Chancellor Boulevard and East Mall Intersection: Detailed Design

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University of British Columbia

CIVL 446

April 08, 2016

Westcoast Consulting Group Inc.

CHANCELLOR BOULEVARD AND EAST MALL INTERSECTION: DETAILED DESIGN

Submitted to Krista Falkner
UBC Campus and Community Planning

By Team 4
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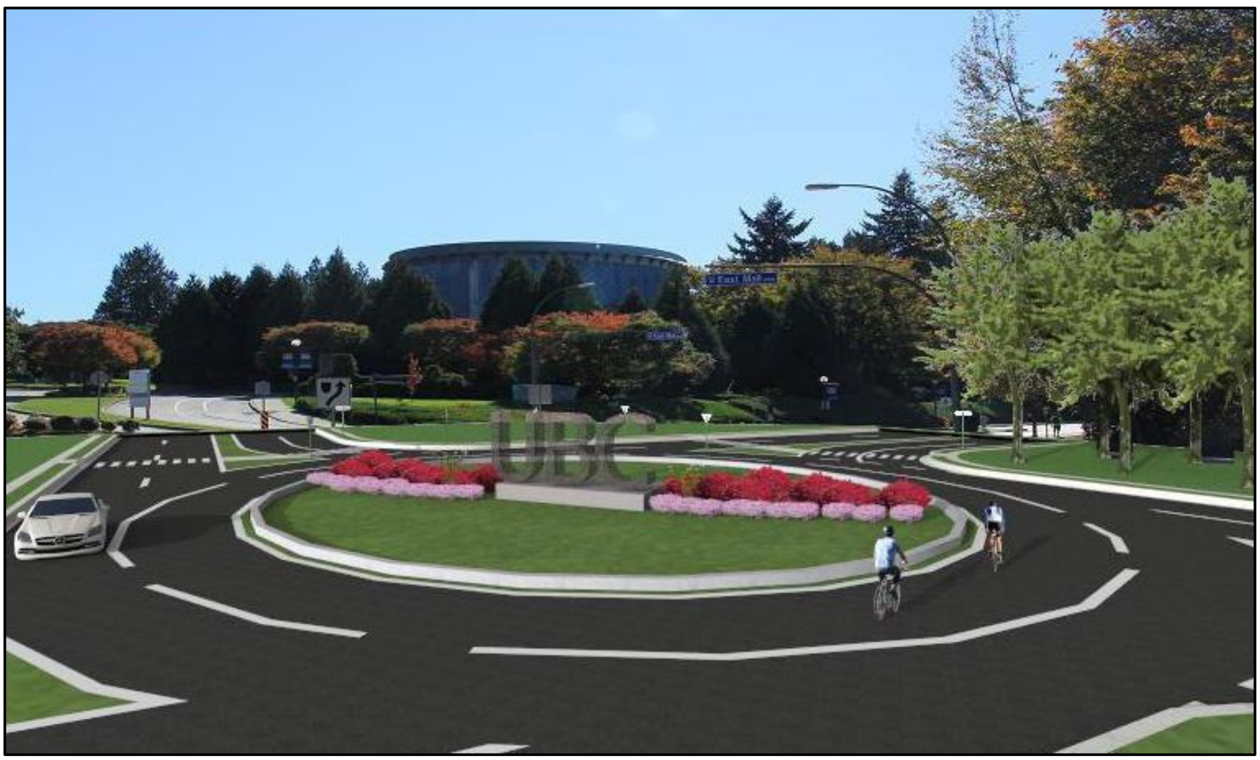


University of British Columbia
CIVL 446 – Capstone Design Project
April 8, 2016

Executive Summary

The intersection at Chancellor Boulevard and East Mall is currently facing several challenges and requires a complete redesign. The University of British Columbia (UBC) Campus and Community Planning group has commissioned Westcoast Consulting Group Inc. to prepare detailed design plans for the intersection redevelopment. The chosen design addresses the anticipated future demands of the intersection, creates a safe and efficient traffic flow, accommodates alternative modes of transportation, and follows UBC's sustainable vision, all while creating a welcoming gateway to the UBC campus. Technical aspects of the design focused on were: Roadway Geometry, Wastewater Management, Construction Management, Structural design, and geotechnical design

The new intersection is a traffic circle with a two-lane entry and one-lane exiting system. Included in this report is a number of drawings detailing the geometry of the intersection. A welcome sign and structural arch have been incorporated into the design to address the aesthetic requirements. Based off Qualhymo Water Balance Model outputs, a comprehensive Stormwater Management Plan has been assembled to accommodate a potential flooding events. Additionally, an extensive Construction Management Plan has been developed to minimize traffic impacts, time of construction, and any social or environmental impacts on the adjoining private neighbourhood. The project is estimated to cost $4.7 million and is scheduled for a 6-month permitting phase followed by a 4-month construction phase.

Contents

List of Figures

List of Tables

1.0 Introduction

1.1 Project Background

Located at the north end of the University of British Columbia (UBC) campus, the Chancellor Boulevard and East Mall intersection connects private housing north of Chancellor Boulevard to the university campus. The intersection contains four separate approaches in an unconventional orientation, including bike lanes and pedestrian crossings as seen in Figure 1. Users on the road include cyclists, pedestrians, single occupancy vehicles, and heavy vehicles, such as trucks and busses. Recently, the University of British Columbia (UBC) Campus and Community Planning group commissioned Westcoast Consulting Group to prepare a feasibility design for intersection redevelopment. With appropriate design considerations and construction planning, this site can be transformed to meet all the future requirements of UBC's growing community.

Figure 1: Existing Intersection Layout (google Earth)

1.2 Detailed Design Project Scope

In the feasibility design report, a number of recommendations were made on how the intersection could be improved. The purpose of this detailed design report is to implement the feasibility study's findings, and create a comprehensive framework that can be used to complete the proposed design. Westcoast Consulting will consider a number of technical aspects of the design, but the scope will emphasize the following subjects: Roadway Geometry, Wastewater Management, Construction Management, Structural design, and geotechnical design.

1.3 Contributions to Final Design

Westcoast Consulting Group is a multi-faceted civil and environmental engineering team from the University of British Columbia. The roles and responsibilities for each team member can be found in the table below:

Table 1: Member Contributions

Team Member	Role	Responsibilities
Diana Demmers	Project Engineer	Stormwater Catchment Design, Sustainability Initiatives
Christian Slotboom	Assistant Project Engineer	Construction Management Plan, Project Scheduling and Estimate, Geotechnical Design
Ash Laing	Engineer-in-Training	Structural Design, Drafting
Cory Sutherland	Engineer-in-Training	Structural Design, Sketchup Modeling and Rendering
Vickramjit Poonia	Specialist Engineer	Traffic Engineering and Data Analysis, Site Design and Conceptualization
Talen Springer	Technologist	Construction Management Plan, Synchro Modelling, Roundabout Design

2.0 Roundabout Design

2.1 Summary

In the feasibility design report, WestCoast Consulting has developed a comprehensive design package for UBC Campus and Community Planning. The proposed design addresses the anticipated future demands of the intersection, creates a safe and efficient traffic flow, accommodates alternative modes of transportation, and follows UBC's sustainable vision, all while creating a welcoming gateway to the UBC campus. Figure 2 below shows an overview of our roundabout layout.

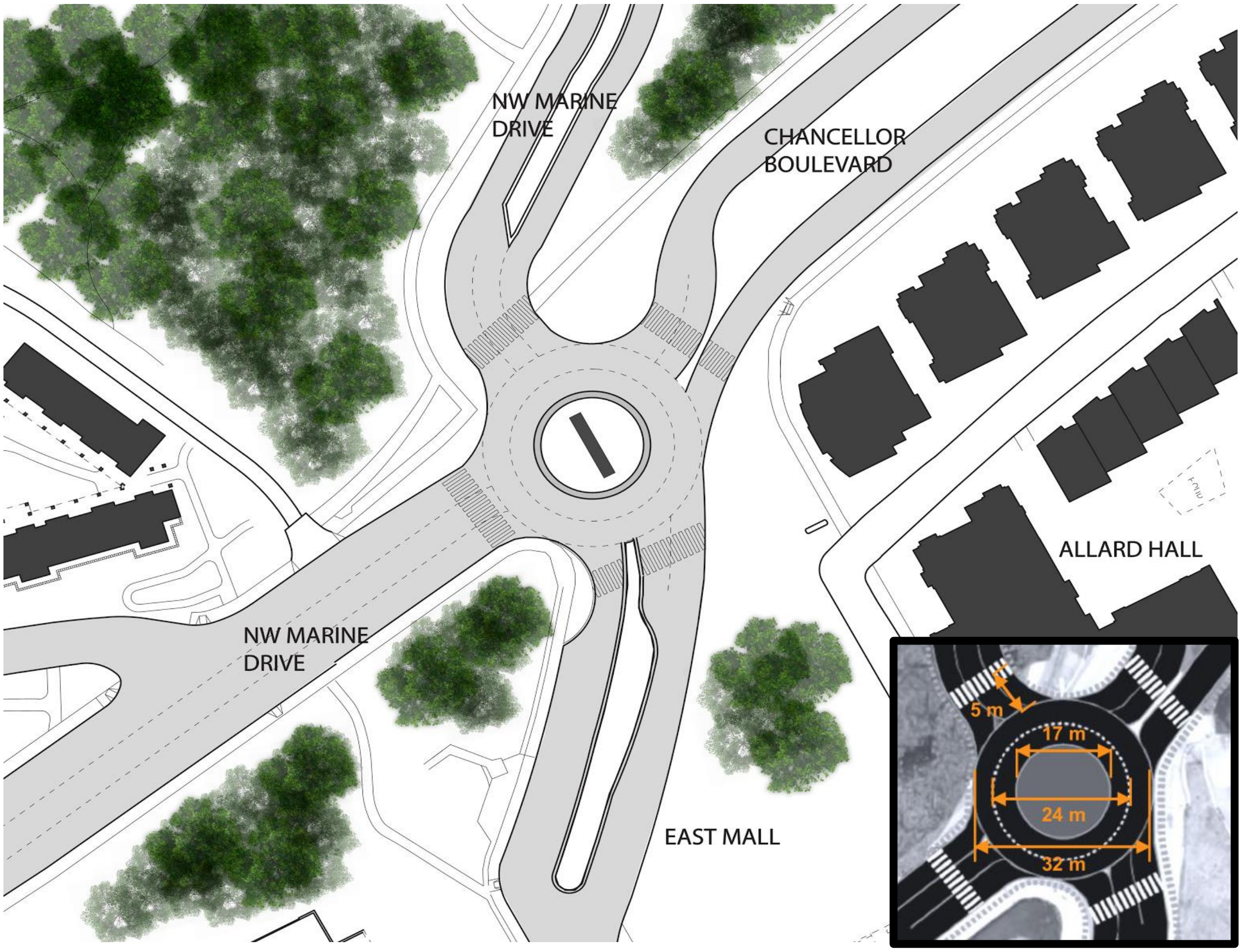


Figure 2: Roundabout Design and Road Alignment

The roundabout design implements a two lane entry system, while also retaining the one lane exit system. The right hand lane acts as a right turn only system for both cyclists, and vehicle traffic, while the interior lane will provide the same utilization for through and left turning traffic. A green space island will be created in the center of the intersection consisting of a 17-meter diameter circle: the minimum required spacing for a roundabout system in the highway capacity manual for a 30km/hr speed limit. Two lanes will be created outside of the 17-meter diameter, each consisting of 3.7 meters. The entire roundabout will be designed with a maximum diameter of 32 meters. The approaches to the roundabout will maintain a 50km/hr speed limit identical to the current limit in place on each of the entry points except for East Mall, which has a reduced speed of 30km/hr. East Mall will maintain its current speed limit. The interior of the roundabout will act as a water management system in the event of significant overland flow, while also providing an area to place a welcome sign to the UBC campus. Figure 3 below shows the proposed road alignment and roundabout design. The road way geometry is specified by a number of construction ready documents in Appendix F.

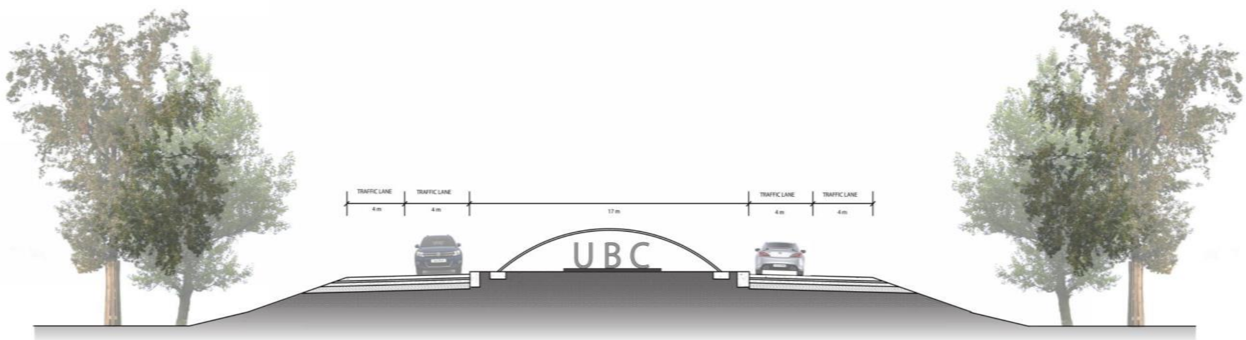


Figure 3: Roundabout and Road Cross Section

2.2 Vehicle Traffic modeling

In designing the roundabout, WestCoast Consulting strived to make the most efficient use of land while maintaining an acceptable level of service at the intersection. It was established that a minimum level of service (denoted by the letter D) would be acceptable and a volume to capacity ratio of 0.95 would act as the maximum delay threshold. Intersection capacity utilization equations were used to develop the level of service.

The modelling software, Synchro 6, was used to model the roundabout design. The software is limited in its ability to analyze highway capacity manual level of service, but allows for intersection utilization capacity and volume-to-capacity ratios to compensate for this limitation. The level of service and volume-to-capacity ratios were analyzed for the AM, Mid-Day, and PM time frames, with the PM time providing the worst case scenario for all modes of transportation.

A level of service "D", with a volume to capacity ratio of 0.93, was found for the PM time frame. This is within the acceptable design limits.

2.3 Cyclist and Pedestrian Traffic

Cyclists will operate the roundabout as a single occupancy vehicle using the same traffic patterns associated with the light and heavy vehicle traffic. Signs indicating shared use cyclist lanes will be placed prior to entering the roundabout along with pavement markers on both the interior and exterior lanes of the roundabout. Approaching the intersection, cyclist lanes will be used and then merged into the shared use lanes prior to the pedestrian crossings outlined below. All current pedestrian crossings except for the crossing on the west side of the intersection will be removed and replaced with new crossings that will not impede the roundabout.

A new pedestrian crossing will be placed on the north-south and east sides of the intersection. Each crosswalk will be a minimum of 5 meters away from the roundabout and yield signs. The purpose of this separation is to allow a single vehicle to stop prior to the crossing without producing congestion in the roundabout when pedestrians are crossing. The crosswalks will also require pedestrian activated flashers to be implemented providing a high visibility notice to drivers that there are pedestrians currently on the roadway. Based on the City of Vancouver's flasher warrant system, this is not required. However, from previous experience, the implementation of high visibility lights can decrease high speed pedestrian collisions during poor visibility periods enough to justify the cost. According to the City of Vancouver's sightline guidance, a minimum stopping sight distance of 65 m is required for adequate intersection visibility when the posted speed limit is 50 km/hr. Elements

2.4 Sustainable Modes of Transportation

The design layout chosen allows intersection access for both pedestrians and cyclists, promoting access and liveability in the surrounding area. Bike lanes create a buffer against cars on approach to the intersection, and there are two vehicle lanes within the roundabout. These lanes allow for an improved flow and reduced accident risk, as cyclists will operate similar to other vehicles in the roundabout. Sidewalks and crosswalks allow for safe crossing of pedestrian traffic. Furthermore, the intersection design is transit-friendly as the roundabout spacing accounts for the turning radius of large vehicles such as buses, shuttles and trucks.

