RedUBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Redesign of Chancellor Boulevard and Wesbrook Mall Intersection

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CIVL 446

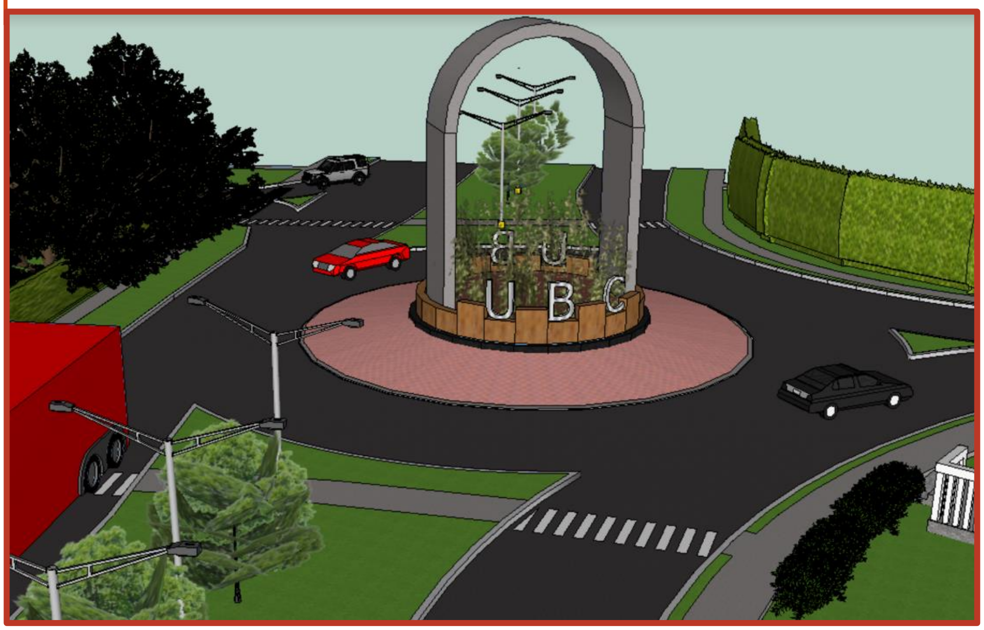
April 7th, 2017

MCKENNA CONSULTANTS

Detailed Design Report:

Redesign of the Chancellor Boulevard and Wesbrook Mall Intersection

Civil 446 – Team #11 Capstone Project



Prepared for: UBC SEEDS Sustainability Program

Prepared by: Team #11 from Civil 446 - University of British Columbia

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April 7th, 2017

UBC SEEDS Sustainability Program
3rd Floor - 2260 West mall
Vancouver, BC, Canada V6T 1Z4

Dear Ms. Krista Falkner,

Re: Detailed Design Report – Letter of Transmittal

McKenna Consultants, Team #11, from Civil 446 at the University of British Columbia (UBC) is pleased to submit (2) electronic copies of the detailed design report for the proposed project at the Chancellor Boulevard and Wesbrook Mall intersection. Our team has been retained by the UBC SEEDS Sustainability Program to develop the design for improving the subject intersection. McKenna Consultants has successfully completed the consulting services required for the detailed design in conjunction with the terms of services agreed upon in the initial phases of this project. A conceptual design presentation and summary report were provided to the client representatives in October 2016, followed by a preliminary design report submitted in December 2016. Our team has successfully moved forward to plan the implementation of the proposed design for the intersection.

The proposed intersection design meets all client objectives of improving the clarity and efficiency of the Chancellor Boulevard and Wesbrook Mall intersection, while promoting environmentally sustainable modes of transportation. The following report discusses detailed design features while highlighting the implementation process of the design.

Alongside the intersection design, our team has designed a gateway structure for the inner island of the roundabout. This iconic structure is intended to be an entrance to the university campus.
The enclosed detailed design report includes a cost breakdown and the construction schedule for the proposed project.

For any questions regarding the enclosed information, please do not hesitate to contact McKenna Consultants. We look forward to working alongside UBC SEEDS throughout the construction phase of this project.

Sincerely,

Monrit Chatha
Principal, McKenna Consultants
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EXECUTIVE SUMMARY

McKenna Consultants has prepared a detailed design report for University of British Columbia (UBC) SEEDS Sustainability Program for the redesign of the Chancellor Boulevard and Wesbrook Mall intersection. This report intends to expand on the preliminary design by providing the final design details as well as a construction plan.

McKenna Consultants conducted desktop reviews and site investigations to better understand the current configuration of the intersection. This allowed our team to understand the areas in need of improvement as well as the design constraints at the project site. From this, we could create a detailed design report which incorporated the client's objectives. As per the BC Ministry of Transportation and Infrastructure Design Guidelines, the roundabout design was selected since it safely accommodates all modes of transportation. Traffic demand is expected to continue to decrease, however there is capacity for a 44% increase of current traffic volumes entering the intersection.

All stakeholders impacted by the proposed work will be consulted by our team to ensure that the project receives public support. A stakeholder management plan is included as part of the detailed design to verify that all stakeholders' opinions and concerns have been addressed, including announcements and open houses for the public.

The detailed design of the redesign of the Chancellor Boulevard and Wesbrook Mall intersection also includes the design of an entrance gateway structure to the UBC campus. McKenna Consultants have designed an iconic structure that encompasses the UBC culture. This gateway structure will reflect the design of other gateway structures around campus to create a sense of integrated community within the university campus, however it will also be aesthetically pleasing to the surrounding University Endowment Lands community.

The proposed roundabout has a safe turning radius for all vehicles while leaving a clearance for crosswalks and sidewalks around the perimeter for pedestrians to safely use the proposed intersection, as well as cycling lanes. The detailed design includes specific roundabout configuration dimensions, traffic modelling and other technical considerations. In addition, there will be information regarding the soil profile below the intersection that has been used to accurately design the foundation of the structure, as well as information on the stormwater management plan for the intersection. The gateway design and the stormwater management plan will meet all codes and requirements, as well as incorporating sustainable methods.

McKenna Consultants recommends UBC SEEDS to move forward to the implementation phase of the proposed intersection design. The project is proposed to begin construction on May 1st, 2017 and extend for approximately 6 weeks with an estimated capital cost of $435, 200.00 (excluding taxes). The cost breakdown and construction schedule included in this detailed design report may be modified upon further investigation during the construction stage due to unforeseeable circumstances.

1. INTRODUCTION

The following report discusses the final detailed design for the intersection at Chancellor Boulevard and Wesbrook Mall at the University of British Columbia (UBC). This report is intended to be read in conjunction with the attached appendices. As identified in the presentation by Krista Falkner from UBC SEEDS in September, 2016, the Chancellor Blvd. and Wesbrook Mall intersection requires a redesign due to its non-standard configuration, inefficiency, and lack of accessibility for all modes of transportation.

The intersection is one of four main entrances to UBC and is mainly used by vehicles and cyclists. The current configuration is confusing to drivers and dangerous for pedestrians and cyclists, made worse at night due to poor lighting. The lack of clarity for users often causes incorrect and dangerous maneuvers such as incorrect yielding and driving the wrong way down the road. The design proposed by McKenna Consultants will mitigate these issues while also adding features that will improve the overall use of the intersection and encourage the use of sustainable modes of transportation to limit the number of single occupancy vehicles driving to and from campus.

The provided intersection design meets all client objectives identified by UBC SEEDS, as well as other important features McKenna Consultants deemed important based on research for sustainable intersection design. A qualified team from McKenna Consultants was put together to create this final design report and to provide recommendations. The team members and their contributions are highlighted in Table 1 below.

1.1. PROJECT DESCRIPTION

The project site is located at the North-East end of the UBC Vancouver campus at the Chancellor Boulevard and Wesbrook Mall intersection. The current configuration of the intersection does not adequately accommodate all modes of transportation, primarily pedestrians and cyclists. Cyclists must perform dangerous lane change maneuvers and pedestrians have no sidewalk access on the southwest corner and lack access to crosswalks. The intersection is near a major TransLink bus loop which accommodates over a dozen bus lines including the 99 B-Line.

The intersection at Chancellor Boulevard and Wesbrook Mall is one of the main entrances to the UBC Vancouver campus, and due to the inefficient layout and lack of accommodation for all modes of transportation, needs a complete redesign. McKenna Consultants has prepared this final design report which highlights the key features of the intersection and confirms the feasibility of the proposed roundabout project. The preferred design option was chosen during the conceptual design phase of the project and has been further developed to optimize the space at the project site and meet the following design objectives:

- Maximize operational efficiency
- Accommodate large vehicles and buses (WB-17 type design vehicle)
- Incorporate adjacent roadways (adjacent roads, sidewalks and bicycle lanes)
- Work within property lines
- Minimize costs
- Keep construction within the surrounding property line
- Incorporate features that support sustainability

This intersection is owned and operated by the BC Ministry of Transportation and Infrastructure and the design considers its rules and regulations. The Ministry requires consideration of a roundabout in intersection control before any other option. The surrounding property is owned by the University Neighbourhood Chancellor Place and the University Endowment Lands. The interests of both groups are considered in the design as part of the stakeholder management plan, covered throughout this report. A key stakeholder group included throughout this project is the Musqueam First Nations. It was essential to consult these stakeholders prior to commencing the project because the UBC Vancouver campus, and thus the project site, resides on the unceded, ancestral, and traditional territory of the Musqueam First Nations.

1.2. Project Scope

The scope of work provided in this report is intended to satisfy the deliverable requirements as identified by the client. The report finalizes design and calculations from the Preliminary Design Report and provides further insight on design components.

Based on projects constraints and the Ministry of Transportation Guidelines, the scope of work for the final design includes a traffic analysis of future volumes, safety analysis, stakeholder engagement plan, complete design analysis and drawings for the new intersection and entrance gateway structure, a Class C cost estimate, construction plan, and final recommendations.

There are three main components to consider for the goal of this project, which include:

- Provide an improved intersection design that will meet the anticipated demands of the future.
- Allow all modes of transportation, including pedestrians and cyclists, to safely and efficiently make use of the intersection.
- Design an entrance structure at the intersection that reflects the welcoming atmosphere of the university campus.

TABLE 1: ROLES AND RESPONSIBILITIES

Team Member	Roles and Contributions
Cambria Banks	• Design Criteria • Strom and Utility Design • Environmental Management • Reviewing Report

Monrit Chatha	• Letter of Transmittal and Executive Summary
	• Gateway Structure
	    o Design Criteria
	    o Design Outputs
	    o Load Calculations
	• Stakeholder Management
	• Moving Forward and Possible Issues
	• Editing Report

Laura Dotto	• Foundation Design • Cost Estimate • Recommendations for Future Work • Editing and Formatting Report

Ian McKenna	• Design Outputs
	    o Roundabout
	• Construction Schedule
	    o Sequence of Work
	    o Anticipated Issues

Thomas van Wermeskerken	• Introduction and Project Description
	• AutoCAD Design
	    o Intersection
	    o Roundabout Geometry
	• Intersection Design Components
	• Editing Report

Nolan Wiebe	• Standards and Regulations
	• Technical Considerations
	    o Roundabout
	    o Gateway Structure
	• SAP2000 modelling for structure

1.3. Site Overview

The proposed intersection design is for the project site located at the Chancellor Boulevard and Wesbrook Mall intersection. This intersection is located in Vancouver, British Columbia at the North-East end of the UBC Vancouver Campus. This intersection allows traffic to travel East-West along Chancellor Boulevard, South to Wesbrook Mall, and North to Wesbrook Crescent. These respective roads and the access point for the intersection is visible in Figure 1 below.

Figure 1: Current Intersection Layout

The current design of the intersection does not support all modes of transportation, primarily pedestrians and cyclists. There are no bike lanes through the intersection which makes the intersection difficult and unsafe for cyclists. Pedestrians do not have sidewalks on the southeast side of the intersection, and lack marked crosswalks on the west and south sides of the intersection. The site is located on the north side of campus and has multiple bus routes that pass through the intersection daily.

2. Design Criteria

2.1. Intersection

For the redesign of the intersection at Chancellor Boulevard and Wesbrook Mall, many aspects were considered to improve the efficiency and safety. The BC Ministry of Transportation guidelines were followed which lead to the selection of the roundabout design. The design will be able to handle both current and projected traffic volumes, as well as all modes of transportation. In accordance with UBC's goal of minimizing the amount of passenger vehicles on campus, the intersection will provide safe travel for pedestrians and cyclists, in addition to supporting large vehicles (trucks and buses). There will be sidewalks added where they are currently non-existent. The proposed design also includes pedestrian activated crosswalks, which achieve safe walking routes around the whole intersection. Cyclists will have bike lanes with the proper signage on how to properly navigate through the roundabout to ensure the safety of all users.

