UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Detailed Design Report:

Replacement of the Spiral Drain

At the North End of UBC Campus

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Abstract

As requested by University of British Columbia, Cascadia Consulting Ltd. has developed a detailed design for the replacement of the spiral drain located at the north end of the UBC campus. This report includes an overview of the project, a description of the proposed design, design inputs (i.e. design loads and parameters), a description of the key design components, project schedule, and a detailed cost estimate.

The proposed design consists of the construction of three stormwater detention tanks throughout the north catchment. Following extensive analysis, the locations of these tanks have been selected strategically in order to minimize flooding and stormwater run-offs. The three underground concrete tanks are placed on the parking lot on West Mall, in front of Allard building, and behind the old Student Union Building. Tank dimensions and other detailed specifications are also included in this report. Furthermore, these detention tanks are equipped with water filtration systems and pumps. This helps ensure a controlled output of high quality water from the tanks, which can be used for various purposes on the UBC campus.

The project is expected to start on **May 1st, 2017,** and be completed by **October 30th, 2017**. A detailed class 1 cost analysis has also been performed by Cascadia Consulting for this project. The construction cost has been estimated to be **$5.1 M**, and the maintenance and operation costs are obtained to be **$14,100** annually.

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1.0 Introduction

The spiral drain located at the north end of the UBC campus was built in late 1930s and has managed to drain storm and groundwater run-off since. However, this structure has been nominated for replacement since it is no longer capable of handling the maximum predicted flow.

Cascadia Consulting Ltd has been contracted to submit an effective design solution for the replacement of this drain. In the following report, a detailed breakdown of the proposed design is presented. This report includes detailed hydrological, geological, and structural analysis; it also provides our client with a project schedule, and a detailed (Class 1) cost analysis. It is worth noting that this design meets all key criteria set by our client, accounts for all site and regulatory constraints, and is capable of handling the maximum predicted flow caused by 100 & 200-year return-period storms.

The new proposed stormwater drainage system consists of 3 concrete detention tanks, located strategically throughout the north catchment of the UBC campus. This system aims to minimize stormwater run-offs and flooding. To ensure the quality and consistency of the outgoing flow, each of these tanks will be equipped with a filtration system and a pump. Crystalline concrete waterproofing technology and SCM materials are also used to make our tanks more durable and sustainable.

1.1) Individual Roles & Contribution of Members

Team Member	Contribution
Alexander Russell	Hydrological/ Geological Analysis
Ardeshir Sedighi	Design Description, Structural Analysis
Seyedsadra Shayesteh	Construction Planning, Scheduling
Romina Shojaee Siuki	Conclusion & Recommendations
Sasan Soleimani-Dashtaki	Abstract, Introduction, Editing & Formatting
Shervin Zahedimazandarani	Cost Analysis

Table 1) Individual roles & contribution of members

2.0 Design Criteria

This section provides a description of issues related to the proposed design and the approaches taken to meet the requirements.

2.1) Regulatory Requirements

Construction and operation of hydraulic detention facilities must be according to certain regulatory acts and guidelines. Our consulting team will ensure that all legislations are adhered to for this project. The following legislations have been found to apply to the proposed project:

- National Building Code of Canada
- Canadian Environmental Protection Act
- Environmental Management Act
- Leadership in Energy and Environmental Design Criteria
- BC Building Code
- Metro Vancouver Storm Water Management Plan

- Water Act
- UBC Development Policy
- Fisheries Act

2.2) Water Quality

To ensure the standard quality of the collected stormwater in the detention tanks, it is necessary to use an effective filtration system for the detention tanks. Imbrium systems provide a variety of water treatment methods. Among these methods, and based on the location and size of the concrete tanks, "Filterra" bio-retention system is the ideal method to ensure an acceptable quality of water for our design. This system effectively removes pollutants such as: phosphorus, nitrogen, metal, oil & grease, and total suspended solids from the water. It also offers a small carbon footprint.

How it works:

Polluted stormwater enters the Filterra bio-retention system through an opening; it then flows through a mulch layer, as well as an especially engineered filter media (contained within a concrete container). The stormwater then flows down through and saturates the especially engineered filter media. The filter media captures and immobilizes the pollutants. Biological systems then break down these pollutants where they are incorporated into the biomass of the Filterra System. The stormwater continues to flow through the media, into a last stop at the bottom of the container, where the treated water is discharged. Treated water is then stored in the detention tanks, which can be used for irrigation or other campus use.

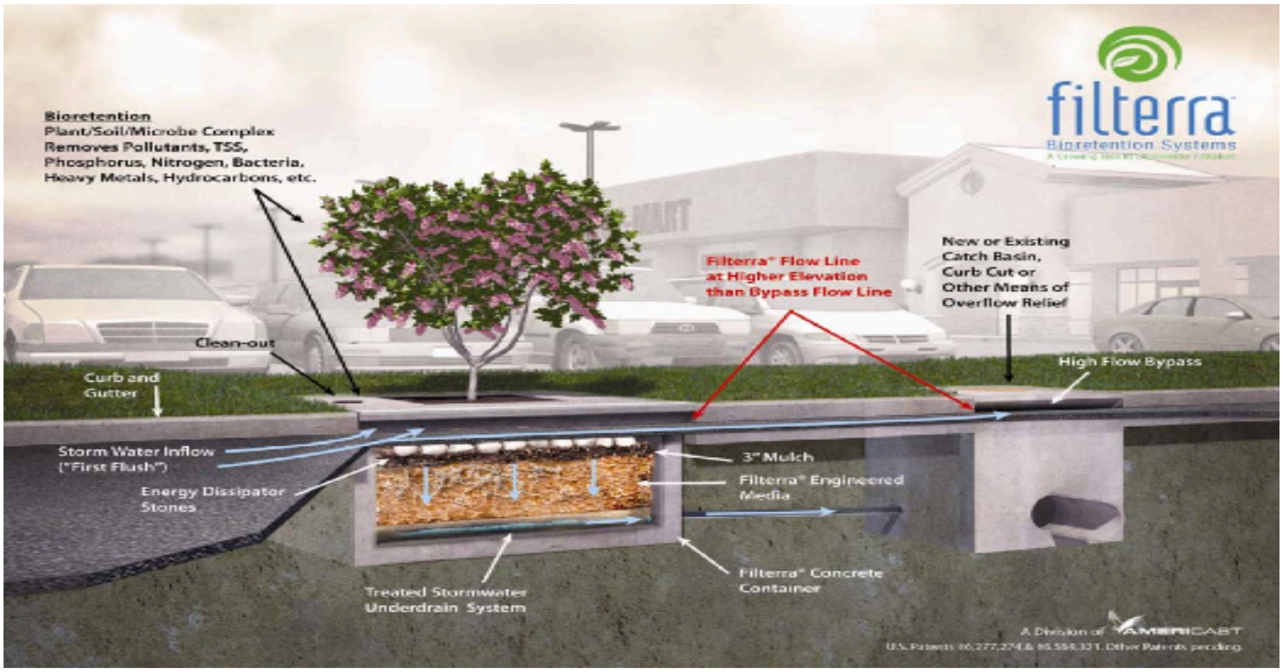


Figure 1) Filterra System's Water Treatment Diagram

2.3) Social Impacts

It is important to address the community's concerns throughout the project. For this reason, Cascadia Consulting ensures sufficient public consultation, education through public meetings, and a consistently updated project website. Moreover, we ensure that the project schedule is updated regularly as the project progresses, and the community is made aware of these updates through our website and social media. Please note that the client will be consulted regarding all scheduling issues and changes in advance.

2.4) Environmental Constraints

Minimizing environmental impacts of this project is an important factor, taken into extensive consideration by our consulting team. As requested by our client, Cascadia Consulting will pay close attention to the project's environmental impacts at all stages. To minimize these impacts and increase sustainability, best possible environmental management methods are selected, and Vancouver's greenest city action plan is followed.

Table 2) Environmental Impacts & Mitigation Techniques

Problem	Minimize the influence
Road/crosswalk closure	Informing students about road closures and alternative routes in advance. Using proper signs to clearly indicate all alternative routes.
Noise Pollution	Minimizing disruptions to noise sensitive activities (such as classes or students studying on campus), by scheduling loud construction tasks for weekends and weekdays after 5pm.
Carbon footprint/waste disposal	Disposing construction waste according to UBC's waste water management regulations.
Safety	Ensuring all WorkSafe BC guidelines are followed and enforced by site supervisors; using fences to cover hazardous areas.

Detention tanks will be constructed according to the design guidelines provided by UBC Vancouver Campus Plan. As of Vancouver's greenest city action plan by 2020, it is also crucial to minimize carbon dioxide emissions, and construct these structures in accordance with the highest sustainability standards. This design requires a minimum of LEED Gold Standard (SSC6.1 and SSC6.2 credits), which Cascadia Consulting can confidently guarantee. In addition, Metro Vancouver's Integrated Storm-water Management Plan (ISMP) is followed which optimizes the design performance.

3.0 Design Description

The stormwater detention system consists of three underground concrete tanks constructed strategically throughout the north campus. This system, designed by Cascadia Consulting, aims to minimize stormwater overflow and flooding in the north catchment of the UBC campus.

