UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Redesign of Intersection at 16th Avenue / SW Marine Drive

FINAL DESIGN REPORT

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Executive Summary

Team 13 has completed a detailed redesign of the intersection of SW Marine Drive and 16th Avenue. The current intersection has not changed to meet the needs of a growing UBC Point Grey population, with issues including high traffic speeds, poor cyclist and pedestrian safety, erosion of Point Grey cliffs, and no sense of arrival to campus.

The redesigned intersection features a turbo roundabout for traffic control, serving to both control traffic speeds entering campus and help prevent collisions with dedicated turning lanes. Road curvature, reduced lanes, and textured roadways further help to slow traffic approaching campus.

Revamped bike lanes protected by sensor activated lights and rain garden buffers address cyclist safety and comfort, while a steel truss pedestrian overpass spanning 16th Avenue completely ensures the safety of pedestrians. Extensive rain gardens and reductions in impervious areas serve to retain all stormwater onsite and prevent erosion. A recycled plastic UBC sign in the center of the roundabout commissioned from indigenous artists welcomes visitors to campus, and affirms UBC's respect for the traditional and ancestral lands of the Musqueam people.

The design conforms to all Ministry of Transportation and Infrastructure requirements, and guidelines from the City of Vancouver Engineering Design Manual and Accessibility Guides. The Class A cost estimate predicts a project cost of $2,246,000 including $33,000 in annual maintenance. Construction in four phases is designed to begin May 1st, 2024, completing September 12th, 2024. Traffic management plans are set to keep access through the intersection open using temporary traffic lights for 3 of 4 phases, with detours for one traffic route required for the fourth phase.

Detailed design drawings, 3D models, SIDRA traffic analyses, structural and foundation calculations, and stormwater management analyses are included in the appendices of this report. Together, the design package is ready to be sent for construction.

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1.0 Introduction

Team 13 has been tasked with the redesign of the 16th Avenue / SW Marine Drive Intersection which is one of four major entrances to UBC and the only entrance not to feature a gateway welcoming people to the campus.

1.1 Background

The University of British Columbia's Vancouver Campus is home to 75,000 students and faculty as well as thousands of residents who live on the UBC Endowment Lands. UBC's growing population is rapidly exceeding the capacities of current methods of transportation. The redesign of the 16th Avenue / SW Marine Drive intersection will have a positive impact on all road users of the intersection. The current highway-style intersection is not cyclist, pedestrian, or transit friendly resulting in a design which cannot sustain the evolving modes of transportation residents and visitors to UBC require. Anticipated UBC residential developments will only exacerbate user dissatisfaction with the current design.

1.2 Project Objectives

The redesign of the intersection will meet and exceed BC Ministry of Transportation standards while also prioritizing safety and sustainability. The project focuses on prioritizing active modes of transportation. A complete list of project objectives is summarized below.

- Redesign the intersection following BC MoTI design requirements;
- Ensure walking, rolling and cycling are supported through safe and attractive facilities;
- Reduce traffic speeds through appropriate traffic calming measures;
- Retain the buffer with the adjacent Botanical Garden property;
- Incorporate infrastructure that retains and reuses stormwater on-site; and
- Incorporate a visual "gateway" feature that creates a sense of arrival to the UBC campus.

Using these objectives, the projects facilitate a shift from the current highway design to an urban-focused solution. This is done by integrating traffic calming measures to ensure the safety of cyclists and pedestrians. Sustainability objectives are achieved by incorporating green infrastructure to manage on-site stormwater.

1.3 Site Overview

The street network adjacent to the site has SW Marine Drive south of W 16th Avenue, Wesbrook Mall, and W 16th Avenue acting as arterial roads, while East Mall and SW Marine Drive north of W 16th Avenue function as collector roads. Key destinations near the site include the UBC Botanical Garden, Thunderbird Stadium, and the Food Garden. Notable destinations along the roads intersecting the site also include residential areas such as Totem Park Residence and Wesbrook Village. A visualization of the site overview can be found in Figure 1.

Figure 1: Site Overview Map

The R4 RapidBus runs through the intersection and connects to other nearby bus routes in the area. There are no bus stops within the site boundary, but it should be noted that a bus stop exists across the UBC Botanical Garden, which is less than a 5 minute walk (400m) away. On all approaches to the intersection, painted bike lanes are present within the extents of the site and continue beyond the site. The bike lane transitions into a shared use lane north of Stadium Road on SW Marine Drive. Pedestrian trails on the northeastern side of the intersection connect to other pedestrian facilities such as sidewalks. Sidewalks are present on both sides of each major road, with the exception of the west site of SW Marine Drive. The southwest side of SW Marine Drive south of Stadium Road lacks pedestrian facilities.

1.4 Team Member Contributions

Table 1 below outlines the individual contributions of each member for this report.

Table 1. Team Member Contributions

Team Member	Tasks
Abbey Seneres	Site Overview, LiDAR Modelling, Transportation Design Criteria, Transportation Design Descriptions, Transportation Rationale, Gateway Feature Description & Rationale, Sidra Analysis, Pavement Marking & Signage Drawing
Alexa Backman-Choo	Traffic Data Processing, Hydrotechnical Analysis, Stormwater Management Design, Preliminary Analysis, Design Rationale, Risk Mitigation, Formatting, Recommendation
Atira Naik	3D Modelling, Design Criteria, Conceptual Design Options and Evaluation, Stakeholder Engagement, Review
Ezra Parker	Executive Summary, Geotechnical Analysis, LiDAR Modelling, Structural Design and Modelling, Foundation Design, Structural Rationale
Michael Dhaliwal	Introduction, Project Schedule & Construction Activities, Construction Design, Maintenance Specifications, Stakeholder Engagement
Tajveer Grewal	Introduction, Cost Estimate, Construction Activities,Construction Design, Maintenance Specifications, Stakeholder Engagement
Shaden Bhuiyan	CAD Drawings, Sidra Analysis, Pavement Paint, Transportation Design

2.0 Design Criteria

2.1 Technical Requirements

Technical requirements were assessed according to design constraints and any relevant transportation, structural, or geotechnical guidelines published within Canada. The following subsections outline the criteria employed within each scope to create the design.

2.1.1 Transportation Design Requirements

The primary goal of the design is to regulate vehicle speeds on SW Marine Drive and at the entrance to UBC to foster a safer environment for active modes of transportation. To meet this goal, the geometric layout criteria in Table 2 was used, based on a number of relevant design guides. Where multiple design guides suggested criteria for the same design element, the most conservative or relevant criteria was used. The design should meet a Level of Service (LOS) C or better, in accordance with industry standards.

Table 2. Transportation Geometric Layout Criteria

Road Geometry Criteria	**Source**
Non-curb non-bus / truck route travel lanes, preferred width of 3.2 m (min 3.0 m)	City of Vancouver Engineering Design Manual (2019), Section 8.7.3
Curb non-bus / truck route travel lanes, preferred width of 3.4 m (min 3.0 m)	
Non-curb bus / truck route travel lanes, preferred width of 3.2 - 3.4 m (min 3.0 m)	
Curb bus / truck route travel lanes, preferred width of 3.5 - 3.7 m (min 3.3 m)	
Grade 1.0% (min 0.5%, max 10.0%)	
Crossfall 2.0% (min 1.0%, max 4.0%)	
Minimum horizontal clearance from street appurtenances 0.55 m	
Horizontal clearance from street light / BC Hydro Pole 0.76 m	
Minimum vertical clearance from paved surface to pedestrian structures 5.5 m	BC Supplement to TAC Geometric Design Guide (2019), Section 960.02.02

Roundabout Geometry Criteria	
Desirable max approach grade 4%	BC Roundabout Geometric Design Information Sheet (2017)
Circulatory Roadway Width (C_w)[2] equal or up to 20% larger than the widest Entry Width (e)[2] *(Dimensions visually displayed in Figure 2)*	
Minimum apron width 2.0 m	
Inscribed Circle Diameter (ICD)[2] 50 - 67 m for 2-lane roundabout *(Dimensions visually displayed in Figure 2)*	BC Supplement to TAC Geometric Design Guide (2019), Section 740.04
Minimum curb radius 12 m where trucks and buses turn frequently	AASHTO Policy on Geometric Design of Highways and Streets, 7th Edition (2018), Section 9.6.1.4 & 9.3.4
Desirable max entry design speed 40 - 50 km/h	
Bicycle Geometry Criteria	
Design speed 30 km/hr	City of Vancouver Engineering Design Manual (2019), Section 8.5.4
One-way protected bicycle lanes, preferred width of 2.4 m - 3.0 m (min 2.0 m)	
Grade 1-3% (max 5%)	
Raised buffer between bicycle lane and travel lane (at grade), preferred width of ≥ 0.8m (min 0.4 m)	

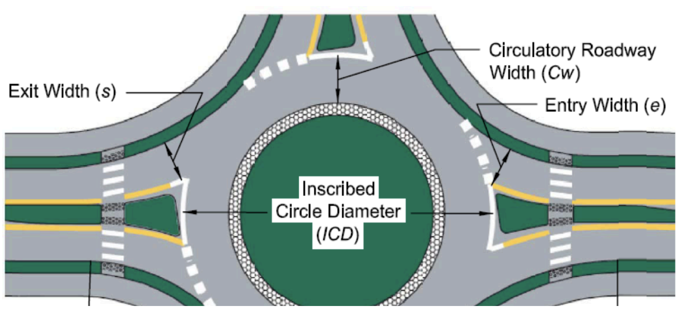


Figure 2: Key Roundabout Dimensions

2.2 Safety & Accessibility Requirements

The primary issue with the intersection lies in the supported elevated speeds which extend into UBC. The intersection lacks sufficient infrastructure for pedestrians and cyclists to travel safely, making it inadequate to meet both present and anticipated demands. The Design-Build

Specifications Standard provided by MoTI (2020) requires that a Base Safety Program must be created by the Contractor before any work can begin. This Safety Plan must be submitted to a Ministry representative at least 7 days before commencement of any work. The following regulatory accessibility guidelines relevant to BC shall be adhered to details in Table 3.

Table 3. Summary of Accessibility Requirements

Accessibility Requirements	**Source**
1.8 m minimum width of a sidewalk/overpass ● The wheelchair user controls as they require the most space	City of Vancouver Engineering Services Accessible Street Design
1:12 maximum slope of overpass Handrails on the overpass ● Between 0.87-0.97 m in height ● Between 30-43 mm in diameter ● 50 mm clear distance to past surface	BC Office of Housing and Construction Standards Building Accessibility Handbook, (2020)
● 150 m maximum distance between resting spots ● Broom-finished concrete with saw cut control joints to prevent vibrations	City of Vancouver Engineering Design Manual, 1st Edition (2019)

2.3 Construction and Traffic Planning Requirements

The Ministry of Transportation and Infrastructure places significant emphasis on meeting the minimum standards of a construction and traffic management plan. This involves giving consideration to multiple factors involved in construction planning, and is expanded upon in the Traffic Management Manual for the Work on Roadways from MoTI.

The construction and traffic management plan is to be created as a dynamic document that continuously updates any changes to the scope of work and roles and responsibilities, with regular evaluation. The traffic management plan should also be to the standard of Category 3 as it is a complex project involving significant impact on the traveling public due to higher volumes and lanes, project duration, lane closures, and others. A Category 3 construction and traffic management plan must include Traffic Control, Incident Management, Public Information, and Implementation Sub-Plans.

2.4 Regulatory Requirements

The provincial government holds ownership of roads within the site and their associated rights of way, thus placing it under the jurisdiction of the Ministry of Transportation and Infrastructure BC (MoTI). UBC operates outside the jurisdiction of the City of Vancouver, entailing distinct regulatory procedures. The project also intersects with TransLink, given its impact on a vital R4 bus route. All of these permit applications require a detailed site plan, design drawings, and at least a Class C cost estimate. The Ministry requires that two working days of notice are provided prior to carrying out any work within the right-of-way.

Table 4. Regulatory Permits

Importance	Permits	Regulatory Body
Necessary	Provincial Public Highway Permit Application	MoTI
Supplementary	Work Notification Request	MoTI
Supplementary	Road Closure Application	MoTI
Supplementary	Certificate of Insurance	MoTI
Necessary	Highway Use Permit - Works on Rights-of-Way	MoTI
Necessary	Development Permit	UBC
Necessary if a structure will need to be constructed within 4.5 m of the right-of-way of a highway	Structures Permit	MoTI
Necessary if any streetlights, traffic signals, drainage, or other utilities need to be constructed or replaced within the scope of the project.	Utilities Permit	MoTI
Necessary if particular landscaping activities and elements fall outside of the initially defined project scope.	Street and Landscape Permit	UBC

TransLink must be contacted for consent if a particular construction project will impact their infrastructure. Team 13 will provide them with preliminary reports, specifications, and drawings. TransLink's response will include specific requirements to be incorporated into the documentation and deliverables mentioned.

2.5 Environmental Sustainability Requirements

Environmental considerations are central to the project's goals, with a focus on integrating green infrastructure, managing stormwater, minimizing tree loss, and maintaining a tree buffer between the site and the UBC Botanical Gardens. The emphasis on stormwater management stems from erosion risks on the cliffs surrounding UBC's campus. UBC has proactively addressed this concern through the creation of an Integrated Stormwater Management Plan, strategically planning for potential issues. This Plan provides a number of best practices that are incorporated into the design to be satisfactory to UBC. These best practices and plans are devised and submitted for approval to various regulatory bodies before development permits can be issued. Obtaining approval from UBC concerning tree removal and erosion control is provided as part of the Development Permit application.

The Ministry of Climate Change and the Ministry of Transportation collaboratively crafted a manual outlining optimal environmental practices for roadway construction. Similar to the construction and traffic management plan, an environmental management plan must undergo approval by the Ministry of Transportation before initiating any work. To assess environmental status, engaging an Appropriately Qualified Professional (AQP) is imperative.

2.6 Indigenous Consultation Requirements

The design must meet the requirements of the Musqueam Indian Band, whose land the project site resides on. The project must remain in line with their land use plans through continuous consultation and engagement over the duration of the project. The development of IR#2, their largest reserve located further south along SW Marine Drive, faces challenges due to traffic and limited access points due to the road, as indicated in the Musqueam Land Use Plan. Although the project site is not directly on SW Marine Drive, the road plays a crucial role in the broader traffic dynamics. In their Land Use Plan, the Musqueam Nation has also established a Healthy Living Community Sub Plan, designed to promote physical and social activity within the community. Identified in this are various established Musqueam paths and greenways/trails in Pacific Spirit Park. Preserving these existing pathways is essential. This aligns with the overarching project objective of maintaining the buffer for the UBC Botanical Gardens.

2.7 Predicted Changes in Land Use

The design is built with the intention of accommodating potential future changes in land use, population, and an increase in users. UBC's Campus Vision 2050 outlines the university's goals and overarching vision for the campus by 2050, addressing infrastructure, transportation, and land use issues. It emphasizes goals such as sustainability and safety for each of these aspects, pinpointing key locations slated for potential rezoning as residential housing by 2050. Two of these locations are situated farther along W 16th Avenue, to the south of the Thunderbird Park Sports Field, and on the University Hill Secondary School surface parking lot. This design criterion is significant as it will impact capacity contingency planning. The roundabout needs to accommodate both its existing users and any additional influx resulting from planned or unforeseen land use changes.

3.0 Preliminary Analysis

3.1 Methodology

Team 13 developed an overarching methodology to the project that prioritizes protecting the people and existing structures within the surrounding area. The effectiveness of the design was measurable by:

The methodology was subdivided to create appropriate approaches for technical work, economic analysis, construction planning, and Indigenous involvement. Technical analysis involved gathering on-site traffic counts for the site at peak hours, analyzing geotechnical conditions, and using LiDAR data to map elevation. Costs were appropriately weighted to assign their priority in the decision matrix and final analysis of design, using cost-effective materials and methods when available. Construction planning utilized substantial stakeholder engagement to minimize significant disruptions to commuters. Clear communication and project goals are necessities when developing a strong long-term relationship with Indigenous communities. The team ensures all project objectives are clear by providing an open line of communication and collaborative community meetings for each stage of project development.

3.2 Decision Making Process

A decision matrix was used to determine which design best met the objectives and constraints of the intersection using parameters such as safety, environmental aspects related to stormwater management and green infrastructure, Indigenous involvement, user friendliness, and cost, regardless of a lack of client defined project budget. This allows selection of the best design which addresses the needs of all users and stakeholders, meets all constraints, and is economically feasible.

3.3 Preferred Design Option

The best conceptual design was chosen using the established methodology to ensure the best functionality of the intersection redesign. This design features a turbo roundabout as the main method of traffic control. Turbo roundabouts provide a flow of traffic that ensures drivers do not change lanes within the roundabout, preventing side-swipe crashes.

This innovative method of traffic control originated in the Netherlands in the 1990s and has proven itself an effective way to decrease congestion and increase safety. As of June 2022, there were only two turbo roundabouts-inspired intersections built in Canada, despite hundreds constructed in Europe. UBC can be at the forefront of innovative roundabout design in North America by implementing this traffic control method.

The following features were included in the original conceptual design:

- Brightly coloured circular bike lanes with artistic designs by Indigenous artists
- Bike-activated crossing lights
- Grass center for the roundabout with a "UBC" sign to signify entrance to the campus
- Priority lane for transit
- Additional of greenery and rain gardens for stormwater retention and clear division between the road and bike lanes
- Pedestrian overpass above east portion of intersection

The preferred design option shown in Figure 3 underwent substantial revision and refinement, such as removing the transit lane and reducing the southbound north leg to single lane traffic, before reaching the final design as described in Section 4.0.

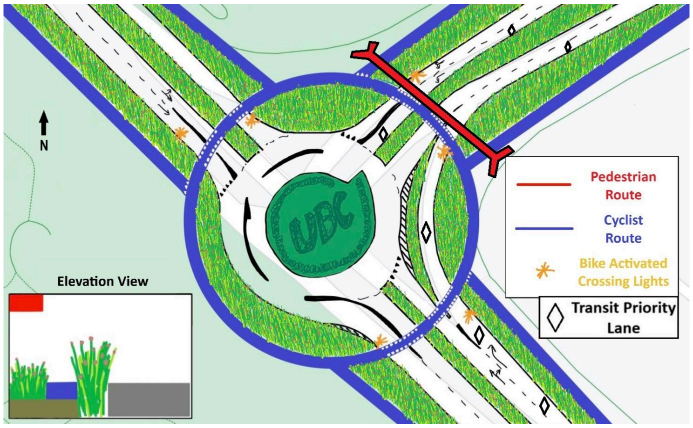


Figure 3: Preferred Design Option

4.0 Key Design Components

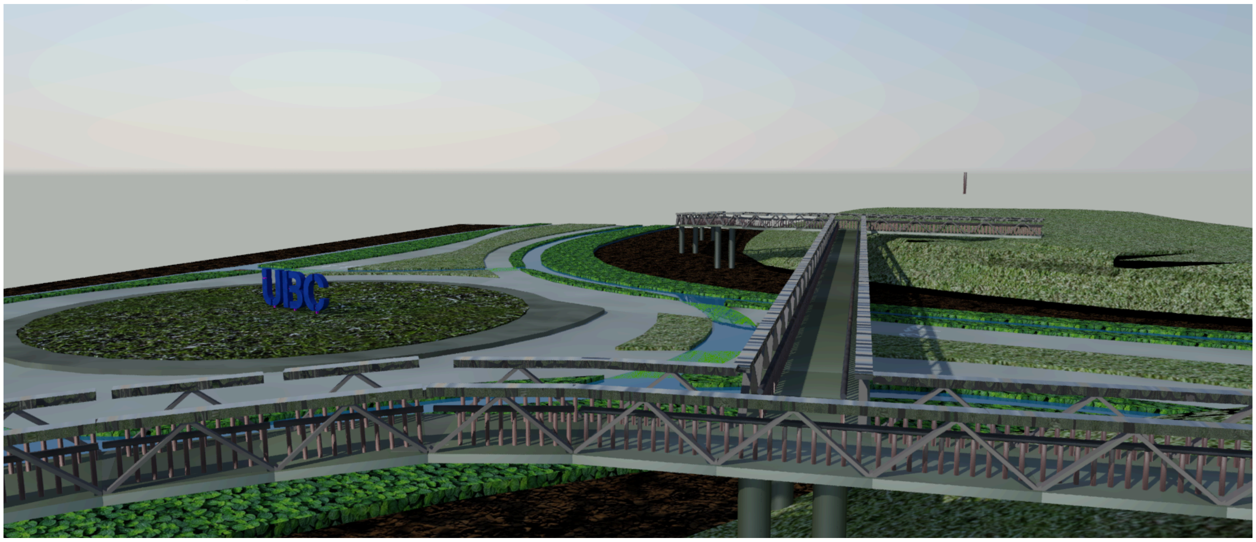


Figure 4: Key Design Components

4.1 Turbo Roundabout

- 38 m diameter grass center island
- 4 m wide lanes and min. 2 m wide truck apron to accommodate large vehicles
- Lanes are divided by stamped brick patterns to prevent lane changes
- Number of lanes reduced to single lanes in both directions on the northwest leg to easily connect to existing infrastructure and reflect traffic demand

4.2 Painted Protected Bike Lanes

- 2.4 m wide one-way protected bike lanes at-grade
- 1.6 m rain garden buffer between bike lanes and roadway
- 3.5 m wide bike crossings to accommodate two-way movement (possible U-turns)
- Bike actuated crossing lights, using induction loops, pavement markings and signage

4.3 Pedestrian Overpass

- Steel truss bridge with a concrete deck
- 3 m clear usable width, 81 m span across the width of 16th Avenue
- 3 m wide accessible ramps
  - Flat grade along 16th to meet path, 20 m long
  - 5% slope down to SW Marine, 3 m landings every 30 m, 100-110 m long

4.4 Rain Gardens

- Total capacity of 1500 m^3 collects all rainwater on site
- Increased pervious area of site by over 25%

4.5 UBC Sign

- Southward facing recycled plastic signage on reinforced concrete footings

5.0 Technical Details

The design's details relating to its key components and parameters in regards to transportation, overpass, and stormwater design were established in the subsections below.

5.1 Transportation Design

The preferred design option features a turbo roundabout geometry, with separated bike lanes and a pedestrian overpass. This section will detail the features relating to the geometric road design, geometric roundabout design, bike infrastructure and features, pavement marking and signage, and materials.

5.1.1 Geometric Road Design

The road dimensions outlined in Table 5 below were used at the approaches to the intersection and are based off of preferred dimensions mentioned in the City of Vancouver Engineering Design Manual (2019). Further details and schematics of the geometric road design can be seen in Appendix G, DWGs 201-210.

Table 5. Key Road Dimensions

Road Element		**Dimension**
SW Marine Drive Northbound (NB) Approach & W 16th Avenue Westbound (WB) Approach Lanes		Curb travel lane: 3.6 m Non-curb travel lane: 3.3 m
SW Marine Drive Southbound (SB) Approach Lanes		Curb travel lane: 3.4 m
Grade	SW Marine Drive NB Approach	0.5%
	SW Marine Drive SB Approach	1.4%
	16th Avenue WB Approach	3.5%
Crossfall		2.5%

All approach lanes within the project site will keep the original road alignment. These lanes will be consistent with minimal narrowing, according to the widths specified in the table above.

The project site extents are as shown in Appendix G DWG 100, T-203, T-205, and T-207 as well as in the below figures. The north leg ends where the existing roads have one lane per direction of traffic, near Totem Park Student Residence, as seen in Figure 5.

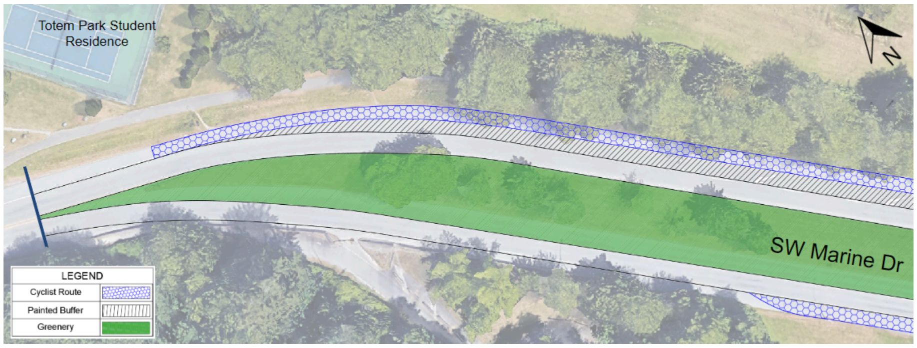


Figure 5: North Leg Tie-in

The W 16th Avenue east leg (Figure 6) extends just before the East Mall intersection, tying into where the existing marked bike lanes begin. The south leg starts at the beginning of the current northbound right turn lanes, to extend the 2-lane roadway up until the intersection.

