University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

East Mall Redesign - Preliminary Design Report

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Prepared for:

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University of British Columbia

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Executive Summary

Team 11 was engaged by UBC SEEDS Sustainability Program for the East Mall Redesign Project to improve and accommodate all modes safely and effectively along the corridor. Throughout the past 8 months, Team 11 has created a comprehensive detailed design to suit the needs of East Mall users. The current layout is tailored for vehicle traffic and parking, while mostly neglecting the need for active mode infrastructure and sports field access. Some of the primary corridor users identified are pedestrian and cyclist commuters, sports field users, vehicle commuters, and maintenance and delivery vehicles.

Starting with the preliminary design, the first step was identifying the project goals and background. Three design options were generated, each being focused on a key client objective, including a multi-use path option, traffic calming option, and enhancing the existing configuration. Once these were conceptualized, a weighted decision matrix was used to organize the client objectives into ranking criteria used to select the optimal design, which was evaluated separately for the transportation and structural components. Acceptance of this procedure and the proposed design by the client in December 2020 led to the finalization of a drawing package and the detailed design elements, which is summarized in this detailed design report.

The final design features primarily shifted corridor space from vehicle traffic to sustainable modes, while minimizing the effect on vehicle traffic and business operations. With a key design constraint being the width of the corridor; the final design removes the existing median and arranging vehicle traffic on the west side of the road, space was created to integrate a multi-use path on the east side, while improving the amount of greenspace and natural character in the corridor. Safety to all road users was always at the forefront of decision making and the corridor has been designed to maximize this.

The proposed design will also need to integrate seamlessly to accommodate all existing and planned infrastructure; one being the planned Stadium Neighborhood development. Finally, the design is

intended to promote mode shift to align with UBC's goal of reducing vehicle traffic and increasing pedestrian and carpooling modes of travel.

Summarizing the goals and objectives stated above, the following list highlights the main features of the final detailed design:

- A 4.6m-wide Pedestrian Weather Canopy extending 65m from East Mall to Health Sciences Mall along Agronomy Road;
- A 5m-wide shared multi-use path from W16th Avenue to Thunderbird Boulevard, including covered bicycle parking at the recreational fields;
- Retain parallel parking along both sides of the corridor, with an emphasis on increasing pedestrian sightlines;
- A 60m separated pick-up/drop-off lane near Stadium Road, with 18 time-restricted diagonal parking stalls;
- Two RRFB systems installed at crosswalks at Stadium Road, and at Eagles Drive;
- Green infrastructure to reduce water quantity, run-off, and add to the aesthetic of the roadway;
- Retain stop-control for the East Mall at Agronomy Road intersection, incorporating landscape changes; and
- Integrate roundabout control at the Thunderbird Boulevard intersection, which will add components of increased road user safety, traffic calming, and emission reductions.

Construction of this project is expected to take place between the period of **May 2021 to October 2021** and the total project capital cost is estimated to be ~ $3,906,000.

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1.0 Introduction

1.1 Project Background

Beginning in September 2020, Team 11 was approached by UBC SEEDS (Social Ecological Economic Development Study) Sustainability Program to develop a new design for the East Mall corridor, beginning with a preliminary design report that was delivered in December 2020. This reported highlighted the project goals and targets, background research, and the design process; including potential design options, weighting criteria, and the final selection process. Over the past 4 months, Team 11 has been refining its proposed design to a detailed, construction-ready package, which is described in detail throughout this report.

The Final Detailed Design Report has been supplied on behalf of Team 11 (CIVL 445 Group 11） for the University of British Columbia. The Detailed Design outlines a full roadway redesign for East Mall located on the University of British Columbia’s Vancouver campus. We acknowledge that the project takes place on the traditional, ancestral, and unceded territory of the Musqueam people.

The purpose of the redesign to update the corridor to better align with UBC Campus Policy and Objectives for sustainable transportation options. Referencing the 2014 UBC Transportation plan, some of the key goals are:

1.0 Sustainable Transportation
   - 1.1 By 2040 at least 66% of trips to and from UBC will be made by walking, cycling, or transit；
   - 1.2 Maintain at least 50% of trips to and from the campus on public transit；

2.0 Single Occupant Vehicles (SOV)
   - 2.1 Reduce SOV travel to and from UBC by 20% from 1996 levels；
   - 2.2 Maintain at least 30% reduction from 1997 levels in daily SOV trips per person to and from UBC；

3.0 Daily Private Automobile Traffic:
   - 3.1 Maintain daily private automobile traffic at less than 1997 levels.

Construction is set to start May 1, 2020 immediately proceeding the submission of the Detailed Design Report. It is estimated that construction will take place over 70 days and cost approximately $3.9M.

1.2 Site Overview

East Mall is approximately 1.0km long running north-west to south-east between West 16th and Agronomy Road. The current East Mall corridor right of way (ROW) is approximately 25.5m wide and consists of single travel lanes separated by a wide median, street bike lanes, curbside parking, and sidewalks on both sides of the roadway. In addition to frequent vehicle speeding and the abundance of impermeable asphalt road surface, safety concerns between cyclists, parking, and pedestrians crossing require urgent addressing. The area sees a high demand of pick-up and drop-off activity due to several sport fields and the Stadium in the immediate vicinity. The East Mall Upgrade will tie in with the new alignment at the south end of the future Stadium Neighborhood but drastically improve the roadway between Stadium and Agronomy Road. A site overview can be seen in Figure 1.

