UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Stadium Neighborhood Underground Parkade and Water Storage

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Executive Summary

The proposed design includes the construction of a stormwater detention facility under the field along with a two storey underground parkade under the stadium building. Collected stormwater is stored under the field and diverted to a water treatment system. The treated water will be distributed to the stadium and the botanical garden and reused for irrigation and flushing toilets. The stored water can also infiltrate into the native soils and act as a groundwater recharge source. In case of an extreme event corresponding to a 10-year and a 100-year return period, water can be diverted to the lower level of the parkade which serves as a secondary water tank and discharged through the UBC's current pipe network. This design is effective and efficient to properly deal with the UBC's current concern related to stormwater management and prevention of floods and potential slope stability around Point Grey.

The demands and capacities of the parkade were analyzed using software such as S-Frame™, S-Steel™ and S-Concrete™. The loads on the structure are composed of the dead load, vehicles load, exit load, soil pressure and snow load. The steel sections and rebar of this structure were chosen based on the CSA S16-14 and determined to be 350W and 400W respectively.

The preliminary schedule for the project indicates a start on May 1st, 2019 and completion in October 2019; a total of 6 months. Additionally, the report reviews a detailed cost estimate including first costs, annual operating cost, and maintenance costs. The total expected cost is estimated at CAD $15.7 million for the parkade, detention tank and accompanying facilities construction. The parkade and water storage facility is mindful of the local environment and stakeholder interests.

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1.0 Introduction

Studies developed in the Point Grey area raised concerns about erosions on the surrounding cliffs, potential flooding, and quality of storm-water on campus. The current storm-water system in place is traditional consisting of massive concrete and plastic pipes, but there is a need for a more natural approach to handle stormwater at UBC. The current system is insufficient in preventing floods during extreme storm events. Hence, a mix design of a parkade and a water storage system is proposed.

The objective of the proposed system is to utilize stormwater captured from Thunderbird stadium and the neighbouring streets located in the southwest catchment of UBC campus. These facilities will be built around the intersection of 16th Avenue and East Mall, to serve the upcoming Stadium Road neighbourhood. The purpose is to minimize the risks associated with increased volume and rate of surface runoff of a 10 year and a 100 year storm event. This is expected to reduce erosion of adjacent cliffs, reduce pressure on current water pipes and improve slope stability. The proposed design solution includes primary water detention tanks and a 2-level underground parkade underneath the stadium field.

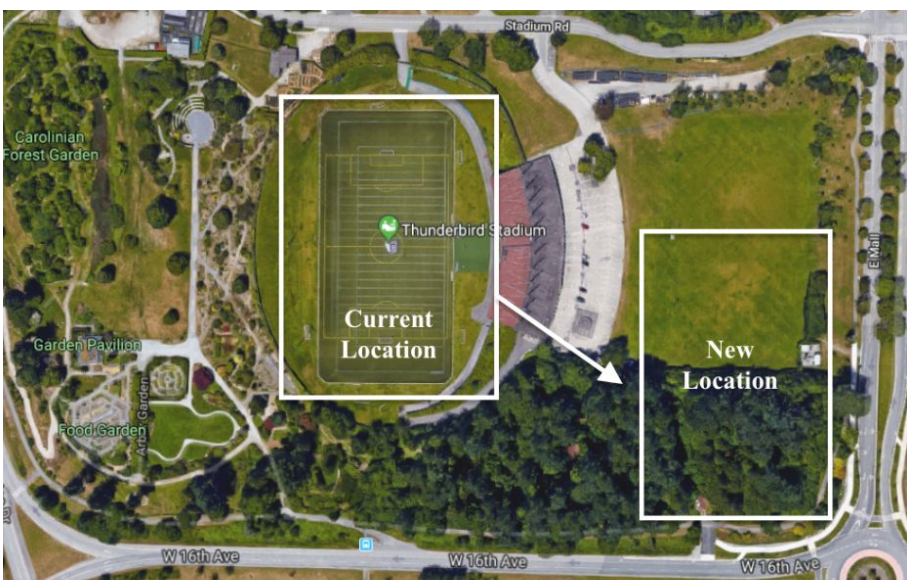


Figure 1: Site Overview

2.0 Design Criteria and Constraints

The underground parkade and water detention facility takes into consideration the technical, economic, regulatory, environmental and societal aspects. First of all, the main objective of this design is to manage a 10 year and a 100 year storm events. Hence, the main goal is to prevent flooding on waterways, overland flow paths and constructed drainage network for the designed volume. It is also important that the parkade structure can withstand all lateral loading, surface loading and seismic loading. The design will follow the UBC Integrated Stormwater Management Plan which includes the preferred design life, priority locations, land zoning requirements and discharge water quality. In addition, it will meet the standards imposed by local governmental bodies such as City of Vancouver and Metro Vancouver.

The major roads will be designed to withstand a 100-year storm event and minor roads a 10-year storm event. The calculations are shown in Appendix A, and summarized below:

Table 1: Volume of water for 10 -year and 100-year Storm Event

10-year Storm-event	Time = 1 hr	Q_{10yr} = 4,335 m^3/hr	V_{10yr} = 4,335 m^3
10-year Storm Event	Time = 24 hr	Q_{10yr} = 4,335 m^3/hr	V_{10yr} = 104,040 m^3
100-year Storm Event	Time = 1 hr	Q_{100yr} = 5,260 m^3/hr	V_{100yr} = 5,260 m^3
100-year Storm Event	Time = 24 hr	Q_{100yr} = 5,260 m^3/hr	V_{100yr} = 126,240 m^3

Secondly, the parkade should enhance the overall experience of the place, while ultimately determining the success and profitability of the structure. Parking is often the first thing people experience when arriving at a destination, and the last thing they experience when leaving. If the parking experience is unpleasant, it will have an impact on their decision to return. Some of the technical aspects of parkade design are the entrance/exit locations, turning radii, floor slopes and parking efficiency.

Sustainability is a key component of the design. It offers an opportunity to create environmentally sound and resource-efficient buildings by using the sustainable design practices. There are several common strategies to incorporate sustainable design into the mixed-use facility that includes using reusable construction materials, providing charging stations for electric vehicles, installing pervious paving and other landscape strategies to increase infiltration.

Stakeholder engagement is a continuous endeavour with this project to ensure that the needs and goals of the community and leaders are met.

Table 2: Stakeholder Summary.

Community	**Government & Authorities**	**Influencers & Providers**
First Nations	City of Vancouver	UBC Campus + Community Planning
UBC athletes	MetroVancouver	UBC Properties Trust
UBC residents and students		

3.0 Proposed Design

The design consists of a primary detention system and a two storey underground parkade underneath the relocated Thunderbird stadium. The primary detention system consists of a subsurface water storage unit underneath the field with dimensions of 35 m wide and 92 m long (current stadium's dimensions). The storage units used for the field are StormTank supplied by Brentwood. The lower level of the underground parkade will act as a secondary water detention tank, being filled in case of an extreme storm. Water from the primary storage tank will be treated and thereafter used for irrigation of the field and the Botanical garden, as well as for use in the stadium and proposed Stadium neighbourhood residences. Water form the secondary detention system will be discharged into the existing storm water drainage system. The floors of the parkade are split by an automated mechanical system during a rain event. Detailed drawings of the design are shown in Appendix B.

3.1 The Primary System - Brentwood StormTank Module and Shield

3.1.1 Objective

The main objectives of this system is to store and utilize stormwater captured in the neighbouring streets via the local pipe network, and reduce water pollution in the effluent. The primary system is located underneath the stadium field with flexibility in volume design to meet site requirements and runoff regulations.

3.1.2 System Description

The system consists of two basic components; a StormTank Module and a StormTank Shield. Firstly, the StormTank Module consists of two subsurface units of different dimensions, an ST-36 at the bottom and an ST-18 at the top. The units are made of high-strength Polypropylene panels and PVC (Polyvinyl Chloride) columns with reinforcing structural ribs. The panels are engineered to provide stability and distribute loads onto the columns uniformly. The dimensions and properties of the module units chosen are given in table 3 below. A side view of the modules system is shown in figure 2;

Table 3: Dimensions and Properties of module units

Code	Dimensions	Storage	Storage Volume	Weight
ST-36	L: 914 mm W: 457 mm H: 914 mm	0.37 m^3	97 %	15 kg
ST-18	L: 914 mm W: 457 mm H: 457 mm	0.18 m^3	95.5 %	10 kg

Where: L, Length - W, Width - H, Height

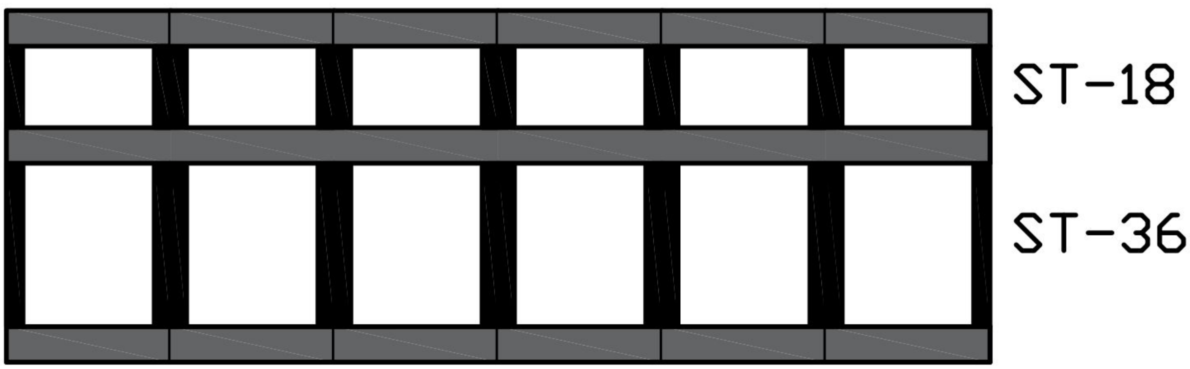


Figure 2: Side View of Brentwood Modules System

Secondly, a 24 inch StormTank Shield is to be installed at the entrance of the tank to decrease pollution and ensure high water quality in the effluent by removing debris and separating oil. In addition, excluding extreme events, the shield will help in maintaining a constant water level in the system due to the shape of the shield opening. Figure 3 below shows the shield and a cross section of the shield installation.

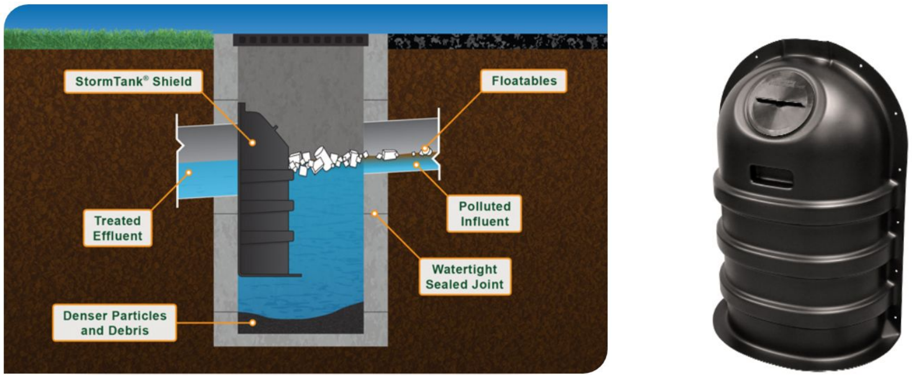


Figure 3: StormTank Shield (Brentwood Industries, Inc.)

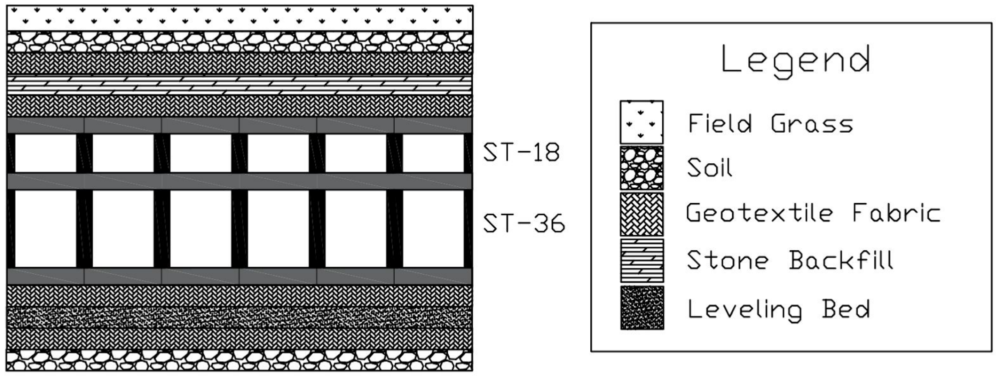
3.1.3 Construction Layout

The primary system underneath the field will need to detain water with minimum (2500 m^3 - 3000 m^3) based on the UBC stormwater management plan. Therefore, the required system with 96.6% storage, would need to occupy a minimum volume of (2600 - 3100 m^3). In addition, the area for the primary system needed to meet the minimum flow rate shown in Appendix A is roughly 4000 m^2, which is 60 m by 60 m, with an excavation depth of 2m, and expected storage capacity of 5300 m^3. The excavation depth accounts for the height of the modules as well as the depth of the accompanying construction layers. These layers include:

1) 4 Geotextile Fabric Layers: These are permeable fabrics that are used in construction to separate layers, serve as effective filters, protect and guard against erosion, prevent the movement of soil and add structural integrity (Leach, 1984). For our design we choose nonwoven geotextiles to increase the permeability of the layer, allowing excess stored water to infiltrate into the native soils.
2) 1 Level Bed Layer: The purpose of this layer is to provide stability prior to the module placement. The layer is constructed from coarse aggregates.
3) 1 Stone Backfill Layer: This layer adds reinforcement and supports the structure while promoting water drainage.

The cross section of the construction layout is shown in figure 4 below.

Figure 4: Side View of Brentwood Modules System with Construction Layers



The water stored in the primary system can be utilized as follows:

- The water can be slowly discharged into a stream at rate of 1.2 m^3/s based on the UBC integrated water management plan.
- The water can slowly infiltrate into the native soil, thus, acting a groundwater recharge source.
- The water can be treated for irrigation purposes and household usage.

3.2 Secondary System - Stormwater Storage Tank

3.2.1 Objective

The main objective of the secondary system is to act as a parkade, however, during extreme storm events, the lower story of the parkade would store excess water that is diverted from the primary system to prevent flooding and equalize runoff flow rate.

3.2.2 System Description

The system is to be constructed as a two story underground parkade with the lower level to be used as a detention tank in extreme storm events. The process of water diversion is initiated by gravity and head difference between the primary and secondary systems. The connection between the systems would be via pipes and automated weirs that maintain a 1.2 m^3/s flow as per regulations stated in the UBC stormwater integrated plan.

3.2.3 Construction Layout

The depth of each story is designed to be 12ft with an area of 40,000 m^2 per level. According to the CSA A23.1, the slabs and columns for the parkade would fall under the F-1, F-2, S-1, S-2 and C-XL classes. The slabs and columns of the upper storry parkade will be constructed from regular concrete and steel rebars. However, due to possible contact with water, the slabs and columns of the lower story are to be constructed from impermeable high density concrete to prevent corrosion of steel, chloride attack, sulfate attack, alkali aggregate reaction (AAR) and freeze and thaw cycles. Admixtures such as silica fume and supplementary cementitious materials can be added to achieve that. Also, control fibers such as fiberglass and polypropylene are to be added to mitigate the development of cracks.The Plan views of each floor of the parkade can be seen in Appendix B. They were drawn in AutoCad 2019, with a scale of 1:250.

3.2.4 Main features and Characteristics:

The secondary system is characterized by movable weirs that control the opening of the connection pipe between the primary and secondary systems. The weirs will gather information from water level sensors placed on specific locations, that are known for flooding under extreme storm events based on long term data. In addition, the sensors would notify systems similar to the USGS ShakeAlert, an earthquake early warning system used by the US geological survey, to alert lower parkade users via a text message to clear the premises. Advisory and parking time limit signs will be used for visual interpretation.

In case of flooding, a small scale pump house will help in draining the water out which could be used for irrigation purposes. On the other hand, the water will be discharged over time into a stream via the installed drainage system. Additional features in the system include an airtight and watertight enclosure that helps in the drainage of water.

4.0 Piping System

The proposed project has a piping system that diverts water from the UBC drainage system to the primary tank, water is then treated and distributed to the botanical garden and the stadium for irrigation and flushing toilets. The piping system is designed to also accommodate a 100-year storm event for a 24 hours duration.

4.1 Demands

Three main demands were considered: the botanical garden, the stadium building and a future residential building in the new stadium neighbourhood. The two scenarios are shown below, during a game and normal conditions, and during an extreme storm event. The demand for the stadium building is based on the Gillette Stadium in Foxborough, Massassuettes. The demand for the botanical garden is based on the Australian Botanical Garden in Mount Annan, Australia. Sample calculations can be found in Appendix C. Tables 4 and 5 show the flow rate going through each major pipe for scenario 1 - Normal Conditions During a Game, and scenario 2 - Extreme Storm Event (100-Year 24 hours)

Table 4: Normal Conditions Flow Rates

From	**To**	**Rate (m^3/hr)**
Stormwater Sewer	Primary Tank	58.07
Primary Tank	Treatment	181.44
Treatment	Cistern	2,548.80
Cistern	Botanical Garden	34.25
Cistern	Stadium	135.94
Cistern	Potential Res	11.25
Stadium Collection		3.88

Table 5: Extreme Storm Event Flow Rates

From	**To**	**Rate (m^3/hr)**
Stormwater Sewer	Primary Tank	4,930
Primary Tank	Treatment	35.17
Treatment	Cistern	2,548.80
Cistern	Botanical Garden	17.12
Cistern	Stadium	6.80
Cistern	Potential Res	11.25
Primary Tank	Secondary Tank	5110.0
Secondary Tank	Stormwater Sewer	4320.0
Stadium Collection		329.60

4.2 Treatment Facility

The treatment facility used is a rainwater harvesting solution from Contech Engineered Solutions.The system can treat stormwater at a rate up to 708 L/s. The system has a 120 inches diameter DuroMaxx cistern (figure 5), that can hold up to 20,000 US gallons of clean water. The Rainwater Harvesting Cisterns is made of DuroMaxx Steel Reinforced Polyethylene (SRPE). The eighty (80) ksi steel reinforcing ribs provide strength and the pressure rated polyethylene (PE) resin provides durability. In addition the facility has two treatment devices, a hydrodynamic separator for the pretreatment and a stormfilter for the main treatment. The CDS® hydrodynamic separator (figure 6) is an underground stormwater pretreatment device that uses swirl concentration and continuous deflective separation to screen, separate and trap trash, debris, sediment, and hydrocarbons from runoff. The Stormwater Management StormFilter® (figure 7), uses rechargeable and media-filled cartridges that absorb and retain the most challenging target pollutants including dissolved metals, hydrocarbons, nutrients, metals and other common pollutants found in the pretreaded stormwater runoff.

Figure 5: The Cistern

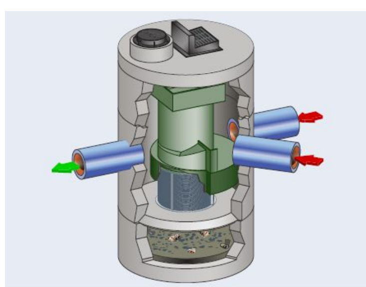


Figure 6: The Separator

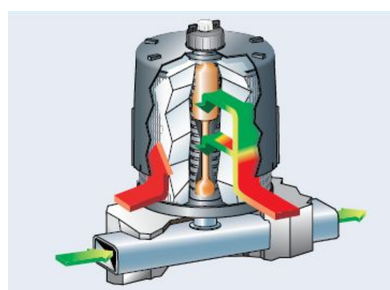


Figure 7: The Stormfilter

4.3 Pumps

The usage of three pumps to convey water is suggested. The pumps will convey water from the existing UBC drainage system to the primary tank (1st pump), from the secondary tank to the UBC drainage system (2nd pump), and from the cistern to the stadium building (3rd pump). The pumps used in all three locations are supplied by Grundfus Sp 35S (35 gpm 0.75 hp), the pump curves, friction losses and system curves can be found in Appendix D. A disadvantage is that there is a speed reduction by up to 42% for 1st pump, and up to 55% for the 2nd pump. Figure 8 shows the location of each pump.

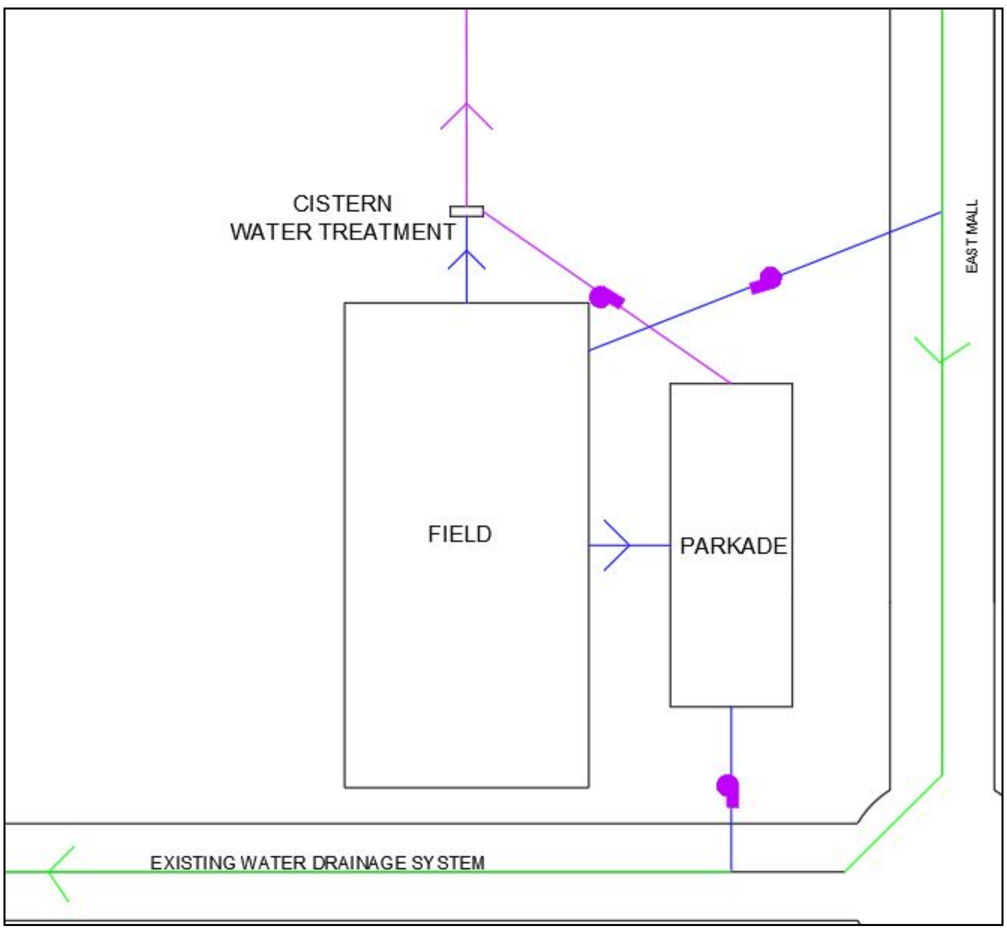


Figure 8: Pump Locations

4.4 The Piping System

The table below summarizes the main characteristics and flows for each pipe within the system in scenario B. A negative slope indicates a presence of a pump. Given that the pipes going to the botanical garden must follow the road, there are four pipes of similar diameter that will convey the water. The flow capacity for each pipe is estimated using Manning's equation and the sample calculations are detailed in Appendix C.

Table 6: Piping System Summary

	Pipe Slope	**Pipe Dia.**	**Length**	**V Capacity**	**Q Capacity**	**Q Demand**	**Pump Speed Reduction**
From-To	%	(mm)	(m)	(m/hr)	(m^3/hr)	(m^3/hr)	%
Storm Sewer-Primary	-2.14%	350	116.7	184484.2	4930.4	4930.4	42%
Primary-Cistern	0.87%	250	28.8	14627.7	199.5	181.4	
Cistern-Garden							
1	0.77%	200	172.1	11857.8	103.5	34.2	
2	2.23%	200	38.3	20218.8	176.4	34.2	
3	0.39%	200	238.7	8495.2	74.1	34.2	
4	2.02%	200	82.0	19238.7	167.9	34.2	
Cistern-Stadium	-1.65%	250	92.2	9969.9	135.9	135.9	100%
Primary-Secondary	6.24%	200	100.2	2872393.7	25066.4	5110.0	
Secondary-Storm Sewer	-10.7%	250	51.4	316822.7	4320.0	4320.0	55%

5.0 Infiltration Analysis

5.1 Groundwater Recharge

One option for the stored water is to recharge the existing aquifer underneath UBC. The water table is located approximately 55 m below the designed stormtank. According to the hydrogeological study conducted by UBC properties trust, much of the campus is underlain by a glacial till overlying a glaciofluvial sand unit known as the quadra sand. The soil beneath the site is composed of Quadra Sand, Capilano Sediments, and Glaciofluvial Till, they are located at 0-65m, 65-75 m and 75-80 m below ground respectively. A summary profile is shown in figure 9 below.

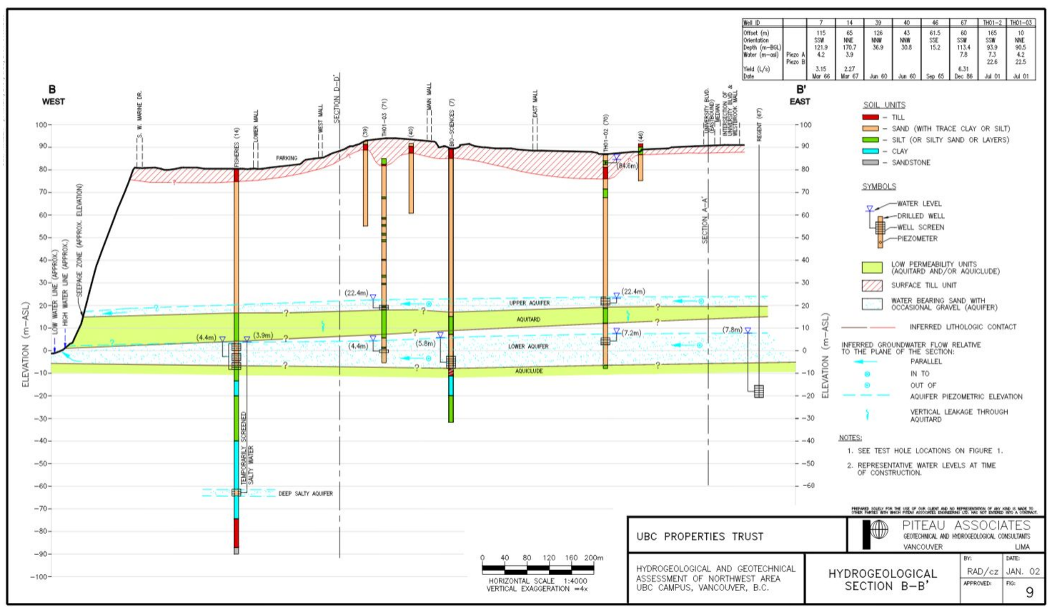


Figure 9: UBC geological profile (Piteau Associates, 2002).