The multimodal connectivity of the intersection design is user-friendly and promotes sustainable modes of transportation. By providing safe modes of active transport, the project encourages decreased use of motorized transport and therefore decreased greenhouse gasses (GHG) emissions.

2.5 Greenroads Rating System

Greenroads is a rating system that awards credits for sustainable reconstructed and rehabilitated roads. This roundabout design meets many of the Greenroads Rating System project requirements, including minimal land use at the project site, use of recycled materials, and low impact development through stormwater management. Furthermore, the proposed intersection design has a positive social impact, as it supports all modes of transportation. During construction the project management team will implement systematic quality management practices through a Quality Control Plan (QCP) that will monitor processes, test materials and track deficiencies. Throughout the demolition and construction process the project team will ensure the proper handling of recyclable materials through training for all site employees by implementing a Waste Management Plan. The project will minimize or eliminate impact on peak hour traffic and aim for early project completion.

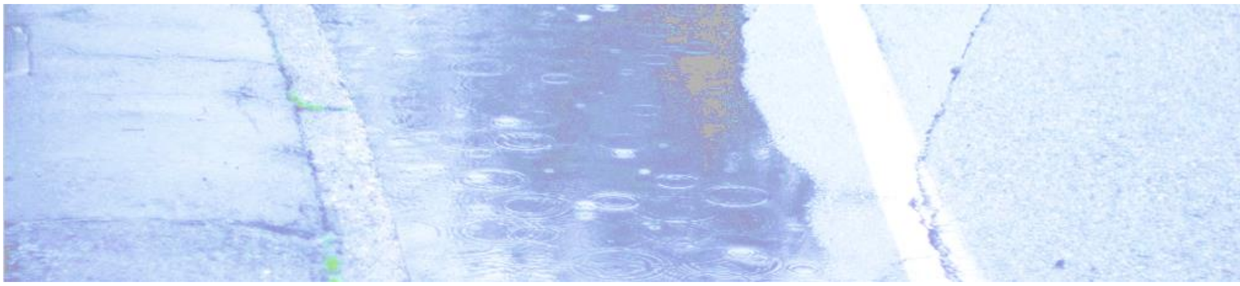
The proposed intersection design also considers Greenroads *Environment & Water* credits through the inclusion of native plant species (Bog and reduction of stormwater flow impacts. Additionally, the project staff will identify utility conflicts and provide solutions in order to avoid interference with the construction activities and the proposed Stormwater Management Plan discussed section 3.0.

2.6 Lighting Design

Following BC Hydro's province wide initiate to transition from HPS (High Pressure Sodium) fixtures to LED (Light-emitting diode) fixtures, LED fixtures are used in streetlights leading up to the intersection approach, and within the intersection itself as part of the lighting for the welcome sign structure. LED fixtures present a number of advantages over the traditional HPS fixtures including efficiency, light control, reduced pollution, and colour correctness.

LED lamps are a much more efficient use of energy: using up to 40-50% less electricity than HPS lamps in standard use. LED fixtures also have a much longer lifespan than the traditional HPS fixtures, and repairs often consist of replacing portions of the diodes rather than complete lamp fixture. Furthermore, as LED lamps are adjustable in brightness and intensity, they allow greater flexibility in usage situations. The white colour of light presented by LED fixtures also improves visibility and clarity as colours are preserved when viewed compared with the yellow light of HPS lamps.

3.0 Stormwater Management



3.1 Stormwater Management

On February 1, 2016, two WestCoast Consulting team members visited the intersection to conduct a field assessment and take pictures of current site conditions. Due to wet weather conditions during the site visit, there was evidence of stormwater management issues at the current site location. Depressions in the current impervious pavement design caused water pooling at various locations. Runoff issues were clearly evident on a day of average precipitation conditions, which raises concerns regarding current stormwater management performance in the event of a large storm. Due to problems with the current intersection, WestCoast Consulting is providing a runoff plan that works in conjunction with the University of British Columbia Integrated Stormwater Management Plan.

Figure 4. UBC Storm Sewer and Catchment Outfalls Map

The intersection is located in the North Catchment of the UBC storm sewer catchments and outfalls (Figure 4). Stormwater at the intersection flows northwest towards the spiral drain located next to the Museum of Anthropology. Currently, there are limited measures in place to stop the flow of water travelling down Marine Drive and over the cliffs or towards Spanish banks.

Measures need to be taken to reduce to runoff at the project site as there is concern regarding erosion of the cliffs along the beach at Spanish banks. Furthermore, piping in the North Catchment area is now undersized for the total quantity of water that must be moved. In a sufficiently large storm, the drains will back up into the street and the Spiral Drain has limited capacity and water will back up into the upstream piping system.

3.2 Stormwater Infiltration Gallery

A number of measures have been taken in order to reduce stormwater runoff including the design of an infiltration gallery below the centre of the roundabout (Figure 6). The inner lane of the roundabout will have a 2.5% slope towards the centre and the curb will include c-cuts (Figure 5) so runoff can easily flow to the centre of the roundabout. Below the vegetation will be a small lift of topsoil to support growth of the rainwater vegetation; below the topsoil will be a 1.5 meter section of fine soil fill followed by 1 meter of 50 mm clear crush drainage rock. The fine soil fill will have a void space ratio of 0.6 while the drainage rock will have a void space ratio of 0.4. Based on the void spaces, the total capacity of the central circle will be 295 cubic meters. The average rainfall in Vancouver during a significant storm event equates to 58 millimeters per day, the roundabout would be able to absorb the direct rainfall along with the runoff from the interior lane.

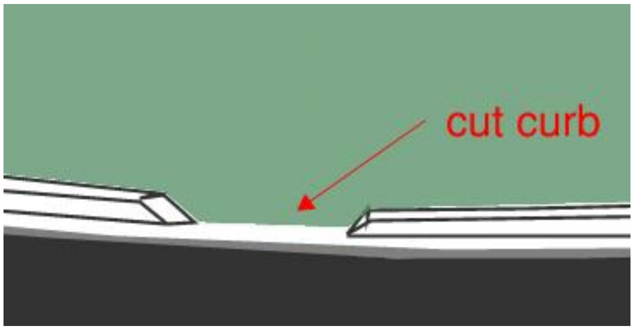


Figure 5. Roundabout Centre Curb Cut

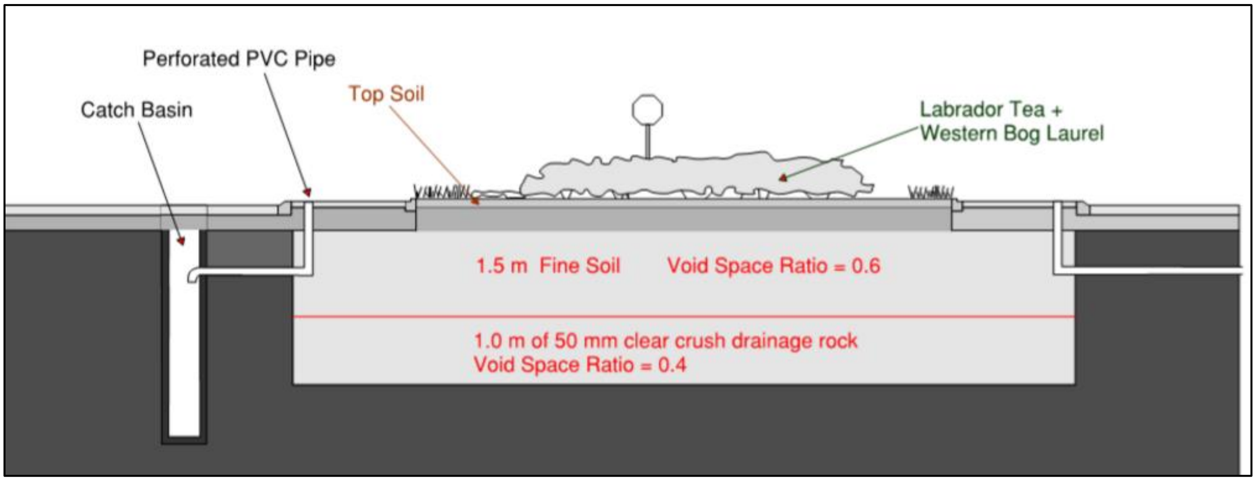


Figure 6. Stormwater Infiltration Gallery Design

3.3 Stormwater Rain Garden

The centre of the roundabout will be sunken in order to include a rain garden where runoff can pond and infiltrate the stone gallery below. The centre of the roundabout will include Labrador tea and western bog laurel, which are both native plants for wet site conditions.

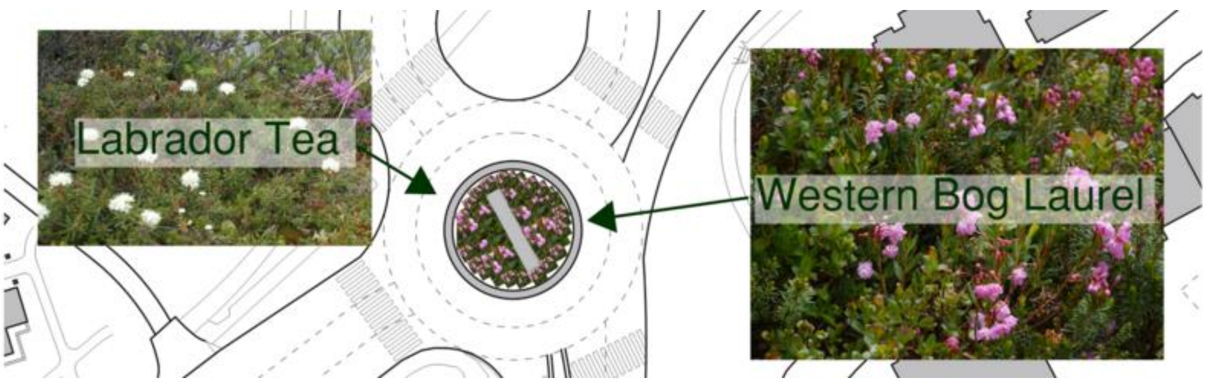


Figure 7. Rain Garden Landscaping Layout

Bio retention techniques provide removal of pollutants through sedimentation and filtering processes. Densely landscaped areas with a lot of ground cover over fine soil and sand filter media will provide enhanced pollutant removal rates. Should the green space in the roundabout become overwhelmed catch basins will be located upstream from the roundabout and underneath the road. The basins will work to direct runoff to perforated PVC pipes that will enter the infiltration gallery of stones and soil situated beneath the roundabout. Any underground piping will be placed to avoid existing utility lines. Runoff in excess of the gallery infiltration capacity will be directed to the UBC storm system. The exterior lane of the system will be graded away from the central circle and drive any excess overland flow to culverts located along the perimeter of the intersection. The culverts will tie into the main stormwater trunk line located below the intersection as provided by the UBC utilities and services office. Furthermore, the road to shoulder transition will have a 30mm drop from the road surface to the grass shoulder. There will be a 5% grass buffer to ensure that water and sediment continues to move and gravel will be used as a transition buffer.

3.4 Qualhymo Water Balance Model

In order to quantify the reduction in runoff conditions the Qualhymo Water Balance Model has been used to obtain values for source control infiltration and catchment infiltration from the addition of surface source controls. Two analyses were performed using the water balance model including the addition of the rain garden to the centre of the roundabout and the option for pervious pavement on road sections. Additional information on water balance model inputs and outputs can be found in Appendix A.

3.4.1 Qualhymo Water Balance Inputs

The base case scenario without the addition of additional surface conditions (rain garden) was considered to be 100% impervious pavement. The following table summarizes the water balance model inputs the addition of rain garden source controls:

Table 2. Water Balance Model Site Condition Inputs

Drainage Areas	Native Soil Types	Land Uses	Surface Conditions	Source Controls
<u>Modelled Area</u> Area **168.9 sq. m** Length **17 m**	<u>Sandy Loam</u> **Area** 168.9 sq. m **Depth** 100 mm **Field**	<u>Street-Residential</u> **Area** 168.9 sq. m **Description** Typical Row Width = 20.1 m Typical Paved Road	<u>Impervious Pavement</u> **Initial Area** 168.9 sq. m **Source Control Area** 0 sq. m	

Slope **0.025 m/m**	**Capacity** 20.3% **Wilting Point** 13.7%	Width = 7.5-8.5m Typical Concrete Sidewalk Width = 1.5-1.8m (2 sides) *Note: Surface conditions are based on maximum values where ranges are shown*	Pervious Cover **Initial Area** 0 sq. m **Source Control Area** 168.9 sq. m **Depth** 100mm	Rain Garden **Size** 67.56 sq. m Rain Garden with Underdrain **Size** 101.34 sq. m

The below table summarizes rain garden inputs:

Table 3. Rain Garden Water Balance Model Inputs

Soil Properties	
Soil Name	Clean Sand
Type	Pervious
Depression Storage	7 mm
Rational Coefficient	0.2
Retardance Roughness	0.03
Field Capacity	12.1%
Wilting Point	11.7%
Rain Garden Properties	
Crop Coefficient	1
Soil Rooting Depth	200 mm
Ponding Depth	100 mm

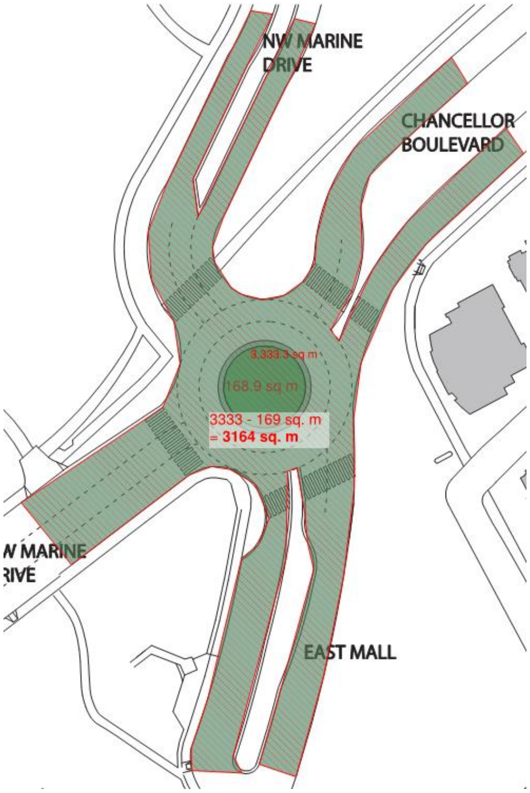


Figure 8: Impervious Area

Too much impervious to rain garden area can overwhelm plants and sediment plumes for, which decreases infiltration rates. The use of pervious pavement could improve conditions by reducing the amount of sediment reaching the rain garden area. The addition of pervious pavement would allow plants to recover more easily. Further information regarding the option to add pervious pavement to the roundabout design, including additional costs, is discussed in Section 5. Figure 8 shows the area that has been considered for the addition of pervious pavement. All other water balance model inputs were the same as Table 3 above.