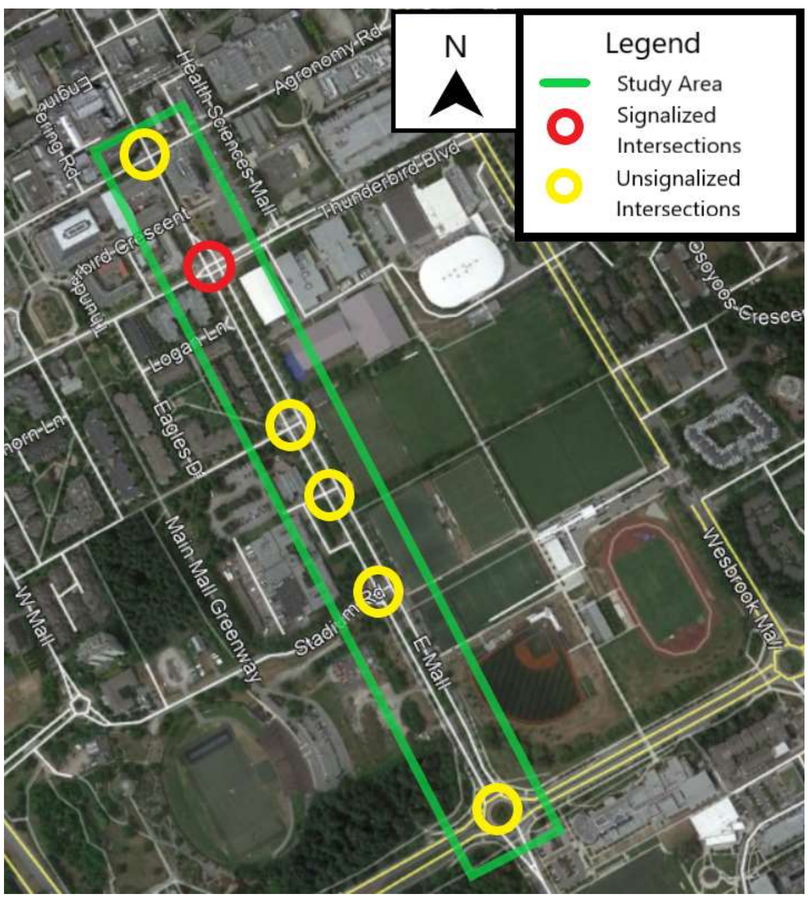

Figure 1: Site Overview

1.3 Project Objectives

A full redesign of East Mall between W16th Avenue and Agronomy Road is required to align with UBC's Transportation Plan for sustainable transportation goals. These goals include promoting active transportation through walking, cycling, or transit, reducing single occupant vehicles, and maintaining private automobile traffic at less than 1997 levels. The planned upgrades will improve pedestrians and cyclists' access to convenient infrastructure and increase mobility such that trips are easily connected from the core of campus to the south commercial district, and to the Pacific Spirit Park Trail System.

The client identified objectives for the work to be undertaken include：

- **Prioritize buses, cyclists, and pedestrians over personal vehicles**

  By enhancing the existing pedestrian and cyclist facilities to promote mode shift towards sustainable options over single occupancy vehicles， the East Mall Redesign will align with the goals set by UBC's Transportation Plan.

- **Minimize costs and maximize safety for all roadway users**

  While costs are a key component of the project that should be minimized, safety must be held paramount as one of the key design objectives for the East Mall redesign. This includes fostering a safe active transportation network through visibility and infrastructure upgrades. In addition, vehicle speeds along the corridor should be reduced through traffic calming measures such as curb bulb outs and narrower travel lanes.

- **Incorporate either a pedestrian tunnel OR a covered walkway for pedestrians along Agronomy Road**

  By providing pedestrian weather protection through the incorporation of a pedestrian canopy along Agronomy Road, students and other users will prioritize walking in Vancouver's wet climate. If the pedestrian tunnel option is exercised, intersection performance at Agronomy and East Mall will be greatly improved.

- **Incorporate green infrastructure to retain rainwater on-site**

  The wide median that currently separates the travel lanes along the East Mall corridor provides a significant green space for stormwater infiltration and management. This large area provides an opportunity for redesign to better organize the ROW into an effective rainwater strategy. The corridor redesign is expected to provide similar or increased drainage performance, which includes green space for aesthetic appeal, and adding green infrastructure where applicable for effective storm water management. Our team has looked to the City of Vancouver's Rain City Strategy for applicable infrastructure and rainwater management techniques.

- **Accommodate pick-up/drop-off needs for fields safely and efficiently**

  The section of the East Mall corridor adjacent to the Stadium Road intersection is a hotspot for pick-up and drop-off due to the numerous recreational fields. Parents often crowd the currently insufficient drop-off space at peak hours, which results in blocking of the on-street bike lanes and creates an unsafe situation for both the vulnerable road users and on-street traffic. Designing a pick-up/drop-off hub where parents can safely deliver their kids while simultaneously incentivizing active transportation modes by providing upgraded bicycle parking will provide a safe and sustainable, long term solution to the pick-up/drop-off issue.

1.4 Design Constraints

The proposed East Mall Redesign must align with the UBC Design Guidelines and UBC Transportation Plan among other design documents. To adhere to these documents, a series of constraints ranging from the retention of on-street parking to the overall project cost will guide our preliminary design. Some of the primary design constraints are mentioned and explained below.

- **Integration with the planned Stadium Neighbourhood**

The design requires a seamless alignment at the south end of the future Stadium Neighborhood development, including a reduction in curb-to-curb space between W16th Avenue and Stadium road, and provisions for the incorporation of the East-West promenade mid-block.

- **Space Constraints**

  One of the major design constraints for the East Mall redesign are the space constraints, including the cross-section right-of-way, green space integration, and the space constraints for the intersection designs at Agronomy Road, and at Thunderbird Boulevard. Additionally, incorporating one of the structural elements to the final design requires space, whether it for the physical framing of the weathering canopy, or the lengthy access ramps of the pedestrian underpass.

- **Project Cost**

  A key component of any major design, our team is committed to optimizing road user safety while minimizing the total project costs. This relates to vital design considerations such as material selection, major intersection changes, and infrastructure upgrades.

- **Emergency and Maintenance Access**

  On the East side of the corridor, two existing access points exist for emergency access to the UBC Tennis and Robert F. Osbourne centers, and to the Thunderbird Fields maintenance shed. The proposed design will need to account for these access points, and seamlessly integrate them into the proposed design.

- **Transit Facilities**

  There are currently two bus stops along the East Mall corridor for the 68 UBC Exchange / Westbrook Village bus route. The proposed design will need to incorporate these stops, and also include provisions for rerouting during construction.

- **On-street Parking**

  While one of the key project objectives is to incentivize a mode shift towards sustainable modes, sufficient on-street parking must be retained in certain areas adjacent to the Tamarack House and Logan Lane Townhouses.

- **Construction Considerations**

Accommodating all forms of traffic, both vehicular and active, along East Mall during the construction phase of the project needs to be considered during the design phase. Rerouting and construction techniques should be considered to minimize the impact on the UBC community. Additionally, noise and social complaints should have a plan to minimize the total impact on the existing community. Further, easements may need to be obtained during the construction phase for residential buildings in the area.