The results of the UBC properties trust study does not give a full image of the complete geological profile underneath the proposed site. Thus, three scenarios were developed to fully understand the profile, these are shown in figure 10 below.

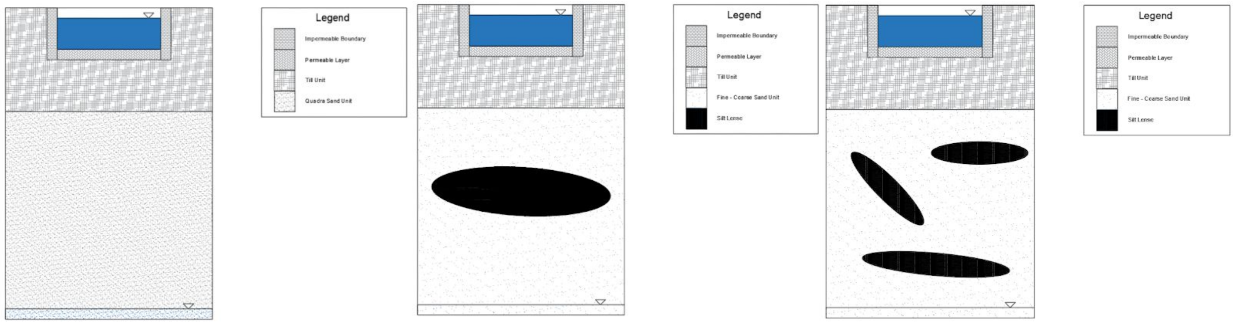


Figure 10: Scenarios 1, 2 & 3 respectively

Depending on the height of water in the tank, the average recharge rate for each scenario was approximated and is summarized below:

Table 7: Scenarios Characteristics

Scenario	Soil	Recharge Rate
Scenario 1	Full quadra sand unit includes fine and coarse sand and silt	3.5 m^3/day
Scenario 2	Full sand with a single slit lense	3.2 m^3/day
Scenario 3	Full sand unit with several silt lenses	2.5 m^3/day

Based on the scenarios shown, it is recommended to conduct further hydrogeological studies with borehole tests on site as the UBC Properties Trust study focused mainly on the northwest area of UBC. Since we are considering the recharge option, it would be helpful to conduct laboratory analysis on the soils obtained from the borehole test to develop soil moisture characteristics curves, which will improve our estimation of the recharge rate through the vadose zone.

5.2 Quadra Sand Contamination

The proposed increase in infiltration rate has the potential to remobilize current contaminates, mainly Magnesium (Mg), found in the quadra sand layer. Effects of such metals can cause an increase of water hardness which appears to be negatively influencing the environment and human health. This impact is beyond the scope of this work but it is recommended to investigate the magnitude and mitigation of the hazard if required. This could be achieved by using modeling software such as MODFLOW™.

6.0 Structural Analysis of Parkade

Hand calculations, S-Frame, S-Steel, and S-Concrete were used to analyze the demands, and capacities of the structure. The structure consists of composite steel W-section beams of various sizes with various concrete slab thicknesses , and W-section steel columns (Appendix B and G). All steel sections are 350W, the strength and density of all the concrete is fc' = 30 MPa and ɣ=2400 kg/cm, and the MSA is 20mm. Furthermore, all steel rebar is 400W steel and various sizes of steel reinforcement are used. The walls are designed as basement walls 500mm thick sitting strip foundation that is 4.5m wide. Furthermore, the W-section columns sit on top of 4500x4500x1200mm square spread foundation with a 600x1200x25 mm steel bearing plate of 400W strength steel shown in (Appendix G.) Drawings of the parkade can be seen in Appendix B.

6.1 Loadings

The loadings consist of dead, live, snow, and soil loads. The live load consists the thunderbird stadium on top of the parkade (4.8kPa,) vehicles loads (2.4kPa,) and exit loads (4.8kPa.) The dead load consists of a the weight of the beams and columns, which S-Frame includes in the analysis, the weight of the reinforced concrete slabs, and the weight of the thunderbird stadium conservatively estimated to be 20 kPa applied to the "roof" of the structure. The soil pressure varied from with depth (H) based on the following equation that was obtained by a previous geotechnical report of the site:

$$\sigma = 25H\ (psf)$$ (minimum 400 psf for Safety)

Furthermore, the allowing soil bearing stress for foundation design was determined to be 12000 psf based on the same geotechnical report of the site.

Lastly, the snow load on top of the thunderbird stadium will be applied to the top of the structure, and has a value of 2.12kPa based on the following equation (NBCC 4.1.6.2:)

$$S = Is*(Cb*Cw*Cs*Ca*Ss + Sr) = 1*(0.8*1*1*1*2.4+0.2) = 2.12 \text{ kPa}$$

6.2 Structural Demands

S-Frame was used to calculate the demands of the steel frame structure. The structural demands of each member is shown in Appendix G graphically. Load combinations from NBCC were all used, and the graphical moments, shears and axial forces for each member and the governing load combination (1.25D + 1.5L + 1.5Soil +1.0Snow companion load) are graphically shown with legends for max and min values in Appendix G.

6.3 Structural Capacities of Steel Frame Members Based on S16-14

S-Steel was used to code check each member of the steel frame structure for each load combination. Appendix G shows a graphical image of the structure and the values of the ratio of demand to capacity for each member. Ratios less than 1 have enough capacity to meet the demands. Furthermore, sample calculations generated in S-Steel for a column and beam member are shown for reference. The beams consisted of W-Steel composite concrete sections and are shown in Appendix G. There is no deck, and pins should be placed 200mm apart on center. The columns are all W1000x976 sections. 350W grade steel is used for all the steel.

6.4 Foundation Design

Foundation design calculations were done by hand and are shown in Appendix X. The walls are supported by 4500x1200mm strip foundations and each column is supported by 4500x4500x1200mm spread foundations. The drawings of the spread foundation and the strip foundation and basement wall can be seen in Appendix B. The analysis of the spread foundation was done by hand, and used the maximum axial load of all of the columns. For the spread foundation the allowable soil bearing stress used was 12000psf from previous geotechnical studies. 30 MPa concrete was used with MSA of 20mm for both foundations. Reference calculations can be seen in Appendix G. The steel rebar used in the strip foundation consists of 400W 15M steel

6.5 Concrete Wall design

Hand calculations were done to analyze the Concrete basement walls, and are shown in appendix G as reference. The basement walls consisted of 500mm thick concrete of 30 MPa strength and a MSA of 20mm. We assumed that the steel frame and concrete slabs carried all the gravity load, and designed the outer concrete walls to carry the soil pressures only that varied with depth H ($\sigma = 25H\ (psf)$ (minimum 400 psf for Safety).) The concrete walls have 15M grade steel rebar that are spaced 200mm vertically and 260mm horizontally. A section of the walls can be seen in Appendix B. The inner walls should be designed the same since minimum steel reinforcement governed the design.

6.6 Two Way Slab and Slab on Grade Design

Hand calculations were done for the slab design. For simplicity in manufacturing and construction, only one slab thickness was used for all the slabs, 600mm. The slabs were designed to be made from 30 MPa concrete with a MSA of 20mm. The slabs consist of 45M rebar spaced 60mm apart for negative moments (tension on top), and 35M rebar spaced 55mm apart for positive moments (tension on bottom). The rebars are all 400W grade steel. Both rebars are spaced transversely and longitudinally in the slab (in both NS and EW directions). A typical slab section can be seen in Appendix B, and sample calculations for reference are in Appendix G.

7.0 Construction Management

7.1 Site Plan and Constraints

The construction site is located near East mall and West 16th Avenue as shown in figure 11 below. The arrows show vehicular access to the site during construction. Due to the low volume of traffic on stadium road, limited traffic disruption is expected. However, pipes are to be laid across SW Marine Drive to connect the storage facility to the UBC Botanical garden for irrigation purposes. This will necessitate closing of SW Marine Drive to allow construction work to proceed. This will be precisely scheduled to minimize interruption to traffic and at no point in time will the entire road be closed to traffic.

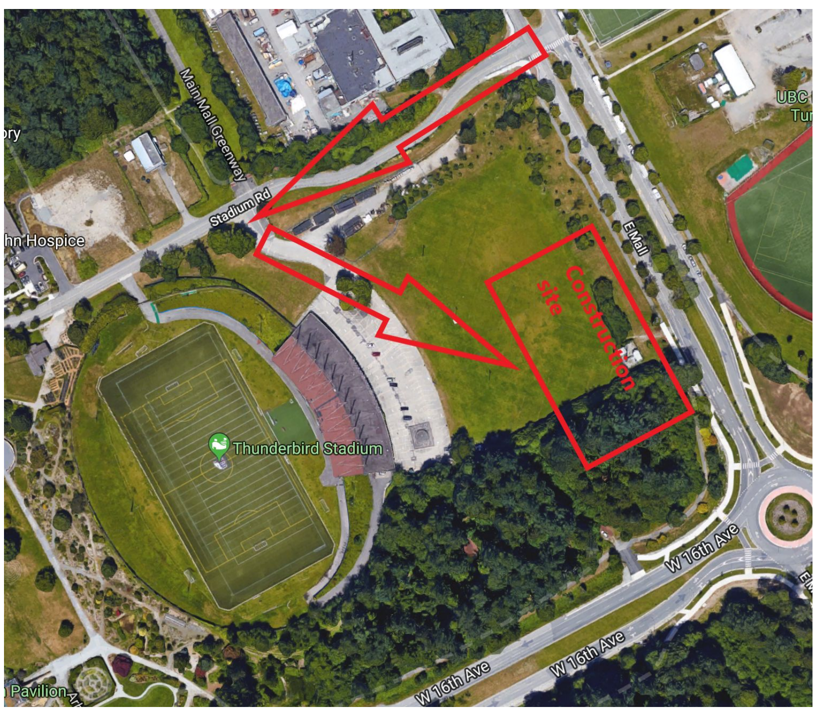


Figure 11: Site plan

The location of the construction site, keeping in mind UBC's plan for the Stadium neighbourhood, requires cutting down of several trees. Therefore, efforts will be made to conserve the trees to the South of the construction site. The site is also located near a residential area and therefore the Noise Control Bylaws set by the University Neighbourhoods Association (University Neighbourhoods Association, 2012) must be followed. Work hours are to be between 7:30 am and 7:00 pm on weekdays and 9:00 am to 5:00 pm on weekends.

7.2 Construction Schedule

Construction is expected to start in May 2019 and last for six months. Construction will commence after project funding has been approved and the contracts have been drawn and signed. Construction documents should be reviewed and finalized and necessary permits, including building permit, excavation and grading permit, should be obtained. The area will be surveyed and the site mobilized in May. This will be followed by construction of the parkade. Installation of the primary detention tank will begin shortly after, and thereafter the drainage system and water treatment facility will be installed. Construction is expected to end in October 2019.

The gantt chart below shows a summary of the construction schedule. A detailed construction schedule, made using Project 2016, is shown in Appendix E.

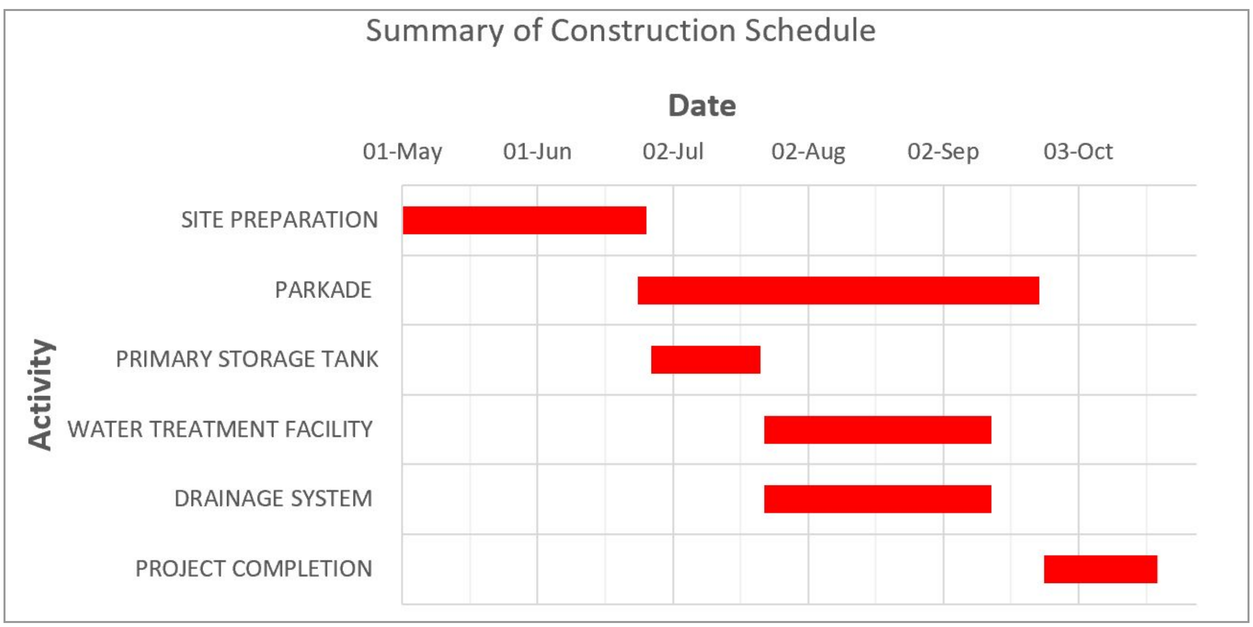


Figure 12: Summary of the Construction schedule

8.0 Cost Analysis

8.1 Construction Costs

The cost calculations were made using the data provided by RSMEANS Square Foot Costs, 2012 and Building Construction Cost Data, 2006 as well as online resources and requests to manufacturers for specific equipment or site work costs approximations. The cost model for a typical underground two-storey parkade was reworked and accompanied by external resources to suit the needs of the project. The table containing the breakdown of costs for construction of the parkade and field detention tank is attached with the Appendix. The cost of the parkade and parts of the detention system were calculated based on the adjusted model for a two-storey underground parkade for 2012 in US Dollars and then converted into Canadian Dollars for the first quarter of 2019 for Vancouver. Architectural fees (7%), contractor fees (25%) such as overhead and profit, insurance of the project (3%), testing (2%) and contingency (10%) were added to the total costs for both parts of the project. The sub-total for the project excluding the above mentioned fees is $10,726,000. The total for the whole project has changed compared to the preliminary design from $14,090,000 to $15,713,000 due to the addition of a water treatment facility, pumps and a more accurate tank installment cost estimate received from the supplier.

8.2 Underground parkade

The parkade calculation includes all divisions of construction such as substructure (excavation and foundation), shell (floors and walls), interiors (partitions, stairs and finishes), services (elevators and plumbing), heat and ventilation (fire protection and electrical work), equipment (ticket dispensers and alarm system). The structure as a whole consists of a concrete foundation, walls and slabs, roof made as other floor slabs to accommodate for future stadium construction and avoid rebuilding. The parkade has two staircases with two adjacent elevators at the opposite sides of its rectangular area. Each floor has water drainage that is connected with the main detention system and the public sewers. The cost of piping and pumps for all connections is contained within this cost estimate.

8.3 Field detention system

The field system requires a more careful approach due to its uniqueness and specialness. Its construction process includes excavation, leveling, stone backfill and installation of tanks covered with geotextile fabric. The cost for such a storage was requested from Layfield Group and is \$450 for 1 m^3 of storage with its installation. The additional equipment the system will require consists of three pumps, one for each tank and treatment facility, water treatment system to be located above the ground by the field area as well as irrigation system across it. The pricing for these was determined based on Building Construction Cost Data, 2006 as well as online resources offered by individual manufacturers and compared to create a reasonable cost estimate for this project.

8.4 Rainwater treatment facility

According to the research on an average price of greywater reuse systems for commercial use, the cost varies between \$20,000 to \$500,000 including installation and \$40,000 to \$50,000 per year for its maintenance. Therefore, it is reasonable to allocate, according to one of the case studies on a governmental building (Administration Building in Belmont) construction of a similar size, \$150,000 for such a facility and \$40,000 per year for its maintenance. (EMRC, 2011)

8.5 Operation and maintenance

According to a parking consultant Gerard Giosa and an engineer, specializing in the rehabilitation of existing buildings, Michael Pond, an average maintenance of each parking space varies from $100 to $500 per year. (Pond, 2015 and Wenk) A conservative value that is chosen is therefore $500/space/year that leads to $125,000 per year for 250 parking spaces. The detention field system requires cleaning; pumps, pipes, water treatment and irrigation systems need regular check-ups and occasional hose and oil replacement. All these are usually combined into an initial cost percentage that varies between 1 to 13%. (USEPA, 1999) A value of 5% is chosen for this system's cost per year for the following 10 years and further maintenance of 7% for the rest of its life period that is chosen to be 100 years. The rainwater treatment facility has been recommended to allocate $40,000 per year for its maintenance. The total for both facilities comes to $354,300 a year.

9.0 Conclusion

A stormwater detention facility and underground parkade mix design was proposed to be constructed at the intersection of 16th Avenue and East Mall. The purpose is to reduce surface runoff resulting from a 10-year and 100-year storm events, that are expected to cause erosion of the adjacent cliffs and increase pressure on the current stormwater network. The design consists of a primary detention tank, secondary detention tank with a parkade, a water treatment facility along with additional features. The stored water is to be used for irrigation, household and recharge purposes. All design criteria were based on the UBC Stormwater Management Plan, City of Vancouver and Metro Vancouver bylaws. The construction period of the project is expected to run from May 2019 to October 2019, with an expected total cost of CAD$ 15.7 M.

Software such as SketchUp™ and AutoCAD™ were used to develop the detailed design drawings, whereas, data analysis were conducted through S-Frame™, S-Steel™ and S-Concrete™. Tabulated calculations were performed on Microsoft Excel.

10.0 References

Canadian Nursery Landscape Association. *Life Cycle Cost Analysis Of Natural On-site Stormwater Management Methods*.

Contech Engineered Solutions. *DuroMaxx Stromwater Detention Detention and Infiltration.* https://www.conteches.com/stormwater-management/detention-and-infiltration/duromaxx-detention-systems

Eastern Metropolitan Regional Council. *Reuse of Greywater for Local Governments in Western Australia.*July, 2011. Discussion Paper.

Grundfos Data Booklet. *Submersible Pumps, Motors, and Accessories.* https://ca.grundfos.com/products/product-list/in-line-pump.html

Piteau Associates, UBC Properties Trust: Hydrogeological and Geotechnical Assessment of Northwest Area UBC Campus, Vancouver. September 2002.

Pond, Michael. *A guide to condo parking garage maintenance. Corporations can maximize their return on investment by preserving waterproofing*. March 3, 2015. Condo Business, REMI Network. Retrieved from https://www.reminetwork.com/ on February 3, 2019.

RS Means Engineering. *Square Foot Costs.* (2012) Robert S Means Co. UBC Library resources.

RS Means Engineering. *Building Construction Cost Data.* (2006) 64th edition. Robert S Means Co. UBC Library resources.

United States Environmental Protection Agency. *Preliminary Data Summary of Urban Stormwater Best Management Practices* (August, 1999).

University Neighbourhoods Association. (August 2012). *Noise Control Bylaw ("Bylaw").* http://www.myuna.ca/wp-content/uploads/2010/04/UNA-Noise-Bylaw_Approved_Aug-2012.pdf

Wenk, Jocelyn. *Financing Parking Garages: Q&A with Parking Consultant Gerard Giosa*. Build a better burb.

11.0 Appendices

Appendix A - Expected Volume Calculation

$$Q = I\,C\,A$$

Q = Flow
I = Average rainfall intensity (mm/hr)
A = Drainage Area (km^2) – Catchment Area
C = Run off coefficient

Average Rainfall Intensity

UBC is within Zone 3 (Vancouver UBC) with annual precipitation 1277 mm

Based on observations the time of concentration:

- t_c = 6hr (For 100-year for major roads)
- t_c = 2hr (For 10 -year for minor roads)
  - 10 yr + 2 hr: i = 10.2 m/hr*
  - 100 yr + 6 hr: i = 9.9 m/hr*

*Reference table on the following page

Runoff Coefficient

Asphalt/concrete C = 0.85
10-year : C = 0.85
100 – year: C = 0.85 x C_f (Frequency Adjustment Factor) = 0.85 x 1.25 = 1.063

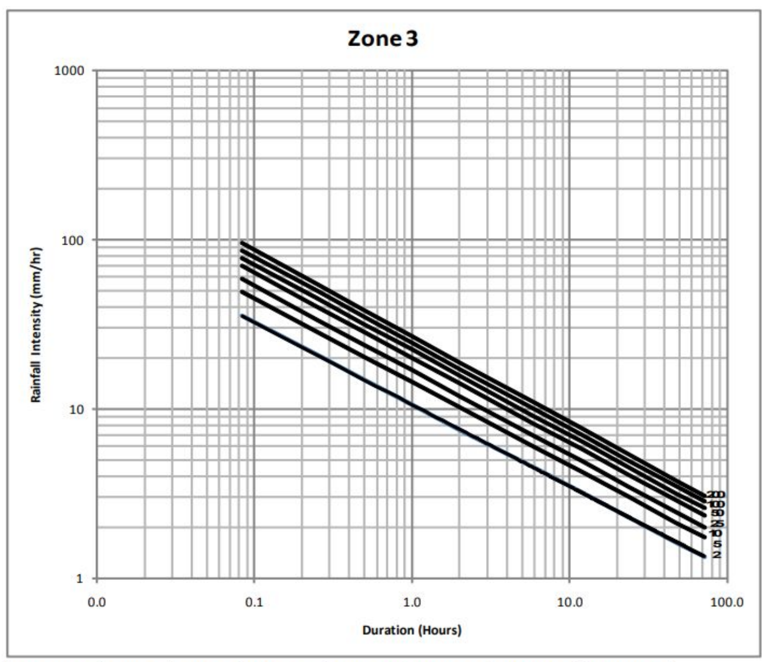
Drainage Area

A = 0.5 km^2 (16th Ave Catchment)

Q_{10yr} = (10.2 mm/hr) (10-3m/mm) (0.85) (0.5 km^3) (10-6 m^2/km^2) = 4335 m^3/hr

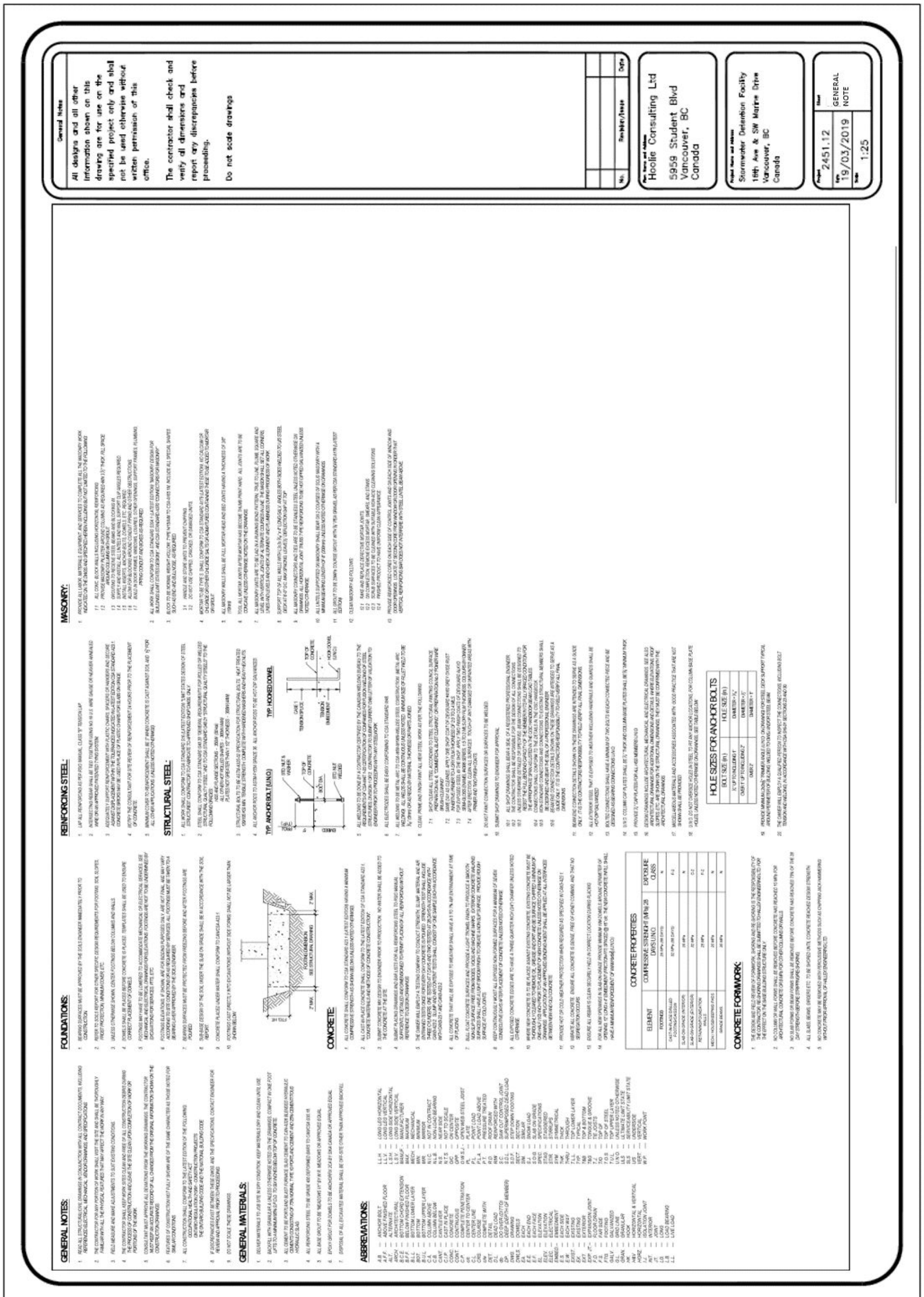
Q_{100yr} = (9.9 mm/hr) (10-3m/mm) (1.063) (0.5 km^2) (10-6 m^2/km^2) = 5260 m^3/hr

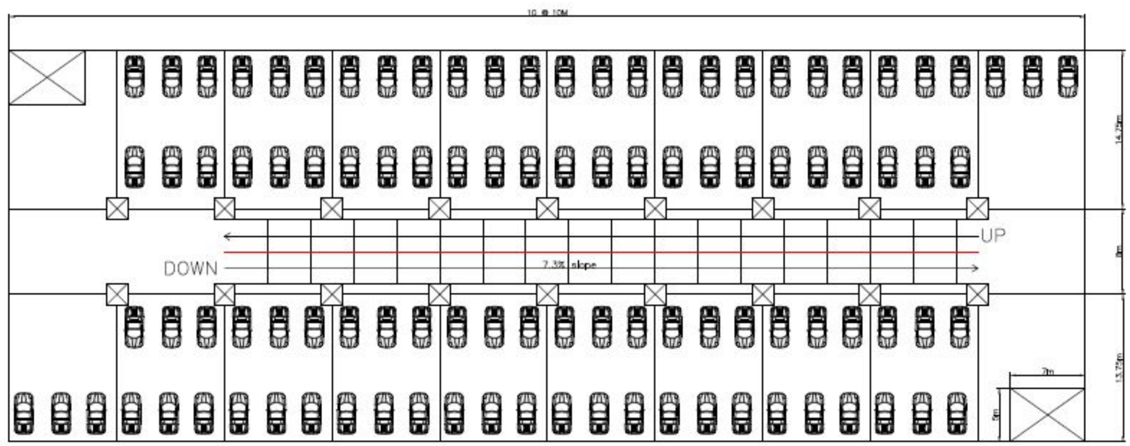
- For 1 hr storm events:
  - V_{10yr} = Q x t = (4335 m^3/hr) x 1 hr = 4335 m^3
  - V_{100yr} = Q x t = (5260 m^3/hr) x 1hr = 5260 m^3
- For 24 hr storm events:
  - V_{10yr} = Q x t = (4335 m^3/hr) x 24hr = 104040 m^3
  - V_{100yr} = Q x t = (5260 m^3/hr) x 24hr = 126240 m^3



Appendix B - Drawings

AutoCAD:





General Notes

All designs and all other information shown on this drawing are for use on the specified project only and shall not be used otherwise without written permission of this office.