3.4.2 Qualhymo Water Balance Outputs

Outputs from the water balance model provide water volumes for source control infiltration, catchment infiltration, total losses, and total discharge. The addition of rain garden source controls (Table 3) has been to decrease total discharge to 24% from 60% of total rainfall volume of 5580m^3 as measured at Vancouver International Airport. Table 4 and Figure 9 below show water balance model outputs.

Table 4. Water Volume Allocation for Base Case Scenario with Rain Garden

	Base Case	Source Control
Rainfall Total	**5580 m^3**	**5580 m^3**
Total Discharge	3354 m^3	1364 m^3
Total Losses	2202 m^3	2052 m^3
Catchment Infiltration	24 m^3	2164 m^3
Source Control Infiltration	0 m^3	0 m^3

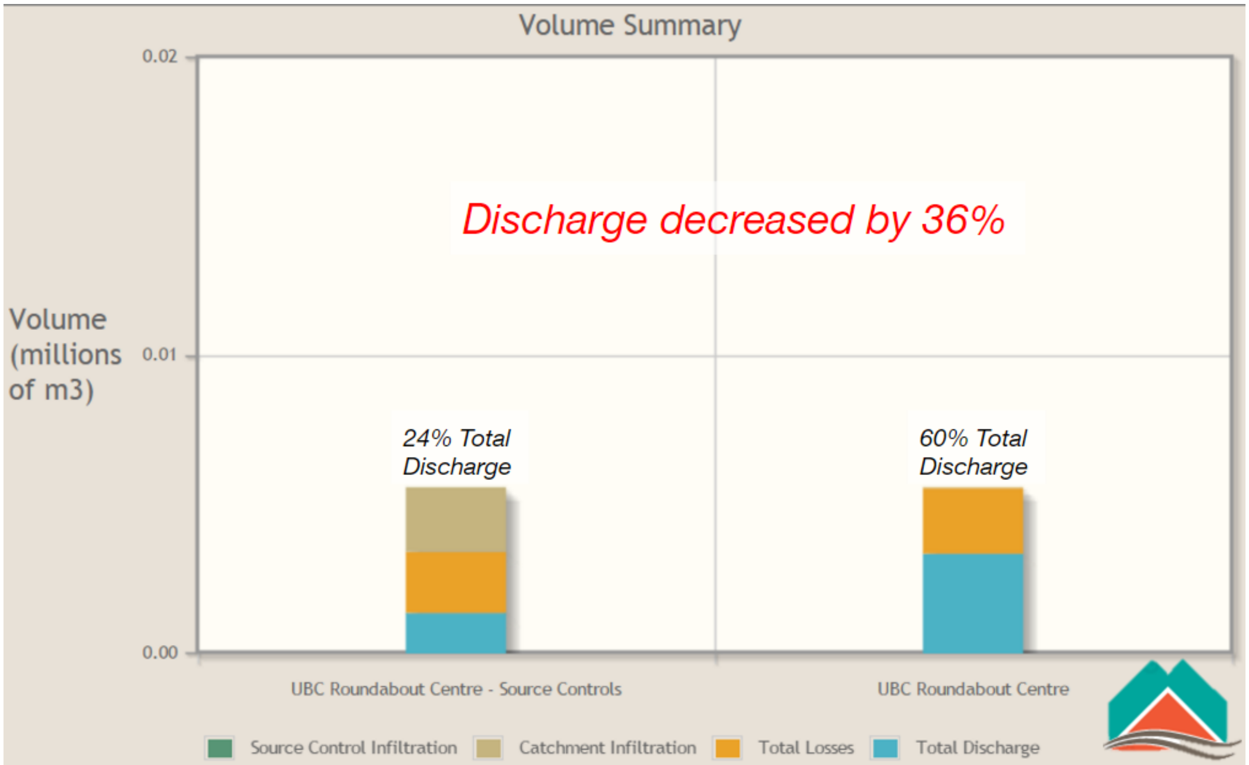


Figure 9. Water Balance Model Volume Summary for Rain Garden Source Control

The above figure demonstrates the difference in precipitation volume allocation. The bar on the right is the base condition without the addition of any source controls. Furthermore, the bar on the left shows the decrease in discharge and increase in catchment infiltration with the addition of a rain garden with the properties outlined in the previous section. The addition of a rain garden to the centre of the roundabout will decrease discharge volumes by 36%.

Figure 10 below shows a decrease in discharge for the addition of pervious pavement to the area outlined in the previous section. Discharge volumes were found to decrease from 92784 m^3 to 48228 m^3. This is a 43% decrease in total rainfall volume allocated to discharge. Furthermore, as outlined in Table 4, catchment infiltration was found to increase from 464 m^3 to 36620 m^3. The addition of pervious pavement to the intersection design is an option that could significantly decrease discharge volumes in the North Catchment of the UBC storm sewer catchments and outfalls.

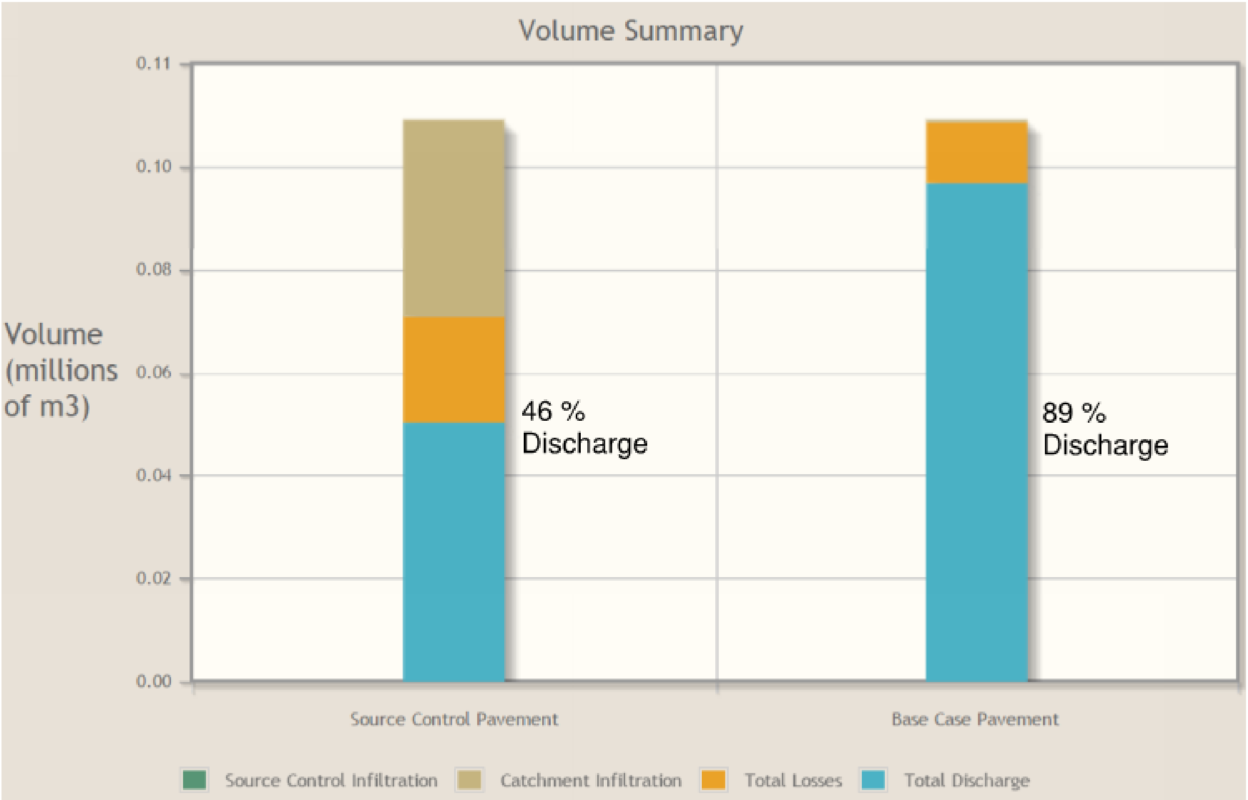


Figure 10. Water Balance Model Volume Summary for Pervious Pavement Source Control

Table 5. Water Volume Allocation for Base Case with Pervious Pavement Surface

	Base Case	Source Control
Rainfall Total	**104533 m^3**	**104533 m^3**
Total Discharge	92784 m^3	48228 m^3
Total Losses	11285 m^3	19685 m^3
Catchment Infiltration	464 m^3	36620 m^3
Source Control Infiltration	0 m^3	0 m^3

4.0 Structural Design

Site aesthetics were identified as an important area of focus for the design. To meet this requirement, the roundabout design incorporates a unique artistic piece that welcomes visitors to the UBC campus. Chancellor Boulevard and NW Marine Drive are major entry points to the campus, and should provide a warm welcome to visitors and passerby. The sign consists of steel, wire mesh UBC letters that are supported by a concrete base. The wire mesh is staggered, which creates a semi-transparent gossamer shape. In conjunction with the Vancouver Bird Strategy, the wire mesh has small openings that provide shelter for small birds. Furthermore, the steel wire is completely sourced from recycled steel, as the structural requirements are minimal.

Figure 11: Welcome Sign Rendering

4.1 Structural Arch

As an original deliverable for this project, a pedestrian observation platform was suggested as a way to enhance the aesthetics of the area. However, an evaluation and feasibility analysis indicated this would not be the most practical, aesthetic, practical, or economical addition to the roundabout. An observation platform would encourage pedestrians to congregate around the intersection, potentially endangering those users. Additionally, there is a land use restriction and the view is obstructed by surrounding trees. Several UBC students were interviewed and 91% said they would not be interested in a pedestrian observation platform in that area of campus. When investigating alternatives, a structural welcome arch was determined to be the best option. Not only does it create an additional aesthetic component to the roundabout, but an arch does not cause pedestrians to congregate in the middle of the intersection. This welcome arch is an optional design addition and its incorporation will be UBC Campus and Community Planning's decision. A rendering of the intersection with an arch is shown below in Figure 12.

Figure 12: Roundabout Design Rendering

4.2 Structural Loading

Westcoast has considered different structural loading scenarios for each major component of the project. These considerations include loading on the structural steel arch and welcome sign, concrete footing and foundation design for both structures, and geotechnical considerations.

All structural components have been designed in accordance with the National Building Code of Canada (NBCC) and Canadian Institute of Steel Construction (CISC) engineering standards. Various load combinations from the NBCC have been considered including dead load, live load, wind loading, and snow loads. Due to the close proximity to traffic, impact loading was also considered. Seismic design was not considered for structural loading cases because the arch and welcome sign act as artistic components of the intersection, and will not be inhabited. The structure will be evaluated for environmental weathering and rust protection along with all welded connections of the arch.

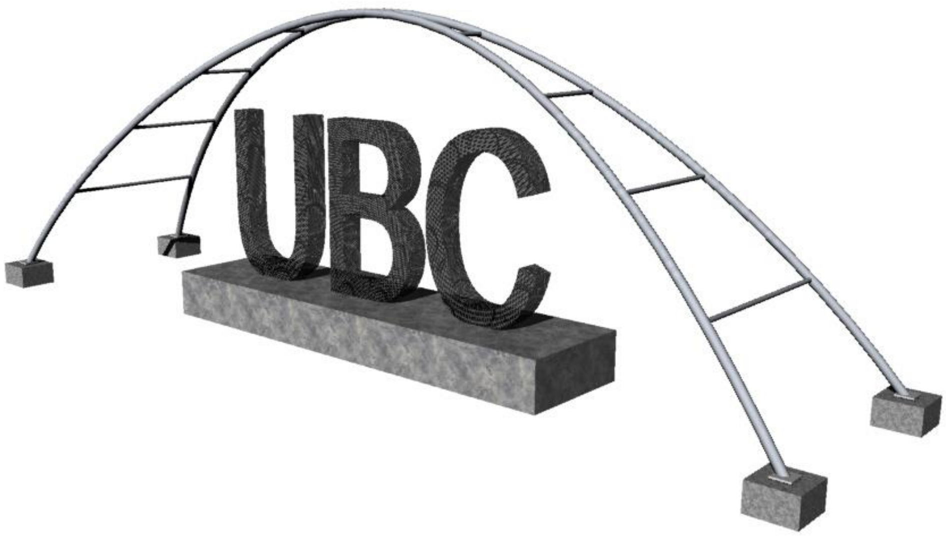


Figure 13: Structural Configuration of the Arch

To ensure a steel arch is feasible given the site geometry, SAP2000 (structural analysis & design software) was used to design a suitable steel cross section and member sizing. Optimization and analysis produced an arch constructed of 10.75 x 0.25 G40.20 Type W hollow structural steel, spanning 12m across the intersection island and over the welcome sign. In-depth rigorous structural calculations related to the arch design can be found in Appendix A, along with construction details and sections in Appendix F.

4.3 Recycled Steel and Aggregate

The proposed design will incorporate the use of recycled materials to reduce the need for extraction and production of virgin materials. The welcome sign component of the design will be primarily comprised of recycled steel which conserves energy and resources while reducing greenhouse gas emissions. Additionally, the project will include the use of recycled hot mix asphalt and a reduction in the amount of portland cement by increasing the use of supplementary cementing materials (SCMs).

4.4 Foundation Design

Westcoast Consulting will commit to completing a full geotechnical assessment, which will include addressing several of the potential challenges examined in section 4.1.7.2. Several assumptions have been made regarding the current on-site situation. All soil characteristic assumptions are clearly stated in Appendix B.

4.5 Sign Foundation Design

The sign foundation will be placed on top of the proposed infiltration gallery. As a result, beneath this foundation there is approximately 1.5 m of Native Fill Sand a filter fabric barrier followed by 1m of 50mm clear stone. The infiltration gallery figure shown in Appendix F provides an example of the proposed geotechnical design. The welcome sign's foundation design dimensions are described in Table 6 below.

Table 6: Concrete foundation sizing for UBC Welcome Sign

	Length	**Width**	**Height**
Dimension (m)	3	1.5	0.6

The total weight of the UBC steel sign is 15 kN (1540 kg) and the footing beneath it weighs 64.9 kN (6584 kg). The soil withstands an allowable stress of 200 KN/m2. The sign and footing combined have a total distributed load of 29.35 KN/m2. Comprehensive calculations can be found in Appendix C, along with detailed construction drawings in Appendix F.

4.5.1 Structural Arch Foundation Design

Similar to the welcome sign, beneath the arch's foundation there is approximately 1.5 m of Native Fill Sand, a filter fabric barrier, and 1m of 50mm clear stone. The structural arch's foundation design dimensions are described in Table 5 below.

Table 7: Concrete Foundation Sizing for Structural Arch

	Length	**Width**	**Height**
Dimension (m)	0.5	0.5	0.3

The structural arch's weight will be distributed through four concrete shallow footings. The total weight of the arch is 12 kN (1223 Kg) and the weight of the footing is 1.79 kN (183 Kg). The allowable stress the ground can withstand has been found to be 92 kN/m2. The sign and footing combined have a total distributed load of 10.2 kN/m2. Comprehensive calculations can be found in Appendix C, along with detailed construction drawings in Appendix F.

5.0 Geotechnical Design

The geotechnical conditions of the site have a significant influence on the design because of the amount of construction required to change the intersections configuration. The road must be designed so that it can resist traffic loads, without long-term settling occurring. The roadway itself also must be designed to Unfavorable soil conditions could potentially. In the following section we will address these issues.