The required geometry and size of the roundabout will not impede on property lines. This design increases accessibility of the intersection by allowing the traffic travelling south on Wesbrook Crescent to enter the intersection to travel east on Chancellor Boulevard, which the current configuration does not allow. The new design will require minimal construction which would benefit the client and the surrounding neighbourhood, in addition to reducing the project's environmental footprint. To ensure the project follows UBC's sustainability goals and aesthetic, the centre of the roundabout will include green life and any trees taken out during construction will be replanted. The opinions and concerns of neighbourhoods surrounding the intersection and First Nations will also be addressed with the stakeholder management plan discussed throughout this report.

2.2. Gateway Structure

As per the project scope, the proposed redesign of the subject intersection includes the addition a gateway structure. This intersection is intended to be a main entrance to the UBC Vancouver campus. As such, our team has designed a gateway structure that will welcome road users to the university as they approach from Chancellor Boulevard. McKenna Consultants has designed a large concrete arch that will feature the iconic 'UBC' letters at the base on either side facing Chancellor Boulevard.

The gateway structure is designed to be incorporated in the central island of the roundabout. The size of the arch allows it to be viewed from a large distance away along Chancellor Boulevard, creating an eye-catching aesthetic for stakeholders and public coming to campus. The design incorporates UBC's culture and values while remaining within a reasonable budget. The budget has been balanced by economically choosing the material for the structure and the 'UBC' letters. The design also allows for ample green space to be featured directly underneath the arch. The structure is not intended for occupant use; however, it has been designed to support dead load, snow load, and wind load as outlined by the National Building Code of Canada 2015 and CSA A23.3 for concrete design. The proposed design also considers earthquake loads, and extreme environmental impact, such as impact from collisions. The design outputs are discussed throughout this report.

3. Preliminary Analysis

3.1. Methodology

Prior to creating design options for the redesign of the Chancellor Blvd. and Wesbrook Mall intersection, McKenna Consultants followed a top down approach to ensure that all constraints and design issues were incorporated into each of the feasible design options. Figure 2 below represents the methodology that was used by our team.

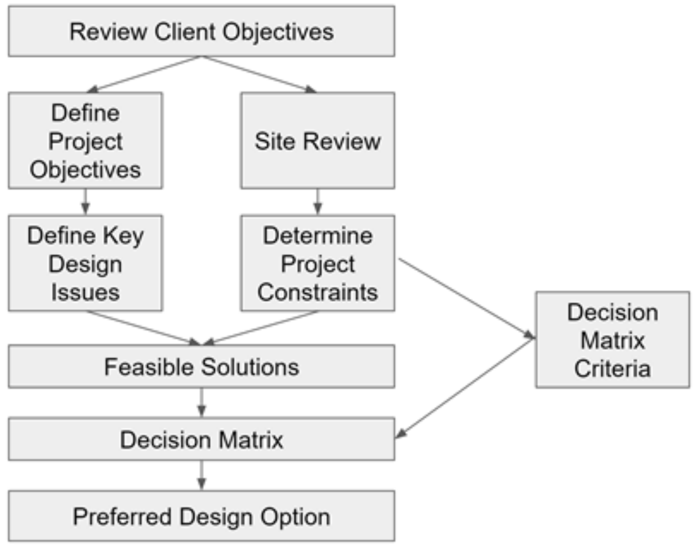

FIGURE 2: DECISION METHODOLOGY

As represented in Figure 2 above, our team began the project with a thorough review of the client objectives, which allowed us to define the project objectives and key design issues. Through the site review and additional research, the project specific constraints were determined. Each of these factors led to the development of a decision matrix which was used to quantify and evaluate three feasible design options. The highest score on the decision matrix determined the preferred design option.

3.1.1. DESIGN GUIDELINES

McKenna Consultants developed a list of design guidelines that were referenced during the development of each of the three conceptual design options. The basis for these guidelines included the project objectives, as outlined by the client and the key design issues, as identified by the McKenna Consultants team. A key design guideline that influenced the project decisions included the BC Ministry of Transportation and Infrastructure Design guidelines. Information on roundabout design was also extracted from other sources including:

- *Austroads Guide to Traffic Engineering Practice, Part 6 – Roundabouts*

- *Transportation Association of Canada (TAC) Guidelines*
- *BC Supplement to TAC Geometric Design Guide, 2007 Edition*
- *NCHRP Report 672 Roundabouts: An Informational Guide*

These additional design guidelines are included as decision matrix criteria used to evaluate the design options.

3.1.2. Decision Matrix

McKenna Consultants developed a weighted decision matrix to evaluate the three feasible design options and confirm the preferred design option of a roundabout during the preliminary design phase of this project. The complete decision matrix with the quantified values is attached as Appendix C. A few of the key criteria that heavily weighed the decision matrix include:

- BC Ministry of Transportation and Infrastructure Design Guidelines
- Safety (for all users)
- Traffic Volumes (expected increases in the future)
- Environmental Concerns (throughout construction and the life cycle of the project)
- Cost (minimizing cost for the client)

3.2. Assumptions

While short term plans for UBC are readily available, estimating traffic demand for a thirty-year life span requires assumptions and comes with a high level of uncertainty. The following assumptions were made regarding development in the region:

- Personal vehicle mode share would continue to decrease in keeping with City of Vancouver 2040 Transportation Plan.
- Vehicle traffic would continue its downward trend. See Appendix D for traffic volume predictions.

- No major developments on adjacent single occupancy UEL properties throughout the thirty-year lifespan of the project.

Due to a lack of information on current infrastructure, the following assumptions were made:

- It is desirable to move the sidewalk that currently exists on private property on the southwest corner of the intersection.
- Minimal below grade work will be done on sewer, water, and gas mains during the construction period. Minor work such as catch basin movement is expected.
- The current layout of the intersection is unconventional and therefore not possible to model properly. This prevents direct comparison of before and after improvements.

3.3. Preferred Design Option

As per the BC Ministry of Transportation Design Guidelines, a roundabout design must be considered as the first choice for an intersection of this caliber. Other design options may only be considered if a roundabout is not feasible. This is the key reasoning behind why McKenna Consultants decided to move forward with the roundabout as the preferred option for the intersection design. Other designs were also considered due to the compactness required to implement a roundabout design; however, the other designs were rejected as it was determined that the roundabout was possible and feasible. The roundabout design was finalized when it was shown to meet requirements provided by the client. The roundabout offers a safe and efficient way of managing traffic during peak volumes as well as low periods.

The roundabout allows the opportunity to accommodate all types of users. Large trucks and buses can use the roundabout safely, with longer vehicles able to navigate using the mountable apron if necessary. Bicycle lanes will be added to the new intersection design as well. Sidewalks on the south sides of the intersections will be added. Pedestrian activated crosswalks will be added to connect all sidewalks to increase safety and accessibility. The geometry and size of the roundabout fits within property right-of-way.

4. Key Design Components

4.1. Intersection

Prior to developing the preliminary design for the proposed project, the key design components were determined and assessed. After a roundabout design was deemed feasible in the conceptual design report, further design components were identified. The design components can be identified in the following three categories:

- Accessibility
- Safety
- Constructability

The main improvements to the intersection design are regarding accessibility for vehicles and pedestrians. Adequate sidewalks must be added to all corners of the intersection, notably the south-east corner which currently has no pedestrian access and the south-west corner which encroaches on private property. Crosswalks are necessary at each leg of the intersection to provide a safe travel path for pedestrians and cyclists walking their bikes to cross the road. Chancellor Boulevard is a popular route for cyclists and it was necessary to ensure cyclist accessibility did not decrease. The proposed design provides marginal increase in accessibility to cyclists. Vehicle traffic volumes are relatively low with no major increases predicted for the future. It is important, however, that the intersection design does not become a limiting factor for future development. As such, the extra capacity in the roundabout will accommodate moderate future development.

The redesigned intersection requires significant upgrades to improve safety. Key design components include improved lighting, and wider vehicle and bicycle lane widths. Other considerations are made such as driver sight visibility and flashing lights for the pedestrian-activated crosswalks.

Constructability is also a design component for the project, influencing the overall sustainability. The time and cost of construction are an important consideration as well as the impact of construction such as road closures, and changes to the amount of ground cover, services and drainage paths.

4.2. Gateway Structure

Upon review of the design criteria requested by the client and reviewing the preliminary design with the stakeholders group, it was evident that an aesthetically appealing, large structure was preferred. The community and client representative preferred a large structure so it can be seen from a further distance away as people approach the intersection. The proposed design consists of a large reinforced concrete arch that features hollow steel 'UBC' letters around the base of the structure. The reinforced concrete arch has been designed with two key components:

1. Two rectangular columns supporting the arch beam
2. An arched reinforced concrete beam

The connection of the columns to the beam has been analyzed as a simply supported connection (pin) which allows overturning moment. The structure has been analyzed for dead, snow, wind, and earthquake loads, however the final design was completed by considering dead, snow, and wind loads only. Earthquake loads were deemed negligible as the proposed structure is not intended for occupant use.

FIGURE 3: PROPOSED DESIGN (3D MODEL)

4.3. FOUNDATION

Due to the height and weight of the arch structure, a foundation design is required. The foundation of the gateway arch will ensure that the arch remains stable and safe for the roadway design. The foundation will be constructed on the glacial till at a depth of 1m below ground. The foundation is composed of two square slab foundations. The connection between the arch structure and the foundation is modelled as a rigid support. The following section of this report discusses the technical considerations for the design.

5. TECHNICAL CONSIDERATIONS

5.1. ROUNDABOUT

To produce a safe roundabout design, the following technical considerations were carefully assessed. The BC Ministry of Transportation and Infrastructure Design Guidelines and the Transportation Associations of Canada (TAC) Guidelines were used to determine the feasibility of a roundabout. These technical guidelines focused on the geometric requirements, including determining the required diameter required for the design vehicle (WB-17).

The roundabout has been designed to efficiently accommodate expected traffic volumes. The future traffic volumes were predicted using the current volumes and considering UBC's goals to reduce single passenger vehicle traffic. Details of traffic predications can be seen in the Section 6.1.2 of this report. Additional safety components, including proper bike lanes and crosswalks, were added to ensure the intersection would be safe for all types of users. The overall environmental impact of the project was considered throughout the life cycle of the project to ensure all environmental regulations would be met.

5.2. Gateway

The gateway structure has been designed to create a welcoming aesthetic for road users travelling to the UBC Vancouver campus along Chancellor Boulevard. The structure is relatively large and occupies a majority of the space in the center island of the roundabout. The National Building Code of Canada (NBCC 2015) was referenced to determine the applied load on the structure. The structure has been designed to safely support dead, snow, and wind loads. The project site is in a region that faces seismic concerns, and thus all structures must be designed to withstand earthquake loads. However, the proposed structure is not intended for occupant use and therefore it does not need to withstand a seismic event. Based on NBCC Ultimate Limit States Design, Load Case 1 governs the design of the structure. Load Case 1 does not include earthquake loads and thus they are negligible for the design.

The gateway structure has been designed as two reinforced concrete columns supporting a reinforced concrete arch beam. The material was chosen based on feasibility of construction, structure weight, and cost. The connection between the columns and the beam has been analyzed as a simply supported connection. The reinforcement design has been completed as per CSA A23.3 regulations. The cover and rebar sizing has been chosen based on design guidelines and minimum reinforcement required for axial and shear loading cases.

Since the structure is directly in the center of the roundabout island, it is possible that damage may occur if there is a collision at the intersection. Although the intersection has been designed to safely accommodate all modes of transportation, there is the rare possibility of a collision occurring. To limit the harm to human life, the structure has been designed to fail during extreme impacts such as impact from a vehicle collision. This structure will break within the center island should this impact occur and thus not negatively harm human life.