The contractor shall check and verify all dimensions and report any discrepancies before proceeding.

Do not scale drawings

No.	Revision/Issue	Date

Hoolie Consulting Ltd

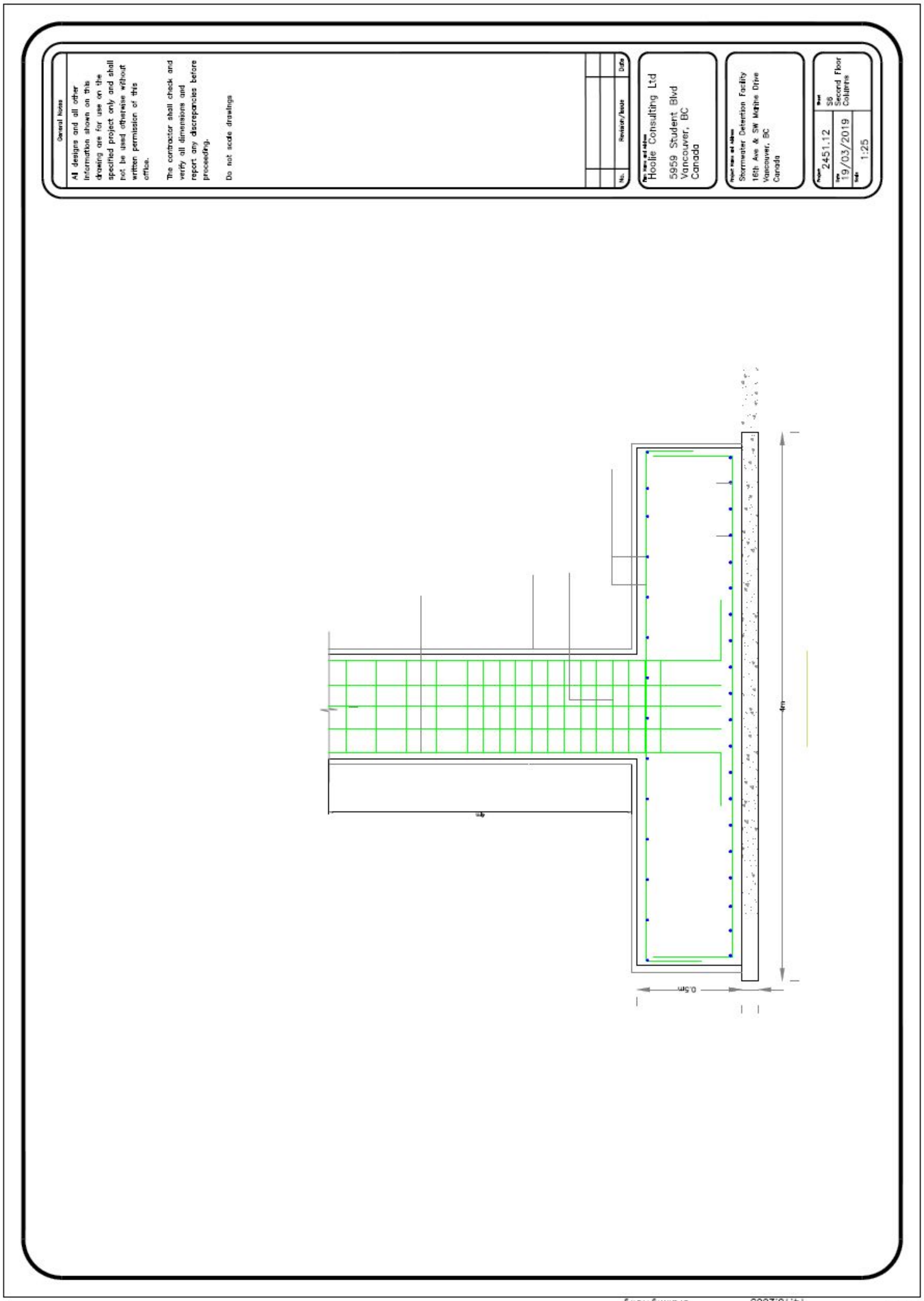
5959 Student Blvd
Vancouver, BC
Canada

Project Name and Address

Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada

Project 2451.12	Sheet S1 First Level Plan
Date 19/03/2019	
Scale 1:100	

Drawing1.dwg 14.10.2003


General Notes
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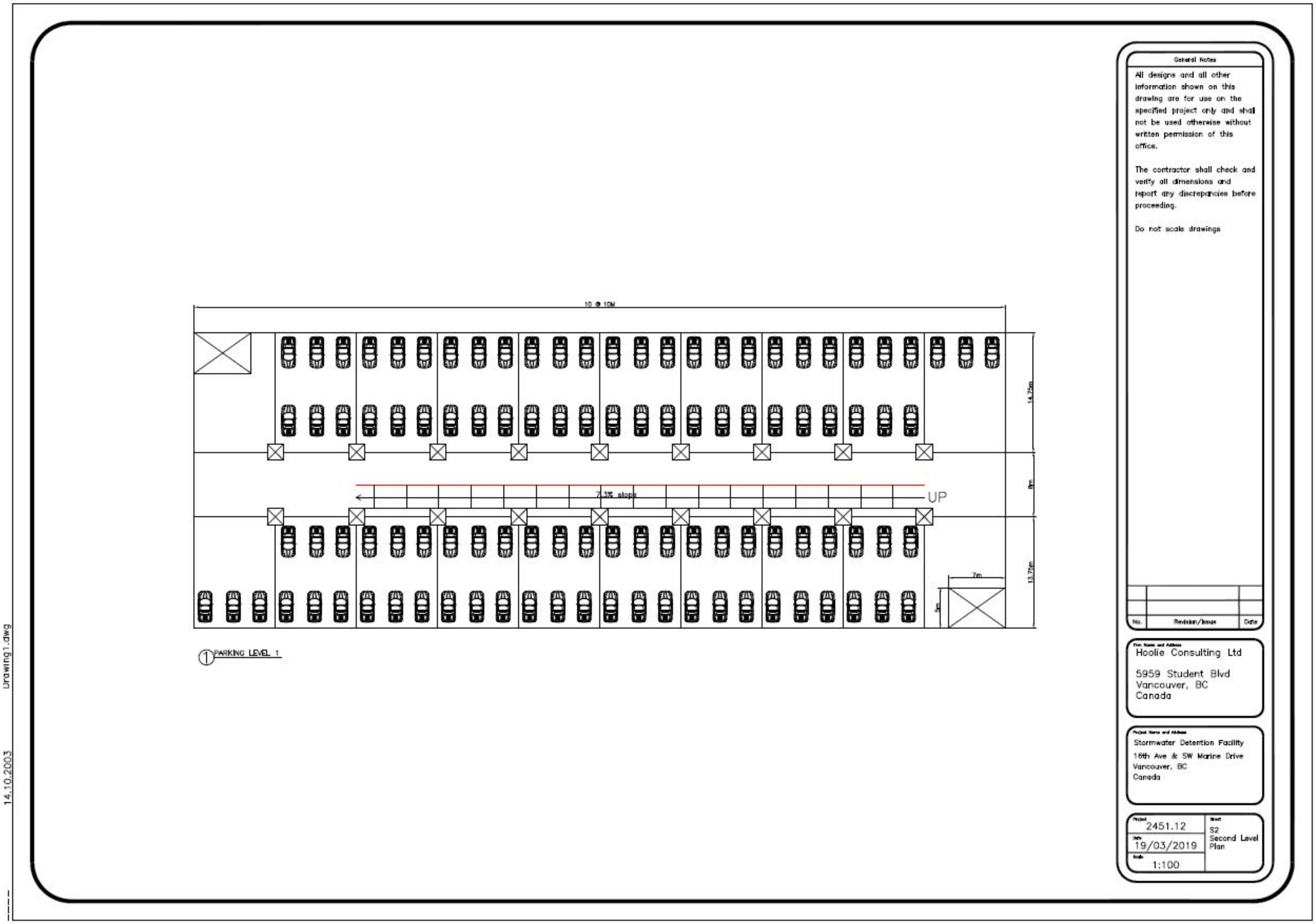
The contractor shall check and verify all dimensions and report any discrepancies before proceeding.
Do not scale drawings
No.
Revision/Issue
Date
Hoolie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
19/03/2019
1:25
S6
Second Floor
Columns
0.5m
4m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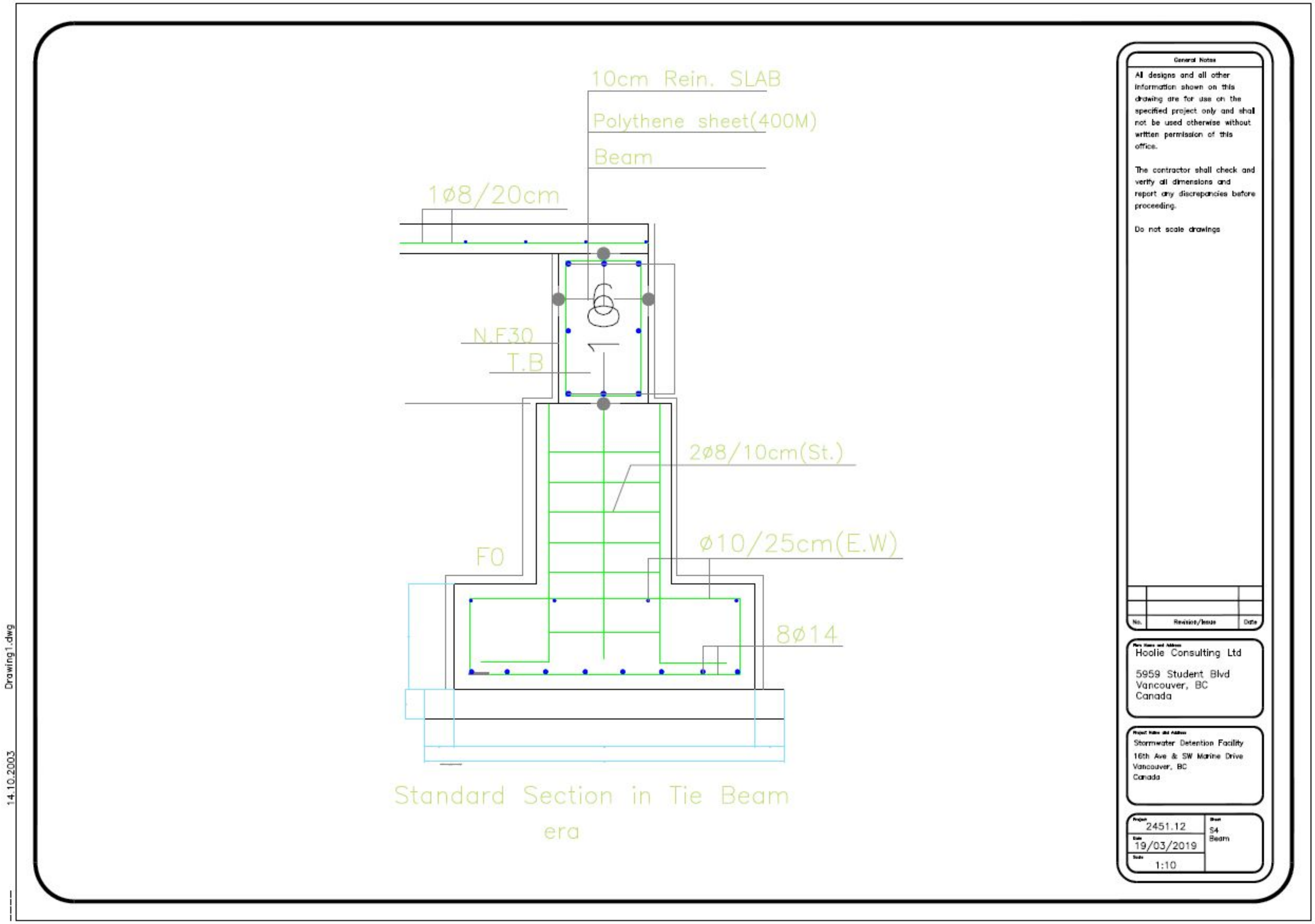
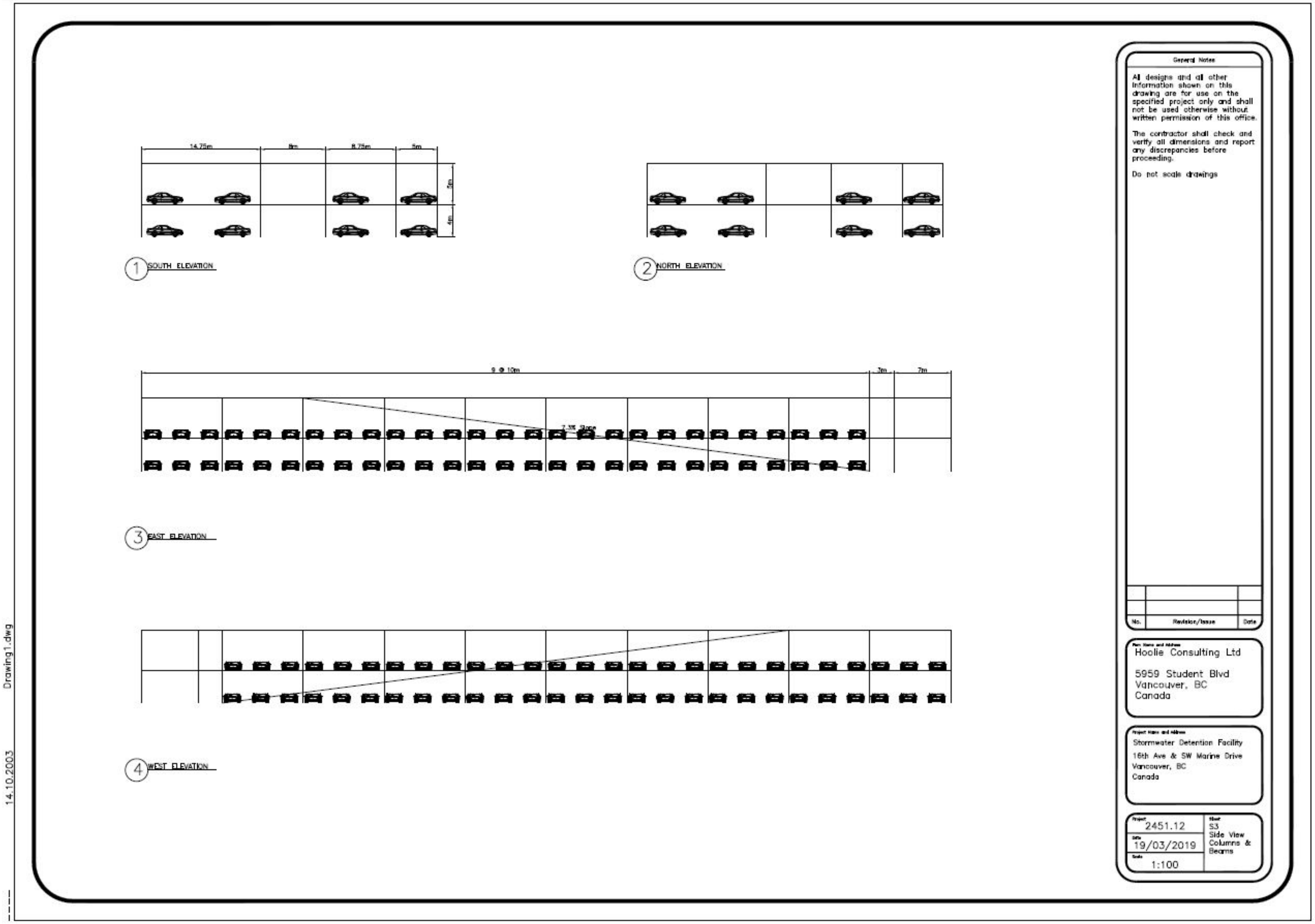
The contractor shall check and verify all dimensions and report any discrepancies before proceeding.
Do not scale drawings
No.
Revision/Issue
Date
Hoolie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
19/03/2019
1:100
S2
Second Level Plan
10 @ 10M
14.75m
8m
13.75m
7m
5m
7.3% slope
UP
1 PARKING LEVEL 1
14.10.2003
Drawing1.dwg



10cm Rein. SLAB
Polythene sheet(400M)
Beam
1ø8/20cm
N.F30
T.B
2ø8/10cm(St.)
ø10/25cm(E.W)
F0
8ø14
Standard Section in Tie Beam
era
General Notes
All designs and all other information shown on this drawing are for use on the specified project only and shall not be used otherwise without written permission of this office.
The contractor shall check and verify all dimensions and report any discrepancies before proceeding.
Do not scale drawings
No.
Revision/Issue
Date
Hoolie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
19/03/2019
1:10
S4
Beam
14.10.2003
Drawing1.dwg


14.75m
8m
8.75m
5m
5m
4m
1 SOUTH ELEVATION
2 NORTH ELEVATION
9 @ 10m
3m
7m
3 EAST ELEVATION
4 WEST ELEVATION
General Notes
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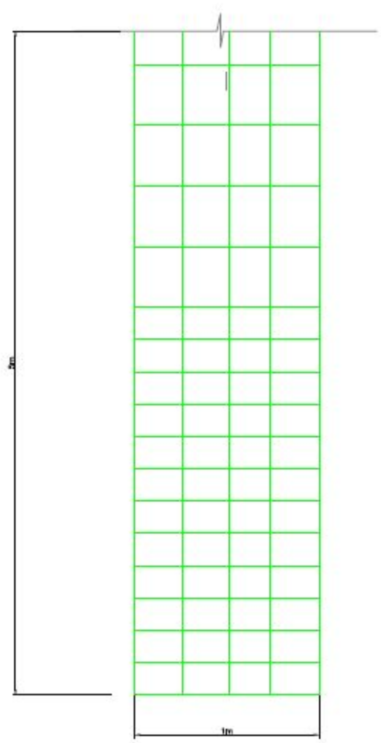
The contractor shall check and verify all dimensions and report any discrepancies before proceeding.
Do not scale drawings
No.
Revision/Issue
Date
Hoolie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
19/03/2019
1:100
S3
Side View
Columns &
Beams
Drawing1.dwg
14.10.2003



General Notes

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The contractor shall check and verify all dimensions and report any discrepancies before proceeding.

Do not scale drawings

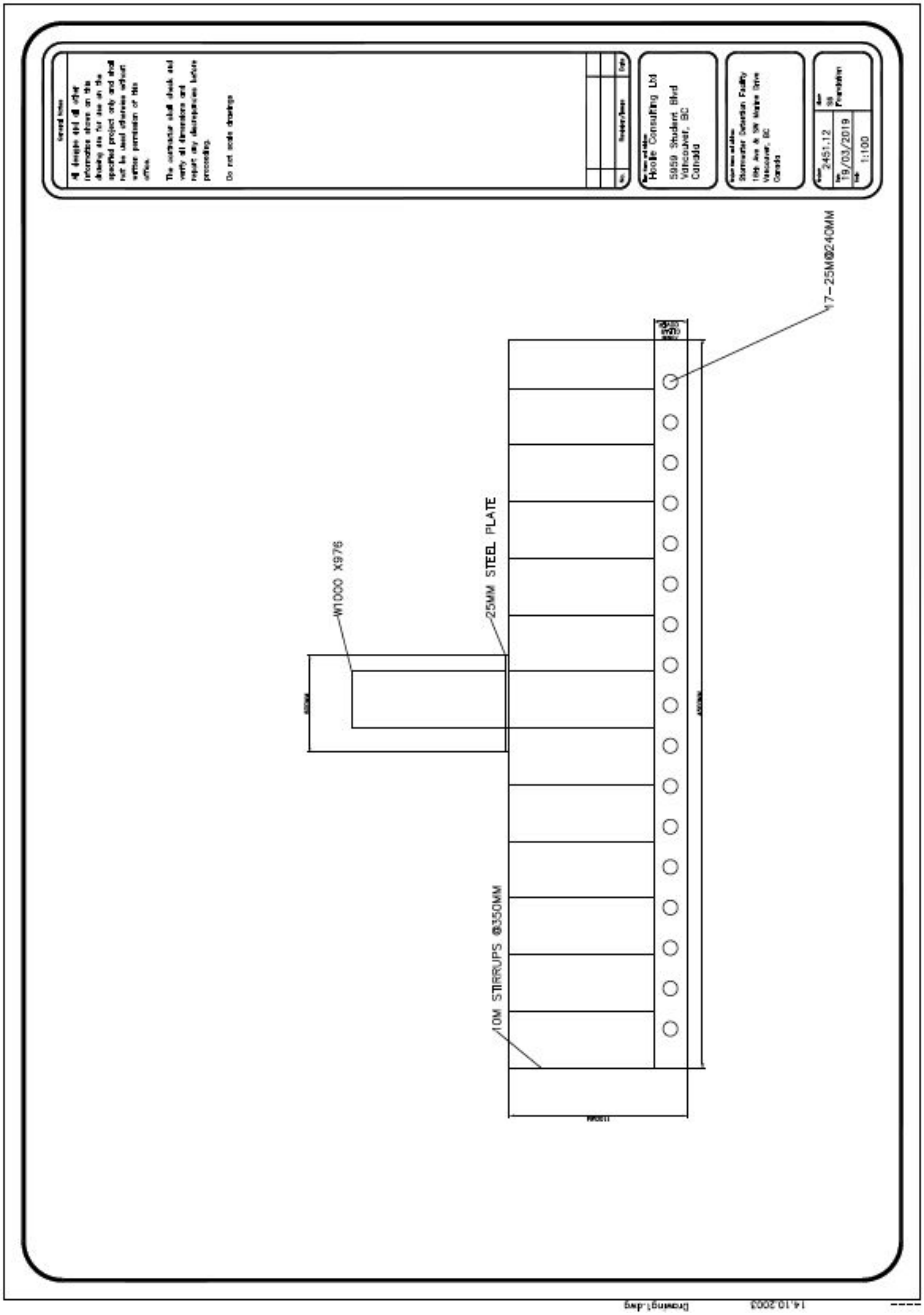
No.	Revision/Issue	Date

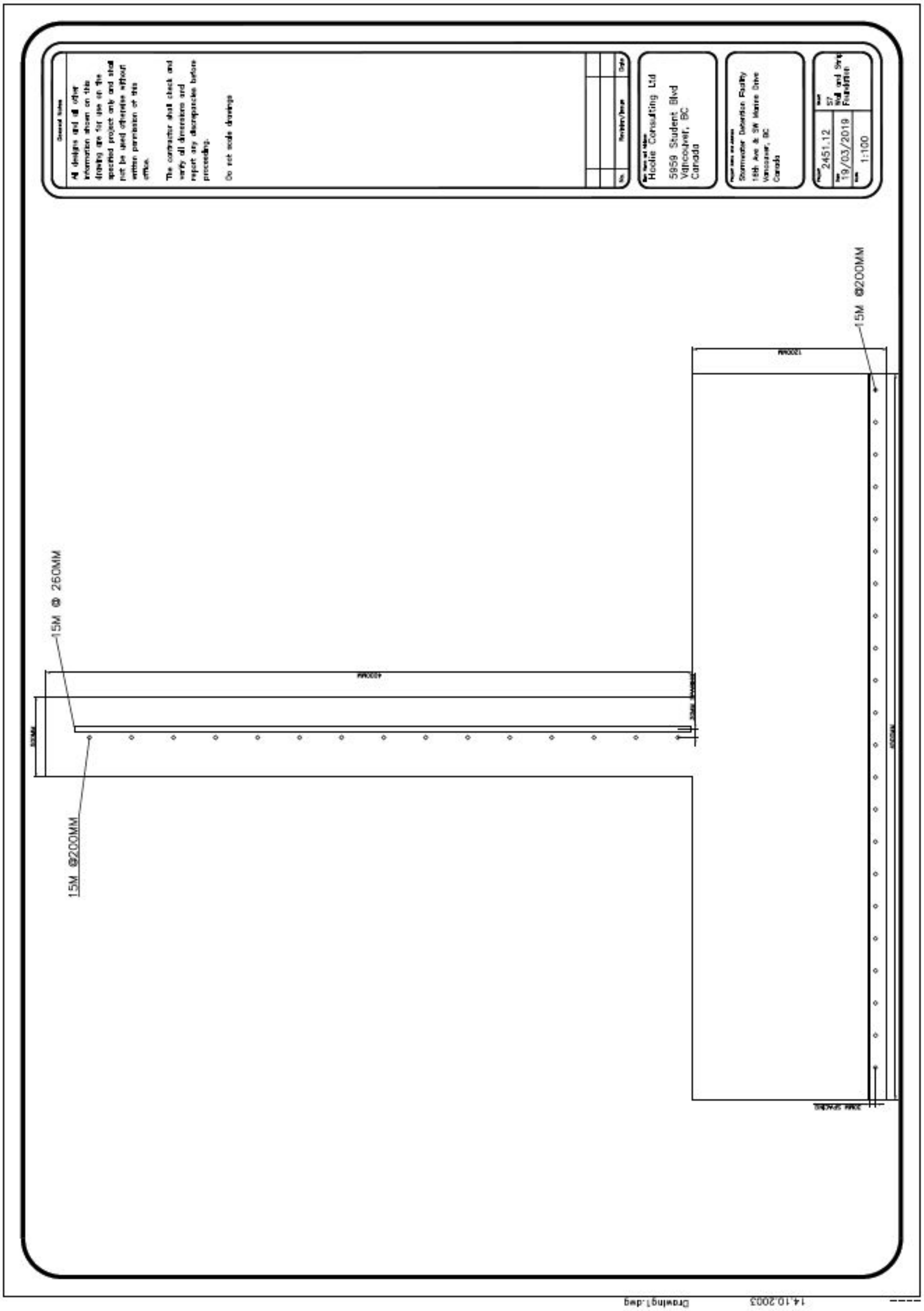
Firm Name and Address
Hoolie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada

Project Name and Address
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada

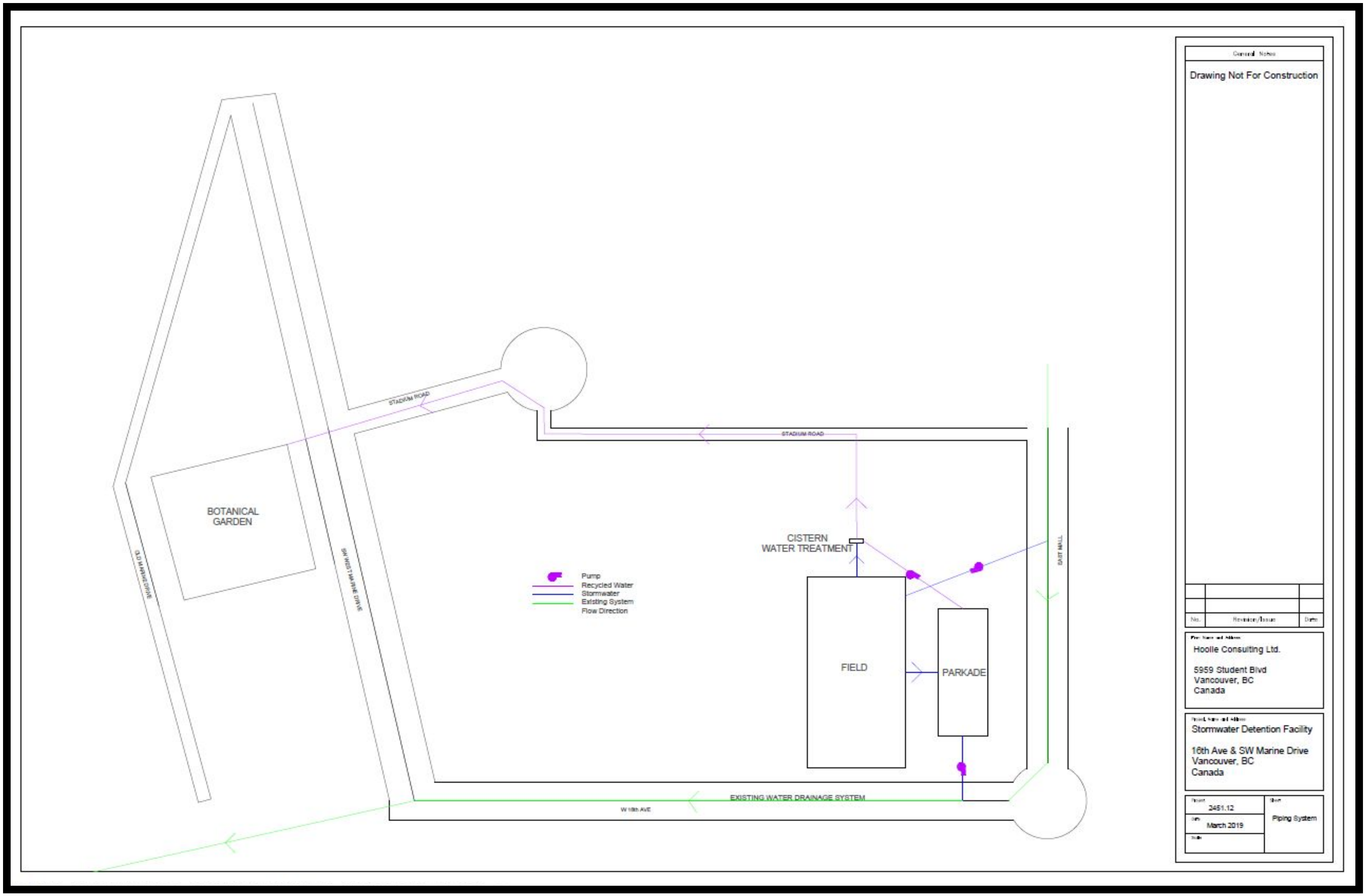
Project 2451.12	Sheet S5 First Floor Columns
Date 19/03/2019	
Scale 1:25	

Drawing1.dwg 14.10.2003


10M STIRRUPS @350MM
W1000 X976
25MM STEEL PLATE
17-25M@240MM
Hoole Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
2451.12
19/03/2019
1:100



All designs and all other information shown on this drawing are for use on the specified project only and shall not be used otherwise without written permission of this office.
The contractor shall check and verify all dimensions and report any discrepancies before proceeding.
Do not scale drawings
Hodie Consulting Ltd
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
19/03/2019
1:100
S7
Wall and Strip Foundation
15M @ 260MM
15M @200MM
15M @200MM
Drawing1.dwg
14.10.2003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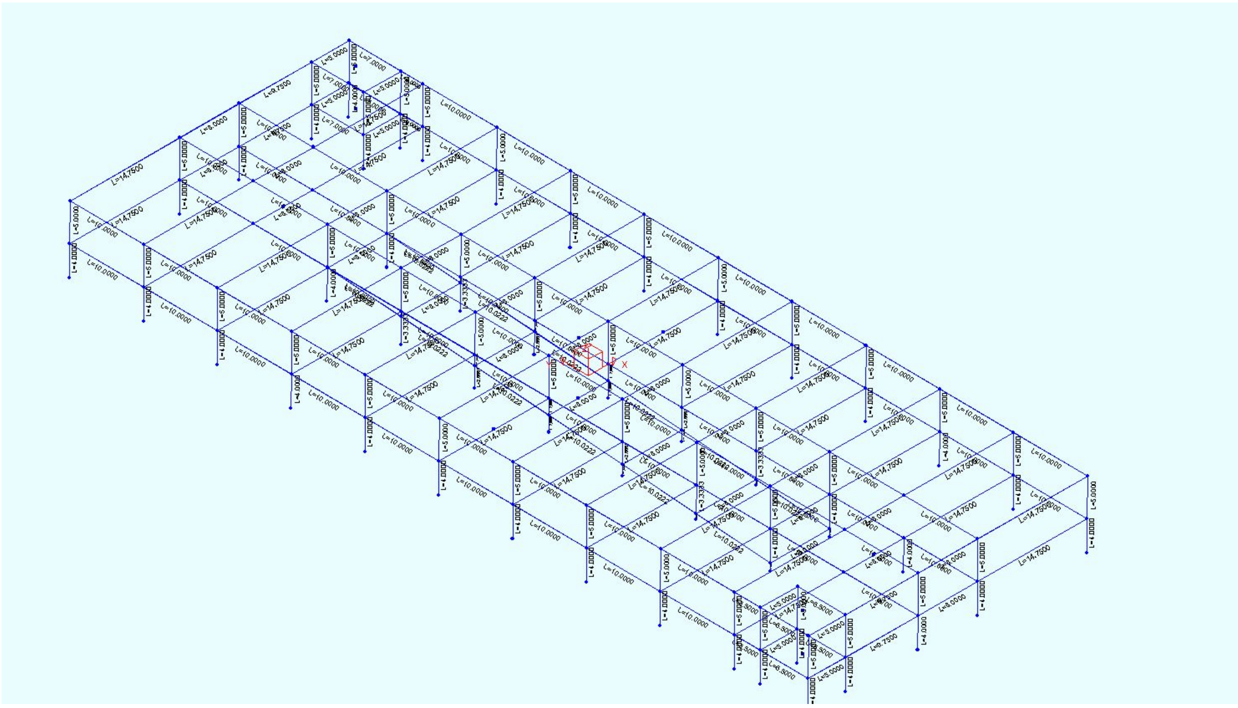
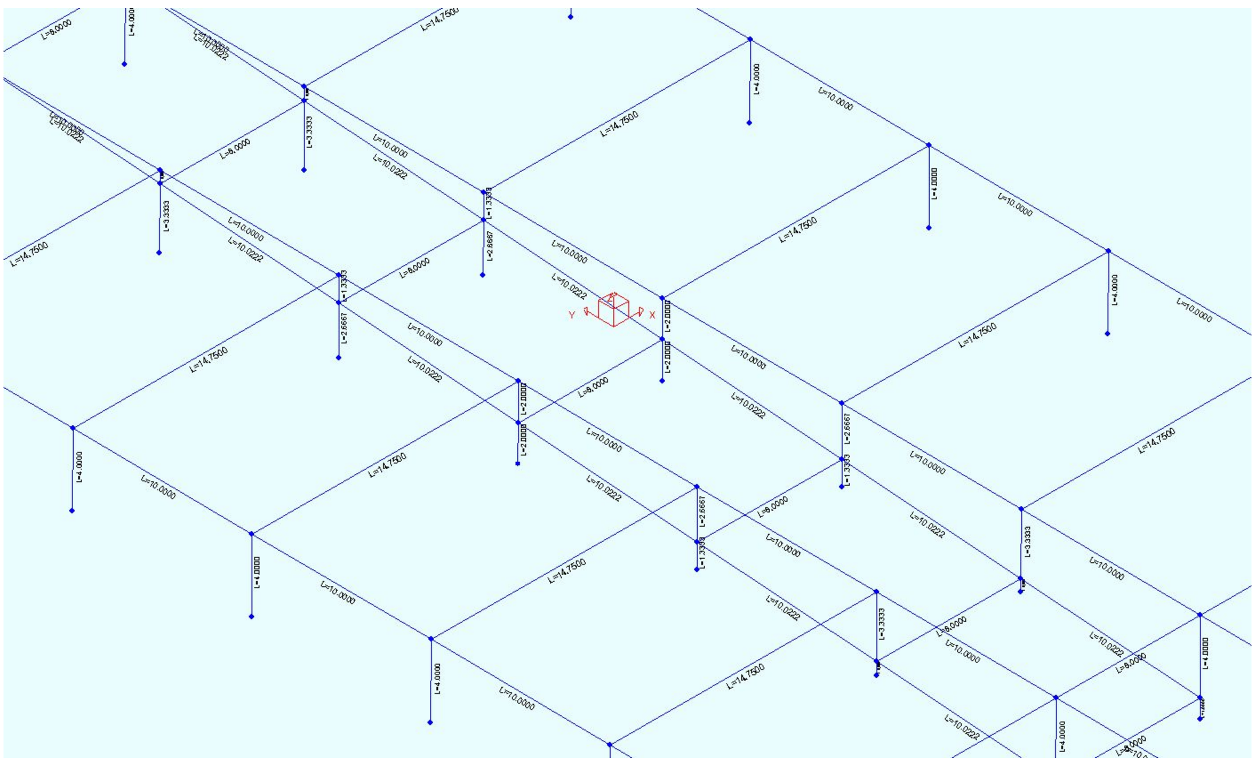
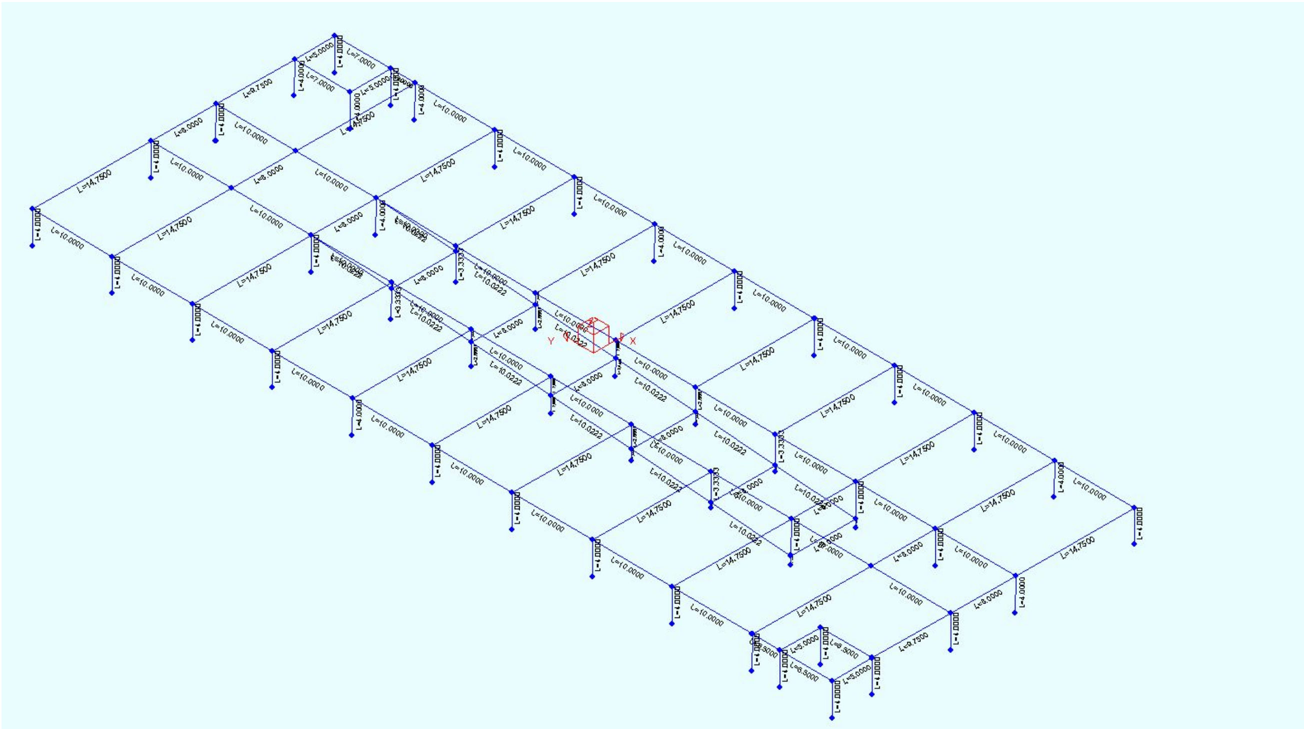
Drawing Not For Construction
No.
Revision/Issue
Date
Hoolie Consulting Ltd.
5959 Student Blvd
Vancouver, BC
Canada
Stormwater Detention Facility
16th Ave & SW Marine Drive
Vancouver, BC
Canada
2451.12
March 2019
Piping System
BOTANICAL GARDEN
OLD MARINE DRIVE
SW WEST MARINE DRIVE
STADIUM ROAD
STADIUM ROAD
CISTERN
WATER TREATMENT
FIELD
PARKADE
EAST MALL
EXISTING WATER DRAINAGE SYSTEM
W 16th AVE
Pump
Recycled Water
Stormwater
Existing System
Flow Direction

S-Frame:







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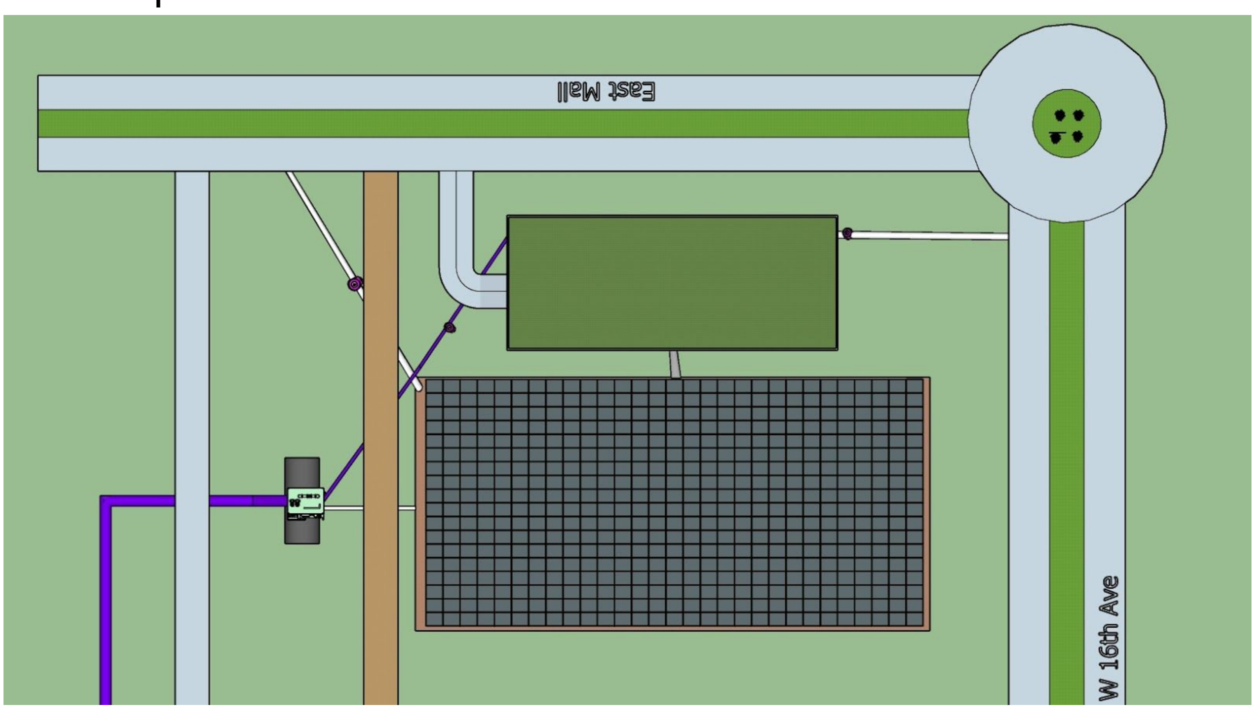
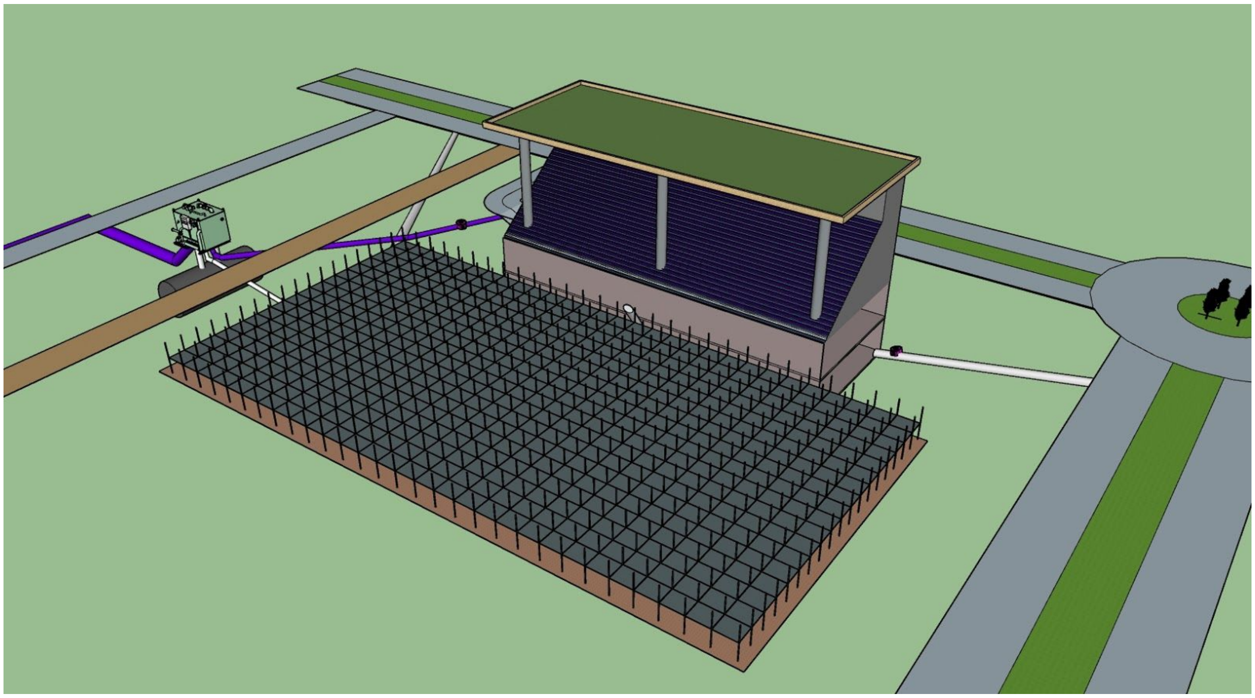
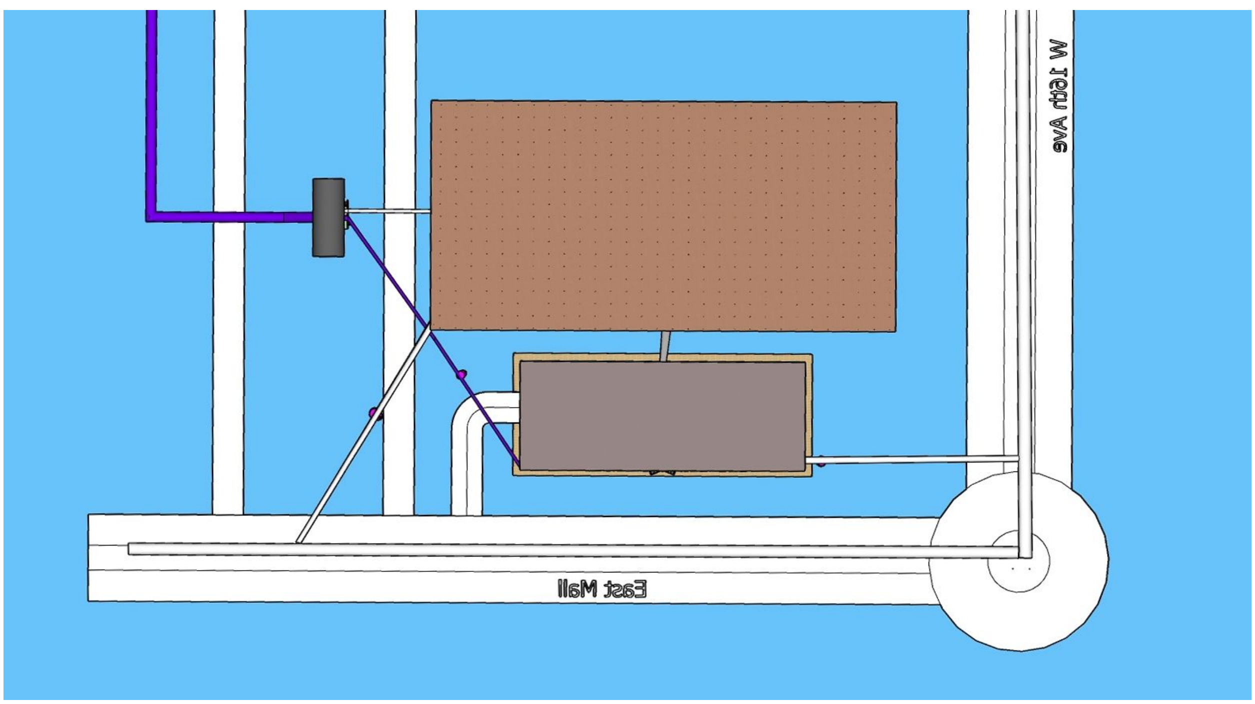
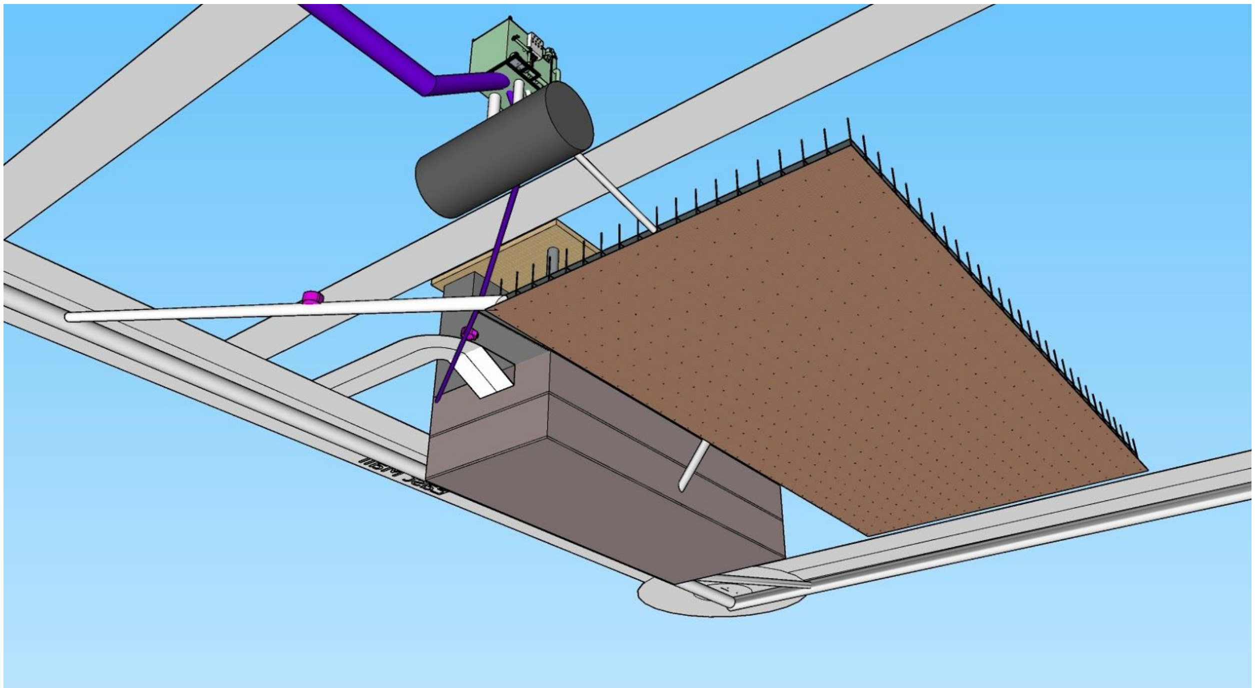
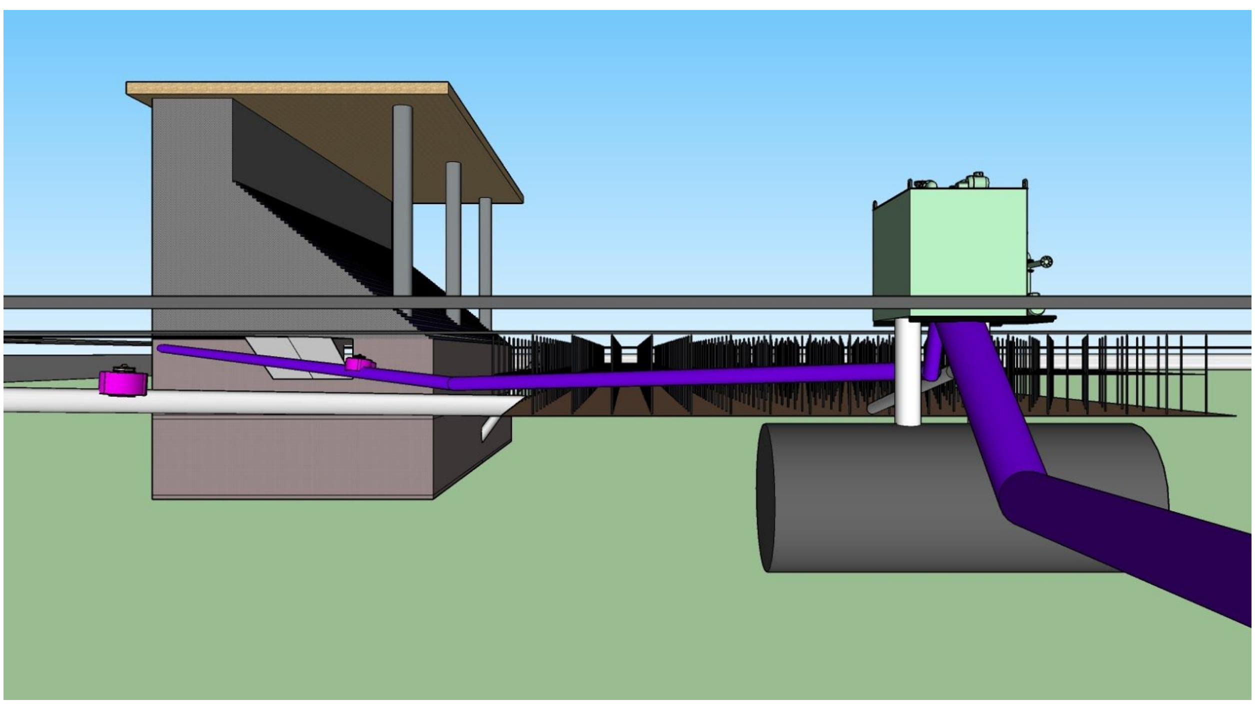


