 kg/m3

SCMs and Admixtures

Air Entraining Admixture (6% air content)
Superplasticizer
Silica Fume (5%)

Appendix E - Slope Condition & Soil Nail Design

Slope Stability

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File Information

File Version: 8.15
Title: capstone-project
Created By: shivtaj sivia
Last Edited By: shivtaj sivia
Revision Number: 41
Date: 2017-04-04
Time: 3:43:36 PM
Tool Version: 8.15.5.11777
File Name: capstone-project.gsz
Directory: C:\Users\shivt\Downloads\
Last Solved Date: 2017-04-05
Last Solved Time: 2:24:03 AM

Project Settings

Length(L) Units: Meters
Time(t) Units: Seconds
Force(F) Units: Kilonewtons
Pressure(p) Units: kPa
Strength Units: kPa
Unit Weight of Water: 9.807 kN/m³
View: 2D
Element Thickness: 1

Analysis Settings

Slope Stability

Kind: SLOPE/W
Method: Morgenstern-Price
Settings
- Side Function
  - Interslice force function option: Half-Sine
- PWP Conditions Source: Piezometric Line
- Apply Phreatic Correction: No
- Use Staged Rapid Drawdown: No

Slip Surface
- Direction of movement: Right to Left
- Use Passive Mode: No
- Slip Surface Option: Entry and Exit
- Critical slip surfaces saved: 1
- Resisting Side Maximum Convex Angle: 1 °
- Driving Side Maximum Convex Angle: 5 °

Optimize Critical Slip Surface Location: No
Tension Crack
Tension Crack Option: (none)
F of S Distribution
F of S Calculation Option: Constant
Advanced
Number of Slices: 30
F of S Tolerance: 0.001
Minimum Slip Surface Depth: 0.1 m
Search Method: Root Finder
Tolerable difference between starting and converged F of S: 3
Maximum iterations to calculate converged lambda: 20
Max Absolute Lambda: 2

Materials

1st layer

Model: Mohr-Coulomb
Unit Weight: 18.345 kN/m³
Cohesion': 0 kPa
Phi': 35 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

2nd layer

Model: Mohr-Coulomb
Unit Weight: 15.696 kN/m³
Cohesion': 0 kPa
Phi': 32 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

3rd layer

Model: Mohr-Coulomb
Unit Weight: 14.126 kN/m³
Cohesion': 0 kPa
Phi': 36 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

4th layer

Model: Mohr-Coulomb
Unit Weight: 21.995 kN/m³
Cohesion': 0 kPa
Phi': 34 °

Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

5th layer

Model: Mohr-Coulomb
Unit Weight: 20.6 kN/m³
Cohesion': 0 kPa
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

6th layer

Model: Mohr-Coulomb
Unit Weight: 19.425 kN/m³
Cohesion': 0 kPa
Phi': 34 °
Phi-B: 0 °
Pore Water Pressure
Piezometric Line: 1

Slip Surface Entry and Exit

Left Projection: Point
Left Coordinate: (25, 15) m
Left-Zone Increment: 4
Right Projection: Range
Right-Zone Left Coordinate: (145, 95) m
Right-Zone Right Coordinate: (180, 95) m
Right-Zone Increment: 4
Radius Increments: 4

Slip Surface Limits

Left Coordinate: (25, 15) m
Right Coordinate: (180, 95) m

Piezometric Lines

Piezometric Line 1

Coordinates

	X (m)	Y (m)
Coordinate 1	25	15

Coordinate 2	40	20
Coordinate 3	45	25
Coordinate 4	180	25

Surcharge Loads

Surcharge Load 1

Surcharge (Unit Weight): 115 kN/m³
Direction: Vertical

Coordinates

	X (m)	Y (m)
	25	25
	40	30
	70	60
	145	105

Surcharge Load 2

Surcharge (Unit Weight): 90 kN/m³
Direction: Vertical

Coordinates

	X (m)	Y (m)
	145	105
	180	105

Reinforcements

Reinforcement 1

Type: Nail
Outside Point: (141.06796, 92.64069) m
Inside Point: (152.17705, 80) m
Slip Surface Intersection: (143.48748, 89.887592) m
Length: 16.828515 m
Direction: 131.31 °

F of S Dependent: Yes
Pullout Resistance: 165 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.4810365 kN/m
Max. Pullout Force: 24.923646 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 12.317129 kN
Pullout Force per Length: 0.93571573 kN/m
Available Length: 13.163323 m
Required Length: 13.163323 m
Governing Component: Pullout Resistance

Reinforcement 2

Type: Nail
Outside Point: (138.58849, 91.15295) m
Inside Point: (155, 75) m
Slip Surface Intersection: (142.67259, 87.133198) m
Length: 23.027276 m
Direction: 135.45 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 31.003852 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 14.713542 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 17.296809 m
Required Length: 17.296809 m
Governing Component: Pullout Resistance

Reinforcement 3

Type: Nail
Outside Point: (135, 88.99978) m
Inside Point: (155, 70) m
Slip Surface Intersection: (141.24755, 83.064681) m
Length: 27.586077 m
Direction: 136.47 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 37.141807 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 16.135834 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 18.968813 m
Required Length: 18.968813 m
Governing Component: Pullout Resistance