5.3. FOUNDATION

Prior to designing the foundation for the arch structure, McKenna Consultants reviewed the site and subgrade conditions. For the project site and the surrounding area for the University Endowment Lands, the soil conditions underneath the intersection are classified as Bose-Heron Soil Management Group, as per the Vancouver Soil Map (Vancouver Soil Map, 2017). For Bose-Heron soil, the first meter of soil is composed primarily of gravelly sand, which sits on top of glacial till parent material. Since there is glacial till underneath this intersection, a shallow foundation design has been chosen due to ease of construction.

5.4. REGULATORY STANDARDS AND SOFTWARE PACKAGES USED

The detailed design presented throughout this report has been completed in compliance with multiple regulatory agencies. Each of these regulatory agencies impact the design on varied levels. Some agencies require permits to be approved, while others identify guidelines that must be followed. The regulatory requirements are shown in the following table.

TABLE 2: REGULATORY REQUIREMENTS

Regulatory Agency	Requirement
BC Ministry of Transportation	Complete and obtain approved Lane Closure Request.
BC One Call	Have BC One identify all underground utilities prior to beginning to construction. Identification is crucial due to gas, water, and sewer mains, as well as electrical conduit for street lights being present in the construction area.
UBC Guidelines	Complete and obtain approved Streets and Landscape permit.
UBC Guidelines	Have contractor submit appropriate Traffic management plan.
University Endowment Lands and BC Ministry of Transportation	All design and construction work to be done in accordance with the 2009 MMCD Design Guidelines Manual.
CSA A.23.3	Details and detailing of concrete reinforcement
National Building Code of Canada (NBCC 2015)	Ultimate Limit States Design and Load Cases
UBC Design Guidelines for Structures on Campus	Specified loads applied on structure, factors to magnify the load for a conservative design

Software Packages

McKenna Consultants used different software packages to complete the proposed detailed design. Software was used to model the roundabout and the gateway structure to determine the geometry.

Software was also used to analyze the intersection and determine the performance during different traffic patterns for the roundabout, and different load cases for the gateway structure. The table below summarizes the software used throughout this project and the function of the software for the purposes of this project.

TABLE 3: SOFTWARE PACKAGES USED IN DESIGN

Software	**Use of Software in Design**
AutoCAD	• Develop and implement construction plan • Determine geometry of the roundabout and structure • Design the reinforcement for the structure
SAP2000	• Structural analysis based on loads on the gateway structure
Sketch-Up	• Used to develop architectural models for public and clients
Synchro	• Roundabout design
Microsoft Office	• Report, Excel Calculations

6. DESIGN OUTPUTS

6.1. ROUNDABOUT

6.1.1. DESIGN DRAWINGS

As per the scope of work agreed upon in the initial phases of this project, McKenna Consultants has completed detailed design drawings for the proposed design. Appendix E attached contains the Project Plan Drawing. This drawing is to be used for tendering and is subject to minor changes in the upcoming

"Issued for Construction" revision.

Also, attached in Appendix C is a 3D model of the intersection design, complete with the arch design. This model should not be used for construction or tendering purposes; it is merely for advertising and conceptual planning purposes.

6.1.2. *Traffic Data*

Traffic modeling was completed using data obtained by CTS Ltd. in October of 2015. Mckenna Consultants believe this data to be accurate and the most up-to-date, and values were found to be comparable to City of Vancouver traffic counts at a nearby intersection in 2007.

UBC has successfully reduced traffic volumes on campus over the last two decades by increasing parking rates, reducing number of parking stalls, and improving transit to the campus. Additionally, UBC has had success with staggering class times to avoid congestion during peak AM and PM periods. With the use of City of Vancouver traffic data, traffic commuting to UBC along Chancellor Blvd has decreased between 2003 and 2007. These values were also comparable to the data recorded in 2015. See Appendix D for more information on traffic data predictions.

6.1.3. *Geometric Design*

The roundabout is to be single-lane with four approaches and three exits. The inner island is to have an outer diameter of 10m while the edge of the mountable apron will have an outer diameter of 20m. The WB-17 design vehicle can navigate this design and additional clearance is provided for contingency.

The road geometries are based on best practices using the *Transportation Association of Canada (TAC) Guidelines* and the *NCHRP Report 672 Roundabouts: An Informational Guide*. The geometric guidelines are based on current posted speeds on each approaching leg of the roundabout.

Based on recommendations for number of entry and circulating flow from the Austroads *Guide to Traffic Engineering Practice TAC Guidelines (Appendix D)*, a single lane roundabout will accommodate projected traffic volumes for a thirty-year design life. Synchro analysis allows for peak hour volume increases of 44%. A summary of geometric standards and practices for design are included in Table 4 below:

TABLE 4: ROADWAY DESIGN CRITERIA

Intersection Leg	Chancellor Blvd. (East Leg)	Chancellor Blvd. (West Leg)	Wesbrook Mall (South Leg)
Posted Speed	50 km/h	50 km/h	50 km/h
Design Speed	60 km/h	60 km/h	60 km/h
High Speed Approach	No	No	No
Design Vehicle	WB-17	WB-17	WB-17
Lane Width	4.0m	4.0m	4.9m
Bike Lane	Yes	Yes	No
Bike Lane Width	1.8m	1.8m	N/A
Shoulder Width	2.0m	2.0m	0m
Roundabout Features	Minimum Circulatory Lane Width		5.0m
Inscribed Circle	1-Lane Inscribed Circle		35.0m

In review of *TAC Geometric Design Guidelines* for inscribed circles, the range of recommended inscribed circle for an urban single lane roundabout is 37m-46m for a WB-20 design vehicle (Appendix D). Given limited intersection dimensions, in conjunction with a smaller design vehicle specific to the project (WB-17 type design vehicle), McKenna Consultants chose an inscribed circle diameter of 35.0m for roundabout analysis. The required dimensions are summarized in Table 14 attached in Appendix K of this report.

High speed approaches only need to be considered for posted speeds of 80 km/h or higher per the *NCHRP Report 672 – Roundabouts: An Information Guide,* therefore high speed entry features will not be considered for design.

The approaching medians on Chancellor Blvd. will be flared to prepare approaching traffic by lowering speeds and aligning the vehicles with the traffic flow inside the roundabout.

Bicycle lanes will have a width of 1.8m on Chancellor Blvd, exceeding the minimum requirement of 1.5m for BC Ministry of Transportation. As there is not adequate space for bicycle lanes on Wesbrook Mall, sharrow decals shall be painted on the asphalt to indicate shared traffic use.

FIGURE 4: BICYCLE SHARROW DECAL

Curb radii for right turning vehicles are indicated on the plan drawing in Appendix E. This radius does not pose an issue to the WB-17 design vehicle.

6.2. GATEWAY STRUCTURE

The reinforced concrete arch has a finished height of 11.75 m, a width of 8.5 m, and a thickness of 1 m. A plan drawing of the structure with geometry identified is attached in Appendix G. The arch is supported by a slab foundation design. The base of the arch features 'UBC' letters that add to aesthetic value of the entrance structure and has a timber frame that outline the center island. The following section of the report discusses the design outputs for the gateway structure and the modelling and analysis procedures. This section of the report is intended to be read in conjunction with Appendix F: Gateway Structural Analysis and Appendix G: Load Calculations and Drawings for the Structure

6.2.1. Load Calculations

The initial phase of designing the entrance structure involved determining the material for the structure. The material option dictated the type of design required, the regulations that needed to be implemented, and load applied on the structure. After thorough review and consideration, McKenna Consultants finalized the arch structure to be composed of reinforced concrete, and the 'UBC' letters to be composed of steel. Our team designed the arch with 25 MPa concrete and steel reinforcement.

The load calculations for the structure are based on NBCC 2015 Ultimate Limit States Design load cases. The dead load for the structure was determined using weight of concrete and the volume of the structure. The load calculations are attached in Appendix G of this report. The snow load and wind load for the structure was obtained from the UBC Design Guidelines for structures on the university campus. Snow load, wind load, and dead load were calculated and factored. These loads were then inputted in the NBCC 2015 load cases to determine the governing load case. Load Case 1 governed the design with a factored load of 567.7 kN.

6.2.2. Structural Analysis

The load calculations and arch geometry was then used to design and analyze the structural system. The structure was modelled as two reinforced concrete columns supporting an arch beam. The connections were analyzed as simple supports. The concrete and steel capacity was determined to ensure the design is safe under the dead load.

SAP2000 Model

The structural system was analyzed using CSI SAP2000. This model allowed our team to assess the performance of the proposed structure under the ultimate limit states load case. The arch geometry and load calculations were used as inputs for the SAP2000 model. The structure was modelled with 3 frame elements and the factored dead load was then applied along the structure's length. From this analysis, our team could determine the critical areas for the structure and applied loads. The outputs of the SAP2000 analysis is attached in Appendix G of this report.

Reinforcement Design

The arch gateway has been analyzed and designed for moment loads, shear forces, and axial forces. The applied moment, shear, and axial loads were obtained from the SAP2000 model. The reinforcement design was completed by designing the columns and determining their capacity against withstanding the respective loads. Once the reinforcement for the columns was designed, the rebar placement pattern was extended throughout the arch beam.

The columns have a geometry of 1000 mm x 500 mm. It is assumed that the columns will be concentrically loaded. Other design assumptions can be viewed along with the reinforcement design calculations in Appendix G of this report. 10 – 20M bars have been designed for the longitudinal reinforcement and 10 M stirrups @ 300mm spacing. This reinforcement placement is based on minimum reinforcement requirements as per CSA A23.3.

6.2.3. Foundation Design

To ensure that the gateway arch is stable and secure, an analysis of a foundation design was completed. Since the first meter of soil below the intersection is composed of gravelly sand, on top of glacial till, this first meter of soil will be removed and refilled. This decision was made for two reasons. Firstly, the gravelly sand soil at the site would require compaction before any heavy structure could be placed on top of it. Secondly, there is a potential for a high-water table at this site, which could easily liquefy if the gravelly sand were to remain underneath the intersection. For these reasons, it was determined that removal and replacement of the gravelly sand was ideal for the site.

A shallow foundation design was chosen due to the unpredictability of glacial till, as well as the cost of boring through hard till. This shallow foundation is made of one large slab footing, which will be located one meter below grade close to the start of the glacial till soil. This slab footing provides the main support for the columns of the arch. The foundation has been designed as two square slabs that will support each of the columns. The dimensions for the foundation are 1.7m x 1.7m with a depth of 0.8m. For further calculations, please refer to Appendix H.

7. Environmental Management

7.1. Stormwater Management

The proposed intersection design reduces required changes to existing stormwater infrastructure. The centre of the roundabout and the medians will be filled with green life and are designed to capture water to absorb into the ground, which contributes to the reduction of impervious surfaces. There is currently a catch basin located on the Chancellor Boulevard meridian, east of the existing intersection. Since the meridian will be extended to curve with the roundabout, the catch basin will need to be moved. The catchment area of the new design will contain approximately 9% less impervious surface area, and therefore upsizing of the existing storm sewer is not required. The catch basin will be moved to the north side of the intersection which will require a 10.4m long catch basin lead to connect to the manhole. The main detention tanks will remain in the same location; however, drainage pipes will need to be relocated. The manholes will remain in their current configuration however manhole covers will be raised to meet new surface elevation. The manhole in the center of the roundabout will not be moved and will be surrounded by green life to absorb runoff.

7.1.1. Utilities Management Plan

The infrastructure under the intersection consists of gas, storm, sewer and water lines. These all lay approximately 1m below the surface. During excavation and construction, the gas, sewer and water pipes will remain untouched. Four light posts must be relocated to ensure the intersection will be safely light at night. The flashing crosswalk lights will be put in to ensure the safety of the pedestrians while crossing the intersection. The new utility setup can be seen in the plan drawings attached in Appendix E of this report. A BC One Call must be made to identify underground utilities before construction begins.

7.1.2. Waste and Contamination Management

To minimize the effect of construction, McKenna Consultants will ensure that the used material will be recycled and properly disposed of. As well, to reduce the amount of waste created, the construction plan aims to leave as much of the existing infrastructure in place. Waste material storage and disposal will follow the guidelines set by UBC Risk Management Services (RMS). Proper procedures will be followed when handling and disposing of any encountered toxic material. Construction staff must be prepared for a toxic spill to ensure contaminants do not enter the storm sewer network. Erosion and sediment control plans must be completed to ensure that the project site meets all environmental requirements outlined by Environmental Management Systems from UBC's RMS. The stormwater system is connected to a detention tank which will capture runoff contaminants before being discharged into the environment. Sock and donuts must be installed over the catch basins surrounding the project to prevent sediment from the construction site entering the storm sewer network.