1.5 Team Member Contributions

Team Member (Student #)	Contributions
Kristian Biela (30167167)	• Primary Drafter – Plan View, X-Section, Utilities, Greenspace • Greenspace Design • Stormwater Management
Dylan Galovich (28829877)	• Project Background/ Site Overview • Project Objectives • Stormwater Management • Groundwater and Drainage
Dylan Grier (48529168)	• Bike Canopy Design & Drawing • Road Base Design • Executive Summary & Report Formatting • Financial Analysis and Risk Management • Design Criteria
Rossi Gu (49859796)	• Pedestrian Weathering Canopy Design • Partial Bike Canopy Design • Structural Foundation & Connection Design, Drawing Set
Ben Maquignaz (31688161)	• Roundabout Design & AutoTurn Analysis • Traffic Forecasting • Construction Schedule • Site Visit and documentation • Waste Disposal & Recycling Plan
Steve Martin (34447169)	• Multi-modal, Ped X-ing Design • Pick-Up/Drop-off Lane Design • Synchro Modelling • Safety Considerations – sightlines, speeds • Signage & Pavement Markings Drawing Set • TMM Classification
Braeden McCowan (90201617)	• Construction Planning, Requirements, Sequencing • Permitting & Anticipated Issues • Service Life Maintenance Plan • Class C Cost Estimate

2.0 Key Design Components

Team 11 has developed a design for the East Mall corridor that achieves all identified preliminary design criteria specified in the previous section. A concise summary of the general design rationale and how the proposed design mitigates the design constraints outlined in Section 1.4 is provided in Table 1 below.

Table 1 Design Constraints and Rationale

Design Constraint	Rationale
Integration with Stadium Neighborhood	• Fully compatible with the proposed stadium plan road alignment; • Incorporating new bike parking nearby that may accommodate for TDM for parking reduction of stadium residential usage.
Space Constraints	• Reoptimizing limited space along the corridor into green space; • Reoptimizing space usage at Agronomy Road to increase sightlines and increase aesthetic appeal; • Incorporating a pedestrian weathering canopy with limited spatial impacts along Agronomy Road; • Restructuring the limited right of way along East Mall to prioritize active modes over private vehicles.
Project Cost	• Hold paramount public safety while minimizing project costs by selecting appropriate materials and construction methods.
Emergency and Maintenance Access	• Integration of access points to both the tennis facility emergency access and to the field maintenance shed from East Mall.
Transit Facilities	• Retaining the current placement of bus stops along the corridor.
On-street Parking	• Retaining most on-street parking near residential facilities; • Removing parking to improve crossing sightlines, improve vulnerable road user safety, align with UBC mode shift targets.
Construction Considerations	• The key components of the construction plan, including sequencing, traffic management, noise reduction, and social complaints are addressed in the Construction Planning section of this report

The following sections describe each component of the proposed design in detail, including their respective design rationale and development methodology.

2.1 Road Design

The proposed roadway for the East Mall Redesign reimagines the wasted boulevard area by repurposing the greenspace into more a functionally sustainable configuration and converts the traffic operations into a 2-lane, 2-way unseparated roadway with on-street parking in certain areas.

2.1.1 Traffic Forecasting and Synchro Modelling

Synchro 11 models were developed to compare the proposed design to the existing condition of East Mall. Existing volumes collected from traffic counts were forecasted to future proposed volumes in 2040 through a growth rate of 1% and new trips generated through the proposed Stadium Neighbourhood development. A full sample calculation of these volumes is provided in Appendix E. These modelling results were used for a direct comparison between LOS performance at key intersections along the corridor and justify the implementation of new traffic control, including these key outputs:

- A NBL turning lane at Stadium Road is required to accommodate the forecasted volumes due to the planned Stadium Neighbourhood development;
- Removing the left turn lanes at FP Innovations and Eagles Drive have no major impact on delays along the corridor;
- At East Mall and Thunderbird Boulevard, a roundabout performs slightly worse than an optimized traffic signal, however Team 11 recommends proceeding with a roundabout (See **Section 2.2.2**); and
- At East Mall and Agronomy Road, retaining stop-control with future volumes does not result in a significant change to performance.

A sample Synchro report used to determine measures of effectiveness for the intersections along the corridor can be found in Appendix D.

2.1.2 Typical Cross-Sections

The road has been designed to meet the City of Vancouver Engineering Design Guidelines, including a 2.5% crown, 3.5m driving lanes, and 2.5m on-street parking lanes. A typical cross section for the road can be found in Drawing No. 14 in Appendix A.

2.1.3 Sub-grade Cross Section

As stated by the City of Vancouver Engineering Design Guidelines (2019), this roadway is classified as a "Higher Zoned Collector" (> 100,000 trips/year). This standard specifies that the road by decreasing elevation will have a minimum of 50 mm Superpave Surface Mix, 90 mm Superpave Base Mix, 150 mm of 19 mm Crushed Granular Base and 300 mm of 75 mm Crushed Granular Sub-Base. The standard cross section of the road can be found on Drawing No. 14 in Appendix A and the Figure below.

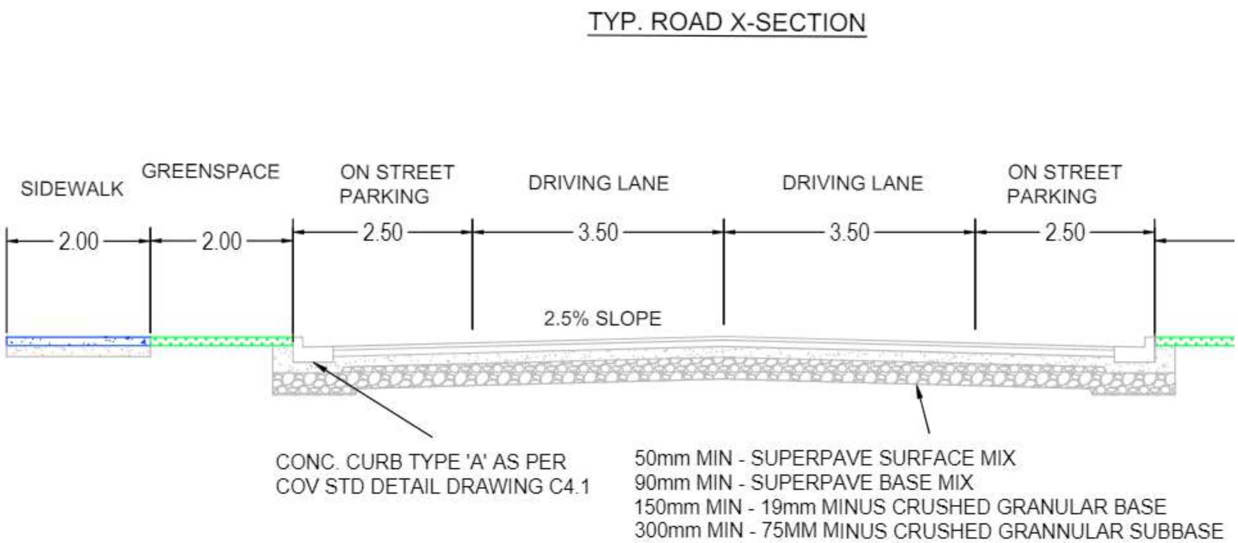

Figure 2: Typical Road Base Sub-grade

2.1.4 Signage and Pavement Markings

The Signage and Pavement Marking Drawing Package can be found in Appendix A, Drawings no.7-13. This drawing package includes roadway, navigation, and multi-use path signage as indicated in the latest edition of the MoTI's Manual of Standard Traffic Signage and Pavement Markings.