Reinforcement 4

Type: Nail
Outside Point: (130, 85.99967) m
Inside Point: (155, 65) m
Slip Surface Intersection: (139.27216, 78.211175) m
Length: 32.649443 m
Direction: 139.97 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 43.959108 kN
Factored Tensile Capacity: 47.142857 kN

Pullout Force: 17.472538 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 20.540204 m
Required Length: 20.540204 m
Governing Component: Pullout Resistance

Reinforcement 5

Type: Nail
Outside Point: (126.5978, 83.95846) m
Inside Point: (155, 60) m
Slip Surface Intersection: (137.64285, 74.641492) m
Length: 37.157674 m
Direction: 139.85 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 19.316401 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 22.707795 m
Required Length: 22.707795 m
Governing Component: Pullout Resistance

Reinforcement 6

Type: Nail
Outside Point: (121.92884, 81.15724) m
Inside Point: (150, 60) m
Slip Surface Intersection: (135.71083, 70.769751) m
Length: 35.15137 m
Direction: 142.99 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1

Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 15.220894 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 17.893237 m
Required Length: 17.893237 m
Governing Component: Pullout Resistance

Reinforcement 7

Type: Nail
Outside Point: (117.50491, 78.50295) m
Inside Point: (150, 55) m
Slip Surface Intersection: (133.58653, 66.871488) m
Length: 40.103859 m
Direction: 144.12 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 17.231385 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 20.256712 m
Required Length: 20.256712 m
Governing Component: Pullout Resistance

Reinforcement 8

Type: Nail
Outside Point: (113.42265, 75.95856) m
Inside Point: (153.3332, 49.99965) m
Slip Surface Intersection: (131.81322, 63.996831) m
Length: 47.610052 m
Direction: 146.96 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1

Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 21.837555 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 25.67159 m
Required Length: 25.67159 m
Governing Component: Pullout Resistance

Reinforcement 9

Type: Nail
Outside Point: (105, 71) m
Inside Point: (150, 45) m
Slip Surface Intersection: (127.70379, 57.882257) m
Length: 51.971146 m
Direction: 149.98 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 21.904439 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 25.750217 m
Required Length: 25.750217 m
Governing Component: Pullout Resistance

Reinforcement 10

Type: Nail
Outside Point: (110, 74) m
Inside Point: (150, 50) m

Slip Surface Intersection: (130.40478, 61.757135) m
Length: 46.647615 m
Direction: 149.04 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 19.438866 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 22.851762 m
Required Length: 22.851762 m
Governing Component: Pullout Resistance

Reinforcement 11

Type: Nail
Outside Point: (101.32129, 68.79277) m
Inside Point: (145, 45) m
Slip Surface Intersection: (125.87198, 55.419461) m
Length: 49.738573 m
Direction: 151.42 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 18.528693 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 21.781789 m
Required Length: 21.781789 m

Governing Component: Pullout Resistance

Reinforcement 12

Type: Nail
Outside Point: (96.33041, 65.79824) m
Inside Point: (145, 40) m
Slip Surface Intersection: (122.89748, 51.715861) m
Length: 55.084282 m
Direction: 152.07 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 21.27958 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 25.015651 m
Required Length: 25.015651 m
Governing Component: Pullout Resistance

Reinforcement 13

Type: Nail
Outside Point: (92.97608, 63.78565) m
Inside Point: (140, 40) m
Slip Surface Intersection: (121.03886, 49.590929) m
Length: 52.697307 m
Direction: 153.17 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m

Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 18.075291 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 21.248783 m
Required Length: 21.248783 m
Governing Component: Pullout Resistance

Reinforcement 14

Type: Nail
Outside Point: (88.04845, 60.91839) m
Inside Point: (143.33328, 35.00011) m
Slip Surface Intersection: (118.35445, 46.710525) m
Length: 61.058739 m
Direction: 154.88 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 23.467412 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 27.587603 m
Required Length: 27.587603 m
Governing Component: Pullout Resistance

Reinforcement 15

Type: Nail
Outside Point: (85, 59) m
Inside Point: (135, 35) m
Slip Surface Intersection: (115.88823, 44.173651) m
Length: 55.461698 m
Direction: 154.36 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes

Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 18.033308 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 21.199428 m
Required Length: 21.199428 m
Governing Component: Pullout Resistance

Reinforcement 16

Type: Nail
Outside Point: (80, 56) m
Inside Point: (125, 35) m
Slip Surface Intersection: (112.35233, 40.902245) m
Length: 49.658836 m
Direction: 154.98 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 11.872596 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 13.957076 m
Required Length: 13.957076 m
Governing Component: Pullout Resistance

Reinforcement 17

Type: Nail
Outside Point: (75, 53) m
Inside Point: (125, 30) m
Slip Surface Intersection: (108.49405, 37.592738) m
Length: 55.036352 m
Direction: 155.3 °
F of S Dependent: Yes

Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 15.455088 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 18.168549 m
Required Length: 18.168549 m
Governing Component: Pullout Resistance

Reinforcement 18

Type: Nail
Outside Point: (70, 50) m
Inside Point: (115, 30) m
Slip Surface Intersection: (104.62258, 34.612185) m
Length: 49.244289 m
Direction: 156.04 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 9.6601486 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 11.356188 m
Required Length: 11.356188 m
Governing Component: Pullout Resistance

Reinforcement 19

Type: Nail

Outside Point: (67.65715, 47.65715) m
Inside Point: (110, 30) m
Slip Surface Intersection: (102.52131, 33.118647) m
Length: 45.876921 m
Direction: 157.36 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 6.8927287 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 8.10289 m
Required Length: 8.10289 m
Governing Component: Pullout Resistance

Reinforcement 20

Type: Nail
Outside Point: (65, 45) m
Inside Point: (110, 25) m
Slip Surface Intersection: (98.202434, 30.243362) m
Length: 49.244289 m
Direction: 156.04 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 10.982141 kN
Pullout Force per Length: 0.85065066 kN/m

Available Length: 12.910283 m
Required Length: 12.910283 m
Governing Component: Pullout Resistance

Reinforcement 21

Type: Nail
Outside Point: (62.45936, 42.45936) m
Inside Point: (110, 20) m
Slip Surface Intersection: (93.84291, 27.633004) m
Length: 52.578848 m
Direction: 154.71 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 15.200589 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 17.869368 m
Required Length: 17.869368 m
Governing Component: Pullout Resistance

Reinforcement 22

Type: Nail
Outside Point: (60, 40) m
Inside Point: (100, 20) m
Slip Surface Intersection: (89.450177, 25.274912) m
Length: 44.72136 m
Direction: 153.43 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1

Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 10.033476 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 11.795061 m
Required Length: 11.795061 m
Governing Component: Pullout Resistance

Reinforcement 23

Type: Nail
Outside Point: (57.59284, 37.59284) m
Inside Point: (90, 20) m
Slip Surface Intersection: (84.557976, 22.954306) m
Length: 36.874545 m
Direction: 151.5 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 5.2674135 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 6.1922171 m
Required Length: 6.1922171 m
Governing Component: Pullout Resistance

Reinforcement 24

Type: Nail
Outside Point: (55, 35) m
Inside Point: (90, 15) m
Slip Surface Intersection: (79.632312, 20.924393) m
Length: 40.311289 m
Direction: 150.26 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m

Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 47.142857 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 10.157617 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 11.940997 m
Required Length: 11.940997 m
Governing Component: Pullout Resistance

Reinforcement 25

Type: Nail
Outside Point: (52.82914, 32.82914) m
Inside Point: (80, 15) m
Slip Surface Intersection: (74.01889, 18.924721) m
Length: 32.498213 m
Direction: 146.73 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 43.755492 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 6.0853997 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 7.1538176 m
Required Length: 7.1538176 m
Governing Component: Pullout Resistance

Reinforcement 26

Type: Nail
Outside Point: (50, 30) m
Inside Point: (72.51135, 15) m
Slip Surface Intersection: (68.882452, 17.418046) m
Length: 27.051079 m

Direction: 146.32 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 36.421488 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 3.709446 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 4.3607161 m
Required Length: 4.3607161 m
Governing Component: Pullout Resistance

Reinforcement 27

Type: Nail
Outside Point: (47.48284, 27.48284) m
Inside Point: (65, 15) m
Slip Surface Intersection: (63.451811, 16.10325) m
Length: 21.509816 m
Direction: 144.53 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 28.960749 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 1.6171426 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 1.9010654 m
Required Length: 1.9010654 m
Governing Component: Pullout Resistance

Reinforcement 28

Type: Nail
Outside Point: (45, 25) m
Inside Point: (60, 15) m
Slip Surface Intersection: (59.487759, 15.341494) m
Length: 18.027756 m
Direction: 146.31 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 24.272514 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 0.52369224 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 0.61563726 m
Required Length: 0.61563726 m
Governing Component: Pullout Resistance

Reinforcement 29

Type: Nail
Outside Point: (42.54778, 22.54778) m
Inside Point: (52.60663, 15) m
Slip Surface Intersection: (52.60663, 15) m
Length: 12.575748 m
Direction: 143.12 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 16.931948 kN
Factored Tensile Capacity: 47.142857 kN

Pullout Force: 0 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 0 m
Required Length: 0 m
Governing Component: Pullout Resistance

Reinforcement 30

Type: Nail
Outside Point: (40, 20) m
Inside Point: (45, 15) m
Slip Surface Intersection: (45, 15) m
Length: 7.0710678 m
Direction: 135 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 9.5204634 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 0 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 0 m
Required Length: 0 m
Governing Component: Pullout Resistance

Reinforcement 31

Type: Nail
Outside Point: (35, 18.33333) m
Inside Point: (40, 15) m
Slip Surface Intersection: (40, 15) m
Length: 6.0092503 m
Direction: 146.31 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1

Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 8.0908357 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 0 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 0 m
Required Length: 0 m
Governing Component: Pullout Resistance