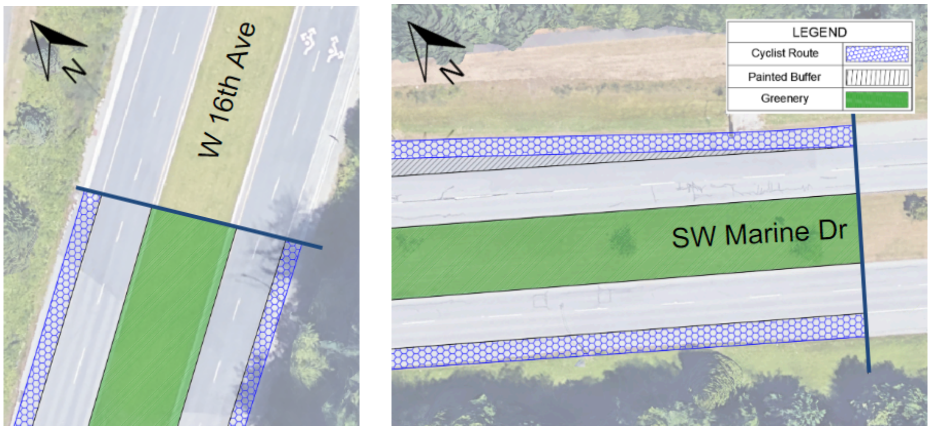


Figure 6: East Leg (left) and South Leg (right) Tie-ins

As the level of service of the design is higher than desired (LOS A), as seen from the Sidra analysis conducted in Appendix A2, this can induce higher speeds. To combat this as well as to meet one of the main project goals of slowing vehicle traffic, special measures have been implemented as seen in Figure 7. Prior to reaching the intersection, a section of the roadway will be painted. This change in texture will be another reminder for drivers to reduce their speed. In addition, added curves at the approaches to the intersection will assist in slowing down vehicles, which will in turn give time to perceive any crossing cyclists at the intersection.

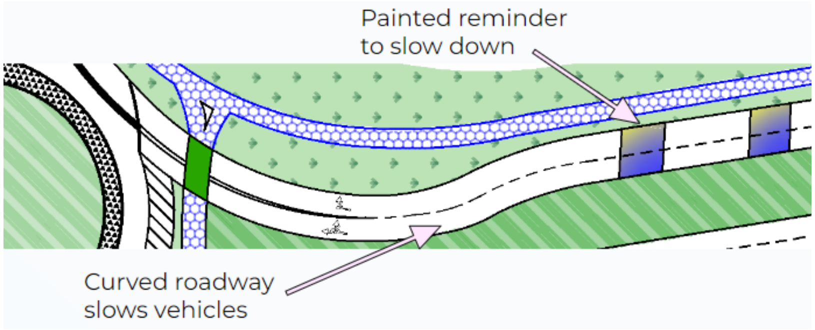


Figure 7: Roundabout Design Safety Features

5.1.2 Geometric Roundabout Design

The roundabout follows a turbo roundabout design shown in Figure 8, where physical barriers are used to assist with directing traffic such that vehicles do not change lanes within the roundabout. The physical barriers will use a stamped concrete brick pattern with a brick-like colour, similar to the existing turbo roundabout at Electra Boulevard and Willingdon Road (in North Saanich near the Victoria International Airport), as shown in Figure 9. This will be a visual and textural indication to not drive over the area. It will also be at grade with the travel lanes to ensure snow clearing activities are not interrupted.

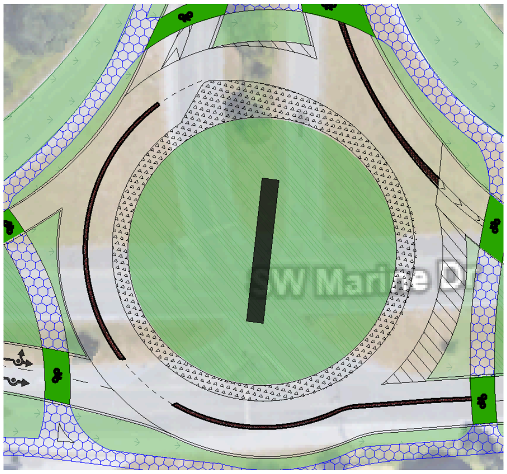


Figure 8 / 9: Roundabout Design / Example of Physical Barrier within Turbo Roundabout at Electra Boulevard and Willingdon Road, North Saanich, BC

A summary of the key roundabout elements are shown in Table 6 below, while a detailed schematic of the roundabout can be found in Appendix G, DWG T-201. Design values were chosen according to prescriptions from the BC Roundabout Geometric Design Sheet (2017), the BC Supplement to TAC Geometric Design Guide (2019), and the AASHTO Policy on Geometric Design of Highways and Streets, 7th Edition (2018), where BC guides were used when possible.

Table 6. Key Roundabout Dimensions & Components

Roundabout Element		**Dimension / Value**
Posted Advisory Speed of Roundabout		40 km/h
Entry Design Speed		50 km/h
Approach Grades		As specified in Table 5
Inscribed Circle Diameter (ICD)[2]		58.8 m
Island Diameter		38.0 m
Truck Apron Width		Minimum 2.4 m
Circulatory Roadway Width (C_w)[2]		8.0 m
Number of Lanes	SW Marine Drive NB Approach	2 entry / 2 exit
	SW Marine Drive SB Approach	1 entry / 1 exit
	16th Avenue WB Approach	2 entry / 2 exit
Approach Lane Width		As specified in Table 5
Entry Radius / Angle[1]	SW Marine Drive NB Approach	45.0 m / 24°
	SW Marine Drive SB Approach	46.0 m / 19°
	16th Avenue WB Approach	30.3 m / 13°
SW Marine Drive SB Approach: Left and Straight Thru Lane Length		50.0 m

Notes: 1. This is the interior angle measured between the approach leg tangent and the adjacent right side exit leg tangent.
2. Dimensions mentioned are visually displayed in Figure 2 of Section 2.1.1.

5.1.3 Bike Infrastructure Design & Additional Features

The preferred design features protected one-way at-grade (to the roadway) bicycle lanes on each side of the road with a rain garden buffer between the bike lane and roadway. Within the roundabout, the bike lanes will remain physically separated from the roadway, with the exception of paths that cross the vehicular approach lanes. Bike crossings within the intersection have been designed to allow for cyclists to make u-turns. Key design elements are summarized in Table 7 below, while a schematic of the typical bike infrastructure can be seen in Figure 10 below. Elements were designed based on the City of Vancouver Engineering Design Manual (2019).

Figure 10: Bike Infrastructure

Table 7. Key Bicycle Dimensions & Components

Bicycle Element	Dimension / Value
Design Speed	30 km/h
Bike Lane Widths	2.4 m
Bike Crossing Widths	3.5 m
Grades	As specified in Table 5
Rain Garden Buffer (separating bike lane and roadway) Width	1.6 m minimum

The bike lanes on the SW Marine Drive northbound and W 16th Avenue westbound legs, as well as the lanes adjacent to the southbound vehicle lanes on the SW Marine Drive southbound approach, are to keep the existing bike lane alignment with minor transition tapers to existing bike lanes to account for the difference in width. The bike lane adjacent to the northbound vehicle lanes on the SW Marine Drive southbound approach will feature a transition to the existing bike lane, due to the proposed road geometry described in Section 5.1.1. Within this transition segment, the bike lane will follow the proposed geometry while retaining the 1.4 m transition. At the extents of the project site, minor transition tapers similar to the other legs will be put in for small differences in width from the existing bike lane.

Additionally, the bike lanes will have bike sensors that will correspond to bike warning lights, warning vehicles to stop for the oncoming bicycle. It will use induction loops for detection, in conjunction with pavement markings and signage that denote the optimal location for a cyclist to position their bike to be detected. Locations of the warning lights and sensors are as shown in Appendix G, DWG T-208.

5.1.4 Pavement Markings & Signage

Pavement markings and signage used, and placements of these items are as specified in Appendix G, DWG T-210 in accordance with the Manual of Uniform Traffic Control Devices (MUTCD) for Canada (2021), suggestions from the BC Supplement to TAC Geometric Design Guide (2019). Installation shall be done as per the MoTI Manual of Standard Traffic Signs & Pavement Markings (2000). Current speed posting signs are to be detained. Wayfinding signs are to include the appropriate custom destinations and road names; they are also to be stylized in conformance with the UBC Wayfinding: Exterior Signage Standards and Guidelines (2019). Details on bike crossing pavement markings and signage are as seen in Appendix G, DWG T-208. Streetlights are to remain as is, with additional lighting at the roundabout itself as per Appendix G, DWG T-201.

5.1.5 Materials

The typical cross section design for roads is detailed in Appendix G, DWG T-209, with materials based on the City of Vancouver Construction Specifications (2019). It includes the following materials and thicknesses:

- 50 mm asphalt surface mix
- 180 mm (2 x 90 mm lifts) asphalt base mix
- 150 mm of 19 mm crushed granular base
- 300 mm of 75 mm crushed granular subbase
- Granular fill as needed

Similarly, the following materials and thicknesses are to be used for all bike lanes:

- 50 mm of 9.5 mm asphalt surface mix
- 150 mm of 19 mm crushed granular base
- 300 mm native or 75 mm granular subbase
- Granular fill as needed

5.2 Overpass Design

The intersection design features a pedestrian overpass spanning 16th Avenue, connecting the NE and SE corners of the intersection. The following sections outline the design of the typical overpass span, column and footing designs, and geometric detailing.

5.2.1 Geometric Design

The overpass features a 81 m straight span with 3.03 m of usable width connecting the existing pedestrian paths on the north and south sides of 16th Avenue. The main span is angled at a bearing of 135° running NW to SE, and is supported by 7 columns at a minimum 5.5 m clear height to the road, with a maximum clear span of 17.5 m. The clear span passes over the entire section of road to the center median, including car lanes, bike lanes, and rain gardens. The placement of columns is shown below in Figure 11, with the column to column span lengths shown in Table 8.

Figure 11: Overpass Column Placement Visualization on Site LiDAR

Table 8. Column to Column Span Lengths

Span	Length	Slope
Column 1 to Column 2	3.5 m	None
Column 2 to Column 3	17.5 m	1:20
Column 3 to Column 4	17.5 m	None
Column 4 to Column 5	17.5 m	None
Column 5 to Column 6	17.5 m	1:20
Column 6 to Column 7	7.5 m	1:20

Both ends of the main overpass span connect to existing pedestrian paths with ramps. All ramps and sloped sections of the overpass have a maximum 1:20 slope for accessibility considerations, with 3 m landings every 30 m. The ends of the ramps connecting to pedestrian paths (green) are shown relative to the bridge column placements (red) in Figure 12, with ramp lengths and bearings listed in Table 9.

Figure 12: Overpass Ramp Extents (Green) Visualization on Site LiDAR

Table 9. Column to Column Span Lengths

Ramp Location	Label on Figure 12	Length	Bearing	Slope
N 16th Avenue	1	20 m	70.81°	Horizontal
S 16th Avenue	2	12.5 m	44.26°	Horizontal
NE SW Marine Dr	3	100 m	Curved	1:20
SE SW Marine Dr	4	110 m	Curved	1:20

Overpass and ramps have a 3.2 m slab width, with a 3.03 m clear width between 35 mm diameter handrails on either side. Handrails are at 915 mm height with 50 mm clear space to the structural members. A second horizontal bar is provided with 100 mm clear space from the slab, and vertical bars are spaced 100 mm apart. For geometric details, see DWG S-301 and DWG S-302 in Appendix G.

5.2.2 Structural Design

The overpass utilizes a steel half-through Warren truss system, with a 17.5 m maximum span. Pairs of trusses create triangles 1.25 m high and 2.5m long. A 3D model profile view of the overpass span can be seen in Figure 13.

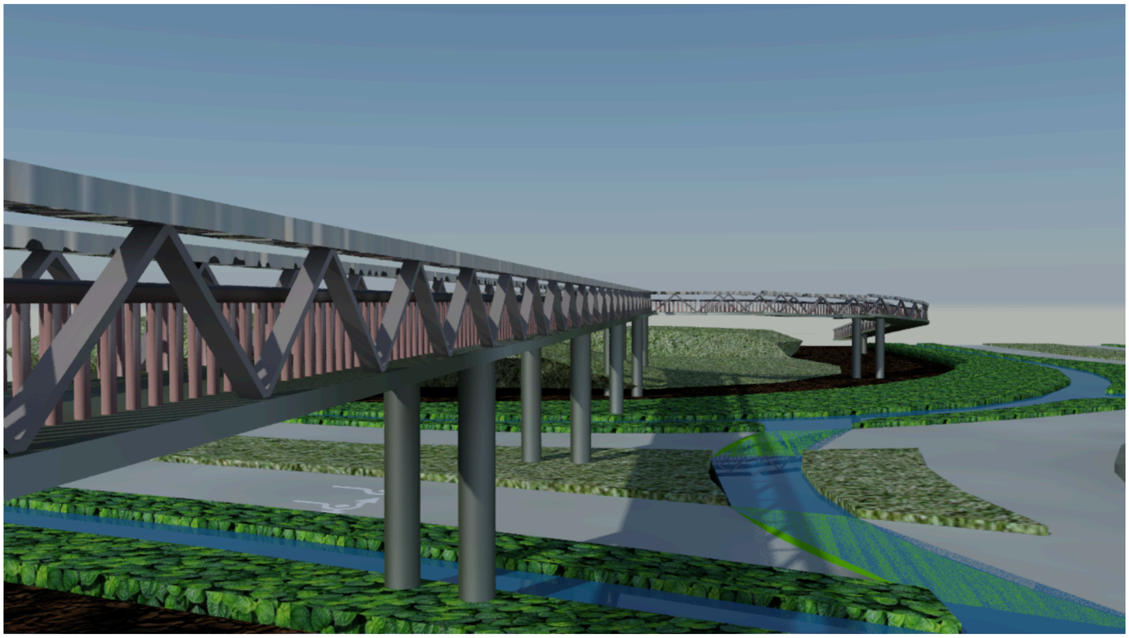


Figure 13: Profile View of 16th Avenue Overpass Span

Each overpass superstructure section has two parallel truss sections composed of a top chord, a bottom chord, and truss members, which are designed to carry loads purely axially. Bottom chords at the joints of the trusses support 3.2 m beams, which support a 125 mm fluted composite deck made of steel and concrete. Girders at the ends of the spans support the bottom chords, which in turn are supported by steel columns with a steel plate. Eccentric longitudinal braces are provided every fourth span and concentric transverse braces are provided every other span for lateral stability. Members are made of CSA G40.21-13 350 W steel, and all connections between steel members are welded. For detailing, see DWG S-301, DWG S-302, and DWG S-303 in Appendix G. Structural member sizing is listed in Table 10.

Table 10. Structural Steel Member Sizing

Structural Element	**Member Detailing**
Deck	Canam P-2432 Type 20 125mm
Beam	HS102x102x6.4
Top Chord	HS102x102x8.0
Bottom Chord	HS102x102x8.0
Truss	HS102x102x4.8
Girder	HS305x305x8.0
Transverse Brace	HS114x114x4.8
Longitudinal Brace	HS152x152x4.8
Column	W200x46
Girder Plate	250x250x8

Overpass sections are designed for the critical factored load combinations of 1.25 D + 1.5L + 1.0 S, and 1.0 D + 1.0 E. The design slab loading uses a dead load of 2.15 kPa, a live load of 4.8 kPa, and a snow load of 1.9 kPa. Factored point loads of 5 kN were included on each beam joint to support the weight of steel members, as well as any superimposed dead loads from utilities and decorative elements. Calculations of loads and member capacities can be found in Appendix A3.

5.2.3 Foundation Design

Columns supporting overpass sections are grounded through a baseplate into square shallow reinforced concrete footings, with a concrete specified strength of CSA A23.3-19 25MPa. The footings have a width of 1250 mm wide, and a depth of 325 mm, the base of which is grounded 1.5 m into the medium sands below the loose organic surface soils. The baseplate is 250x250x12 mm, placed in the center of the top of the footing.

The footings are designed to carry a 413.2 kN unfactored load, amplified by a factor of safety of 3.5 due to the relatively unexplored ground conditions, for a factored load of 1446 kN. Further exploration and testing of the soil profiles in the area of interest are recommended, and would reduce necessary factors of safety.

Longitudinal steel reinforcement is included with 17x15M bars in each direction, with a minimum grade of CSA G40.21-13 400W. The reinforcement has a clear cover of 75 mm, and 25 mm hooked ends. For structural details, see DWG S-304 in Appendix G.

5.3 Stormwater Management

The intersection design features a robust stormwater management system, with several new rain gardens tied into the current infrastructure. The following sections outline the existing stormwater facilities that exist on site, the locations of new green infrastructure, and the typical detailing and geometry of the rain gardens.

5.3.1 Existing Facilities

Currently, there are catch basins located on 16th Avenue near the intersection with East Mall (indicated in red in the following Figure 14). The new rain gardens will begin after the two catch basins and the corresponding existing concrete infrastructure near East Mall to ensure that all stormwater on site is collected as it travels down slope towards the intersection at SW Marine and 16th Avenue. The existing greenery and trees will be maintained along the sides of 16th Avenue and will be added upon on SW Marine as the narrower rain gardens transition to the larger area rain gardens. The west side of the intersection will be minimally touched due to its closer proximity to the erosion-prone cliff area. All construction on the west side will take place where asphalt already exists, without further encroaching into Pacific Spirit Park.

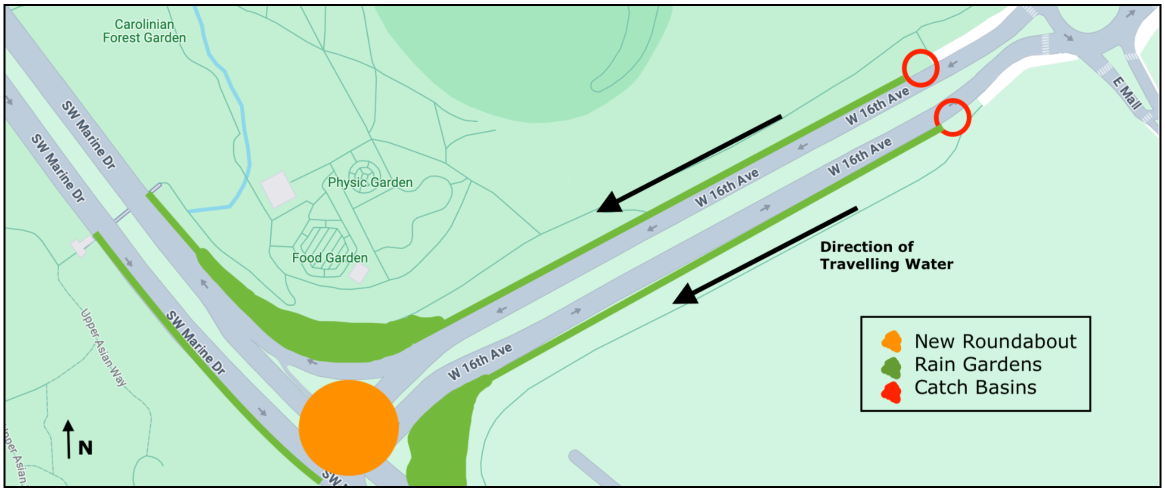


Figure 14: Catch Basins with Rain Garden Placement (Google Maps)

5.3.2 Rain Gardens

The on-site source control network consists of a network of rain gardens to capture the lot and road surface runoff considering the Volumetric Reduction Criteria of 72% of the 2-year, 24-hour rainfall event. The source controls consist of the water being either held in the region's topsoil, or a rock pit for any overflow of water. Rain gardens reduce runoff and create a barrier between modes of transportation. The slopes of the roadway allow for easy drainage of the rain on all impervious road surfaces into the adjacent rain garden medians that are placed between the road and the bike lanes. The stormwater on the vehicle lanes is directed towards drainage curbs that are located along the median, and convey the stormwater into the rain gardens. The geometry of the rain gardens within the bike lane median, and the geometry of the additional rain gardens located at the base of 16th Avenue are described in Table 11 (drawings in Appendix G).

The Simplified Rainfall Capture Method is used to calculate the input and capture volumes for the required source controls with the following assumptions:

- The region is 43% impervious area (57% pervious area).
- The post-development infiltration rate of the soil is 1.5 mm/hr.
    - A soil mixture of approximately 60-70% sand (2mm or finer particles), 10-20% clay and slit, and 15-20% organics will achieve the appropriate infiltration rate.
- The evaporation rate of the soil is 1 mm/day.
- The field capacity of the soil is 25% and the wilting point of the soil is 5%.
- Rock porosity is 40%.
- Topsoil depth can be within the range of 150 mm to 600 mm.

Table 11. Rain Garden Dimensions

Parameter	**Bike Lane Median**	**Base of 16th Avenue**
Design Rainfall	48.4 mm	
Width of Growing Medium	1.6 m	Varying widths
Depth of Growing Medium	0.6 m	0.45 m
Width of Rock Pit	0.8 m	Varying widths
Depth of Rock Pit	0.8 m	0.4 m
Total Area	2620 m^2	2200 m^2
Total Capacity	830 m^3	670 m^3
Total Site Capacity	**1500 m^3**	

All rain gardens are to use naturally occurring vegetation and growing medium approved by the City of Vancouver. The rain gardens have three planting zones: Zone 1 is designed to experience frequent flow of water in the center of the rain garden, Zone 2 is designed to be saturated during larger storms, and Zone 3 will typically have dry soil and transitions the rain garden into the existing landscape. Plants are to be selected and placed according to their respective growing conditions. Native plants from the Lower Mainland for all zones are listed in Table 12.

Table 12. Planting Zones for Rain Gardens

Zone 1	**Zone 2**	**Zone 3**
• Western Sword Fern • Deer Fern • Soft Rush • Grooved Rush • Pacific Ninebark	• Tufted Hair Grass • Kelsey Dogwood • Oregon Iris • Small Flowering Lupine • Canada Goldenrod	• Yarrow • Kinnikinnick • Blue Oat Grass

The rock pits are made from various gravel and scoria sizes such that the rock porosity is approximately 40%, allowing water to collect in a controlled way before infiltrating back into the soil. The bike lane median rain gardens are present along all roadways between road lanes and bike lanes. A 15 cm tall x 10 cm wide concrete curb with gratings in the curb at 30 m intervals allow the water to enter the rain garden along the entire roadway. The curb-edge material between the rain gardens and the bike lanes is a 20 cm wide border of gravel, which acts as a transition bugger to keep water and sediment traveling into the rain garden.

The rain gardens also act as an aesthetic transition on the pedestrian pathways from the student campus to UBC Botanical Gardens. Figure 15 depicts a sample rain garden used by the City of Vancouver in the Still Creek watershed.