2.2 Intersection Design

2.2.1 Stadium Road

The intersection incorporates a new lane alignment heading northbound due to the proposed pick-up/drop-off lane that will also serve as a traffic calming measure. Signage along the NB approach will be supplied to illustrate this new alignment, as well as a navigation signage indicating the presence of the drop-off lane. The NBL turning lane has been retained due to the forecasted traffic volumes from the

Stadium Neighborhood development, and the existing crosswalk has been retained and upgraded per the specifications in Section 2.3.3. The plan view of this intersection can be found in Drawing No. 2 in Appendix A, and a sample of the intersection is provided in Figure 3.

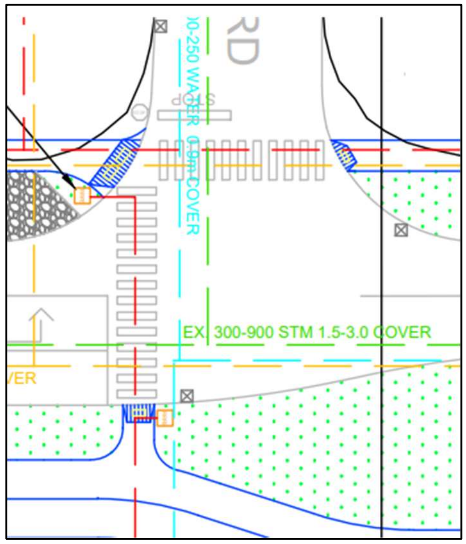

Figure 3: Stadium Road Intersection

2.2.2 Thunderbird Boulevard

The Thunderbird Boulevard Intersection is receiving a full overhaul and be redesigned from the ground up as a low-speed roundabout. Due to the wide lanes in both directions, there was ample room to fit a roundabout that would calm traffic and increase flow. The roundabout features a 5.5m radius center circle with a 2.0m apron around the outside. This ensures that large semi-trailers that frequent the forestry buildings can traverse the roundabout. Using AutoCAD's AutoTurn software, we were able to optimize the traffic circle for this situation. There are pedestrian crosswalks on all four sides, and refuge islands are available at the center point of each crosswalk to ensure pedestrians feel safe, which has been designed in accordance with the CoV Standard Details. The large multi-use path crosses on the east side of the intersection and allows continuity through the intersection for anyone using the path.

While there is a slight decrease in performance compared to preserving a signalized intersection, there are several benefits to the roundabout that lead to it being the superior alternative. Most importantly, it increases the safety of roundabout users on all modes of transportation. There are fewer severe conflict points that can lead to KSI collisions (angle and rear-ends). It also helps work towards the goal of traffic-calming, as it encourages a speed reduction, while still allowing for traffic flow at an appropriate LOS through peak hours.

The plan view of this intersection can be found in Drawing No. 5 in Appendix A, and a sample plan view is provided in Figure 4 below.

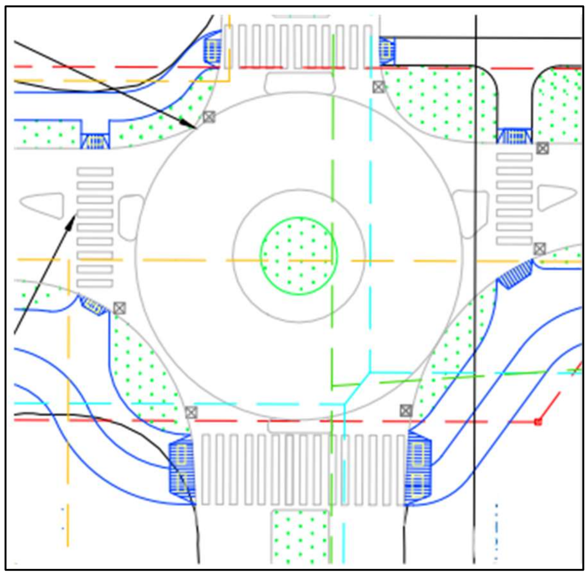

Figure 4: Thunderbird Roundabout Configuration

2.2.3 Agronomy Road

The Agronomy Road intersection remains largely unchanged from the existing stop-controlled configuration; however, the new design is centered around safety improvements. To improve sightlines and pedestrian visibility, the large tree on the southeast corner is set to be replaced with low-rising vegetation. Further, new tree(s) will be planted on the northeast corner along with a new alignment for the sidewalks, pending an arborist analysis of the area. The sidewalk on the southeast corner is narrow and will be widened to accommodate increased foot traffic to and from the area due to the proposed multi-use path. Additionally, new upgraded lighting will be installed and signage for cyclists will be installed to alert them of the new multi-use path. The proposed configuration has been provided in Appendix A, Drawing 6; and a stripped down sample is provided in Figure 5.

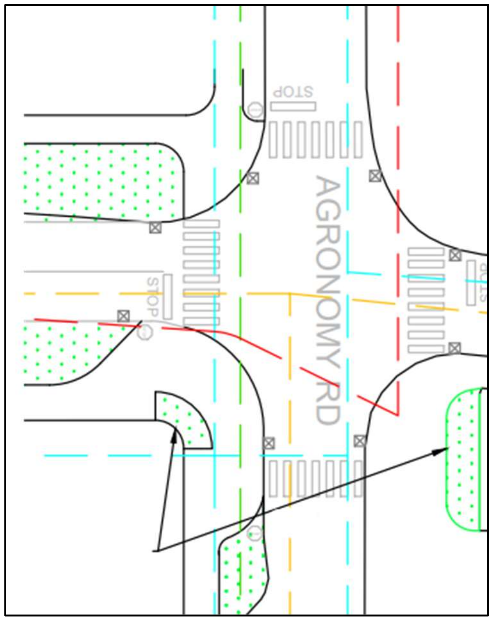

Figure 5: Agronomy Road Intersection

2.3 Multi-Modal Design

2.3.1 Multi-use Path

The keystone design element of the proposed design is the multi-use path that extends from W16th to Thunderbird Boulevard. The 5m wide, asphalt-paved pathway is warranted via vehicle and pedestrian volumes under the BC Active Transportation Guidelines (BCATDG) for the East Mall corridor, and connects the heart of campus to Westbrook Village, the future Stadium Neighborhood, and the Thunderbird Sports Fields. The BCATDG (2019) and UBC's Design Guidelines were primarily referenced in the development of the multi-use path.