Reinforcement 32

Type: Nail
Outside Point: (30, 16.66667) m
Inside Point: (35, 15) m
Slip Surface Intersection: (35, 15) m
Length: 5.2704638 m
Direction: 161.57 °
F of S Dependent: Yes
Pullout Resistance: 150 kPa
Resistance Reduction Factor: 1
Bond Diameter: 0.04 m
Nail Spacing: 14 m
Force Distribution: Concentrated
Anchorage: Yes
Tensile Capacity: 660 kN
Reduction Factor: 1
Shear Force: 0 kN
Shear Reduction Factor: 1
Shear Option: Parallel to Slip
Factored Pullout Resistance: 1.3463969 kN/m
Max. Pullout Force: 7.0961359 kN
Factored Tensile Capacity: 47.142857 kN
Pullout Force: 0 kN
Pullout Force per Length: 0.85065066 kN/m
Available Length: 0 m
Required Length: 0 m
Governing Component: Pullout Resistance

Points

	X (m)	Y (m)
Point 1	130	85.99967
Point 2	180	85

Point 3	180	95
Point 4	145	95
Point 5	180	80
Point 6	120	80
Point 7	180	40
Point 8	60	40
Point 9	70	50
Point 10	180	35
Point 11	55	35
Point 12	180	25
Point 13	45	25
Point 14	180	15
Point 15	25	15
Point 16	40	20

Regions

	Material	Points	Area (m^2)
Region 1	1st layer	1,2,3,4	407.51
Region 2	2nd layer	2,5,6,1	304.99
Region 3	3rd layer	5,7,8,9,6	3,700
Region 4	4th layer	8,7,10,11	612.5
Region 5	5th layer	10,12,13,11	1,300
Region 6	6th layer	13,12,14,15,16	1,425

Current Slip Surface

Slip Surface: 4
F of S: 1.583
Volume: 2,889.4765 m³
Weight: 48,325.199 kN
Resisting Moment: 13,128,626 kN-m
Activating Moment: 8,293,463 kN-m
Resisting Force: 105,233.46 kN
Activating Force: 66,495.702 kN
F of S Rank (Analysis): 8 of 25 slip surfaces
F of S Rank (Query): 8 of 19 slip surfaces
Exit: (25, 15) m
Entry: (145, 95) m
Radius: 106.91444 m
Center: (41.214865, 120.6777) m

Slip Slices

	X (m)	Y (m)	PWP (kPa)	Base Normal Stress (kPa)	Frictional Strength (kPa)	Cohesive Strength (kPa)
Slice 1	26.875	15	6.129375	1,199.2165	804.7474	0
Slice 2	30.625	15	18.388125	1,302.5729	866.19357	0
Slice 3	34.375	15	30.646875	1,412.6699	932.18633	0
Slice 4	38.125	15	42.905625	1,528.2757	1,001.8948	0
Slice 5	42.5	15	73.5525	1,703.142	1,099.172	0
Slice 6	46.666667	15	98.07	1,904.3926	1,218.38	0
Slice 7	50	15	98.07	2,075.5164	1,333.8044	0
Slice 8	53.333333	15	98.07	2,247.4805	1,449.7957	0

Slice 9	56.214865	15	98.07	2,396.4202	1,550.2568	0
Slice 10	58.714865	15.213246	95.978698	2,064.0018	1,327.4484	0
Slice 11	61.666667	15.751351	90.701498	2,048.6528	1,320.6549	0
Slice 12	65	16.456574	83.785377	2,003.2278	1,294.6803	0
Slice 13	68.333333	17.274035	75.768542	1,943.1227	1,259.5463	0
Slice 14	71.892729	18.278174	65.920944	1,854.1017	1,206.1431	0
Slice 15	75.678188	19.489857	54.037971	1,744.9617	1,140.5425	0
Slice 16	79.463647	20.859764	40.603297	1,631.6054	1,073.1445	0
Slice 17	83.249106	22.394522	25.551922	1,516.1371	1,005.4124	0
Slice 18	87.034565	24.102007	8.8066171	1,403.7582	940.90669	0
Slice 19	90.957409	26.067357	-10.467573	1,294.3493	873.04966	0
Slice 20	95.017637	28.317319	-32.532943	1,186.1038	800.03711	0
Slice 21	99.077865	30.807006	-56.949308	1,085.0567	731.87999	0
Slice 22	103.13809	33.557045	-83.918937	995.07747	671.18823	0
Slice 23	106.71877	36.202337	-109.86132	918.90194	619.80719	0

Slice 24	109.81989	38.702337	-134.37882	862.31416	581.63824	0
Slice 25	113.52784	41.982419	-166.54658	798.27688	579.9821	0
Slice 26	117.84261	46.184027	-207.75176	748.42412	543.76195	0
Slice 27	121.66667	50.308692	-248.20234	708.82961	514.99485	0
Slice 28	125	54.318499	-287.52652	674.98564	490.40577	0
Slice 29	128.33333	58.768149	-331.16423	646.55145	469.74712	0
Slice 30	131.68144	63.787272	-380.38678	621.54948	451.58213	0
Slice 31	135.04432	69.546654	-436.86903	592.68273	430.60921	0
Slice 32	138.4072	76.316113	-503.25712	558.42337	405.71833	0
Slice 33	141.17666	82.877229	-567.60198	556.35289	347.64787	0
Slice 34	143.63234	90.377229	-641.15448	462.82964	324.07681	0