3.1) Design Overview

Proposed detention tanks will be constructed in three key locations of the north catchment of the UBC campus. The first tank will be located underneath UBC's north outdoor parking lot on West Mall; the second detention tank will be in front of Allard building on East Mall; and the third tank will be constructed in the empty field behind the old Student Union Building (SUB). These proposed locations, shown in Figure 2, are selected primarily based on flooding proneness of each sub-district, and land availability on UBC's northern campus; other factors influencing the system layout are explained in **Section 3.2**.

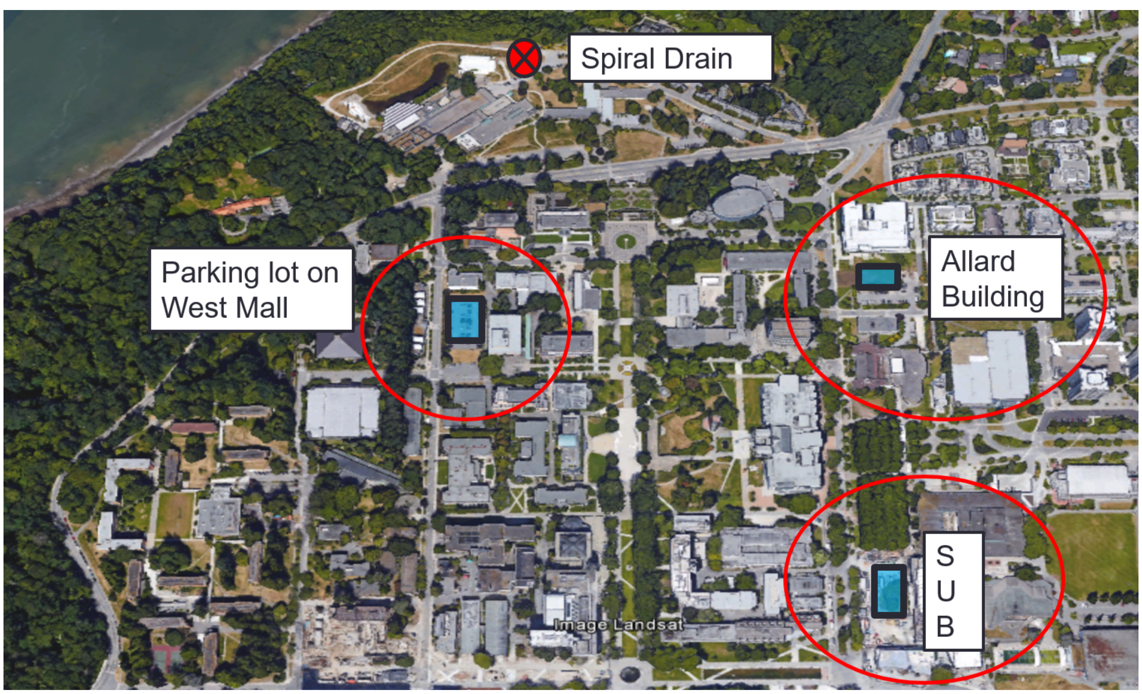


Figure 2) Detention Tank Locations

Water filtration systems are used to ensure that the quality of water in the tanks meets the desired standard. The filtered water can be used for irrigation of lands in the vicinity, or other campus use.

As the output flow of the tanks are controlled, the water can also be used to supply water to UBC buildings. Please note, further filtration may be required for the water to be used for drinking.

3.2) System Layout

When determining the optimum layout for the stormwater detention facilities, our team considered the following:

Land Use – Ideally, the tanks should not occupy much of UBC's precious real estate. For this reason, detention tanks are placed underground. They are also located in areas with low foot traffic (parking lots, fields, and courtyards) to minimize campus life disruptions and to mitigate any potential by-stander injuries.

Existing Pipe Configuration – Strategic placement of the tanks will minimize rerouting of the current underground pipeline and, therefore, reduce cost.

Key Flooding Areas – Another important factor is placement of tanks in key areas of concern in the north catchment. These areas were identified by the UBC ISMP and verified by Cascadia Consulting.

Equal Collection Areas – To ensure the entire sub-catchment is properly drained, tanks must be dispersed evenly throughout the region. This way, tanks are draining approximately equal landmasses, or areas proportional to their respective sizes.

3.3) Design Advantages

In addition to meeting the criteria set our client, this design also has the following added advantages:

- Reduced flooding throughout campus;
- Reduced erosion of outfalls;
- High quality water output;
- Preventing hydraulic overload of downstream sewers;
- Sustainable and follows LEED gold expectations;
- Reduced CO_2 emissions (by 25%);
- Extended life cycle - due to usage of advanced admixtures (i.e. the crystalline technology);
- Easy construction permitting process as selected spaces are owned by UBC (the client).

4.0 Hydrological Analysis

This section outlines the hydrological analysis performed for this project. Using the analyzed data and results, optimal tank sizes were then selected as explained further in Section 4.2.

4.1) Storm Water Modelling

To determine how the three hydraulic detention tanks would perform in the case of 100 and 200-year return period storms, a hydraulic model was required. An EPA Storm Water Management Model of the entire UBC campus was provided to our team by the client. This model included a 24-hour rain profile for a 100-year return period storm which can be found in Figure 3.

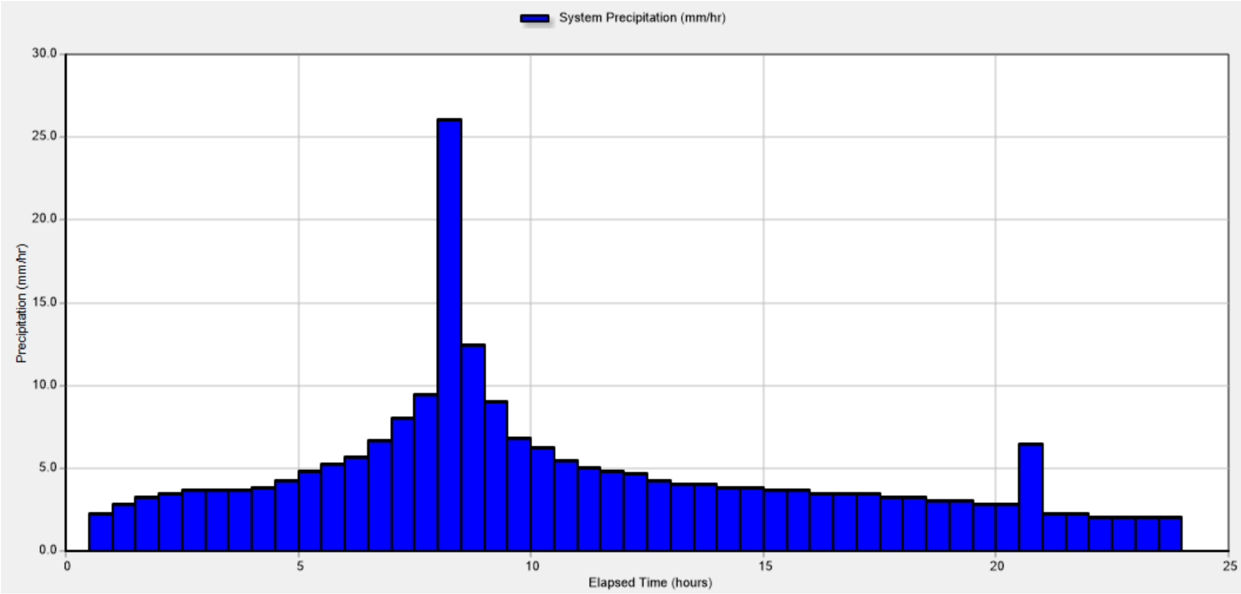


Figure 3) Hourly Rainfall (mm/hr) – Used for 100-year return period storm modelling

The model allowed our team to forecast the magnitude of potential flooding, which governed the tanks' size. Furthermore, the model outputted the flooding for each node in the system shown in full detail in Appendix A. This data was crucial in determining the critical flooding areas in the north catchment. These critical areas were a major consideration when determining tank location. The most critical areas for flooding were found to be in the Northwest section of the catchment near Marine Dr. and Chancellor Blvd. The Allard Building tank location was chosen in response to this.

4.2) Tank Sizing

Using the model described above, the dimensions of the hydraulic detention tanks were determined to eliminate flooding for a 200-year return period storm. To start our analysis, our team began by computing the sizing required to prevent flooding for a 100-year return period storm. The total amount of flooding in the north catchment for this storm was calculated by summing the flooding at each node, which was found to be found to be 5,980 cubic meters. Since our team did not have access to the 24-hour rain profile for a 200-year return period storm event, the amount of flooding for this event was taken from the report GeoAdvice made for UBC. This flooding was found to be approximately 9,100 cubic meters and seeing as our results for the 100-year storm was equal, our team feels justified in using this number. Then, to account for error, and since the tanks will not always be full, this volume was increase by 30%. Finally, the tanks were sized per land availability of each site and other inputs described in Section 3.2. The final tank dimensions are tabulated below.

