UBC BOTANICAL GARDEN REDEVELOPMENT
FINAL DESIGN REPORT

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University of British Columbia

April 04, 2014

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FINAL DESIGN REPORT

CIVIL 446 GROUP 10
April 4, 2014

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LETTER OF TRANSMITTAL

April 4, 2014

UBC Botanical Garden
6804 SW Marine Drive,
Vancouver, BC V6T 1Z4

Dear Sir/Madam:

RE: UBC Botanical Garden Traffic System Redevelopment File No.: VAN 12346.P001

Diversified Engineering Services is pleased to present the enclosed detailed design report for the UBC Botanical Garden Traffic System Redevelopment.

This document has been prepared for the UBC Botanical Garden in response to a request for a redevelopment plan for the roadways and intersections in the vicinity of the Garden, including the intersection of SW Marine Drive and 16th Avenue, the intersection of SW Marine Drive and Stadium Road, and the adjacent sections of SW Marine Drive.

Diversified Engineering Services has completed the UBC Botanical Garden Traffic System Redevelopment Design Report with a methodology that will maximize the benefit to the UBC Botanical Garden while meeting all of the project objectives.

Thank you for using Diversified Engineering Services for your engineering consulting needs. Please do not hesitate to contact us if you have any questions.

Yours truly,
DIVERSIFIED ENGINEERING SERVICES LTD.

Kamal Braich (
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UBC Botanical Garden

Traffic System Redevelopment

Detailed Design Report

April 4, 2014

Prepared for:

UBC Botanical Garden
6804 SW Marine Drive,
Vancouver, BC V6T 1Z4

Prepared by:

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EXECUTIVE SUMMARY

The UBC Botanical Gardens (UBCBG), located on the University of British Columbia's Vancouver campus, houses a world-class collection of plants for the purposes of research and teaching. Its gardens are open to the public year round. Previous studies and conceptual designs commissioned by UBCBG have identified an opportunity to improve traffic flow and safety in the area around the Gardens by implementing roundabouts on SW Marine Drive at both 16th Avenue and Stadium Road. This report presents a traffic flow redevelopment plan that meets the goals of increased safety and ease of access for pedestrians, cyclists and motorists with a focus on sustainable design.

Intersection Redevelopment

The two intersections on SW Marine Drive at 16th Avenue and Stadium Road will be modernised by converting the existing road (three-way and four-way intersections) to roundabouts. Roundabouts will provide a safer commute for motorists, cyclists, and pedestrians while allowing for higher volumes through the intersection which will improve traffic conditions in the area surrounding the Botanical Garden.

Several critical components of the roundabout design include the traffic study and geotechnical investigation, design of the geometry and layout of the roadway and intersections, and the selection of materials used in the roadway surface and foundation based on environmental goals.

Traffic Study and Site Investigation

In order to support the detailed design of the roundabouts and adjustments to the adjacent roadway, a traffic study has been performed. This study provides a detailed profile of the vehicular, cyclist and pedestrian traffic using the roadways surrounding the UBCBG. A geotechnical site investigation will support design of the roadway foundation.

Roadway and Roundabout Design

The roundabouts and connected roadways will be designed to meet current and projected traffic demand through the UBCBG area based on BC Ministry of Transportation guidelines. This includes considerations for vehicle counts, the types of vehicles using the intersections, traffic speed, and drainage.

Materials Selection

Materials used in the road foundation will generally be specified in accordance with BC MOT guidelines. Where possible, in order to be more in line with the spirit of UBC's sustainability plan, roadway materials will be chosen and sourced based on the goal of minimizing environmental impact while meeting or exceeding performance criteria.

1. INTRODUCTION

As requested by Garden Director of the UBC Botanical Garden, Diversified Engineering Services Ltd. (Team 10) has prepared a Detailed Design Report for the renovation of the traffic system surrounding the UBC Botanical Garden, located at 6804 SW Marine Drive in Vancouver, BC. The purpose of this report is to introduce a detailed design of the concepts for the traffic system renovation in the area surrounding the UBC Botanical Garden. The traffic system renovation will consist of redeveloping the existing intersections of SW Marine Drive at Stadium Road and SW Marine Drive at 16th Avenue. This report will provide a detailed design from three engineering disciplines, as outlined in Figure 1, with Transportation Engineering being the primary discipline.

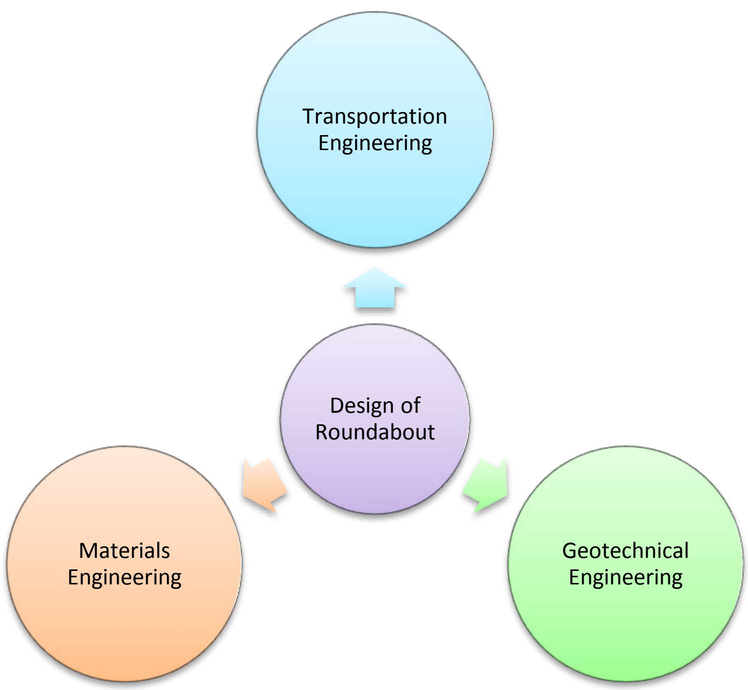


Figure 1 - Three engineering disciplines for detailed design of roundabout

1.1. Objectives

The detailed design for the traffic system renovation will incorporate the guidelines and objectives set out by the University of British Columbia (UBC) and the BC Ministry of Transportation (BCMoT) and be consistent with the sustainability goals of UBC and the UBCBG. The transportation design will consist of converting the intersections of SW Marine Drive at 16th Avenue and SW Marine Drive at Stadium Road to roundabouts and narrowing SW Marine Drive from four lanes to two north of 16th Ave. with the objective of providing safety for all road users in the area by reducing speed and minimizing conflicts. Special consideration will be taken with the construction methods and materials used in the design by selecting practices and materials that meet the sustainability goals of UBC and the UBCBG. Figure 2 outlines the proposed traffic system redevelopment concept.

Figure 2 - Traffic System Conceptual Design

1.2. Existing Conditions

The UBC Botanical Garden is located in the southwest corner of the campus. The South Garden is bounded by Old Marine Dr. to the south and SW Marine Dr. to the North. The North Garden is bounded by W 16th Ave. to the east, SW Marine Dr. to the south and Stadium Rd. to the west and north. SW Marine Dr. consists of a four lane road (two lanes in each direction) divided by a grass median. The intersection of SW Marine Dr. at 16th Ave. is signalized, and the intersection of SW Marine Dr. at Stadium Rd. is unsignalized. See for site location of the UBC Botanical Garden.

Figure 3 - UBC Botanical Site Location Plan

2. TRANSPORTATION

SW Marine Drive is the main road to access the garden and we faced speeding and safety issues as drivers use the road to access other areas of campus without any traffic control. On the other hand, safety issues and delays also result from poor connections for left and right turning vehicles, pedestrians, and cyclists.

We found that the poor intersection layout might have been affecting the botanical garden negatively. The proposed roundabouts at the two nearby intersections will improve overall traffic flow, minimizing the existing safety concerns and enhancing transportation access to the garden.

Reducing four lane boulevards to two lanes will accommodate efficient geometric layout for the roundabouts. However, this would not affect the future traffic capacity as road network capacity is determined by the intersections, not by the roads. Also current and future traffic volumes are less than the capacity of a two lane road. A single traffic lane can accommodate up to 2,000 vehicles per hour, whereas the maximum forecast traffic volume in the future is 900 vehicles per hour per lane.

As the Ministry of Transportation (MoT) has the ownership of both 16th Avenue and SW Marine Drive, we require approval from the MoT prior to any construction of this project.

2.1. Benefits of Roundabouts

- **Improve safety for the Garden visitors including pedestrains, cyclists and motorists:** Traffic on SW Marine Drive is expected to be very busy with the planned development of the South Campus Northeast Sub-Area Neighbourhood. Maintaining safety on SW

Marine Drive will be crucial to satisfying visitors comfort and maintaining access to the Garden.

- **Create smooth traffic flow:** The signalized intersection between SW Marine Drive and 16th Avenue has been generating traffic delays for motorists waiting at the lights. Also, the unsignalized intersection at Stadium Road has poor connections for vehicles turning onto SW Marine Drive. With increased traffic due to the new development, the existing intersections will make it even harder for the garden visitors to enter or exit the garden. Implementing roundabouts at these two locations will be key to providing safe and easy access to the UBC Botanical garden.
- **Increase awarenes of the UBC botanical garden**: Slowing down traffic on SW Marine Drive will positively impact on increasing the awareness of the UBC botanical garden. Drivers and pedestrians who use the future roundabout on Stadium road will have to pass the garden entrance,as the west exit of the roundabout. This will not only increase awareness but also promote more visits to the garden for leisure activities.
- **Discourage speeding:** Roundabout can be used as a traffic calming device discouraging speeding. On-going speeding issues along SW Marine Drive can be mitigated through the proposed roundabouts at the intersections with 16th Avenue and Stadium Road.
- **Minimize environmental impacts:** noise at intersections and vehicle emissions will be minimized with the proposed roundabouts.

2.2. Drawbacks of Roundabouts

- **Require more space :** Roundabouts requires more space to be implemented; however, this is manageable as the project area has ample space available for use.

- **Require people to learn how to operate:** Some motorists may be unfamiliar with rules and practices associated with roundabout us (giving right of way to the cars in the roundabout , for example). However, the University has already successfully implemented several roundabouts and traffic circles on campus, including two on 16th Avenue.

2.3. Definition of Roundabouts

A roundabout is a circular intersection that allows traffic to continuously flow counter-clockwise around a central island.