Appendix F - Power Generation Calculations

Turbine Power and Revenue Calculations

Calculation Area of Culvert

$$A_c = w * d$$

$$A_c = 3 * 0.65$$

$$A_c = 1.95\ m^2$$

Calculate Area swept by turbine

$$A_t = \pi r^2$$

$$A_t = \pi (0.32)^2$$

$$A_t = 0.321\ m^2$$

Velocity of Water in Culvert

$$V = \frac{Q}{A}$$

$$V = \frac{1.9}{1.95}$$

$$V = 0.97 \frac{m}{s}$$

Power produced by one turbine

$$P_t = 0.5 \eta \rho A_t V^3$$

$$P_t = 0.5(0.35)(1000)(0.321)(0.97)^3$$

$$P_t = 52.08\ kW$$

Energy produced in 24 hours

$$P = P_t * 24$$

$$P = 52.08 * 24$$

$$P = 1249.84\ kWh$$

Energy for 2 turbines

$$P_2 = P * 2$$

$$P_2 = 1249.84 * 2$$

$$P_2 = 2500\ kWh$$

Revenue from turbines

$$R_{day} = P_2 * \left(\frac{8.96}{100}\right)$$

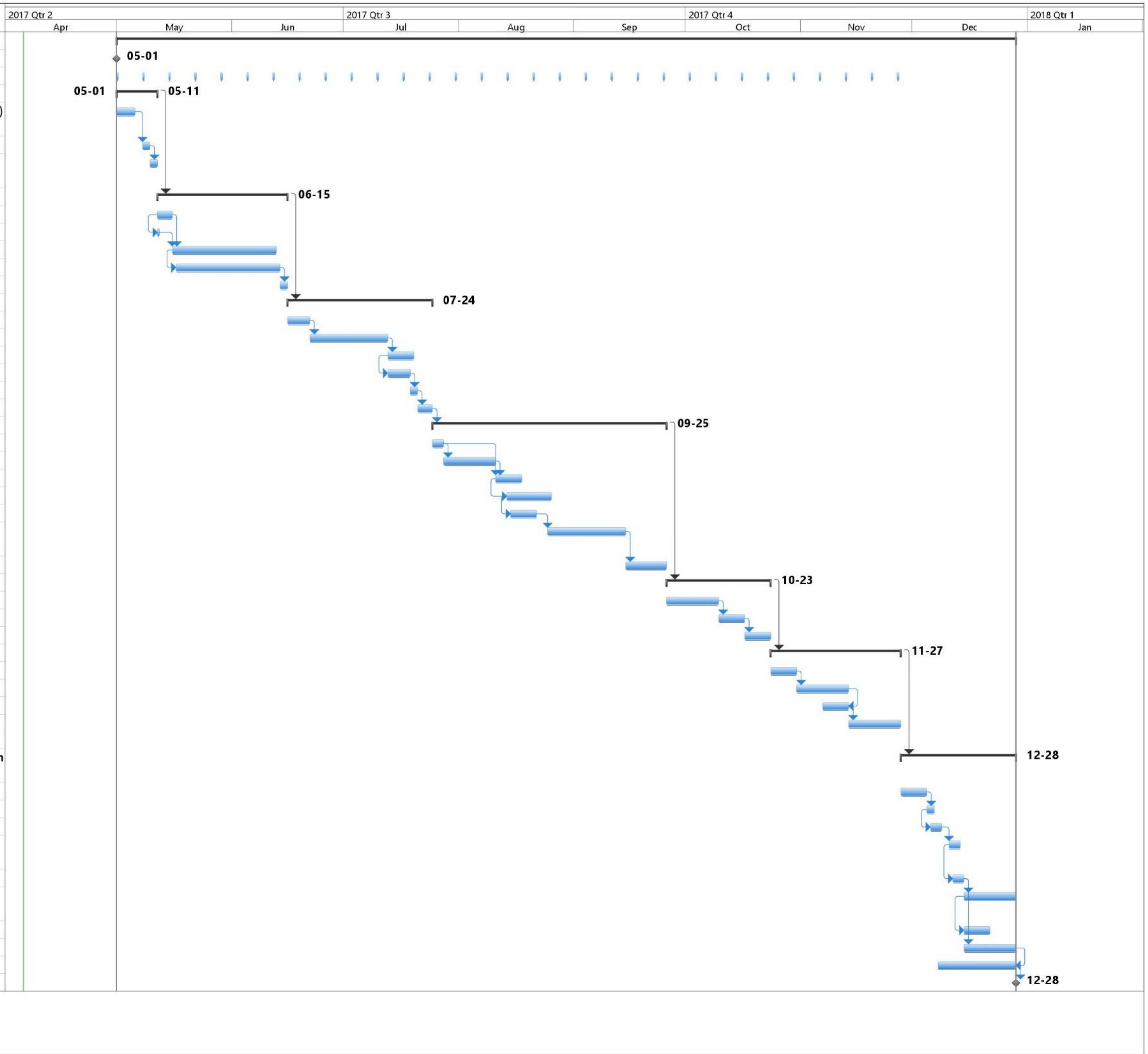
$$R_{day} = 2500 * \left(\frac{8.96}{100}\right)$$