2.3.1.1 Subgrade Design

As stated by the City of Vancouver Engineering Design Guidelines (2019), this multi-use pathway is classified as a "protected bicycle lane." This standard specifies that the pathway by decreasing elevation will have a minimum of 50mm MMCD Upper Course #2/9.5mm and 150mm Granular Base. The grass median does not require a standard sub-grade and will be constructed as fill. The standard cross section of the pathway can be found on Drawing No. 14 in Appendix A and the figure below.

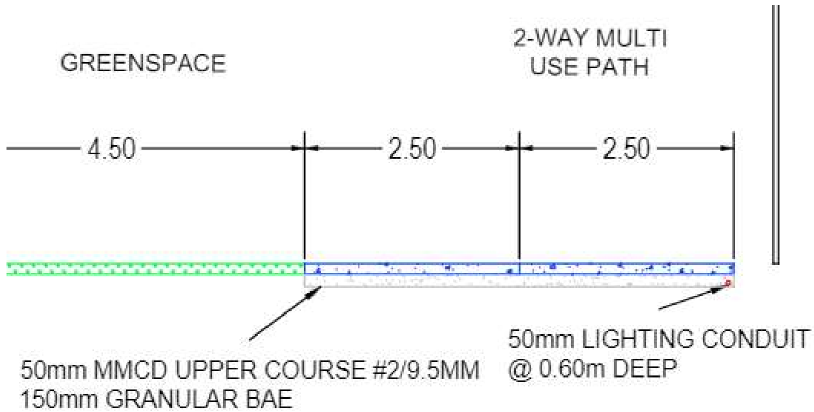

Figure 6: Typical Multi-use Path Sub-grade

2.3.1.2 Pavement Markings and Signage

The path is separated into separated 2.5m N/S lanes though pavement markings and is shared use for bicycles, pedestrians, and other active modes. Navigation kiosks in accordance with UBC's Design Guidelines are planned along the length of the multi-use path, with implementation being deferred to align with the development of the new stadium neighbourhood. The pavement marking and signage drawing package, shown in Appendix A Drawings no. 7-13, can be referenced for the full length of the path.

2.3.1.3 Lighting and Safety

Upgraded pedestrian-priority lighting fixtures (Saturn 2 Cutoff Luminaires) will be installed 35 m apart, in reference to UBC's Design Guidelines for Pedestrian Priority corridors. These fixtures are designated for 'Pedestrian Priority' zones, which the East Mall corridor falls on the boundary. This will provide a safe connector from the heart of campus to the Westbrook Village residential area. Rest benches are provided along the length of the multi-use path for accessibility of all vulnerable users.

2.3.1.4 Additional Considerations

The multi-use path can provide additional benefits to the community through the integration of decorative art, or pavement designs that can highlight UBC's commitment to equity and diversity. Further, collaboration with First Nations communities can be explored for naming and culture integration through art displays or banners.

2.3.2 Covered Bicycle Parking

The bicycle canopy is located North of Stadium Road on the East side of East Mall. The goal of this area is to provide users of the sports facilities a safe place to house their bicycles. The addition of this structure will further incentivize mode shift which aligns with UBC's 2050 goals. Further providing bicycle parking can act as a transportation demand measure which may reduce the amount of vehicle parking spaces in the new stadium neighbourhood. Full details of this structure of this design can be found in Section 2.8.2 Bicycle Canopy.

2.3.3 Crosswalk Upgrades

Integration with the proposed multi-use path is of utmost importance for the two major mid-block crossing locations along the corridor at Stadium Road and at Eagles Drive. The ramp letdowns have been designed in conformance with the City of Vancouver's 'Single Curb Ramp' standard detail, which lead off into standard zebra pavement markings. The Rapid Rectangular Flashing Beacons (RRFBs) detail incorporates a push button, required signage, and solar charging equipment; these RRFB units are warranted under a study by *Ashur & Alhassan (2015)* including expected crosses per day and vehicle volumes along the roadway. The mid-block crosswalk designs are accentuated by parking offsets to increase pedestrian visibility. The RRFB detail design, prepared originally by Kerr Wood Leidal for the Dsitrcit of Saanich, has been provided in Figure 7.

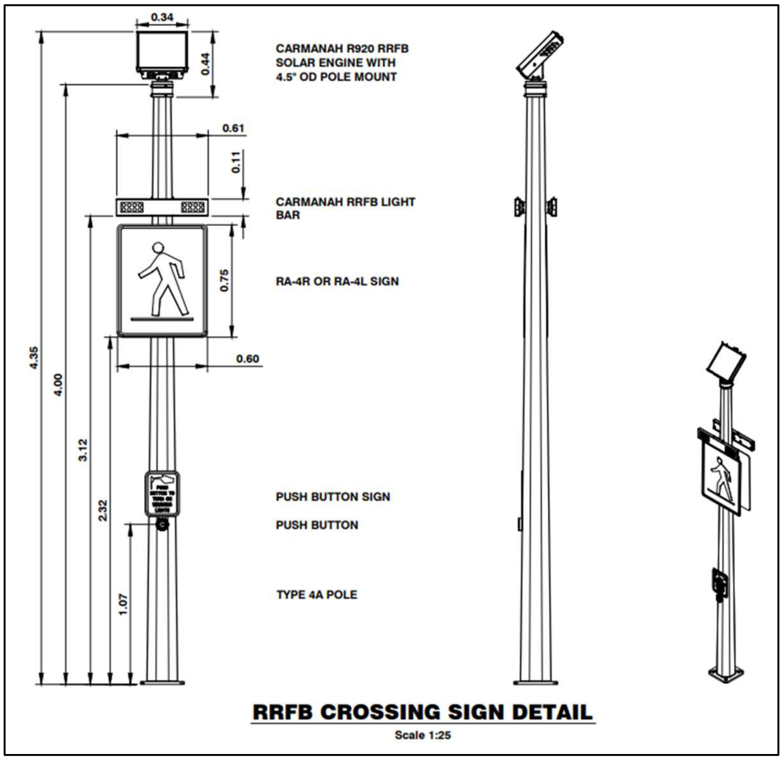

Figure 7: RRFB Detail

2.3.4 Bus Stops

The corridor design will retain bus stops in their current positions on East Mall at the Eagle Dr crossing. This will eliminate unneeded planning with TransLink, public consultation, and confusion for bus users and bus drivers. TransLink will still be informed of the project as a stakeholder and engaged with as needed to satisfy any requirements for upgrading a bus route corridor. Bus stops will be upgraded to 20m long (vs. 15m existing) to provide ample room for buses and possible future bus upgrades, as the width of the roadway is being constrained along the corridor. The bus stops are illustrated as a part of the standard detail designs in Appendix A, Drawing 23.