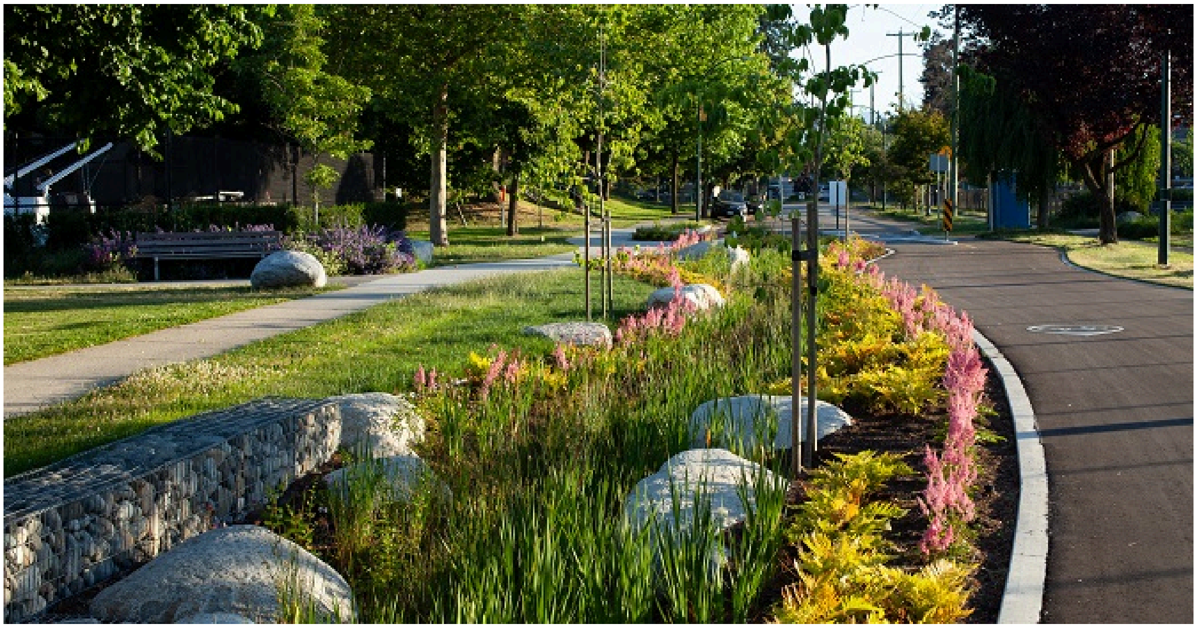


Figure 15: Still Creek watershed, City of Vancouver (Shannon Mendes)

5.4 UBC Gateway Feature Design

Within the roundabout central island, a UBC sign will be placed in the center to create a sense of arrival to the UBC campus. The central island will consist of grass and the UBC sign will be made of recycled plastics in alignment with UBC's 2030 Zero Waste Action Plan. A detailed drawing of the gateway feature can be seen in Appendix G, DWG S-305. Though the gateway feature was originally to be a mounded hedge, rationale discussed in Section 5.1.4 supports the decision to use a recycled plastic sign instead.

6.0 Rationale of Design

6.1 Fulfillment of Design Objectives

The detailed design emphasizes addressing the client's foremost concerns, with priorities encompassing safety for multimodal transportation, Indigenous engagement, green infrastructure, and the incorporation of a gateway feature to UBC. The subsequent sections elaborate on how the design effectively addresses these concerns.

6.1.1 Safety for Multimodal Transportation

Safety for pedestrians is prioritized by implementing the overpass design. It was determined from site visits that the intersection was not a safe environment for pedestrians due to high cyclist and vehicular speeds. Consequently, Team 13 recommends eliminating conflicts between cyclists and vehicles by placing pedestrians at a different grade, on the overpass. Most pedestrians using the intersection were runners who were impatient to cross the intersection. In lieu of breaking their pace, some would make dangerous crossings, ignoring the crosswalk “do not walk” lights. An overpass will improve both safety and convenience for these users.

Bicycle safety, comfortability, and attractiveness are increased by providing wide bike lanes which are physically separated from the roadway. Moreover, the added bike activated crossing lights increases vehicle drivers’ attention to crossing cyclists and overall enhances safety. Further details on how chosen bicycle features increase cyclist safety can be found in Table 13 of Section 6.2.

6.1.2 Green Infrastructure for Stormwater Management

An abundance of green infrastructure in the form of rain gardens is incorporated into the intersection design to retain stormwater on-site. These source controls are used to capture frequently occurring rainfall, and reduce the flow volume of stormwater. Therefore, the stormwater slowly filters into the ground rather than running into a storm drain or exiting the site as runoff. This LID (Low Impact Development) approach helps protect water resources and watershed hydrology, and is both functional and aesthetic. The versatility of dimensions when creating rain gardens allows them to be placed easily throughout the site without encroaching into already existing infrastructure and UBC Botanical Gardens.

6.1.3 Gateway Feature to UBC

The UBC sign used for the gateway feature is recommended to be placed in the center of the roundabout due to its high visibility. Though the gateway feature concluded in the preferred design (see Section 3.4) was to be a grass mounded hedge, it was decided that the recycled plastic sign from Design 2 (see Section 3.1.2) will be used instead of the hedge. This is to avoid the more rigorous maintenance that would be required to keep the grass hedge in shape. As there are no pedestrian crossings / facilities at grade of the roundabout, there is no safe access to the roundabout for the maintenance team, frequent maintenance would be unsafe.

6.2 Technical Transportation Design Rationale

All transportation design elements were designed to preferred dimensions and values as specified in relevant design guides. When possible, the BC Supplement to TAC Geometric Design Guide (2019) was used in order to comply with BC Ministry of Transportation, as they have jurisdiction over SW Marine Drive. Though the project is not within the boundaries of the City of Vancouver (CoV), the City's Engineering Design Manual (2019) was consulted to provide a good idea of urban roadway and bike specifications, to give the intersection a more urban feel. This urbanization of the roadway will be more compatible with the future nearby residential developments proposed by UBC Campus Vision 2050. Doing so tackles one of the major issues of SW Marine Drive, in which it was designed as a highway and thus creates an environment for increased speeds. For design elements not mentioned within these two design guides, the AASHTO Policy on Geometric Design of Highways and Streets (2018) was used, as is common to refer to in the industry. Any design decisions made outside of the desirable ranges described in the design criteria in Table 2 of Section 2.1.1, as well as further rationale is summarized in Table 13 below.

Table 13. Rationale for Technical Transportation Design Elements

Roadway Design Element	**Rationale**
Approach Lane Widths	The SW Marine Drive northbound approach and W 16th Avenue westbound approach lanes follow CoV's recommendations for truck/bus lanes, as these approaches are within truck and bus routes. In contrast, the SW Marine Drive southbound approach follows recommendations for non-truck/bus lanes, as there are currently no bus routes and trucks are not likely to use this way to reach their intended destinations.
Approach Grades	It will follow existing approach grades for easy vertical alignment.
Single Northbound Lane on SW Marine Drive Southbound Approach	This lane was cut from a double lane to a single lane, to match the transition into a single lane north of Stadium Road. Team 13 suggests that UBC transform the entire northbound segment from W 16th Avenue to north of Stadium Road to be a single lane.
Roundabout Design Element	
Inscribed Circle Diameter (ICD), Circulatory Roadway Width (C_w)	Dimensions for these elements were made to be similar to measured dimensions from the nearby W 16th Avenue and East Mall, and W 16th Avenue and Wesbrook Mall roundabouts while staying within the recommended values from the BC Supplement to TAC Geometric Design Guide (2019). Measured dimensions for ICD and C_w, respectively, were approximately 50-60 m and 5 m, while design dimensions are 58.8 m and 4.0 m. ICD was determined to be 58.8 m as site constraints limited the ICD to be 60 m max, then 1.2 m of this diameter was used for additional rain gardens.
Addition of short entry lane on north leg	To avoid confusion and lane changes entering the roundabout, an additional entry lane was added to the north leg. The lane was kept short at 50m as the remainder of the road going north does not require two lanes.
Bicycle Design Element	
Physically Separated Bike Lanes	Bike lanes were designed to be physically separated from the roadway due to the high cyclist and vehicle speeds observed in this intersection. It also greatly improves safety for cyclists, a key goal for this project.
Bike Activated Warning Lights	To increase cyclist safety further, the decision was made to implement bike activated warning lights for vehicles. Again, this is due to fairly high

	cyclist speeds observed. The high cyclist speeds may make it difficult for drivers to notice cyclists entering the intersection and cyclists are already in the blind spot of vehicles exiting the roundabout. The warning lights will bring attention to potential cyclists crossing and allow sufficient time for a vehicle to slow down.
Widened Bike Crossings	The bike crossings were widened to 3.5 m to facilitate two-way movement. This allows for cyclists to make u-turns at all approaches to the intersection. Overall geometry of the bike lanes and crossings considered this as well.

6.3 Overpass Geometry

The overpass span length of 17.5 m was designed to clear roadway elements with the shortest length to the center of the median, with allowances for spacing to avoid potential vehicle impacts. A clear height of 5.5 m over the road conforms to Ministry of Transportation and Infrastructure guidelines, and ramp slope and handrail geometry is informed by BC Building Code 2018 requirements.

Orientations and straight paths of ramps to pedestrian pathways were chosen over switchbacks to maximize user convenience, and prevent jaywalking caused by unattractive ramp pathing. Switchbacks additionally would have encroached on existing trees and greenspace more than the proposed orientations, which was deemed unacceptable.

6.4 Overpass Technical Aspects

Steel truss bridges are visually attractive and materially efficient for pedestrian footbridges. HSS sections are commonly used for ease of bridge construction and connections, and for smooth continuous lines. Structural member demands were analyzed using Oasys GSA modeling software, with member force diagrams shown in Appendix A3.

Soil conditions and bearing capacities were informed by a conservative assumption of medium sand near the surface profile. Geotechnical data was gathered from Piteau Associates Engineering Ltd., with the closest borehole located at East Mall and 16th Avenue. Relevant soil properties were inferred and can be seen in Appendix E.

6.5 Rain Gardens

The on-site source control network consists of a network of rain gardens to capture the road surface runoff considering the Volumetric Reduction Criteria of a 6-month storm which consists of 72% of the 2-year, 24-hour rainfall event. The 6-month storm covers approximately 90% of all 24-hour rainfall events. The design rainfall of 48.4 mm as described in Table 14 is based on Climate Data Canada's most recent RCP4.5 climate change scaled IDF data modeling, which assumes a medium global emission scenario. This scenario includes measures to limit and mitigate climate change for the years of 2071-2100. The RCP (Representative Concentration Pathway) provides a plausible future scenario of human emissions patterns including consideration of future emissions, deforestation, and population growth. This gives the design longevity as it has the capacity to handle expected future stormwater demands.

Source control solutions typically include open drainage, rain gardens, amended soils, and rock pits, all in an attempt to reduce imperviousness and allow water to drain away without flooding topsoil and roots. The landscape and stormwater management is designed with functionality in mind, and is approached in a way that helps protect water resources and watershed hydrology. This methodology conserves natural areas, minimizes development impacts, maintains site runoff rates, implements pollution prevention, and makes communities more attractive overall. The rain gardens act as a barrier between different modes of transportation and an aesthetic feature on the pedestrian pathways surrounding the site, all while reducing runoff of stormwater. The choice of rain gardens gives a large versatility of dimensions, allowing them to be placed easily throughout the site without encroaching into already existing infrastructure and UBC Botanical Gardens.

The design has been developed regarding Metro Vancouver's Integrated Stormwater Management Plan (ISMP) to ensure environmental quality and flood protection. By reducing the amount of stormwater runoff, there can be less erosion and flooding, reductions in pollution in the nearby environment, and improvement to groundwater conditions. The guidelines within the LEED (Leadership in Energy and Environmental Design) Offsite Rainwater Management program also help guide the design to reduce runoff volume and improve retention from offsite low-impact development (LID) to provide a functional landscape.

To ensure full functionality of the rain gardens, the selection of plants, as well as their locations within the rain garden, are determined following the guidelines of the City of North Vancouver. Native plants are used because they require less fertilizer and make better use of the native soil structure and nutrients than non-native species. Trees are not used as plants for rain gardens due to their high maintenance. Their height can block driver visibility and their foliage can prevent water from moving into the rain gardens as intended and smother vegetation. Also, grass buffers are not used as a curb-edge material as they are very efficient at trapping sediment and can quickly block movement of water into the rain garden.

6.6 Risk Management and Mitigation

Several risks were identified in the original risk assessment such as pedestrian-cyclist collisions, cyclist-vehicle collisions, traffic disruptions, utilities interference, overflooding, ground failure, budget deficit, and public opposition. These were mitigated mainly through design changes. In order to mitigate the significant risk of pedestrian-cyclist collisions, it was decided that an overpass be constructed across W 16 Ave so as to separate the two completely. A site visit revealed that there were no points of interest on the southwest side of the site, close to the intersection. UBC Botanical Gardens was further up and had existing infrastructure to reach it. Thus it was decided to dissuade pedestrians from crossing the intersection across SW Marine Drive using signage. This should mitigate the risk of pedestrian-cyclist collisions on that side as well. In order to mitigate the risk of overflooding, it was decided that a large number of rain gardens with sufficient capacity be incorporated into the design. Further details regarding risk mitigation strategies can be found in Appendix E.

6.7 Indigenous Involvement and Impact

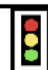
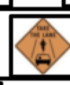
The design avoids having any negative impact and attempts to have some positive impacts on the indigenous community. As there are some trails in Pacific Spirit Park that they use and are important to them, care was taken to ensure that no encroachment was made into the park whatsoever. This aligns with the client’s objective to retain the tree buffer between the road system and UBC Botanical Gardens. The increased cycling infrastructure will ensure enhanced connectivity for them, which aligns with their Healthy Communities Sub-Plan and their Transportation Sub-Plan.

7.0 Construction

7.1 Construction Specifications

For the construction of the turbo roundabout, there are four phases of construction to minimize the disruption to traffic. The first three phases will use temporary traffic signal lights on all sides of the intersection to help manage traffic flow. For the fourth phase, the roundabout will flow as intended until the construction of the pedestrian overpass, during which traffic will be detoured away from the intersection towards Stadium Road. After completion of the overpass, the road will open again. Table 14 shows the signages required through the construction process.

Table 14. Construction Signs

PORTABLE TRAFFIC LIGHTS	
STOP HERE ON RED SIGN	
C-029	
C-130-R/L	 / 
C-018-1A	
C-053L/R	 / 
C-184	
C-006-R/L	 / 
C-006-A	
R-012	
R-015-R/L	 / 
C-030-6A	

7.2 Construction Sequence

The first phase is highlighted in red and will be related to the construction of the roadway. The second phase (blue) and third phase (magenta) include the construction of the roadway and the column supports for the pedestrian overpass. The fourth phase (black) will be the construction of the areas outside the roadway such as the cyclists lanes, the UBC gateway feature, rain gardens, landscaping, and the pedestrian overpass. Figure 16 shows the construction area for each phase.

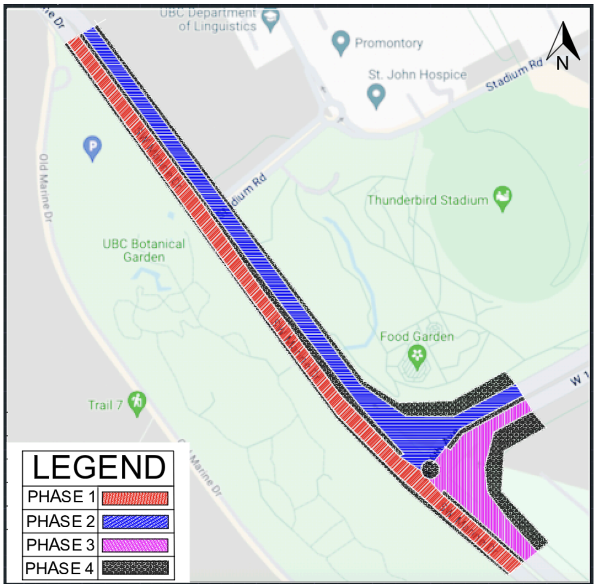


Figure 16: Construction Sequence

A detailed drawing for each phase can be seen in Appendix G, DWG C-501 to C-504 which includes the area of construction during each phase, the signages required with the distances between the signage, temporary roads, and traffic signal light locations based on the BC 2020 Traffic Management Manual for Work on Roadways (TMM).

7.3 Anticipated Issues

Anticipated issues which a contractor may face during construction of this project are largely related to unexpected weather and site conditions. Site conditions pertaining to the soil conditions are a large concern as poor conditions will delay the project and increase costs. Unexpected weather events will delay construction in all phases, pushing back project completion and increasing costs. Underground utilities may also create issues in relation to concrete foundations and footings around the site. Careful consultation with BC Hydro must happen before moving forward with the placement of footings and foundations.

7.4 Service Life Maintenance Plan

To achieve the intended service life of the project, maintenance will be required on all components of the project, including the roundabout, the roadway and bike lanes, the pedestrian overpass, and rain gardens. These include tasks such as snow and ice removal, lighting maintenance, general inspections and repairs to the overpass, and landscaping. See Section 8.0 for the details on the related costs. The maintenance plan will avoid traffic disruptions and the design allows for roadway and roundabout maintenance without the need for closures. Roadway and roundabout work should however, be completed separately to minimize traffic disruptions and work should occur in the summer as traffic to and from UBC is minimized then. The pedestrian overpass will need closures if serious repairs are needed. Serious repairs can be caused by structural issues arising from overpass strikes and physical damage to the columns. However, typical maintenance can occur while keeping the overpass open to users. Rain gardens also require annual maintenance during dry seasons as not to interfere with the drainage functions rain gardens provide during wetter months.

Details on the maintenance plan are found in Appendix F. The maintenance plan was developed in accordance with The Highway Maintenance Specifications created by the BC Ministry of Transportation. It covers all roadway and roadside maintenance, as well as the maintenance required by the pedestrian overpass. All costs for the service life maintenance plan are referenced in the detailed cost estimate (Appendix C) under the Annual Maintenance subheading.

7.5 Project Schedule

A summary of the scheduling of the design and construction of the intersection can be seen in Figure 17 with a full breakdown of the schedule in Appendix B. The construction of the project is set to begin on May 1, 2023 and will be split into the four phases. Phase 1 will occur on the Northwest of the intersection on SW Marine Drive. Phase 2 will occur on SW Marine Drive going towards the UBC botanical garden and East Mall from the intersection. Phase 3 will occur on the Southeast side towards East Mall and SW Marine Drive from the intersection. Phase 4 will occur on the areas outside the intersection, as well as the construction of the pedestrian overpass. The majority of the construction is to be completed during the spring and summer months to be able to reduce the impact on traffic in and out of the UBC Vancouver Campus. Completion of the project is predicted for September 11th , 2024.

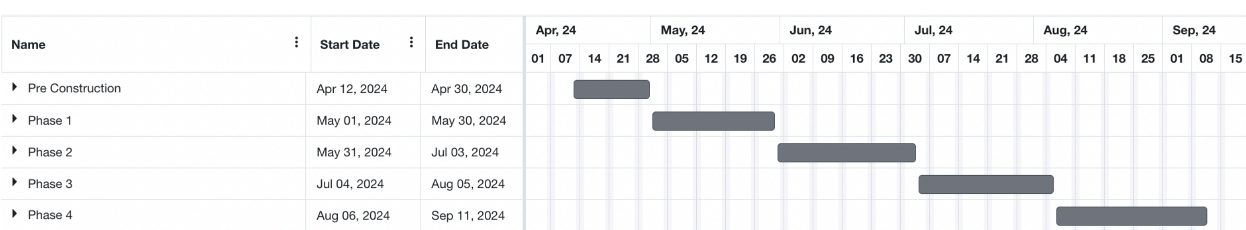


Figure 17: Summary of the Schedule

8.0 Cost Estimate

The Class A Cost Estimate was developed to quantify major costs that would need to be undertaken to complete this project. The costs are summarized below in Table 15 while a detailed estimate is available in Appendix C. The cost estimate covers a wide range of potential costs that Team 13 felt necessary. These include planning, engineering, design, construction, finishing costs (landscaping, painting, lighting), and maintenance. The cost estimate also includes a materials and labor cost for the construction of the pedestrian overpass.

Table 15. Simplified Class A Cost Estimate

Description	**Cost**
Pre-Construction Costs	$278,000
Site Preparation	$76,000
Turbo Roundabout Construction	$949,000
Pedestrian Overpass Construction	$173,000
Bike Lane	$22,000
Stormwater Management	$70,000
Traffic Management	$52,000
Gateway Feature	$44,000
Other Costs	$345,000
Annual Maintenance	$33,000
Contingency	$204,000
Total	**$2,246,000**

Unit costs for materials and labor are derived from average market prices from contractors located in the Lower Mainland of British Columbia. Also included is a 10% contingency, which for a Class A cost estimate is typically between 5-15%. This contingency takes into account delays, price changes, and design changes which may occur between the publishing of this report and the start of construction.

9.0 Closing Recommendations

Team 13 strongly recommends the described roundabout design for the intersection at SW Marine Drive and 16th Avenue at the south end of UBC’s Vancouver campus. The design is innovative, aesthetically appealing, and promotes active transportation through features catered to safety and accessibility. The design features a turbo roundabout as the main traffic control method, a steel footbridge across 16th Avenue, and rain gardens throughout the entirety of the site. The new traffic control methods prioritize public and active modes of transportation, over single occupancy vehicles, and improves upon their safety within the intersection. Elements from rain gardens, green architecture, and waste reuse in a prominent welcoming sign showcase UBC’s dedication to sustainability and environmental consciousness. The long spanning overpasses, artistic cycling paths, and state-of-the-art traffic controls will create a sense of pride in UBC’s students, faculty, and residents.

UBC’s southern rainwater catchment is relatively large and with the increasing magnitude and duration of storms and structural developments on campus, the demands on the stormwater management system will continue to increase over time. The proposed design accounts for this increase and is in alignment with the UBC Integrated Stormwater Management Plan and UBC Campus Vision 2050. Overall, the design satisfies the requirements of the project and the client, and it is advised that construction of the new intersection design commences in May of 2023 to be complete by October of 2024.

As UBC continues to grow and develop, the demand for well-designed roads and active transportation paths will only continue to rise. Foresight driven design approaches used in this design will ensure that these facilities will continue to offer benefits to UBC for years to come.

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Appendix A - Design Calculations

A1 - Full Traffic Volume Counts

Time Frame	Vehicle Type	WB L	WB R	NB R	NB T	SB L	SB T
3:00-3:14	Car	148	20.5	65	67	3	79.5
	Bike	5	2	6	2	0	6.5
	Truck	2	1.5	3	0	0	0
	Bus	5	0	8	0	0	1
	Ped	0	0	0	0	0	0
3:15-3:29	Car	125	20	74	57	16	95
	Bike	4	2	4	5	0	7
	Truck	1	0	1	0	0	0
	Bus	3	0	5	0	0	0
	Ped	0	0	0	0	0	0
3:30-3:44	Car	123	18	73	76	35.5	231.5
	Bike	1	7	2	5	3.5	7
	Truck	0	0	0	0	0	2
	Bus	3	0	7	0	0	0
	Ped	0	0	0	0	0	1
3:45-3:59	Car	98	19	70	45	16	80
	Bike	2	3	0	3	0	19.5
	Truck	1	0	2	0	0	1
	Bus	5	0	7	0	0	0
	Ped	3	0	0	0	0	0
4:00-4:14	Car	109	21	59	68	27.5	114
	Bike	3	1	1	7	0	4.5
	Truck	1	0	1	0	0	1
	Bus	4	0	6	0	0	0
	Ped	0	0	0	0	0	4
4:15-4:29	Car	118	8.5	64	54	21	89
	Bike	3	3	0	4	2	12
	Truck	1	0	1	0	0	1
	Bus	3	0	4	0	0	1
	Ped	2	0	1	0	0	2
4:30-4:44	Car	112	15.5	80	50	21	94

	Bike	3	5	3	8	2	17
	Truck	0	0	1	0	0	0
	Bus	5	0	4	0	0	0
	Ped	1	0	0	0	0	0
4:45-4:59	Car	120	9.5	95	59	26	112.5
	Bike	6	2	0	6	3	14.5
	Truck	3	0	1	0	0	1
	Bus	3	0	4	0	0	0
	Ped	0	0	0	1	0	1
5:00-5:14	Car	160	12.5	96	46	37.5	150
	Bike	8	1	1	5	1	12.5
	Truck	1	0	1	0	0	1.5
	Bus	6	0	5	0	0	0
	Ped	1	0	0	0	0	3
5:15-5:29	Car	140	17	79	50.5	28	90
	Bike	4	1	0	2	2.5	16
	Truck	1.5	0	0	2	0	1
	Bus	3.5	0	5	0	0	0
	Ped	1	0	2	0	0	1
5:30-5:44	Car	93.5	14	83	45	13.5	73.5
	Bike	2.5	6	1	14	4	8
	Truck	0	0	1	0	0	0
	Bus	8	0	3	0	0	0
	Ped	1	0	1	0	0	2
5:45-5:59	Car	100.5	11	76	40	21	81
	Bike	1	10	1	3	1	14.5
	Truck	1	0	0	0	0	0
	Bus	4.5	0	3	0	0	0
	Ped	2	0	0	3.5	0	2

A2 - Sidra Analysis Results

A Sidra analysis was conducted to meet capacity goals of LOS C. To complete the analysis, afternoon peak traffic data was first collected on October 5, 2023 from 3:00 - 6:00 pm. A summary of the peak hour volumes (which was found to be from 4:30 - 5:30 pm) is presented in Table 16 below.