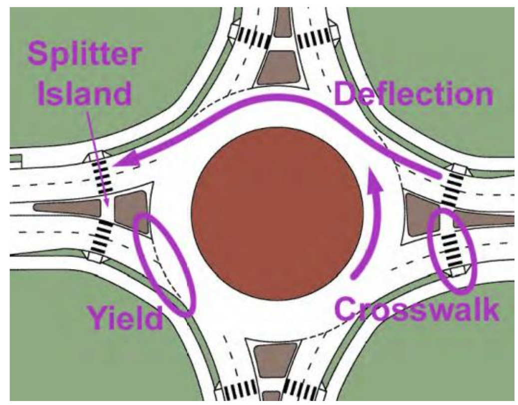


Figure 4 - Roundabout Characteristics (from Roundabout-consultation report-6-Feb-06)

Yeild on entry: without traffic control such as stop signs or traffic lights, yield control is used on all entries to a roundabouts. Traffic within the circulatory roadway has the right of way.

Deflection: Having deflections in a roundabout helps vehicles slow down and support the yield on entry.

Splitter islands: splitter islands play a crucial role in creating appropriate angles of entry. They also provide a median refuge area for pedestrians.

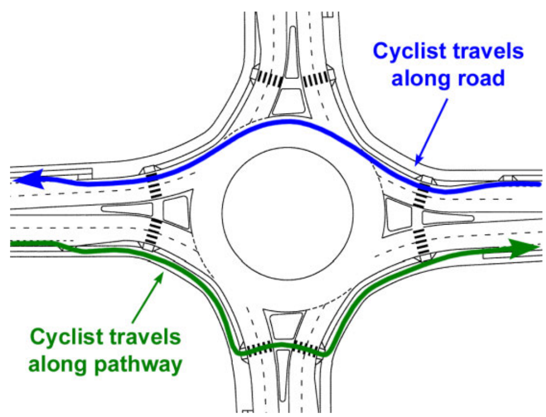


Figure 5 - Cyclist Routes Through a Roundabout (from Roundabout-consultation report-6-Feb-06)

Crosswalks: the location of the crosswalk is a minimum 7 meters setback from the roundabout, allowing motorists encounter pedestrians before entering onto the roundabout. Consequently, traffic flows within the roundabout are not likely interrupted.

Cycling: cyclists will feel comfortable sharing the road in a roundabout with the sufficient width on the outer lane of the roundabout, 4.3 meters.

2.4. Comparison with traffic lights

UBC's roundabout consultation report included a summary comparison between roundabouts and traffic signals. The table below clearly indicates that roundabouts can achieve many of the criteria of UBC's transportation plans better than traffic signals.

Table 1 - Comparison of Roundabouts and Traffic Signals on 16th Avenue (from the UBC Roundabout Consultation Report 2006)

Criteria	Measure	Roundabouts	Signal
Safety	Number and severity of crashes	✓	×
Speeding	85th percentile speeds	✓	×
Traffic operations	Average vehicle delay	✓	×
Road lanes	Number of lanes	✓	×
Environmental	Vehicle emissions, noise	✓	×
Cost	Construction, operating and societal costs	✓	✓
Overall		✓	×

2.5. Detailed Geometric Design of Roundabouts

16th Avenue and SW Marine Drive fall under the jurisdiction of the Ministry of Transportation and Infrastructure.

- Design standards for roadways and intersections will follow guidelines set forth by the Canadian Institue of Transportation Engineers (CITE) and Transportation Association of Canada (TAC).

- Design of new roundabouts and intersection networks will follow the UBC Strategic Roundabout Plan and UBC Road Network Plan.

2.5.1. Software Analysis

Utilizing traffic analysis software (Vissim), the future traffic volumes on SW Marine Drive were simulated in two senarios, two intersections at 16th Avenue and Stadium road with roundabouts or traffic signals. Under our test conditions, better levels of service with shorter delay times were provided by a roundabout than traffic signals. Table 2 summarizes the findings.

Table 2- Traffic Operations on SW Marine Drive (Forecast 2021 Traffic Volumes by VISSIM)

Intersection	Peak Hour	Roundabouts		Traffic Signals	
SW Marine Drive		Average Delay	Level of Service	Average Delay	Level of Service
16th Avenue	AM	9.8 sec	A	17.8 sec	B
	PM	8.8 sec	A	18.1 sec	B
				Unsignalized	
Stadium Road	AM	6 sec	A	15 sec	B
	PM	5 sec	A	17 sec	B

2.5.2. Classification of roadways

SW Marine Drive and 16th Avenue east of Westbrook Mall are classified as arterial roads. Stadium Road is a local street serving nearby residents.

2.5.3. Roadway Dimensions

According to the Transportation Association of Canada's Geometric Design Guide, motor vehicles and bicycles can operate safely side-by-side on a minimum of 4.0 meter wide roads with low volume traffic (TAC, 1999). The width of outer lane of the roundabouts will be 4.3 meters allowing sufficent space for transit buses and cars to pass cyclists comfortably. The width of inner lane of the roundabouts will be 3.5 meters with 2 meters of low profile mountable apron. The low profile mountable apron on the inside of the circle will satisfy the 9.3 m turning radius of a WB-20 design vehicle. Maintaining enough space for pedestrians, cyclists and cars on Stadium Road east of SW Marine Drive is important to improve access of the garden. The bus stop of C-20, public transit that carry the garden visitors is also located on Stadium Road. According to the Kansas Roundabout Guide, the roundabout entry curve radii should be designed within 10 – 30 m, and the exit curves should have a radius of no less than 35 m to prevent speeding at the entries and exits of the roundabouts. The curvature of the roundabout should also minimize the traveling velocities though the roundabout by reviewing the fastest travel paths and velocities.

2.5.4. Inscribed Circle Diameter (ICD)

The Inscribed Circle Diameter (ICD) for the proposed roundabouts is designed to be 50 meters for Stadium Road and 55 meters for 16th Avenue accodring to TAC Geometric design. This fits into the suggested range of the ICD in urban double lane, from 46 to 67m.

Table 3 - Recommended Inscribed Circle Diameter Ranges (from TAC Manual)

Table 740.A Recommended Inscribed Circle Diameter (ICD) Ranges

Site Category	Inscribed Circle Diameter Range*
Urban Single Lane	37 – 46 m
Urban Double Lane	46 – 67 m
Rural Single Lane	40 – 61 m
Rural Double Lane	53 – 76 m

* Assumes approximately 90-degree angles between entries and no more than four legs.

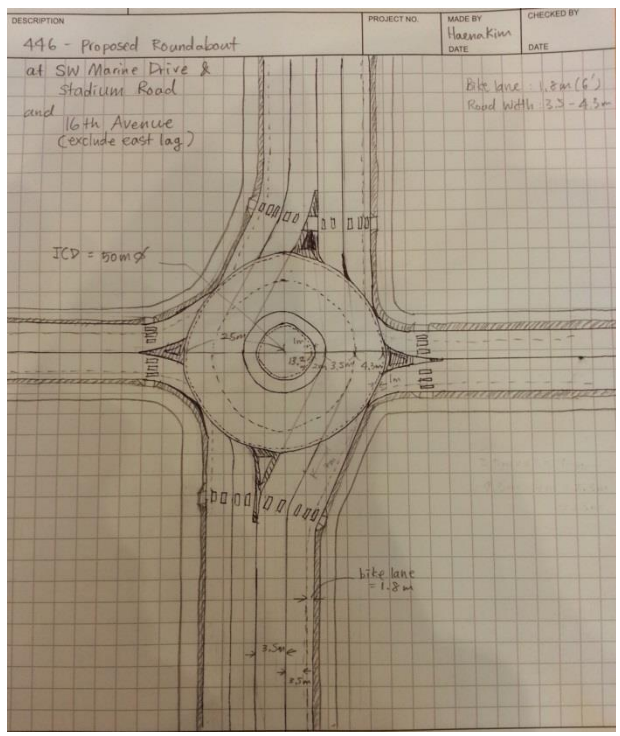
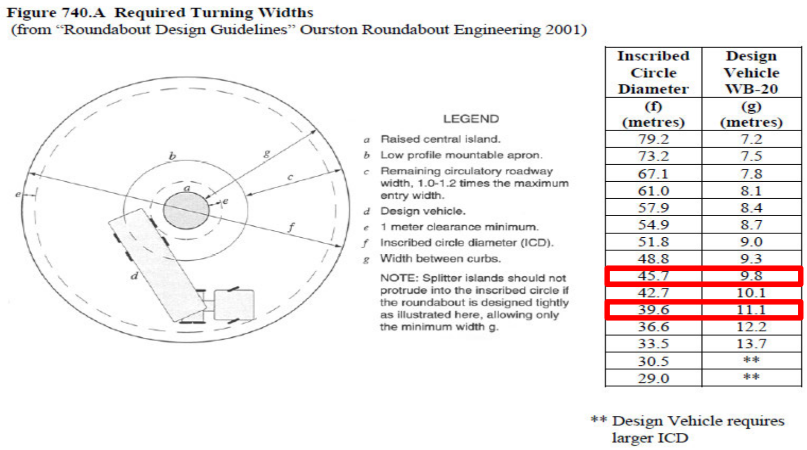


Figure 6 - A hand-sketch of the proposed roundabouts

This ICD was selected in order to accommodate the WB-20 design vehicle from Figure 7.



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	**

Figure 7 - Required Turning Widths (from TAC Manual)

2.5.5. Number of lanes

Future traffic volumes due to the development south of 16th Avenue were estimated based on the traffic studies used for the similar Westbrook mall development. Peak hour trip generation rates were used to analyze traffic volumes.