2.4 Pick-up / Drop-off Lane

The one-way, ~60m pick-up/drop-off lane is located on the Northbound side of East Mall and has been designed to accommodate the significant volume of thunderbird field users. Consisting of 18 drop-off spaces oriented at 45°, the wide 2.7m stall width is optimal for dropping off children, while the 5.8m stall depth in accordance with City of Vancouver design standards. The 15-minute timed restrictions will be accentuated by enforcement during peak hours, and 4 additional spaces have been provided on the SB side of the street. The dedicated drop-off lane has a 1.5m buffer from the travel lanes and has been designed to maximize safety of the vulnerable field users. No stopping / blocking signage and pavement markings are integrated along the lane to maximize efficiency, as shown in the Signage and Pavement markings drawing package. A sample overview of the drop-off lane is shown in Figure 8.

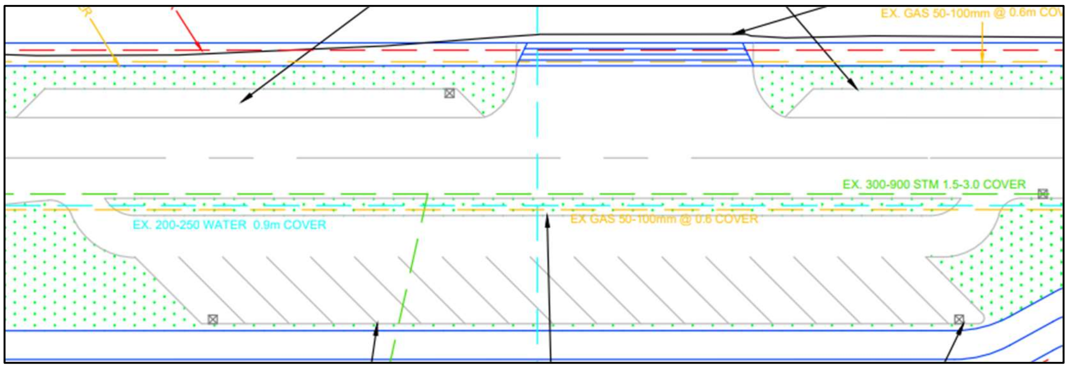

Figure 8: Pick-up Drop-Off Lane

2.5 Vehicle On-Street Parking

Parking capacity was slightly reduced to increase sight lines and pedestrian safety at all intersections with crosswalks; a sample calculation of the existing vs. required sightline distances for each crossing is provided in Appendix E. There are now 94 total stalls along the corridor, reduced from 107. A priority was placed on retaining on-street parking along all sections of East Mall with residences directly adjacent. All spots remain pay-parking, with the exception of four 15-minute drop-off spots directly across from the proposed drop-off lane. On-street parking spots are all 2.5 meters wide and 5.5 m long (in accordance with the CoV Design Guidelines), providing ample room for safe ingress and egress from the vehicle. A buffer zone has been provided between parked cars and pedestrian pathways on both sides of the roadway, further increasing the safety of both modes of transportation.

2.6 Stormwater Management

The existing Storm Water Sewer System at work area is sufficient in handling existing inflows of the redesign. A description of the work undertaken includes removing and replacing existing single and twin inlet catch basins and PVC leads that run from catch basin to manhole riser. New catch basins in conjunction with the CoV's Standard Detail S11.3 are to be installed at each side of an intersection, at pedestrian crosswalks, and at a maximum distance of every 75ft. Each catch basin is connected to the existing storm sewer system with 200mm PVC SDR35 pipe with a 2% slope as per CoV standards. Refer to Appendix A plan view drawings for location of catch basins, and for standard details.

2.6.1 Groundwater & Drainage

Stormwater management is required for all new development projects on UBC campus. Projects are required to incorporate design aspects that reduce the quantity of water that would flow offsite to slow the rate and amount of water that leaves the campus. Current stormwater management infrastructure on the UBC campus include large detention tanks, wet and dry ponds, and green infrastructure such as bioswales, rain gardens, and green roofs. UBC created the Integrated Stormwater Management Plan to:

- Reduce the flow of water off campus;
- Reduce the impacts of stormwater flows off campus; and
- Maintain or enhance water quality at campus boundaries to that it meets or exceed municipal best practices.

There are several underground utilities on the roadway. However, the deeper utilities (1.0-1.5m and below) are not a major concern. The existing Storm Water infrastructure is outlined in green and includes Storm manholes, mains, and miscellaneous. The 300mm to 900mm sized mains are buried 1.5m to 3.0m down on East Mall, north of University Boulevard. Other buried utilities include, electrical, communications at a depth of 0.6m, and natural gas lines at a depth of 50mm to 100mm. Sanitary Sewers are at a dept of 1.5m to 3.0m and ranging from 200mm to 450mm. The existing and proposed underground utilities are shown in the detailed design drawing package in Appendix A, Drawings 2-6.

The scope of the project does not require a full hydraulic analysis of the site. The existing Storm Water Sewer System is sufficient in handling existing inflows of the redesign. Incorporating improved landscaping and engineered green infrastructure will reduce the inflows entering the system. A description of the work undertaken includes removing and replacing existing single and twin inlet catch basins and PVC leads that run from catch basin to manhole riser. The City of Vancouver Engineering Design Manual outlines the following:

- Double catch basins with leaf catchers (side inlets) placed at all major low points (provide alternative overland route, system, or capacity to handle major storm where possible);
- Not located within painted crosswalks or curb ramps;
- Located at the beginning of the curb return or higher side of crosswalk;
- Prevent overflows to driveways, bicycle lanes, private properties, boulevards, and sidewalks;
- All catch basins located at low points should provide a double catch basin with leaf catcher (side inlet) if adjacent to treed boulevard.