Table 16. Peak Hour Volumes 2023 (4:30 - 5:30 pm)

Approach	**Movement**	**Volumes (per hour)**			
		Cars	**Buses**	**Trucks**	**Bikes**
WB	L	532	18	6	21
	R	55	0	0	9
NB	T	206	0	2	21
	R	350	18	3	4
SB	L	113	0	0	9
	T	447	0	4	60

The peak hour volumes were then input into Sidra. A design speed of 50 km/h and growth rate of 3% per year (typical growth rate for rural communities; this area can be considered rural as there is currently minimal development within the surrounding areas; more rapid growth is expected due to the future residential development proposed by UBC Campus Vision 2050) was also input into the analysis. Capacity analysis results showing level of service for present volumes, 5 years and 20 years into the future are summarized in Table 17 below. Detailed schematics of the analysis can be found in Figures 18-20.

Table 17. Summary of Sidra Analysis Results (LOS)

Scenario	**Approaches**			**Intersection**
	Northbound	Southbound	Westbound	
Present (2024)	A	A	A	A
Present + 5 years (2029)	A	A	A	A
Present + 20 years (2044)	A	B	B	B

Results are justifiable, as no queues were observed during the traffic count. However, the analysis is unable to account for unpredictable drastic land use changes, such as the arbitrarily proposed doubling of non-student residential housing in the UBC Campus Vision 2050 Plan. Furthermore, an AM peak will need to be conducted to ensure consistent results, as high volumes were observed in the morning peak in previous tube counts by CTS. To combat high LOS results, special safety measures were put in place as described in Section 5.1.2.

	Approaches			Intersection
	Southeast	Northeast	Northwest	
LOS	A	A	A	A

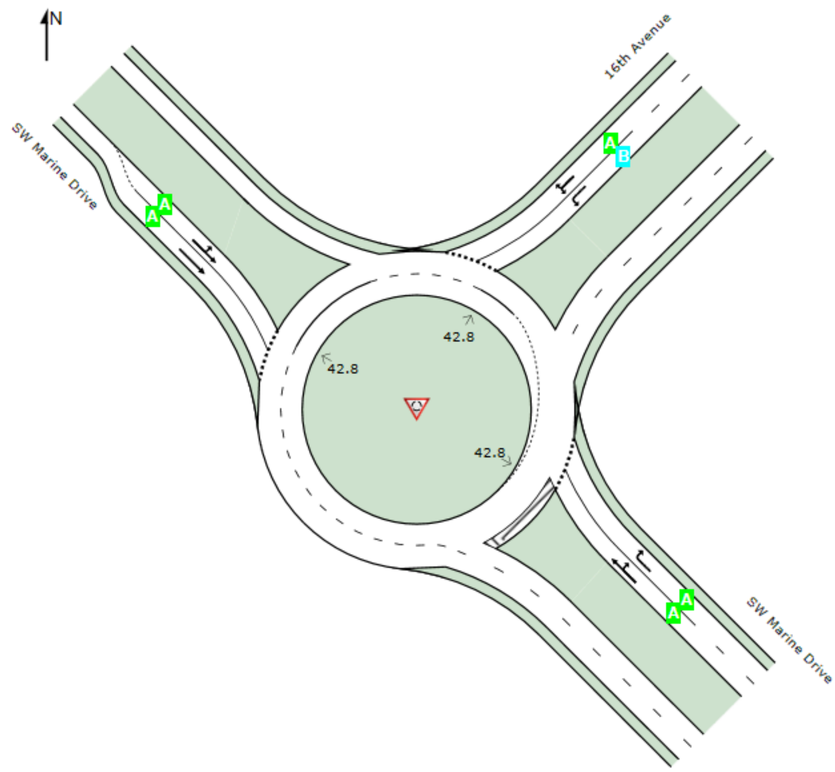


Figure 18: Present Volumes (2023) Analysis in Sidra

	Approaches			Intersection
	Southeast	Northeast	Northwest	
LOS	A	A	A	A

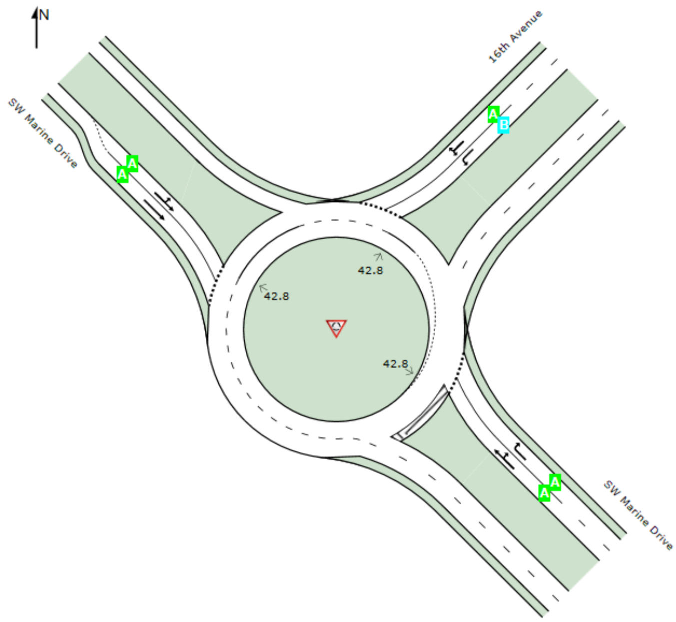


Figure 19: Present Volumes + 5 Years (2028) Analysis in Sidra

	Approaches			Intersection
	Southeast	Northeast	Northwest	
LOS	A	B	B	B

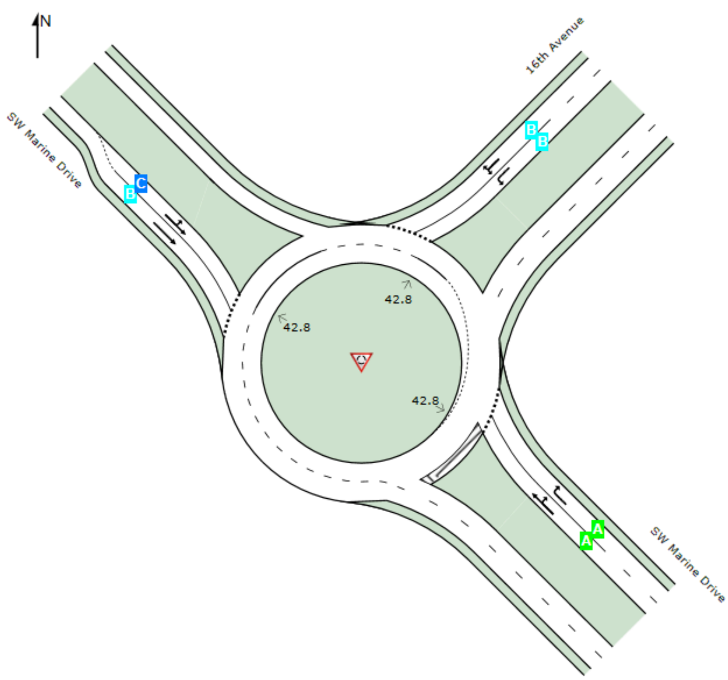


Figure 20: Present Volumes + 20 Years (2043) Analysis in Sidra

A3 - Structural Design Calculations

Structural demands were determined with 2 critical load combination cases of:

- Case 2: 1.25 D + 1.5 L + 1.0 S
- Case 5: 1.0 D + 1.0 E + 0.25 S

Total deck loading for a typical span for Case 2 was 11.8 kPa based on a 2.15 kPa slab dead load, a 4.8 kPa prescribed pedestrian overpass live load, and a 1.9 kPa snow load for UBC. An allowance of 5 kN was given to account for steel member weights and superimposed dead loads. Models were run with the prescribed loading for Case 2, and Case 5 in both longitudinal and transverse directions. Critical member demands were then calculated using Oasys GSA, with sized member capacities shown in Table 18 and relevant model results compiled in Table 19. Model diagrams are shown in Figures 21 through 30. Member capacities were calculated using Equations 1 through 5 below.

<u>Tensile Capacity</u>

Equation 1: $$T_r = \phi A_g F_y$$

<u>Compressive Capacity</u>

Equation 2: $$\lambda = \frac{L}{r}\sqrt{\frac{F_y}{\pi^2 E}}$$

Equation 3: $$C_r = \phi A_g F_y (1 + \lambda^{2n})^{-\frac{1}{n}}$$

<u>Flexural Capacity</u>

Equation 4: $$M_r = z \phi F_y$$

Given that all flexural members are laterally supported by the composite slab, no lateral torsional buckling was considered.

<u>Shear Capacity</u>

Equation 5: $$V_r = \phi A_w F_s$$

All F_s were determined to be 0.66 F_y given that all flexural members were HSS sections with low h/w ratios.

Table 18. Sized Member Capacities

Member	Section	Capacity
Beam	HS102x102x6.4	110 kN Shear
		20.3 kNm Bending
Top Chord	HS102x102x8.0	730 kN Tension
		456 kN Compression
Bottom Chord	HS102x102x8.0	730 kN Tension
		456 kN Compression
Truss	HS102x102x4.8	387 kN Tension
		330 kN Compression
Girder	HS305x305x8.0	2020 kN Tension
		901 kN Shear
		324 kNm Bending
Column	W200x46	708 kN Compression
Transverse Brace	HS114x114x4.8	643 kN Tension
		176 kN Compression
Longitudinal Brace	HS152x152x4.8	869 kN Tension
		270 kN Compression

Table 19. Critical Structural Member Loads

Member	Load Type	Loading			
		Case 2	Case 5 Y Axis	Case 5 X Axis	Critical Demands
Beam	Shear	33 kN	6 kN	6 kN	33 kN
	Bending	17 kNm	3 kNm	3 kNm	17 kNm
Top Chord	Tension	365 kN	151 kN	148 kN	365 kN
	Compression	300 kN	39 kN	100 kN	300 kN
Bottom Chord	Tension	225 kN	50 kN	46 kN	225 kN
	Compression	280 kN	114 kN	189 kN	280 kN
Truss	Tension	200 kN	54 kN	107 kN	200 kN
	Compression	200 kN	54 kN	107 kN	200 kN
Girder	Tension	43 kN	27 kN	18 kN	43 kN
	Shear	300 kN	62 kN	18 kN	300 kN
	Bending	17 kNm	63 kNm	70 kNm	70 kNm
Column	Compression	300 kN	154 kN	146 kN	300 kN
Transverse Brace	Tension	0 kN	55 kN	0 kN	55 kN
	Compression	128 kN	161 kN	50 kN	161 kN
Longitudinal Brace	Tension	0 kN	0 kN	137 kN	137 kN
	Compression	98 kN	48 kN	175 kN	175 kN