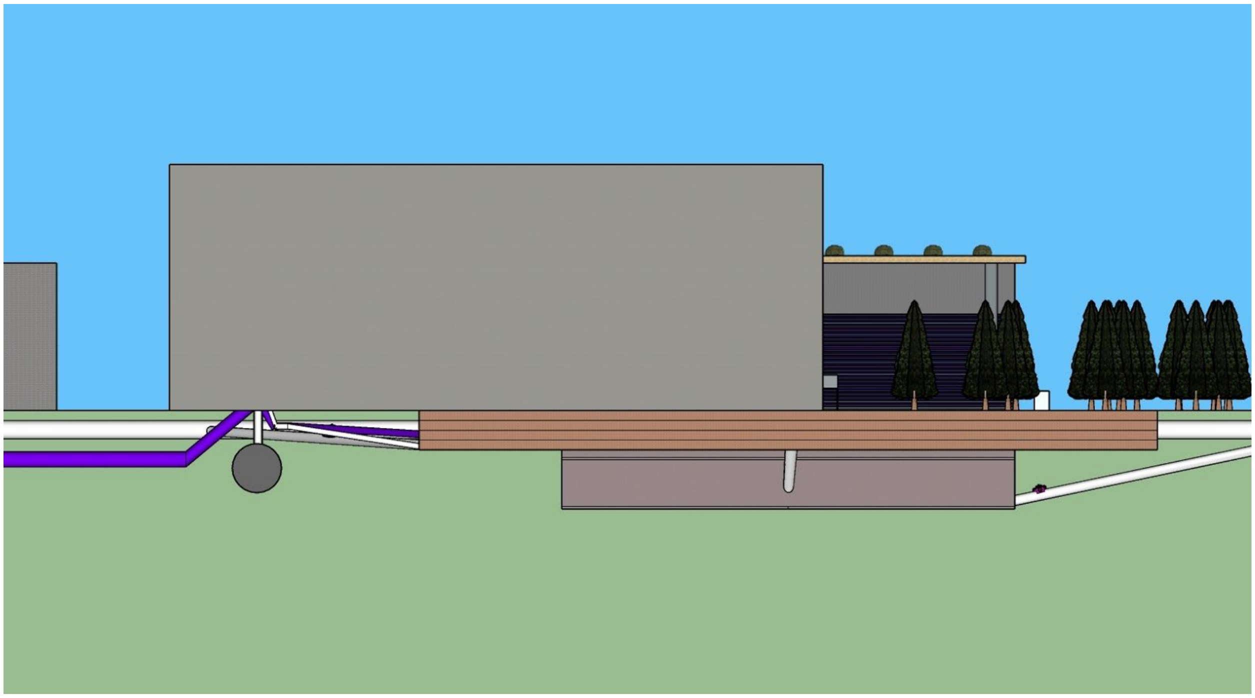


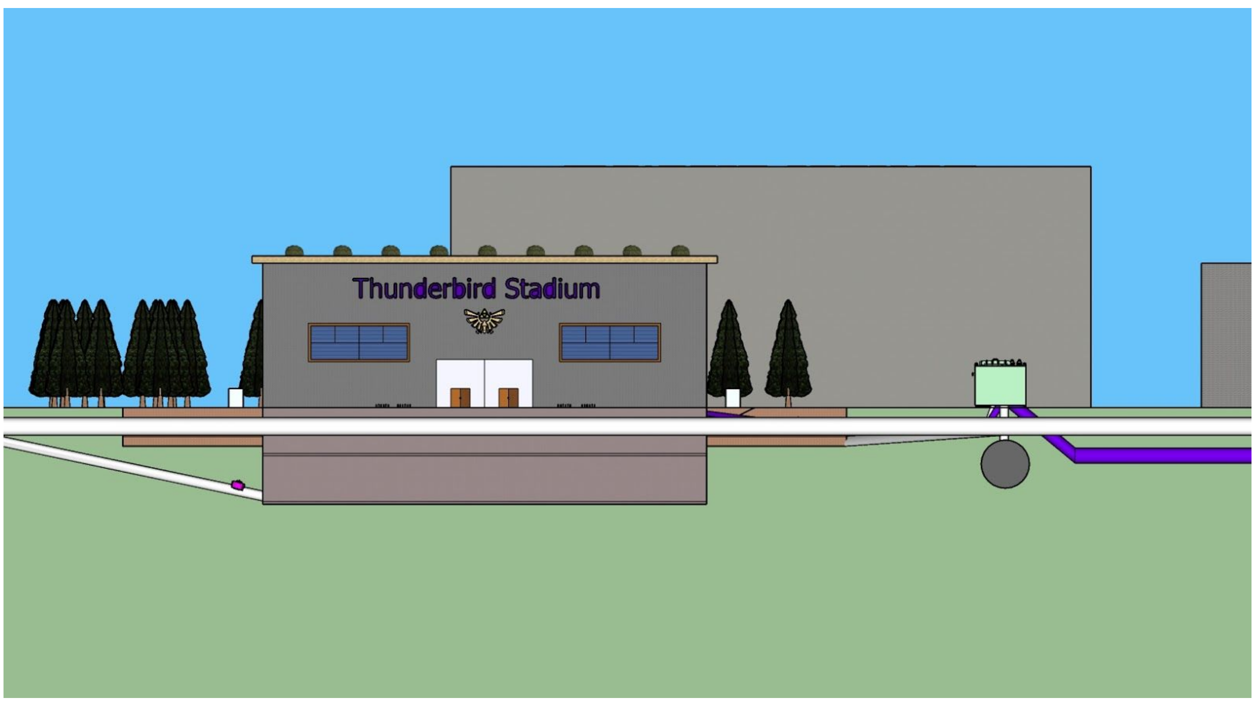

W 16th Ave
East Mall

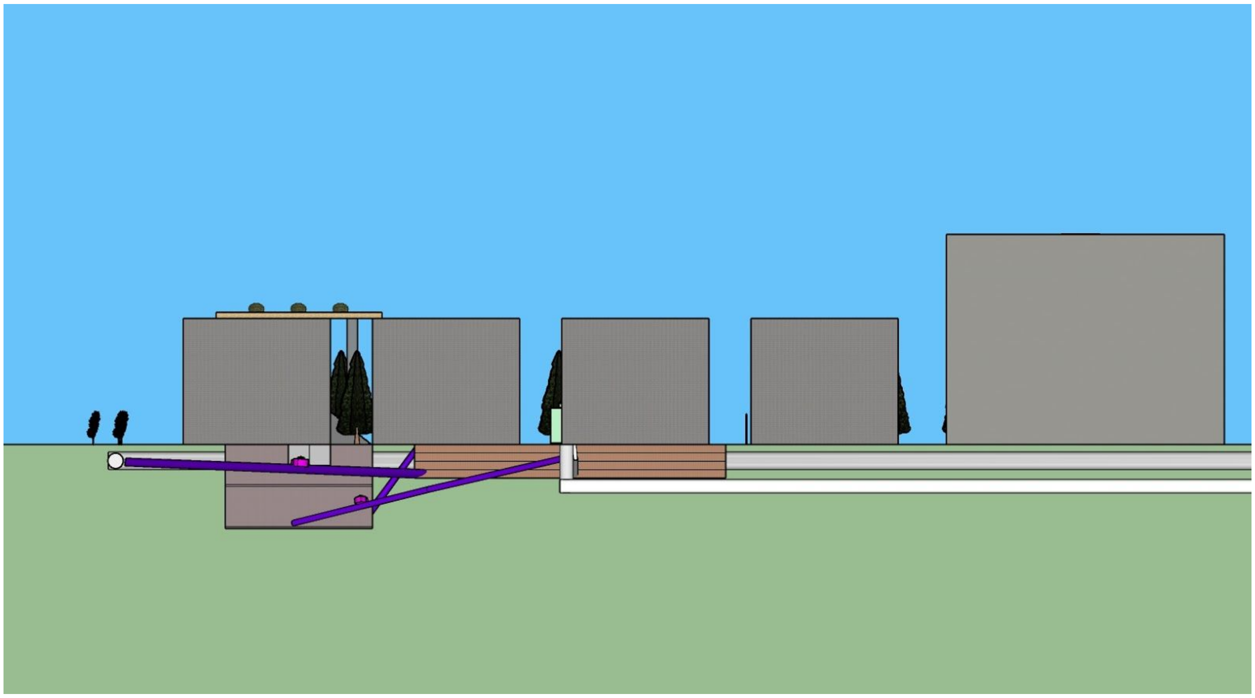


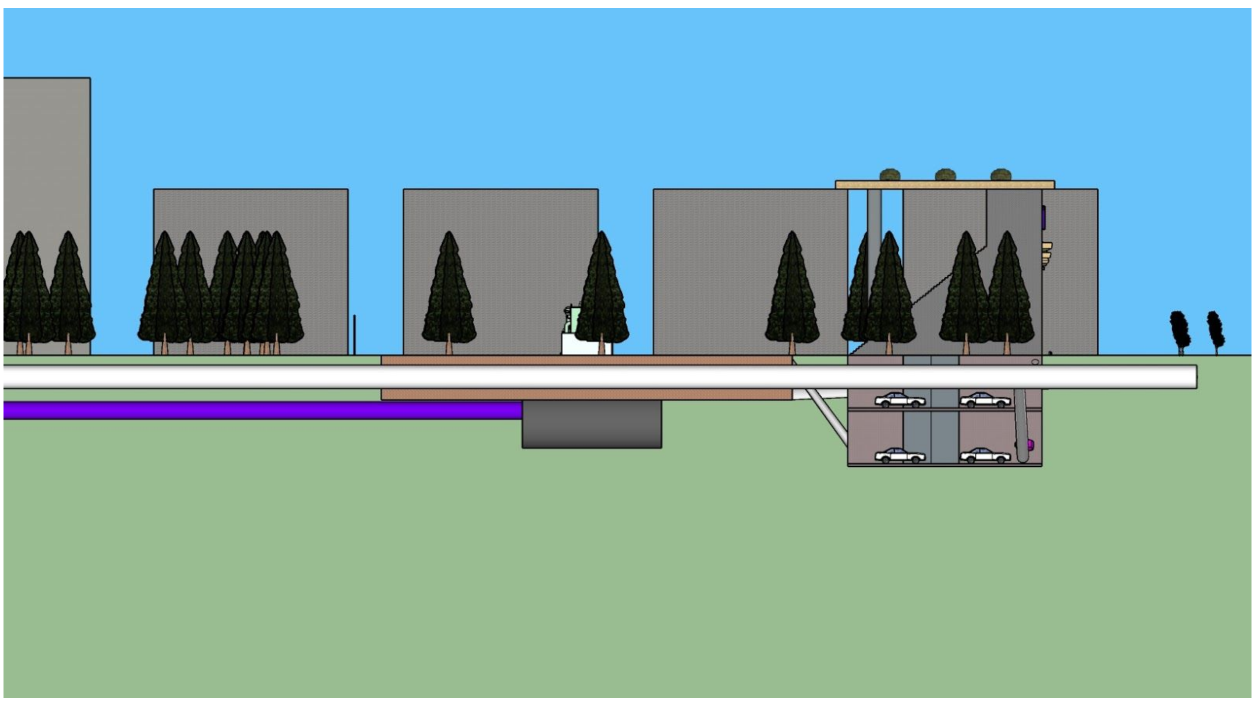


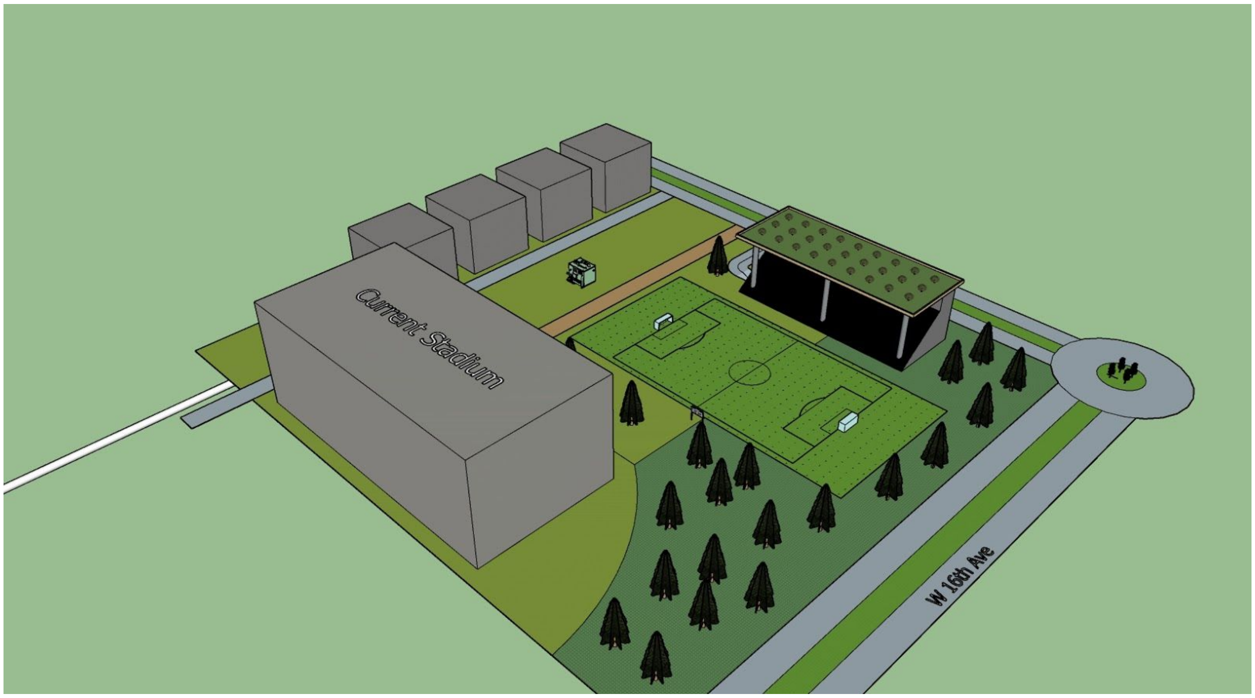

East Mall
W 16th Ave
Current Stadium

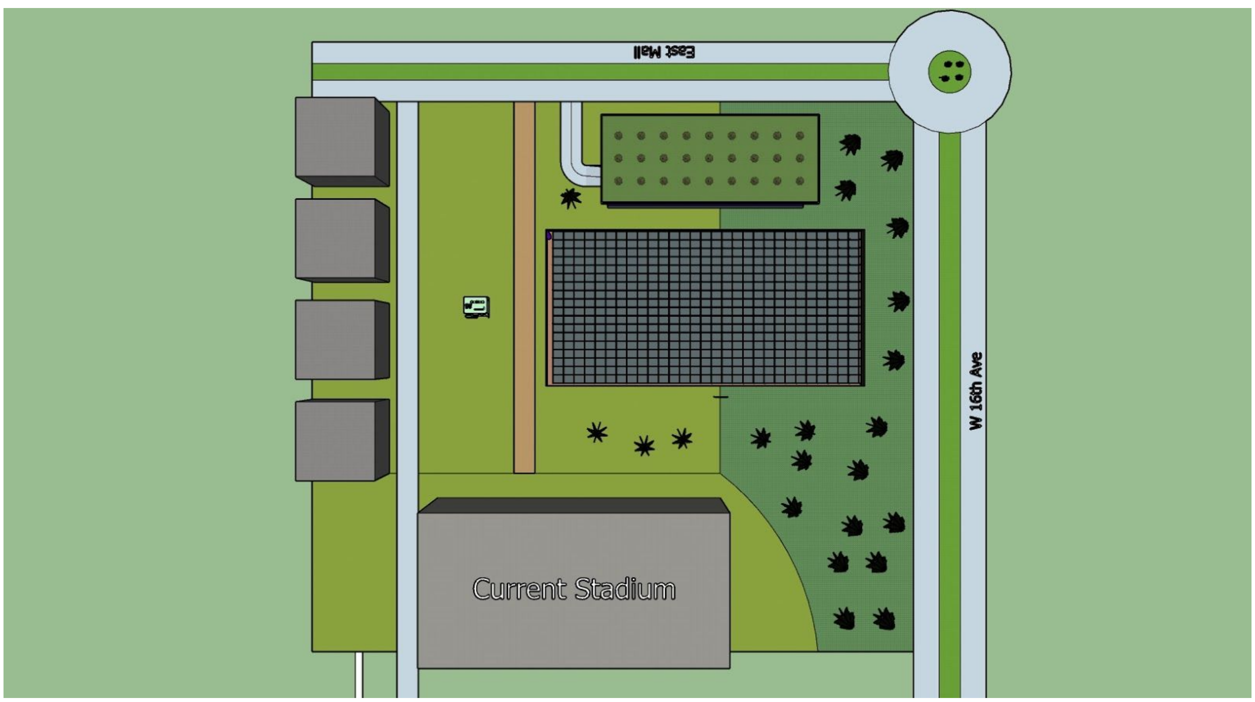



Thunderbird Stadium



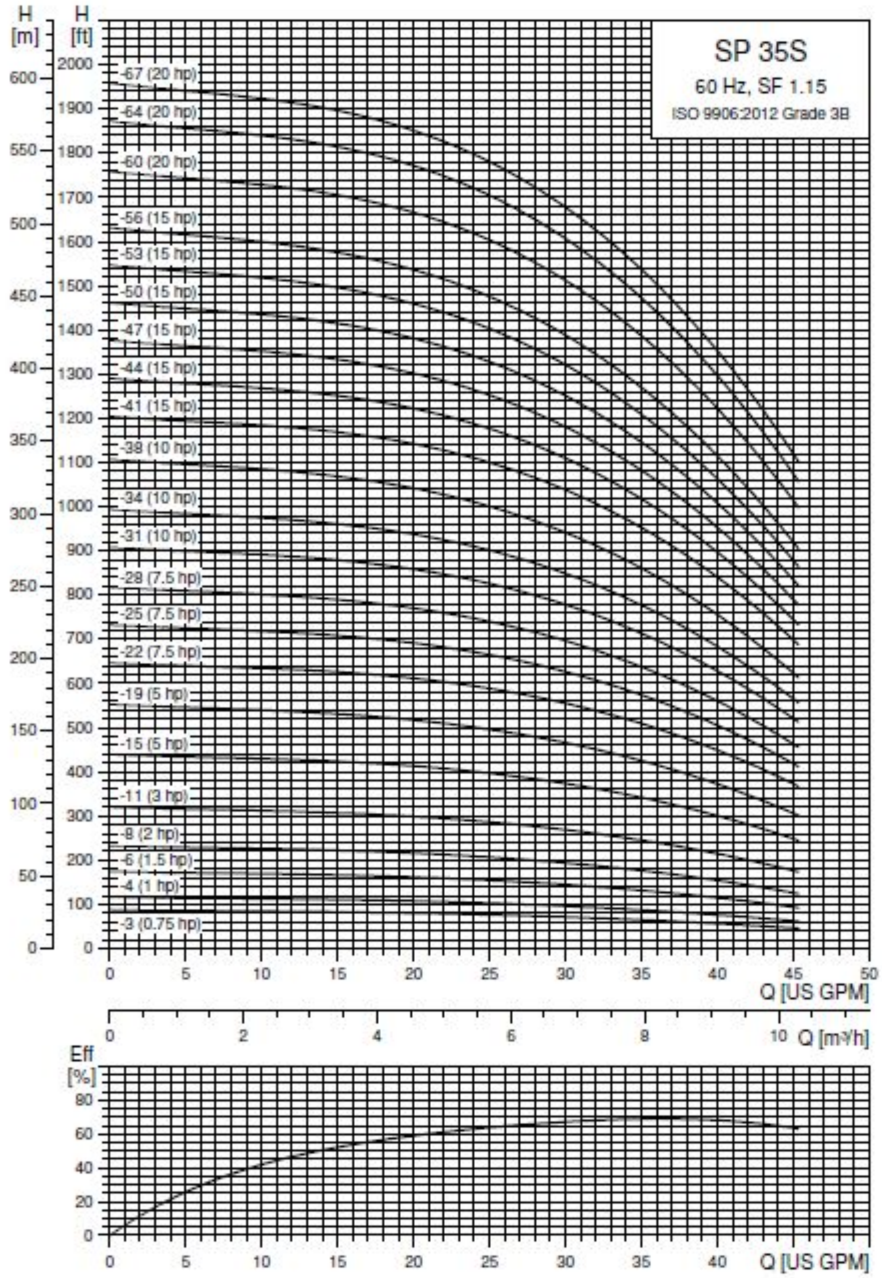



Current Stadium
W 16th Ave


East Mall
W 16th Ave
Current Stadium

Appendix C - Pumps

SP 35S (35 gpm)



Pump 1 - Cistern to Stadium

Stormwater Detention Facility
Pump Selection

Cistern to Stadium		Extreme Storm Event
Pumps Operating	1	
Flow	37.8	L/s
Discharge HGL=	77.39	m
Suction HGL=	71.89	m
Hazen-Williams C Value	130.00	