Tank ID	Length	Width	Depth	Volume
Allard Building	45 m	45 m	2 m	4,050 m^3
Adjacent to SUB	40 m	40 m	2m	3,200 m^3
West Mall Parkade	40 m	60 m	2 m	4,800 m^3
		Total:		12,050 m^3

Table 3) Detention Tank Sizes & Volumes

5.0 Geotechnical Analysis

As all three tanks are located below ground level, geotechnical considerations are extremely important for design. To perform calculations and analysis, Cascadia Consulting has used the geotechnical report from Piteau conducted in 2002 for the North Catchment of UBC. However, in order to have a better idea of the subsurface conditions, our team recommends that borehole sampling be conducted at all three locations prior to construction of the tanks.

5.1) Lateral Earth Pressure

To ensure retaining wall stability for all sides of the tanks a lateral earth pressure analysis was conducted. **Table 4** below shows the depths of the ground water table below ground level (BGL) for different areas around UBC.

Well ID		12	13	15	17	18	22	25	27	Buchanan	Sedgewick	Brock	44	67	TH01–01	TH01–02	Fairview
Offset (m)		65	10	115	165	60	220	69	145	155	345	23	156	55	115	115	20
Orientation		NNE	NNE	SSW	SSW	SSW	SSW	SSW	SSW	SSW	SSW	SSW	SSW	NNE	SSW	SSW	SSW
Depth (m–BGL)		103.9	105.5	76.2	66.4	63.4	76.2	13.4	15.2	9.2	15.2	5.2	30.5	113.4	75.6	93.9	n/a
Water (m–asl)	Piezo A	9.9	9.9	22.0	21.5	15.3								7.8	4.9	7.3	
	Piezo B	dry													23.3	22.6	
Yield (L/s)			1.58	1.64										6.31			
Date		Mar 63	Apr 63	Apr 74	Jul 75	Jul 75	Jun 67	Apr 67	Jan 93	Feb 95	Jun 69	Nov 89	Sep 65	Dec 86	Jun 01	Jul 01	Jul 01

Table 4) Piezometer Readings Across UBC Campus (Piteau 2002)

Seeing as most of these are much greater than 10 meters BGL and they do not vary substantially during the year, Cascadia Consulting has assumed dry conditions for the hydraulic detention tank sites. For the design of the retaining walls, the following additional assumptions were made, as they are commonly made in practice:

- There is no friction between the wall and the soil;
- The soil is loose and initially at rest;
- The soil surface is horizontal and there are no shear forces acting on the horizontal and vertical surfaces.

Furthermore, analysis of borehole samples form the geotechnical report indicate that soil properties do not change drastically for the first 4 meters below ground level. Therefore, the coefficient of friction and the density of the soil were taken as the average along this depth, resulting in a single homogeneous soil layer. Figure 4 demonstrates the lateral earth pressures on the tank.

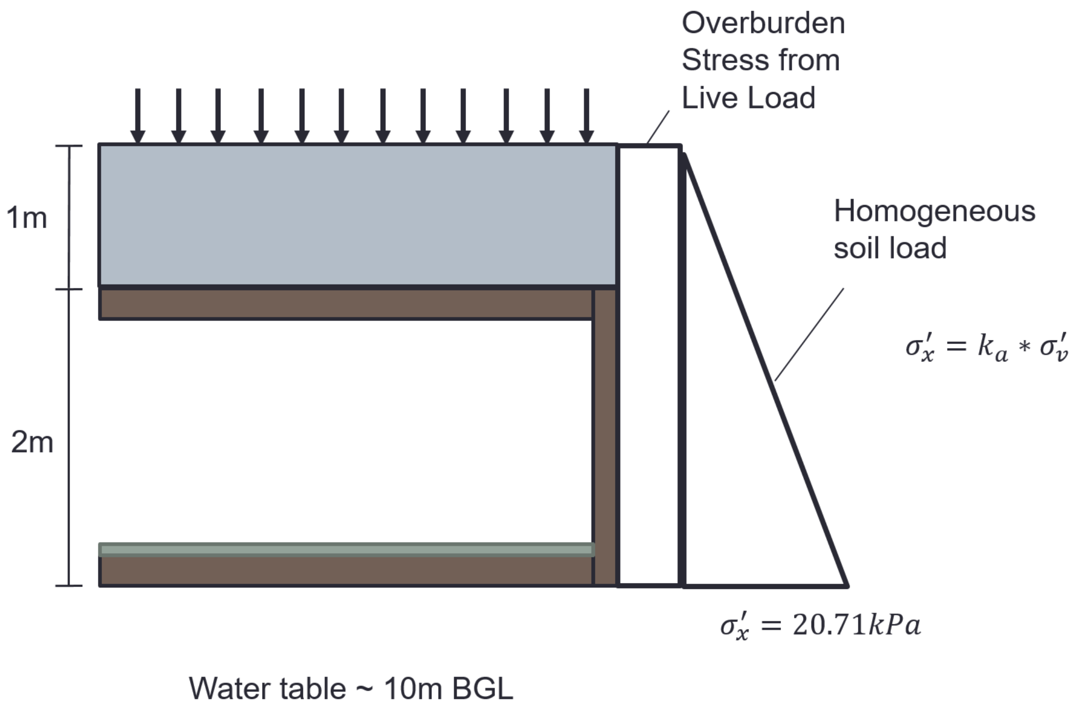


Figure 4) Lateral Loads on the Tank

Using this analysis, the design of the retaining walls could be completed and will be described in the structural design section of the report - Section 6.

5.2) Bearing Capacity

A bearing capacity analysis was conducted to ensure the soil does not fail in shear under the applied loads. Using the governing load case described in the structural analysis section, the calculations were performed for the West Mall Parkade tank, as it is the largest tank. The maximum allowable bearing capacity for medium sand is approximately **144 kPa** (IBC, 2006). Using a factor of safety of 3 for our design, the imposed bearing capacity was found to be tolerable for this soil. However, as the site has not been thoroughly investigated in quite some time, our consulting team suggests further site preparations. Prior to pouring the slab on grade, it is recommended that a layer of crushed rock be placed under the footing. This will increase the bearing capacity and will eliminated the potential for any differential settlement.

6. Structural Analysis

To construct the hydraulic detention tanks, structural analysis must be conducted to ensure the tanks can support their self-weight, the weight of stored water, as well as the weight of soil above. The Canadian Standard Association's concrete design code (CSA A23.3) is used to design these structures. The National Building Code of Canada and the Building Code of British Columbia must also be followed for this design. The following section provides a detailed structural analysis for each detention tank.

6.1) Concrete Mix Design

It is recommended by Cascadia Consulting that normal density concrete (w/c = 0.4, TYPE 10 Cement) is used. Usage of Supplementary Cementing Materials (SCMs) is recommended to reduce CO_2 emissions as well as cost. All structural elements will use a 30 MPa mix design that incorporates 30% supplementary cementing materials. The SCM recommended for this mix design is Fly Ash. The concrete will be designed according to F-1 specifications for concrete exposed to "freeze and thaw" in a saturated condition. The material proportioning in the 30 MPa structural concrete mix is as follows, which is in accordance with the concrete design code guidelines:

- Cement: 210 kg (10 kg of cement per 1 MPa of required strength);
- SCM: 90 kg (30% replacement);
- Coarse Aggregate: 1100 kg (60% of 80% total weight);

- Fine Aggregate: 750 kg (40% of 80% total weight);
- Water: 150 kg (w/c ratio = 0.5).

It is also essential that concrete waterproofing admixtures are used to reduce concrete permeability. This will increase durability of concrete, reduce reinforcement corrosion risks, and reduce the erosion risks of surrounding soil. Cascadia recommends Kryton's Krystaline Internal Membrane (KIM) admixture to be used for this purpose. In addition to internal waterproofing, concrete cold joints also need to be waterproofed (Kryton's Kritonite Swelling Waterstop is recommended).

6.2) Structural Loading & Analysis

The following section provides a summary of design loads and analysis for the elements subjected to gravity loads. The gravity loads are: dead loads from the soil and pavement, live loads from vehicles (and other non-permanent loads), and snow loads. The factored load was determined based on NBCC 2010 as shown in Appendix B. The gravity loads on the detention tanks are demonstrated in Figure 5 below.