Future traffic volume is anticipated to increase 12% in the morning peak hour and 14% in the afternoon peak hour as compared with the existing traffic volumes. Total circulating flow on SW Marine Drive in the future is estimated at 1250 vehicles/ hour. Based on the guideline shown in

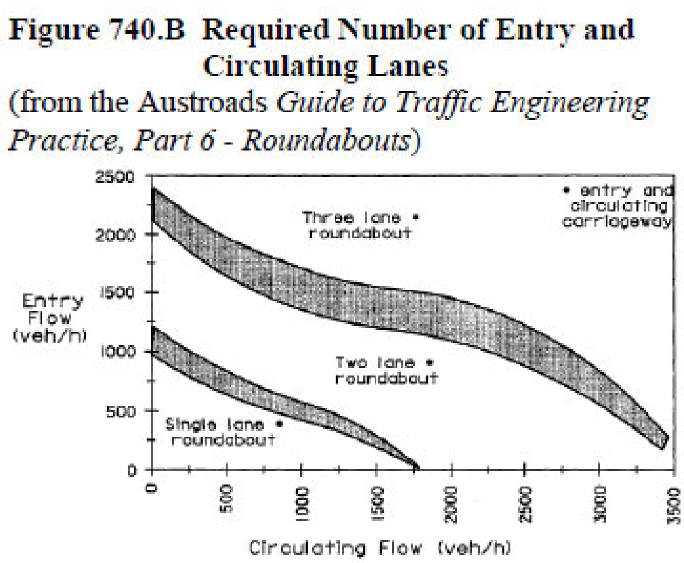


Figure 8 - Required Number of Entry and Circulating Lanes (from TAC Manual)

Figure 8, the number of entry and circulating lanes were chosen.

Stadium road: Northbound and southbound entry/exit in the roundabouts will be comprised of two-lane entry/exit for the through vehicles on SW Marine Drive; while westbound and eastbound entry/exit will be one lane due to lower traffic volumes and turning movement. The northbound two lane exits will extend a minimum of 175m beyond the roundabout before tapering back to a single lane.

16TH Avenue: All entries/exits will be two lane systems due to higher volumes and turning movement.

2.5.6. Drainage and Grading

BCMOT refers to the US Federal Highways Administration report entitled "Roundabout: An Informational Guide" (FHWA-RD-00-067) for drainage considerations (BCMOT, 2007). The recommendations presented by FHWA for drainage and grading create an outwardly sloped circulatory roadway designed to transport water away from the central island (FHWA, 2000). Additionally, BCMOT suggests that the entire roundabout profile be tilted at a 0.5-1.0% slope so that water drains to one catchbasin and does not stop flowing at the outer curb.

In accordance with FHWA recommendations, the circulatory roadway of both roundabouts will be sloped at 2.0% away from the central island. Drains will be located along the outer curb. The truck apron shall have an outward slope of 3.0%. The central islands will have an approximate dome shape with its high point in the centre so as to drain outward onto the truck apron.

The profile of both roundabouts will have a 0.5% slope to promote drainage to the southwest. This does not affect the prescribed slopes of any of the roundabout features.

3. MATERIALS

3.1. Concrete for curbs

Concrete curbs are designed according to BC Ministry of Transportation 2012 Standard Specifications for Highway Construction section 582.

3.1.1. Concrete mix design

The Specification states that concrete for curb should have

- Minimum compressive strength of 30 MPa at 28 days,
- Maximum coarse aggregate of 25 mm,
- Minimum cement content of 350 kg/m^3,
- Entrained air of 6-8%,
- Slump between 10 mm and 25 mm for extruded and maximum 65 mm for poured in place, and
- Maximum water to cementing ratio of 0.45

Using absolute volume method, concrete mix design is proposed as in Table 4. Due to lack of lab data, the standard deviation of f'c, fineness modulus of coarse aggregate, and density of coarse and fine aggregate were assumed. The assumptions may be corrected by lab tests.

Table 4 - Concrete Mix Proportions

	Volume	Mass	density
	m^3	kg	kg/m^3
Cement	0.128	383	3000
Water	0.160	160	1000
Coarse aggregate	0.412	1104	2680
Fine aggregate	0.220	582	2640
Air	0.080	-	-
Air entraining admixture	-	0.191	-
Concrete	1.000	2229.0	-

3.1.2. Curb designs

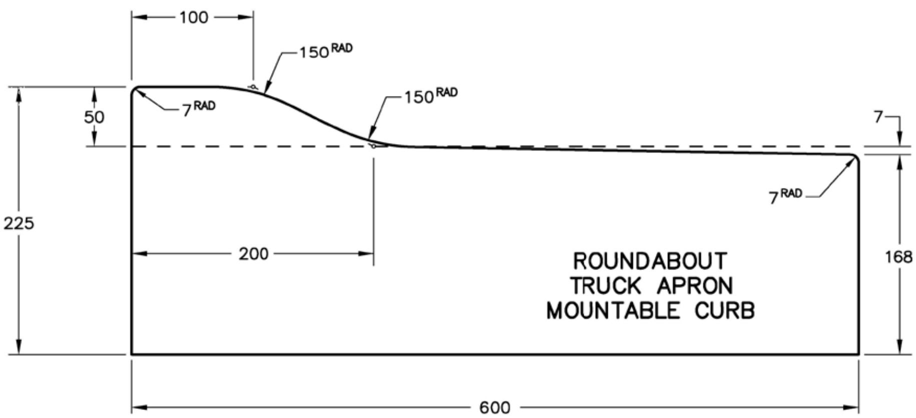


Figure 9 - Roundabout Truck Apron Mountable Curb (from 2012 Standard Specifications for Highway Construction

Dimensions of curb will be designed as specified in section 582. Figure 9 above shows the design standard for roundabout truck apron mountable curb.

3.1.3. Sustainability

Every ton of cement produced creates about 1 ton of greenhouse gas. The cement industry accounts for about 7-8% of global CO_2 emission and 1.8% of CO_2 emission in Canada. In the Greater Vancouver Regional District, the cement manufacturing industry produces approximately 50% of industrial CO_2 emissions, and 13% of the total CO_2 emission in the GVRD. Therefore, sustainability objectives can be achieved by reducing the amount of cement needed for curbs.

First, the cement content can be reduced by using Supplementary Cementing Materials (SCMs). Fly ash is a commonly used SCM in Canada. BC Ministry of Transportation specifies that fly ash can take up to 25% of the cementing material in the concrete. By replacing some portion of cement, fly ash reduces greenhouse gas emission. Since fly ash is a by-product from coal manufacturing industry, it is also cost-effective. Also, it decreases the heat of hydration and increases long term strength. Another example of SCM that can be used is silica fume, a by-product of the silicon metal industry. Silica fume is a highly pozzolanic SCM with much finer size than cement. Silica fume increases density of concrete by allowing particle packing due to its small particle size. Increased density reduces the permeability of concrete, and therefore decreases the rate of corrosion and deterioration to the concrete. Silica fume is not as commonly used as fly ash due to its price and increased water content required.

Use of high performance concrete can be an option to improve the sustainability of a concrete structure. High performance concrete is a type of concrete that intentionally increased the strength and durability so that the concrete structure will have longer service life. By using high performance concrete, the amount of concrete needed is decreased, which leads to decreased amount of greenhouse gas emission. High performance concrete increases durability of the structure, and as result, the maintenance cost can be saved. However, high performance concrete may increase the initial cost of the project.

Recycling materials for concrete also improves sustainability of concrete curbs. For example, aggregates from old concrete can be washed by water pressure and used for new concrete design. However, concrete with recycled materials has a risk that it is not guaranteed to have the same strength and durability of normal concrete.

3.2. Asphalt Pavement

3.2.1. Asphalt design

The asphalt pavement will be designed according to BC MOT 2012 Standard Specifications for Highway Construction section 502, 507, and 515, and TC01-04 Pavement structure design guidelines.

Twenty year design Equivalent Single Axle Loads (ESALs) are used to divide the roads into four types: High, medium, and low volume roads and subdivision roads. Type A, high volume roads, are ones with ESAL larger than 1,000,000, and Type B, medium volume roads, are ones with ESAL between 100,000 and 1,000,000. Type C, low volume roads, and Type D, subdivision roads, are ones with ESAL less than 100,000 (BCMOT TC01-04). ESAL for base year is the product of AADT, HVP, HVDF, NALV, and TDY. AADT is an average annual daily traffic for all lanes of both directions, HVP is the heavy vehicle percentage divided by 100, HVDF is the heavy vehicle factor as a decimal of heavy vehicles in design land, NALV is the number of equivalent axle load per vehicle, and TDY is the traffic days per year. The ESAL of 20 years can be obtained by multiplying 20 by the ESAL for the base year.

Assuming that the roundabout is installed on road type B, medium volume road, the design requires 75 mm AP, 150 mm of 2 5mm CBC, 150 mm of 75 mm, 50 mm, or 25 mm CBC, and SGSB of 300mm over soil sub-grade or 150 mm over Rock subgrade. AP, CBC, and SGSB stand for asphalt pavement, crushed base course, and select granular sub-base. The design is shown in Figure 10.

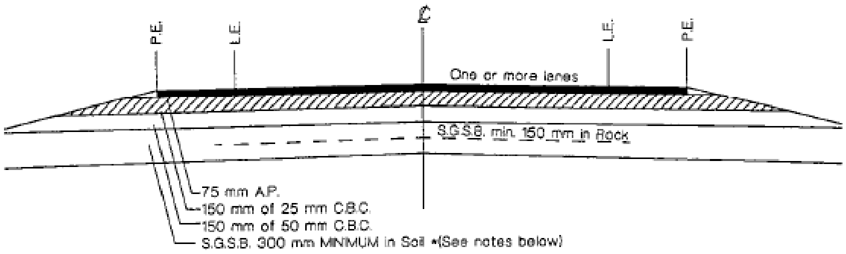


Figure 10 - Asphalt pavement design (from T01-04 Pavement Structure Design Guidelines)

3.2.2. Sustainability of Asphalt Pavement

Sustainability of asphalt paving can be improved through several methods including reducing aggregate stockpile moisture, use of reclaimed asphalt pavement in hot-mix asphalt, and use of rubberized asphalt.

Largest source of greenhouse gas (GHG) emission in asphalt production is the drying process of aggregates. Minimizing its moisture content can significantly reduce fuel used. It is a relatively low-cost, low-tech method of reducing GHG emission. The practice of this method is limited by the volume of aggregate mining and frequency of use than any other technical constraints. A permanent roofed structure with open sides for air circulation over the stockpiles is preferred, but it would be cost-effective only if the aggregate pits are large as those close to urban centres. As well as its environmental benefit, it also saves fuel cost of about $46,700 for 50,000 tonne of hot-mix asphalt.