Flow in L/s, head in m

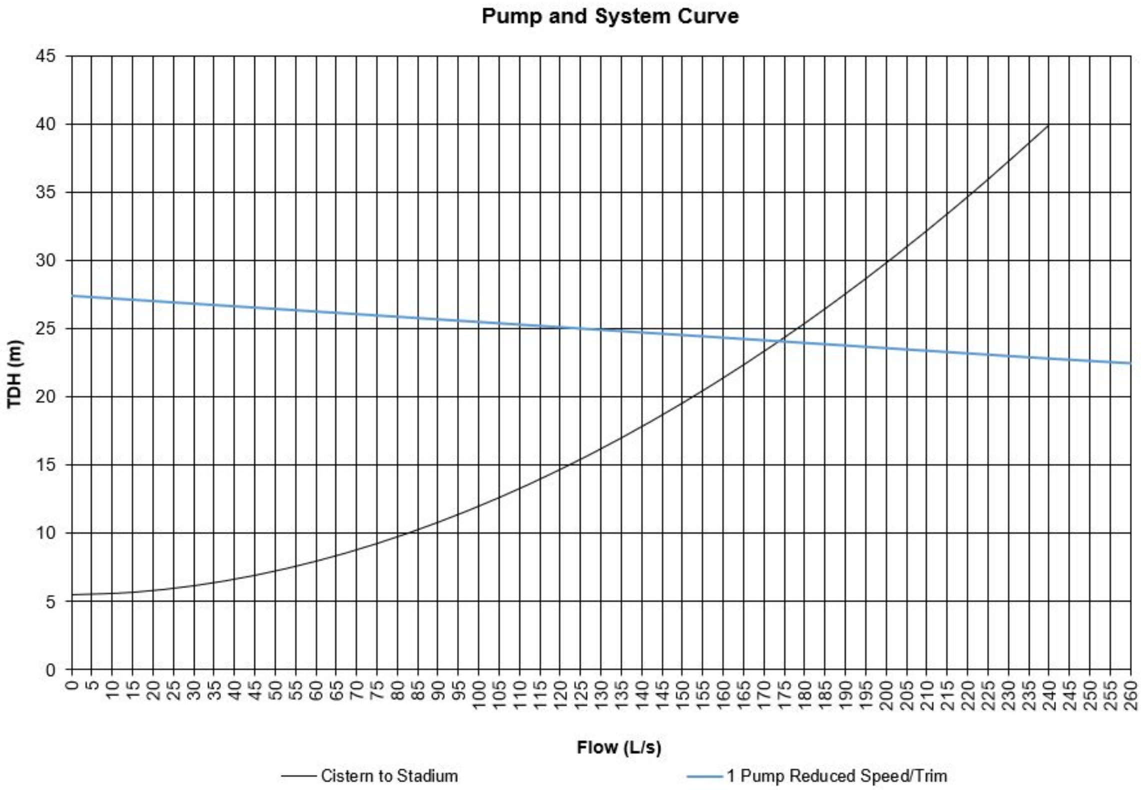
	6.52	**No. of Pumps** 1	2	3	4
Flow (L/s)	0	5.500	5.500	5.500	5.500
	15	5.677	5.583	5.563	5.556
	30	6.158	5.816	5.747	5.722
	45	6.921	6.195	6.049	5.995
	60	7.955	6.716	6.466	6.374
	75	9.252	7.377	6.999	6.859
	90	10.806	8.176	7.646	7.450
	105	12.615	9.113	8.407	8.146
	120	14.673	10.186	9.281	8.947
	135	16.979	11.394	10.268	9.853
	150	19.530	12.737	11.368	10.863
	165	22.323	14.215	12.580	11.977
	180	25.356	15.826	13.904	13.196
	195	28.628	17.570	15.340	14.519
	210	32.137	19.447	16.888	15.945
	225	35.882	21.456	18.547	17.475
	240	39.860	23.597	20.318	19.110

Element	**Dia (nom) in**	**I.D. mm**	**Total Flow L/s**	**Flow in Element L/s**	**Length m**	**"C"**	**"K"**	**"CV"**	**Velocity m/s**	**Delta H m**
Discharge elbow		200	38	37.76			0.05			
Sch. 40 Steel Pipe		200	38	37.76	92.19	130			1.20	0.70
Gate valve		200	38	37.76			0.30		1.20	0.02
Minor Losses		200	38	37.76			3		1.20	0.22
Exit		200	38	37.76			1.00		1.20	0.07
Total Head Losses (m)										**1.02**
Static Head										5.50
Total Dynamic Head (m)										7

Stormwater Detention Facility
Pump Curve

Pump Model										
1,750		**RPM**	**100%** **Speed**							
1	**Stages**									
1		**Pump Operating**					**2**	**Pumps Op.**	**3**	**Pumps Op.**
Flow (USgpm)	**TDH (ft/stage)**	**TDH (ft)**	**Eff (%)**	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
0	125.0	125.0		0	27.4		0	27.4	0	27.4
300	120	120.0	65.0%	79	25.9	41.5	159	25.9	238	25.9
500	117	117.0	70.0%	159	24.4	72.5	317	24.4	476	24.4
800	109	109.0	75.0%	238	22.9	95.1	476	22.9	713	22.9
900	105	105.0	80.0%	317	21.3	111.0	634	21.3	951	21.3
1000	101	101.0	85.0%	396	18.3	111.9	793	18.3	1,189	18.3
1200	90	90.0	85.0%	476	15.2	111.9	951	15.2	1,427	15.2
1300	83	83.0	82.0%							
1,400	73.0	73.0	76.0%							
1,500	61.0	61.0	70.0%							

Reduced Speed								
1750	**RPM**	**100%** **Speed**					1750 RPM - 100%	
1	**Pump Operating**				**2**	**Pumps Op.**	**3**	**Pumps Op.**
	Eff (%)	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
	0.0%	0	27.4		0	27.4	0	27.4
	65.0%	79	25.9	41.5	159	25.9	238	25.9
	70.0%	159	24.4	72.5	317	24.4	476	24.4
	75.0%	238	22.9	95.1	476	22.9	713	22.9
	80.0%	317	21.3	111.0	634	21.3	951	21.3
	85.0%	396	18.3	111.9	793	18.3	1,189	18.3
	85.0%	476	15.2	111.9	951	15.2	1,427	15.2
	82.0%							
	76.0%							
	70.0%							
	0.0%							



Pump 2 - Secondary Tank to Storm Sewer

Stormwater Detention Facility
Pump Selection

Secondary Tank to Sewer

Pumps Operating	1	
Flow	1200.0	L/s
Discharge HGL=	77.39	m
Suction HGL=	71.89	m
Hazen-Williams C Value	130.00	

Flow in L/s, head in m

		No. of Pumps			
	55.11	1	2	3	4
Flow (L/s)	0	5.500	5.500	5.500	5.500
	15	5.510	5.506	5.506	5.505
	30	5.538	5.525	5.522	5.521
	45	5.583	5.555	5.550	5.548
	60	5.646	5.598	5.588	5.584
	75	5.725	5.652	5.637	5.631
	90	5.820	5.717	5.697	5.689
	105	5.931	5.795	5.767	5.757
	120	6.059	5.884	5.848	5.835
	135	6.203	5.984	5.940	5.924
	150	6.363	6.096	6.043	6.023
	165	6.538	6.220	6.156	6.133
	180	6.729	6.355	6.280	6.252
	195	6.937	6.502	6.415	6.383
	210	7.159	6.660	6.560	6.523
	225	7.398	6.830	6.716	6.674
	240	7.651	7.011	6.882	6.835

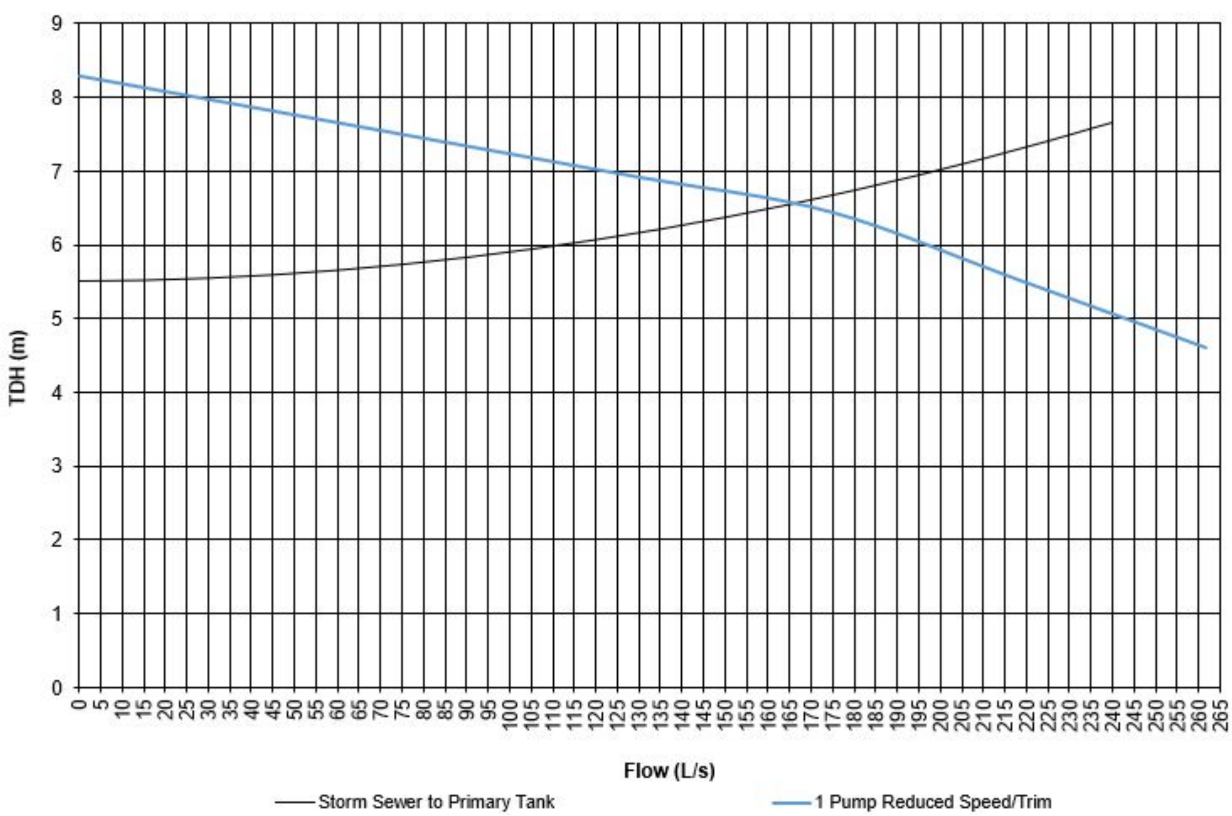
Element	Dia (nom) in	I.D. mm	Total Flow L/s	Flow in Element L/s	Length m	"C"	"K"	"CV"	Velocity m/s	Delta H m
Discharge elbow		350	1,200	1200.00			0.05			
Sch. 40 Steel Pipe		350	1,200	1200.00	51.39	130			12.47	15.51
Gate valve		350	1,200	1200.00			0.30		12.47	2.38
Minor Losses		350	1,200	1200.00			3		12.47	23.79
Exit		350	1,200	1200.00			1.00		12.47	7.93
Total Head Losses (m)										**49.61**
Static Head										5.50
Total Dynamic Head (m)										55

Stormwater Detention Facility
Pump Curve

Pump Model										
1,750		**RPM**	**100% Speed**							
1	**Stages**									
1		**Pump Operating**					**2**	**Pumps Op.**	**3**	**Pumps Op.**
Flow (USgpm)	**TDH (ft/stage)**	**TDH (ft)**	**Eff (%)**	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
0	125.0	125.0		0	27.4		0	27.4	0	27.4
300	120	120.0	65.0%	79	25.9	41.5	159	25.9	238	25.9
500	117	117.0	70.0%	159	24.4	72.5	317	24.4	476	24.4
800	109	109.0	75.0%	238	22.9	95.1	476	22.9	713	22.9
900	105	105.0	80.0%	317	21.3	111.0	634	21.3	951	21.3
1000	101	101.0	85.0%	396	18.3	111.9	793	18.3	1,189	18.3
1200	90	90.0	85.0%	476	15.2	111.9	951	15.2	1,427	15.2
1300	83	83.0	82.0%							
1,400	73.0	73.0	76.0%							
1,500	61.0	61.0	70.0%							

Reduced Speed									
963	**RPM**	**55%**	**Speed**						963 RPM - 55%
1	**Pump Operating**					**2**	**Pumps Op.**	**3**	**Pumps Op.**
		Eff (%)	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
		0.0%	0	8.3		0	8.3	0	8.3
		65.0%	44	7.8	6.9	87	7.8	131	7.8
		70.0%	87	7.4	12.1	174	7.4	262	7.4
		75.0%	131	6.9	15.8	262	6.9	392	6.9
		80.0%	174	6.5	18.5	349	6.5	523	6.5
		85.0%	218	5.5	18.6	436	5.5	654	5.5
		85.0%	262	4.6	18.6	523	4.6	785	4.6
		82.0%							
		76.0%							
		70.0%							
		0.0%							

Pump and System Curve



Pump 3 - Storm sewer to Primary Tank

Stormwater Detention Facility
Pump Selection

Storm Sewer to Primary Tank

Pumps Operating	1	
Flow	1369.4	L/s
Discharge HGL=	79.89	m
Suction HGL=	77.39	m
Hazen-Williams C Value	130.00	

Flow in L/s, head in m

	91.91	No. of Pumps 1	2	3	4
Flow (L/s)	0	2.500	2.500	2.500	2.500
	15	2.516	2.508	2.506	2.506
	30	2.559	2.531	2.525	2.523
	45	2.629	2.568	2.556	2.551
	60	2.723	2.619	2.598	2.590
	75	2.841	2.684	2.652	2.640
	90	2.983	2.762	2.718	2.702
	105	3.148	2.855	2.795	2.774
	120	3.337	2.960	2.885	2.857
	135	3.548	3.080	2.985	2.951
	150	3.782	3.212	3.098	3.055
	165	4.039	3.359	3.222	3.171
	180	4.317	3.518	3.357	3.298
	195	4.618	3.691	3.504	3.435
	210	4.941	3.877	3.662	3.583
	225	5.286	4.076	3.832	3.742
	240	5.653	4.288	4.013	3.912

Element	Dia (nom) in	I.D. mm	Total Flow L/s	Flow in Element L/s	Length m	"C"	"K"	"CV"	Velocity m/s	Delta H m
Discharge elbow		350	1,369	1369.44			0.05			
Sch. 40 Steel Pipe		350	1,369	1369.44	116.73	130			14.23	45.01
Gate valve		350	1,369	1369.44			0.30		14.23	3.10
Minor Losses		350	1,369	1369.44			3		14.23	30.98
Exit		350	1,369	1369.44			1.00		14.23	10.33
Total Head Losses (m)										**89.41**
Static Head										2.50
Total Dynamic Head (m)										92

Stormwater Detention Facility
Pump Curve

Pump Model

1,750		**RPM**	**100% Speed**
1	**Stages**		

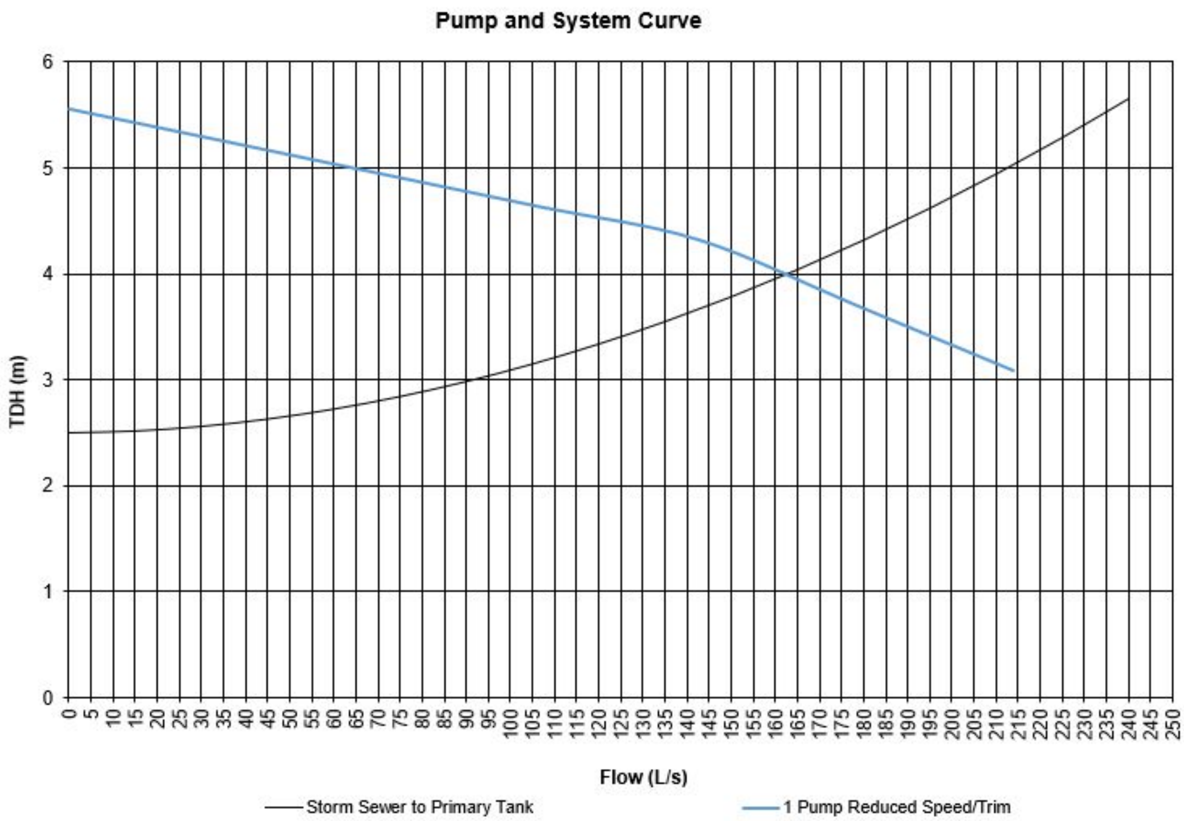
1		Pump Operating					2	Pumps Op.	3	Pumps Op.
Flow (USgpm)	**TDH (ft/stage)**	**TDH (ft)**	**Eff (%)**	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
0	125.0	125.0		0	27.4		0	27.4	0	27.4
300	120	120.0	65.0%	79	25.9	41.5	159	25.9	238	25.9
500	117	117.0	70.0%	159	24.4	72.5	317	24.4	476	24.4
800	109	109.0	75.0%	238	22.9	95.1	476	22.9	713	22.9
900	105	105.0	80.0%	317	21.3	111.0	634	21.3	951	21.3
1000	101	101.0	85.0%	396	18.3	111.9	793	18.3	1,189	18.3
1200	90	90.0	85.0%	476	15.2	111.9	951	15.2	1,427	15.2
1300	83	83.0	82.0%							
1,400	73.0	73.0	76.0%							
1,500	61.0	61.0	70.0%							

Reduced Speed

788 **RPM** **45%** **Speed**

788 RPM - 45%

1	Pump Operating				2	Pumps Op.	3	Pumps Op.
	Eff (%)	**Flow (L/s)**	**TDH (m)**	**Power (HP)**	**Flow (L/s)**	**TDH (m)**	**Flow (L/s)**	**TDH (m)**
	0.0%	0	5.6		0	5.6	0	5.6
	65.0%	36	5.2	3.8	71	5.2	107	5.2
	70.0%	71	4.9	6.6	143	4.9	214	4.9
	75.0%	107	4.6	8.7	214	4.6	321	4.6
	80.0%	143	4.3	10.1	285	4.3	428	4.3
	85.0%	178	3.7	10.2	357	3.7	535	3.7
	85.0%	214	3.1	10.2	428	3.1	642	3.1
	82.0%							
	76.0%							
	70.0%							
	0.0%							


Pump and System Curve
TDH (m)
6
5
4
3
2
1
0
0
5
10
15
20
25
30
35
40
45
50
55
60
65
70
75
80
85
90
95
100
105
110
115
120
125
130
135
140
145
150
155
160
165
170
175
180
185
190
195
200
205
210
215
220
225
230
235
240
245
250
Flow (L/s)
Storm Sewer to Primary Tank
1 Pump Reduced Speed/Trim

Appendix D - Piping System Sample Calculations

Volume Capacity

$V_{Cap} = Q_{Cap} / (\pi D^2/4)$

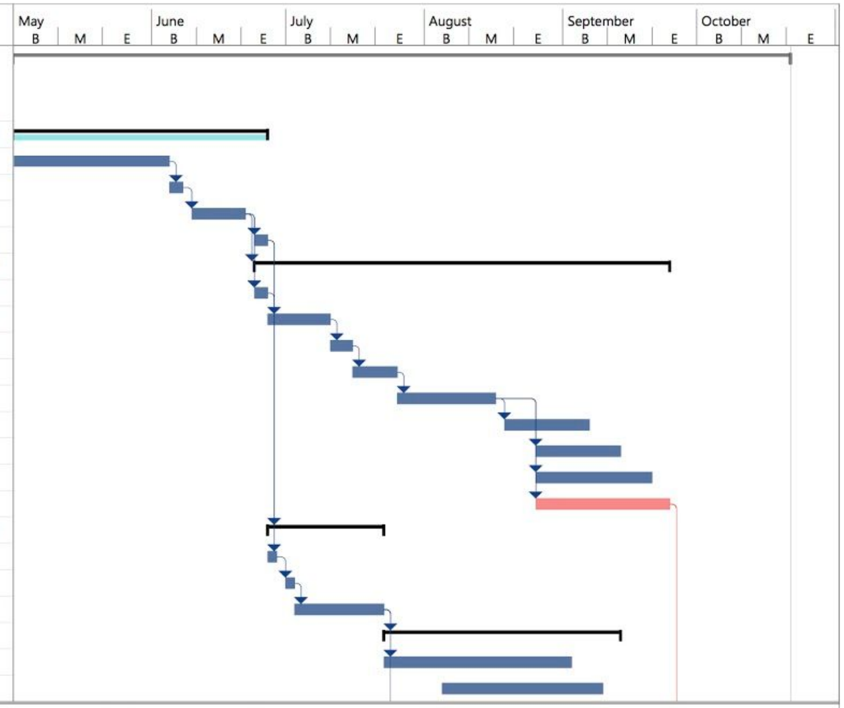
Flow Capacity

$Q_{Cap} = \pi D^2/4 \, (D/4)^{2/3} slope^{1/2} n$

	Elevation (m)
Primary (Entrance)	79.885
Primary (Exit-Cistern)	79.385
Primary (Exit-Secondary)	79.635
Cistern (Entrance)	79.135
Cistern (Exit)	78.861
Stadium	80.385
Secondary (Entrance)	73.385
Secondary (Exit)	71.885
Storm Sewer	77.385
Botanical Garden	70.058
1	71.38
2	72.236
3	73.177
4	74.835

Appendix E - Detailed Construction Schedule

ID		Task Mode	Task Name	Duration	Start	Finish
0			**STADIUM NEIGHBOURHOOD UNDERGROUND PARKADE AND WATER STORAGE**	**124 days**	**Wed 5/1/19**	**Mon 10/21/19**
1			**1 SITE PREPARATION**	**41 days**	**Wed 5/1/19**	**Wed 6/26/19**
2			1.1 Site Preparation Survey	25 days	Wed 5/1/19	Tue 6/4/19
3			1.2 Site Moblization	3 days	Wed 6/5/19	Fri 6/7/19
4			1.3 Devegetation and site clean u	10 days	Mon 6/10/19	Fri 6/21/19
5			1.4 Utility check and rerouting	3 days	Mon 6/24/19	Wed 6/26/19
6			**2 UNDERGROUND PARKADE**	**67 days**	**Mon 6/24/19**	**Tue 9/24/19**
7			2.1 Ground survey	3 days	Mon 6/24/19	Wed 6/26/19
8			2.2 Bulk excavation	10 days	Thu 6/27/19	Wed 7/10/19
9			2.3 Footing excavation	3 days	Thu 7/11/19	Mon 7/15/19
10			2.4 Foundation	8 days	Tue 7/16/19	Thu 7/25/19
11			2.5 1st floor structure	16 days	Fri 7/26/19	Fri 8/16/19
12			2.6 2nd floor structure	15 days	Mon 8/19/19	Fri 9/6/19
13			2.7 Electrical work	15 days	Mon 8/26/19	Fri 9/13/19
14			2.8 Mechanical work	20 days	Mon 8/26/19	Fri 9/20/19
15			2.9 Plumbing	22 days	Mon 8/26/19	Tue 9/24/19
16			**3 PRIMARY STORAGE**	**18 days**	**Thu 6/27/19**	**Mon 7/22/19**
17			3.1 Ground survey	2 days	Thu 6/27/19	Fri 6/28/19
18			3.2 Excavation	2 days	Mon 7/1/19	Tue 7/2/19
19			3.3 Installation of tanks	14 days	Wed 7/3/19	Mon 7/22/19
20			**4 DRAINAGE SYSTEM**	**39 days**	**Tue 7/23/19**	**Fri 9/13/19**
21			4.1 Excavation	30 days	Tue 7/23/19	Mon 9/2/19
22			4.2 Lay pipes	26 days	Mon 8/5/19	Mon 9/9/19

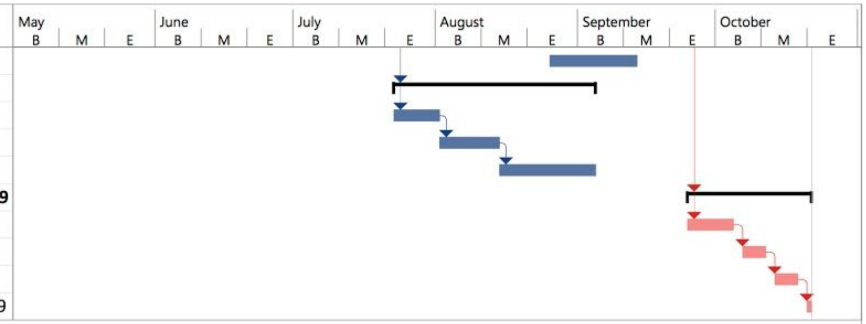


Project: STADIUM NEIGHBOUR
Date: Mon 4/1/19

Task	Inactive Milestone	Start-only	Critical Split
Split	Inactive Summary	Finish-only	Progress
Milestone	Manual Task	External Tasks	Manual Progress
Summary	Duration-only	External Milestone	
Project Summary	Manual Summary Rollup	Deadline	
Inactive Task	Manual Summary	Critical	

Page 1

ID	Task Mode	Task Name	Duration	Start	Finish
23		4.3 Backfill	15 days	Mon 8/26/19	Fri 9/13/19
24		**5 WATER TREATMENT FACILITY**	**32 days**	**Tue 7/23/19**	**Wed 9/4/19**
25		5.1 Excavation	8 days	Tue 7/23/19	Thu 8/1/19
26		5.2 Install cistern	9 days	Fri 8/2/19	Wed 8/14/19
27		5.3 Install equipment	15 days	Thu 8/15/19	Wed 9/4/19
28		**6 PROJECT COMPLETION**	**19 days**	**Wed 9/25/19**	**Mon 10/21/19**
29		6.1 Landscapping	8 days	Wed 9/25/19	Fri 10/4/19
30		6.2 Final clean up	5 days	Mon 10/7/19	Fri 10/11/19
31		6.3 Final inspections	5 days	Mon 10/14/19	Fri 10/18/19
32		6.4 Commissioning	1 day	Mon 10/21/19	Mon 10/21/19