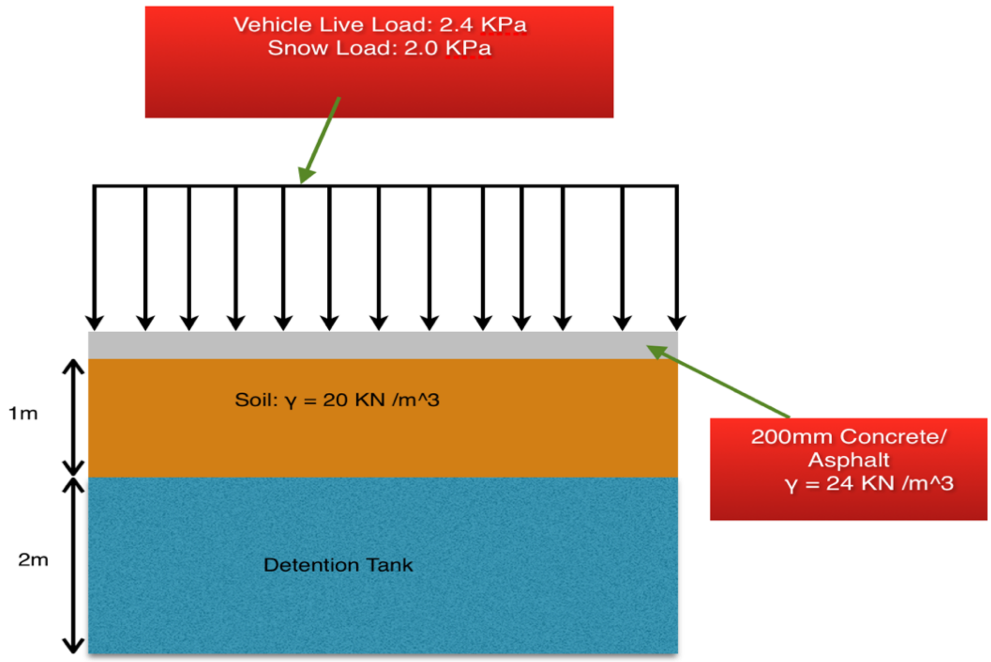


Figure 5) Gravity Loads on the Detention Tanks

Then using SAP2000, the loads shown above were applied along the top slab of the detention tank. Based on the NBCC 2010 code, the governing load combination was determined to be as follows:

Governing Load Combination: 1.25 DL + 1.5 LL + 0.5 SL

Based on this governing load combinations and using SAP2000 software, the maximum bending moment and shear force in the slab were determined to be:

Maximum Bending Moment: 74.8 kN.m

Maximum Shear Force: 89.8 kN

The shear and bending moment diagrams for the top slab are shown in **Figure 6** below.

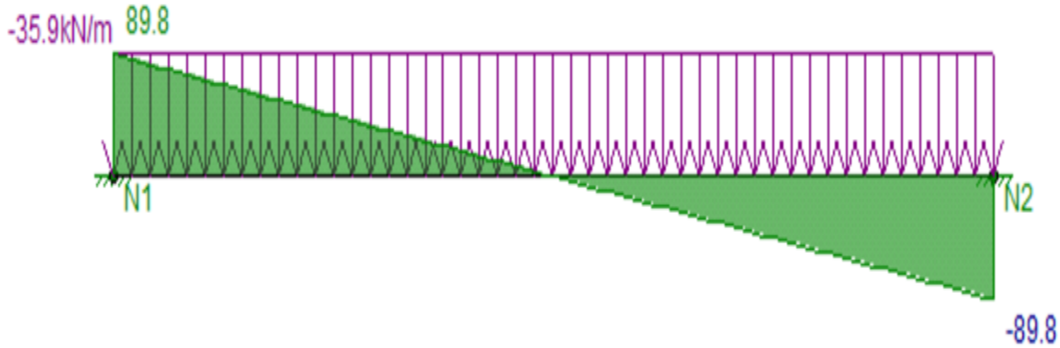


Figure 6a) Shear Force Diagram for the Top Slap of the Tank

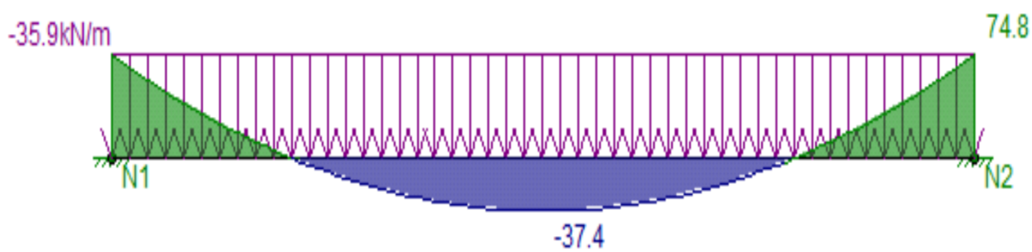


Figure 6b) Bending Moment Diagram for the Top Slap of the Tank

Member sizes and required amount of reinforcement for each element were obtained using the obtained loads and following the CSA A23.3 guidelines.

6.3) Structural Reinforced Concrete Design

The National Building Code of Canada and the Building Code of British Columbia must be followed for the design of the detention tanks. Major structural elements of each tank are explained and analyzed in this section. The calculations for each element can be found in Appendix B.

6.3.1 Slab Design

The cover slab is designed to transfer the loads described above into the columns and retaining walls and then into the slab on grade and finally into the soil. The cover slab is designed to be 300 mm thick with 20M reinforcement spaced at 350 mm going both directions. The slab on grade is designed to have the same reinforcement with a depth of 200 mm. The slab on grade is designed to be shallower as there is no unsupported length; it is supported by crushed rock the entire way.

6.3.2 Partition Wall Design

The partition walls were designed to help support lateral loads imposed by the surrounding soil. They do so by reducing the unsupported length of the retaining walls which was especially critical in the case of the West Mall Parkade tank, which spans 60 meters. Therefore, they were simply designed to carry axial loads which are the reaction forces from the retaining wall design. They are to be built 200mm thick and are only reinforced with stirrups to protect against shear failure.

6.3.3 Column Design

The columns were designed to transfer the loads from the cover slab into the base slab. The columns are to be spaced 5 meters from each other or from the retaining walls. They are designed as square tied columns measuring 300 mm by 300 mm. The columns are reinforced longitudinally by six 25M bars to protect against buckling. They are also reinforced by 10M stirrups spaced at 300 mm to prevent shear failure.

6.3.4 Retaining Wall Design

The retaining walls are designed to resist the lateral earth pressures from the soil surrounding each tank. They are designed to be 800 mm thick with 30M steel reinforcing bars placed at every 200-mm running in both directions. It is also reinforced with 10M stirrups every 250 mm to prevent shear failure. More information about the retaining wall design can be found in the geotechnical analysis section, Section 5.

Table 5) Major Components of the West Mall Outdoor Parkade Detention Tank

Component	Parameters
Cover	300 mm thick reinforced slab
Retaining Walls	800 mm thick reinforced slabs
Partition Walls	200 mm thick unreinforced slabs
Slab on Grade	200 mm thick reinforced slab
Columns	300mm X 300mm reinforced square column

7. Construction Planning

Construction Site: Detention Tank 1:

This detention tank is going to be placed in front of the new Student Union Building (SUB). This location will take the longest time for excavation and preparation compared to other tank locations because this area is one of the most crowded areas on UBC campus. There will be alternate routes provided for students to access the SUB building. The site preparation starts on May 1st, 2017 and the major construction will end by beginning of September. This time span is preferred because there will be less number of students on campus in summer time. The connection of the new piping system to the existing one, and the optimal location for placement of the filtration system is demonstrated in Figure 7.

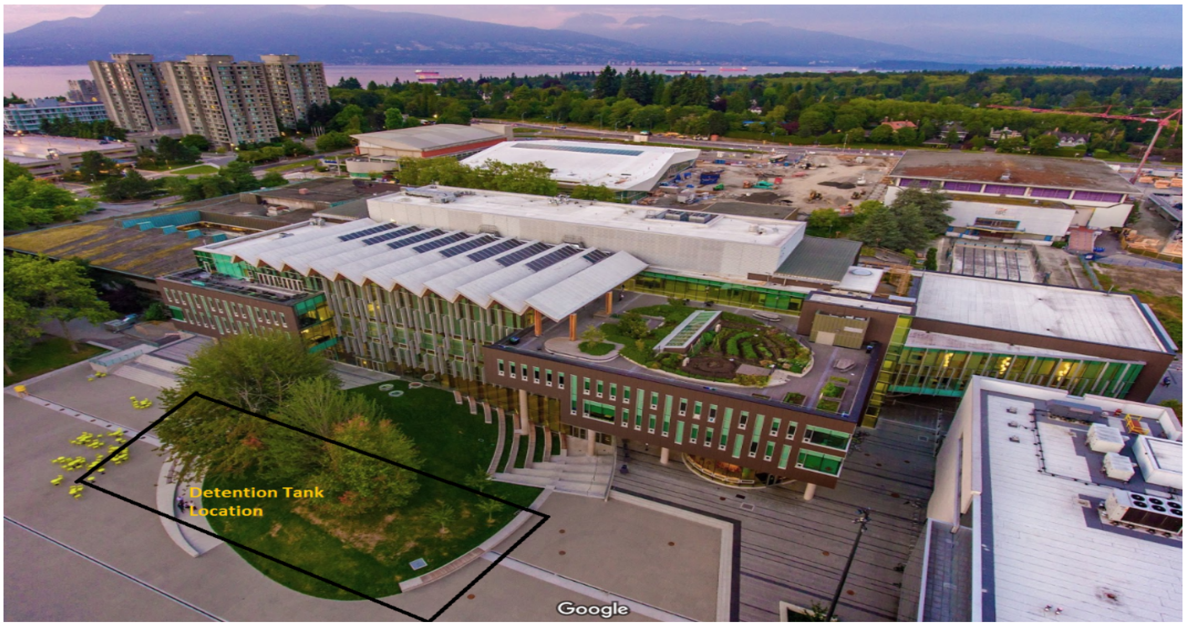


Figure 7a) First Detention Tank - By the SUB Building – 3D View

Figure 7b) First Detention Tank - By the SUB Building – Plan View

Construction Site: Detention Tank 2:

The second detention tank will be placed in the empty space beside Allard School of Law Building. This Location is equipped with convenient truck routes and is low in student traffic. Compared to the other two locations, this tank has the smallest tributary area; the dimensions of this tank are 40m x 40m. Tank outlines and the connection of the new piping system to the current pipes is shown in Figure 8.