5.1 Ground Settlement

To reduce the risk of post-construction ground settlement for the newly constructed road, preload of construction sites is often required. For the Chancellor BLVD. intersection, preloading is only necessary for the portion of the road that enters Pacific Spirit Park as annotated below in Figure 14. In this region the current load and ground conditions are highly different from that of the proposed design. It is suggested that preloading is done using soil piled to a height of 3m, for a minimum of one month, or 2m for two months. It is recommended to use silty sand as preloading, as this sand surcharge can be used as the road base during construction.

The intersection and road construction is the replacement of the existing road and intersection, preloading is not required in these areas. Based on existing and estimated future traffic volume data, the stresses from traffic volumes are comparable to expected traffic loads and stresses, and hence can already be considered as sufficient preload.

5.2 Material Specifications

The proposed pavement design includes layers of 19mm, 50mm and 100mm thick clear stone as well as silty sand and asphalt. These numbers were based on guidelines from “Housing Foundations and Geotechnical Challenges”. The 19mm thick clear stone is included to allow adequate drainage through the road surface, while the 50mm clear stone adds stability to the 19mm clear stone above, as well as contributes to controlling drainage. The 100mm clear stone helps stabilize and carry load exerted from road traffic.

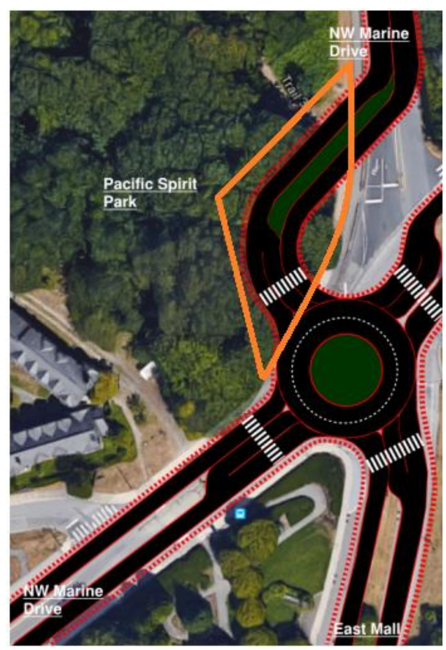


Figure 14: Area of Required Preloading

If these layers are placed in individual lifts, and are properly compacted no future settling on the site is expected. These materials and thicknesses are visually represented below in Figure 15.

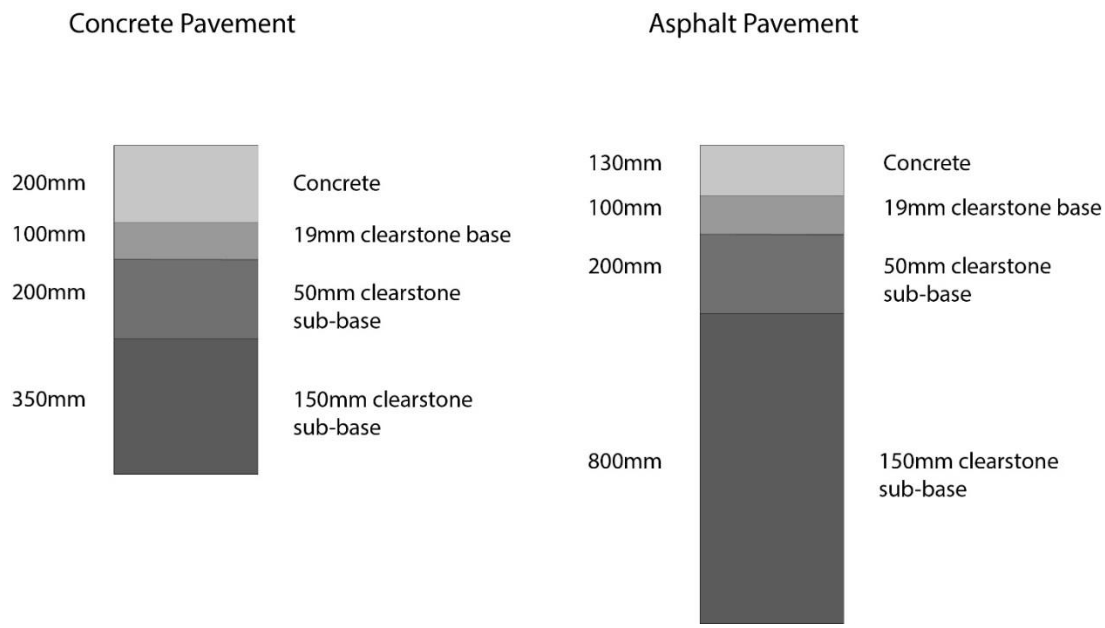


Figure 15: Sidewalk and Asphalt Material Specifications and Thickness

Exp engineering services has classified the governing subgrade as sand fill and silty sand with a material stiffness of 30 MPa when compacted. This subgrade is adequate for the design of road subgrade and will have no issues taking the weight of a road or associated traffic volume stresses. This sand fill will be used as road subgrade underneath the 150mm clear stone sub-base.

Another possible option for the road surface used is Open-Graded Friction Course (OGFC) asphalt. OGFC asphalt is designed in such a way where the void spaces in the concrete are interconnected. OGFC asphalt presents a number of advantages over standard asphalt such as increased water drainage and reduction of traffic noise; however, there are also a number of disadvantages such as costs and maintenance. Due to the open voids in the asphalt, water readily drains through the surface, improving wet driving conditions as well as stormwater runoff and water management for the road. Open voids in the road also have an effect of decreasing traffic noise pollution by 30%. The main disadvantages of OGFC asphalt are the costs associated with the initial construction, as well as maintenance. As OGCF asphalt requires more specialized construction and particular material grading, upfront costs can be significantly higher. The life of OGCF asphalt is also only rated for an average of 20 years, compared to the 30-50 for standard asphalt and concrete.

6.0 Construction Management

6.1 Construction Management and Traffic Plan

The goal of the construction management process is to maintain a safe and efficient site while minimizing impact to the surrounding area. Traffic flow must be possible through the corridor at all times due to the high volume of traffic the UBC campus experiences daily. Residents in the area also use the route to access the rest of the city. Construction should also be sure to mitigation, environmental and water contamination. A phased construction schedule was used to meet all of these technical objectives.

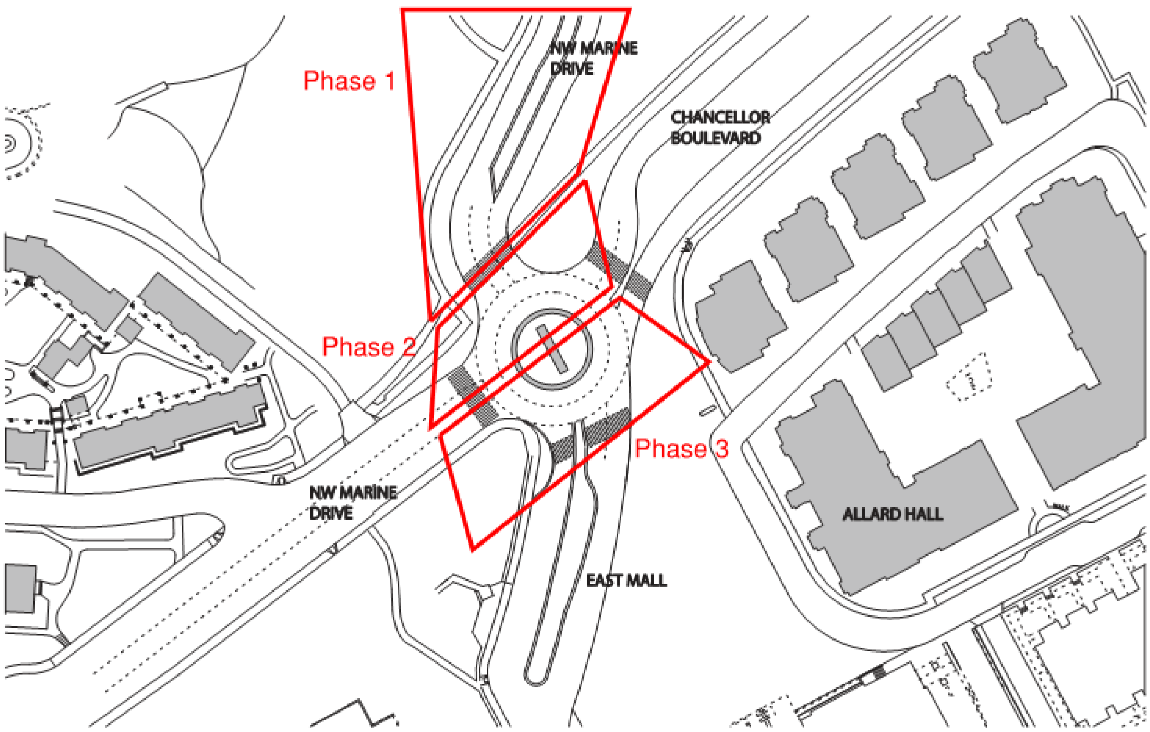


Figure 16: Phased Construction Plan

6.1.1 Phase One

The first phase of the project will involve the transportation and movement of all goods and services required for construction to the site. Due to the limited space available for onsite storage parking lots adjacent to Allard Hall will be used to store materials and equipment. The parking lots north and east of the Buchanan complex will be used to house site offices and safety orientation conference rooms. As can be seen in figure 16 above, the first phase of the project will begin within Pacific Spirit Park (PSP). The clearing of trees and cut/fill of the location must be done before any work can be done on the existing streets. Approximately 9 trees will be removed at the location and transplanted to an offsite location until they can be brought back for replantation where the existing road space for NW Marine Drive is located.

Flag staff will be on site during construction hours to direct traffic around any equipment that is impinging on the existing road space during the clearing of PSP. The westbound lane of NW marine drive will be rerouted periodically for dump trucks to remove soil and trees. All equipment remaining on location will be situated in storage parking lots, or off the road to prevent issues with traffic when construction is not ongoing.

Construction will commence with the removal of the trees in the northern most section of the Park and progress to the southernmost part of the addition. Once the trees have been removed cut and fill will commence. Approximately 2 tonnes of dirt will need to be brought on site and compacted to level the cleared park land. Compaction will take approximately 3 weeks to ensure 95% compaction for traffic loads. Once compaction is complete paving as per the geotechnical specifications outlined in this report will commence.

6.1.2 Phase Two

The second phase of the project will can be seen in figure 16 above. The northern portion of the intersection will be cordoned off and traffic westbound and north/southbound will be rerouted around the section. The pavement will be broken up in the section and removed by dump truck. Removal will require dropping traffic east and westbound down to one lane periodically throughout the day. The new fill and vegetation will be placed as per the water management design in section 3, with north side of the curb being slip-formed last. Once the roundabout is in place the removed pavement sections will have new asphalt laid. Approximately 10 square meters of new asphalt will be placed, along with 14 linear meters of curb. It should be noted that for this phase of work construction personnel will be working in isolation in the center of traffic and will require flagging staff throughout construction hours. This phase will impact traffic the most in comparison to phases one and three.

6.1.3 Phase Three

The final phase of the project will see the opening of phase two and the northern half of the roundabout to traffic. The eastbound traffic will be routed through phase two along with eastbound traffic. Traffic leaving east mall will be redirected to the NW Marine Drive access on west mall for the duration of this phase. The road will be broken up with pneumatic jacks similarly to phase two. The pieces will be picked up by dump truck and shipped off site. Fill and vegetation will be added and in the southern half of the roundabout slip-forming will commence. Another 10 square meters of asphalt will be paved in phase three with the other 14 linear meters of curb. Tie-ins with the storm system will also be done during fill on this section of the roundabout.

Once the roundabout is in place the section of roadway marked for removal in the northeastern section of the intersection will be removed and the sign work for the center of the roundabout will be completed. Placement of the sign will be done over a single day and will be the only day that requires the use of a portable crane for placement. Trees removed from PSP and stored offsite will be replanted during this phase as well. Phase three will also see the removal of all site equipment and left over stored material. Since material will be stored on the lawn of Allard Hall, new grass will be seeded upon removal of equipment. A detailed breakdown of site scheduling can be seen in the next section. The sites where offices and conference rooms will be located will be broken down and removed as the last presence on site.

6.2 Subcontracting

A number of companies will be brought in do the geotechnical, traffic, roadway, and structural work for the duration of this project. Due to UBC's guidelines and awarding practices specific companies will not be mentioned in this section of the report, however, once the RFP process for the project is complete the contractors awarded with the different sections of the project will be amended to this report.

6.3 Environmental and Water Management Mitigation

A truncated assessment of the location and the impact of machinery on it will be conducted prior to the start of construction. Due to the sensitive nature of work in PSP, this report will detail where and how machinery can be placed and operated. The study will also outline how to deal with rainfall in the area and how it may destabilize the slope once trees are removed. If destabilization is predicted, reinforcing pillars columns may be added to the soil base where the new roadway will be placed. This will ensure the ground is stable enough for traffic loads. Exposed soil during removal of shrubbery will be covered with tarps to divert as much water as possible. All spills of oil and fuel will be remediated as soon as they are detected and extra precautions will be taken to reduce the possibility of spillage. Security fencing will be used for all sections of the project to deter pedestrians and security will be onsite at night to both monitor equipment and the construction locations for each phase of the project.

6.4 Construction Schedule

Construction is scheduled to commence May 9, 2016 with the projected date of substantial completion as September 2, 2016. As previously mentioned, the construction team will be working on an accelerated schedule in order to minimize traffic disruptions. Important project dates and milestones are noted below: A more detailed schedule is provided in Appendix E.

Table 8: High level Construction Schedule

Schedule Activity	Start	Finish
Permitting	November 18, 2015	May 31, 2016
Site Preparation	May 9, 2016	June 1, 2016
Demolition	June 2, 2016	June 29, 2016
Excavation, Utilities + Backfill	June 30, 2016	July 29, 2016
Concrete formwork, reinforcement + supply	August 8, 2016	August 29, 2016
Welcome Sign	July 25, 2016	August 22, 2016
Roadway Asphalt	August 26, 2016	August 29, 2016
Landscaping	August 23, 2016	September 1, 2016
Painting + Signage	August 30, 2016	September 2, 2016

7.0 Economic Analysis

Based on the detailed design presented, an economic analysis was completed on initial costs of permitting and construction, as well as maintenance costs of the roundabout. These figures are estimates using a simple unit costing method. Costing calculations can be found in Appendix D. It should be noted that these calculations are still subject to uncertainty and Westcoast Consulting does not guarantee with absolute accuracy that the final cost will reflect the estimates given in the following sections.

7.1 Initial Costs

Many design components and construction procedures have been evaluated in order to develop the preliminary initial costs. Each item has been calculated on a cost per lineal meter basis, unless stated in Appendix D. The following is a list of key items that have been considered in the costing of this project:

- Asphalt pavement removal
- Sidewalk removal and installation
- Access reinstatement or realignment
- Concrete roundabout installation
- Asphalt approach and road construction
- Topsoil and seeding
- Signing/striping installations
- Land Acquisition

A summary of the total preliminary cost estimate of the 2-lane roundabout can be found in Table 9. This includes the $1.1 million purchase of parkland to the north of the site. Furthermore, the below cost estimate includes an option for the addition of pervious asphalt to the roundabout design. These costs are not binding and will most likely be subject to change throughout the projects life. Any costs associated with changes in design will be re-assessed and incorporated into the overall cost of the project. Westcoast Consulting will continually work with all parties to ensure that project costs remain reasonable and within the budget of UBC Campus and Community Planning. It should be noted that the pervious pavement option cost considerably more than the impervious option, at $8.1 million total (see Appendix D for a more detailed cost breakdown).