Project: STADIUM NEIGHBOUR
Date: Mon 4/1/19

Task		Inactive Milestone		Start-only		Critical Split	
Split		Inactive Summary		Finish-only		Progress	
Milestone		Manual Task		External Tasks		Manual Progress	
Summary		Duration-only		External Milestone			
Project Summary		Manual Summary Rollup		Deadline			
Inactive Task		Manual Summary		Critical			

Appendix F - Cost Excel Calculations

Dimensions and other parameters used for cost calculation, parkade

		Units		Units
Width	37.50	m	123.03	feet
Length	100.00	m	328.08	feet
Height of each floor	3.66	m	12.00	feet
Perimeter	275.00	m	902.23	feet
Area per floor	3,750.00	square m	40,364.63	square feet
Volume, per floor	13,716.00	cubic m	484,376.41	cubic feet
Total area	7,500.00	square m	80,729.25	square feet
Depth of excavation	9.29	m	30.48	feet
Excavation Volume	34,834.47	cubic m	1,230,168.84	cubic feet
Slab thickness, floors and foundation	0.15	m	0.49	feet
Total wall area	2,011.68	square m	21,653.54	square feet
Concrete block partitions	75.81	square m	816.00	square feet
Pipes	920.4	m	3019.69	feet
Stairs, flights (2 per floor)	8			
Floors	2.0			
Interior doors	6			
Exterior doors	4			
Elevators	2			

Dimensions and other parameters used for cost calculation, field tank

Width	60.0	m	196.9	feet
Length	60.0	m	196.9	feet
Depth of excavation	2.0	m	6.6	feet
Depth of tank	1.37	m	4.5	feet
Perimeter	240.0	m	787.4	feet
Area	3,600.0	square m	11,811.0	square feet
Storage Volume	4,932.0	cubic m	174,172.1	cubic feet
Stone backfill		cubic m	1437.4	cubic yards
Leveling bed		cubic m	38750.1	cubic feet
Number of modules, ST-18 + ST-36	2625			

Annual maintenance

Parkade	$ 125,000.00
Detention Tank	$ 189,303.21
Water Treatment Facility	$ 40,000.00
Total	**$ 354,303.21**

Indices used for cost calculations

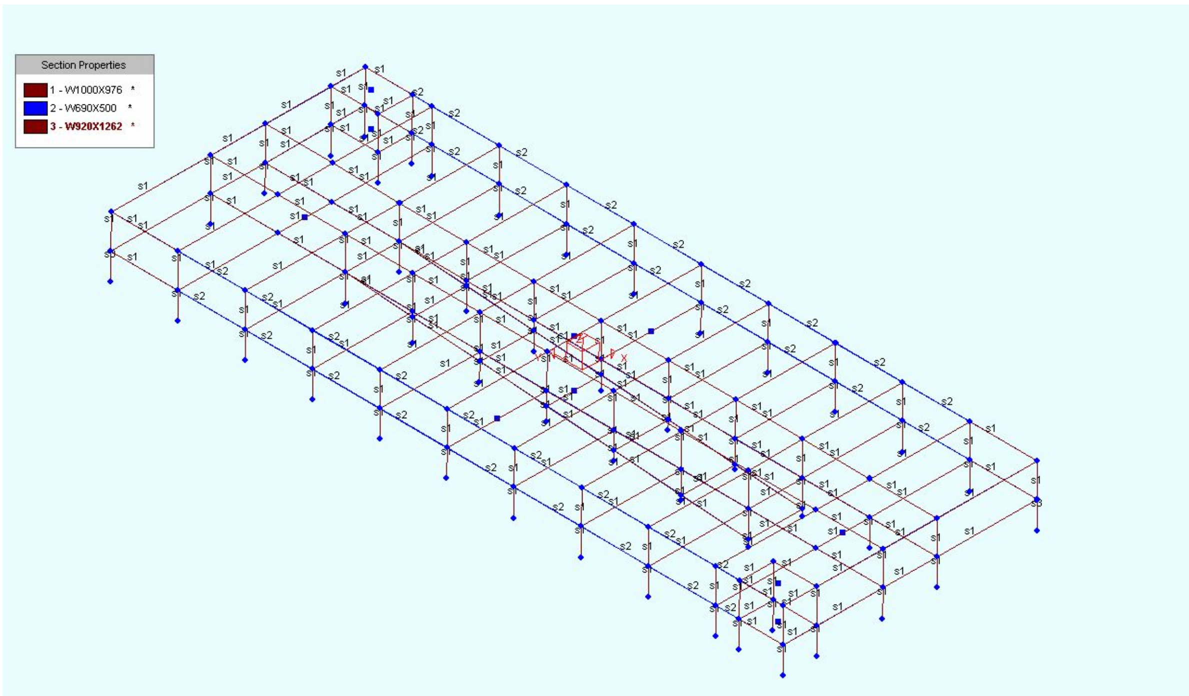
Vancouver Index, CAD	1.11
Average National Index, USD	1.00
Historical Cost Index, 2012	85.6
Historical Cost Index, 2019	100

Project Total Costs Summary

Project subtotal:	$ 8,833,913.47	$ 9,528,410.59	**$ 10,725,743.26**
Project total:	$ 12,941,683.23	$ 13,959,121.52	**$ 15,713,213.88**

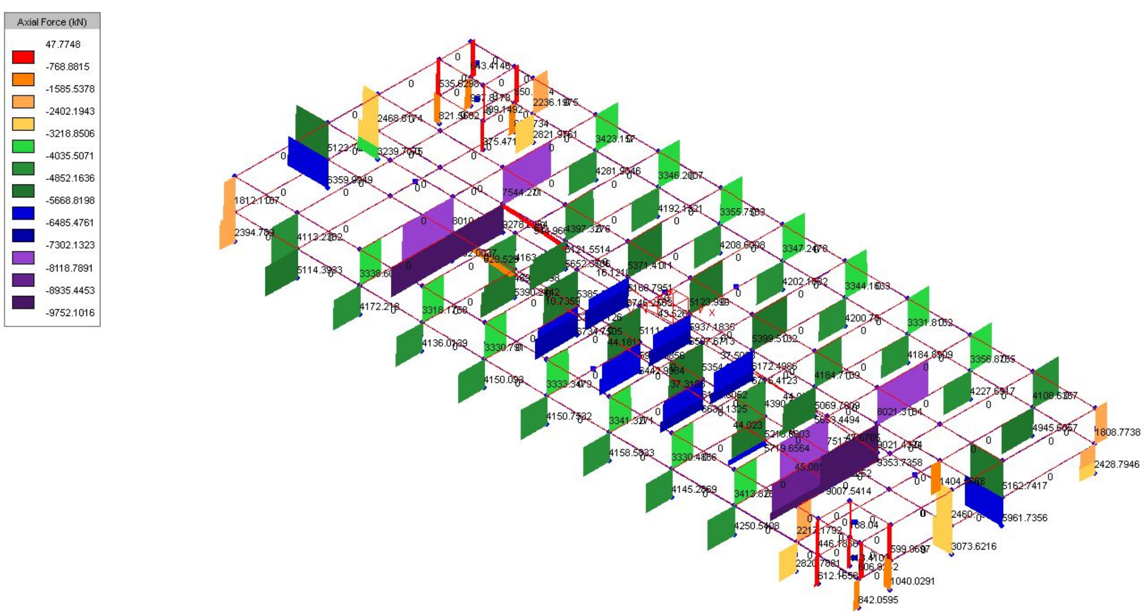
Appendix G - Structural Analysis Calculations

Steel Sections

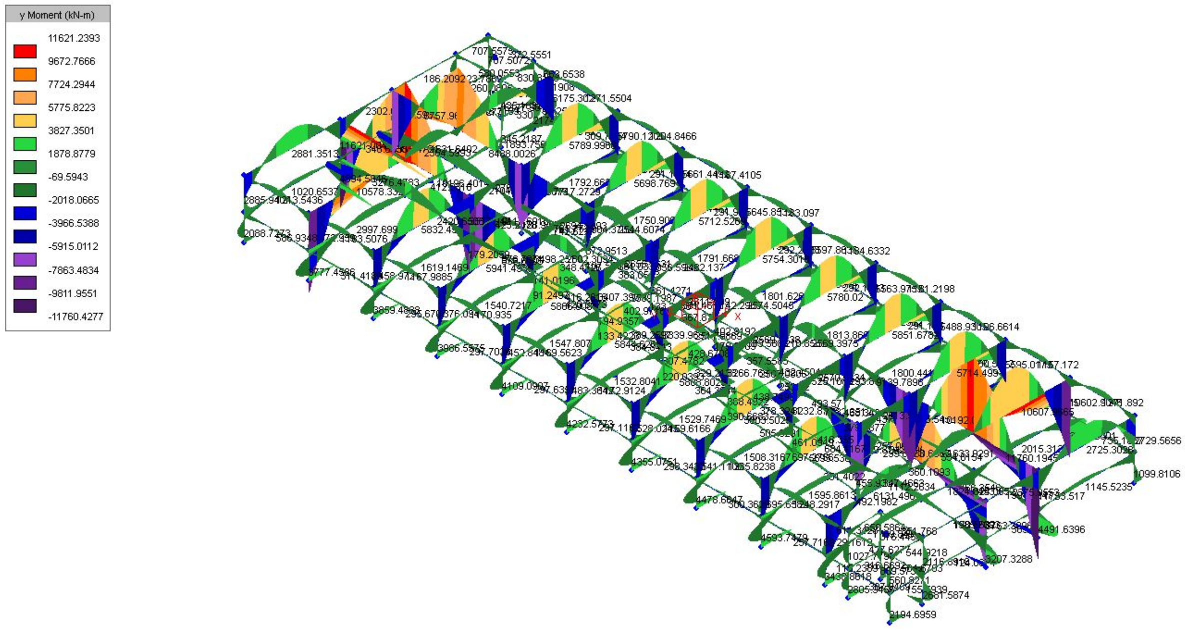


Demands

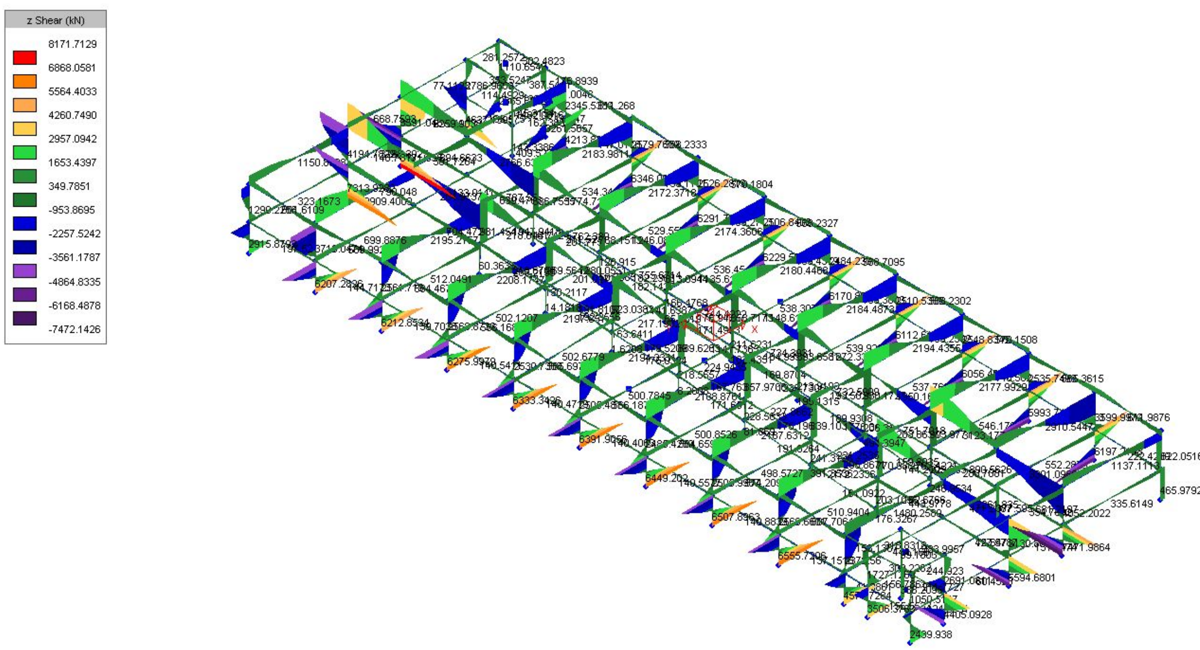
Axial:



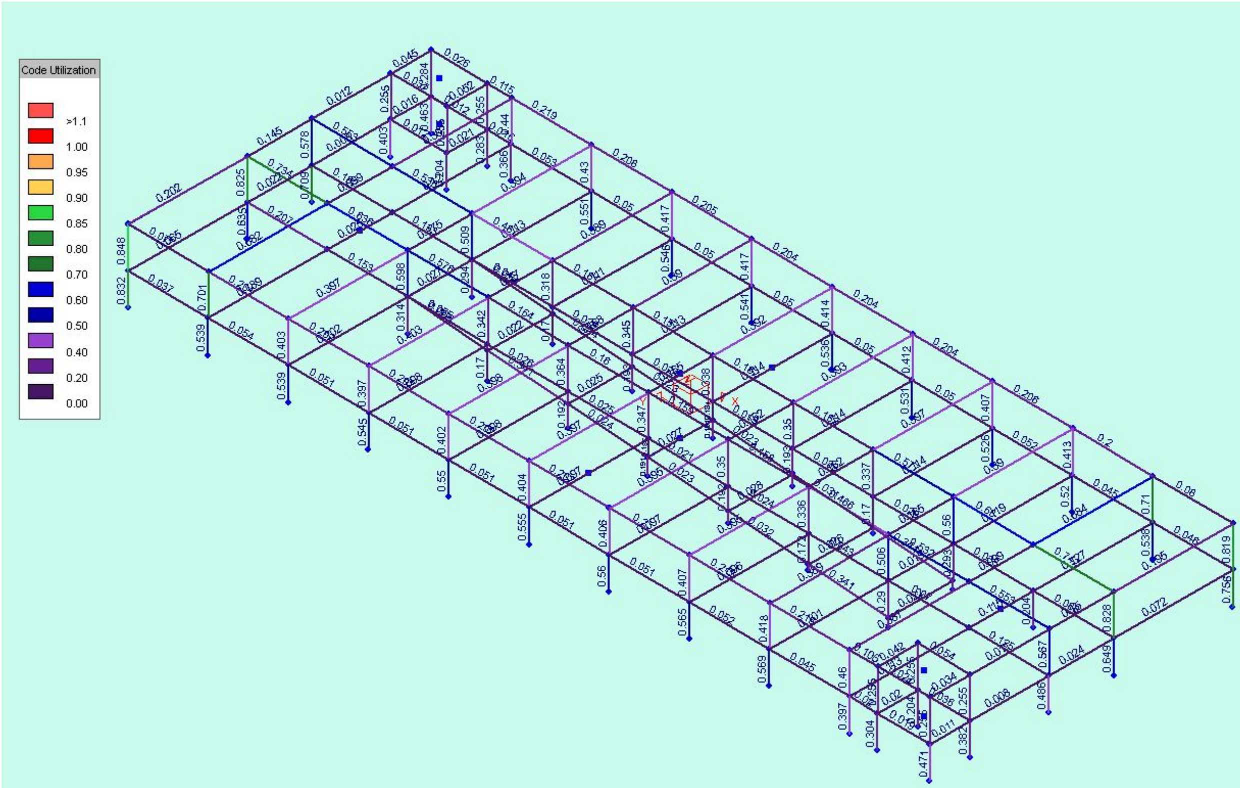
Moments:



Shear:



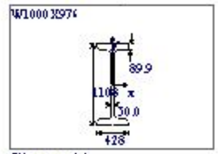
Capacity to Demand Ratios



Example Capacity Calculations for a Column and Composite Beam Generated in S-Steel

,	***Code Details*** Project: 446Project Structure: Filename: 446PROJ.TEL Engineer:	Page: 1 Date:02/03/2019

Member: 52 S-FRAME Section is W1000X976 *
Member is part of group: SECTION 1
Note: Neglecting: axial<1.0 kN, shear<1.0 kN, moment<1.0 kNm
Note: Member in braced frame(s).



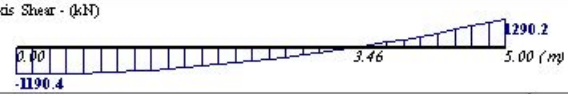
Load Combination 1 Load Comb 1 (Bending + Compression)

Section classification (f_y=350 MPa); Section Class =	2		Clause 11
Governing geometrical slenderness ratio k_x=1.00; k_y=1.00; k_xL/r_x=11.5;	$\frac{k_y L/r_y}{200} = \frac{51}{200} =$	0.255	Clause 10.4.2.1

Axial Load - (kN)

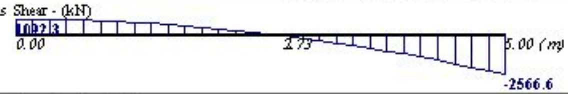
Factored Compressive Resistance Check n=1.34; λ_y=0.680	$\frac{C_f}{C_{ry}} = \frac{C_f}{\phi A F_y (1+\lambda^{2n})^{-1/n}} = \frac{C_f}{\phi A\ (279\ \text{MPa})} = \frac{1812}{31133} =$	0.058	Clause 13.3.1

Strong Axis Shear - (kN)



Strong axis shear strength check A_w= 55400 mm^2;	$\frac{V_{fy}}{\phi A_w F_s} = \frac{V_{fy}}{\phi A_w 0.66F_y} = \frac{1290}{11518} =$	0.112	Clause 13.4.1.1(a)(i)

Weak Axis Shear - (kN)

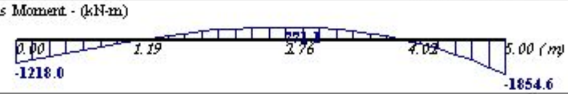


Weak axis shear strength check A_w= 76954 mm^2;	$\frac{V_{fx}}{\phi A_w F_s} = \frac{V_{fx}}{\phi A_w 0.66F_y} = \frac{2567}{15999} =$	0.160	Clause 13.4.1.1(a)(i)

Strong Axis Moment - (kN-m)

Bending Stability Check L_u=5.00 m; ω_2=2.500;	$\frac{M_{fx}}{M_{rx}} = \frac{2886}{15845} =$	0.182	Clause 13.6(a)

Weak Axis Moment - (kN-m)



Weak axis section capacity in bending	$\frac{M_{fy}}{M_{ry}} = \frac{M_{fy}}{\phi F_y Z_y} = \frac{1855}{2785} =$	0.666	Clause 13.5(a)
Axial Compression and Bending cross-sectional Strength Check ω_{1x}=1.00; ω_{1y}=1.00; U_{1x}=1.00; U_{1y}=1.02;	$\frac{C_f}{\phi A F_y} + \frac{0.85\ U_{1x} M_{fx}}{\phi Z_x F_y} + \frac{0.6 U_{1y} M_{fy}}{\phi Z_y F_y} =$	0.609	Clause 13.8.2(a)

Design Code: CAN/CSA S16-14
Steel Table : Canadian (CISC)
Analysis Program: S-FRAME (Linear static analysis)
ACADEMIC VERSION NOT FOR COMMERCIAL USE

S-STEEL
Version 2017.2.3

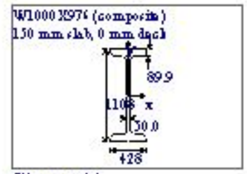
	Code Details	
,	Project: 446Project Structure: Filename: 446PROJ.TEL Engineer:	Page: 1 Date:02/03/2019

Member: 310 S-FRAME Section is **W1000X976 ***

Member is part of group: SECTION 1

Note: Neglecting: axial<1.0 kN, shear<1.0 kN, moment<1.0 kNm

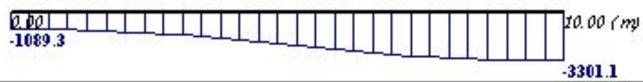
Note: Member in braced frame(s).



Load Combination 1 Load Comb 1 (Bending)

Section classification (f_y=350 MPa); Section Class =	1	Clause 11
Strong Axis Shear - (kN)		
Strong axis shear strength check A_w= 55400 mm^2; $\frac{V_{fy}}{\phi A_w F_s} = \frac{V_{fy}}{\phi A_w 0.66F_y} = \frac{3301}{11518} =$	0.287	Clause 13.4.1.1(a)(i)
Strong Axis Moment - (kN-m)		
Bending Stability Check L_u=10.00 m; ω_2=2.197; $\frac{M_{fx}}{M_{rx}} = \frac{11760}{15845} =$	0.742	**Clause 13.6(a)**
Shrinkage deflection for pin end condition (mm).Ribs parallel. $\Delta_s = L^2 \varepsilon_f A_c y/(8n_s I_{ts}) =$	1.325	Clause 17.3.1(c)
Composite beam moment resistance (35 MPa, 2560 kg/m3 concrete, qr=102.07 kN) Q_r=1123 kN (41%, 11 studs/shear span); b_1=1000 mm; $\frac{M_{fx}}{M_{rc}} = \frac{10192}{16553} =$	0.616	Clause 17.9.3(c)
Effective moment of inertia including creep (mm4 x 10^6) p=0.41; I_t=31296; $I_e = 0.85(I_s + 0.85(p)^{0.25}(I_t - I_s)) =$	24482	Clause 17.3.1(b)

Strong Axis Shear - (kN):



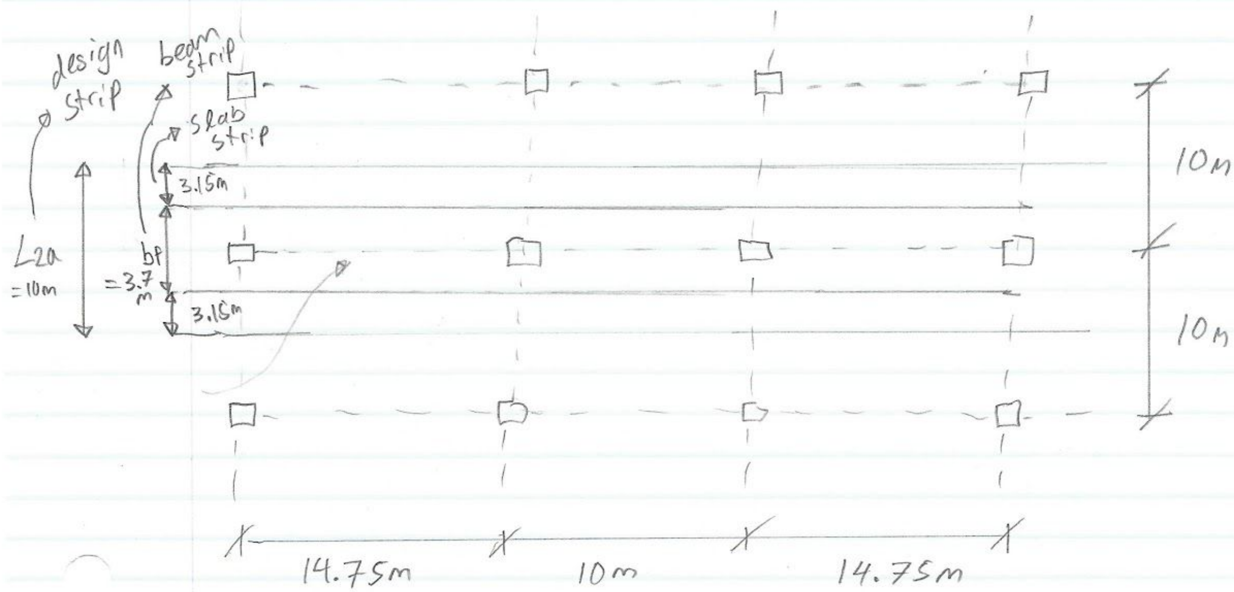
Strong Axis Moment - (kN-m):

Design Code: CAN/CSA S16-14
Steel Table : Canadian (CISC)
Analysis Program: S-FRAME (Linear static analysis)

S-STEEL
Version 2017.2.3

Calculations

Two-Way slab design using DDM − A23.14



$L_{2a} = 10m$

$$b_f = \min \begin{cases} 0.25 \times 14.75m \\ 10m \end{cases} = 3.7m$$

* Approximate clear spans as distance from ℄ of supports

1. Determine the required slab thickness based on deflection control requirements

$$h_s \geq \frac{l_n \left(0.6 + \frac{f_y}{1000}\right)}{30 + 4\beta\alpha_m}$$

β for interior slab pannel $= \frac{10m}{10m} = 1.0$

β for exterior slab pannel $= \frac{14.75}{10} = 1.475$

∴ design for interior slab pannel

W1000×976

assume $\alpha_m = 2.0$ for now

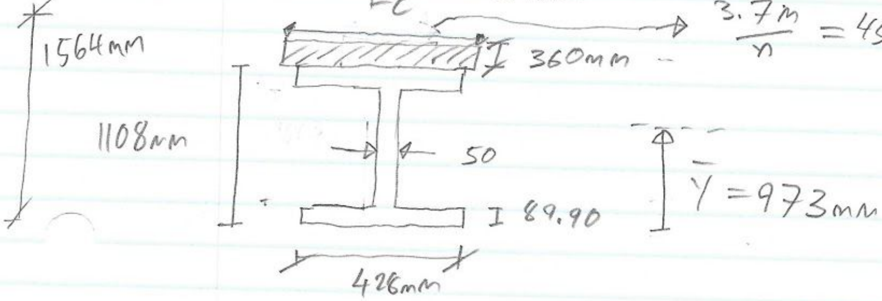
$$h_s \geq \frac{l_n \left(0.6 + \frac{400}{1000}\right)}{30 + 4 \times \beta (2.0)} = \max \begin{cases} 353\,mm & \text{exterior pannel} \\ 263\,mm & \text{interior panel} \end{cases} = 353\,mm$$