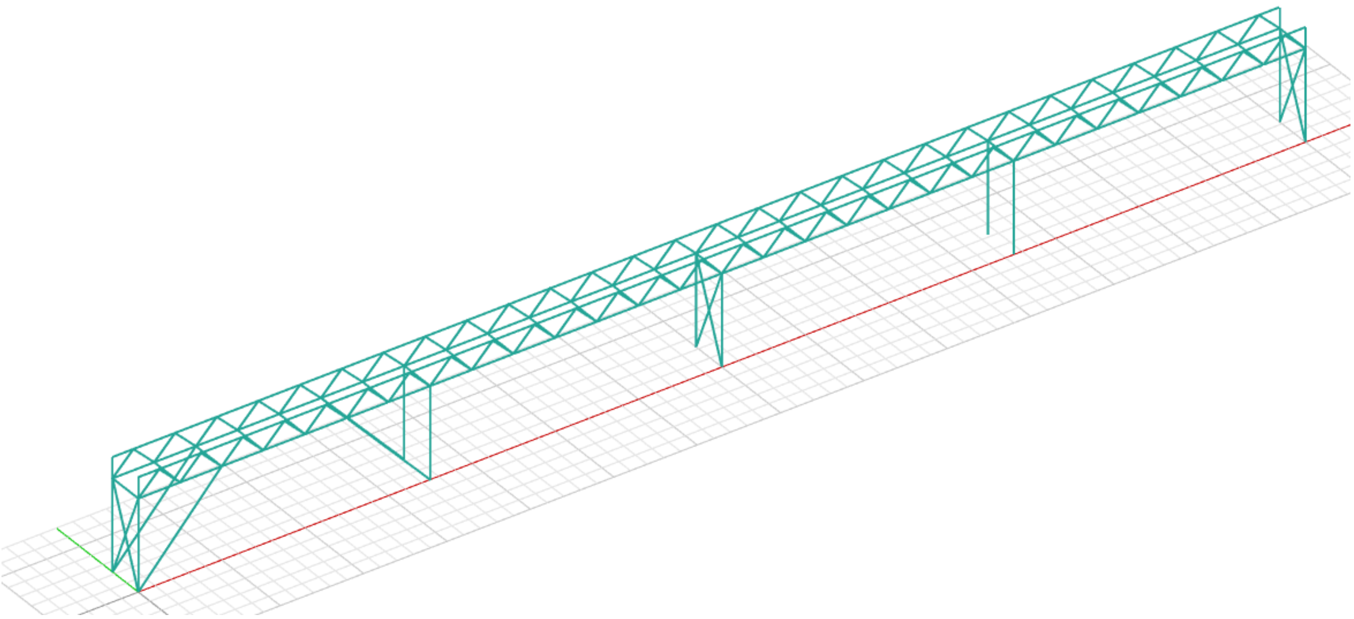


Figure 21: Overpass Span Model

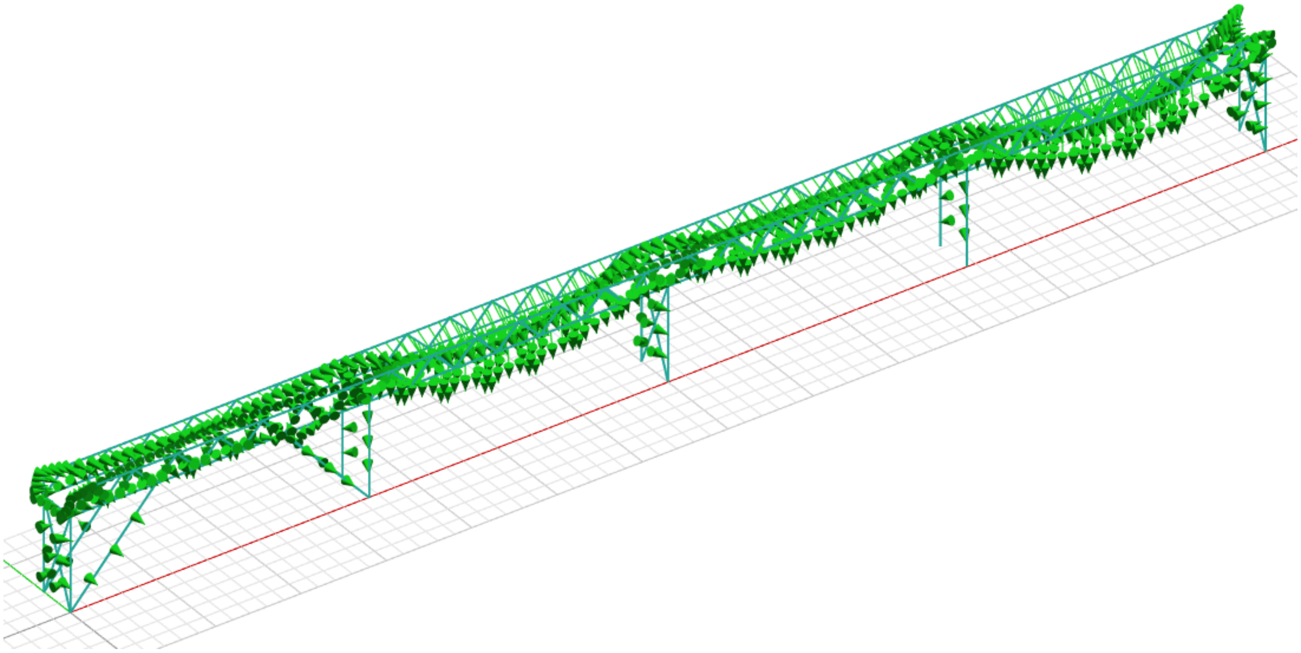


Figure 22: Overpass Case 2 Deflections

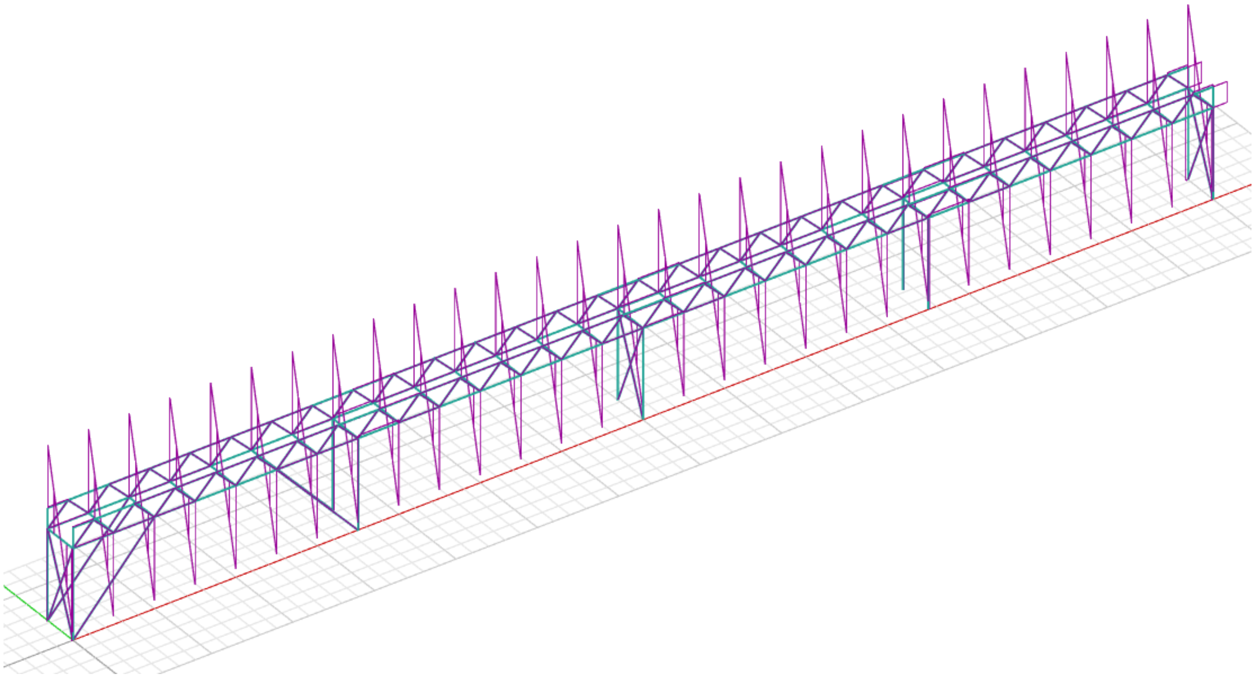


Figure 23: Overpass Case 2 Shear Demands

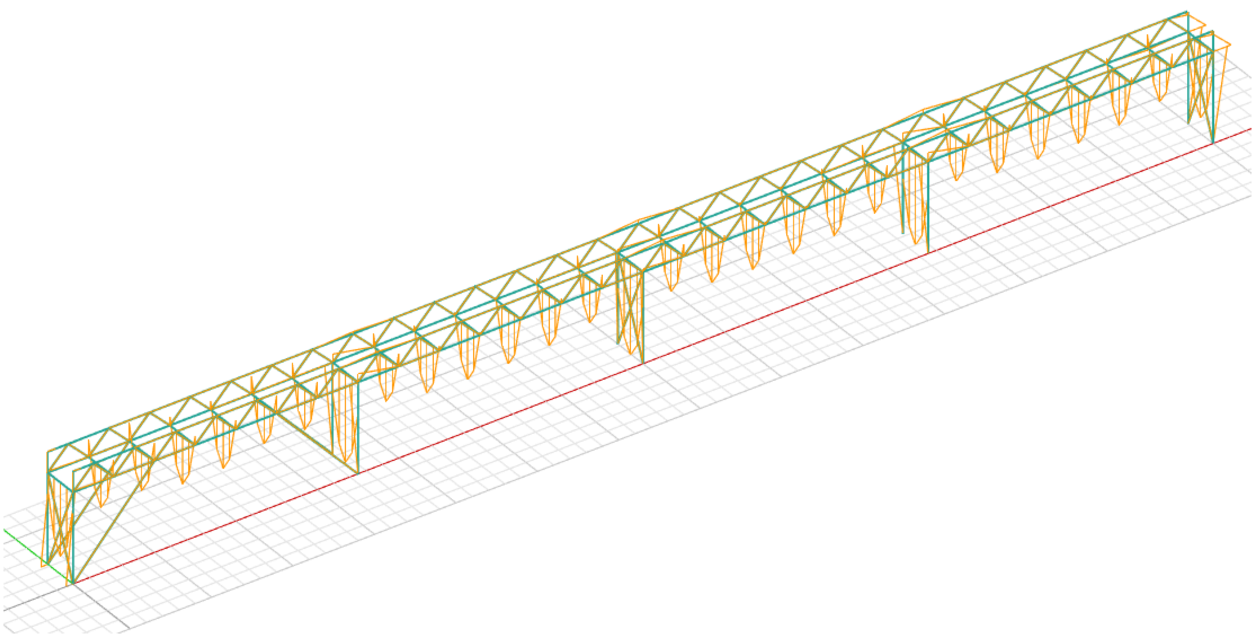


Figure 24: Overpass Case 2 Bending Demands

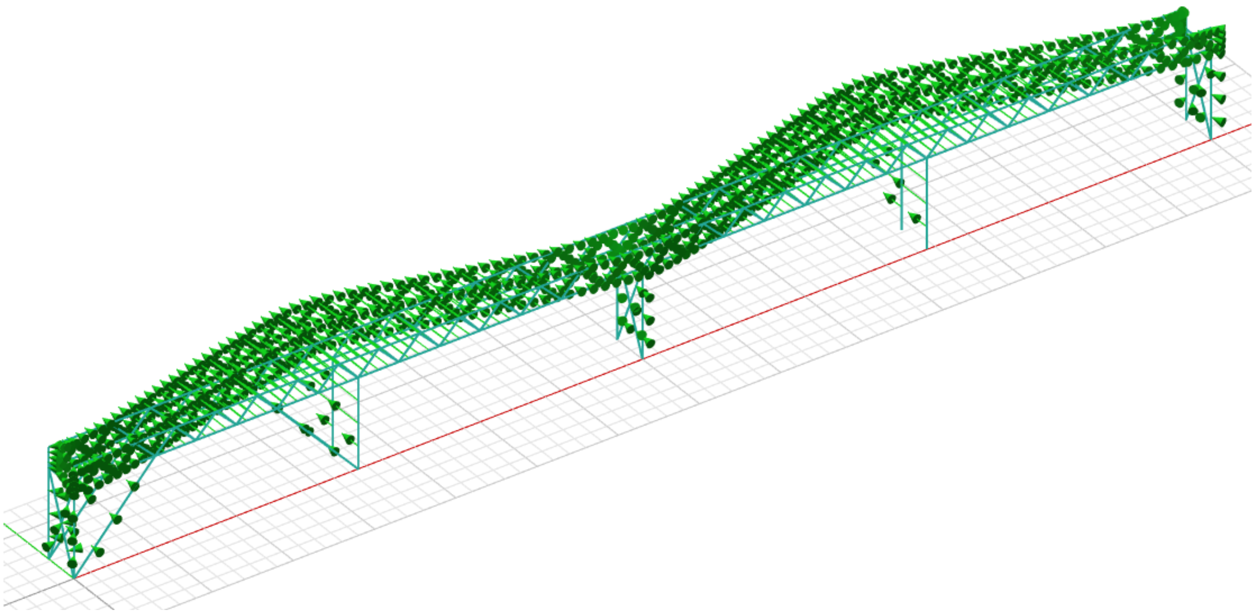


Figure 25: Overpass Case 5 Y Axis Deflections

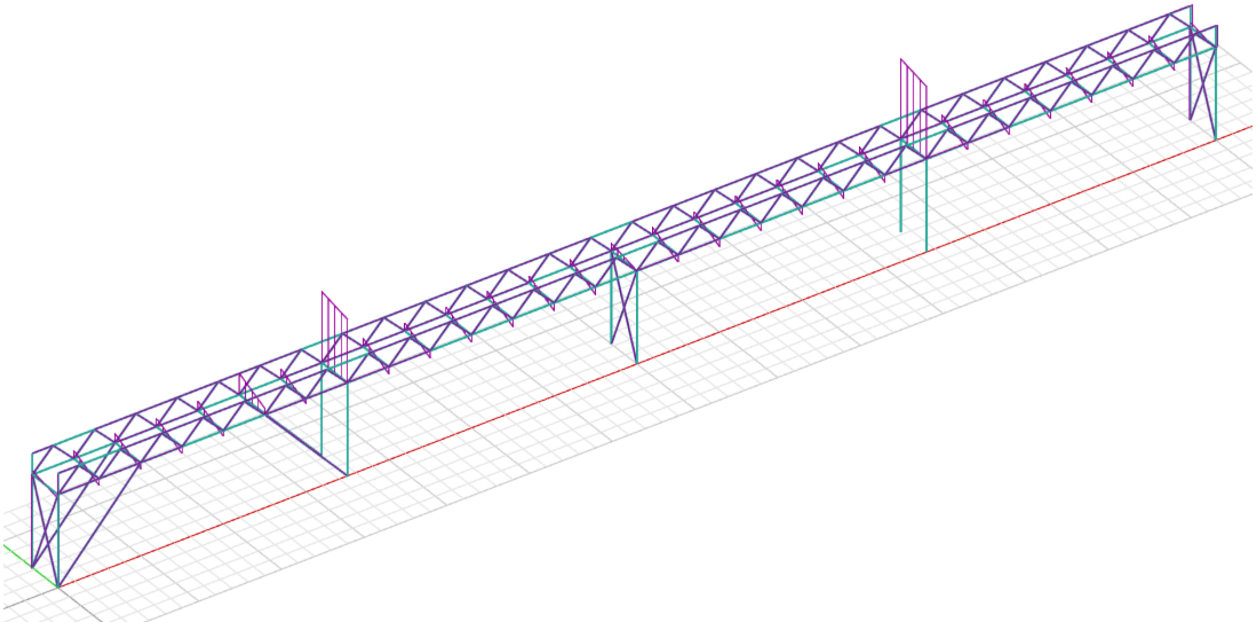


Figure 26: Overpass Case 5 Y Axis Shear Demands

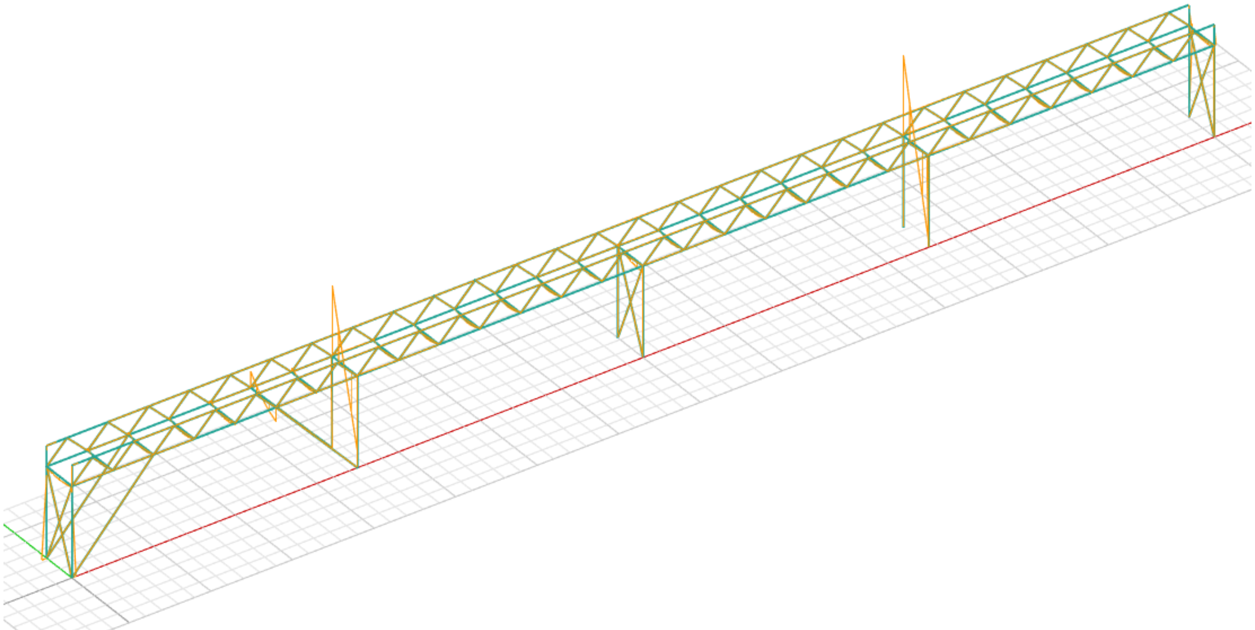


Figure 27: Overpass Case 5 Y Axis Bending Demands

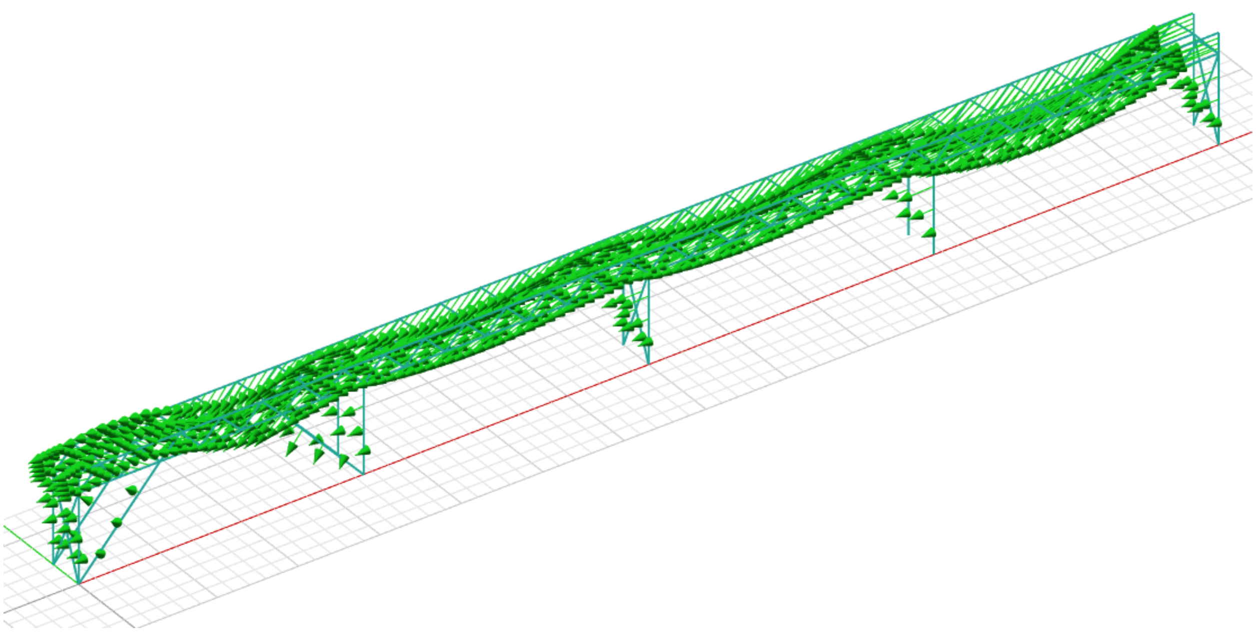


Figure 28: Overpass Case 5 X Axis Deflections

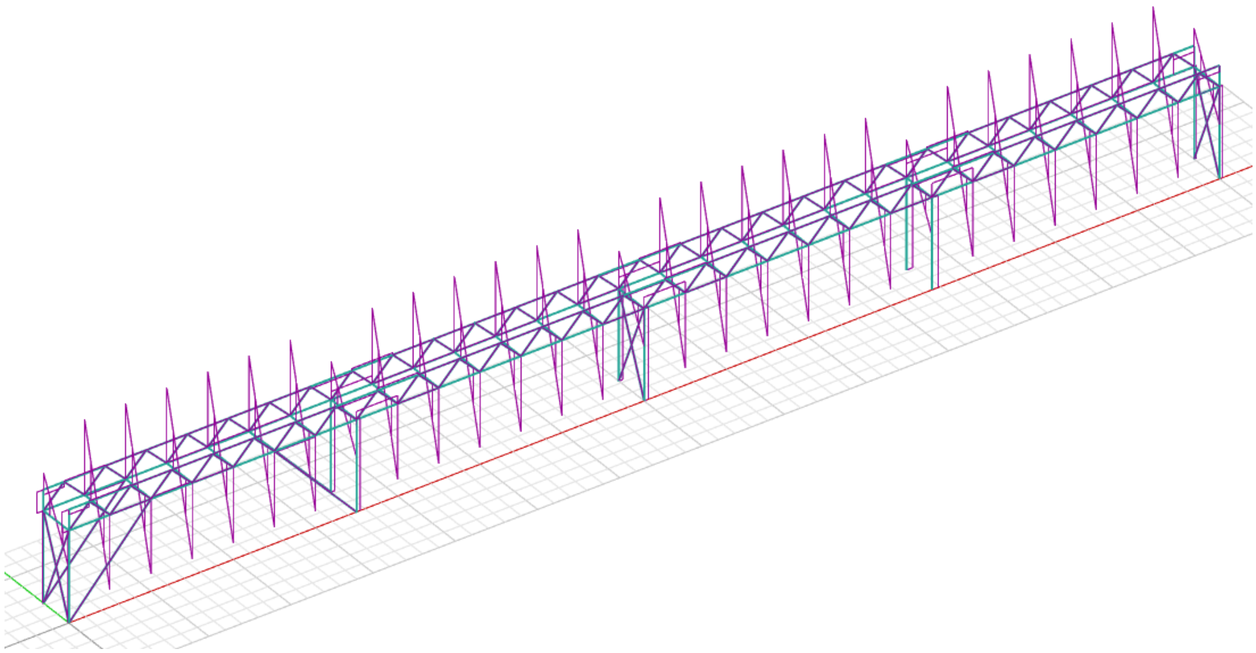


Figure 29: Overpass Case 5 X Axis Shear Demands

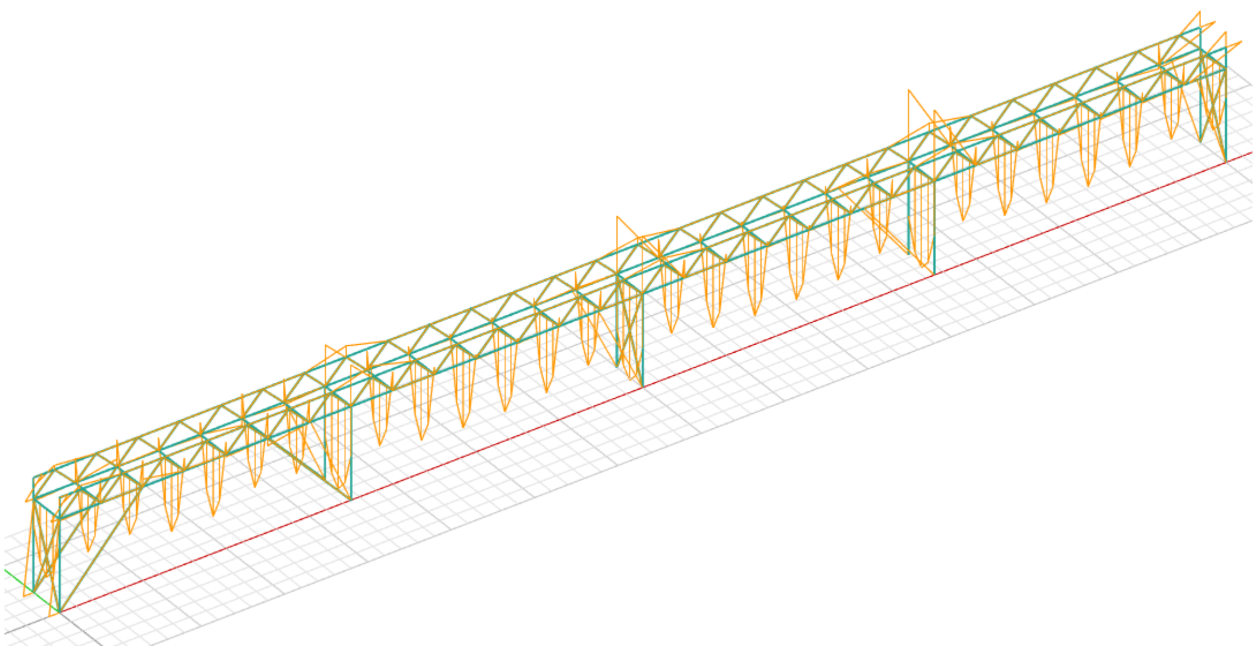


Figure 30: Overpass Case 5 X Axis Bending Demands

A4 - Foundation Design Calculations

There is a lack of reliable geotechnical data for the project site, but a combination of glacial tills and dense sands at the intersection of East Mall and 16th Avenue. A relatively conservative approximation of the project site using "medium sand" was taken by averaging typical values of dense and loose sands, as below in Table 20. Additionally, a factor of safety of 3.5 was implemented given the uncertain site conditions.

Table 20. Approximated Soil Properties

Soil Type	ϕ' (deg)	γ' (kN/m³)	γ
Dense Sand	38	18	21
Loose Sand	30	14.5	19
Medium Sand	34	16	20

The capacity of a footing was then given by the following equation for bearing capacity in kPa.

Equation 6: $$q_{ult} = \sigma'_D N_q + 0.4\gamma' B N_\gamma$$

Where N_q is 29.4 and N_γ is 28.8 based on a ϕ' angle of 34 degrees according to Hansen bearing capacity factors, and σ'_D is dry effective stress based on an assumed 1.5 m depth of footing base. The unfactored loads applied to the typical column were determined to be 413 kN, which given a FOS of 3.5 results in a factored load of 1446 kN. An assumed B = 1.25 m results in a footing area of 1.563 m^2, resulting in an applied load of 925 kPa. Applying Equation 6 above gives the factored capacity of the footing as 937 kPa, 1.25 m is thus an acceptable base.

Footing thicknesses and reinforcements were designed according to CSA A23.3-19 to meet shear and moment demands. Calculations for footing capacities were determined using Equations 7 and 8 for one-way and two-way shear respectively.

Equation 6: $$V_r = V_c = \phi_c \beta \sqrt{f'_c}\, b_w d_v$$

Equation 7: $$V_r = V_c = (1 + \frac{2}{\beta_c})\, 0.19\, \phi_c \sqrt{f'_c} < (\frac{\alpha_s d}{b_o} + 0.19)\, \phi_c \sqrt{f'_c}$$

Where ϕ_c is 0.65, β is 1.0, and α_s is 3 for a conservative edge column. A footing depth of 225 mm with an additional 75 of clear cover results in one way shear demands shown in Table 21.

Table 21. Footing Shear Capacities and Demands, d = 225 mm

	Demand	Capacity
One-Way Shear	127 kN	157 kN
Two-Way Shear	1218 kN	1235 kN

Later iterations of the footing decided on a 325 mm total depth over 300 mm, which would by necessity have greater shear capacity.

Total reinforcement area of 3400 mm^2 was determined as 8% of 1250x325mm, to be provided in each axis of the footing by 17x15M bars. Calculating the factored moment demands at half the projection from the face was determined to be 214 kNm. Using Equations 8 and 9, the factored moment capacity of the footing with 17x15M bars was 2195 kNm.

Equation 8: $$\beta_1 c = \frac{\phi_s f_y A_s}{\alpha_1 \phi_c f'_c b}$$

Equation 9: $$M_r = \phi_s f_y A_s (d - \frac{\beta_1 c}{2})$$

Where α_1 is 0.81 for 25 MPa concrete, ϕ_s is 0.85, and ϕ_c is 0.65.

A5 - Stormwater Management Design

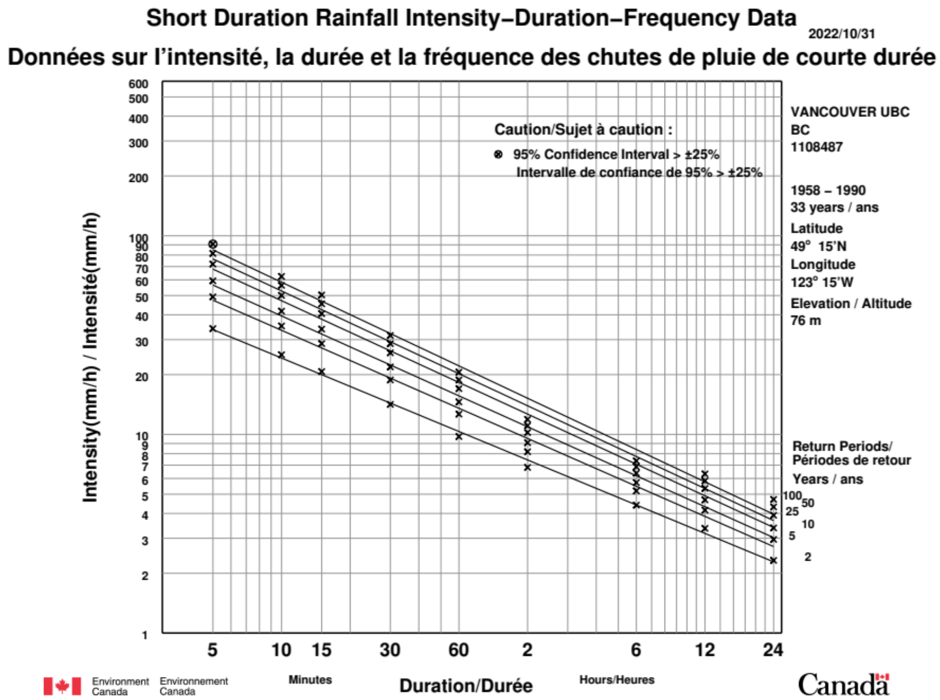


Figure 31: Short Duration Rainfall Intensity - Duration - Frequency Data

Table 22. Vancouver, UBC Climate Change-Scaled IDF Data for Moderate Emissions (2071-2100)

Duration	2-year Median (mm/hr)	5-year Median (mm/hr)	10-year Median (mm/hr)	25-year Median (mm/hr)	50-year Median (mm/hr)	100-year Median (mm/hr)
5 min	41	59	71	87	98	109
10 min	30	42	50	60	68	75
15 min	25	34	41	49	55	60
30 min	17	23	26	31	34	38
1 h	12	15	18	20	23	25
2 h	8.2	9.9	11	12	13	14
6 h	5.3	6.3	6.9	7.7	8.3	8.9
12 h	4.1	5.1	5.7	6.4	7	7.6
24 h	2.8	3.6	4.1	4.7	5.2	5.7

Table 23. Design Rainfall & Area of Site

Parameter	**Design Value**
Assumed Rainfall Intensity	2.8 mm/hr
6-Month Rainfall Capture Target	48.4 mm
Area of Site	47,500 m^3
Area of New Impervious	20,500 m^3
Additional Rain Garden 1	1300 m^2
Additional Rain Garden 2	900 m^2
Old Pervious Area	44%
New Pervious Area	57%

The calculated results in Tables 24 and 25 abide by the Simplified Rainfall Capture Method outlined in the given formulae.

Input Volume = (Tributary Area) x (Capture Rainfall Amount)

Output Volume = Evaporation + Infiltration + Growing Medium + Rock Pit

Evaporation = (24-hr Evaporation Rate) x (Total Pervious Area)

Infiltration = (24-hr Infiltration Rate) x (Total Pervious Area)

Growing Medium = (Total Pervious Area) x (Soil Depth) x (Field Capacity - Wilting Point)

Rock Pit = (Volume of Rock Pit) x (Rock Pit Porosity)

Table 24. Bike Lane Median Rain Garden Calculations

Required Capacity of Bike Lane Medians	823	m3
Capacity Volume	830	m3
Total Rainfall on Site	2300	m3
Width of Rain Garden	1.6	m
Length of Rain Garden	1636	m
Total Area of Rain Garden	2617.6	m2
DEPTH growing	0.6	m
WIDTH growing	1.6	m
VOLUME of growing medium	1570.6	m3
DEPTH rock pit	0.8	m
WIDTH rock pit	0.8	m

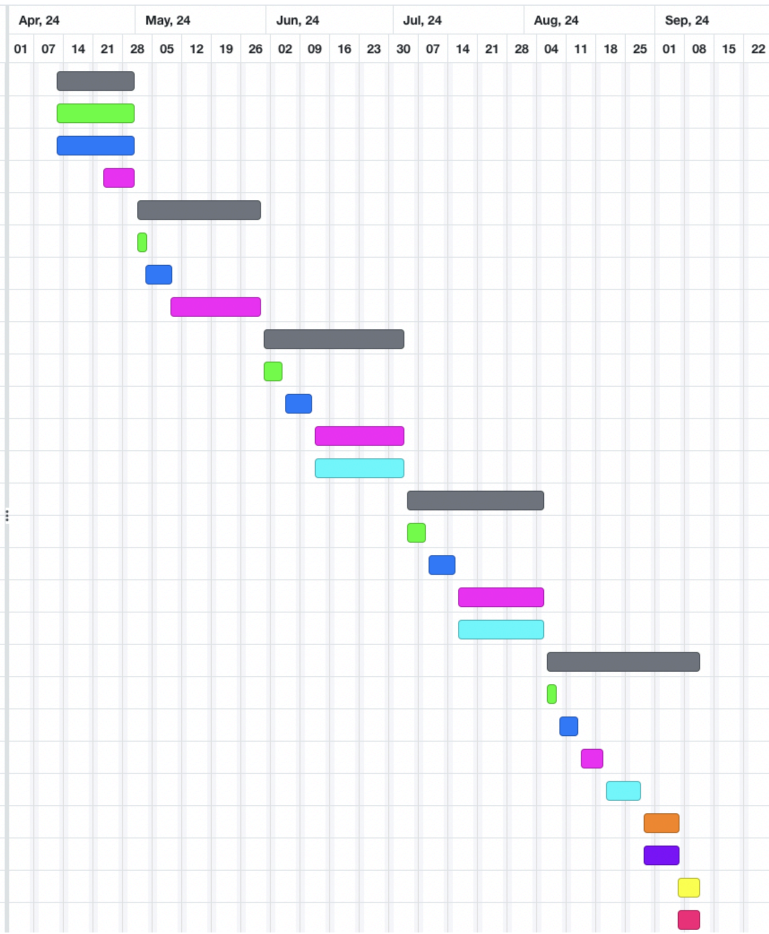
VOLUME of rock pict	1047.0	m3
Evaporation	2.6176	m3
Rate	1	mm/day
Infiltration	94.2336	m3
Rate	1.5	mm/hr
Hours/day	24	
Growing	314.112	m3
(Capacity - Wilt)	0.2	
Rock Pit	418.816	m3
Porosity	0.4	

Table 25. Additional Rain Garden Calculations

Required Capacity of Rain Garden "Ponds"	348	m3
Capacity Volume	675	m3
Total Rainfall on Site	2300	m3
Total Area of Rain Garden	2200	m2
DEPTH growing	0.45	m
VOLUME of growing	990.0	m3
DEPTH rock pit	0.45	m
VOLUME of rock	247.5	m3
Evaporation	2.2	m3
Rate	1	mm/day
Infiltration	79.2	m3
Rate	1.5	mm/hr
Hours/day	24	
Growing	198	m3
(Capacity - Wilt)	0.2	
Rock Pit	396	m3
Porosity	0.4	