Table 9. Updated Cost Estimate

	Percentage	Value	Adjusted	Cost with Addition of Pervious Asphalt
Construction Work		$3,027,917	$3,413,592	$5,815,992
Contingency	20%	$605,583	$682,718	$1,163,198
Engineering Costs	15%	$545,025	$614,447	$1,046,879
Total		$4,178,525	$4,710,758	$8,026,070

The following are a list of suggested areas that can potentially reduce the overall cost of the project.

Maintenance of traffic – Detours for a large majority of traffic during non-peak hours would reduce costs due to reducing interruptions. This would also reduce construction time.

Landscaping - Scaling back the landscaping to simple and low-maintenance designs will reduce the labour spent on up keep each year as well as the initial costs of planting.

Paving - Instead of adding resurfacing beyond the limits of the project an efficient construction plan could limit the resurfacing to that which is actually needed for the roundabout. This would not only reduce waste but decrease the amount of costly asphalt or concrete material needed.

Signing and lighting - Look to integrate several signs on the same structural support. Furthermore, by using solar powered luminance systems the costs of running conventional electricity throughout the site would be reduced. This would also reduce the maintenance costs over the lifespan of the project due to details covered in section.

Maintenance costs must also be considered over the project's design life. These costs will be covered in more detail in the next section.

7.2 Annual Operating & Maintenance Costs

Westcoast Consulting used the City of Vernon's Cost Assessment to estimate life cycle costs of this project. When compared to other options, roundabouts have an advantage as they do not require periodic signal timing changes, bulb replacement or signal plant replacement. The table below has been obtained from Roundabouts in Canada: A Primer for Decision-Makers and clearly shows that roundabouts are less expensive in terms of annual maintenance costs, and replacement costs down the road.

Table 10: City of Vernon Roundabout Cost Assessment

Method of Control	Annual Maintenance Costs	10 Year Replacement Costs	25 Year Replacement Costs
Roundabout	$3,785 (1)	$12,000 (3)	$27,000 (5)
Traffic Signals	$4,816 (2)	$51,000 (4)	$44,000 (6)

(Canadian Institute of Transportation Engineers, 2013)

The “Roundabouts in Canada” notes that were used to produce cost estimates can be found in Appendix D and were obtained from the Canadian Institute of Transportation Engineers report on Roundabouts in Canada. Westcoast Consulting is confident that the roundabout option can be completed in a cost efficient manner and produce savings for UBC over its entire lifespan.

8.0 Risk Management Plan

Risk is something unavoidable for any construction project; in even the most thought out project it is rare for every aspect of a plan to be complete as predicted. The Chancellor BLVD intersection in no exception, so to mitigate potential adverse events Westcoast consulting has put together a risk management plan for the project. The goal of this plan is to increase the likelihood of success by establish risks early in the projects lifecycle, and continually monitoring them through the design and construction process.

Risks are categorized as a definable event, which occurs at some probability and has a consequence on the project. The severity of each risk is based on its consequence, and probability of occurring, i.e. a risk with high consequence, but very low probability of occurring may have a medium severity rating. For the Chancellor BLVD. intersection risks were sorted under the following categories: Planning, Design, Finances, Procurement, Construction, Operational, Organizational, and Environmental. Once identified, a risk can either be avoided by eliminating the risk or changing the project scope, mitigated by reducing a risks likelihood/consequence, transferred to another party, or assumed with no modification. A more detailed analysis of each risk can be found in the risk registry, in appendix G. This document is a continuation of the registry presented in the feasibility study, and will continue to be monitored and updated through the project, with each risk assigned to a relevant party.

Before construction begins, Westcoast consulting will also complete a Construction Hazard Assessment and Implication Review (CHAIR) with key construction participants and stakeholders. A CHAIR review is structured risk assessment program that involves various parties involved in Construction. The goal of this particular study will be to facilitate discussion between contractors and subcontractors to and further identify environmental and safety risks that may occur during construction

9.0 Conclusion

WestCoast Consulting is proud to present these details to UBC's Campus and Community planning department. The technical details provided in this report create a rigorous design framework, which could be used to construct the intersection presented in Westcoast Consulting's feasibility design study. Given the set of drawings, it would be possible to fully construct the road surface, and manufacture the proposed structural details. The analysis also shows that these are sufficiently strong to bear the forces that would likely be applied to them, in addition to fulfilling aesthetic requirements of the project. The stormwater management system presented meets UBC's sustainability requirements, and prevents excess runoff from damaging fragile nearby ecosystems. By following the design details presented, the intersection would be constructed in a timely and economic manner. The team looks forward to working with UBC, through the procurement and construction process.

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APPENDIX A – Qualhymo Water Balance

BASE CASE SCENARIO

Report Details

Project

Site Name	UBC Intersection
Site Description	
Site Location	Vancouver, City of
Site Type	Site
Site Size	168.9 sq. m
Stream Present	No
Climate Data File	Vancouver International Airport
Climate Start & End Dates	01/01/1965 to 12/31/1990

Scenario

Scenario Name	UBC Roundabout Centre
Scenario Description	
This is the base case or pre-development scenario for: UBC Intersection	

Timestamps

Report Generated	Sun, 28 Feb 2016 23:44:56 -0600
Processed by QUALHYMO	Sun, 28 Feb 2016 23:44:53 -0600

Drainage Area Configuration

Drainage Areas

Drainage Areas	Native Soil Types	Land Uses	Surface Conditions	Source Controls
Modelled Area **Area** 168.9 sq. m **Length** 17 m **Slope** 0.025 m/m	Sandy Loam **Area** 168.9 sq. m **Depth** 100 mm **Field Capacity** 20.3% **Wilting Point** 13.7%	Street - Residential **Area** 168.9 sq. m **Description** Typical ROW Width = 20.1m Typical Paved Road Width = 7.5m - 8.5m Typical Concrete Sidewalk Width = 1.5m - 1.8m (2 sides) Note: Surface Conditions are based on maximum values where ranges are shown.	Impervious Paving **Area** 168.9 sq. m	

Surface Conditions

Name	Area	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Impervious Paving	168.9 sq. m	Impervious	2 mm	-	.013	-	-

Stored Results of Last Scenario Run

Volume Summary (m³)

Rainfall Total	5580.18
Total Discharge	3.353774e+3
Total Losses	2.201570e+3
Catchment Infiltration	2.484000e+1
Source Control Infiltration	0.000000e+0

Exceedance Summary

Duration (hours)	Rate (m³/sec)
0	0.001
1	0.001
7	0
21	0
66	0
216	0
712	0
2415	0
7720	0
227904	0

SOURCE CONTROL SCENARIO

Report Details

Project

Site Name	UBC Intersection
Site Description	
Site Location	Vancouver, City of
Site Type	Site
Site Size	168.9 sq. m
Stream Present	No
Climate Data File	Vancouver International Airport
Climate Start & End Dates	01/01/1965 to 12/31/1990

Scenario

Scenario Name	UBC Roundabout Centre - Source Controls
Scenario Description	

Timestamps

Report Generated	Sun, 28 Feb 2016 23:39:15 -0600
Processed by QUALHYMO	Sun, 28 Feb 2016 23:39:13 -0600

Drainage Area Configuration

Drainage Areas

Drainage Areas	Native Soil Types	Land Uses	Surface Conditions	Source Controls
Modelled Area **Area** 168.9 sq. m **Length** 17 m **Slope** 0.025 m/m	Sandy Loam **Area** 168.9 sq. m **Depth** 100 mm **Field Capacity** 20.3% **Wilting Point** 13.7%	Street - Residential **Area** 168.9 sq. m **Description** Typical ROW Width = 20.1m Typical Paved Road Width = 7.5m - 8.5m Typical Concrete Sidewalk Width = 1.5m - 1.8m (2 sides) Note: Surface Conditions are based on maximum values where ranges are shown.	Impervious Paving **Area** 0 sq. m	
			Pervious Cover **Area** 168.9 sq. m **Depth** 100 mm	Rain Garden **Size** 67.56 sq. m 101.34 sq. m Treated By Rain Garden With Underdrain

Surface Conditions

Name	Area	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Impervious Paving	0 sq. m	Impervious	2 mm	-	.013	-	-
Pervious Cover	168.9 sq. m	Pervious	6 mm	-	.03	See Underlying Native Soil Type	

Source Controls - Surface Enhancements

Rain Garden

[Rain Garden - Without Underdrain]

Size	Crop Coefficient	Design Soil Rooting Depth	Ponding Depth (Optional)
67.56 sq. m	1	200 mm	100 mm

Soil Definition

Name	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Clean Sand	Pervious	7 mm	0.2	0.03	12.1%	11.7%

Source Controls - With Storage

Rain Garden With Underdrain

[Rain Garden - With Underdrain]

Treated Area	Crop Coefficient	Design Soil Rooting Depth	Infiltration Rate	Average VoidSpace Ratio (Optional)	Depth Of Reservoir (Optional)	Ponding Depth (Optional)
101.34 sq. m	1	200 mm	100 mm/hours	60%	250 mm	50 mm

Soil Definition

Name	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Clean Sand	Pervious	7 mm	0.2	0.03	12.1%	11.7%

This Source Control has not been assigned to the drainage area.

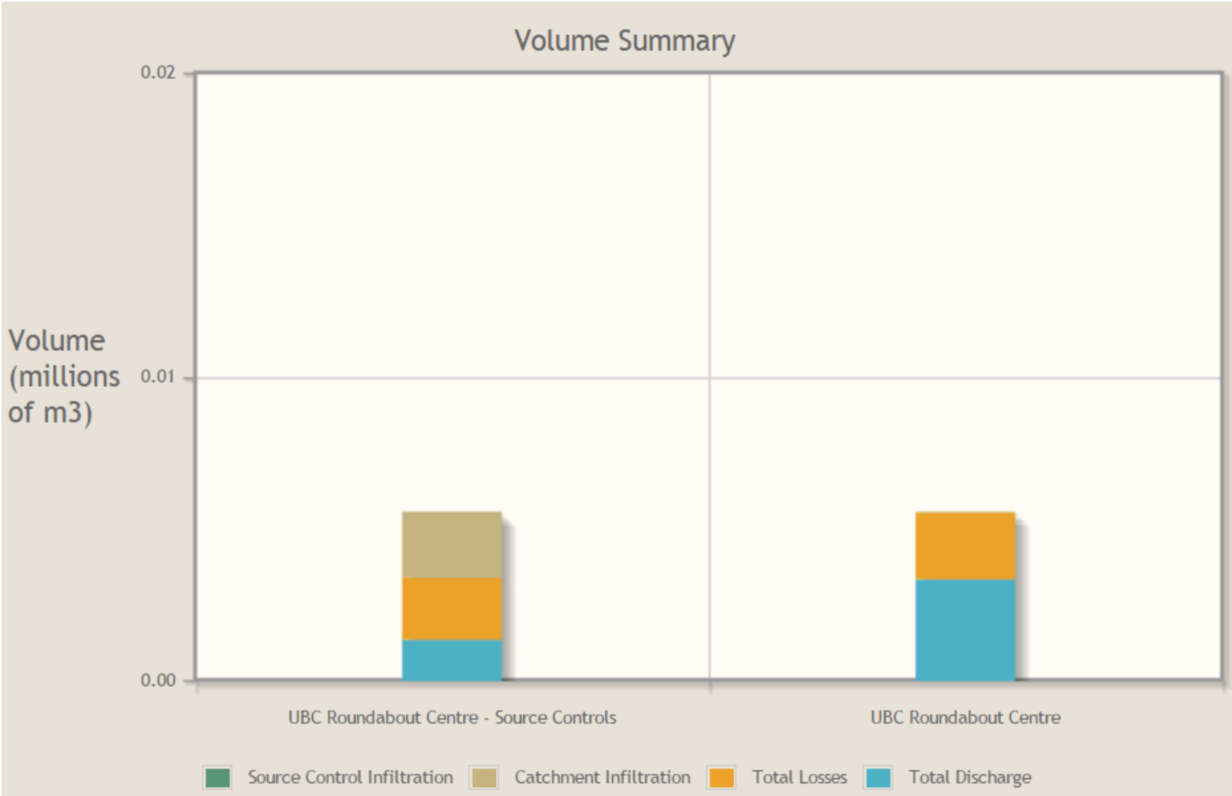
Stored Results of Last Scenario Run

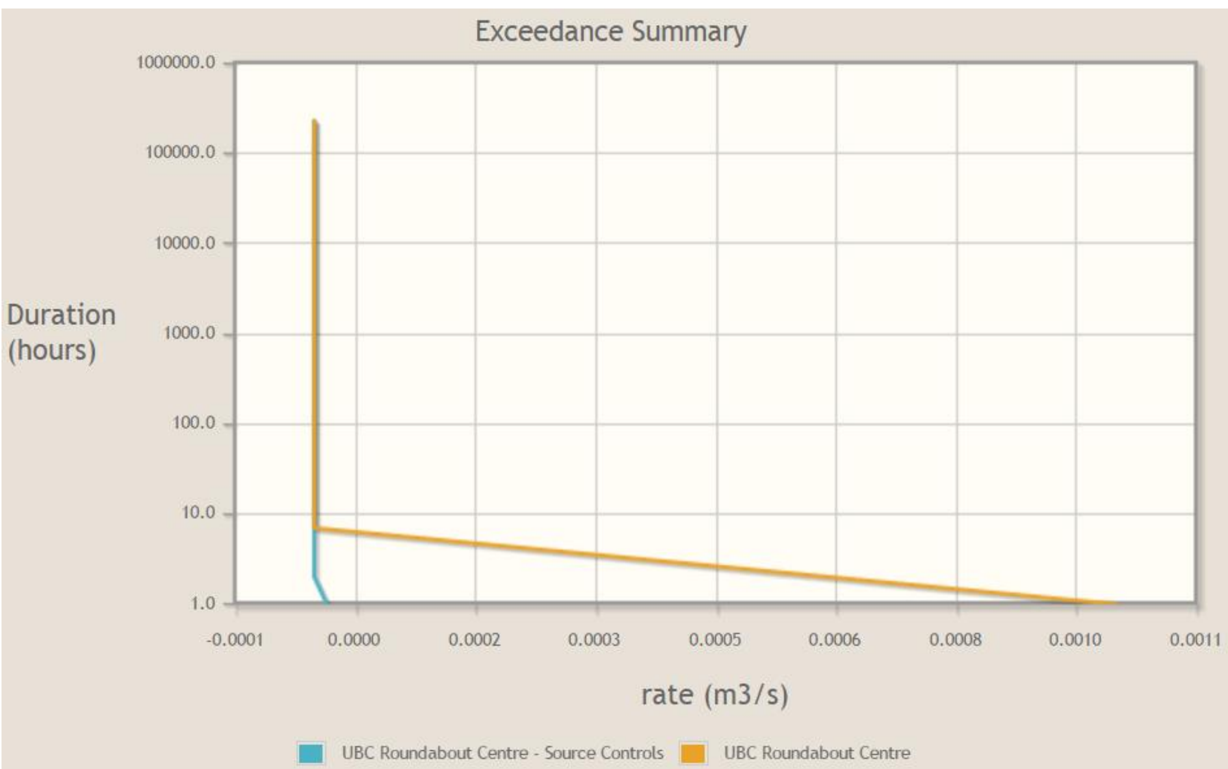
Volume Summary (m³)