$\therefore$ use $h_s = 360\,mm$

$$E_c = 4500\sqrt{f_c'} = 4500\sqrt{30} = 24650\,MPa$$

$$n = \frac{E_s}{E_c} = \frac{200 \times 10^3}{24650} \cong 8.11$$

$$\frac{3.7\,m}{n} = 456\,mm$$



$$\bar{Y} = \frac{44.95(89.9 \times 428) + 1063.05(89.9 \times 428) + 360 \times 456 \times 1288 + 50 \times 928 \times 554}{360 \times 456 + 928 \times 50 + 2(89.9 \times 428)}$$

$= 973\,mm$

$$I_b = 1190 \times 10^6\,mm^4 + (973 - 554)^2 \times 124000$$

$$+ (456 \times 360)(411)^2 + \frac{1}{12}(456)(360)^3$$

$= 1190 \times 10^6 + 2.177 \times 10^{10} + 2.773 \times 10^{10} + 1.773 \times 10^9$

$= 5.25 \times 10^{10}\,mm^4$

beam to slab stiffness ratio

$$\alpha_1 = \frac{E_b I_b}{E_s I_s} = \frac{5.25 \times 10^{10} \times 200 \times 10^3}{24650 \times \frac{1}{12}(3700 \times 360^3)} = 29.6$$

$$\alpha_2 = \alpha_1 = 29.61$$

$$\alpha_m = \frac{29.61 + 29.61}{2} = 29.61 > 2.0$$

$\therefore$ use $\alpha_m = 2.0$

$$2.0 < \frac{\alpha_1 l_1^2}{\alpha_2 l_2^2} < 5.0 \rightarrow \text{Checked} \rightarrow \frac{14.75^2}{10^2} = 2.175 \checkmark \quad \frac{10^2}{10^2} = 1 \checkmark$$

2. Find loads action on slab:

$$DL = 1.25 \times \left(20\,kPa + \frac{2400 \frac{kg}{m^3} \times 9.81 \times (.360m)}{1000}\right)$$

$$= 1.25\,(20 + 8.5) = 35.6\,kPa$$

$$LL = 1.5 \times (7.2\,kPa) = 10.8\,kPa$$

$$SL = 2.12\,kPa$$

$$w_f' = 35.6 + 10.8 + 2.12 = 48.52\,kPa$$

$$w_f = w_f' \times \overset{10m}{l_{2a}} = 485\,\frac{kN}{m}$$

3. Determine factored bending moments on slab

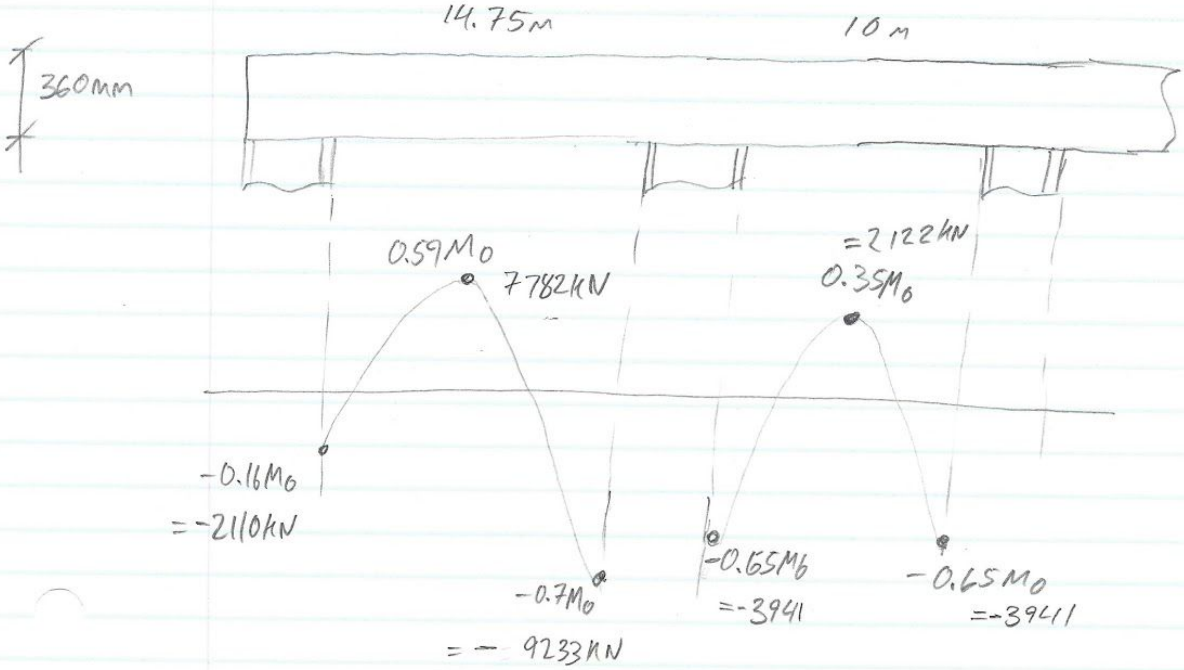
exterior pannel:

$$M_o = \frac{w_f \times 14.75^2}{8} = 13190\,kNm$$

interior pannel

$$M_o = \frac{w_f \times 10^2}{8} = 6063\,kNm$$

distribute moment in longitudinal direction



distribute moment transve

For interior span
with in beam strip

$$M_b = \frac{\alpha_1}{0.3+\alpha_1}\left(1-\frac{l_2}{3l_1}\right) M$$

$$= \frac{29.6}{0.3+29.6}\left(1-\frac{1}{3}\right) M$$

$$= 0.66M$$

for exterior span

$$M_b = \frac{29.6}{0.3+29.6}\left(1-\frac{10}{3\times14.75}\right) M = 0.77M$$

interior span: transverse disturbution with

	supports	midspan
within beam strip	$0.66\times(-3941) = -2601$ kNm ($A_s = 15538\ mm^2$)	$0.66(2122)$ 1400 kNm ($A_s = 7988\ mm^2$)
within slab strip	$-(3941-2601) = -1340$ kNm ($A_s = 7694$)	$2122-1400 = 722$ ($A_s = 4042$)

exterior span transverse disturbution

	ext support	midspan	first interior support
beam strip	-2110 kNm ($A_s = 12361\ mm^2$)	5992 kNm ($A_s = 40345\ mm^2$)	-7109 kNm ($A_s = 52199\ mm^2$)
slab strip	0	($A_s = 10463\ mm^2$) 1790 kNm	($A_s = 12568\ mm^2$) -2114 kNm

$\left(A_s = 0.0015\, b \times 30 \left(d - \sqrt{d^2 - \frac{3.85\, M_f}{b \times 30}} \right) \right)$

determine required slab depth:

$$d > \sqrt{\frac{3.85 \times 7109 \times 10^6}{30 \times 3700}}$$

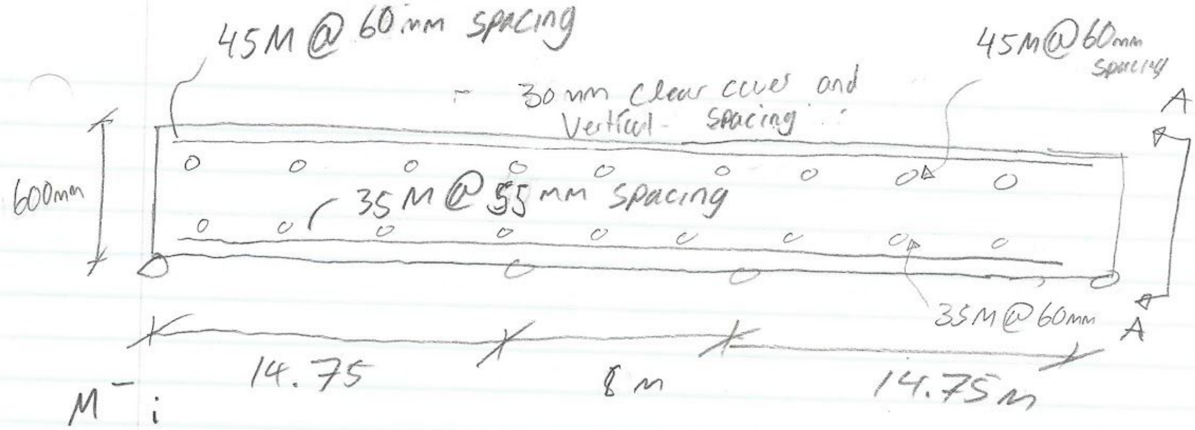
$$d > 496.6$$

$\therefore$ choose $h_s = 600$ mm

$d = 600 - 50\,mm = 550$ mm

↳ 1 layer of reinforcement (20mm cover)

→ For construction purposes use 1 spacing/steel area for entire design strip for both M+ and M− steel → (governing are −7109 kNm and +5992)



M^- :

$$\rho = \frac{1500\,mm^2 \times 41}{3700 \times 550} = 0.026 < \rho_b = 0.027$$

Governing Area / spacing check:

45M = 1500 mm²

$$\# \text{ of } 45M = \frac{3700\,mm}{\underbrace{45}_{\text{diameter}} + \underbrace{66}_{\text{spacing}}\,mm} = 35$$

$$s = \frac{3700 - d \times N}{N}$$

$N =$

$35 \times 1500 = 52500\,mm^2 > 52199.8\,mm^2$

$M+$:

35M = 1000 mm²

$$\frac{37000\,mm}{35 + 55} = 41 - 35M$$

$41 \times 1000 = 41000\,mm^2 > 40345\,mm^2$

$$\rho = \frac{41000}{3700 \times 550} = 0.02 < \rho_b \therefore O.K$$

Foundation analysis

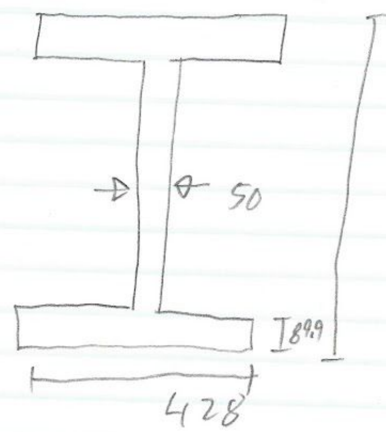
$q_{all} = 12{,}000\ psf = 575\ kPa$

$P_{f,max} = 9752\ kN$

$$A \geq \frac{P_f}{q_{all}} = \frac{9752}{575} = 16.96\ m^2$$

width required = 4.116 m for square foundation

Steel column section: W1000 x 976



Area of base plate required:

$$A_1 = \frac{9752\ kN}{0.85 \times \phi_c f_c'} = \frac{9752 \times 10^3}{0.85 \times 0.65 \times 30} = 588{,}355.96\ mm^2$$

$B = C = 770\ mm$ width of plate required

Column is too big ∴ increase base plate:

$B = 600$, $C = 1200$ $BC = 600{,}000\ mm^2 > A_1$ ∴ O.K

$$n = \frac{B - 0.8 \times 428\ mm}{2} = \frac{600 - 0.8 \times 428}{2} = 129\ mm$$

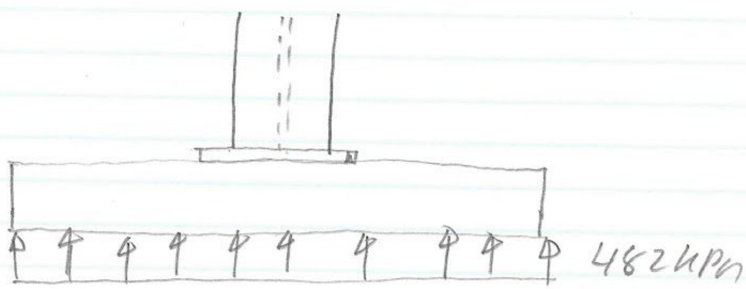
$$m = \frac{C - 0.95d}{2} = \frac{1200 - 0.95 \times 1108}{2} = 74\ mm$$

$$t_p = \left(\begin{matrix} m \\ \text{or} \\ n \end{matrix}\right) \times \sqrt{\frac{2 \times 9752 \times 10^3}{1200^2 \times 0.9 \times 400}} = 25\text{ mm thick plate}$$

design a 4.5 x 4.5m spread foundation

① factored Soil pressure:

$$q_f = \frac{9752}{4.5 \times 4.5} = 481.6\,kPa = 482\,kPa$$



② determine footing thickness:

$$V_f = P_f = 9752\,kN$$

$$V_c = 0.38\,\lambda\,\phi_c \sqrt{f_c'} = 0.38 \times 1 \times 0.65\sqrt{30} = 1.35\,MPa$$

$$V_c\ 1.35\,MPa = 1350\,kPa$$

$$V_c = v_c\, b_o \times d$$

$$V_c = V_f = 9752\,kN$$

$$b_o d = \frac{9752\,kN}{1350\,kPa} = 7.22\,m^2$$

$$b_o = 2B' + 2C + 4d$$

$$b_o d = (2 \times 0.6 + 2 \times 1.2 + 4d)\,d = 7.22$$

$$d = 0.967\,m \simeq 1\,m$$

$b_0 = 7.47$

$\beta_c = \frac{C}{B} = \frac{1.2}{0.6} = 2$

$v_c = \left(1 + \frac{2}{2}\right) 0.19 \lambda \phi_c \sqrt{f_c'}$

$= 2 (0.19) \cancel{1} 0.65 \sqrt{30} = 1.35 MPa$

$v_c = \left(\frac{4 \times 1}{7.4} + 0.19\right) \times 0.65 \sqrt{30} = 2.6 MPa$

$\therefore v_c = 1.35 MPa$ is governing one

$\Rightarrow d = 0.967 m$

determine overall footing depth h

$d_b = 25 mm$ $\rightarrow$ 25M rebar

Cover $= 75 mm$

$h = 0.967 m + \frac{25}{2} + 75 = 1067 mm = 1100 mm$

$\therefore d = 1100 - \frac{25}{2} - 75 = 1012.5 = 1020 mm$

check one way shear requirements

$V_f = q_f \times b \times \left(\frac{b - (B \text{ or } C)}{2} - d\right) = 1366 kN$ or $1908 kN$

2017

$d_v = \max(0.9d, 0.72h) = 918$ mm

$$\beta = \frac{230}{1000+918} = 0.12$$

$V_c = 0.65 \times 0.12 \sqrt{30}\ 4500 \times 918 = 1765$ kN

$\therefore$ shear reinforcement is required
use 10M

$V_s = V_f - V_c = 2017 - 1765 = 252$ kN

$$S = \frac{0.85 \times 200 \times 400 \times 918 \times 1.43}{252 \times 10^3} = 354 \text{mm} = 350 \text{mm}$$

$\therefore$ 10M @ 350 mm spacing

bending reinforcement:

$$M_f = q_f \left(\frac{b-t}{2}\right)\left(\frac{b-t}{4}\right) b$$

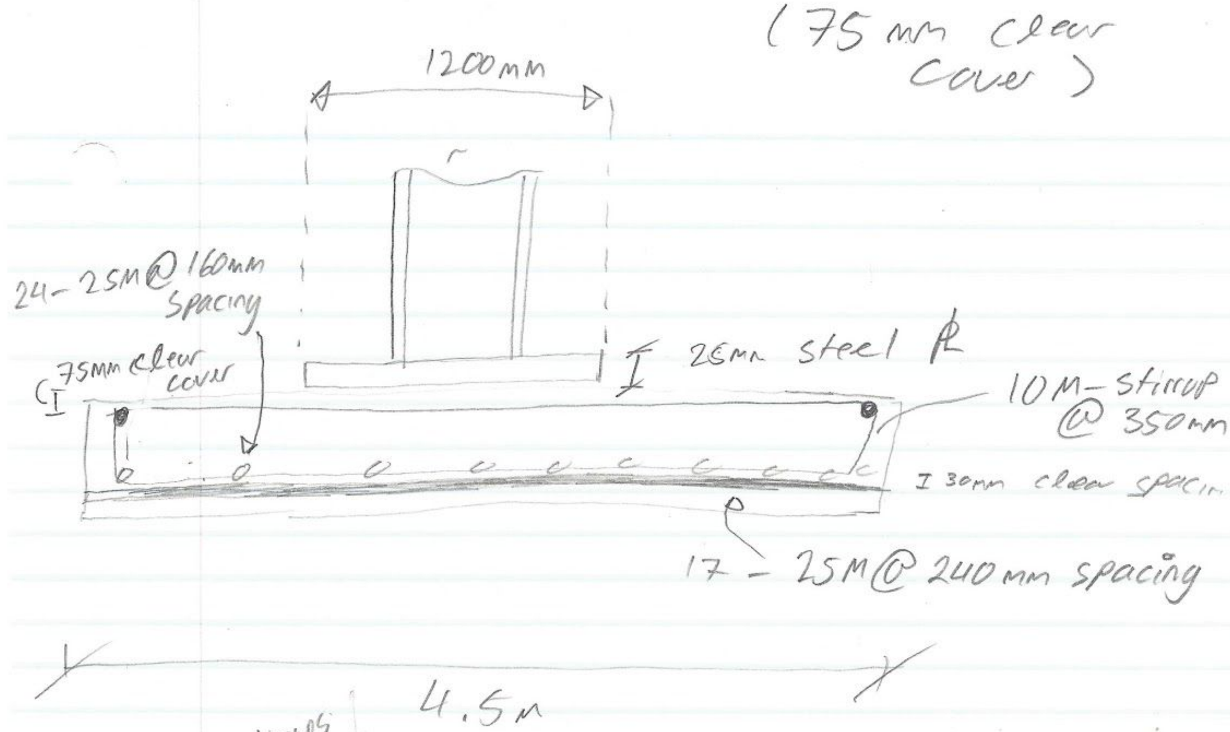
$t = B$ or $C = 0.6$ m or 1.2 m

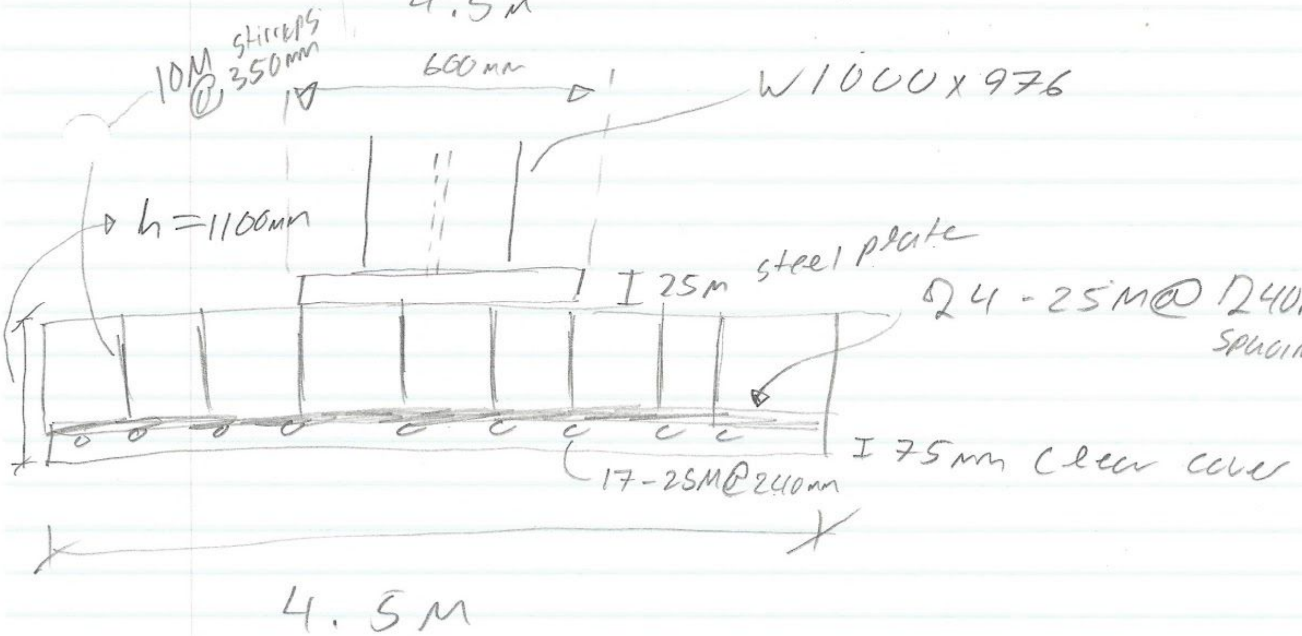
$\therefore M_f = 2953$ kNm (C) or 4124 (B)

$A_s^{(+)} = 8536\ \text{mm}^2$ $\quad$ $A_s^{(+)} = 12024\ \text{mm}^2$

17-25M $\quad$ 24-25M

$$S = \frac{4500 - 17 \times 25 - 2 \times 75}{16} = 245 \text{mm} \qquad S = 163 \text{mm}$$


(75 mm clear cover)
1200mm
24-25M@160mm spacing
75mm clear cover
25mm steel PL
10M-stirrup @ 350mm
30mm clear spacin
17-25M@240mm spacing
4.5m


10M stirrups @ 350mm
600mm
W1000x976
h=1100mm
25m steel plate
24-25M@240m. spacin
75mm clear cover
17-25M@240mm
4.5M

basement wall analysis:

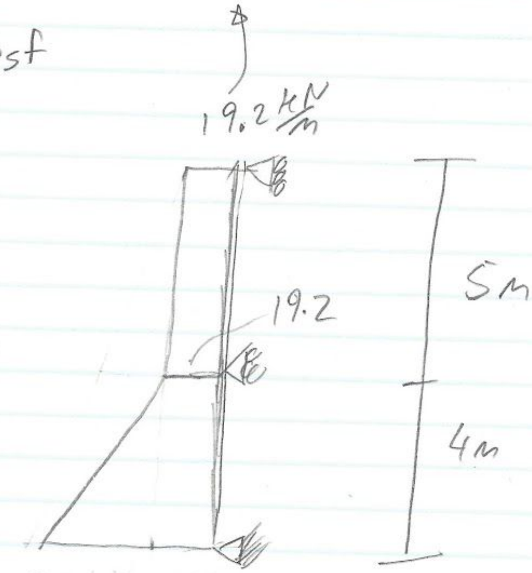
$\sigma = 25H$ (min 400 Psf)

$\sigma_{max} = 738$ psf

$\sigma = 35$ kPa

$w_f = 35 \text{ kPa} \times 1\text{m}$

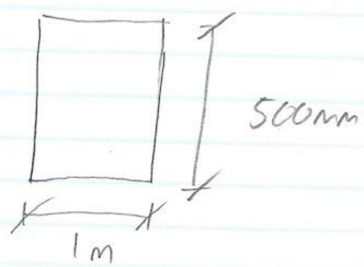
$= 35 \frac{kN}{m}$



$M_f = 44$ kNm → from sframe

$V_f = 58$ kN

$d_b = 15M$



$d = 500 - 75 - \frac{15}{2}$

$= 418$

$$A_s = 0.0015(30)(1000)\left(418 - \sqrt{418^2 - \frac{3.85(44)\times10^6}{30\times1000}}\right.$$

$= 306 \text{ mm}^2$

$$S \leq 200\frac{1000}{306} = 653$$

∴ use $S_{max} = 500$mm 15M@ 500 mm

$A_s = 400\,mm^2$

$$\rho = \frac{A_s}{bd} = \frac{400}{1000 \times 418} = 0.0096 << 0.027 = \rho_b$$

$\therefore$ o.k

shear design

$$d_v = 0.9 \times 418 = 376$$

$$\beta = \frac{230}{1000 + 376} = 0.17$$

$$V_c = 0.65 \times 1 \times 0.17 \sqrt{30} \times 1000 \times 376 = 228\,kN < V_f$$

$\therefore$ no shear reinforcement needed

Min horizontal reinforcement

$$A_g = 1000 \times 500 = 500 \times 10^3\,mm^2$$

$$A_{min} = 0.002 A_g = 1000\,mm^2$$

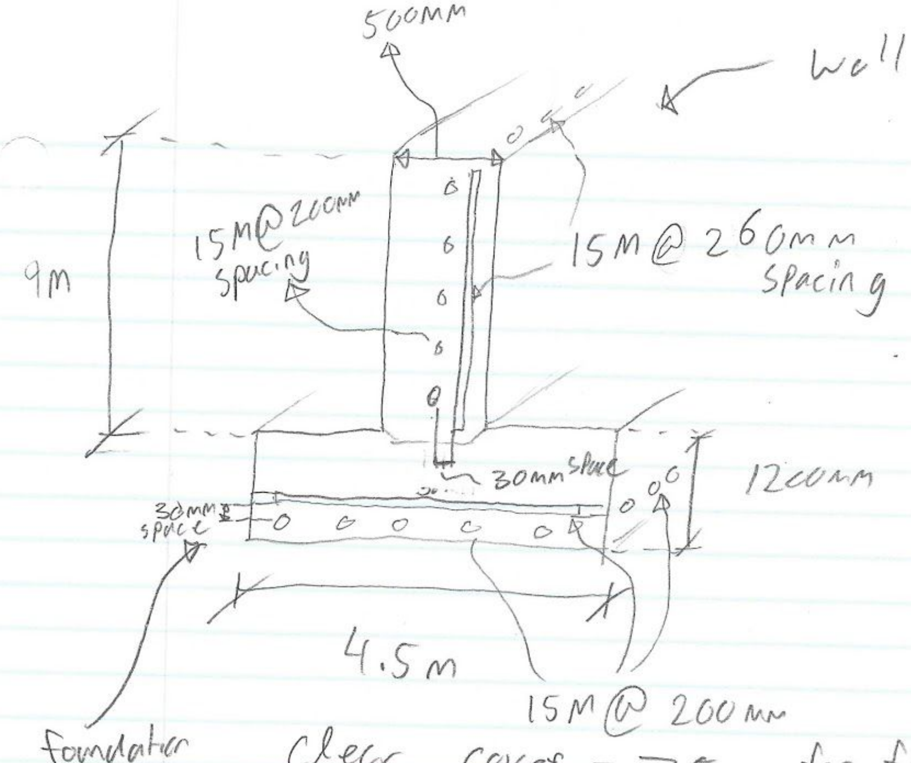
$$S \leq A_b \frac{1000}{A_s} = 200$$

$\therefore S = 200\,mm$

Min vertical reinforcement

$$A_s = 0.0015 \times 500 \times 10^3 = 750\,mm^2$$

$$\therefore S = 200 \frac{1000}{750} = 260\,mm$$ for vertical reinforcement



Clear cover = 75mm for foundation and 30mm for wall for rebar