Appendix B - Detailed Project Schedule

Name	Start Date	End Date
Pre Construction	Apr 12, 2024	Apr 30, 2024
Permit Acquisition	Apr 12, 2024	Apr 30, 2024
Project Tendering	Apr 12, 2024	Apr 30, 2024
Equipment Mobilization	Apr 23, 2024	Apr 30, 2024
Phase 1	May 01, 2024	May 30, 2024
Removal Of Current System	May 01, 2024	May 03, 2024
Site Prep	May 03, 2024	May 09, 2024
Construction of Roadway	May 09, 2024	May 30, 2024
Phase 2	May 31, 2024	Jul 03, 2024
Removal Of Current System	May 31, 2024	Jun 04, 2024
Site Prep	Jun 05, 2024	Jun 11, 2024
Construction of Roadway	Jun 12, 2024	Jul 03, 2024
Construction of Columns for Overpass	Jun 12, 2024	Jul 03, 2024
Phase 3	Jul 04, 2024	Aug 05, 2024
Removal of Current Sytem	Jul 04, 2024	Jul 08, 2024
Site Prep	Jul 09, 2024	Jul 15, 2024
Construction of Roadway	Jul 16, 2024	Aug 05, 2024
Construction of Columns for Overpass	Jul 16, 2024	Aug 05, 2024
Phase 4	Aug 06, 2024	Sep 11, 2024
Removal of Current System	Aug 06, 2024	Aug 08, 2024
Site Prep	Aug 09, 2024	Aug 13, 2024
Construction of Pedestrian Overpass	Aug 14, 2024	Aug 19, 2024
Construction of Bike Paths	Aug 20, 2024	Aug 28, 2024
UBC Gateway	Aug 29, 2024	Sep 06, 2024
Landscaping and Rain Garden	Aug 29, 2024	Sep 06, 2024
Indigenous Artwork	Sep 06, 2024	Sep 11, 2024
Lighting	Sep 06, 2024	Sep 11, 2024



Appendix C - Detailed Cost Estimate

Class A Cost Estimate for Redesign of 16th Ave & SW Marine Dr Intersection

Description	Units	Quantity	Unit Cost	Total Cost
Pre-Construction Costs				
Environmental Assessment & Permitting	Lump Sum	1.00	250,000.00	$250,000.00
BC MOTI Road Closure Fee	Lump Sum	1.00	15,000.00	$15,000.00
Traffic Management Plan	Lump Sum	1.00	12,500.00	$12,500.00
Total Pre-Construction Costs				$277,500.00
Construction Costs				
Site Preparation				
Remove Existing Dividers/Slip Lanes	Lump Sum	1.00	15,000.00	$15,000.00
Remove Lane Dividers	Lump Sum	1.00	10,000.00	$10,000.00
Remove Traffic Signals	Lump Sum	1.00	1,000.00	$1,000.00
Repair Pathways along 16th Ave	Lump Sum	1.00	10,000.00	$10,000.00
Grind up Existing Asphalt as Required	Lump Sum	1.00	40,000.00	$40,000.00
		Total for Site Preparation		$76,000.00
Turbo Roundabout Construction				
Excavate Roundabout Base	sqft	50,000.00	15.00	$750,000.00
19mm minus Granular Fill	tonne	700.00	19.00	$13,300.00
75mm minus Granular Fill	tonne	700.00	15.10	$10,570.00
Final Grading & Compaction	sqf	40,000.00	1.45	$58,000.00
Asphalt Paving + Base Mix	tonne	800.00	120.00	$96,000.00
Concrete for Roundabout & Dividers	m3	60.00	350.00	$21,000.00
	Total for Roundabout Construction			$948,870.00
Pedestrian Overpass				
Foundation Excavation	sqft	1,000.00	15.00	$15,000.00
Concrete for Foundation + Pouring	m3	10.00	350.00	$3,500.00
Structural Steel Costs	ft	175.00	150.00	$26,250.00
Overpass Decking Materials	sqft	500.00	150.00	$75,000.00
Labour - 10 man crew	Man Hours	960.00	55.00	$52,800.00
		Total for Pedestrian Overpass		$172,550.00
Bike Lane				
Asphalt Paving + Base Mix	tonne	100.00	120.00	$12,000.00
19mm minus Granular Fill	tonne	75.00	19.00	$1,425.00
75mm minus Granular Fill	tonne	75.00	15.10	$1,132.50
Concrete for Curb	m3	20.00	350.00	$7,000.00

			Total for Bike Lane	$21,557.50
Other Construction Costs				
Lighting	Lump Sum	1	300,000.00	$300,000.00
Traffic Signs & Signals	Lump Sum	20	500.00	$10,000.00
Landscaping	Lump Sum	1	20,000.00	$20,000.00
Painting of Bike Lanes & Road Markings	Lump Sum	1	15,000.00	$15,000.00
			Total Other Construction Costs	$345,000.00
Stormwater Management				
Material Costs	Lump Sum	1	15,000.00	$15,000.00
Excavation of Rain Gardens	Lump Sum	1	50,000.00	$50,000.00
Backfilling Rain Gardens	Lump Sum	1	20,000.00	$20,000.00
			Total for Stormwater Management	$70,000.00
Traffic Management				
Temporary Signs	Per Sign	41	500.00	$20,500.00
Temporary Light Signals	Per Signal	3	2,000.00	$6,000.00
Flaggers & Signal Operators	Man Hours	1000	25.00	$25,000.00
			Total for Traffic Management	$51,500.00
Gateway Feature				
Engineered Design of Artwork	Lump Sum	1	8,000.00	$8,000.00
Engineered Design of Footing	Lump Sum	1	12,000.00	$12,000.00
Footing Excavation	sqft	100	15.00	$1,500.00
Concrete Pouring & Materials	m3	50	350.00	$17,500.00
Gateway Feature Materials	Lump Sum	1	5,000.00	$5,000.00
			Total for Gateway Feature	$44,000.00
Annual Maintenance				
Rain Garden Maintenance	Lump Sum	1	7,000.00	$7,000.00
Snow Removal & Salting	Lump Sum	1	10,000.00	$10,000.00
Asphalt Roadway Maintenance	Lump Sum	1	10,000.00	$10,000.00
Pedestrian Overpass Maintenance	Lump Sum	1	5,000.00	$5,000.00
Gateway Feature Upkeep	Lump Sum	1	1,000.00	$1,000.00
			Total for Annual Maintenance	$33,000.00
Total Construction Costs				$1,762,477.50
Total Cost				$2,039,977.50
Contingency (10% of Construction & Design)	Lump Sum		10%	$203,997.75
Total Design & Engineering Cost				**$2,243,975.25**

Appendix D - Project Risk Assessment

The general types of risk associated with this design project include management, health & safety, design/technical, financial, and construction risks. Effective handling of risk will promote the successful outcome of the project. Table 26 describes the mitigation strategies of several pertinent risk factors likely to cause problems throughout the implementation process of the design.

Table 26. Risk Mitigation

Risk Factor:	Risk Mitigation Strategy:
Delays during the construction process	Pre-plan tasks and works carried out each day; give scheduling and revision more importance; prepare backup action items
Lack of coordination	Daily report of tasks completed; biweekly meetings and summary reports; direct line of communication between workers and engineers
Safety equipment for workers	Workers given proper training and PPE (Personal Protective Equipment) regarding construction site safety and COVID-19 safety
Excessive modifications made to design	Ensure adequate investigation of side conditions; engage stakeholders and rights holders in decision-making; distribute surveys and flyers to the public
Unavailability of land and restricted access to the site	Develop a healthy relationship between the local bodies and Indigenous groups; frame a contract before the commencement of work
Budget deficit	Clear documentation of costs to better visualize budget distribution; overestimate general costs; research inflationary trend of material cost
Geotechnical failure	Thorough and extended site survey; rock strata analysis; regular maintenance and tracking of geology around site
Unexpected weather	Schedule general construction to occur during dry weather season; prepare equipment and site for bad weather; review forecast frequently and reschedule accordingly

Appendix E - Geotechnical Profile

E1 - Approximated Site Profile (Data from Piteau Associates)

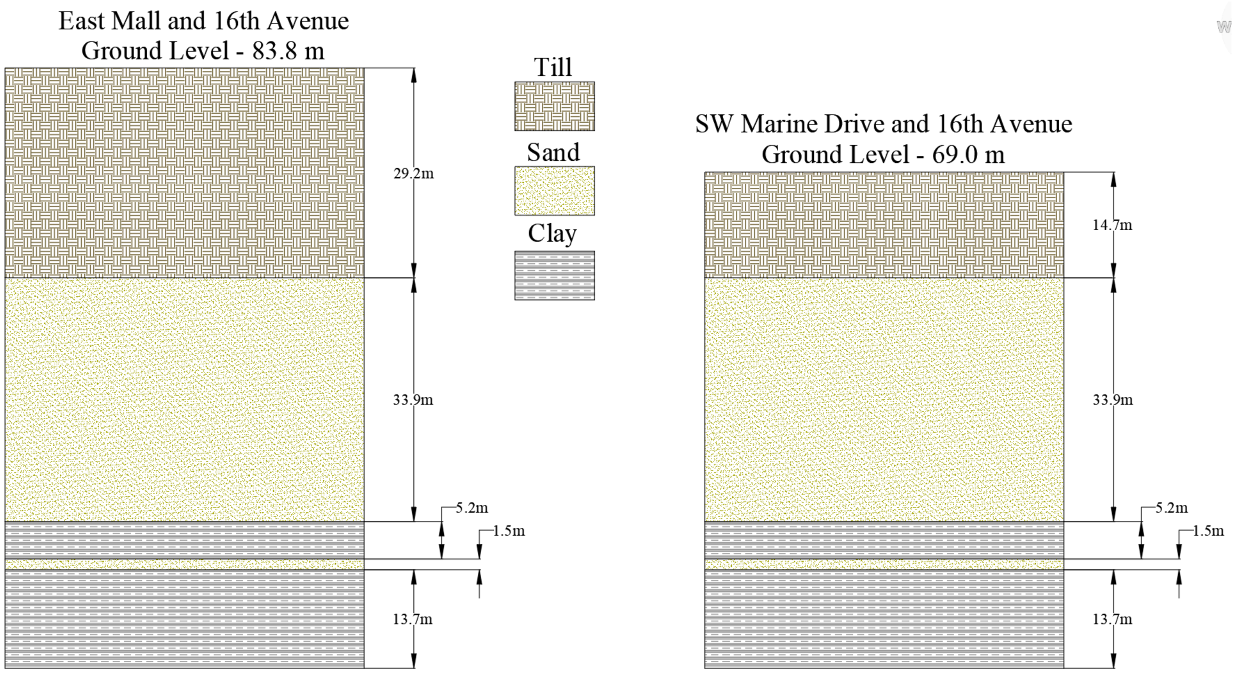


Figure 32: Borehole Profile of East Mall and 16th Ave and Approximated Site Profile

E2 - Approximated Soil Properties

Piteau Associates' study of the soil profiles at UBC classified the majority of the sand present as "medium sand". Given the uncertainties of the site, it was decided to conservatively assume a medium sand profile in the depth of interest instead of the glacial till, which would have higher strength properties. Medium sand properties were taken as the average properties of dense sand and loose sand. Typical properties of sands are shown in Table 27 below.

Table 27. Typical Sand Properties

Soil Type	Friction Angle Φ - Degrees	Dry Unit Weight - kN/m^3
Dense Sand	38	18
Loose Sand	30	14.5
Medium Sand	34	16

Appendix F - Service Life Maintenance Plan

Maintenance Type	Maintenance Measure	Maintenance Specifications
Surface Maintenance	Asphalt Pavement Maintenance	PM1.01.2-1 - Temporary Patches PM1.01.3-1 - Permanent Patches PM1.01.3-2 - Crack Sealing/Filling **Residual material must be removed within 1 day as per PM1.01.3-3
	Surface Treatment	PM1.02.3-1 - Surface Treatments
	Dust Control and Base Stabilization	PM1.04.3-1 - Dust Control Application by June 1st of each year Apply/Reapply within 10 days at areas with deficiencies
	Road Base Maintenance	PM1.06.3-1 - Remove unsuitable materials and provide free drainage
	Surface Cleaning	PM1.07.2-1 - Remove accumulations PM1.07.2-2 - Remove blockage that impedes drainage
	Debris Removal	PM1.08.2-1 - Remove Debris PM1.08.2-2 - Remove Debris within 24 Hours from Railway Crossing
Drainage Maintenance	Drainage Appliance Maintenance	PM2.02.2-1 - Remove Debris Affecting Water Flow PM2.02.3-1 - Remove Debris Affecting Water Flow where Heavy Equipment is required Minimum Response Time of 7 days
Winter Maintenance	Highway Snow Removal	PM3.01.2-1 - Remove Accumulations from Traveled Lanes **Removal of Accumulations from Paved Shoulders, Compact on Traveled lanes to be done after Weather Event
	Snow and Ice Bonding Prevention and Control	PM3.02.2-1 - Deploy resources in advance of a Weather Event to treat Traveled Lanes **When slippery conditions arise outside of a Weather Event, resources must be deployed within 60 min

	Other Snow Removal and Ice Control	PM3.03.2-1 - Snow Removal from Pedestrian Overpass **Must be removed within 8 hours of accumulation
Roadside Maintenance	Vegetation Control	PM4.01.3-1 - Cut Vegetation from Shoulder Tops to 1.8m from Shoulder Edge
	Brush, Tree and Danger Tree Removal	PM4.02.3-1 - Remove Brush that cause Sight Distance Obstructions
	Litter Collection	PM4.03.2-1 - Dispose of Litter **Within 7 days unless excessive
Traffic Maintenance	Sign System Maintenance	PM5.01.2-1 - Maintain Sign Systems **Need to be clean, visible, erected and properly placed **Must be completed within 2 days of recognition
	Temporary Pavement Markings and Eradication	PM5.02.2-1 - Place temporary pavement markings within 3 hours
	Traffic Management	PM5.03.2-1 - Respond immediately to unplanned events and provide traffic management services
Structures Maintenance	Bridge Deck Maintenance	PM6.01.2-1 - Temporarily Repair **Minimum Response Time 4 hours PM6.01.3-1 - Permanent Repair **Minimum 6 month time period
	Structures Cleaning Maintenance	PM6.02.2-1 - Remove Accumulations by June 30 of each calendar year
	Structures Drainage Maintenance	PM6.03.2-1 - Repair/Replace immediately any damaged grates/drain pipes within 14 days **All clogged drains must be cleared within 1 hour
	Steel, Aluminum and Multi Plate Structure Maintenance	PM6.09.2-1 - Restrict load-carrying capacity or access to Structure as directed **Respond Immediately
	Bridge Railing Maintenance	PM6.11.3-1 - Repair any damaged or deteriorated railings as directed **Repair Immediately or within 6 months depending on severity

Network Management	Highway Incident Response	PM7.01.2-1 - Traffic Related Incidents PM7.01.2-5 - Dangerous Goods Incidents ** Respond Immediately PM7.01.2-3 - Eliminate Potential Contaminants
	Major Event Response	PM7.02.2-1 - Monitor Area suspected of risk **Initial response to occur immediately
	Highway Inspection	PM7.03.2-1 - Inspection **Immediate Response following reporting by Province and others

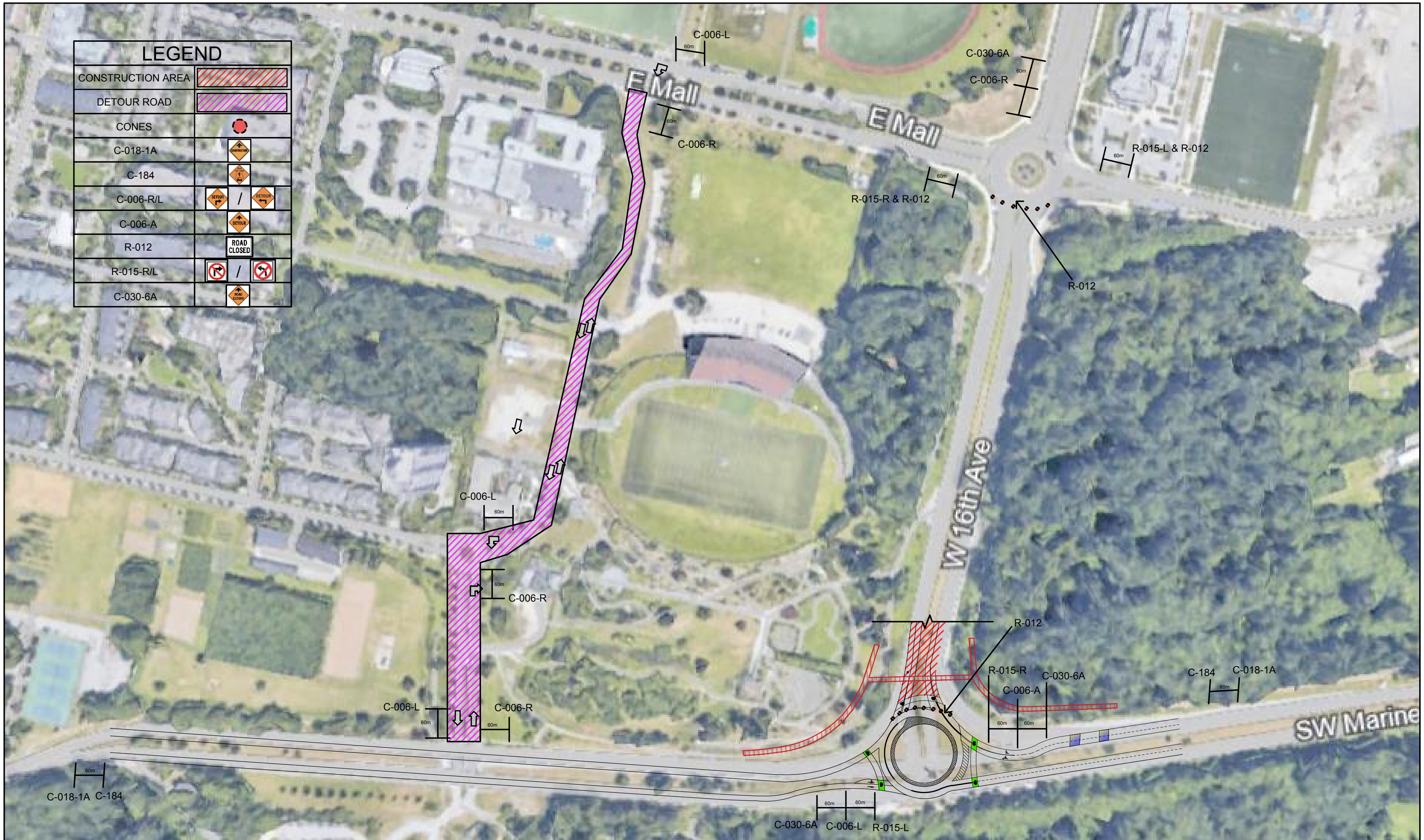
Appendix G - Design Drawings

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	PROJECT OVERVIEW	
CIVL 446	Living Structures Ltd.	0	Preliminary Design	Dec. 7, 2023		
TEAM 13		1	Detailed Design	Apr. 10, 2024	DWG # 100	SHEET: 1 OF 23
	ENGINEERING SEAL				Drafted By: Shaden Bhuiyan	

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	16TH AVENUE AND SW MARINE DRIVE CONSTRUCTION LAYOUT
CIVL 445	Living Structures Ltd.	0	PHASE 1 CONSTRUCTION	MAR 31, 2024	DWG # 100
TEAM 13	ENGINEERING SEAL				Drafted By: Michael Dhailwal — SHEET: 1 OF 5

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	16TH AVENUE AND SW MARINE DRIVE CONSTRUCTION LAYOUT
CIVL 445		0	PHASE 3 CONSTRUCTION	MAR 31, 2024	DWG # 100
TEAM 13	Living Structures Ltd.				SHEET: 3 OF 5
	ENGINEERING SEAL				Drafted By: Michael Dhailwal

CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	16TH AVENUE AND SW MARINE DRIVE CONSTRUCTION LAYOUT	
CIVL 445	Living Structures Ltd.		0	PHASE 4 CONSTRUCTION	MAR 31, 2024		
TEAM 13						DWG # 100	SHEET: 4 OF 5
		ENGINEERING SEAL				Drafted By: Michael Dhailwal	



CLIENT : UBC S.E.E.D.S.

CIVL 445

TEAM 13

Living Structures Ltd.

ENGINEERING SEAL

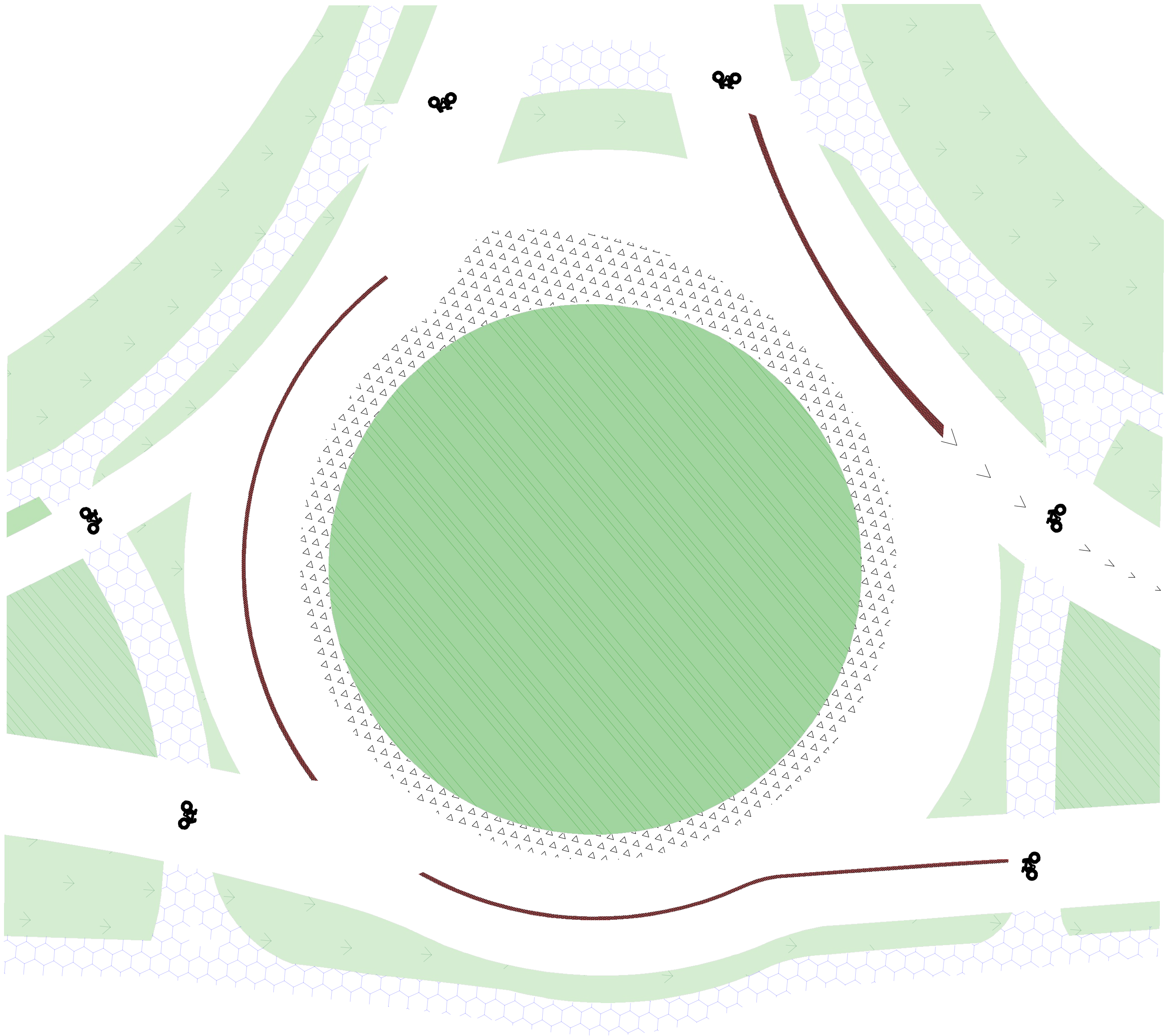
Rev	Description	Date
0	OVERPASS CONSTRUCTION	MAR 31, 2024