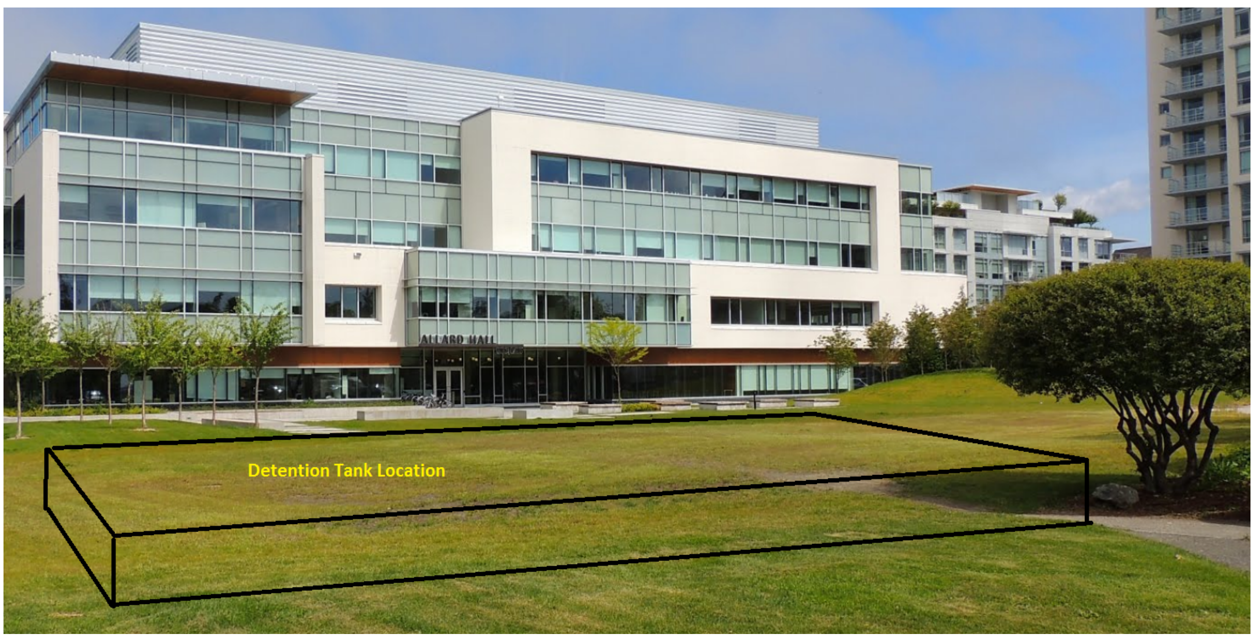


Figure 8a) Second Detention Tank – By Allard School of Law – 3D View

Figure 8b) Second Detention Tank – By Allard School of Law – Plan View

Construction Site: Detention Tank 3:

Final tank will be placed under ground in the parking lot space on West mall on north of UBC campus. The parking lot will be removed initially, after construction of the detention tank and covering the ground surface, the space will be available to be reused as a parking lot. This area is accessible for concrete pouring trucks. This area is also the least congested compared to the other two tank locations.

The construction of the third tank will take the shortest time. The detention tank located in the parking lot has the largest tributary area compared to other locations. Figure 9 (b) demonstrates the plan view of the tank and conveys how the new and existing pipelines are connected.

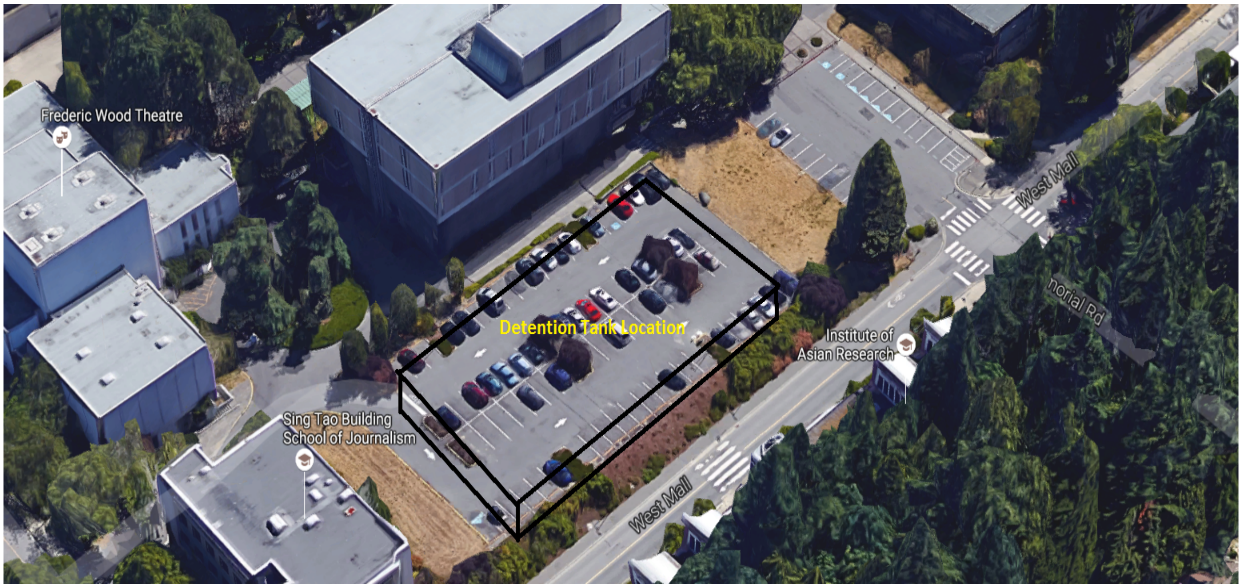


Figure 9a) Third Detention Tank – on West Mall – 3D View

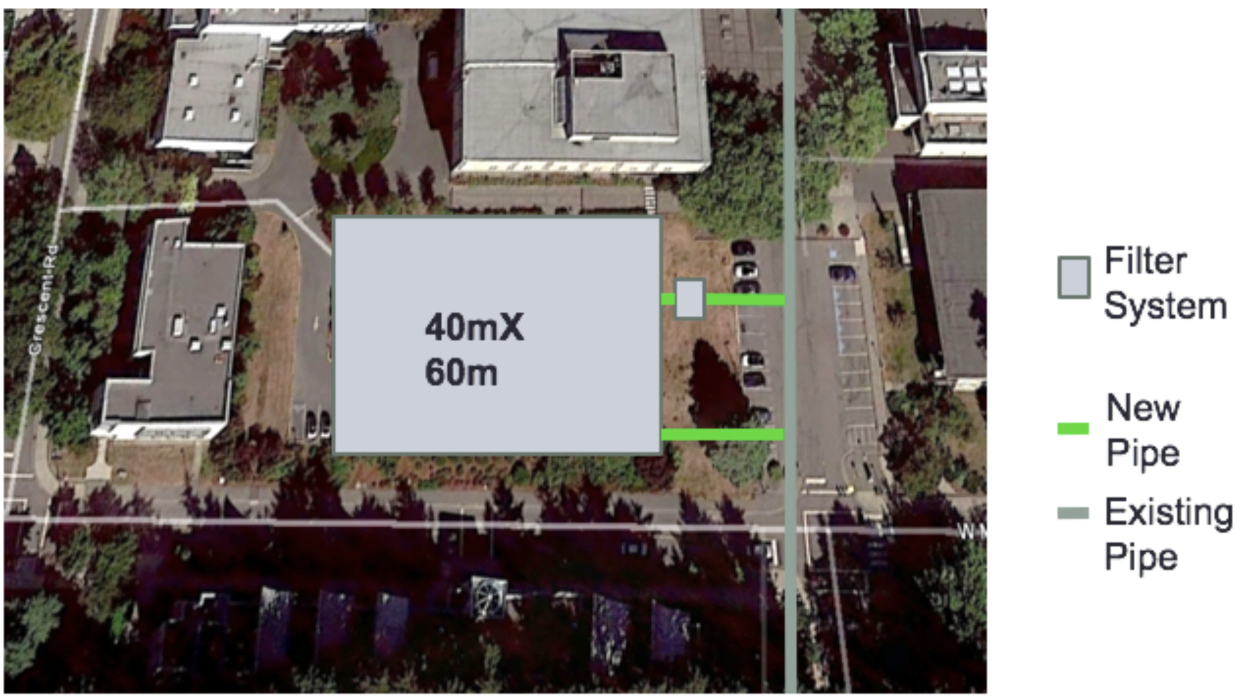


Figure 9b) Third Detention Tank – on West Mall – Plan View

8. Scheduling

The scheduling phase consists of five major components: start of the project, engineering and cost estimation, site preparation, concrete foundation work, and final inspection. It is assumed that the project will progress at 8 hours a day Monday-Friday, 6 hours on Saturdays, and 0 hours on Sundays. With every project, there is always the possibility that certain tasks are delayed unexpectedly, due to poor weather condition or other unforeseeable factors. Therefore, this schedule can be subjected to change and must be updated regularly. The client will be notified and consulted on these changes. A more detailed project schedule can be found in Appendix C.