$$R_{day} = \$224.00$$

$$R_{year} = \$81{,}750.00$$

Appendix G - Project Schedule

ID	Task Name
1	**Project**
2	Project Start
3	**Weekly Client/Trade Meeting**
35	**Startup**
36	Site Setup (site trailers/safety station)
37	Startup Meetings with Client
38	Trade initiation & site safety orientations
39	**Logging**
40	Tree Marking
41	Equipment setup
42	Tree cutting
43	Stockpiling Logs
44	Log/Material Removal
45	**Excavation**
46	Surveying + staking
47	Excavation
48	Removal of excess soil
49	Compaction
50	Slope Finishing
51	QA/QC
52	**Precast Concrete Installation**
53	Surveying + staking
54	Set up crane pads
55	Drilling anchor/soil nail holes
56	Soil nail installation
57	Grouting
58	Lowering pre-cast sections in place with crane
59	QA/QC
60	**Generator Installation**
61	Install Generator & Cables
62	QA/QC
63	Backfill
64	**Tie-in System**
65	Surveying + staking
66	New pipe installation
67	Oil/Grit seperator installation
68	Connect new pipe to existing system
69	**Trail Construction/Bio retention garden**
70	Surveying + staking
71	Compaction
72	Geotextile installation
73	Gravel/coarse aggregate install
74	surface finishing
75	Fencing + Handrailing Installation
76	Signage installation
77	Landscaping
78	Commissioning + Testing
79	Project Completion



Appendix H - Class B Cost Estimate

CATEGORY	ITEM #	DESCRIPTION	UNIT	QUANTITY	RATE	COST
FINAL DESIGN COST ESTIMATE (CLASS B)						
Materials	M1	Stormceptor Max[1]	1	1 unit	$ 130,000 /unit	$ 130,000
	M2	Precast Concrete[2]	27	20 m^3	$ 300 /m^3	$ 162,000
	M3	50 mm OD Soil Nail Anchor Bolt[3]	100	6.5 m	$ 5 /m	$ 3,250
	M4	Streambed Gravel/Soils[4]	320	1 yd^3	$ 15 /yd^3	$ 4,800
	M5	Streambed Vegetation[5]	1	405 yd^2	$ 30 /yd^2	$ 12,150
	M6	Corrugated Steel Reinforced HDPE Pipe[6]	1	20 m	$ 65 /m	$ 1,300
	M7	Turbine (optional)[7]	2	1 unit	$ 6,000 /unit	$ 12,000
	M8	Generator (optional)[8]	1	1 unit	$ 900 /unit	$ 900
	M9	Power Cable (optional)[9]	2	200 m	$ 15 /m	$ 6,000
	M10	Inverter (optional)[10]	1	1 unit	$ 8,800 /unit	$ 8,800
	M11	20M Rebar[11]	2.8	1 tonne	$ 1,763 /tonne	$ 4,932
	M12	25M Rebar[12]	24.5	1 tonne	$ 1,763 /tonne	$ 43,195
	M13	30M Rebar[13]	6.9	1 tonne	$ 1,764 /tonne	$ 12,097
	M14	35M Rebar[14]	4.6	1 tonne	$ 1,763 /tonne	$ 8,096
	M15	45M Rebar[15]	46.3	1 tonne	$ 1,763 /tonne	$ 81,667
	M16	50MPa Concrete[16]	673	1 m^3	$ 236 /m^3	$ 158,828
	M17	40mm Diameter Soil Nail[17]	1186	1 m	$ 21 /m	$ 24,906
Construction	C1	Logging[11]	130	1 tree	$ 350 /tree	$ 45,500
	C2	Excavation[12]	1	15700 yd^3	$ 120 /yd^3	$ 1,884,000
	C3	Grading[13]	1	810 yd^2	$ 2 /yd^2	$ 1,215
	C4	Drilling[14]	100	6.5 m	$ 150 /m	$ 97,500
	C5	Grouting[2]	100	0.0184 m^3	$ 300 /m^3	$ 551
	C6	Crane Operation[15]	1	100 hr	$ 340 /hr	$ 34,000
	C7	Geotextile Installation[13]	1	41 ft	$ 30 /ft	$ 1,234
	C8	Landscaping[16]	1	405 ft^2	$ 15 /ft^2	$ 6,075
	C9	Trail Signage Installation (optional)[17]	20	1 ft^2	$ 15 /ft^2	$ 300
	C10	Trail Fences, Handlebar, Steps Installation (optional)[18]	2	450 ft	$ 15 /ft	$ 13,500
Project Management	P1	Construction Superintendent[19]	1	8000 hr	$ 40 /hr	$ 320,000
	P2	Skilled Labor[19]	10	800 hr	$ 18 /hr	$ 144,000
	P3	Electrician[19]	1	40 hr	$ 30 /hr	$ 1,200
	P4	Land Surveyor[19]	2	20 hr	$ 24 /hr	$ 960
	P5	Project Manager (Class E4)[20]	1	288 hr	$ 195 /hr	$ 56,160
	P6	Project Engineer (Class E3)[20]	1	960 hr	$ 159 /hr	$ 152,640
	P7	Field Engineer (Class E1)[20]	1	960 hr	$ 121 /hr	$ 116,160
Miscellaneous	MSC	Tree Removal Permit[21]	113	1 tree	$ 190 /tree	$ 21,470
Contingency	CNT	Estimated @ 20% of Implementation Cost				$ 714,277
INITIAL IMPLEMENTATION TOTAL						$ 4,285,665
Operation & Maintenance (Assume 100 yr Service Life)	OM1	Gardener[19]	2	100 yr	$ 35,360 /yr	$ 7,072,000
	OM2	Maintenance Worker[19]	2	100 yr	$ 39,520 /yr	$ 7,904,000
	OM3	Sediment Removal[13]	1	100 yr	$ 500 /yr	$ 50,000
	OM4	Turbine and Generator Parts (5% Installation Cost) (optional)[22]	1	100 yr	$ 27,700 /yr	$ 2,770,000
	OM5	Power Generation Revenue (optional)	1	100 yr	-$ 81,750 /yr	-$ 8,175,000
SERVICE LIFE TOTAL						$ 13,906,665
Consultation Fee	CF1	Professional Service charge				$ 18,443
	CF2	Disbursement Charge				$ 1,820,708
CONSULTATION FEE TOTAL						$ 1,839,150
PROJECT OVERALL COST						$ 15,745,815