16TH AVENUE AND SW MARINE DRIVE CONSTRUCTION LAYOUT

DWG # 100

Drafted By: Michael Dhailwal

SHEET: 5 OF 5



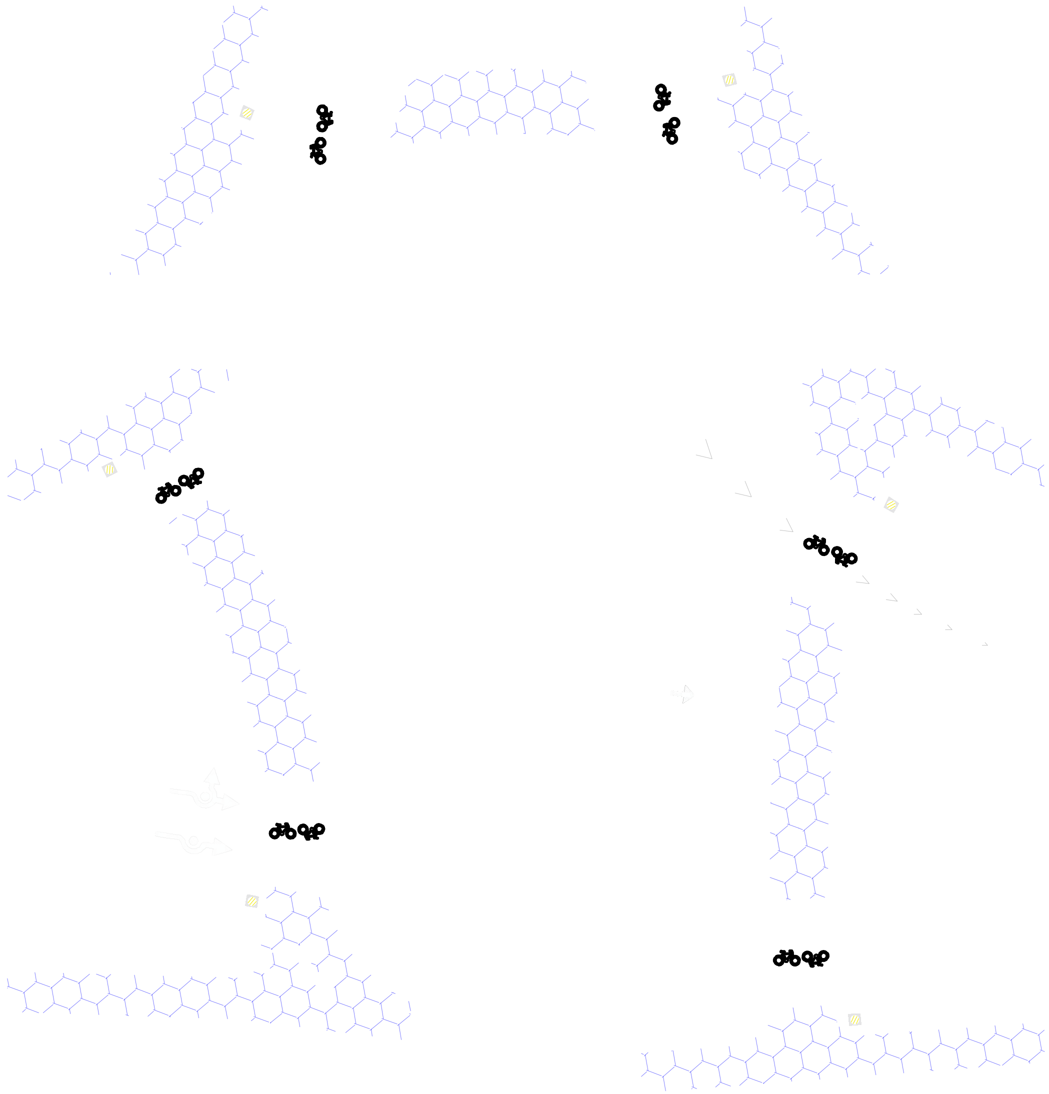
LEGEND	
Cyclist Route	
Rain Gardens	
Truck Apron	
Painted Island	
Greenery	

NOTES

1. Minimum 2.4m wide.
2. Physical barrier - min. 20cm stamped brick pattern.
3. Simplified crossings shown in this drawing. See bike crossing details in DWG T-208

50m

CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	ROUNDABOUT PLAN	
CIVL 446	Living Structures Ltd.		0	Preliminary Design	Dec. 7, 2023		
TEAM 13			1	Detailed Design	Apr. 10, 2024	DWG # T-201	SHEET: 3 OF 23
		ENGINEERING SEAL				Drafted By: Shaden Bhuiyan	



North Leg Bike Crossing

South Leg Bike Crossing

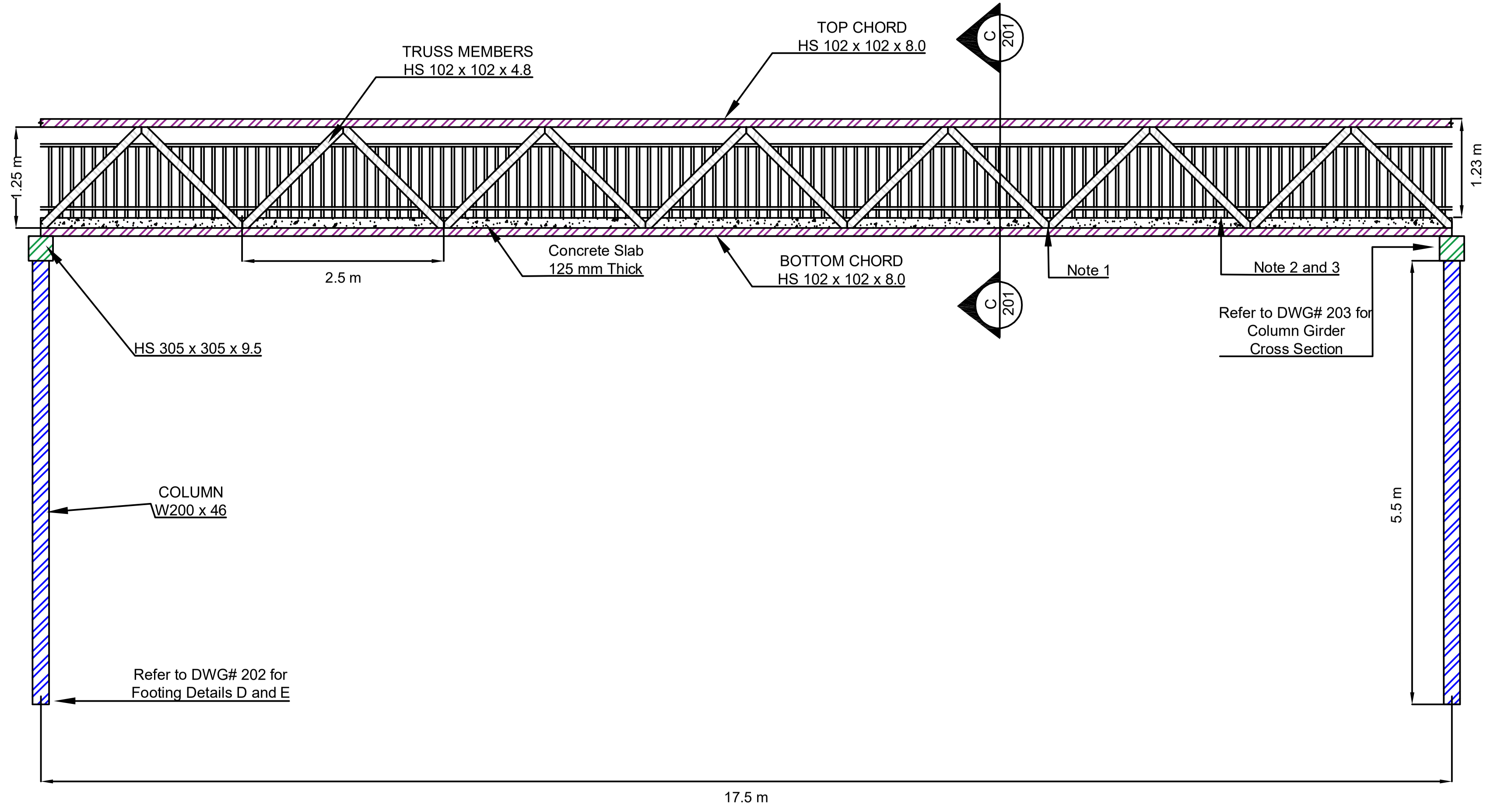
LEGEND	
Cyclist Route	
Cyclist Crossing	
Bike Crossing Signal	
Bike Crossing Trigger	

NOTES

1. Bike actuated signals present at each crossing. Must be a minimum of 0.7m from the road. Refer to note 2 for sign trigger.
2. Bike actuated signal trigger location must be clearly marked out for cyclists.

15m

CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	BIKE CROSSINGS
CIVL 446	Living Structures Ltd.		0	Detailed Design	Apr. 10, 2024	
TEAM 13		ENGINEERING SEAL				DWG # T-208
						Drafted By: Shaden Bhuiyan
						SHEET: 11 OF 23



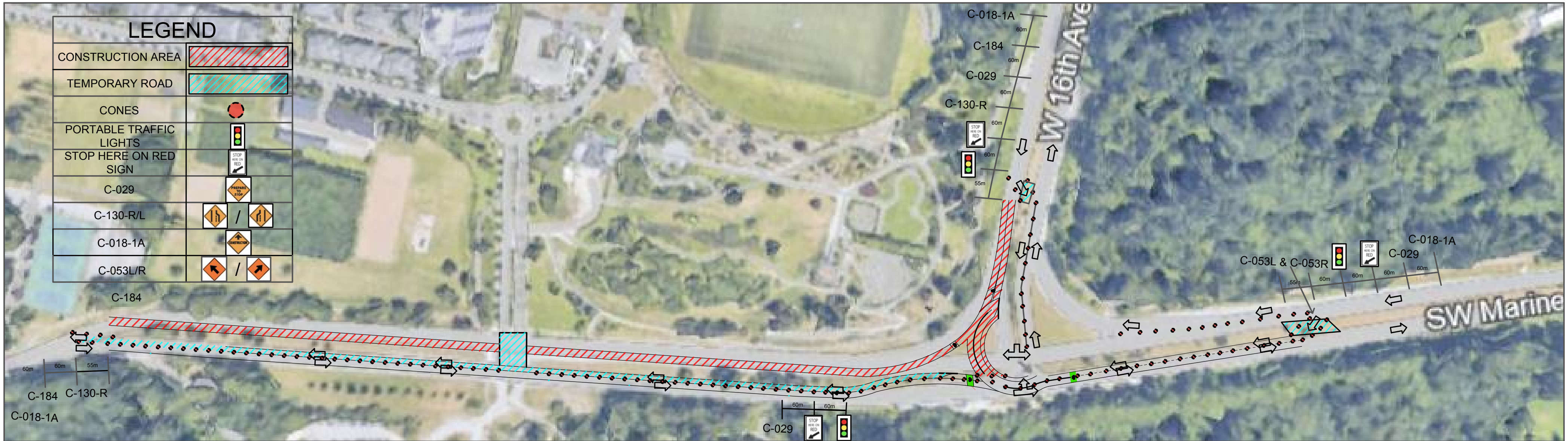
LEGEND

HS 102 x 102 x 9.5	
HS 102 x 102 x 8.0	
HS 305 x 305 x 4.8	
W200 x 46	
Concrete Slab	
Handrail	

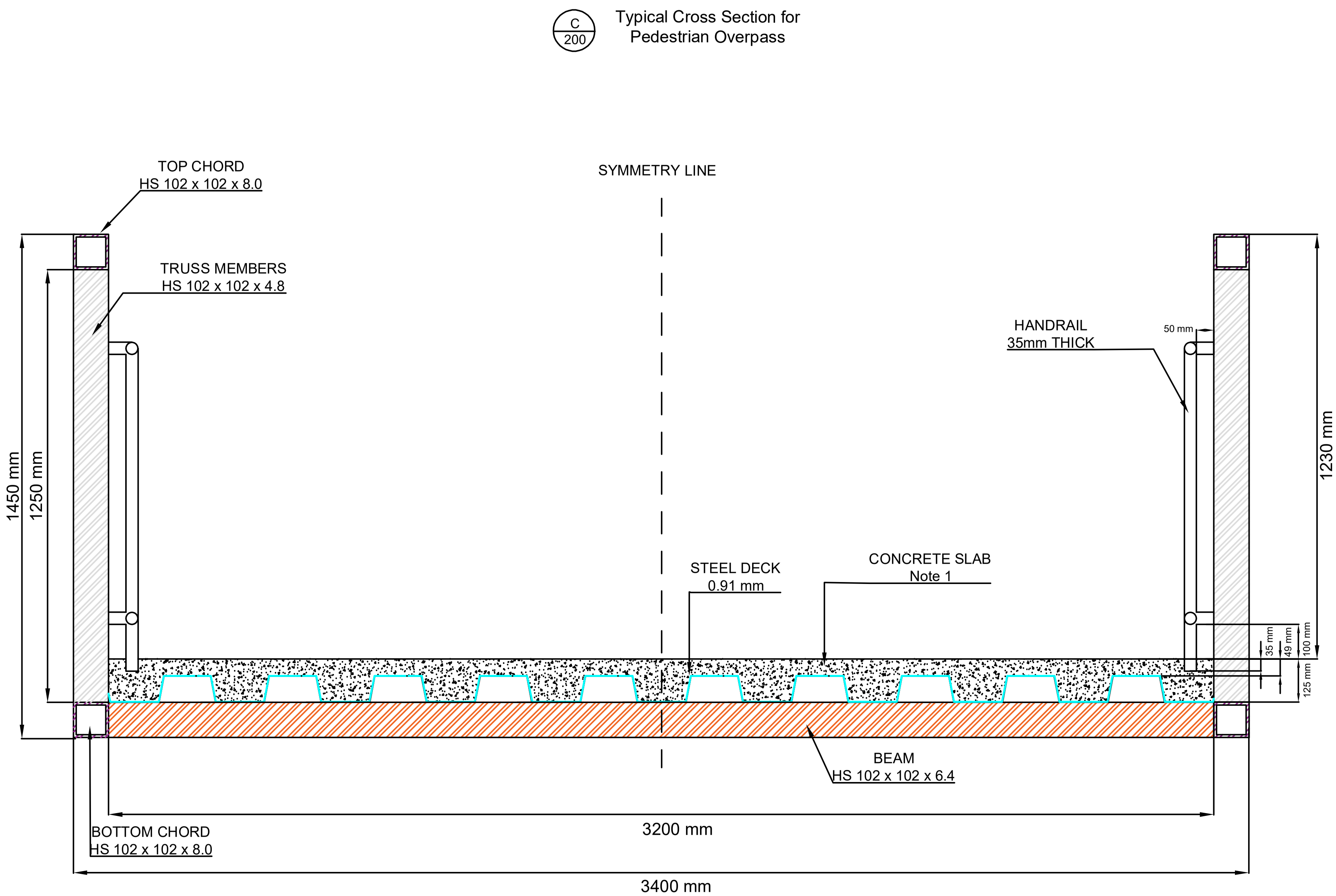
NOTES

1. Truss corner to corner connection equal to 1768 mm.
2. Vertical spacing between handrails equal to 100 mm.
3. Horizontal spacing between slab and bottom handrail bar equal to 100 mm.

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	PEDESTRIAN OVERPASS PROFILE
CIVL 446	Living Structures Ltd.	0	Preliminary Design	Dec. 7, 2023	
TEAM 13		1	Detailed Design	Apr. 10, 2024	DWG # S-301
	ENGINEERING SEAL				Drafted By: E. Parker & S. Bhuiyan
					SHEET: 14 OF 23



CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	16TH AVENUE AND SW MARINE DRIVE CONSTRUCTION LAYOUT
CIVL 445	Living Structures Ltd.	0	PHASE 2 CONSTRUCTION	MAR 31, 2024	DWG # 100
TEAM 13	ENGINEERING SEAL				Drafted By: Michael Dhailwal — SHEET: 2 OF 5



LEGEND	
HS 102 x 102 x 8.0	
HS 102 x 102 x 6.4	
HS 102 x 102 x 4.8	
Steel Deck	
Concrete Slab	
Handrail	

NOTES

1. Canam P-2432 Type 20 125mm, Longitudinally Spanning Flutes

500 mm

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date
CIVL 446		0	Preliminary Design	Dec. 7, 2023
TEAM 13	Living Structures Ltd.	1	Detailed Design	Apr. 10, 2024
ENGINEERING SEAL				

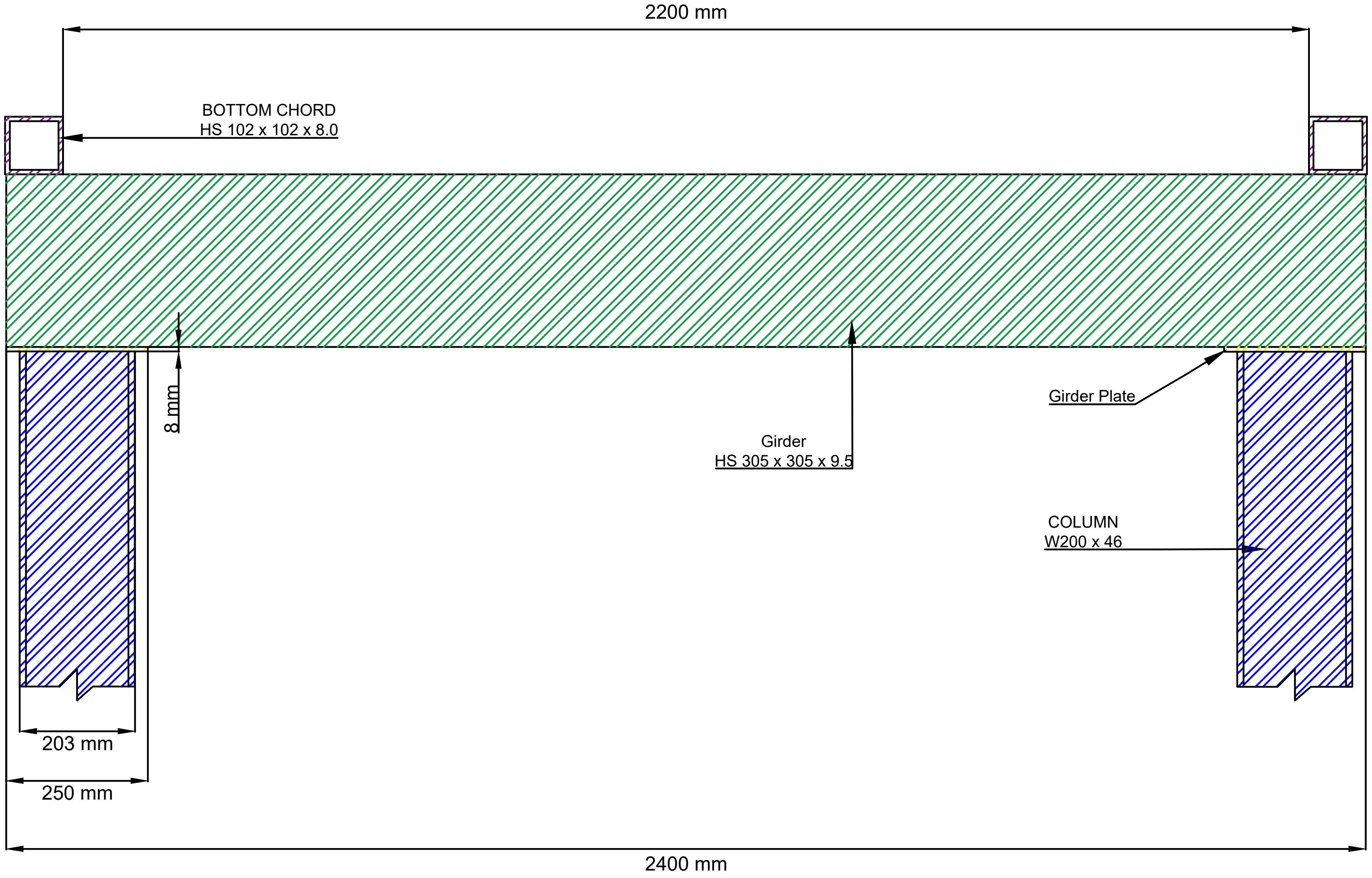
PEDESTRIAN OVERPASS TYPICAL CROSS SECTION

DWG # S-302

Drafted By: E. Parker & S. Bhuiyan

SHEET: 15 OF 23

LEGEND
HS 102 x 102 x 9.5
HS 305 x 305 x 8.0
W200 x 46
Girder Plate



NOTES

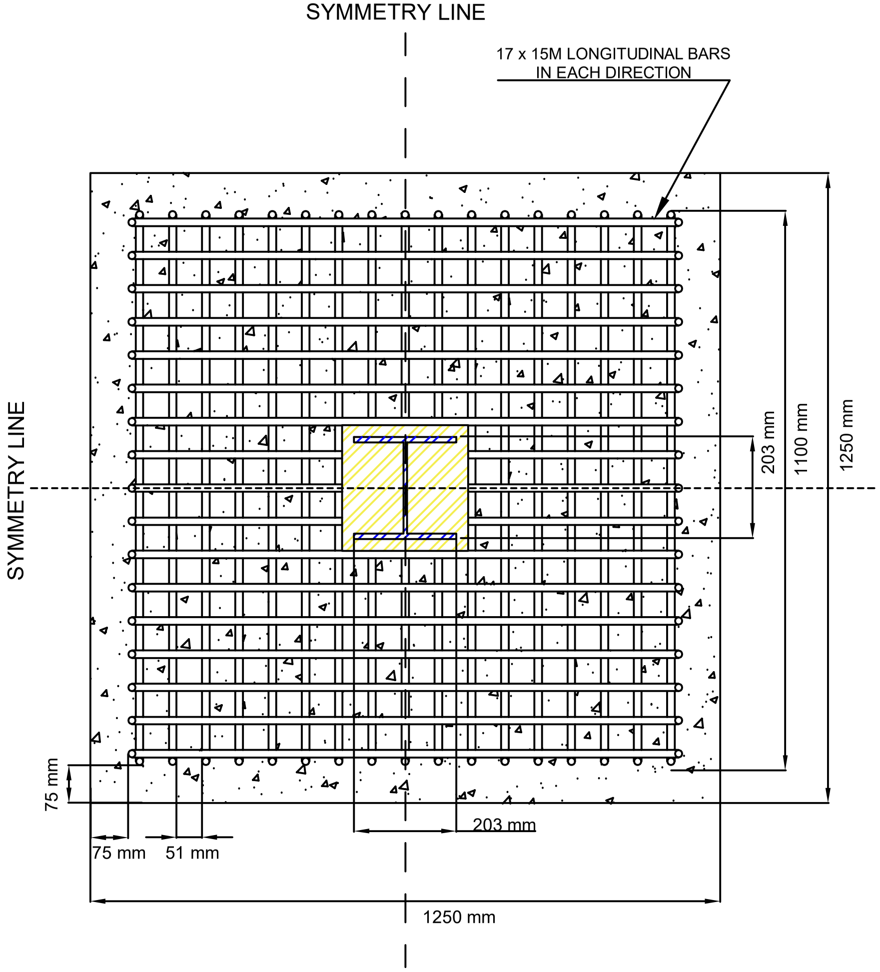
1. Canam P-2432 Type 20 125mm, Longitudinally Spanning Flutes

500 mm

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date
CIVL 446		0	Preliminary Design	Dec. 7, 2023
TEAM 13	Living Structures Ltd.	1	Detailed Design	Apr. 10, 2024
	ENGINEERING SEAL			

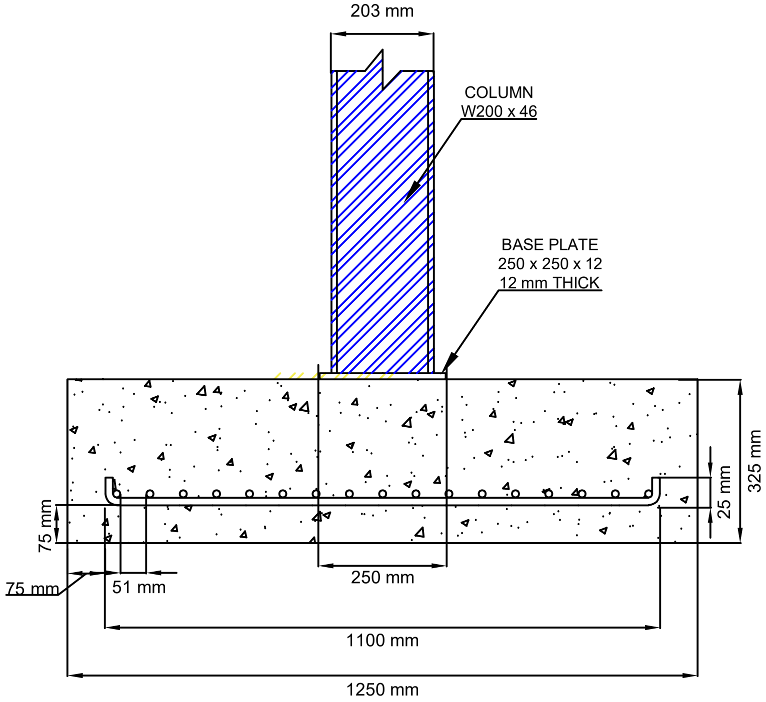
PEDESTRIAN OVERPASS - TYPICAL COLUMN GIRDER

DWG #	S-303	SHEET: 16 OF 23
Drafted By: E. Parker & S. Bhuiyan		



D
200

Plan View



E
200

Cross Section

LEGEND	
W200 x 46	
Concrete Slab	
17M Bars	
Base Plate	

NOTES

1. None

500 mm

CLIENT : UBC S.E.E.D.S.