Table 6) Project Schedule Summary

Phase	Start	End	Duration
Start of Project	May 1st, 2017	May 4th, 2017	4 days
Engineering and Cost Estimation	May 06th, 2017	May 16th, 2017	8 days
Site Preparation	May 17th, 2017	June 05th, 2017	12 days
Concrete Foundation Work	June 06th, 2017	October 26th, 2017	106 days
Final Inspection	October 26th, 2017	October 28th, 2017	2 days
Total Project Length	May 1st, 2017	October 30th, 2017	131 days

9. Cost Analysis

A preliminary cost analysis for this project was performed and presented to the client in December 2016. This section now presents a more detailed, Class I, cost analysis of the project.

This cost analysis takes into account all due taxes (5% GST and 7% PST) and a 15% risks and contingencies factor. Inflation, however, was not considered as this project is scheduled to be completed within the year. If the client wishes to start construction at a later date, an inflation factor must also be taken into account.

Major costs associated with the project have been identified and placed in one of the two major categories: construction costs, and maintenance and operation costs.

9.1) Construction Costs

The total projected construction cost is estimated to be **$5.1 million**. A detailed table with all cost breakdowns can be in **Appendix D**. A summary of construction costs is presented in below in Table 7.

Table 7) Construction Costs Summary

Initial Costs	
Project Start-up	$9,200.00
Engineer and Labor	$209,850.00
Engineering Firms	$580,000.00
Site Mobilization	$124,400.00
Construction	$3,001,785.00
End of Project	$89,600.00
Subtotal	$4,014,835.00
Contingency (15%)	$602,225.25
Taxes [GST (5%) & PST (7%)]	$481,780.20
Total	**$5,098,840.45**

9.2) Maintenance & Operation Costs

The maintenance and operation costs involved with this design have been obtained to be **$14,100**.

A summary of these costs is presented in Table 8; a full breakdown can be found in Appendix D.

Table 8) Operation & Maintenance Costs Summary

Operation and Maintenance	Per tank	Yearly Cost
Pump Maintenance	$1,500	$4,500
Utility	$1,200	$3,600
Other maintenance costs (Including labor & special equipment)	$2,000	$6,000
Total:		**$14,100**

10. Potential Sources of Error

Cascadia Hydraulic Consulting Ltd. has practiced the highest degree of professional engineering judgement and knowledge throughout the design of this new system. However, various improvement opportunities exist.

For instance, the design inputs required for completion of geotechnical, hydrological, and structural analysis were obtained from the available published reports (Piteau, 2000- GeoAdvice Engineering- IBC, 2006 - ASCE2001). As a result, there may be unforeseen errors due to a potential discrepancy between the actual values and the ones used in the design. Although we believe that the confidence interval for the values used is acceptable, Cascadia recommends a thorough geotechnical survey be performed before finalization of the design.

11. Conclusion

Cascadia Hydraulic Consulting Ltd has proposed an effective design solution for the replacement of the spiral drain located at the north end of the UBC campus. The new stormwater management system is designed according to all criteria set by our client as well as site and regulatory constraints.

This system consists of three underground concrete detention tanks equipped with filtration systems and pumps. These tanks are located throughout the north catchment strategically to minimize flooding. This design is capable of handling the maximum predicted flow from 100 & 200-year return period storms. After a detailed cost analysis performed by Cascadia Consulting, the proposed design has been estimated to cost **$5.1 M** during the construction phase, and **$14,100** annually for operation and maintenance.

In conclusion, our consulting team believes that this innovative and sustainable design solution will be an effective replacement for the current stormwater management system.

Appendix A – Hydrological Analysis

Flooding Information for the North Catchment Nodes for a 100-year Return Period Storm;

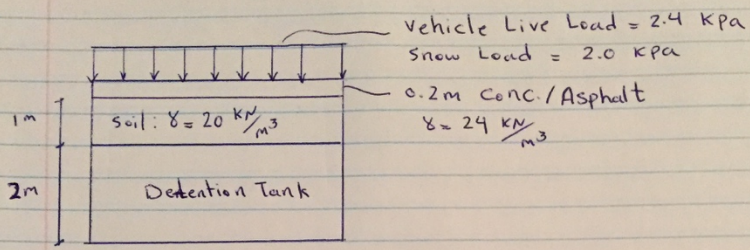
Red highlights areas of concern:

Node	Hours Flooded	Max Rate (LPS)	Time of Max. Flooding	Total Flood Volume (10^6 ltr)
A4D-N1	0.01	257.38	8:19	0.002
A4D-N2	0.01	422.55	8:15	0.001
A4D-N61	1.07	1035.34	8:30	2.414
A4D-N82	0.82	276.5	8:28	0.499
B4D-N2	0.2	346.69	8:19	0.039
B5D-N62	0.01	283.19	8:16	0
B5D-N64	0.01	369.85	8:15	0.001
B5D-N82A	0.01	239.91	8:15	0.001
B5D-N82B	0.01	140.79	8:15	0.001
B5D-N83	0.53	210.5	8:15	0.128
B6D-N70	0.01	60.69	8:15	0
B6D-N94	0.97	659.14	8:30	1.214

C5D-N88	0.01	12.26	8:16	0
C6D-N86E	0.01	4.92	8:18	0
D3D-N33	0.15	31.92	8:30	0.009
D4D-N31A	0.27	8.01	8:29	0.006
D4D-N31B	0.16	5.4	8:30	0.002
D6D-N106G	1.38	189.16	8:29	0.661
D6D-N70	0.49	628.09	11:15	0.473
D7D-N108	0.01	33	8:13	0
E6D-N73A	0.45	64.78	8:30	0.063
E7D-N108J	1.01	43.56	8:30	0.071
E7D-N115D	0.17	6.69	8:30	0.002
F2D-N30	0.01	4.63	8:18	0
F2D-N30A	0.48	79.35	8:30	0.083
F5D-N77B	0.13	5.23	8:30	0.001
F6D-N113A	0.01	76.71	8:15	0
F6D-N76	0.28	113.05	8:31	0.065

F6D-N86	0.15	45.94	8:31	0.011
G3D-N56A	0.3	28.63	8:30	0.017
G3D-N58	0.33	34.07	8:30	0.022
G3D-N58B	0.01	0.17	8:29	0
G5D-N81H	0.01	6.91	8:31	0
G5D-N81J	0.01	1.04	8:31	0
H3D-N56B	0.07	2.14	8:30	0
J5D-NW299	0.05	5.7	8:28	0.001
J6D-N127B	1.15	35.52	8:30	0.06
J6D-NW127	0.44	11.55	8:30	0.01
JUNC-10	0.03	1.54	8:31	0
JUNC-19	0.01	0.53	0:00	0
JUNC-34	0.75	82.04	8:30	0.114
JUNC-41	0.57	5.5	8:15	0.01

Appendix B – Structural Analysis



Dead Load = Soil weight (20 KN/m³) + pavement weight (24 KN/m³)

Soil weight = 20 KN/m³ x 1m = 20 KN/m²

Pavement weight = 24 KN/m³ x 0.2m = 4.8 KN/m²

Dead Load = 20 kpa + 4.8 kpa = 24.8 kpa ≅ 25 Kpa

Live Load = Vehicle Live Load = 2.4 kpa

Snow Load = 2.0 kpa

. Based on the NBCC requirements, the governing loading case for the structure is :

$W_f = 1.25\ D.L. + 1.5\ L.L. + 0.5\ S.L.$

$W_f = 1.25(25\ kpa) + 1.5(2.4\ kpa) + 0.5(2\ kpa) = 35.9\ kpa$

$W_f = 35.9\ kpa \times 1\ m = 35.9\ KN/m$

Overburden pressure = w_f from load calcs

$w_f = 35.9\ kPa = \sigma_z$ @ cover

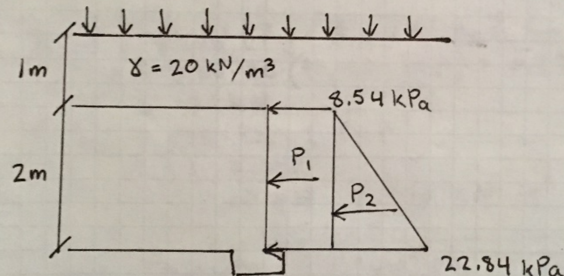
$$K_a = \frac{1-\sin\phi}{1+\sin\phi} = \frac{1-\sin(38)}{1+\sin(38)} = 0.238$$