Rainfall Total	5580.18
Total Discharge	1.364440e+3
Total Losses	2.052200e+3
Catchment Infiltration	2.163540e+3
Source Control Infiltration	0.000000e+0

Exceedance Summary

Duration (hours)	Rate (m³/sec)
0	0.001
0	0.001
2	0
5	0
14	0
53	0
216	0
816	0
3158	0
227904	0


Volume Summary
Volume (millions of m3)
0.02
0.01
0.00
UBC Roundabout Centre - Source Controls
UBC Roundabout Centre
Source Control Infiltration
Catchment Infiltration
Total Losses
Total Discharge


Exceedance Summary
Duration (hours)
1000000.0
100000.0
10000.0
1000.0
100.0
10.0
1.0
-0.0001
0.0000
0.0002
0.0003
0.0005
0.0006
0.0008
0.0010
0.0011
rate (m3/s)
UBC Roundabout Centre - Source Controls
UBC Roundabout Centre

Report for

Base Case Pavement

Pavement Base Case

Report Details

Project

Site Name	Pavement Base Case
Site Description	
Site Location	Vancouver, City of
Site Type	Site
Site Size	3164 sq. m
Stream Present	No
Climate Data File	Vancouver International Airport
Climate Start & End Dates	01/01/1965 to 12/31/1990

Scenario

Scenario Name	Base Case Pavement
Scenario Description	
This is the base case or pre-development scenario for: Pavement Base Case	

Timestamps

Report Generated	Mon, 04 Apr 2016 20:38:43 -0500
Processed by QUALHYMO	Mon, 04 Apr 2016 20:37:00 -0500

Drainage Area Configuration

Drainage Areas

Drainage Areas	Native Soil Types	Land Uses	Surface Conditions	Source Controls
Modelled Area **Area** 3164 sq. m **Length** 110 m **Slope** 0.025 m/m	Sandy Loam **Area** 3164 sq. m **Depth** 100 mm **Field Capacity** 20.3% **Wilting Point** 13.7%	Street - Residential **Area** 3164 sq. m **Description** Typical ROW Width = 20.1m Typical Paved Road Width = 7.5m - 8.5m Typical Concrete Sidewalk Width = 1.5m - 1.8m (2 sides) Note: Surface Conditions are based on maximum values where ranges are shown.	Impervious Paving **Area** 3164 sq. m	

Surface Conditions

Name	Area	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Impervious Paving	3164 sq. m	Impervious	2 mm	-	.013	-	-

Stored Results of Last Scenario Run

Volume Summary (m³)

Rainfall Total	104533.35
Total Discharge	9.278360e+4
Total Losses	1.128450e+4
Catchment Infiltration	4.652500e+2
Source Control Infiltration	0.000000e+0

Exceedance Summary

Duration (hours)	Rate (m³/sec)
1	0.009
1	0.011
7	0.008
21	0.007
65	0.006
211	0.005
703	0.004
2252	0.002
7441	0.001
227904	0

Report for

Source Control Pavement

Pavement Base Case

Report Details

Project

Site Name	Pavement Base Case
Site Description	
Site Location	Vancouver, City of
Site Type	Site
Site Size	3164 sq. m
Stream Present	No
Climate Data File	Vancouver International Airport
Climate Start & End Dates	01/01/1965 to 12/31/1990

Scenario

Scenario Name	Source Control Pavement
Scenario Description	

Timestamps

Report Generated	Mon, 04 Apr 2016 20:27:05 -0500
Processed by QUALHYMO	Mon, 04 Apr 2016 20:25:05 -0500

Drainage Area Configuration

Drainage Areas

Drainage Areas	Native Soil Types	Land Uses	Surface Conditions	Source Controls
Modelled Area **Area** 3164 sq. m **Length** 110 m **Slope** 0.025 m/m	Sandy Loam **Area** 3164 sq. m **Depth** 100 mm **Field Capacity** 20.3% **Wilting Point** 13.7%	Street - Residential **Area** 3164 sq. m **Description** Typical ROW Width = 20.1m Typical Paved Road Width = 7.5m - 8.5m Typical Concrete Sidewalk Width = 1.5m - 1.8m (2 sides) Note: Surface Conditions are based on maximum values where ranges are shown.	Impervious Paving **Area** 3164 sq. m	**Pervious Pavement** **Size** 3164 sq. m

Surface Conditions

Name	Area	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Impervious Paving	3164 sq. m	Impervious	2 mm	-	.013	-	-

Source Controls - Surface Enhancements

Pervious Pavement
[Pervious Paving]

Size	Design Soil Rooting Depth
3164 sq. m	100 mm

Soil Definition

Name	Type	Depression Storage	Rational Coefficient	Retardance Roughness	Field Capacity	Wilting Point
Sandy Loam	Pervious	7 mm	0.2	0.03	20.3%	13.7%

Stored Results of Last Scenario Run

Volume Summary (m³)

Rainfall Total	104533.35
Total Discharge	4.822730e+4
Total Losses	1.968518e+4
Catchment Infiltration	3.662087e+4
Source Control Infiltration	0.000000e+0

Exceedance Summary

Duration (hours)	Rate (m³/sec)
0	0.009
0	0.011
2	0.008
6	0.007
17	0.006
59	0.005
252	0.004
896	0.002
3278	0.001
227904	0


Exceedance Summary
1000000.0
100000.0
10000.0
1000.0
100.0
10.0
1.0
Duration (hours)
-0.0011
0.0005
0.0022
0.0038
0.0055
0.0071
0.0088
0.0104
0.0121
rate (m3/s)
Source Control Pavement
Base Case Pavement

APPENDIX B - Geotechnical Calculations

Shallow Footing Allowable Stress Calculation

Welcome Sign

Note: Values with * have been assumed

$\pi = 3.14$
$Df = 0.3048\ m\ (Depth\ from\ FG\ to\ BOF)$
$B' = B = 1.5\ m$ (Footing Width)
$L' = L = 3\ m$ (Footing Length)
$Z = 2.5m\ (Depth\ to\ Ground\ Water\ Table, Assuming\ Infiltration\ Gallery\ is\ Full)$
$* \phi' = 33°$ (dry)
$* \phi = 38°$ (sat)
$* \gamma_{dry} = 17\ KN/m^3$ (Effective Unit Weight of Soil in Dry Conditions)
$* \gamma_{sat} = 20\ KN/m^3$ (Effective Unit Weight of Soil in Wet Conditions)

Design

$Steel = 15\ KN = 1529\ Kg$
$Footing\ Size = 1.5m\ X\ 3m = 4.5\ m^2$

$$Weight\ of\ Concrete = W_c = \frac{Vx9.81}{1000} = \frac{2.7432x9.81}{1000} = 64.58\ KN = 6584\ Kg$$

$$\boldsymbol{Distribution\ to\ Soil = \frac{W_c}{Footing\ Size} = 29.35\ KN/m^2}$$

Vertical Centric Load:

Bearing Capacity Factors

$$N_q = e^{\tan(\phi')} tan^2\left(45 + \frac{\phi'}{2}\right)$$
$$N_q = e^{\tan(33°)} tan^2\left(45 + \frac{33°}{2}\right)$$
$$\boldsymbol{N_q = 26.09}$$

$$N_\gamma = 0.1054e^{(9.6x\phi'_b)}\ (For\ Rough\ Foundations)$$
$$N_\gamma = 0.1054e^{(9.6x\frac{33°}{180}\pi)}$$
$$\boldsymbol{N_\gamma = 26.55}$$

Shape Factors

$$S_q = 1 + \left(\frac{B'}{L'}\right)\tan(33°)$$
$$S_q = 1 + \left(\frac{1.5}{3}\right)\tan(33°)$$
$$\boldsymbol{S_q = 1.32}$$

$$S_\gamma = 1 - 0.4\left(\frac{B'}{L'}\right)$$
$$\boldsymbol{S_\gamma = 0.6}$$

Embedment Factors

$$d_q = 1 + 2\tan\phi_b' \,(1 - \sin\phi_b)^2 \left(\frac{D_f}{B'}\right)$$
$$d_q = 1 + 2\tan 33° \,(1 - \sin 33°)^2 \left(\frac{0.3048}{1.5}\right)$$
$$\boldsymbol{d_q = 1.08}$$

$$\boldsymbol{d_\gamma = 1}$$

Groundwater Factors

$$\boldsymbol{W_q = 1}\ (Case\ 1{:}\ Z > (B + D_f) = 2.5 > 0.652)$$

$$\boldsymbol{W_\gamma = 1}\ (Case\ 1{:}\ Z > (B + D_f) = 2.5 > 0.652)$$

Allowances

Ultimate Net Bearing Capacity

$$Q_u = \gamma D_f (N_q - 1)(S_q d_q W_q)$$
$$\boldsymbol{Q_u = 389.5\left(\frac{KN}{m^2}\right)}$$

Ultimate Gross Bearing Capacity

$$Q_{ult} = Q_u + \gamma D_f$$
$$\boldsymbol{Q_{ult} = 394.7\left(\frac{KN}{m^2}\right)}$$

Allowable Bearing Capacity

$$Q_a = \frac{Q_u}{FOS} + \gamma D_f\ (FOS = 2)$$

$$Q_a = 200 \left(\frac{KN}{m^2}\right)$$

Results

$$Q_{ult} = 200 \left(\frac{KN}{m^2}\right) > Distribution\ to\ Soil = \frac{W_c}{Footing\ Size} = 29.35\ KN/m^2$$

Design OK ☑

Structural Arch

Note: Values with * have been assumed

π = 3.14
$Df = 0.154\ m\ (Depth\ of\ Footing\ Below\ Ground\ Surface)$
$B' = B = 0.5\ m$ (Footing Width)
$L' = L = 0.5\ m$ (Footing Length)
$Z = 2.5m\ (Depth\ to\ Ground\ Water\ Table, Assuming\ Infiltration\ Gallery\ is\ Full)$
$* \phi' = 33°$ (dry)
$* \phi = 38°$ (sat)
$* \gamma_{dry} = 17\ KN/m^3$ (Effective Unit Weight of Soil in Dry Conditions)
$* \gamma_{sat} = 20\ KN/m^3$(Effective Unit Weight of Soil in Wet Conditions)

Design

$Steel = 12\ KN = 1223\ Kg$
$Footing\ Size = .5m\ X\ .5m = .25\ m^2$

$$Weight\ of\ Concrete = W_c = \frac{Vx9.81}{1000} = \frac{.0762x9.81}{1000} = 1.79\ KN = 183\ Kg$$

$$\boldsymbol{Distribution\ to\ Soil} = \frac{\boldsymbol{W_c}}{\boldsymbol{Footing\ Size}} + \frac{\boldsymbol{W_s}}{\boldsymbol{4^*}} = \mathbf{10.2\ KN/m^2}$$

*Note: Divided by 4 because the steel is distributed proportionately between the 4 separate foundations.

Vertical Centric Load:

Bearing Capacity Factors

$$N_q = e^{\tan(\phi')} tan^2\left(45 + \frac{\phi'}{2}\right)$$

$$N_q = e^{\tan(33^\circ)} tan^2\left(45 + \frac{33^\circ}{2}\right)$$
$$\boldsymbol{N_q = 26.09}$$

$$N_\gamma = 0.1054e^{(9.6x\phi_b')}\ (For\ Rough\ Foundations)$$
$$N_\gamma = 0.1054e^{(9.6x\frac{33^\circ}{180}\pi)}$$
$$\boldsymbol{N_\gamma = 26.55}$$

Shape Factors

$$S_q = 1 + \left(\frac{B'}{L'}\right)\tan(33^\circ)$$
$$S_q = 1 + \left(\frac{0.5}{0.5}\right)\tan(33^\circ)$$
$$\boldsymbol{S_q = 1.649}$$

$$S_\gamma = 1 - 0.4\left(\frac{B'}{L'}\right)$$
$$\boldsymbol{S_\gamma = 0.6}$$

Embedment Factors

$$d_q = 1 + 2\tan\phi_b'\,(1 - \sin\phi_b)^2\left(\frac{D_f}{B'}\right)$$
$$d_q = 1 + 2\tan 33^\circ\,(1 - \sin 33^\circ)^2\left(\frac{0.1524}{0.5}\right)$$
$$\boldsymbol{d_q = 1.04}$$

$$\boldsymbol{d_\gamma = 1}$$

Groundwater Factors

$$\boldsymbol{W_q = 1}\ (Case\ 1: Z > \left(B + D_f\right) = 2.5 > 0.652)$$

$$\boldsymbol{W_\gamma = 1}\ (Case\ 1: Z > \left(B + D_f\right) = 2.5 > 0.652)$$

Allowances

Ultimate Net Bearing Capacity

$$Q_u = \gamma D_f(N_q - 1)(S_q d_q W_q)$$
$$\boldsymbol{Q_u = 179.3\left(\frac{KN}{m^2}\right)}$$

Ultimate Gross Bearing Capacity

$$Q_{ult} = Q_u + \gamma D_f$$
$$\boldsymbol{Q_{ult} = 181.9 \left(\frac{KN}{m^2}\right)}$$

Allowable Bearing Capacity

$$Q_a = \frac{Q_u}{FOS} + \gamma D_f \; (FOS = 2)$$
$$\boldsymbol{Q_a = 92.26 \left(\frac{KN}{m^2}\right)}$$

Results

$$\boldsymbol{Q_a = 92.26 \left(\frac{KN}{m^2}\right) > Distribution\ to\ Soil = \frac{W_c}{Footing\ Size} = 10.2\ KN/m^2}$$

Design OK ☑

APPENDIX C - Structural Calculations

SAP2000®

License #2A8BD

Chancellor Boulevard & East Mall Roundabout

Project Number: 063

SAP2000 Analysis Report

Prepared by

Westcoast Consulting Group

Model Name: Chancellor Boulevard & East Mall - Final Arch Design.sdb

27 November 2015

1. Model geometry

This section provides model geometry information, including items such as joint coordinates, joint restraints, and element connectivity.

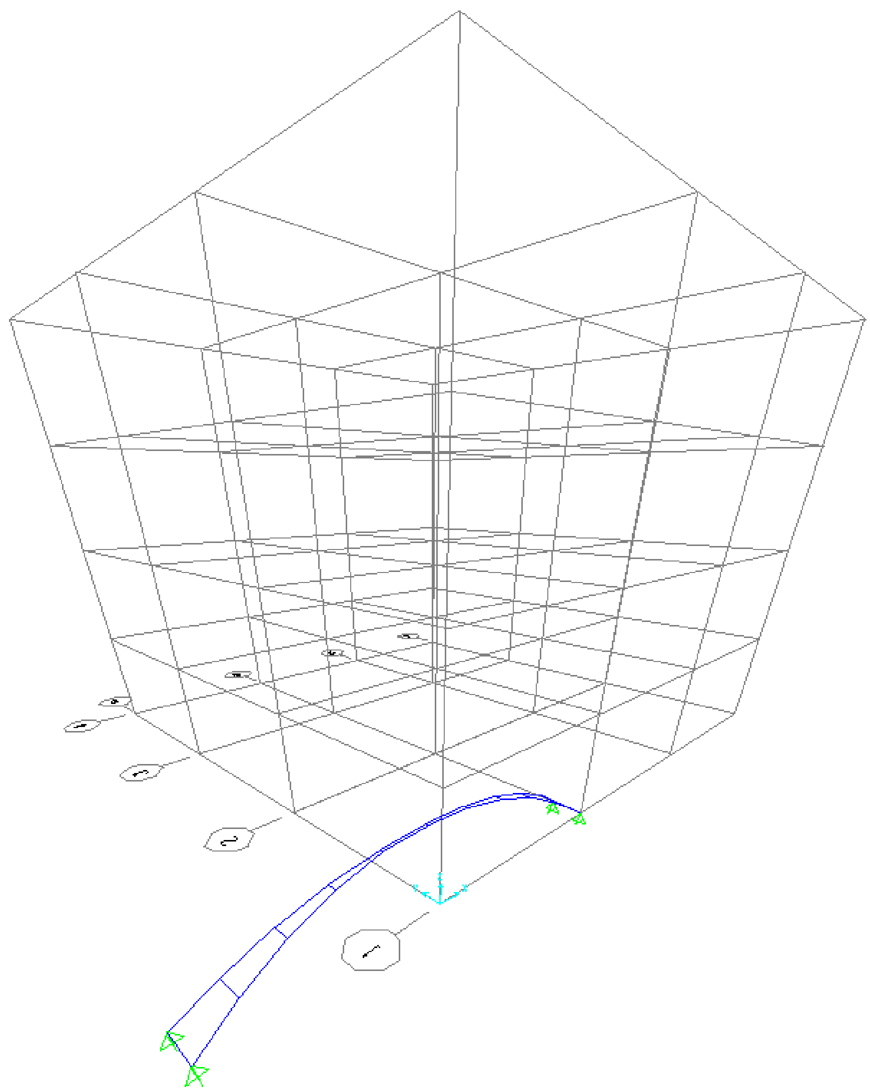


Figure 1: Finite element model

2. Material properties

This section provides material property information for materials used in the model.