Reclaimed asphalt pavement (RAP) can reduce material cost, energy use, and emissions significantly. RAP is a method of recycling asphalt by using milled or crushed RAP as an aggregate substitute and asphalt supplement in new asphalt mixes. In BC, the Ministry of Transportation and Infrastructure allows 10% RAP on secondary highways and up to 30% RAP on low volume roads in top lift, and for bottom lift, the Ministry allows up to 30% RAP on highways and up to 100% RAP on low volume roads.

Rubberized asphalt concrete (RAC) is another sustainable paving material that has been selected for the road surfaces at both roundabouts as well as the new two-lane sections of SW Marine Drive. RAC was developed as both a waste reduction strategy and a way to improve the performance of paved roadways. Discarded rubber tires can be recycled into crumb rubber and added to the asphalt mixture, improving durability and flexibility of the pavement and reducing landfill waste. Rubberized asphalt also has the effect of reducing noise levels by 3-5 decibels (FHWA). In British Columbia, RAC has been used in several municipal jurisdictions, including Delta, North Vancouver, and Vancouver, as well as by the Ministry of Transportation on Hwy 99 near Whistler (Johnson, Sproule & Juristovski).

The cost of RAC was estimated by Vancouver to be about 33% more than a traditional asphalt hot mix, which is believed to be justified by a reduction in maintenance and a lifespan increase (Johnson et al.). This is further offset by the reduced decibel level, as well as the environmental benefit of re-using rubber tires which may otherwise end up in a landfill.

For this project, the asphalt binder shall contain 18% crumb rubber, subject to consultation with the paving contractor. Because it is still an emerging technology, it is recommended that experience with RAC be considered when selecting criteria for qualified paving contractors.

4. GEOTECHNICAL

4.1. Anticipated Ground Conditions

Point Grey was once covered in a glacier, and as a result the soil is overconsolidated; this is ideal for our purposes because it reduces the chance of settlement. A study of Northwest UBC Campus done in 2002 is useful for our geotechnical investigation because the region has the same geological history and will likely have similar soil conditions. The Sonic Drill tests revealed a surficial layer of loose sand, gravel and organic material followed by Quadra sand. This well-sorted medium-grained sand contains feldspar, quartz and volcanic rock and is found in horizontally stratified layers (Piteau Associates, 2002).

4.2. Drilling and Laboratory Testing

Because there is an existing road that shows no indication of settlement, it's likely that the subsurface conditions will be adequate for our purposes; we are not expecting a significant traffic increase as a result of replacing the intersections with roundabouts. However, a basic geotechnical investigation is only a small portion of the overall project cost. Because the geotechnical aspect of most projects carries the highest risk, we recommend going through with a geotechnical investigation despite there being an existing road and the previous testing done on other parts of campus.

A Sonic Drill Rig will be used for the investigation; four holes will be drilled in order to obtain a representation of the subsurface condition. If there is a lot of variation between the drilling results, additional tests can be done. The map below indicates the proposed drilling locations:

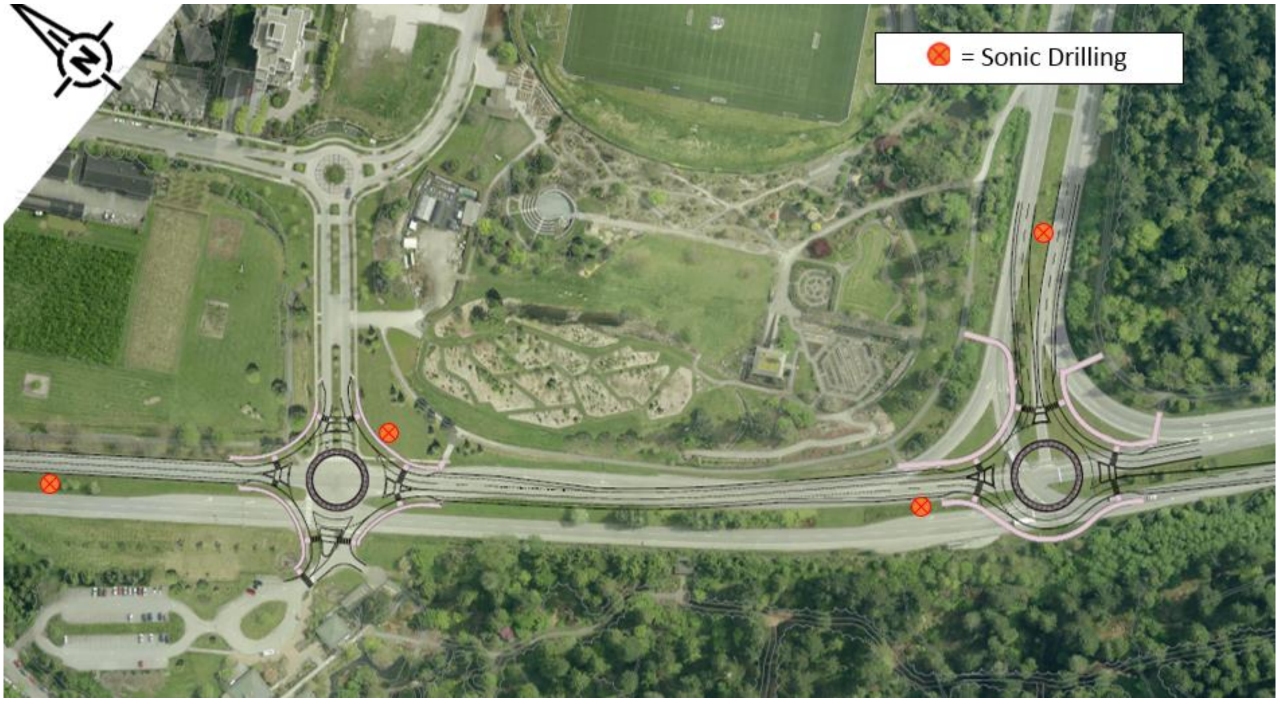


Figure 11 - Proposed Drilling Locations

This testing method was chosen because Sonic Drill Rigs are effective even in the heavily overconsolidated soil found on UBC campus. The vibrations from the sonic drill rig allow for easy penetration because it liquefies the surrounding soil. This method produces a continuous core sample, which can be used for testing in the lab in order to create a geological profile of the site. A shallow depth of 5m was chosen because the small surface area of tires means that the stress is concentrated on the top layers of soil.

Table 5 outlines the laboratory tests that will be conducted in order to determine the soil characteristics and water content.

Table 5 - Laboratory Testing of Soil Samples

Test	Explanation
Specific Gravity	• Saturated unit weight and zero air voids curve
Grain Size Distribution	• For soil classification and grain size specifications

Compaction	• Determine max dry density and optimum water content
Water Content	• Qualitative information about strength and deformation
Unconfined Undrained (UU) Triaxial Shear Test	• Undrained shear strength
California Bearing Ratio (CBR)	• Determine the Subgrade Resilient Modulus • Used to characterize soil for pavement design • Predict roughness, cracking, faulting, etc

Once the Subgrade Resilient Modulus has been determined from the California Bearing Ratio, we can use the equation below to verify that the pavement thickness we chose based on the guidelines for medium volume roads will be sufficient in these soil conditions. The design of this road is based on the AASHTO Design of Pavement Structures (American Association of State Highway and Transportation Officials, 1993).

$$\log_{10}(W_{18}) = Z_R \times S_o + 9.36 \times \log_{10}(SN+1) - 0.20 + \frac{\log_{10}\left(\frac{\Delta PSI}{4.2-1.5}\right)}{0.40 + \frac{1094}{(SN+1)^{5.19}}} + 2.32 \times \log_{10}(M_R) - 8.07$$

where: W_{18} = predicted number of 80 kN (18,000 lb.) ESALs

Z_R = standard normal deviate

S_o = combined standard error of the traffic prediction and performance prediction

SN = Structural Number (an index that is indicative of the total pavement thickness required)

= $a_1D_1 + a_2D_2m_2 + a_3D_3m_3 + \ldots a_i$ = i^{th} layer coefficient, D_i = i^{th} layer thickness (inches), m_i = i^{th} layer drainage coefficient

ΔPSI = difference between the initial design serviceability index, p_o, and the design terminal serviceability index, p_t

M_R = subgrade resilient modulus (in psi)

4.3. Procedure

The loose sand containing gravel and organic material at the soil surface would be a poor choice on which to construct a road, and therefore this layer will be excavated away before construction begins. The site will be backfilled in order to reach the required grade, and the roadbed will be prepared by compacting it. Sub-base course and base course containing lime will then be added, both at 95% compaction, followed by paving the surface with flexible asphalt pavement.

4.4. Potential Challenges

Sometimes glacial till contains large cobble clasts and boulders left behind by the receding glacier, but no evidence of this was found in the 2002 study of UBC campus. There was also no indication of sand or gravel layers (Piteau Associates, 2002). We propose to use the Observational Method, in which the most probably conditions are designed for and then the design can be adjusted if unexpected conditions arise.

Some common geotechnical problems that arise in road design include roadbed swelling due to changing moisture content, cracking due to temperature cycles, and differential settlement. These can typically be prevented through proper design and adequate drainage. Because the area usually doesn’t experience freezing conditions, this also reduces the risk of damage due to freeze thaw cycles (American Association of State Highway and Transportation Officials, 1993). The soil is heavily over consolidated which should prevent differential settlement from occurring.

5. SCHEDULE & COSTS

The total cost for construction of the two roundabouts is estimated to be $2,700,000.00. Both scheduling and estimating was done using RS Means which provided us with costs and durations for each of the tasks necessary for construction. Concrete disposal was a major cost as a conservative estimate of the rate per unit removed was taken. A conservative estimate was used since disposal costs varied from free - $70/tonne. In hopes to prevent any unforeseen disposal costs, a value of $65/tonne was used. However there will be some savings since some of the asphalt removed will be reused in the paving of the new roads. A breakdown of the estimated construction, material, concrete disposal, and labor costs is shown in Table 6. A detailed estimate is also provided in the appendices.