7.1.3. Air and Noise Pollution

To minimize the air pollution from dust, water is to be sprayed onto the loose soil during the construction phase. The material piles will be covered to reduce dust. The air quality and the discharge of contaminants will be regulated in accordance to the Federal (Environment Canada National Pollutant

Release Inventory), Provincial (Greenhouse Gas Reduction Target Act and BC Carbon Neutral Government Regulation) and Metro Vancouver regulations. The majority of the construction is intended to be completed during working hours. The contractor must abide by the UBC Noise Bylaw which limits noise pollution to specific hours of the day.

7.1.4. Other Environmental Concerns

To prevent erosion and runoff, McKenna Consultants aims to minimize the amount of land disturbance. The maximum amount of vegetation will be installed in the project area. The vegetation will help counteract the negative effects of construction including carbon emissions. The vegetation will be selected so to require minimal maintenance. Local materials will be used to reduce the transportation emissions. Workers should be encouraged to take public transit to work or carpool to reduce the impact of their travel time. This can be encouraged by not supplying parking or limiting the construction staging area.

8. Stakeholder Management

To ensure that the proposed project receives public support, a highly-qualified team from McKenna Consultants has been tasked with stakeholder management throughout the design and construction phase of this project. This team is involved with defining the stakeholders impacted by the project, developing a feasible engagement plan, and reviewing design feedback. The review process may involve negotiations with certain stakeholder groups and thus we plan to hire an independent mediation consultant.

8.1. Key Stakeholders

McKenna Consultants assessed the project site and neighbouring areas during the preliminary design phase of this project to determine all the stakeholders that are impacted with the redesign and construction at the Chancellor Blvd. and Wesbrook Mall intersection. McKenna Consultants developed the following list of stakeholders that must be consulted prior to moving forward with the preliminary design:

- UBC SEEDS Sustainability Program
- UBC Students, Faculty, and Staff
- Ministry of Transportation and Infrastructure
- TransLink
- University Endowment Land Residents
- University Neighbourhood Association
    - Chancellor Place Neighbourhood
- Musqueam First Nations
- UBC Building Operations
- UBC Plant Operations

8.2. Engagement Plan

The team from McKenna Consultants tasked with stakeholder management has created an engagement plan that accommodates all stakeholders and promotes constructive feedback. The public notice attached in Appendix B is a sample of the material that has been distributed throughout the community and sent to neighbours to increase awareness for the project plans. This communication will create a platform for each of the stakeholders to interact with our team and discuss their views on the proposed project.

During the conceptual design phase of this project, McKenna Consultants presented the three feasible design options to the client for feedback. Based on this feedback, changes and additions were made to the conceptual design to create a more detailed preliminary design. Since then, McKenna Consultants held a public meeting to discuss the detailed design of the proposed project. This meeting was held in March 2017 and was open to the public. Key design issues, construction plans, and finished product plans were presented at the meeting followed by a Q&A discussion surrounding the proposed work.

8.3. Design Feedback

McKenna Consultants highly values the opinions and beliefs of each of the stakeholder groups. Based on the feedback received from stakeholders such as the Client and UBC faculty, staff, and students, our team can confirm that the project will receive full support from the above mentioned stakeholder groups. During the public meeting the participants asked many questions and gained clarity on the project plan. By the end of the meeting each attendee was supportive of the project and is looking forward for the final product to be complete. Our team continues to welcome feedback from all stakeholders and we will ensure each group is consulted and is in favour of the proposed work. Prior to beginning construction at the project site, our team will hold another meeting to discuss any pressing issues. We do not foresee any major issues at this meeting as we have been working with the stakeholders since the commencement of this project.

9. Construction

9.1. Construction Requirements

All construction work is to be completed in accordance with the Master Municipal Construction Documents Platinum Manual (MMCD, 2009) unless otherwise indicated on construction documents or drawings. The Client, UBC SEEDS, shall oversee the project either personally or through an appointed Contract Administrator (CA) at McKenna Consultants. The contractor must perform all work in accordance with directions and restrictions made by the Client or the CA.

9.2. Sequence of Work and Anticipated Issues

Construction is expected to be completed in the following order of tasks, with the potential issues associated with each task found next to each task. It should be noted that the Contractor may complete the tasks in any order.

Table 5: Sequence of Work

Task Description	Potential Issues
1. Removal of median within roundabout zone and existing concrete curb	Minimize disruption to traffic
2. Removal of specified catch basins and light standards	Current condition and location to be confirmed
3. Asphalt milling and removal	Road closure
4. Installation and adjustment of light bases, catch basins and leads	Traffic disruption
5. Removal and replacement of granular materials (optional)	Determine unsuitable road base and replace
6. Installation of curb (e.g. roundabout island curb, triangular concrete island, crosswalk letdowns)	Minimize disruption to traffic
7. Installation of mountable apron	Road closure for multiple days
8. Roundabout island backfill and installation of university gateway structure	Minimize disruption to traffic, coordinate overlap between structure installation and backfill, concrete strength in structure footings must meet minimum required before start of structure construction, minimize damage to mountable apron.
9. Asphalt paving	Road closure for one day
10. Installation of asphalt markings, new signage, and landscaping	No foreseeable issues

9.3. Construction Schedule

Construction of the intersection and gateway structure is expected to last six weeks, from May 1st to June 7th, 2017. The estimated construction schedule can be found in Appendix I.

9.4. Staging

To minimize traffic disruption, no staging of vehicles should be allowed on Wesbrook Mall. All construction vehicles should be limited to staging inside the construction area. Staging along Wesbrook Crescent may be considered if the Contractor can adequately show that vehicles will not interfere with residents that live near the intersection.

For the phases of construction that require the intersection to be closed, McKenna Consultants have developed a detour map. The map is attached in Appendix I of this report. Figure 11 in Appendix I. These routes have been determined by our team and have been presented to the stakeholders for approval. The red highlighted path indicates the route to be taken by detoured TransLink busses with terminus station at the UBC Bus Loop. The blue highlighted path indicates the route to be taken by local residents, and by a TransLink Community Shuttle that will provide service the segment of Chancellor Boulevard no longer serviced by the detoured busses.

10. Cost Estimate

To assess the economic feasibility of the proposed works, McKenna Consultants completed a cost estimate of the final design presented in this report. This section is intended to be read in conjunction with Appendix J: Cost Breakdown attached in this report.

10.1. Estimate Methodology

To fulfill project objectives, McKenna Consultants strived to minimize the cost of the project by creating cost effective solutions. The project is intended to be contracted as a design-bid-build project and will be awarded to one general contractor. The overhead cost of the contractor is estimated at 7% of the total construction cost, including a 5% profit and a 2% contingency.

Our team estimated the construction cost by quantifying an itemized list of materials and services required during the construction phase of the proposed intersection redesign. The AutoCAD and SketchUp models included throughout this report were referenced for quantity take offs. Material costs have been verified using precedent examples of projects with similar scope completed recently. The consulting services are priced based on McKenna Consultants standard fees. The work outlined in the engineering cost estimate is intended to be completed by our team.

10.2. Cost Estimate

McKenna Consultants estimates a total cost of approximately $435,200.00 (excluding taxes) for the demolition of the existing features and the construction of a roundabout and gateway structure at the Chancellor Blvd. and Wesbrook Mall intersection.

The cost estimate includes construction costs, contractor fees, cost of engineering services, and a contingency of 15%. This contingency was added based on the variability in costs at this level of study.

The cost breakdown associated with each item in Table 5 above is attached in Appendix J of this report. Table 6 below highlights the cost breakdown for the project.

TABLE 6: COST SUMMARY

Total Cost		
Item	**Cost**	
Construction Costs	$	329,527.40
Contractor Overhead and Profit (7%)	$	19,906.28
Engineering Costs	$	29,000.00
Contingency (15%)	$	56,765.05
Total Cost	**$**	**435,198.73**
		*Taxes Excluded
Total Cost (including 12% tax)	$	487,422.58

TABLE 7: OPERATIONS AND MAINTENANCE COSTS

Operations & Maintenance		
Item	**Cost**	
Painting	$	2,100.00
Landscaping Cost	$	10,000.00
Total Annual Cost	**$**	**12,100.00**

The operations and maintenance costs of the project are estimated in Table 7 above. These costs are based on 2017 rates are subject to change each year based on inflation and market conditions. The operations and maintenance costs of the proposed roundabout intersection are minimal and are considered a large benefit of this intersection option as opposed to various other intersection designs, such as a signalized intersection.

10.3. ECONOMIC CONSIDERATIONS

The cost estimated presented in this report is dependent on the project commencing on May 1st, 2017. Any delays to the start date of the construction phase of this project may lead to significant variations in the material and service costs.

11. RECOMMENDATIONS FOR FUTURE WORK

As mentioned throughout this report, the soil properties have been estimated based on geotechnical studies near the project site and geotechnical data provided by the client. The lack of thorough and recent geotechnical site investigation at the intersection raises the concern of variable soil properties. A major unforeseeable site issue is related to the amount of foundation work that will be necessary to support the roundabout and gateway structure. During the excavation process, a geotechnical engineer will be present on site and will determine whether the foundation design will be sufficient to support the proposed work.

McKenna Consultants is prepared to deal with any site issues in an efficient and cost sensitive manner. Should any issues arise, we will aim to limit the disruption to the cost estimate and the construction schedule.

Further analysis is also required for the structure, depending on whether the client prefers to design for the structure to withstand impact from severe environmental considerations. The current design is not intended to withstand impact from collisions, however the capacity for the structure is well above what is required for the dead, snow, and wind loads. This additional capacity can aid in withstanding higher impact loads.

12. Conclusion

McKenna Consultants is pleased to have completed the detailed design for the intersection at Chancellor Boulevard and Wesbrook Mall. Our team has thoroughly designed the roundabout to meet client requirements, regulations, and design criteria. A reinforced concrete arch has been designed for the gateway structure and complies with the requirements outlined by the client representative. The proposed project is planned to begin construction on May 1st, 2017. The proposed design, both the intersection, and the structure, has a design life of a minimum of 30 years. McKenna Consultants hopes to continue providing consulting services on this project during the tendering phase.

REFERENCES

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National Building Code of Canada, 2015. (2015) (1st ed.). [Ottawa, Ont.].

Re: BC Supplement to TAC Geometric Design Guide, 2007 edition. (2007) (1st ed.). Victoria. Retrieved from http://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/engineering-standards-and-guidelines/highway-design-and-survey/tac/tac-2007-supplement/2007bc_supplement_to_tac.pdf

Vancouver Soil Map. (2017). *Vancouversoils.ca*. Retrieved 26 February 2017, from http://vancouversoils.ca/about/

APPENDIX A: DECISION MATRIX

The following weighted average decision matrix was used to evaluate each of the feasible design options during the conceptual design phase of this project. The weighting factors were developed based on the importance of each criterion. The importance was judged based on the client objectives and stakeholder perspectives. The BC Ministry of Transportation and Infrastructure Design Guidelines heavily weighed the outcome of the decision matrix as they state that a roundabout design option must first be considered for intersection redesign, and additional options must only be considered if a roundabout is deemed unfeasible. For the purposes of the conceptual design phase, McKenna Consultants developed three design options, however the roundabout intersection design was preferred from the beginning of the project. Option 3: Roundabout intersection design received the highest score (382) in the decision matrix and thus confirmed our decision of moving forward with this design.

		DESIGN OPTIONS					
CRITERIA	Weighting Factor	Option 1 - Minimal Construction		Option 2 - Signalized Intersection		Option 3 - Roudabout	
BC Ministry of Transportation Guidelines	10	1	10	1	10	3	30
Safety	10	2	20	3	30	3	30
Traffic Volume	10	3	30	3	30	3	30
Environmental Concerns	10	2	20	1	10	3	30
Cost	9	3	27	2	18	2	18
Stakeholder Management	9	3	27	2	18	2	18
Traffic on Chancellor Boulveard	9	2	18	2	18	3	27
Traffic from Wesbrook Mall	9	2	18	2	18	3	27
Pedestrians	8	2	16	3	24	2	16
Cyclists	8	3	24	3	24	2	16
Buses	8	1	8	2	16	3	24
Trucks	7	1	7	2	14	3	21
Sidewalks	7	3	21	3	21	3	21
Construction Time	7	3	21	1	7	2	14
Entrance to the University (Arch)	6	2	12	2	12	3	18
Property Lines	6	3	18	3	18	3	18
Residents on Wesbrook Crescent	5	1	5	3	15	3	15
Landscaping	3	1	3	2	6	3	9
	SCORE:	38	305	40	309	49	382

APPENDIX B: PUBLIC NOTICE FROM ENGAGEMENT PLAN

Below is a sample of the public notices used by the stakeholder management team to create awareness about the proposed project and welcome feedback from all impacted groups.