Table 1: Material Properties 01 - Basic Mechanical Properties

Table 1: Material Properties 01 - Basic Mechanical Properties

Material	UnitWeight	UnitMass	E1	G12	U12	A1
	KN/m3	KN-s2/m4	KN/m2	KN/m2		1/C
Steel	7.6973E+01	7.8490E+00	199947978.8	76903068.77	0.300000	1.1700E-05

Table 2: Material Properties 02a - Steel Data

Table 2: Material Properties 02a - Steel Data

Material	Fy	Fu	Final Slope
	KN/m2	KN/m2	
A992Fy50	344737.89	448159.26	-0.100000

3. Section properties

This section provides section property information for objects used in the model.

Table 3: Frame Section Properties 01 - General

Section Name	Area
	m2
HSS10X.250	0.004152

4. Load patterns

This section provides loading information as applied to the model.

4.1. Definitions

Table 4: Load Pattern Definitions

Table 4: Load Pattern Definitions

LoadPat	DesignType	SelfWtMult	AutoLoad
DEAD	DEAD	1.000000	
LIVE	LIVE	0.000000	
WIND	WIND	0.000000	NBCC2010

5. Load combinations

This section provides load combination information.

Table 5: Combination Definitions

Table 5: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UDSTL1	Linear Add	DEAD	1.400000

Table 5: Combination Definitions

ComboName	ComboType	CaseName	ScaleFactor
UDSTL2	Linear Add	DEAD	1.200000
UDSTL2		LIVE	1.600000
UDSTL3	Linear Add	DEAD	1.200000
UDSTL3		LIVE	1.000000
UDSTL3		WIND	1.600000
UDSTL4	Linear Add	DEAD	1.200000
UDSTL4		LIVE	1.000000
UDSTL4		WIND	-1.600000

6. Structural steel design checks

The following page shows detailed structural design checks for the middle section of the arch – the members experiencing the largest stresses.

APPENDIX D - Cost Estimate

Initial Costs

Note: All unit Prices are not final and can be subject to change.

Table 10: Initial Cost Unit Price Estimate

Description of Work	Quantity	Unit	Unit Price	Cost	Canadian Adjustments (add to original)
Asphalt Pavement Removals	2300	s.m.	$5	$11,500	
Sidewalk Removals	370	s.m.	$12	$4,440	
Path Removals	100	s.m.	$12	$1,200	
Asphalt Road Construction	1320	l.m.	$1,300	$1,716,000	$343,200
Concrete Road Construction	577	s.m.	$205	$118,285	$23,657
Curb Installation				$0	
Barrier curb	0	l.m.	$65	$0	$0
Modified barrier curb	54	l.m.	$70	$3,780	$756
Lip Curb	50	l.m.	$45	$2,250	$450
Ramp Curb	32	l.m.	$80	$2,560	$512
Concrete Median	0	s.m.	$110	$0	$0
Detectable Warning Surface Tiles	8	ea.	$380	$3,040	$608
Sidewalk Installation	500	s.m.	$85	$42,500	$10,200
Grading	2400	s.m.	$2.50	$6,000	
Topsoil and SOD	510	s.m.	$10	$5,100	$1,020

Topsoil and Hydroseeding	227	s.m.	$6	$1,362	$272
New Signing/Striping	1	ea.	$25,000	$25,000	$5,000
Land Acquisition	200	s.m.	$5,382	$1,076,392	

	Percentage	Value	Adjusted	Pervious with Adjusted
Construction Work		3,027,917	3,413,592	5,815,992
Contigency	20%	605,583	682,718	1,163,198
Engineering Costs	15%	545,025	614,447	1,046,879
Total		4,178,525	4,710,758	8,026,070

Adjusted costs are associated with the decrease in value of the Canadian dollar and reflect the increase in material costs sourced from the United States.

Maintenance Costs

(Canadian Institute of Transportation Engineers, 2013)

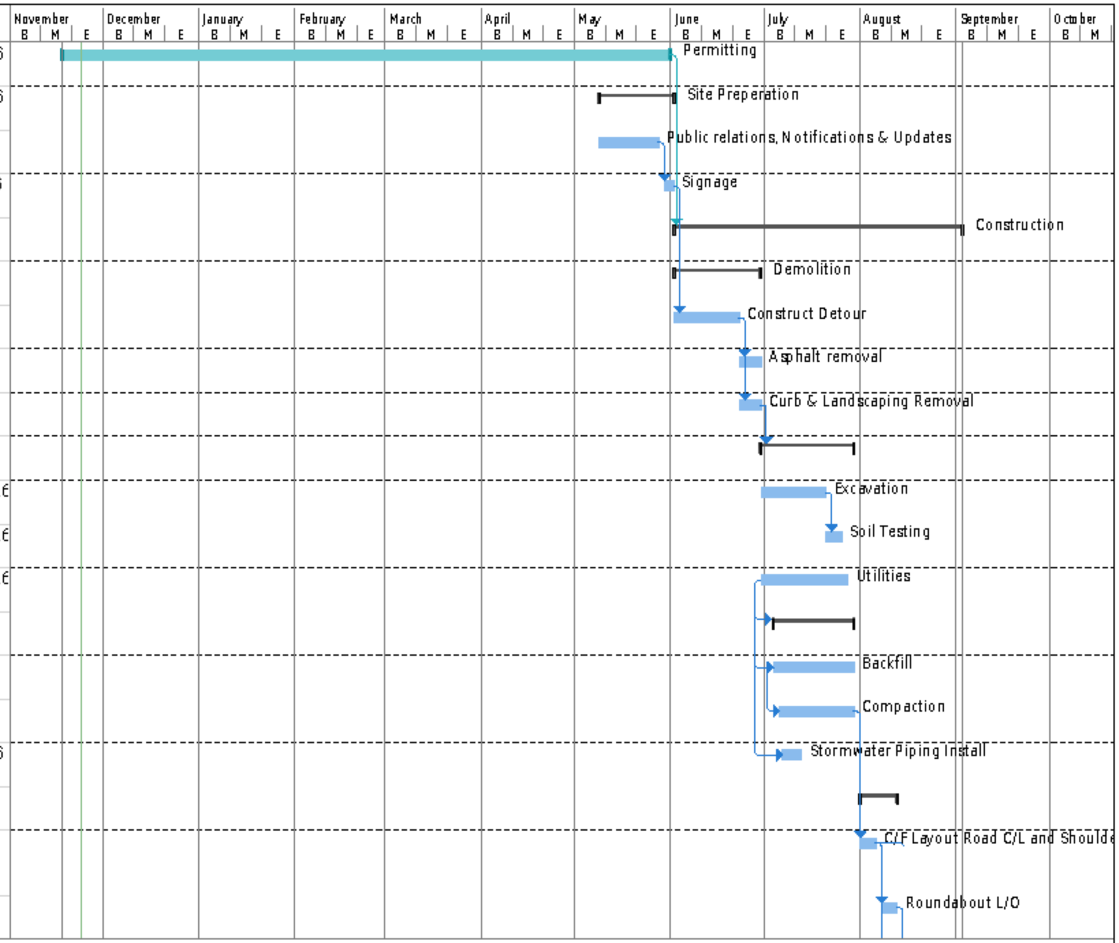
Method of Control	Annual Maintenance Costs	10 Year Replacement Costs	25 Year Replacement Costs
Roundabout	$3,785 (1)	$12,000 (3)	$27,000 (5)
Traffic Signals	$4,816 (2)	$51,000 (4)	$44,000 (6)

Notes:

1. The cost of removal of previous year's and installation of new annuals and bulbs $2485, weeding and irrigation $1300. Street lamp replacement (8) $16 each.
2. The average cost in Vernon per intersection per year (including LED replacement) $4800 + street lamp replacement (4) at $16 each.
3. $1500 ballast replacement in street lamps (8).
4. The life expectancy of the controller is 7 – 10 years at a cost of $30,000; traffic detection system is ten years ($15,000) on four approaches and $1500 ballast replacement in street lamps (4).
5. The life expectancy of a road signs is 20 years $150 (20) and 25 years for street lights on individual posts $3000 (8).
6. The life expectancy of the steel signal poles is 25 years at a current value of $40,000 including removal of the old poles (4) and the installation of the new poles. The life expectancy of the street lights is 25 years (attached to signal poles); current value $1000 (4).

APPENDIX E - Project Schedule

ID		Task Mode	Task Name	Duration	Start	Finish
1			Permitting	140 days	Wed 11/18/15	Tue 5/31/16
2			Site Preperation	18 days	Mon 5/9/16	Wed 6/1/16
3			Public relations, Notifications & Updates	15 days	Mon 5/9/16	Fri 5/27/16
4			Signage	3 days	Mon 5/30/16	Wed 6/1/16
5			Construction	67 days	Thu 6/2/16	Fri 9/2/16
6			Demolition	20 days	Thu 6/2/16	Wed 6/29/16
7			Construct Detour	15 days	Thu 6/2/16	Wed 6/22/16
8			Asphalt removal	5 days	Thu 6/23/16	Wed 6/29/16
9			Curb & Landscaping Removal	5 days	Thu 6/23/16	Wed 6/29/16
10			Civil	22 days	Thu 6/30/16	Fri 7/29/16
11			Excavation	15 days	Thu 6/30/16	Wed 7/20/16
12			Soil Testing	3 days	Thu 7/21/16	Mon 7/25/16
13			Utilities	20 days	Thu 6/30/16	Wed 7/27/16
14			Backfill	20 days	Mon 7/4/16	Fri 7/29/16
15			Backfill	20 days	Mon 7/4/16	Fri 7/29/16
16			Compaction	18 days	Wed 7/6/16	Fri 7/29/16
17			Stormwater Piping Install	4 days	Thu 7/7/16	Tue 7/12/16
18			Survey L/O	10 days	Mon 8/1/16	Fri 8/12/16
19			C/F Layout Road C/L and Shoulders	5 days	Mon 8/1/16	Fri 8/5/16
20			Roundabout L/O	5 days	Mon 8/8/16	Fri 8/12/16



Project: Preliminary Schedule
Date: Tue 11/24/15

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

ID	Task Mode	Task Name	Duration	Start	Finish
21		Concrete	16 days	Mon 8/8/16	Mon 8/29/1€
22		Curbs & Sidewalks	14 days	Mon 8/8/16	Thu 8/25/16
23		Pedestrian Sidewalks	14 days	Mon 8/8/16	Thu 8/25/16
24		Form	10 days	Mon 8/8/16	Fri 8/19/16
25		Reinforcement	10 days	Wed 8/10/1€	Tue 8/23/16
26		Concrete supply	10 days	Fri 8/12/16	Thu 8/25/16
27		Roundabout	6 days	Mon 8/15/1€	Mon 8/22/1€
28		Form	5 days	Mon 8/15/1€	Fri 8/19/16
29		Reinforcement	3 days	Wed 8/17/1€	Fri 8/19/16
30		Concrete supply	1 day	Mon 8/22/16	Mon 8/22/16
31		Roadway	2 days	Fri 8/26/16	Mon 8/29/1€
32		Asphalt	2 days	Fri 8/26/16	Mon 8/29/1€
33		Welcome Sign	21 days	Mon 7/25/1€	Mon 8/22/1€
34		Prefab Steel Sign	20 days	Tue 7/26/16	Mon 8/22/1€
35		Form	10 days	Mon 7/25/1€	Mon 8/8/16
36		Concrete	1 day	Mon 8/8/16	Mon 8/8/16
37		Brick Cladding	10 days	Tue 8/9/16	Mon 8/22/1€
38		Landscaping	8 days	Tue 8/23/16	Thu 9/1/16
39		Sidewalk	3 days	Fri 8/26/16	Tue 8/30/16
40		Roundabout	3 days	Tue 8/23/16	Thu 8/25/16
41		General	5 days	Fri 8/26/16	Thu 9/1/16

Project: Preliminary Schedule
Date: Tue 11/24/15

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

ID		Task Mode	Task Name	Duration	Start	Finish
42			Finishing	4 days	Tue 8/30/16	Fri 9/2/16
43			Painting	2 days	Tue 8/30/16	Wed 8/31/16
44			Signage	2 days	Thu 9/1/16	Fri 9/2/16

November B M E | December B M E | January B M E | February B M E | March B M E | April B M E | May B M E | June B M E | July B M E | August B M E | September B M E | October B M