Table 2: Catch Basin Type and Spacing

Type	Catchment Area / Spacing		
	Minimum	Preferred	Maximum
Typical Catch Basin Catchment Area New / Reconstructed Roads up to 4% Grade	250 sq.m	500 sq.m	600 sq.m
Typical Catch Basin Spacing All Roads	60m	-	150m

Table 3: Catch Basin Design

Characteristic	Requirement
Diameter Size	200mm
Type	PVC SDR35
Slope	2%
Depth	1.5m
Length	30m Max.

The final design incorporates 45 new catch basins that are connected to the existing storm water sewer system. 200mm PVC SDR35 Pipe connects the new catch basin to the existing manhole riser along the corridor. In total, approximately 900m of 200mm PVC pipe is required for the development. The catch basins are to be standard that conform to the City of Vancouver Standard Detail. To calculate the design flow for the drainage area, the rational method was used, which can be found in Appendix E. The site area was segmented into eight distinct sub catchment areas based on the normalized elevation change, size, and land use. The final drawing package contains the Drainage Plan on Sheet 21.

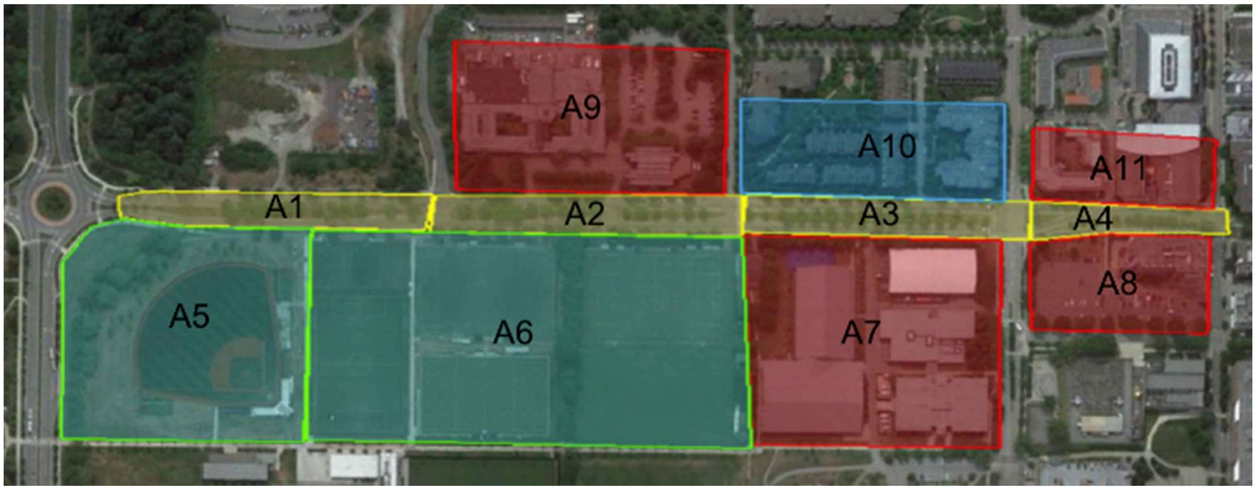

Figure 9: Drainage Sub catchments

Runoff Coefficients vary based on the slope of the ground, type of ground cover, surface, and development population density. The varying coefficient values are determined by the permeance of the ground surface. The least permeable surface resulted in the greatest run off, and thus a greater C value. The relevant Runoff Coefficients used for the sub catchment areas are outlined in Table 4.

Table 4: Runoff Coefficients

Character of Surface	Runoff Coefficient, C
Average (2-7%) Lawns, Sandy Soil	0.13
Average (2-7%) Lawns, Heavy Soil	0.18
Drives and Walks	0.80
Asphalt Streets	0.83
Concrete Streets	0.88

2.6.2 Green Infrastructure

The purpose of green infrastructure is to improve water quality, reduce storm runoff, increase aesthetics, and improve ecology of the area. There are several types of engineered green infrastructure that are to be included in the final design, such as green landscaping through a combination of swales and rock gardens. Along the corridor, approximately 100m^2 of greenspace is to be added. The infrastructure will promote stormwater detention and disposal and retention through infiltration and evapotranspiration. Table 5 and Table 6 indicate Green Infrastructure Design Targets, and typical costs, respectively.

Table 5: Green Infrastructure Design Targets

Objective	Target	Standard
Volume Reduction	Retain the first 24mm of rainfall (50% of the 6 month – 24-hour return period storm, 70% of the average annual rainfall volume)	Infiltrate, evapotranspire and reuse rainwater to the greatest extent practicable.
Water Quality	Treat the first 48mm of rainfall (6 month – 24-hour return period storm, 90% of the average annual rainfall volume)	Remove 80% of Total Suspended Solids for particles > 50microns(1); the total concentration of sediment can be no more than 75mg/L(2).

Table 6: Green Infrastructure Type and Cost

Type	Cost ($ / sq. ft)
Absorbent Landscaping - Infiltration Swales / Trenches	50
Rain Gardens	20

2.7 Landscape and Greenspace Design

One of the main features of our design is the incorporation of greenspace and aesthetic landscaping. Although the landscape design will be contracted to a landscape design firm, we would like to set the precedent and the following guidelines for the firm to reference. The landscaped medians will consist of grass, trees, shrubs, and other plants. In addition to these typical features, our design will include rock gardens within the medians to promote groundwater infiltration and reduce the amount of runoff to the storm sewer system. Perforated pipe such as Big-O pipe will be installed beneath landscaped medians for two purposes; to collect surface water and distribute it into the ground, and to allow excess groundwater to drain into the pipe to reduce unnecessary pore pressure. The perforated pipe will allow all excess water to flow into a retention tank to be used for irrigation or other purposes if treated. No water runoff from the road will be collected in these retention tanks to avoid contamination from oil and other automotive fluids, or other hazardous waste which can be transported from the road into the drainage system. This groundwater retention system provides a solution for the underground water storage option which SEEDs is researching for the Stadium Neighborhood to reduce pore pressure in the adjacent cliffs.

In addition to these design objectives, the design team suggests the list of following plants and landscaping features to achieve the aesthetic goals of creating a natural environment local to the BC coast:

- Salal's
- Ferns
- Rock Gardens (4in-24in diameter)
- Yews
- Cherry Blossoms
- Lily of the Valley
- Grasses
- Red Maples
- Bark Mulch
- Evergreen Trees

A majority of the planned upgrades at East Mall and Agronomy Road are related to landscaping changes to increase sightlines. An investigation into the large tree outside the Starbucks will be performed to determine to what extent the roots infiltration the structural capacity of the roadway and the nearby building; if this tree can be removed, an arborist will be hired to examine the additional impacts and help determine what best practice landscaping can replace the tree. For the north-east corner, the separation between green spaces will be removed to stream pedestrians through one route onto the crosswalks, which will help with sightlines of pedestrians during busy peak hours. A sample of this new landscaping configuration has been provided in Figure 5 above. We will be removing trees in favor of creating a more efficient green landscaped corridor; rock gardens, swales, and flowers are better utilized to meet City of Vancouver and UBC standards.