Public Notice:

Redesign of Chancellor Boulevard and Wesbrook Mall Intersection

McKenna Consultants has been retained by UBC SEEDS for the project regarding the redesign of the Chancellor Boulevard and Wesbrook Mall Intersection. To learn more about the project and share your views please feel free to contact our team.

MCKENNA CONSULTANTS

Contact McKenna Consultants (mail@mckenna.com) for more information:

McKenna Consultants (mail@mckenna.com)

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McKenna Consultants (mail@mckenna.com)
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McKenna Consultants (mail@mckenna.com)
McKenna Consultants (mail@mckenna.com)

APPENDIX C: ROUNDABOUT DESIGN MODELS

FIGURE 5: WEST SIDE OF ROUNDABOUT (3D MODEL)

FIGURE 6: SOUTH SIDE OF ROUNDABOUT (3D MODEL)

FIGURE 7: NORTH SIDE OF ROUNDABOUT (3D MODEL)

APPENDIX D: TRAFFIC DATA PREDICTIONS

CAPACITY

A single-lane roundabout has capacity of 1800 circulating vehicles and 1200 entering vehicles. Circulating vehicles are the number of vehicles passing in front of an specific entrance to the roundabout, while entering vehicles is the number of vehicles entering the roundabout at that specific entrance. Right turning traffic is not included with entering traffic as they are able to turn before entering the roundabout.

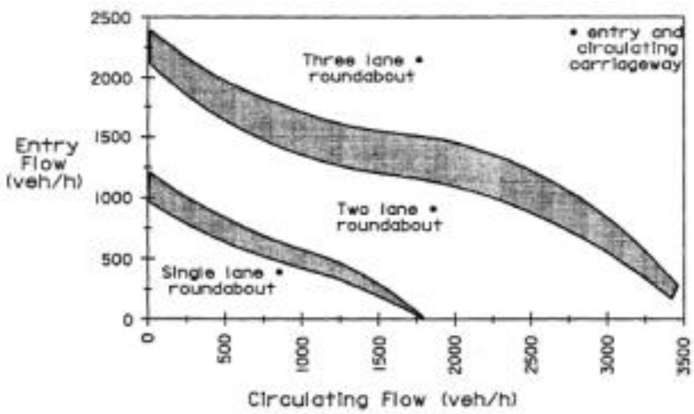


FIGURE 8: REQUIRED NUMBER OF ENTRY AND CIRCULATING LANES

(from the Austroads Guide to Traffic Engineering Practice, Part 6 - Roundabouts)

CURRENT VOLUMES

Current traffic volumes are well within the allowable range for a single lane roundabout. The AM peak has the highest volumes and therefore is the best indicator of suitability for the roundabout design.

Current traffic volumes can be seen in the figure below. As the westbound traffic is the inbound traffic, it is the most concerning. The westbound volume is 832 vehicles which corresponds to the entering flow, while the circulating flow in regard to the westbound traffic is only the 71 left turning vehicles from Wesbrook Mall. This is well within the capacity of a single lane roundabout.

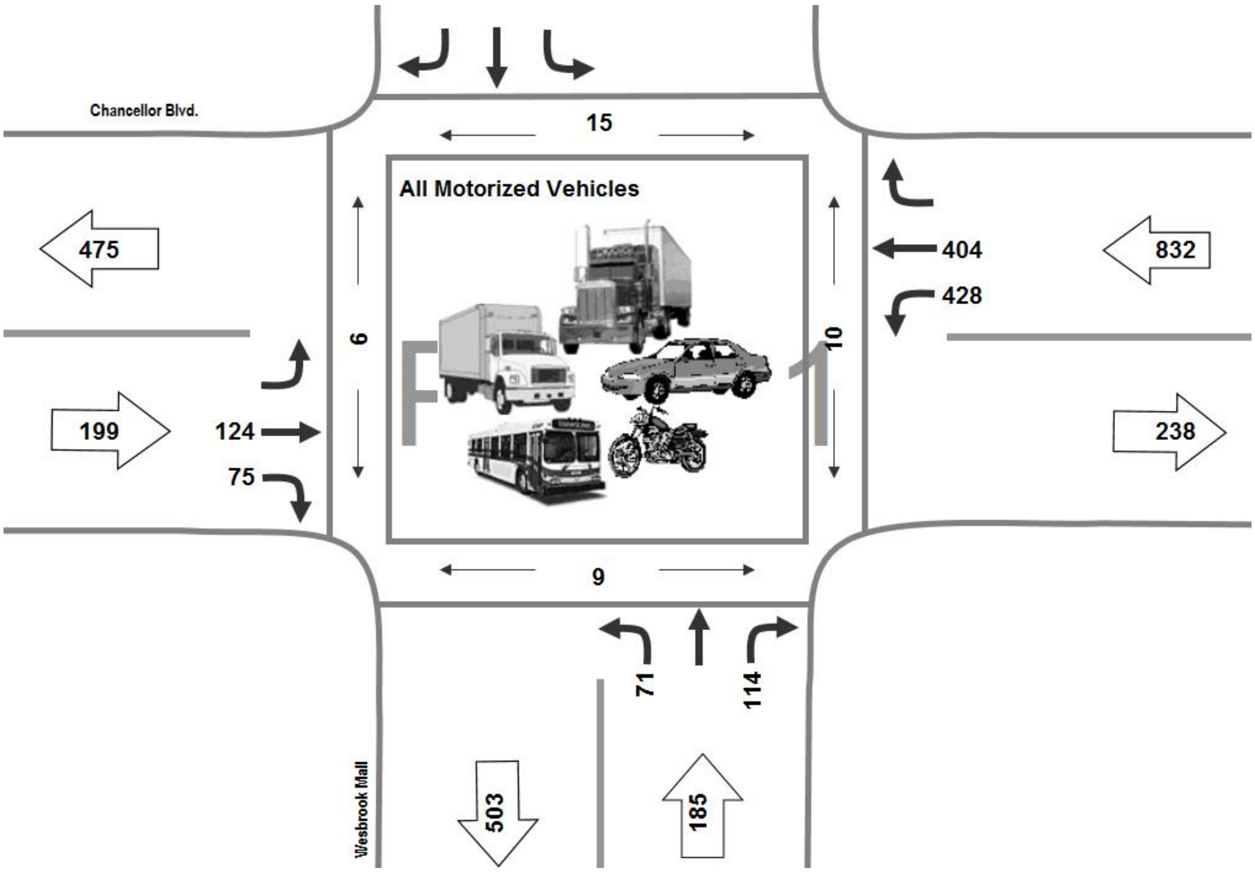


FIGURE 9: 2015 TRAFFIC COUNTS PROVIDED BY CREATIVE TRANSPORTATION SOLUTIONS LTD.

CHANGES TO TRAFFIC PATTERNS

Considering growth of the campus, it is expected that the traffic volumes will change. It is not clear, however, how these volumes will change. There are multiple factors to consider in regard to traffic volume changes:

- The Broadway Subway line is undergoing public consultation as of winter of 2017. The line is part of the City of Vancouver's 10-Year Transit Vision, indicating that the project will be completed within the next 10 years. Rail is seen as significantly more attractive to transit riders, and while the route is not expected to extend all the way to UBC, students wishing to commute from long distances will see the addition of the subway favourably and may elect to take transit over driving.
- Continued parking policy changes around the campus such as increased rates and decreased availability are expected to cull personal vehicle traffic. Over three thousand parking spaces, approximately 27% of existing spaces, have been removed from the campus between 1997 and 2017, while parking rates have increased from $2 per day to $16 per day.
- Class scheduling strategies decrease peak volumes by spreading out class starting times throughout the AM. These strategies also reduce PM peak volumes.
- Millennials continue to shy away from driving. The University of Michigan reported that in 2014 76.7% of youth aged 20-24 possess a driver's license, drastically down from 91.8% in 1983.

- A massive technological change is expected over the next 30 years. Vehicles with self-driving capabilities are making their way to market and these vehicles will cause a serious disruption to traffic trends. With vehicles that are capable of parking themselves far away from the user's destination, safely increasing traffic flow and traffic density, and taxiing users between destinations with no inputs, major effects will be felt in many unforeseen ways.

With these factors taken into consideration, it is very difficult to predict traffic volumes for the next thirty years. It is important, however, to analyse traffic trends to anticipate any predictable issues.

Future Volumes

In 2007 and 2003, traffic counts were taken at Blanca St and West 4th Ave. This intersection is the closest point at which traffic volumes were measured by the City of Vancouver. Between 2003 and 2007, enrolment at UBC increased while traffic decreased. The data for westbound (WB) and eastbound (EB) traffic at this intersection are as follows and are correlated with traffic.

Table 8: Traffic trends at West 4th Ave and Blanca St

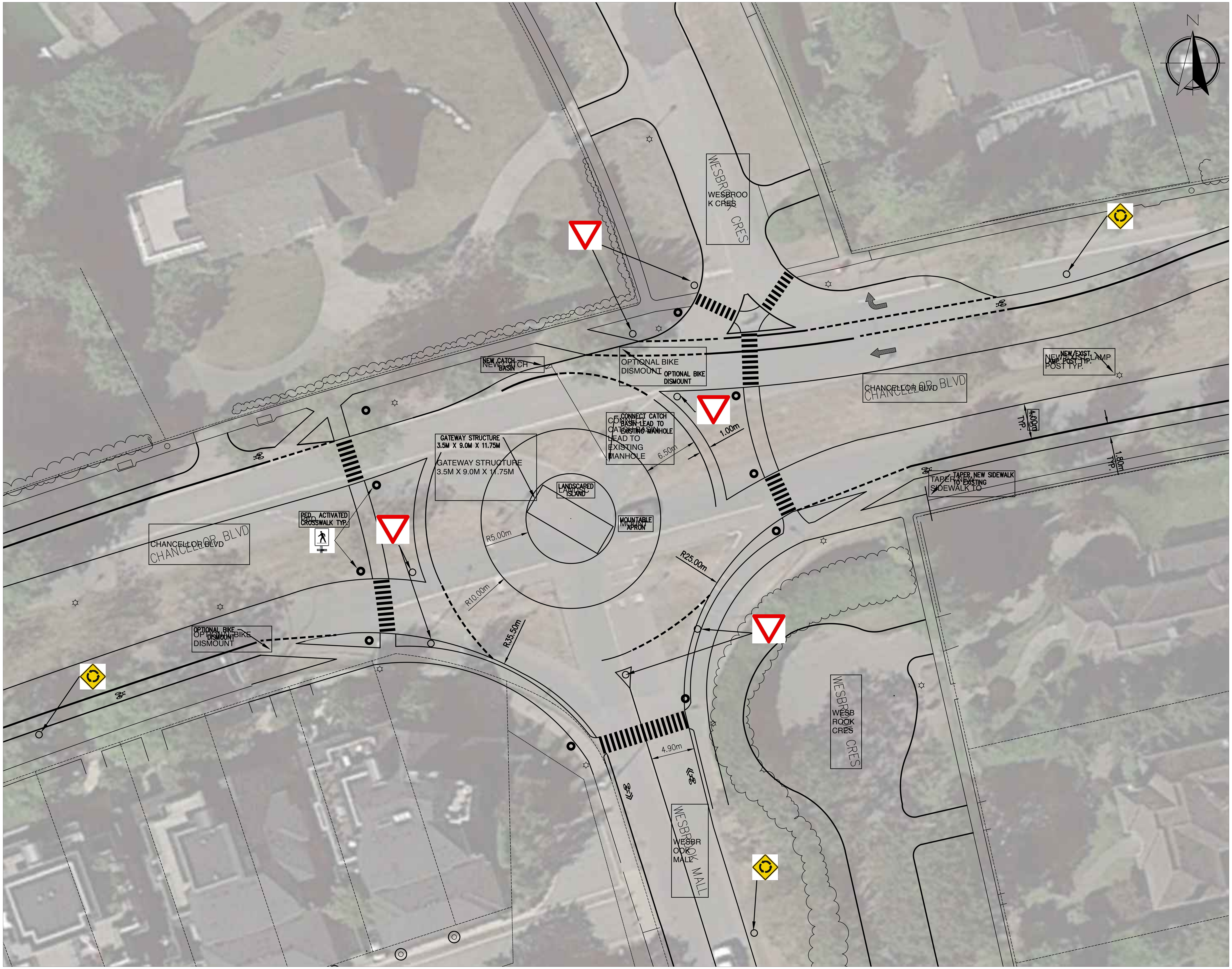
Year	AM Traffic - WB	PM Traffic - EB	Enrolment
2007	683	710	44423
2003	818	723	40864
2001	N/A	735	37776
Trend between 2003 and 2001	N/A	-1.7%	+7.6%
Trend between 2007 and 2003	-16.5%	-1.8%	+8.7%

The decrease in traffic entering UBC during the AM peak contrasts the increase in enrolment, indicating that increased enrolment does not correspond with increased vehicle traffic. We do expect, however, that this data includes an increase in transit traffic.