FINAL DESIGN COST ESTIMATE (CLASS B)						
CATEGORY	ITEM #	DESCRIPTION	UNIT	QUANTITY	RATE	COST
Materials	M1	Stormceptor Max[1]	1	1 unit	$ 130,000 /unit	$ 130,000
	M2	Precast Concrete[2]	27	20 m^3	$ 300 /m^3	$ 162,000
	M3	50 mm OD Soil Nail Anchor Bolt[3]	100	6.5 m	$ 5 /m	$ 3,250
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	M9	30M Rebar[9]	6.9	1 tonne	$ 1,764 /tonne	$ 12,097
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	M11	45M Rebar[11]	46.3	1 tonne	$ 1,763 /tonne	$ 81,667
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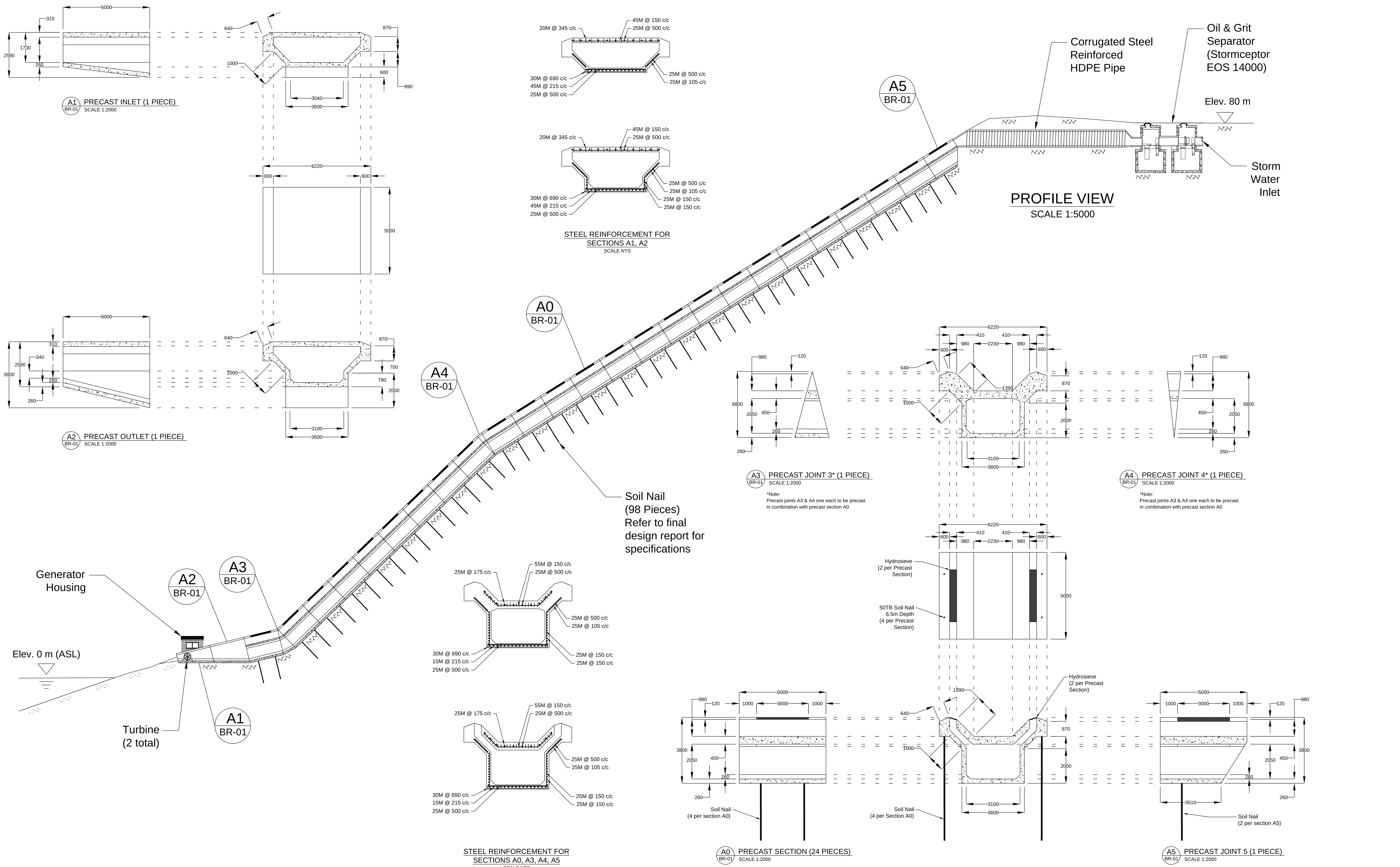
	M13	40mm Diameter Soil Nail[13]	1186	1 m	$ 21 /m	$ 24,906
Construction	C1	Logging[11]	130	1 tree	$ 350 /tree	$ 45,500
	C2	Excavation[12]	1	15700 yd^3	$ 120 /yd^3	$ 1,884,000
	C3	Grading[13]	1	810 yd^2	$ 2 /yd^2	$ 1,215
	C4	Drilling[14]	100	6.5 m	$ 150 /m	$ 97,500
	C5	Grouting[2]	100	0.0184 m^3	$ 300 /m^3	$ 551
	C6	Crane Operation[15]	1	100 hr	$ 340 /hr	$ 34,000
	C7	Geotextile Installation[13]	1	41 ft	$ 30 /ft	$ 1,234
	C8	Landscaping[16]	1	405 ft^2	$ 15 /ft^2	$ 6,075
Project Management	P1	Construction Superintendent[19]	1	8000 hr	$ 40 /hr	$ 320,000
	P2	Skilled Labor[19]	10	800 hr	$ 18 /hr	$ 144,000
	P3	Electrician[19]	1	40 hr	$ 30 /hr	$ 1,200
	P4	Land Surveyor[19]	2	20 hr	$ 24 /hr	$ 960
	P5	Project Manager (Class E4)[20]	1	288 hr	$ 195 /hr	$ 56,160
	P6	Project Engineer (Class E3)[20]	1	960 hr	$ 159 /hr	$ 152,640
	P7	Field Engineer (Class E1)[20]	1	960 hr	$ 121 /hr	$ 116,160
Miscellaneous	MSC	Tree Removal Permit[21]	113	1 tree	$ 190 /tree	$ 21,470