σ_x @ cover $= \sigma_z \times K_a = 35.9 \times 0.238 = 8.54\ kPa$

σ_v @ slab $= \sigma_v$ @ cover $+ \gamma \times 2$

$= 35.9 + 20 \times 2 = 95.9\ kPa$

σ_x @ slab $= \sigma_v \times K_a = 95.9 \times 0.238 = 22.82\ kPa$



$P_1 = 8.54 \times 2 = 17.08\ kN/m$

$P_2 = \frac{1}{2}(22.84 - 8.54) \times 2 = 14.30\ kN/m$

$\Sigma P = 31.38\ kN/m$

Retaining Wall Calcs

From SAP 2000: $M_f = 760\ kNm$, $V_f = 228\ kN$

$\ell_n = 20{,}000 - 400 = 19{,}600\ mm$

For fixed-fixed supported (at ⊥ walls):

$h \geq \frac{\ell_n}{28} \geq \frac{19{,}600}{28} \geq 700\,mm \Rightarrow 800\,mm$, $b = 1000\,mm$ (unit width)

$d = h - cover - d_b/2$ (try 30M rebar)

$= 800 - 40 - 30/2 = 745\,mm$

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

$$= 0.0015 \times 25 \times 1000 \left(745 - \sqrt{745^2 - \frac{3.85 \cdot 760}{25 \cdot 1000}}\right)$$

$= 3167\ mm^2/m$

$s \leq \frac{A_b \cdot 1000}{A_s} \leq \frac{700 \cdot 1000}{3167} \leq 221 \Rightarrow 200\,mm$

try 30M @ 200 mm

$A_s = \frac{700 \cdot 1000}{200} = 3{,}500\ mm^2/m$

$\rho = \frac{A_s}{bd} = \frac{3500}{1000 \cdot 745} = 0.004 < 0.022$ ✓ properly reinforced

$A_{s\,min} = 0.002\,A_g = 0.002 \cdot 1000 \cdot 800 = 1{,}600\ mm^2/m$ ✓

$S_{max} = \begin{cases} 3h = 2{,}400\,mm \\ 500\,mm \leftarrow \text{governs} \end{cases}$ ✓

$a = \frac{\phi_s f_y A_s}{\alpha_1 \phi_c f_c' b} = \frac{0.85 \cdot 400 \cdot 3500}{0.8 \cdot 0.65 \cdot 25 \cdot 1000} = 91.5\,mm$

$M_r = \phi_s f_y A_s (d - a/2) = 0.85 \cdot 400 \cdot 3500 (745 - 91.5/2)$

$M_r = 820\ kNm > M_f$ ✓

$V_f = 228\ kN$

$\beta = \dfrac{230}{1000 + d_v}$

$d_v = \max \begin{cases} 0.9d = 0.9 \times 745 = 670.5\ mm \leftarrow \\ 0.72h = 0.72 \times 800 = 576\ mm \end{cases}$

$\beta = \dfrac{230}{1000 + 670.5} = 0.14$

$V_c = \phi_c \lambda \beta \sqrt{f_c'}\, b_w d_v$

$= 0.65 \cdot 1 \cdot 0.14 \cdot \sqrt{25} \cdot 1000 \cdot 670.5$

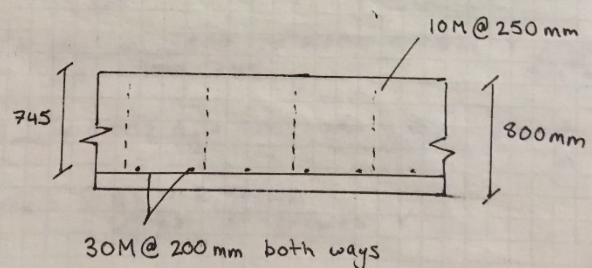
$= 305\ kN > V_f$

However, since slab depth $h = 800\ mm$ (deep), min. shear reinforcement should be placed:

Use 2-10M stirrups:

$s = \dfrac{200 \cdot 400}{0.06\sqrt{25} \cdot 1000} = 266.7\ mm \rightarrow 250\ mm$

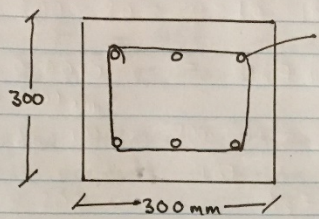
→ Use 2×10M @ 250 mm



Column load = wf + weight of cover

$= (35.9 + 1.25 \cdot 0.3 \cdot 2{,}400) \times 5 \times 5 = 920\ kN$

try



$6-25M \Rightarrow A_{st} = 6 \times 500 = 3{,}000\ mm^2$

$A_g = 300^2 = 90{,}000\ mm^2$

$P_{ro} = \alpha_1 \phi_c f_c' (A_g - A_{st}) + \phi_s f_y A_{st}$
$= 0.8 \cdot 0.65 \cdot 25 \cdot (90{,}000 - 3000) + 0.85 \cdot 400 \cdot 3000$
$= 2{,}150\ kN$

$P_{r,max} = 0.8 \cdot P_{ro}$ (tied)
$= 0.8 \cdot 2{,}150$
$= 1{,}720\ kN >> 920\ kN$ ✓

Bearing Capacity Calculation

$q_a = 144 kPa$ (IBC, 2006) for medium sands

Hydrostatic bearing pressure $= 2^m \times 9.81 = 20 kPa$

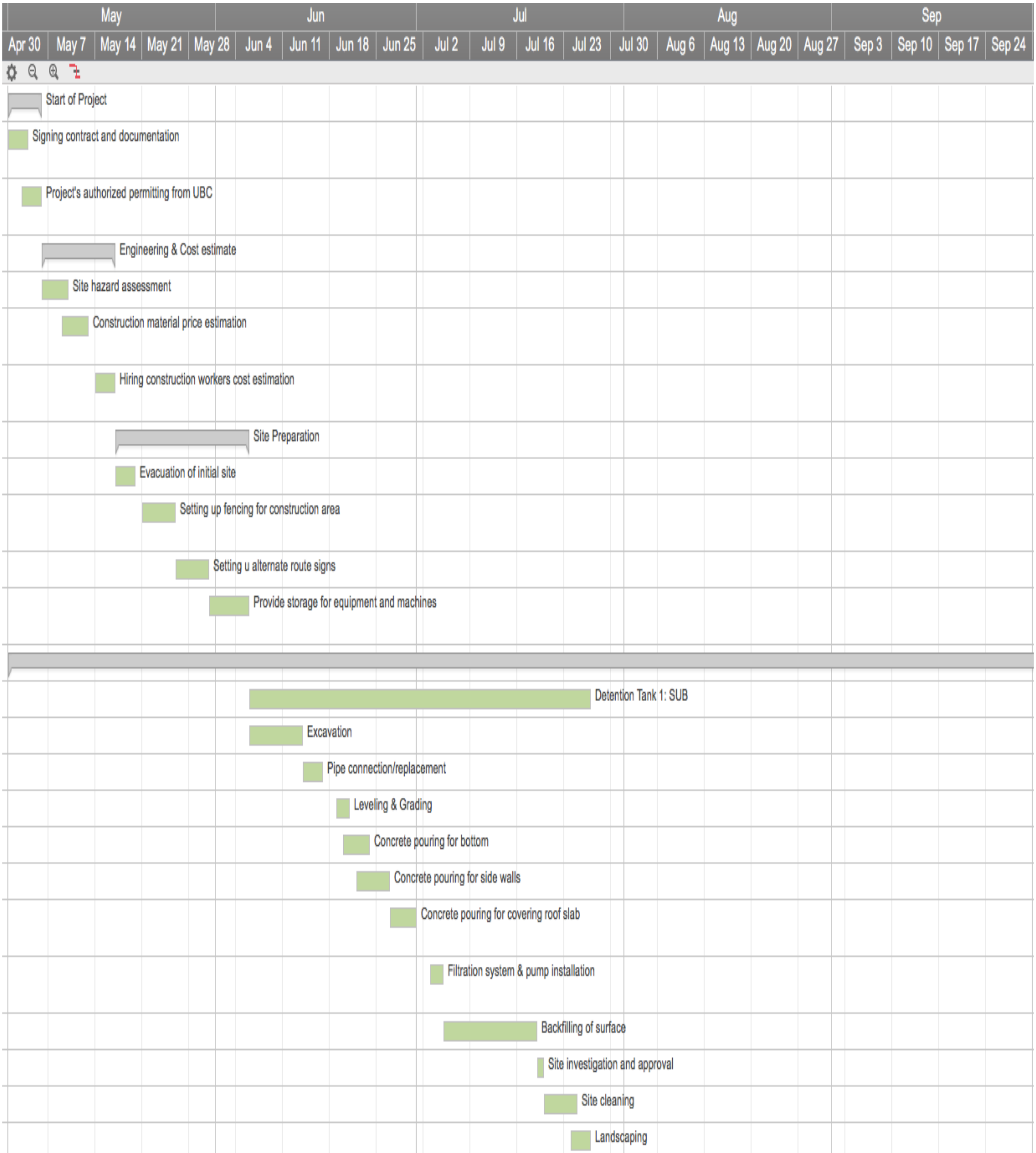
Tank Self-Weight $= (2 \cdot 0.8 \cdot 40 \cdot 2 + 2 \cdot 0.8 \cdot 60 \cdot 2 + 40 \cdot 60 \cdot 0.3 + 54 \cdot 2 \cdot 0.3^2 + 40 \cdot 60 \cdot 0.2 + 2 \cdot 0.2 \cdot 2 \cdot 40 + 1 \cdot 0.2 \cdot 2 \cdot 60) \times 2{,}400$