Current traffic on campus is as shown in Figure 10 previously. The traffic volumes are comparable with volumes at the West 4th Ave and Blanca St intersection shown in Table 7.

As it has been shown that an increase in traffic volumes should not be expected, an evaluation of existing capacity can instead be considered to evaluate the suitability of a one lane roundabout. With a maximum of 1200 entering vehicles per hour and 1800 circulating vehicles, there is capacity for a 44% increase from current entering traffic on the westbound entrance to the roundabout.

APPENDIX E: PROJECT PLAN DRAWING



BENCHMARK:

SURVEYED BY:

CIVIC ADDRESS:

LEGAL DESCRIPTION:

SCALE: 0 — 1:200 — 10m

ISSUED: M/D/Y	REVISION	DESCRIPTION
07/04/17	02	ISSUED FOR TENDER
07/03/17	01	90% COMPLETION
05/12/16	00	PRELIMINARY DESIGN

PROJECT:

REDESIGN OF CHANCELLOR BOULEVARD

CLIENT:

UBC SEEDS

DATE:	MARCH 17, 2017
DRAWN:	TVW
DESIGN:	CB
CHECKED:	IM
SCALE:	1:200

SEAL:

SHEET TITLE:

PLAN VIEW
WESBROOK MALL AND CHANCELLOR BLVD

DRAWING NO.: SP-01

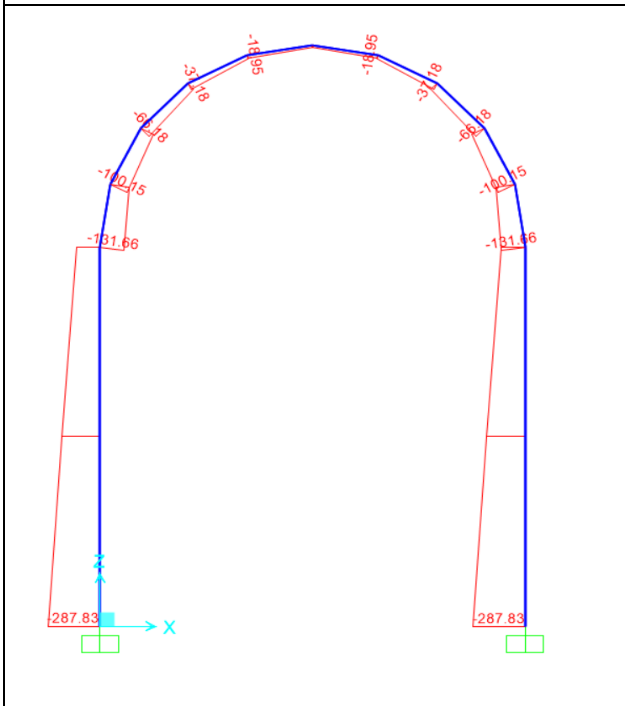
REV.: 02

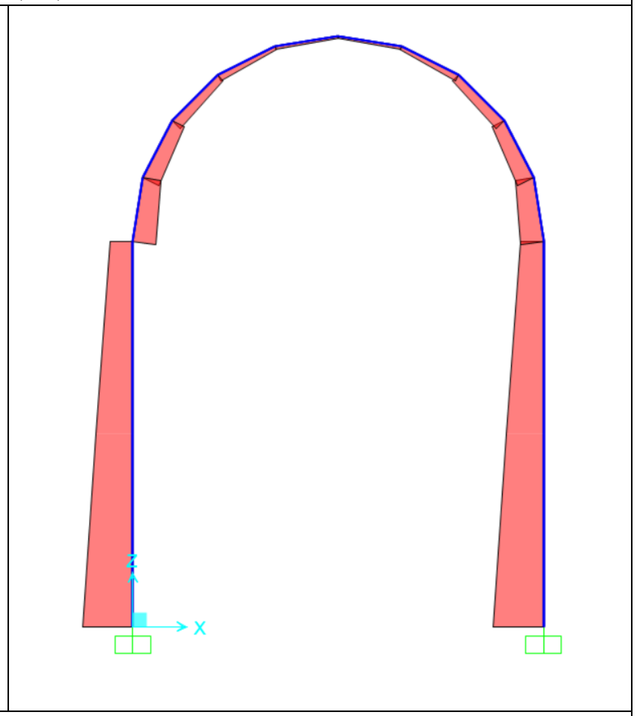
JOB No.:

SHEET 1 OF 1

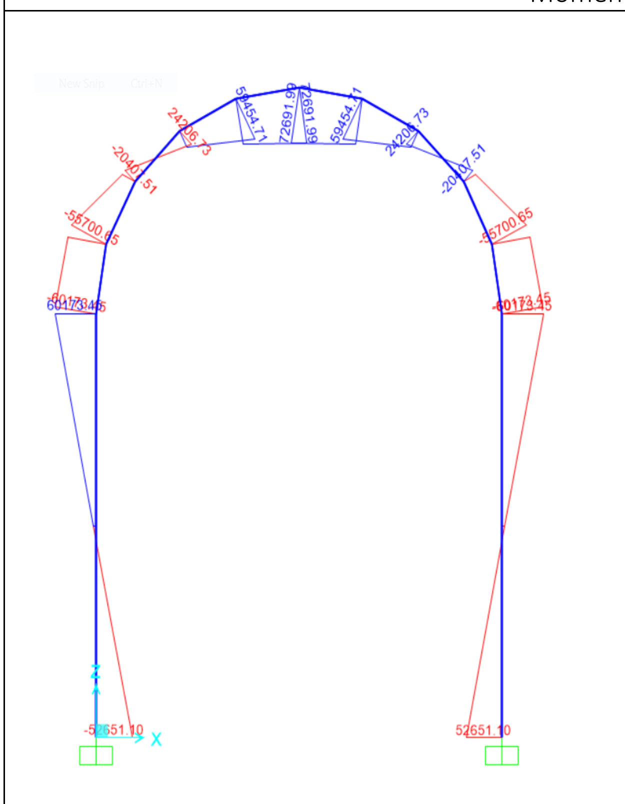
APPENDIX F: GATEWAY STRUCTURAL ANALYSIS

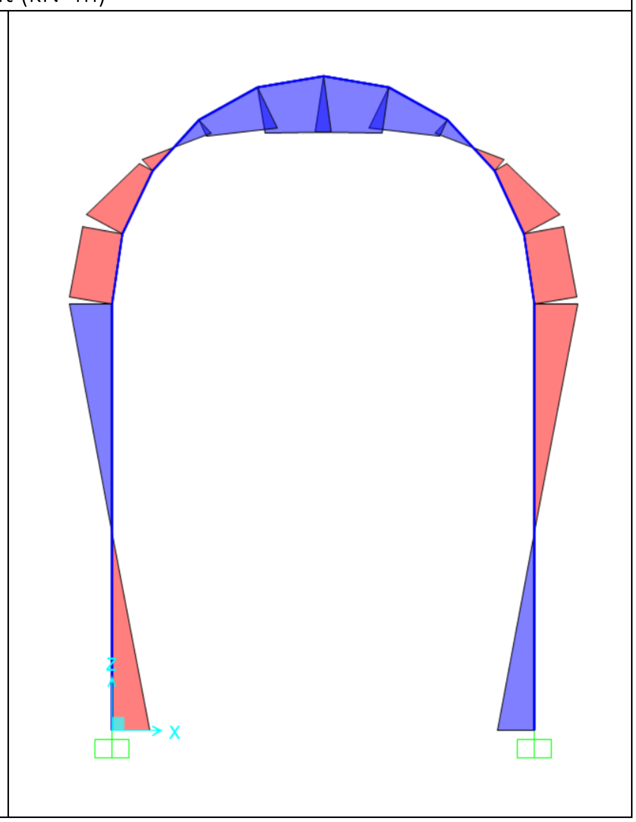
Axial (kN)

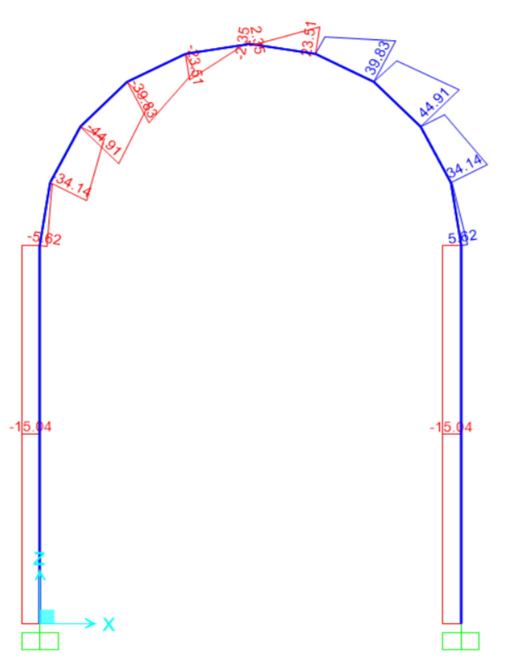
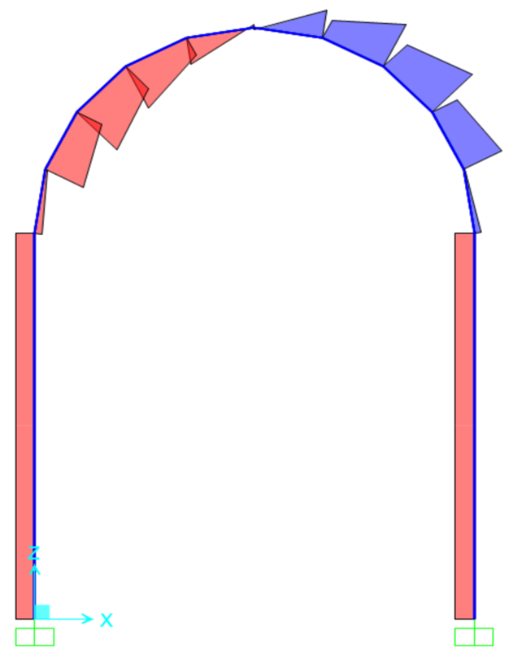




Moment (kN*m)





Shear (kN)	
	

-5.62
34.14
-44.91
-39.83
-23.51
-2.35
2.35
23.51
39.83
44.91
34.14
5.62
-15.04
-15.04
Z
X

APPENDIX G: LOAD CALCULATIONS AND DRAWINGS FOR THE STRUCTURE

Enterance Structure - Concrete Arch Design Calculations

Area = 13780065.2 mm^2 (plan view)

Cross-sectional Area = $A = 11750mm \times 1000mm$
$= 11750000 mm^2$
$= 11.75 m^2$

$\gamma_w = 2400\ kg/m^3$

Volume = Area × 1000mm
↳ thickness of arch

$= 13780065.2\ mm^2 \times 1000mm$
$= 13780065200\ mm^3$
$= 13.78\ m^3$

DL = self-weight
$= \text{Volume} \times \gamma_w \times g$
$= 13.78\ m^3 \times 2400\ kg/m^3 \times 9.81\ m/s^2$
$= 324\ 437.86\ N$
$= 324.4\ kN$

$W_{Df} = 1.25 \times DL = 405.6\ kN$

$W_{DLf} = 405.6\ kN$

no live loads because the structure is not intended for occupant use.

applying a preliminary factor of '1.25' to the dead load to ensure a conservative design and to account for minimum steel reinforcement