Table 6 - Cost Breakdown

Equipment Cost	$220,000.00
Material Cost	$660,000.00
Labor Cost	$350,000.00
Concrete Disposal Cost	$1,200,000.00
Total Construction Cost	$2,430,000.00
Contingency 10%	$243,000.00
Total Cost	$2,673,000.00
Project Duration	8.5 Months

Based on a conultation repord done by UBC the estimated total costs to construct the two existing roundabouts on SW Marine was $1.5 million. The cost includes roadway upgrades on SW Marine Drive such as adding bike lanes and signages, $300,000 for the Stadium Road roundabout and $400,000 for the 16th Avenue roundabout. The summarized proposal estimate is shown below:

Table 7- Proposal Estimate

Construction Costs	Two SW Marine Drive Roundabouts	
Construction + 25% Contingency	$	875,000
Construction Administration	$	300,000
Design & Permitting	$	300,000
Temporary Easements/ Permits	$	30,000
Total Estimated cost	**$**	**1,505,000**

The estimate for these two new roundabouts differs from the estimate on the previous two roundabout by approximately 1.1 million dollars, about the same value that was estimated for asphalt removal. As stated earlier the value used to estimate the asphalt disposal was a conservative one. Also the complete design of the two roundabouts and lane realignment of Marine Drive in the previous proposal is not known; it is possible that this estimate didn't account for the disposal of existing asphalt.

The total duration of the construction project is estimated to be 8.5 months and will be completed in three phases. All three phases will begin with the demolition of the current road and then constructing the new road. The main steps in the construction process will include backfilling, curb construction, and asphalt paving. Demolition of the roads leading into the intersections is required as road realignment is necessary for proper traffic flow in the roundabouts. The three phases in order will be: Phase 1) The removal and construction of the intersection at Marine Drive and 16th Ave, Phase 2) The removal and construction of Marine Drive between Stadium and 16th Ave, Phase 3) The removal and construction of the intersection at Marine Drive and

Stadium. Landscaping will be completed upon completion of the three phases. Details of the construction schedule are provided in Figure 12.

Task Name	Duration	Start
Surveying	7 days	Fri 21/03/14
Existing Concrete Removal 16th	13 days	Tue 01/04/14
Excavation 16th	12 days	Fri 18/04/14
Back fill Top soil	3 days	Tue 06/05/14
Back fill Coarse Agg 16th	2 days	Tue 06/05/14
Compact/Level Coarse Agg 16th	2 days	Thu 08/05/14
Back fill Fine Agg 16th	2 days	Mon 12/05/14
Compact/Level Fine Agg 16th	3 days	Wed 14/05/14
Install Curb 16th	2 days	Mon 19/05/14
Pave Asphalt	2 days	Wed 21/05/14
Concrete Removal Between Intersections	21 days	Fri 18/04/14
Excavation Between Intersections	27 days	Mon 19/05/14
Backfill Top Soil Between Intersections	4 days	Wed 25/06/14
Back fill Coarse Between Intersections	3 days	Tue 01/07/14
Compact/Level Coarse Agg Between Intersections	2 days	Fri 04/07/14
Back fill Fine Agg Between Intersections	2 days	Tue 08/07/14
Compact/Level Fine Agg Between Intersections	3 days	Thu 10/07/14
Pave Asphalt Between intersections	1 day	Tue 15/07/14
Concrete Removal @ Stadium	17 days	Wed 16/07/14
Excavation @ Stadium	22 days	Fri 08/08/14
Back fill Top Soil @ Stadium	4 days	Tue 09/09/14
Backfill Coarse Agg @ Stadium	3 days	Mon 15/09/14
Compact/Level Coarse Agg @ Stadium	3 days	Thu 18/09/14
Backfill Fine Agg @ Stadium	2 days	Tue 23/09/14
Compact/Level Fine Agg @ Stadium	4 days	Thu 25/09/14
Install Curb @ Stadium	4 days	Wed 01/10/14
Asphalt Paving @ Stadium	2 days	Tue 07/10/14
Lane Painting	5 days	Thu 09/10/14
Landscaping	8 days	Thu 16/10/14

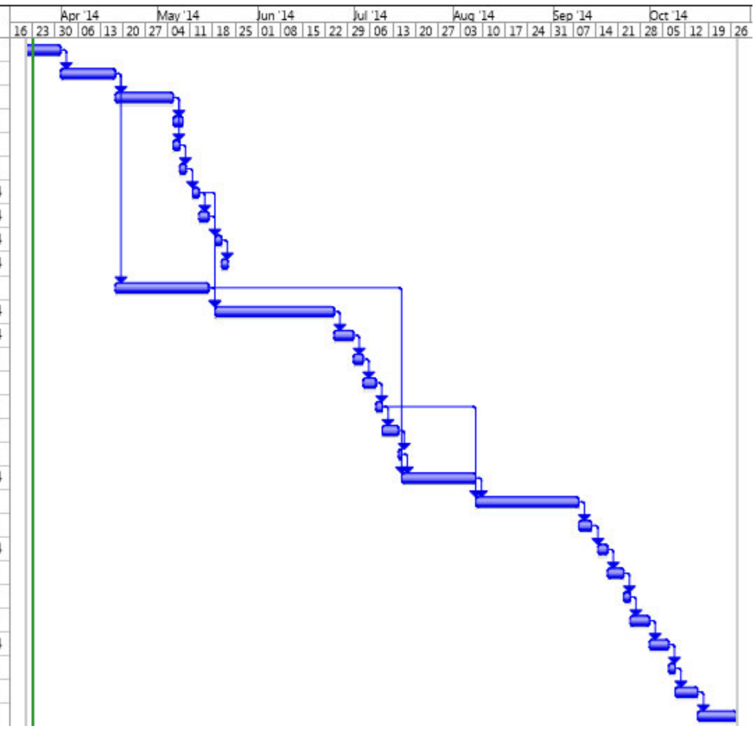


Figure 12 - Detailed Schedule

6. CONCLUSION

This design of the UBC Botanical Garden Traffic System Redevelopment has been guided by three engineering disciplines: transportation, materials, and geotechnical. The principles of these distinct fields have been used to create a solution to the objective of a traffic system that is safer, more sustainable, and provides better service to the UBC Botanical Gardens as well as to the facilities and recreational areas of the University campus in the vicinity of the UBCBG.

6.1. Design Procedure

Transportation engineering has taken a lead role in the detailed design report, providing the basis for the technical design of the roadways and roundabouts with consideration for traffic volume and level of service, safety, and economic feasibility. Materials engineering guided the selection of the roadway pavement and concrete curb materials with respect to road performance and lifespan and environmental sustainability. Geotechnical engineering played an important role in assessing the ground conditions and roadway foundation throughout the project site, as well as outlining the site works and grading during the construction process.

6.2. Final Cost and Schedule Summary

As designed, the project will have an estimated total cost of $2.7 million. This figure includes equipment, materials, labour, and removal of old roadway surfaces, with a 10% contingency for construction overruns. Construction is estimated to take a total of 8.5 months, starting with the removal of the extra road lanes and grading of SW Marine Drive and the conversion of the 16th Ave intersection to a roundabout, progressing to the conversion of the Stadium Drive intersection, and finally to landscaping of the project site.

Closing Remarks

Diversified Engineering Services has been pleased to work with the UBC Botanical Garden to prepare this Traffic System Redevelopment detailed design report. We believe that implementation of the recommendations and design specifications contained within this report will help fulfil the objectives of providing increased safety and ease of access for pedestrians, cyclists and motorists who are visiting the Botanical Garden.

Yours truly,

Team 10

Prepared by:

DIVERSIFIED ENGINEERING SERVICES LTD.

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Stephen Hillier (
Haena Kim (
Garen Mackie (
Julie Park (
Martina Riessner (

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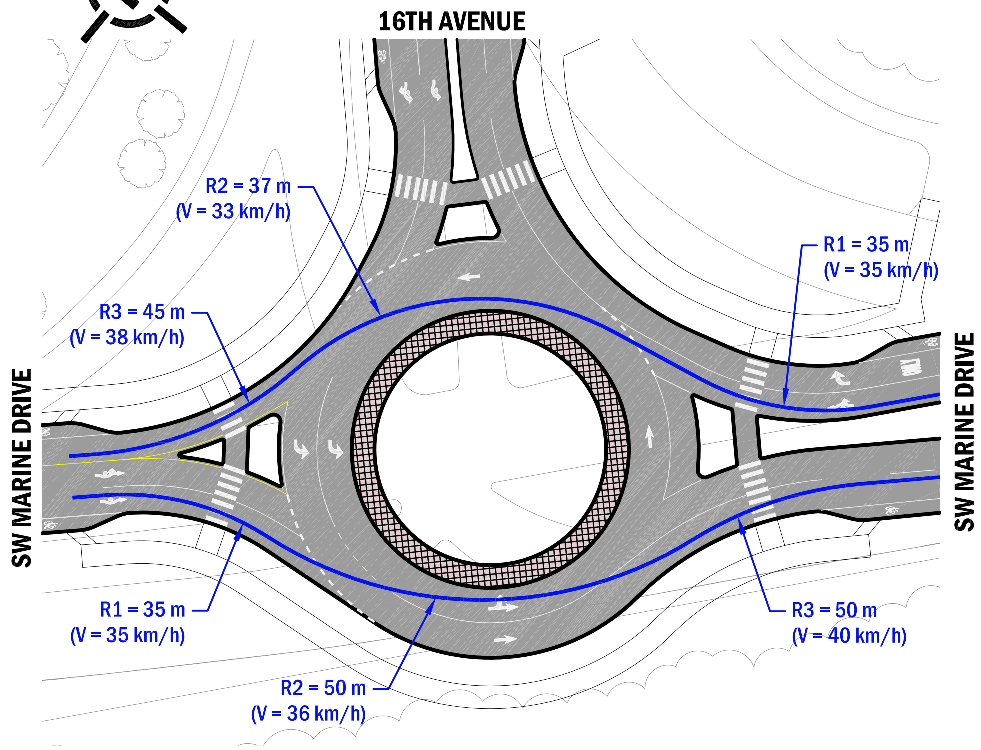
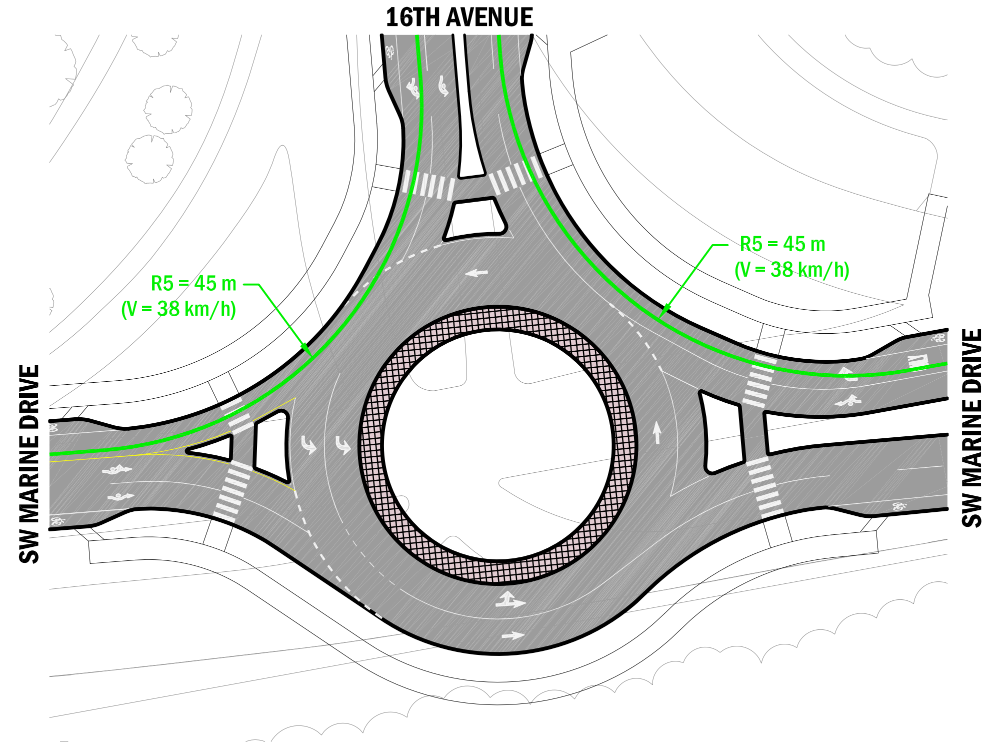
APPENDIX A –COST ESTIMATE DETAIL