Contingency	CNT	Estimated @ 20% of Implementation Cost				$ 705,977
INITIAL IMPLEMENTATION TOTAL						$ 4,235,865
Operation & Maintenance (Assume 100 yr Service Life)	OM1	Gardener[19]	2	100 yr	$ 35,360 /yr	$ 7,072,000
	OM2	Maintenance Worker[19]	2	100 yr	$ 39,520 /yr	$ 7,904,000
	OM3	Sediment Removal[13]	1	100 yr	$ 500 /yr	$ 50,000
SERVICE LIFE TOTAL						$ 19,261,865
Consultation Fee	CF1	Professional Service charge				$ 18,443
	CF2	Disbursement Charge				$ 2,351,248
CONSULTATION FEE TOTAL						$ 2,369,690
PROJECT OVERALL COST						$ 21,631,555

Appendix I - Design Drawing



NOTES:

1. Slope surface profile and elevation is approximated from Piteau Associates drawing "April 2002 Surveyed Cliff Profiles Near the Museum of Anthropology - Figure 13"
2. Precast joints A3 & A4 are each to be cast in the same precast mold with one precast section A0
3. Turbine and generator specifications are detailed in final design report
4. Structural steel reinforcement not to scale see reinforcement design details in final design report
5. For specifications on soil nails refer to final design report
6. OGS Stormceptor installation is by Imbrium Systems, see appendix for specifications document
7. All dimensions are labeled in mm units unless otherwise specified
8. THIS DRAWING IS NOT INTENDED OR TO BE USED FOR CONSTRUCTION

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CIVL 445/446 — TEAM 21

Project	Page
Capstone - UBC Spiral Drain Replacement	1/1

Title	Scale
Bio-Retention Stream & Culvert with Turbines Preliminary Design	As Shown

Date	Prepared By	Dwg #	Rev	Project #
4/07/17	AC	BR-01	0	UBC-CAP