Snow Load:
$S_s = 1.9\ kPa \times A$
$= 1.9 \times 11.75 m^2$

$S_s = 22.325\ kN$

Wind Load: probability of 1/50 (as per UBC Design Guidelines)

$S_w = 0.48 kPa \times A$
$= 0.48 \times 11.75$

$S_w = 5.64\ kN$

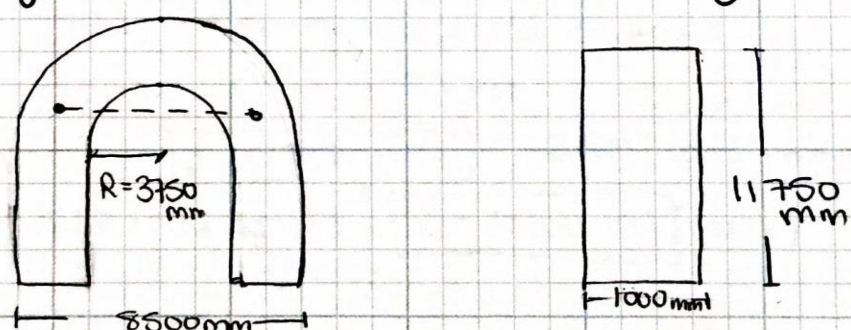
Ultimate Limit States Design

Load Cases

1. 1.4D = 1.4 (405.5) = 567.7 kN
2. 1.25D + 0.4W = 509.13 kN
3. 1.25D + 1.5S or + 0.4W = 540.36
4. 1.25D + 1.4W or + 0.4S = 518.81
5. 1.0D + 1.0E + 0.25S = 411.08

Load Case # results in the highest factored applied load → DL_f = 567.7 kN

analysis has been carried out using this scenario



Front Profile

Side Profile

Analysis: The reinforced concrete arch will be designed as two concrete columns supporting a arch beam.

Assuming simply supported connections at the connection of the columns to the beam

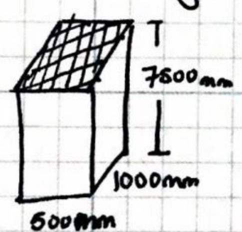
The reinforcement design has been done to meet CSA A23.3 minimum reinforcement requirements.

Design Procedure:

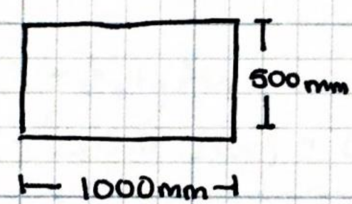
- design columns for axial and shear load
- check · rebar (longitudinal reinforcement) and
  · stirrup (transverse reinforcement) spacing

Since the column is supporting majority of the dead load and lateral loads, we have designed for the column reinforcement and will extend the rebar into the arch beam.

Column Design:



Cross-sectional area:



$A_g = 500 \times 1000\ mm^2$
$= 500\ 000\ mm^2$

$P_f = \frac{1}{2} W_{DLf}$ → simply supported columns
$= \frac{1}{2}(567.7\ kN) = 283.6\ kN$

$\boxed{P_f = 283.6\ kN}$ axial load applied

From SAP 2000 Model : $\boxed{V_f = 44.91\ kN}$ (max) shear force applied

Assumptions:

- $f'_c = 25\ MPa$ ∴ $E_c = 4500\sqrt{25\ MPa}$
  $= 22\ 500\ MPa$

  $\rho_b = 0.022$ and $\rho \leq \rho_b$ for the section to be properly reinforced
- $f_y = 400\ MPa$
- $\phi_c = 0.65$ and $\phi_s = 0.85$
- $\alpha_1 = 0.8$
- $\lambda = 1$

Assumptions Continued...

- cover = 40 mm → freeze/thaw protection w/o chlorides typ. for exterior of a building
- a_{max} = 20 mm
- use 20M rebar and 10M ties

Axial Load Analysis:

assuming the columns are concentrically loaded with 283.6 kN each.

$$P_r = \alpha_1 \phi_c f'_c (A_g - A_{st}) + \phi_s f_y A_{st}$$
$$= 0.8 \times 0.65 \times 25 (500\,000 - A_{st}) + 0.85 \times 400 \times A_{st} \geq P_f$$
$$= 13(500\,000 - A_{st}) + 340 A_{st}$$

$A_{st} = \rho \times A_g$ $\quad \rho \leq \rho_b \quad \therefore$ try $\rho = 0.01$

$= 0.01 \times 500\,000 mm^2$

$= 5000 mm^2$

Trial 1: 10-20M Bars

$A_{st} = 10 \times 300 mm^2 = 3000 mm^2$

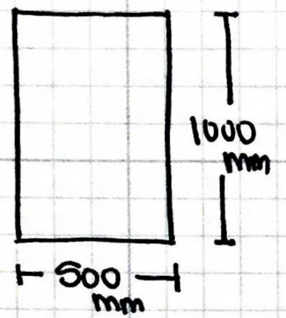
$P_r = 13(500000 - 3000) + 340(3000)$

P_r = 7481.0 kN >> P_f = 283.6 kN ✓good

$$S_{min} \leq max \begin{cases} 1.4 d_b = 1.4 \times 20 = 28 mm \\ 1.4 a_{max} = 1.4 \times 20 = 28 mm \\ 30 mm \end{cases}$$

S_{min} = 30 mm

S_{max} = 500mm



cover, stirrup, rebar:

$d = 1000 - 40mm - 10mm - \frac{1}{2}(20mm)$

$= 940mm$

$d_v = \max \begin{cases} 0.9d = 0.9(940) = 846mm \\ 0.72h = 0.72(1000) = 720mm \end{cases}$ $\therefore d_v = 846mm$

Concrete Shear Capacity:

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

$= 0.85 \times 1 \times \beta \sqrt{25} \times 500mm \times 846mm$

$\beta = \frac{230}{1000 + d_v} = \frac{230}{1846} = 0.124$

$V_c = 223.99kN \rightarrow \boxed{V_c = 224kN} >> V_f = 44.9kN$

$\therefore$ shear reinforcement not required $\therefore$ use minimum stirrups

From axial load analysis, minimum stirrups:

$d_{tie} \geq \max \begin{cases} 0.3d_b = 0.3(20mm) = 6mm \\ 10M \end{cases}$ $d_{tie} = 10mm = 10M$

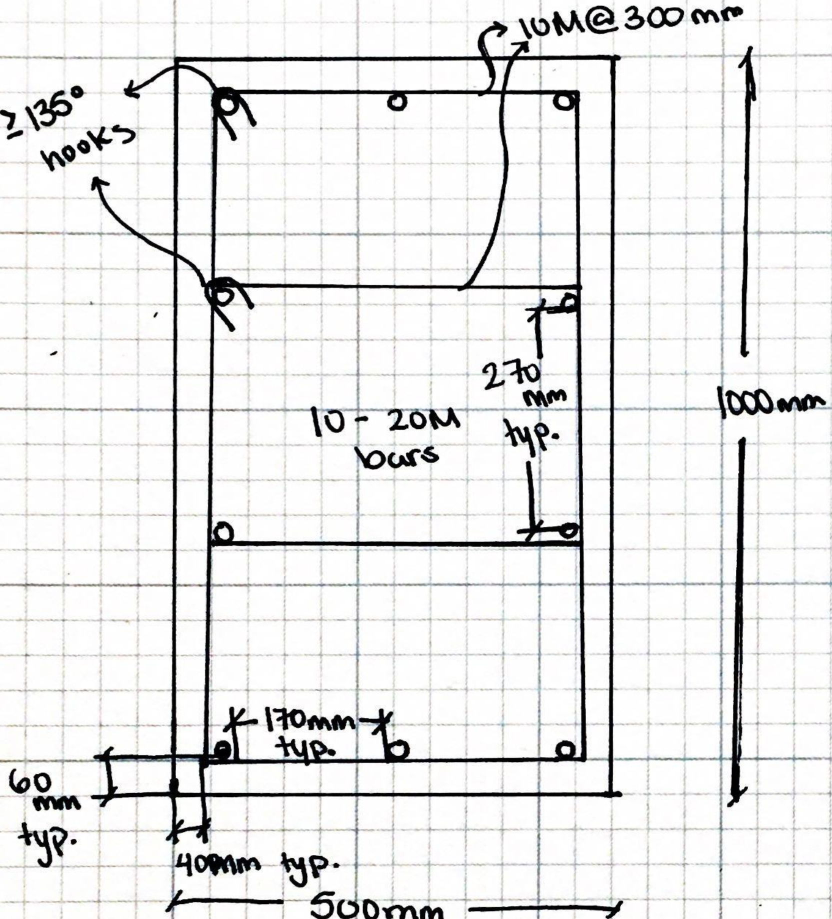
$S_{max} \leq \min \begin{cases} 16d_b = 1.6(20mm) = 320mm \\ 48d_{tie} = 48(10mm) = 480mm \\ \min(b, h) = 500mm \\ 300mm \end{cases}$

$S_{max} \leq 320mm$

use 10M ties @ 300mm

Design Summary included on attached AutoCAD layout

Design Summary (draft):



$$\text{Spacing} = 1000 - 40\times2 - 10\times2$$
$$= 900\text{mm} - 4(20\text{mm})$$
$$= \frac{820\text{mm}}{3\text{ spaces}}$$
$$= 273\text{mm}$$

Use 270mm

$$\text{Spacing of rebar} = 500 - 40\times2 - 10\times2$$
$$= 400\text{ mm} - 3(20\text{ mm})$$
$$= \frac{340\text{mm}}{2\text{spaces}} = 170\text{ mm}$$

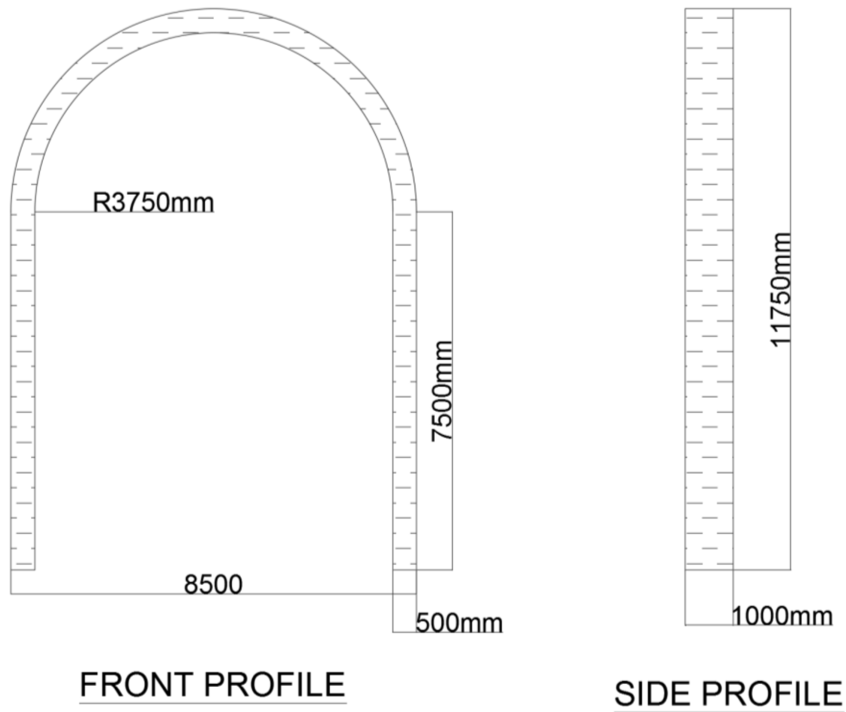
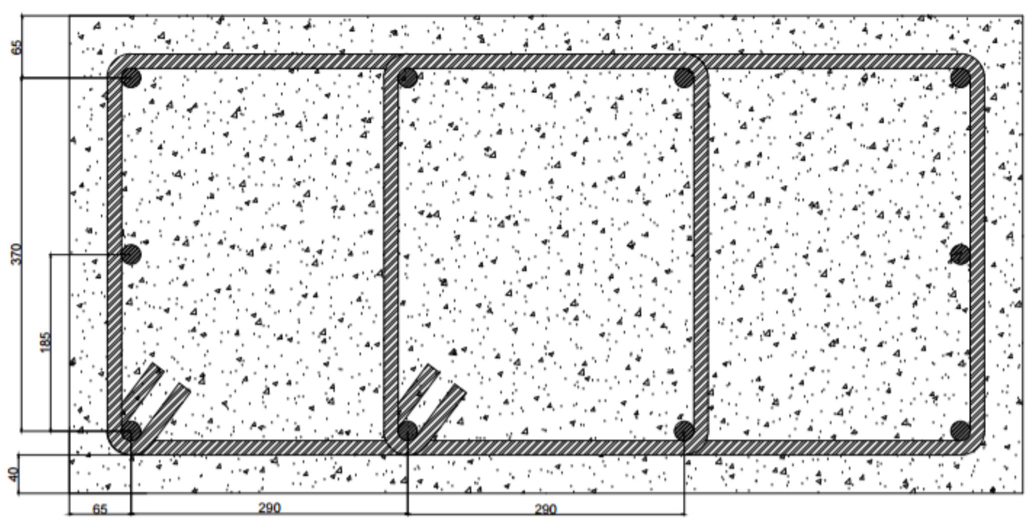


FIGURE 10: PLAN DRAWINGS OF THE STRUCTURE



Section Data	
Longitudinal R.	10-20M bars
Stirrups	15M

FIGURE 11: REINFORCEMENT DESIGN (TYP.)