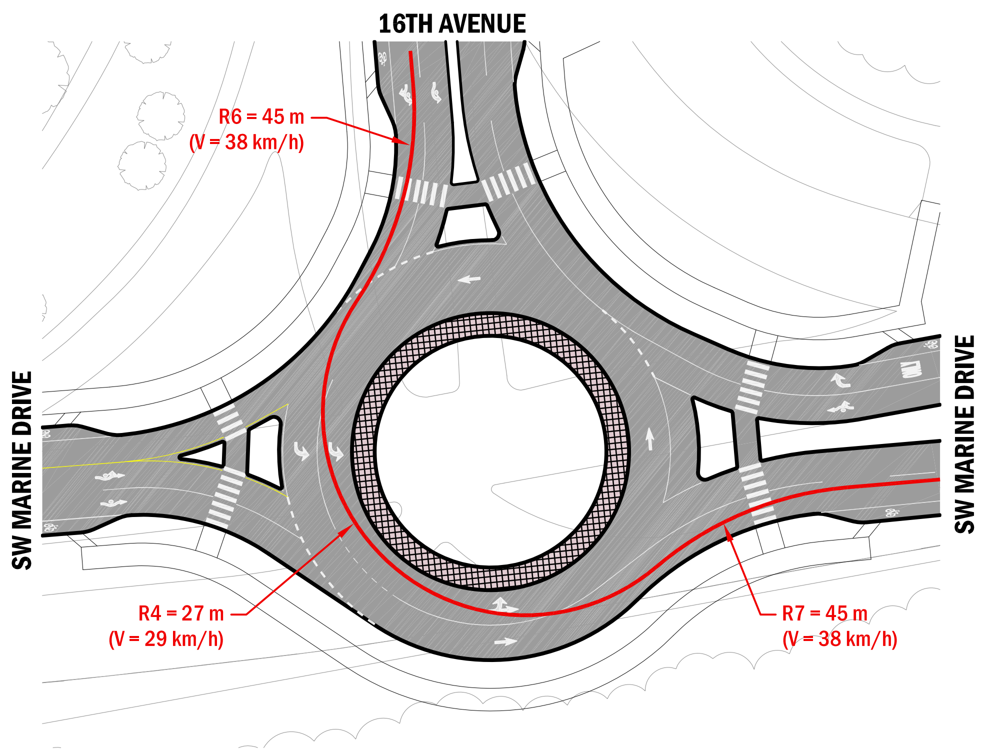
Quantity	LineNumber	Source		Description	Crew	Daily Output	Labor Hours	Unit	Material	Labor	Equipment	Material	Labor	Equipment	Ext. Total O&P	Labor Type	Data Release	CCI Location
10500	321126130500			Asphalt paving, plant mixed asphaltic base courses for roadways and large paved areas, bituminous concrete, 100 mm thick	B25	3800	0.02	m2	$ 30.78	$ 0.96	$ 0.82	$ 353,220.00	$ 15,540.00	$ 9,450.00	$ 378,210.00	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
1482	321613130410			Cast-in place concrete curbs & gutters, concrete, steel forms, straight, 150 mm x 450 mm, includes concrete	C2A	213	0.23	m	$ 24.14	$ 10.37	$ -	$ 39,391.56	$ 23,519.34	$ -	$ 62,910.90	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
16800	024113175050			Demolish, remove pavement & curb, remove bituminous pavement, 100 mm to 150 mm thick, excludes hauling and disposal fees	B38	351	0.11	m2	$ -	$ 5.12	$ 4.11	$ -	$ 131,544.00	$ 75,936.00	$ 207,480.00	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
1145	311413230200			Topsoil stripping and stockpiling, topsoil, sandy loam, ideal conditions, 224 kW dozer	B10M	2294	0.01	m3	$ -	$ 0.25	$ 0.89	$ -	$ 446.55	$ 1,122.10	$ 1,568.65	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
3339	310516100300			Aggregate for earthwork, crushed stone, 1.63 metric tons per m3, 40mm, spread with 150 kW dozer, includes load at pit and haul, 3.2 kilometers round trip, excludes compaction	B15	459	0.06	Lm3	$ 42.85	$ 2.68	$ 6.64	$ 158,535.72	$ 13,623.12	$ 24,441.48	$ 196,600.32	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
2433	310516100340			Aggregate for earthwork, crushed stone, 1.63 metric tons per m3, 13mm, spread with 150 kW dozer, includes load at pit and haul, 3.2 kilometers round trip, excludes compaction	B15	459	0.06	Lm3	$ 41.11	$ 2.68	$ 6.64	$ 109,874.28	$ 9,926.64	$ 17,809.56	$ 137,610.48	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
13770	312216100100			Fine grading, for roadway, base or leveling course, large area	B11L	1672	0.01	m2	$ -	$ 0.44	$ 0.47	$ -	$ 9,363.60	$ 7,298.10	$ 16,661.70	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
13770	312216100200			Fine grading, grade subgrade for base course, roadways	B11L	2926	0.01	m2	$ -	$ 0.25	$ 0.27	$ -	$ 5,370.30	$ 4,131.00	$ 9,501.30	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
2850	312323235020			Compaction, riding, vibrating roller, 3 passes, 150 mm lifts	B10Y	1759	0.01	Em3	$ -	$ 0.34	$ 0.36	$ -	$ 1,453.50	$ 1,111.50	$ 2,565.00	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
2540	329113260300			Planting beds preparation, backfill planting pit, on site topsoil, skid steer loader	B62	260	0.09	m3	$ -	$ 3.97	$ 0.75	$ -	$ 15,544.80	$ 2,108.20	$ 17,653.00	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
16910	329219130100			Seeding, mechanical seeding, 0.024 kg/m2	B66	2090	0	m2	$ 0.16	$ 0.19	$ 0.14	$ 2,874.70	$ 4,903.90	$ 2,705.60	$ 10,484.20	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
16040	312316130062			Excavating, trench or continuous footing, common earth, 0.57 m3 excavator, 300 mm to 1200 mm deep, excludes sheeting or dewatering	B12F	206	0.08	Bm3	$ -	$ 3.64	$ 3.61	$ -	$ 89,342.80	$ 63,678.80	$ 153,021.60	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
4	022113130400			Boundary & survey markers, lot location and lines, for small quantities, maximum	A8	1	32	Acre	$ 71.50	$1,575.00	$ 71.50	$ 316.00	$ 9,600.00	$ 314.00	$ 10,230.00	STD	Year 2014 Quarter 1	National Average
2	023213100200			Subsurface investigation, boring and exploratory drilling, report and recommendations from P.E.		0	0	Total	$ -	$ 775.00	$ -	$ -	$ 1,940.00	$ -	$ 1,940.00	STD	Year 2014 Quarter 1	National Average
2	023213100100			Subsurface investigation, boring and exploratory drilling, drawings showing boring details		0	0	Total	$ -	$ 335.00	$ -	$ -	$ 850.00	$ -	$ 850.00	STD	Year 2014 Quarter 1	National Average
2	023213100020			Subsurface investigation, boring and exploratory drilling, initial field stake out & determination of elevations, for borings	A6	1	16	Day	$ -	$ 730.00	$ 71.50	$ -	$ 2,250.00	$ 157.00	$ 2,407.00	STD	Year 2014 Quarter 1	National Average
4	312213200240			Rough grading sites, open, 3256-3711 m2, grader	B11L	0.9	17.78	Ea.	$ -	$ 821.56	$ 883.91	$ -	$ 4,972.60	$ 3,895.96	$ 8,868.56	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
2	312213200170			Rough grading sites, 753-929 m2, dozer	B10L	1	12	Ea.	$ -	$ 583.74	$ 540.48	$ -	$ 1,772.84	$ 1,193.56	$ 2,966.40	STD	Year 2014 Quarter 1	BRITISH COLUMBIA / VANCOUVER(C31)
Total												**$ 664,212.26**	**$ 341,963.99**	**$ 215,352.86**	**$ 1,221,529.11**			