CIVL 446

TEAM 13

Living Structures Ltd.

ENGINEERING SEAL

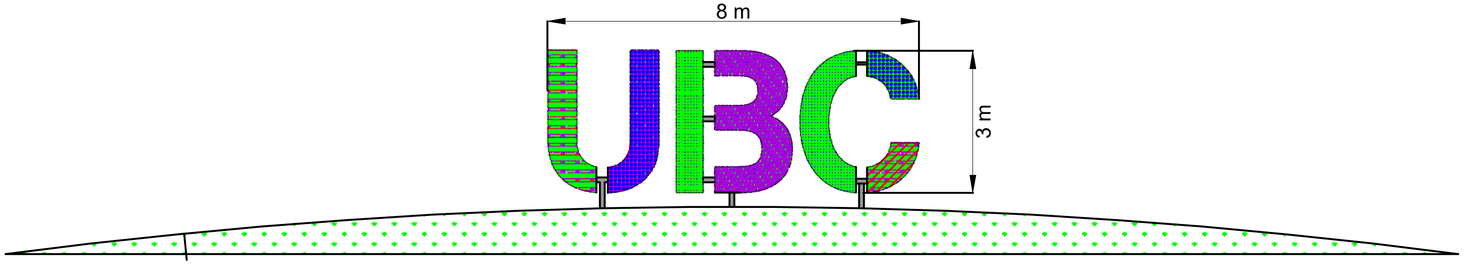
Rev	Description	Date
0	Preliminary Design	Dec. 7, 2023
1	Detailed Design	Apr. 10, 2024

PEDESTRIAN OVERPASS - FOOTING DETAILS

DWG # S-302

Drafted By: E. Parker & S. Bhuiyan

SHEET: 17 OF 23



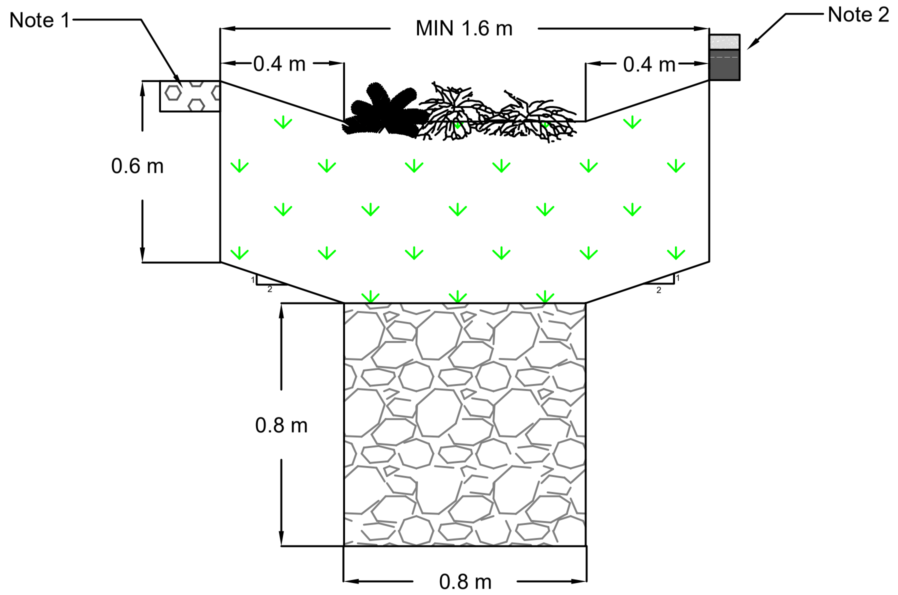
LEGEND	
Centre Median	
Sign Stand	
Sign	

NOTES

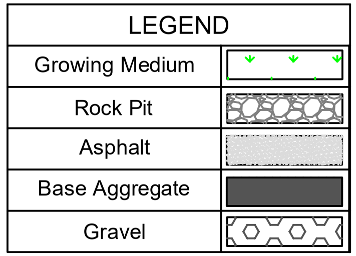
1. Material to be used plastic

10m

CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	UBC SIGN PROFILE		
CIVL 446	Living Structures Ltd.		0	Preliminary Design	Dec. 7, 2023			
TEAM 13			1	Detailed Design	Apr. 10, 2024	DWG #	S-305	SHEET: 18 OF 23
		ENGINEERING SEAL				Drafted By: E. Parker & S. Bhuiyan		

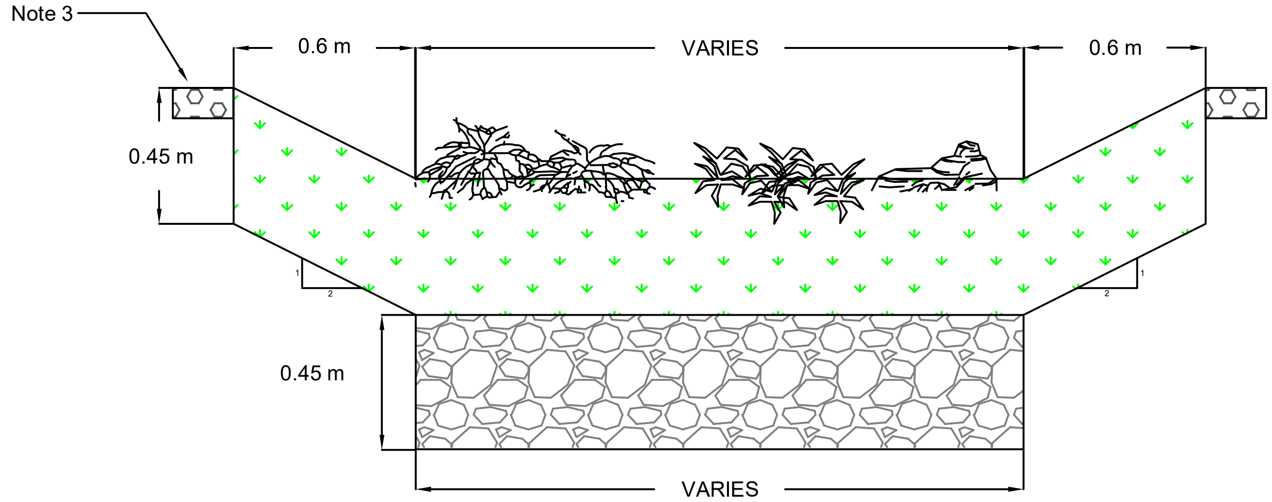


A/101 Bike Lane Median

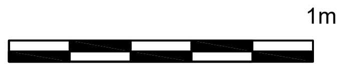


NOTES

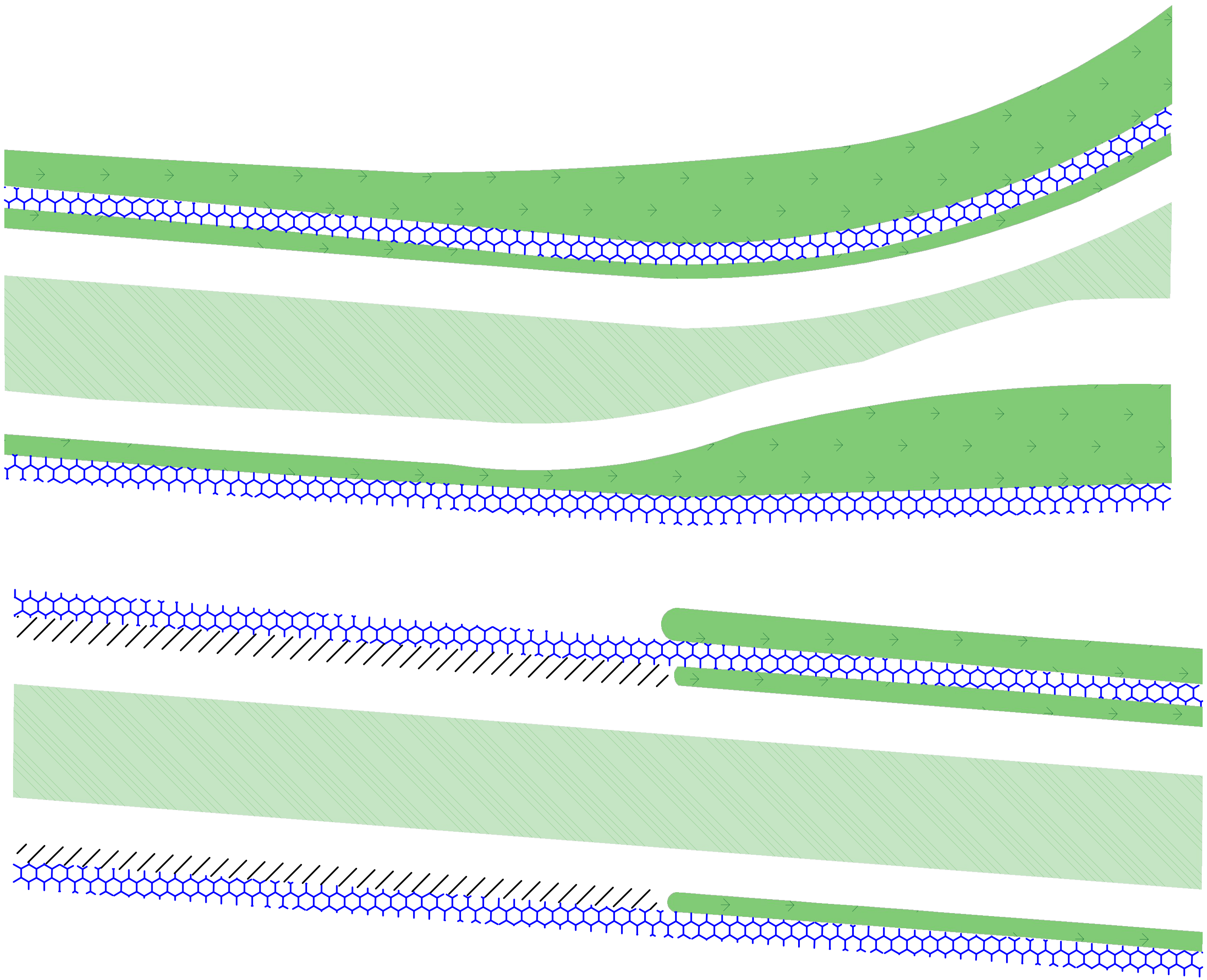
1. Gravel on bike lane side
2. Curb on road side
3. 20cm border of gravel on both sides of the pond



B/101 Rain Garden Ponds



CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	TYPICAL RAIN GARDEN CROSS SECTION
CIVL 446		0	Preliminary Design	Dec. 7, 2023	
TEAM 13 / Living Structures Ltd.		0	Detailed Design	Apr. 7, 2024	DWG # G-401
	ENGINEERING SEAL				Drafted By: A. Backman-Choo & S. Bhuiyan — SHEET: 19 OF 23

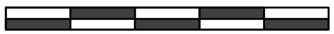


LEGEND

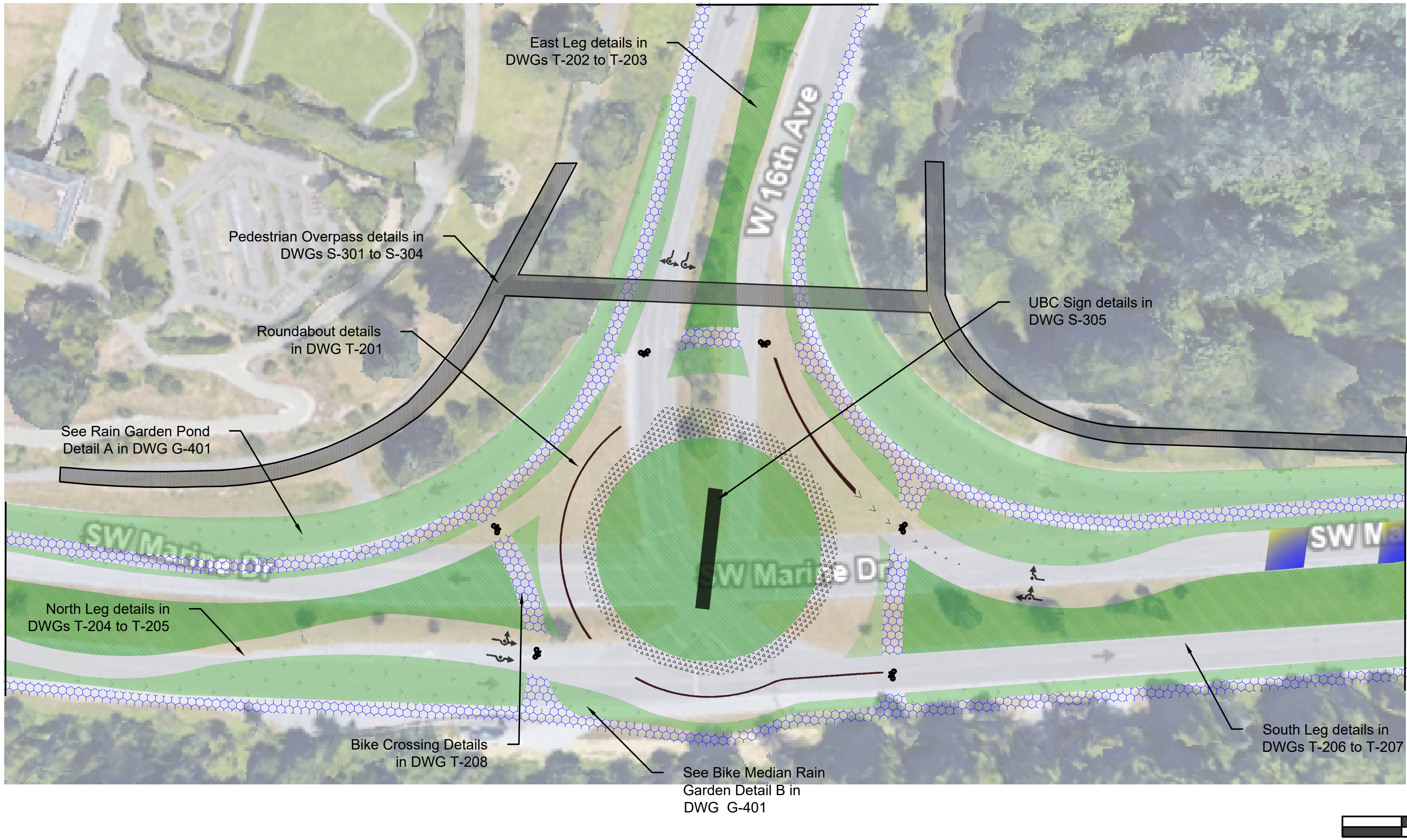
LEGEND	
Cyclist Route	
Greenery	
Painted Island	
Rain Garden	

NOTES

1. Typical road plan from north leg approach to north leg tie in shown in DWG T-205.
2. Streetlights to remain as is.



CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	SW MARINE DRIVE - NORTH LEG ROAD PLAN		
CIVL 446	Living Structures Ltd.		0	Detailed Design	Apr. 10, 2024			
TEAM 13						DWG #	XXX	SHEET: X OF XX
		ENGINEERING SEAL				Drafted By: Shaden Bhuiyan		



LEGEND
Cyclist Route
Pedestrian Overpass
Rain Gardens
Truck Apron
Painted Island
Greenery
Painted Surface

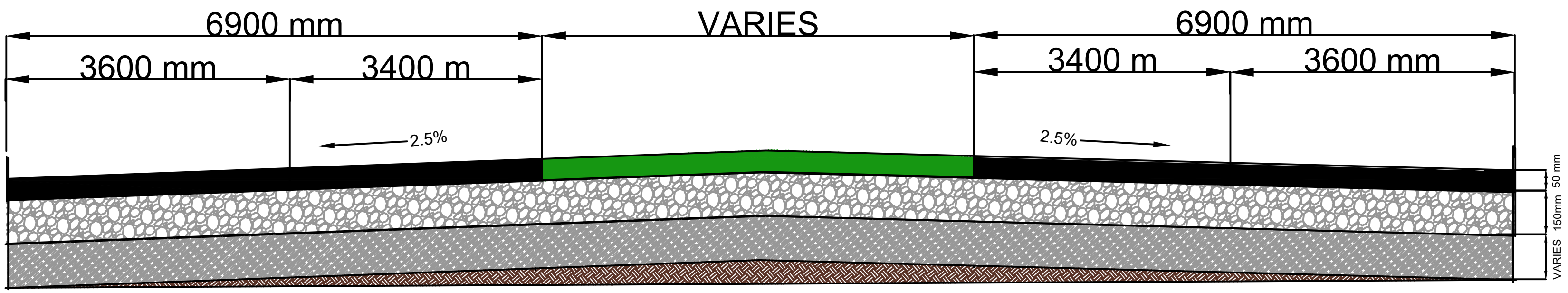
NOTES
1. Bike crossing details simplified for general dwg. See detailed DWG T-208.
2. See general notes for material specifications.

CLIENT : UBC S.E.E.D.S.		Rev	Description	Date	16TH AVENUE AND SW MARINE DRIVE GENERAL LAYOUT	
CIVL 446	Living Structures Ltd.	0	Preliminary Design	Dec. 7, 2023		
TEAM 13		1	Detailed Design	Apr. 10, 2024	DWG # 101	SHEET: 2 OF 23
	ENGINEERING SEAL				Drafted By: Shaden Bhuiyan	

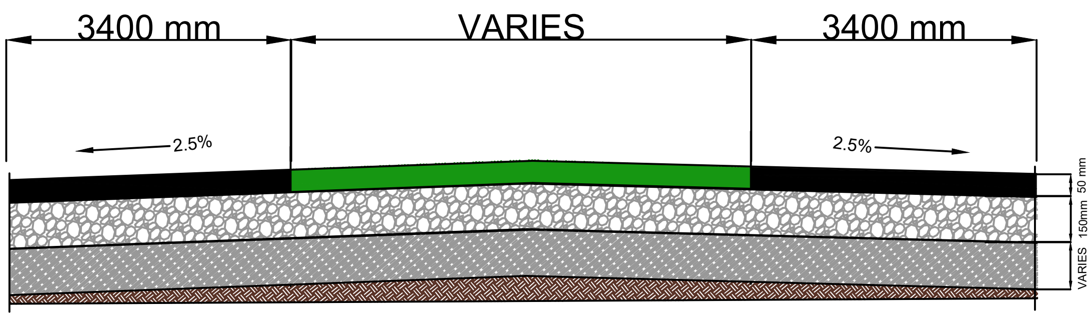
LEGEND	
Asphalt	
Base Aggregate	
Sub Base Material	
Greenery	
Earth	

NOTES

1. Depth of layers may be subject to change depending on additional testing
2. Refer to general notes for material specifications.

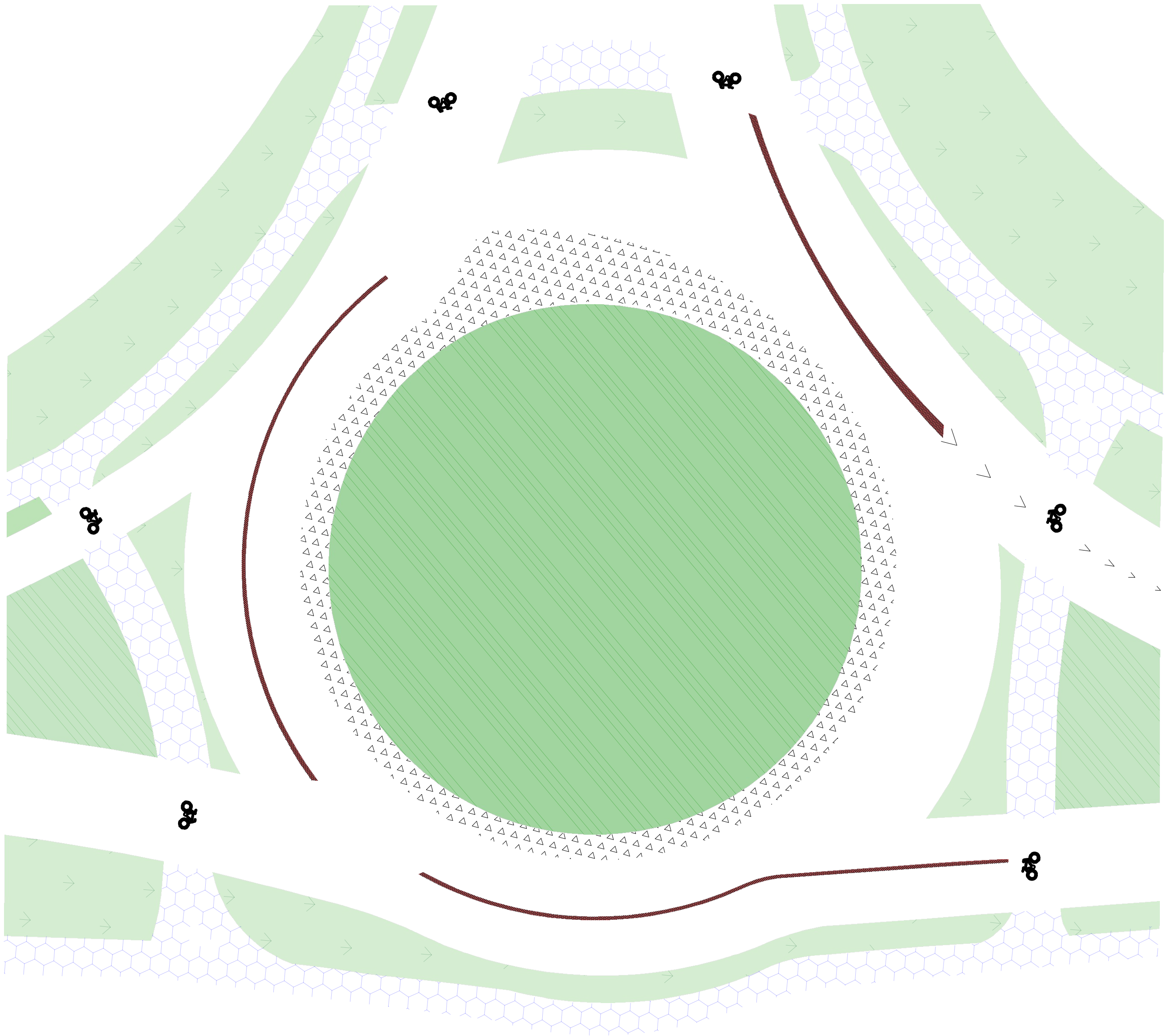


A
101
Typical Cross Section for NE and SE Leg



B
101
Typical Cross Section for NW Leg

			Rev	Description	Date	
CLIENT : UBC S.E.E.D.S.						TYPICAL CROSS SECTIONS FOR APPROACHES
CIVL 446	Living Structures Ltd.		0	Preliminary Design	Dec. 7, 2023	
TEAM 13			0	Detailed Design	Apr. 10, 2024	DWG # 102
		ENGINEERING SEAL				Drafted By: Shaden Bhuiyan
						SHEET: 3 OF 9



LEGEND	
Cyclist Route	
Rain Gardens	
Truck Apron	
Painted Island	
Greenery	

NOTES

1. Minimum 2.4m wide.
2. Physical barrier - min. 20cm stamped brick pattern.
3. Simplified crossings shown in this drawing. See bike crossing details in DWG T-208

50m

CLIENT : UBC S.E.E.D.S.			Rev	Description	Date	ROUNDABOUT PLAN		
CIVL 446	Living Structures Ltd.		0	Preliminary Design	Dec. 7, 2023			
TEAM 13			1	Detailed Design	Apr. 10, 2024	DWG #	T-201	SHEET: 3 OF 23
		ENGINEERING SEAL				Drafted By: Shaden Bhuiyan		