APPENDIX H: FOUNDATION DESIGN

Foundation Design → LOAD CALCULATIONS

Force on foundation = 567.7 kN (from structure load calculations)

Assume: $\phi = 32°$ for site

$\therefore N_c = 35.47$

$N_q = 23.2$

$N_\gamma = 30.2$

$q_{ult} = \sigma'_o N_q + 0.4 \gamma B N_\gamma$ where B = width of slab cross-section

$= 0.9(20.8 - 9.81) \times 23.2 + 0.4(20.8 - 9.81) \times B \times 30.2$

$= 229.47 + 132.78B$

$q_{ult} = \dfrac{\text{Load} \times FS}{B^2}$ where: Load = 567.7 kN, FS = factor of safety = 2.5 (assumed)

$= \dfrac{567.7 \times 2.5}{B^2} = \dfrac{1419.25}{B^2}$

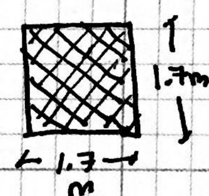
$q_{ult} = q_{ult}$

$(229.47 + 132.78B)B^2 - 1419.25 = 0$

Solve for B = 1.66 m

use B = 1.7 m for design

Square slab



B = 1.7m square footing

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

$= 0.65 \times 1 \times 0.18 \times \sqrt{25\text{MPa}} \times 1.7\text{m} \times d_v = V_f = 567.7\text{kN}$

$d_v = 570\text{mm}$

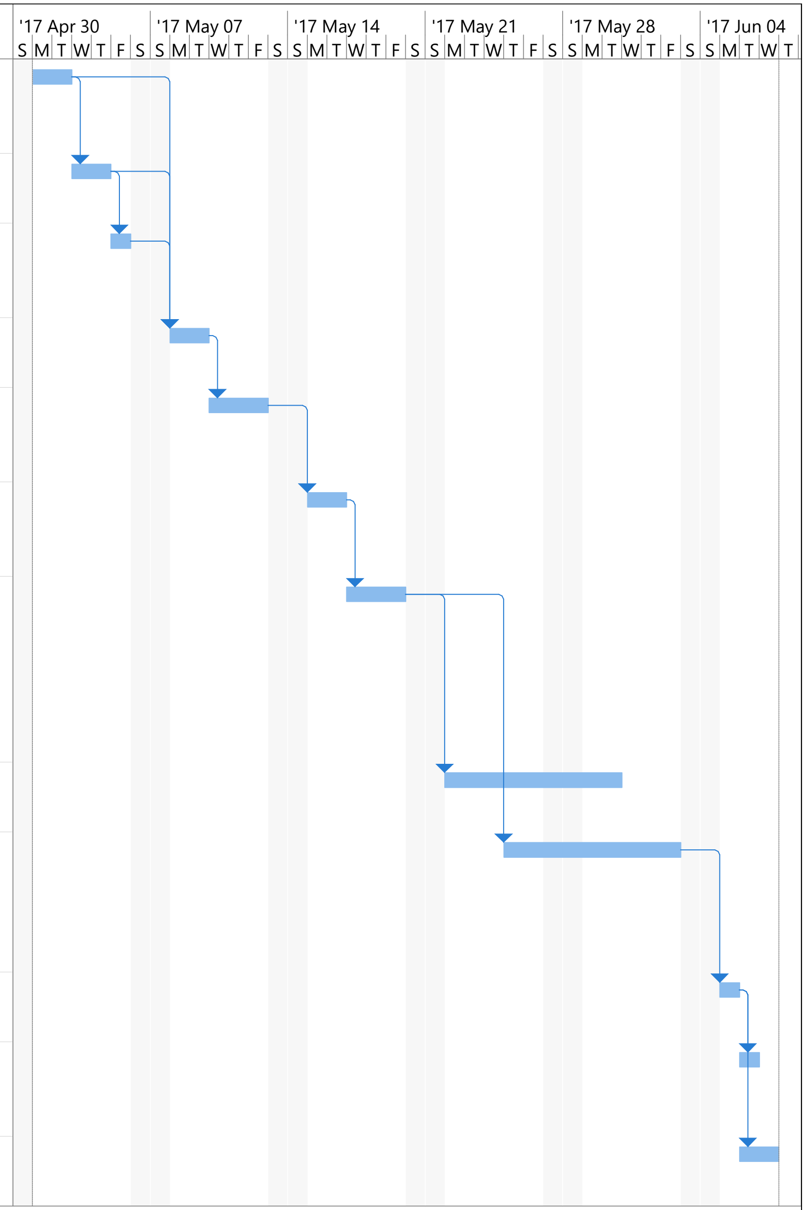
$d_v = 0.72h$ so $h = \dfrac{d_v}{0.72} \doteq 800\text{mm}$

h = 800 mm

APPENDIX I: DETOUR MAP AND CONSTRUCTION SCHEDULE

FIGURE 12: DETOUR MAP

ID	Task Name	Duration	Start	Finish	Predecessors	Resource Names
1	Removal of median within roundabout zone	2 days	Mon 17-05-01	Tue 17-05-02		
2	Removal of existing concrete c	2 days	Wed 17-05-03	Thu 17-05-04	1	
3	Removal of specified catch basins and light standards	1 day	Fri 17-05-05	Fri 17-05-05	2	
4	Asphalt milling and removal	2 days	Mon 17-05-08	Tue 17-05-09	3,1,2	
5	Installation of light bases, catch basins and leads	3 days	Wed 17-05-10	Fri 17-05-12	4	
6	Removal and replacement of granular materials (optional)	2 days	Mon 17-05-15	Tue 17-05-16	5	
7	Installation of curb (including roundabout island curb, bike lane alterations, and new crosswalk letdowns)	3 days	Wed 17-05-17	Fri 17-05-19	6	
8	Installation of mountable apron	7 days	Mon 17-05-22	Tue 17-05-30	7	
9	Roundabout island backfill and installation of university gateway structure	7 days	Thu 17-05-25	Fri 17-06-02	7FS+3 days	
10	Asphalt paving	1 day	Mon 17-06-05	Mon 17-06-05	9	
11	Installation of asphalt markings and new signage	1 day	Tue 17-06-06	Tue 17-06-06	10	
12	Landscaping	2 days	Tue 17-06-06	Wed 17-06-07	10	



Project: Updated Construction
Date: May 1 2017

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

APPENDIX J: COST BREAKDOWN

TABLE 9: COST OF CONSULTING SERVICES

Consulting Services		
Item	**Cost**	
Construction Engineering (includes survey and civil tech)	$	10,000.00
Project Management	$	8,000.00
Site Inspection	$	1,500.00
Geotechnical Analysis (Site Investigation)	$	6,000.00
Environmental Review	$	3,500.00
Total Engineering Cost	**$**	**29,000.00**

TABLE 10: COST OF CONSTRUCTION SERVICES

Construction Services				
Item	**Wage**	**Time**	**Cost**	
Demolition Crew (5 people)	$ 20.00	80	$	8,000.00
Construction Crew (5 people)	$ 20.00	360	$	36,000.00
Landscaping (2 people)	$ 18.00	32	$	1,152.00
Total			**$**	**45,152.00**

TABLE 11: COST BREAKDOWN

Construction Acitivies				
Item	**Unit**	**Rate/Unit**	**Cost**	
Deomlition of Existing Medians	500 m^2	$20/m^2	$	10,000.00
Excavation	1700 m^2	$25/m^2	$	42,500.00
Installation of catch basins and leads, conduits	2 catch basins and 15 meter leads	$10,000/each	$	20,000.00
Manhole Replacememt (Contingency)	2 Manholes	$2,500/each	$	5,000.00
Road Base 30 cm depth	1500 m^2	$27/m^2	$	40,500.00
Installation of curb	300 m	$50/m	$	15,000.00
Asphalt - Paving 15 cm	1500 m^2	$21/m^2	$	31,500.00
Intersection lighting	4 lamp-posts	$3,300/each	$	13,200.00
Signage	8 pedestrian crossing signs	$700/each	$	5,600.00
Painting	6 cross walks	$350/each	$	2,100.00
Installation of mountabale apron	235 m^2	$85/m^2	$	19,975.00
Rebar (10M)	10M rebar (30 units) = approx 1 TON	$1200/TON	$	1,200.00
Concrete Structure and Foundation	18.4	$80/m^3 + (20%) for complexity	$	1,766.40
Concrete Garden Wall Structure (wood cladding) and foundation	100 m^3	80$/m3 - additional cost for complexity and cladding +foundation	$	40,000.00
Landscaping- (center garden)	76 m^2	110$/m^2	$	8,360.00
Landscaping (grass)	333.7 m^2	20$/m^2	$	6,674.00
UBC' Letters - Steel	6 letters	3000$/letter	$	18,000.00
Placement of 'UBC' Letters	6 letters	500$/letter	$	3,000.00
Total Construction Cost			**$**	**284,375.40**

TABLE 12: COST SUMMARY

Total Cost		
Item	**Cost**	
Construction Costs	$	329,527.40
Contractor Overhead and Profit (7%)	$	19,906.28
Engineering Costs	$	29,000.00
Contingency (15%)	$	56,765.05
Total Cost	**$**	**435,198.73**
		*Taxes Excluded
Total Cost (including 12% tax)	$	487,422.58

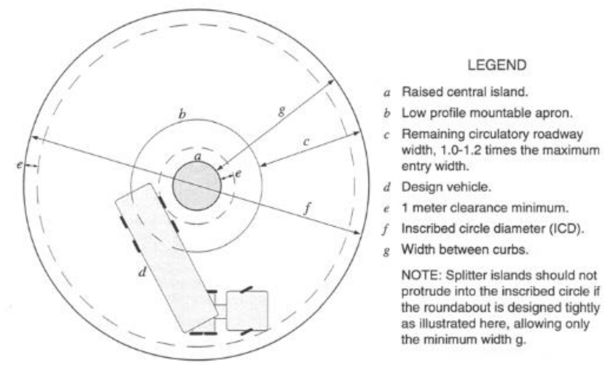
TABLE 13: OPERATIONS AND MAINTENANCE COSTS

Operations & Maintenance		
Item	**Cost**	
Painting	$	2,100.00
Landscaping Cost	$	10,000.00
Total Annual Cost	**$**	**12,100.00**

Appendix K: Geometric Design

The following figure and table describe minimum circle diameters to incorporate turning by a WB-20 vehicle. A WB-20 vehicle has a larger turning radius than the WB-17 design vehicle used in this project, therefore the turning radii incorporate contingency for driver error.

Turning Widths:



Inscribed Circle Diameter (f) (metres)	Design Vehicle WB-20 (g) (metres)
79.2	7.2
73.2	7.5
67.1	7.8
61.0	8.1
57.9	8.4
54.9	8.7
51.8	9.0
48.8	9.3
45.7	9.8
42.7	10.1
39.6	11.1
36.6	12.2
33.5	13.7
30.5	**
29.0	**

** Design Vehicle requires larger ICD

Figure 13: Required turning widths (to be viewed with Table 6 below)

Table 14: Required turning widths

	Dimension
a	10.0m (ø)
b	20.0m (ø)
c	7.5m
d	WB-17
e	1.0m
f	35.0m
g	12.5m