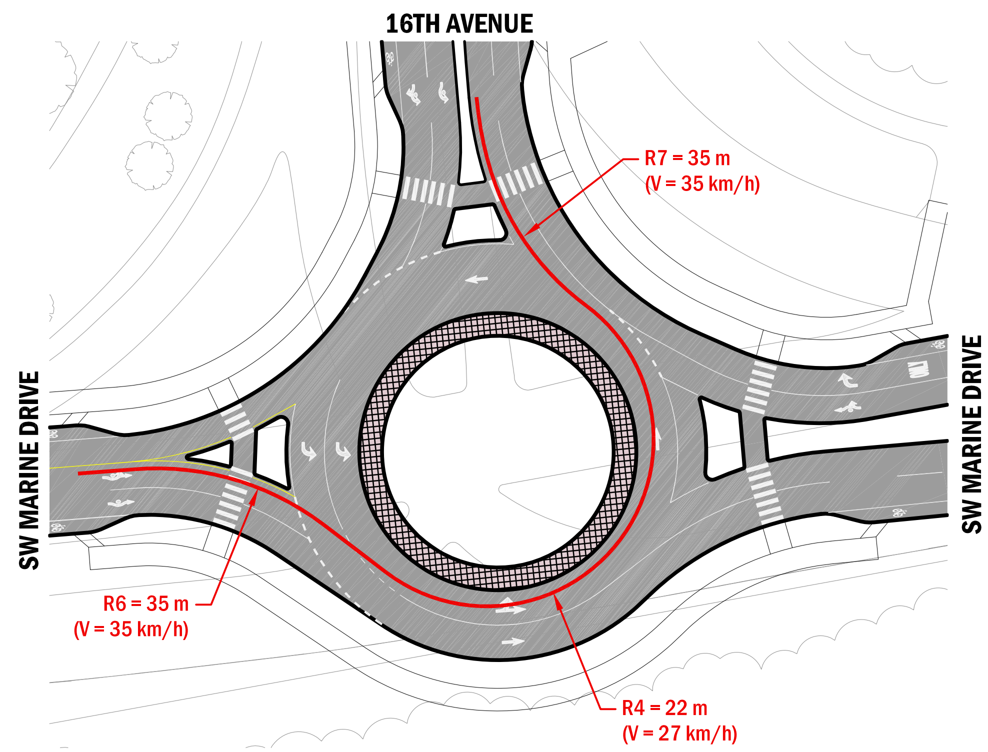
NORTH AND SOUTH BOUND THROUGH PATHS



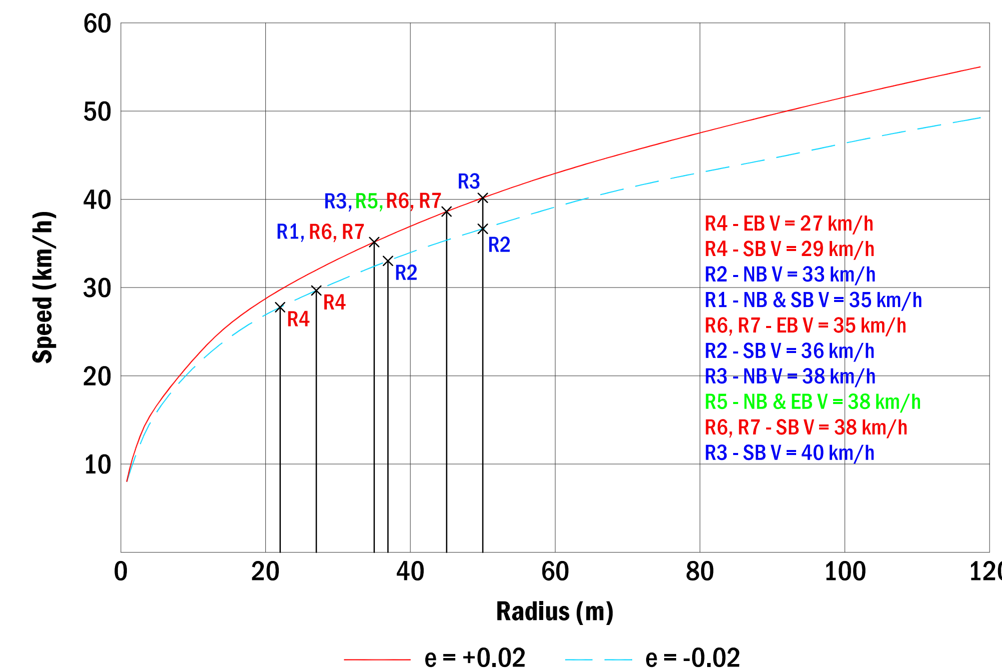
NORTH AND EAST BOUND RIGHT-TURN PATHS



SOUTH BOUND LEFT-TURN PATH



EAST BOUND LEFT-TURN PATH



SPEED-CURVE RELATIONSHIP

The University of British Columbia Botanical Gardens

CIVL446 - Team 10

Traffic System Renovation

Roundabout Fastest Path Curves & Velocities

SW Marine Drive at 16th Avenue

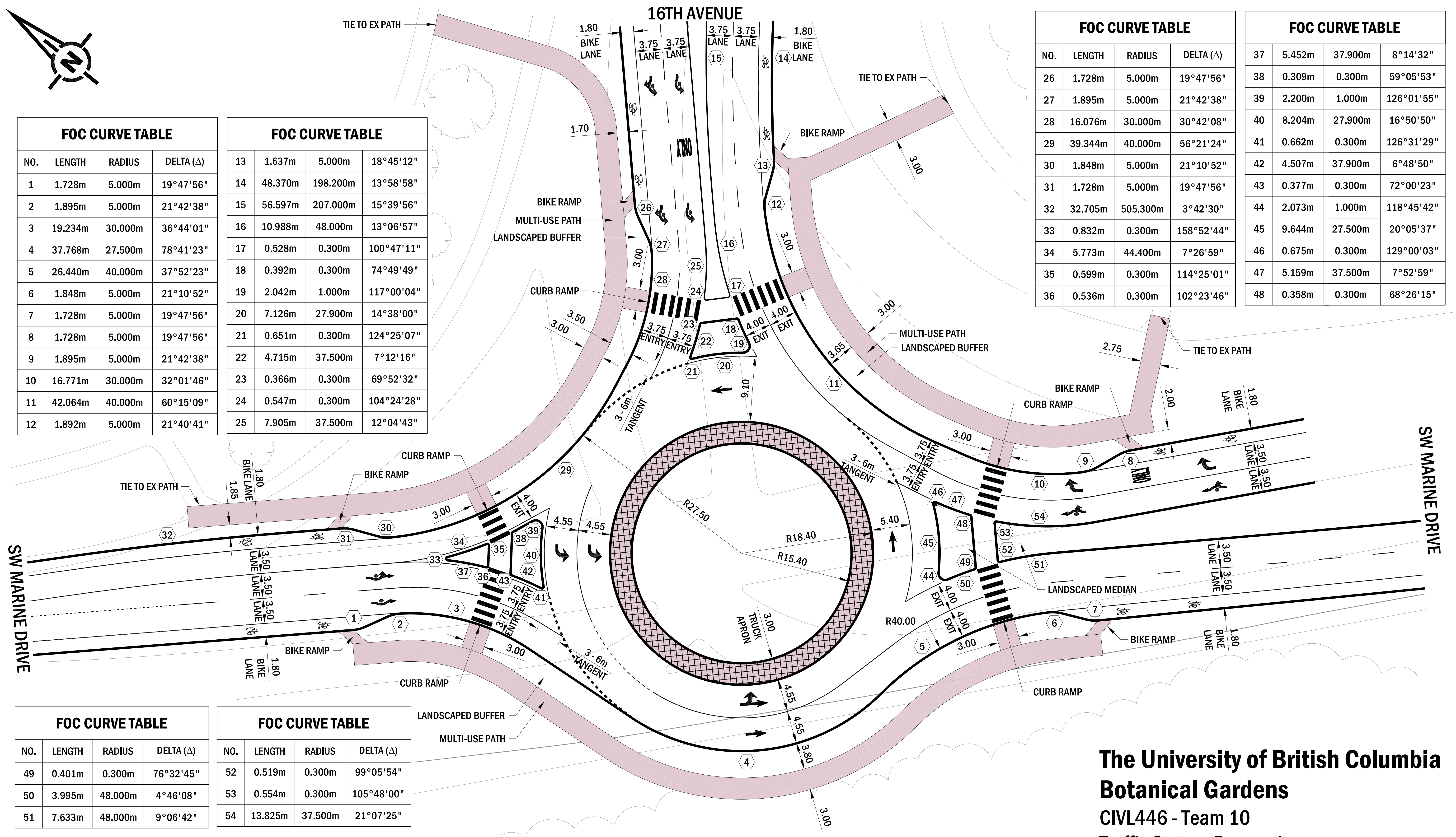
DRAWING 1

0 10 20 30 m SCALE 1:1000

diversified ENGINEERING SERVICES

PLOT DATE: April 3, 2014

SAVED BY: GAREN



FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
1	1.728m	5.000m	19°47'56"
2	1.895m	5.000m	21°42'38"
3	19.234m	30.000m	36°44'01"
4	37.768m	27.500m	78°41'23"
5	26.440m	40.000m	37°52'23"
6	1.848m	5.000m	21°10'52"
7	1.728m	5.000m	19°47'56"
8	1.728m	5.000m	19°47'56"
9	1.895m	5.000m	21°42'38"
10	16.771m	30.000m	32°01'46"
11	42.064m	40.000m	60°15'09"
12	1.892m	5.000m	21°40'41"

FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
13	1.637m	5.000m	18°45'12"
14	48.370m	198.200m	13°58'58"
15	56.597m	207.000m	15°39'56"
16	10.988m	48.000m	13°06'57"
17	0.528m	0.300m	100°47'11"
18	0.392m	0.300m	74°49'49"
19	2.042m	1.000m	117°00'04"
20	7.126m	27.900m	14°38'00"
21	0.651m	0.300m	124°25'07"
22	4.715m	37.500m	7°12'16"
23	0.366m	0.300m	69°52'32"
24	0.547m	0.300m	104°24'28"
25	7.905m	37.500m	12°04'43"

FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
26	1.728m	5.000m	19°47'56"
27	1.895m	5.000m	21°42'38"
28	16.076m	30.000m	30°42'08"
29	39.344m	40.000m	56°21'24"
30	1.848m	5.000m	21°10'52"
31	1.728m	5.000m	19°47'56"
32	32.705m	505.300m	3°42'30"
33	0.832m	0.300m	158°52'44"
34	5.773m	44.400m	7°26'59"
35	0.599m	0.300m	114°25'01"
36	0.536m	0.300m	102°23'46"

FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
37	5.452m	37.900m	8°14'32"
38	0.309m	0.300m	59°05'53"
39	2.200m	1.000m	126°01'55"
40	8.204m	27.900m	16°50'50"
41	0.662m	0.300m	126°31'29"
42	4.507m	37.900m	6°48'50"
43	0.377m	0.300m	72°00'23"
44	2.073m	1.000m	118°45'42"
45	9.644m	27.500m	20°05'37"
46	0.675m	0.300m	129°00'03"
47	5.159m	37.500m	7°52'59"
48	0.358m	0.300m	68°26'15"

FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
49	0.401m	0.300m	76°32'45"
50	3.995m	48.000m	4°46'08"
51	7.633m	48.000m	9°06'42"

FOC CURVE TABLE

NO.	LENGTH	RADIUS	DELTA (Δ)
52	0.519m	0.300m	99°05'54"
53	0.554m	0.300m	105°48'00"
54	13.825m	37.500m	21°07'25"

LEGEND

- EXISTING FEATURES
- PROPOSED STRAIGHT FACE CURB
- CONCRETE WALK
- (1) FACE OF CURB CURVE DATA

m SCALE 1:500
0 5 10 15

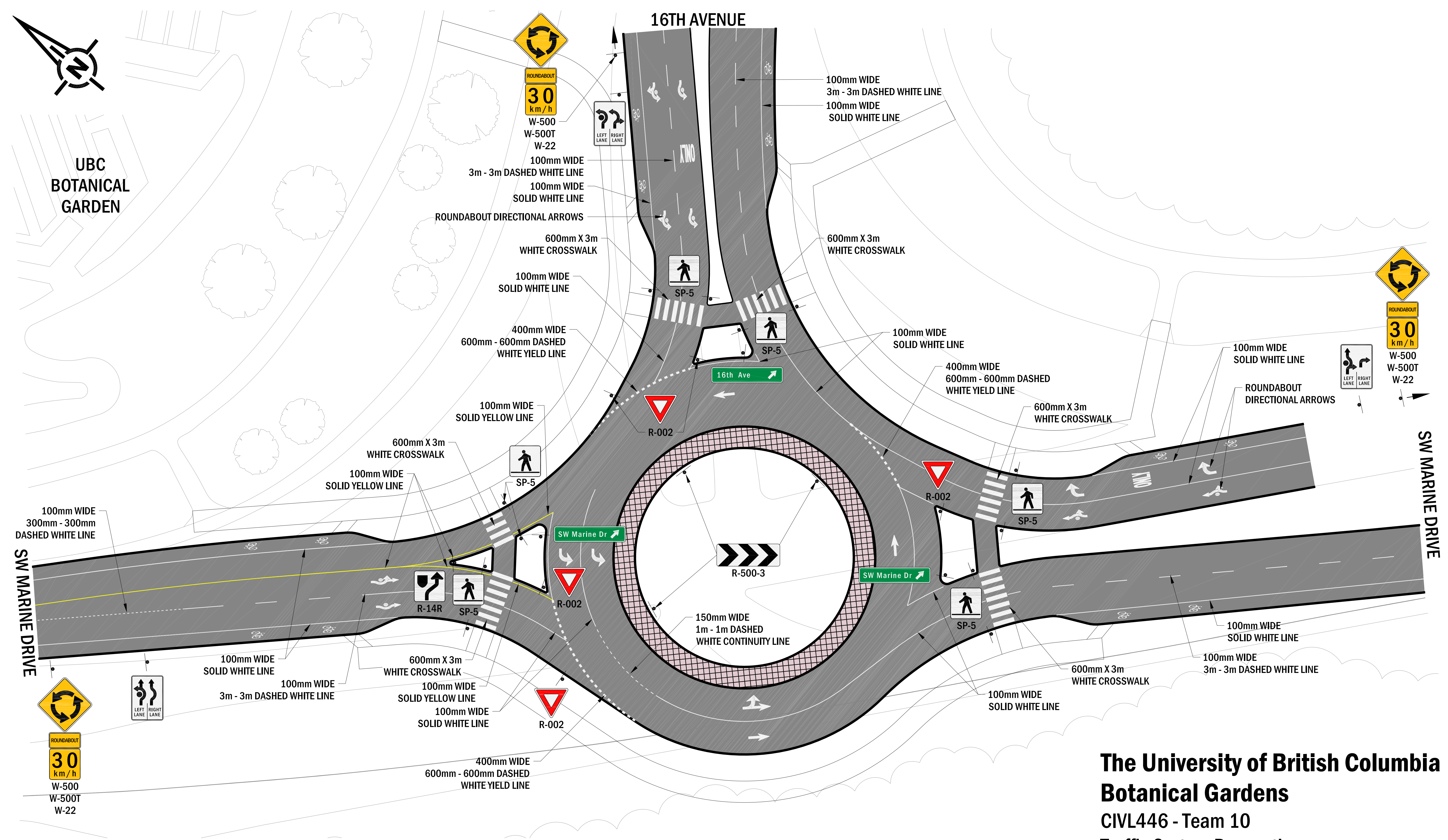
PLOT DATE: April 2, 2014
SAVED BY: GAREN

diversified ENGINEERING SERVICES

The University of British Columbia Botanical Gardens

CIVL446 - Team 10
Traffic System Renovation
Roundabout Geometry
SW Marine Drive at 16th Avenue

DRAWING 2



LEGEND

EXISTING FEATURES
PROPOSED STRAIGHT FACE CURB
ASPHALT
SIGN

0 5 10 15 m SCALE 1:500

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ENGINEERING SERVICES

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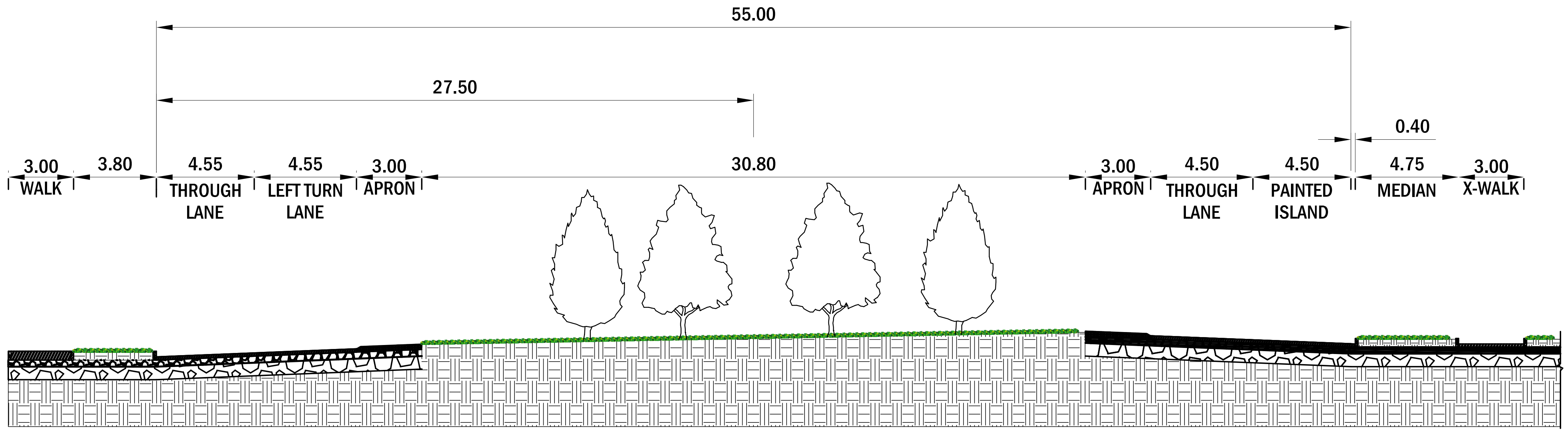
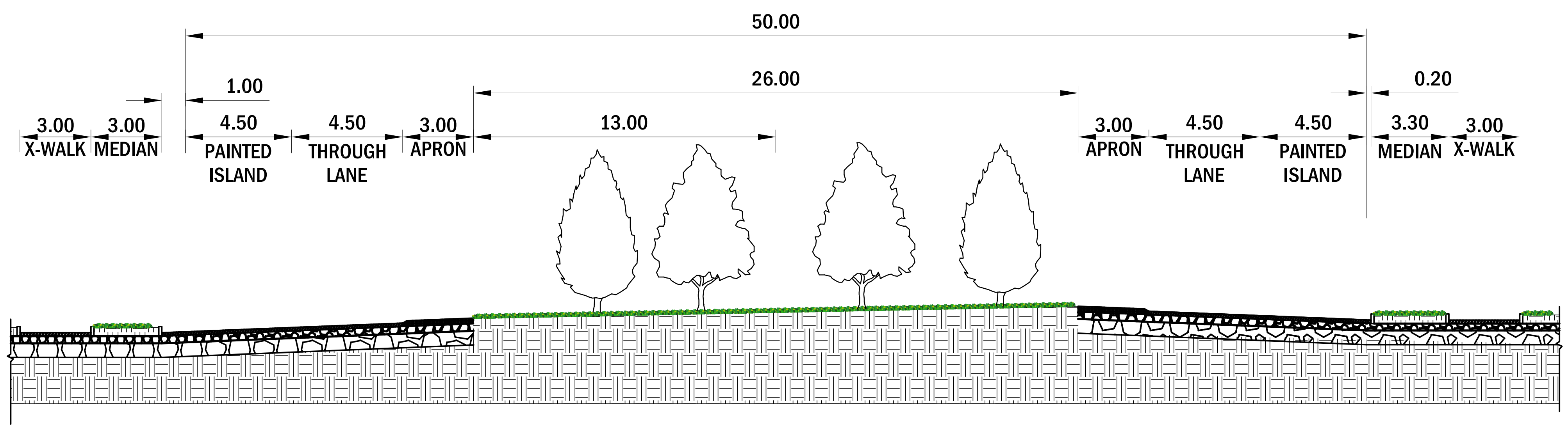
CIVL446 - Team 10
Traffic System Renovation
Roundabout Signage & Pavement Markings
SW Marine Drive at 16th Avenue

DRAWING 3



ROUNDABOUT SECTION AT SW MARINE DR AND 16TH AVE - LOOKING NW



ROUNDABOUT SECTION AT SW MARINE DR AND STADIUM RD - LOOKING NW

SAVED BY: GAREN PLOT DATE: April 2, 2014

diversified ENGINEERING SERVICES

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The University of British Columbia
Botanical Gardens
CIVL446 - Team 10
Traffic System Renovation
Roundabout Cross Sections

DRAWING 4