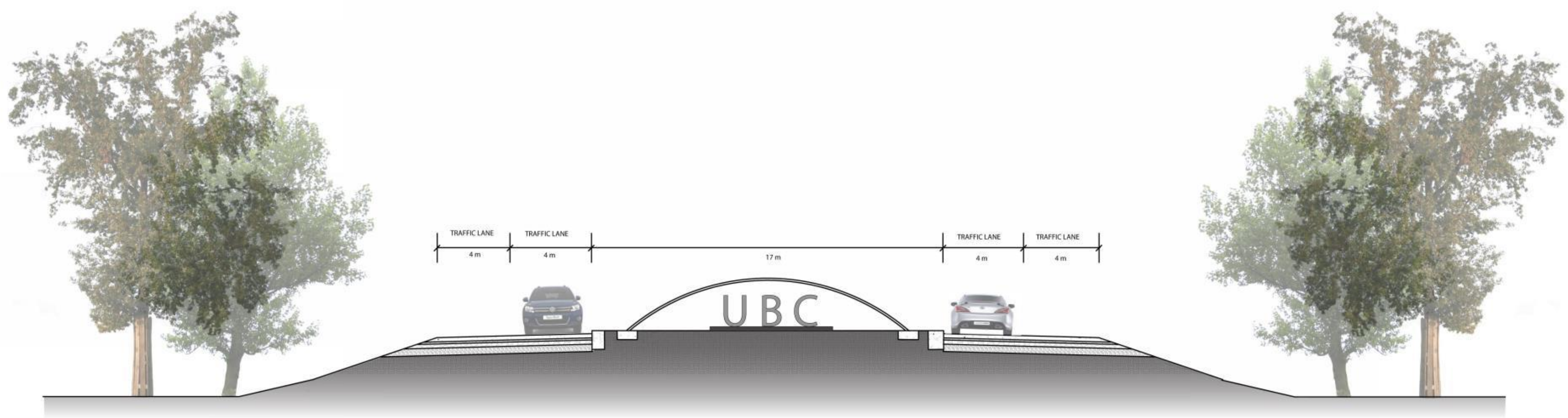
Painting
Signage

Project: Preliminary Schedule
Date: Tue 11/24/15

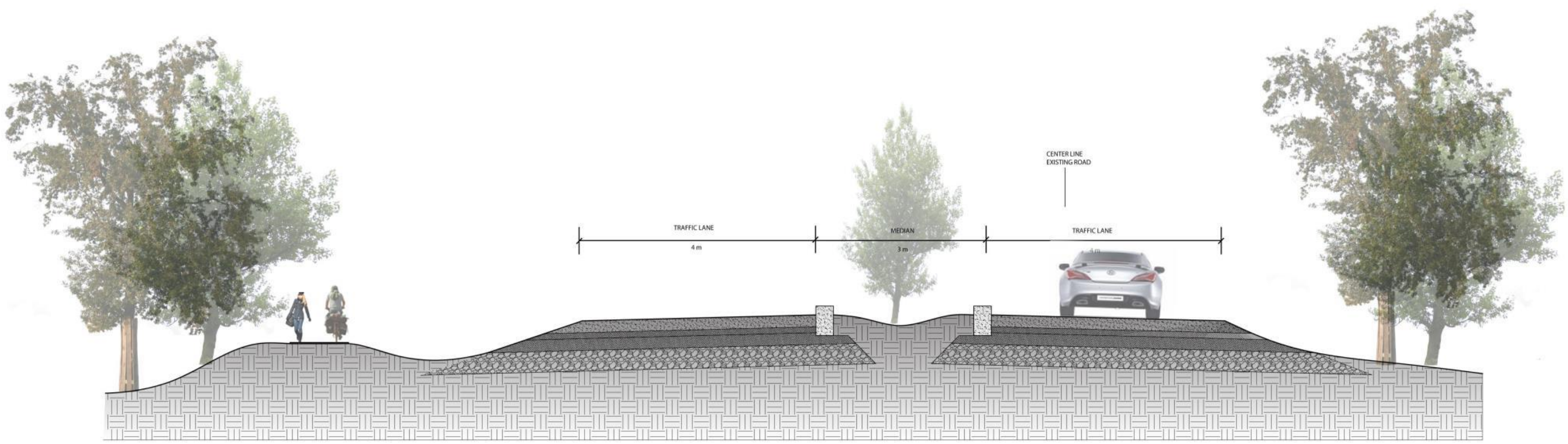
Task, Split, Milestone, Summary, Project Summary, Inactive Task, Inactive Milestone, Inactive Summary, Manual Task, Duration-only, Manual Summary Rollup, Manual Summary, Start-only, Finish-only, External Tasks, External Milestone, Deadline, Progress, Manual Progress

APPENDIX F – Construction Drawings

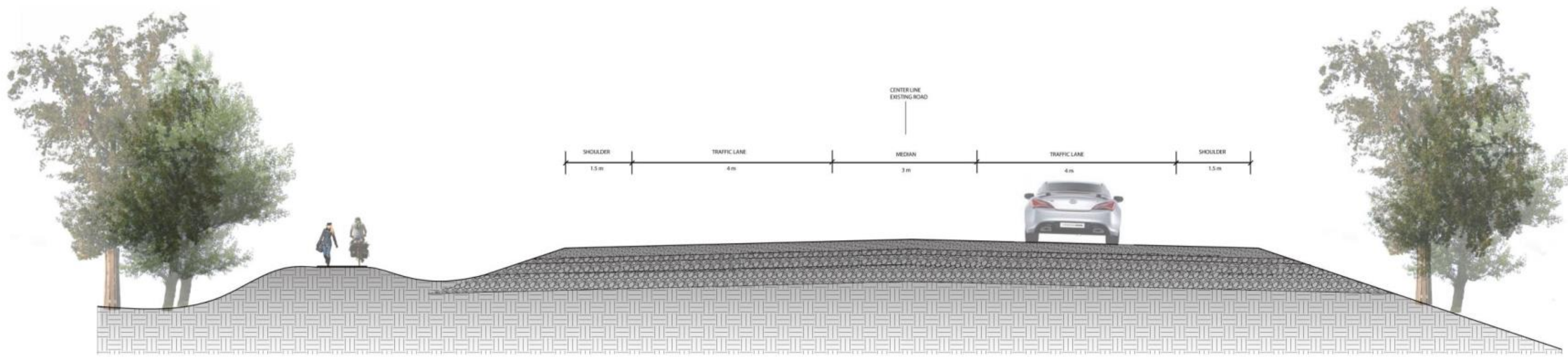
Overall Site Plan.



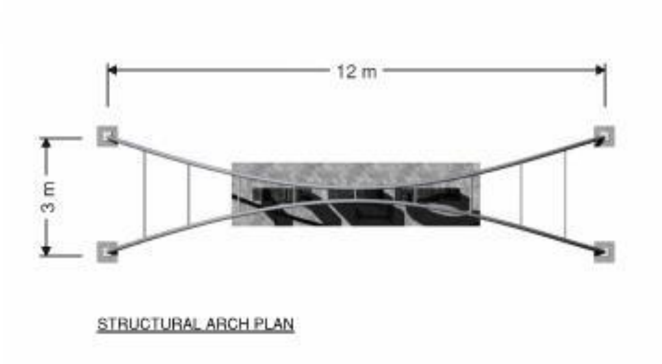
Section View – Traffic Circle

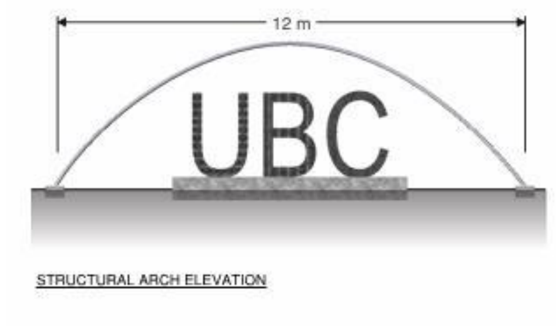


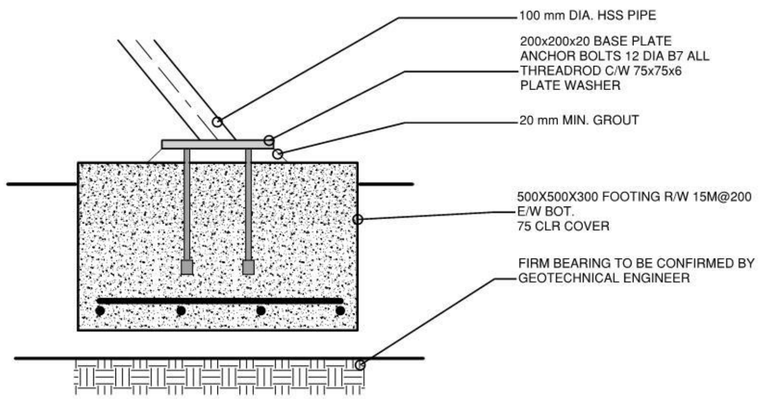
Section View – Pacific Spirit Park / North Marine Drive

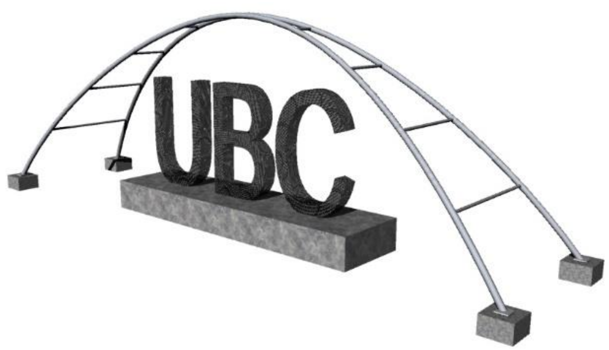


<u>Section View – North Marine Drive Approach / Pacific Spirit Park</u>









Typical Footing Detail

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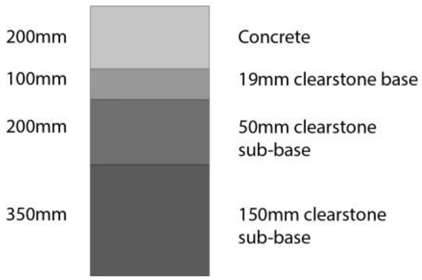
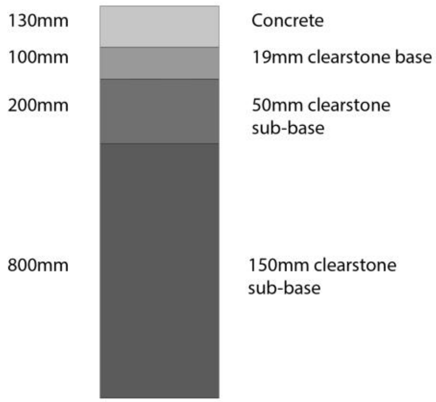
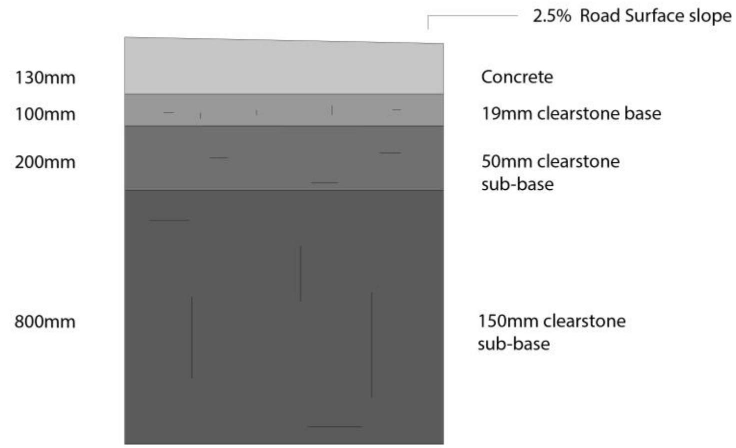
Concrete Pavement



Asphalt Pavement





<u>Typical Road Material Thicknesses</u>

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APPENDIX G - Risk Assessment Register

Risk	Likelihood	Impact	Risk Level	Action	Mitegation Strategy
Planning					
Changes to scope of work required	Possible	major	High	Mitigate	Ensure clear communication between all parties
Scope changes from ongoing stakeholder consultation	Possible	moderate	Medium	Mitigate	Continue coordination during all phases of project
Communication between contracters and sub causes delays	Possible	moderate	High	Mitigate	Ensure clear communication between all parties, ensure clearness of drawings and construction plan
Regularory approvals obtained too late	Unlikely	Major	High	Mitigate	Develop tracking sheet for key permits, hold weekly project meetings with exectutives
Design					
Geotechnical program delays - boreholes, soil surveys, etc.	Unlikely	Major	Medium	Mitigate	Do enough testing for confidence in Borehole conditions
Value engineering comments requre future design	Possible	Minor	Low	Mitigate	Considering optimizing design solutions throughout design
Constructibility required design changes	Possible	Minor	Medium	Mitigate	Design elements as simply as posssible, use contracters experienced in projects of this type
Financial					
cost estimate is inaccurate	Possible	Moderate	Medium	mitigate	Continually evaluate cost estimate when appropriate
Higher than anticipated cost of deconstructing intersection	Unlikely	Moderate	Low	Mitigate	Incorporate existing intersection elements into new design
Material supply and fabrication prices increase	Possible	Moderate	Medium	Mitigate	Monitor costs and advise if there are changes. Award sooner to avoid escalation.
Construction cost escalation	Certain	Major	High	Mitigate	
Tax changes or increased government regulations occur	Unlikely	Moderate	Low	accept	Monitor poteintial changes.
The canadian dolar continues to drop, increasing construction costs	Possible	Moderate	Medium	Mitigate	Monitor costs and advise if there are changes. Award sooner to avoid escalation.
Procurement					
Delay in award of construction contract	Unlikely	Major	Medium	Mitigate	Process flow chart to map out process
Lack of qualified bidder submissions	Unlikely	Minor	Low	Mitigate	Prequalification process during procurment
legal challengees to any contract or award	Unlikely	Moderate	Low	Mitigate	Following bidding proces and ensure fairness throughout. Debriefing of unsuccesful bidders
Designer/contrctor disputes over design	Possible	Major	Medium	Mitigate	Clear contract terms, ensure experienced project team reviews contract
Contractor Banruptcy	Unlikely	Major	Low	Mitigate	review and ver all qualified bidders. Have project insured
Loss of proponent - preach of confidentiality	Possible	Moderate	Low	Mitigate	Confidentiality agreements, restricted reporting
Loss of proponent - response to commercial terms	Possible	Moderate	Low	Mitigate	Ensure fair terms and conditions in draft contract. Collaborative meetings to review commercial concerns
Construction					
Change in site conditions after design	Unlikely	Major	Low	Accept	
Loss of schedule float	Possible	Major	High	Mitigate	Manage schedule with frequent reviews. Update schedule if delays do occur, and ensure communication betwee
Deficiencies	Certain	Moderate	Medium	Mitigate	Have regular construction inspections
Saftey issues arise on site	Likely	Moderate	Medium	Mitigate	Saftey issues delegated to Contractor of Record. Ensure contracture engorces a strong saftey culture on site
Arceological artifacts found, shutting down construction	Unlikely	Major	Medium	Accept	
Indement weather that shuts down work	Possible	Moderate	Low	Mitigate	Clarity in Contract regarding weather Risks
Damage to nearby infastructure (residential, instititutional)	Possible	Moderate	Low	Transfer	Clear contract verbiage placing contractor responsible for all damages
Traffic blockage occurs during construction	Possible	Moderate	Low	Mitigate	Ensure construction plan is clear, have regular construction inspections
Delay in deliveray of key construction equipment	Possible	Moderate	Low	Mitigate	Early contract award, clear transparent scheduling between owner/contractor
Noise complaints from neighbours	Possible	Minor	Low	Mitigate	Contract language regulating noise polution
Site Vandalism/Damage/theft	Unlikely	Moderate	Low	Transfer	Contract making contractor responsible for onsite equipment
Noncompliance with WorksafeBC	Unlikely	Moderate	Low	Mitigate	Contract language requireing ontractors proof of coverage and safty regulations
Schedule delay from UBCCCP	Possible	Major	Low	Mitigate	Clear scheduling specifications
Schedule delay from consultants	Possible	Major	Medium	Mitigate	confirm design, pracurement and construction schedule are coordinated
Schedule delay from contractor	Possible	Major	High	Mitigate	Early contract award. Contract should require schedule revovery process by contractor
Organizational					
Special interest groups cause delay	Possible	Major	Medium	Mitigate	Continued Proactive Communication
Strike by employees/union dispute	Unlikely	Major	Medium	Mitigate	Continued Proactive Communication
Environmental					
Oil spills occur during construction	Possible	Moderate	Medium	Mitigate	Monitoring, and emphasis on
trees are damaged when moved	Likely	Moderate	Medium	Mitigate	Stress the importance of the trees with contractor
Operations and maintenance					
Longterm geotechnical design is inadequete	Unlikely	Moderate	Medium	Mitigate	Continued matinence of site
Drainage system becomes filled with Plant Material	Possible	Moderate	Low	Mitigate	Continued matinence of site