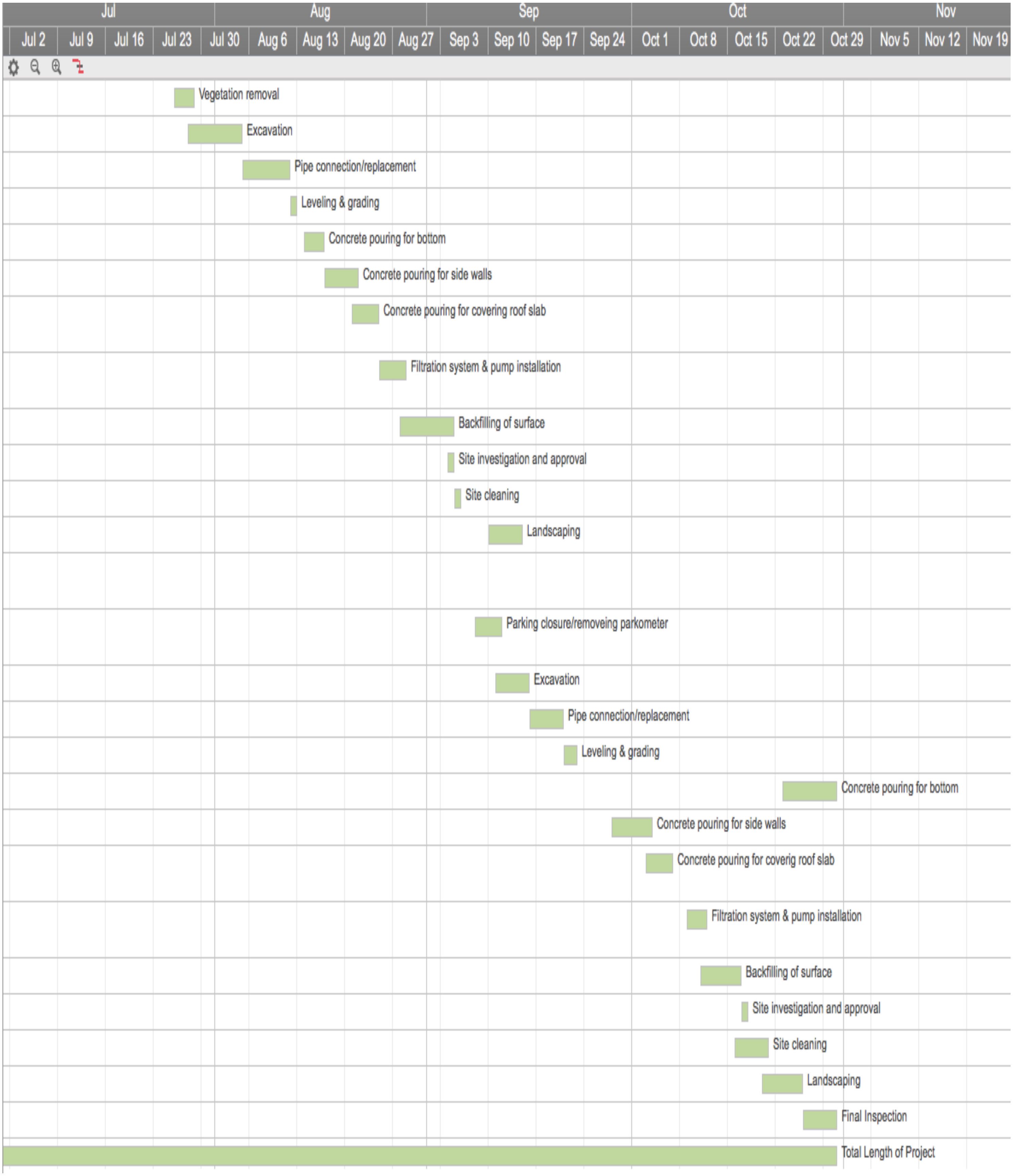
$= 3{,}800{,}000\ kg \times \frac{9.8}{40 \cdot 60} = 15.5\ kPa$

Imposed Load $= wf = 35.9\ kPa$

$q_u = 71.4 kPa < q_a$ ✓ ok.

Appendix C - Scheduling





Jul
Aug
Sep
Oct
Nov
Jul 2
Jul 9
Jul 16
Jul 23
Jul 30
Aug 6
Aug 13
Aug 20
Aug 27
Sep 3
Sep 10
Sep 17
Sep 24
Oct 1
Oct 8
Oct 15
Oct 22
Oct 29
Nov 5
Nov 12
Nov 19
Vegetation removal
Excavation
Pipe connection/replacement
Leveling & grading
Concrete pouring for bottom
Concrete pouring for side walls
Concrete pouring for covering roof slab
Filtration system & pump installation
Backfilling of surface
Site investigation and approval
Site cleaning
Landscaping
Parking closure/removeing parkometer
Excavation
Pipe connection/replacement
Leveling & grading
Concrete pouring for bottom
Concrete pouring for side walls
Concrete pouring for coverig roof slab
Filtration system & pump installation
Backfilling of surface
Site investigation and approval
Site cleaning
Landscaping
Final Inspection
Total Length of Project

Appendix D – Cost Analysis

Initial Costs (Summary Table)	
Project Start-up	$9,200.00
Engineer and Labor	$209,850.00
Engineering Firms	$580,000.00
Site Mobilization	$124,400.00
Construction	$3,001,785.00
End of Project	$89,600.00
Total (Including tax and Contingency)	$5,098,840.45

Operation and Maintenance (Summary Table)	Per tank	Yearly Cost
Pump Maintenance	$1,500	$4,500
Utility	$1,200	$3,600
Other maintenance cost	$2,000	$6,000
	Total	$14,100

ID	Phase	Quantity	Unit	Unit Rate	Amount	Sub-Total
A	Project Start-up					
A.1	Documentation	1	N/A	Lump Sum	4,000.00	
A.2	Project start-up meetings	N/A	N/A	Lump Sum	2,200.00	
A.3	Relevant documents	1	N/A	Lump Sum	3,000.00	
						9,200.00
B	Engineer and Labor					
B.1	Engineer-In-Training	200	hr	$120	$24,000	
B.2	Project Engineer	300	hr	$160	$48,000	
B.3	Specialist Engineer	110	hr	$195	$21,450	
B.4	Management Engineer	250	hr	$220	$55,000	
B.5	Head Technician	180	hr	$130	$23,400	
B.6	Technician	280	hr	$110	$30,800	
B.7	General Labor	400	hr	$18	$7,200	
						$209,850
C	Engineering Firms					
C.1	Structural Consultant	1	N/A	Lump Sum	250,000.00	
C.2	Geotechnical Consultant	1	N/A	Lump Sum	180,000	
C.3	Hydrological Consultant	1	N/A	Lump Sum	100,000	
C.4	Inspection and Testing	1	N/A	Lump Sum	50,000	
						580,000.00
D	Site Mobilization					
D.1	Set up fencing and signs	700	m	$22	$15,400	
D.2	On-site storage for materials	1000	m^2	$10	$10,000	
D.3	Clear and grub sites	7000	m^2	$12	$84,000	
D.4	Traffic Control	1	N/A	Lump Sum	$15,000	
						$124,400
E	Construction					
E.1	Excavation	12250	m^3	$10	$122,500	
E.2	Concrete Pipe	150	m	$1,200	$180,000	
E.3	Formwork	6025	m^2	$80	$482,000	
E.4	Install Shoring cage and strut	1	N/A	Lump Sum	$40,000	
E.5	Footing	1205	m^3	$280	$337,400	
E.6	Top Slab	1808	m^3	$280	$506,240	

E.7	Walls (Partition + retaining)	1080	m^3	$280	$302,400	
E.8	Column	44	m^3	$280	$12,320	
E.9	Steel Reinforcement	N/A	N/A	N/A	$280,000	
E.10	Filteration System and Pump	3	N/A	$120,000	$360,000	
E.11	Backfill and Cover	6025	m^2	$12	$72,300	
E.12	Asphalt	2400	m^2	$90	$216,000	
E.13	Landscaping	3625	m^2	$25	$90,625	
						$3,001,785
F	End of Project					
F.1	Site Clean up	7000	m^2	$12	$84,000	
F.2	Remove fencing	700	m	$8	$5,600	
						$89,600

Subtotal	$4,014,835.00
Contingency (15%)	$602,225.25
GST(5%)	$200,741.75
PST(7%)	$281,038.45
Total	$5,098,840.45

Operation and Maintenace	Per tank	Yearly Cost
Pump Maintenance	$1,500	$4,500
Utility	$1,200	$3,600
Other maintenance cost	$2,000	$6,000
	Total	$14,100