2.8 Structural Designs

2.8.1 Pedestrian Weathering Canopy

With the goal of improving pedestrian walking experience on campus, the weathering canopy design was decided to be incorporated into this project based on its likelihood to be used, the overall improvement of pedestrian safety, the ease of construction and its relatively low capital cost comparing with the pedestrian underground tunnel option. The sections below describe the key aspects of the Detailed Weathering Canopy Design and analysis.

The structures are located on the north side of the roadway in front of the McGavin and Donald Rix buildings, with an opening left in between the two buildings to provide vehicle access for emergency vehicles and trash trucks (see in the figure below). The length of the canopy adjacent to the McGavin Building is 36m and the canopy adjacent to the Donald Rix building is 32m. Both structures have a width of 5m and a minimum height of 2.5m with 1:12 roof slope. The detailed drawings for the structural canopy are provided in Appendix A.

Figure 10: Weathering Canopy Location and Vehicle Access Opening

2.8.2 Bicycle Canopy

The goal of this area is to provide users of the sports facilities a safe place to house their bicycles. A secondary objective is to further incentivize mode shift in throughout the campus. The bicycle canopy is located North of Stadium Road on the East side of East Mall. This cantilever canopy structure rests on a 4 m wide 16 m long and 250 mm deep concrete pad. The structure's dimensions are a 5m in width and a minimum height of 2.5m with 1:12 roof slope. The canopy covers twenty of UBC's standard exterior bicycle racks (Model: SU20-E-G-CB). Full details of this structure can be found on Drawing No. 16 in Appendix A.

2.8.3 Structural Member Sizing

Both the pedestrian and bicycle canopies' structural members are steel hollow sections sized based on the SAP2000 modeling results, assuming the specified yield strength of the steel members being 300MPa. For each type of the members (columns, longitudinal beams and transverse beams), the maximum design loads (axial, shear and bending moment) were extracted from the analysis report, and then checked against various failure mechanisms.

For the columns, the following failure mechanisms were considered:

- Local buckling
- Shear resistance
- Cross-sectional strength
- Overall member strength (85%)

For the beams, the following failure mechanisms were considered:

- Moment resistance for laterally supported beams
- Shear resistance

The table below summarizes the final section sizes for the structural members:

Table 7: Member Sizing

Member	**Weathering Canopy**		**Bicycle Canopy**	
	Section	Utilization	Section	Utilization
Column	HSS102x102x8.0	85.0%	HSS152x152x13	81.2%
Longitudinal Beam	HSS114x114x4.8	75.4%	HSS114x114x4.8	62.0%
Transverse Beam	HSS178x178x6.4	68.9%	HSS178x178x6.4	71.3%

For the detailed sizing and structural design calculations, see in Appendix E arranged using MathCAD 20.

2.8.4 Foundation Design

The canopy column foundation is a concrete pedestal sitting underground with base plates, anchor bolts and welds connecting the concrete and the steel column. Comparing the force resultant in SAP2000 model, the loading difference between the corner columns and the side columns is small. In order to save the effort for designing and construction, only the side column foundations will be designed in detail, and the corner foundations are going to use the same design since the demand in the side column foundation is more critical and governs the design.

The design loads for the foundation were obtained from the SAP2000 analysis report. The structural support was modeled as a “fixed” support as the foundations are intended to be designed as moment connections. All the concrete used for foundation design are assumed to have a specified compressive strength of at least 25MPa, and the reinforcing steel has a specified yield strength of 400MPa.

The failure mechanisms considered are:

For concrete pedestal:

- Concrete compressive strength
- Concrete (column) moment resistance
- Combined axial and moment resistance
- For base plate:
  - “m” edge check based on compression
  - “n” edge check based on compression
- For weld connection:
  - Shear strength of weld metal
  - Shear strength of base metal
  - Minimum and maximum weld size requirements

For cast-in anchor group:

- Anchor rod tensile strength
- Concrete tensile breakout strength
- Concrete pullout strength
- Concrete side-face blowout strength
- Anchor rod shear strength
- Concrete shear breakout strength
- Concrete pryout strength
- Combined tension and shear strength

Both the pedestrian and bicycle canopies’ foundation consist of 500mm deep concrete pedestal (400 x 400mm plan dimension) below ground, a 300mm x 300mm x 22mm base plate, and 4-3/4” anchor bolts connecting all parts together. The dimension checks for the geometry of the base place, anchor bolts and pedestal, according to CSA A23.3 Annex D, were conducted both manually and by Hilti PROFIS (web version), and the below is a schematic drawing of the foundation design generated by Hilti PROFIS:

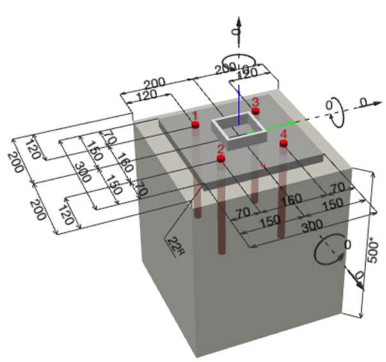

Figure 11: Canopy Foundation Design Arrangement

For the detailed sizing and structural design calculations, see in Appendix E arranged using MathCAD 20.

2.8.5 Shear Connection

The connection between the beams and the columns were designed as shear connections transferring shear forces only (no moment transfer). Modeled as “pin” connections in SAP2000, the analysis result provides the factored shear demands, and the connections were designed based on these values.

The failure mechanisms considered are:

- Bolt shear resistance
- Bolted member bearing capacity
- Block shear resistance
- Member rupture capacity

Between longitudinal beams and columns, the shear connection consists of an L89x89x9.5 angle with both legs bolted to the face of HSS sections using 2-1/2” A325M bolts in a single row. For the transverse beams and the columns, 2-10mm thick base plates, a gusset plate which is to be shop welded to the two base plates, and 2 rows of 2-1/2” A325M bolts are used to connect to the face of HSS sections. The two shear connections are different because the canopy roof has a 1:12 slope for drainage purpose. A PVC drainage channel will be installed on the long side of the slope end, and then connect to a vertical drainage pipe and a concrete splash pad on the ground level.

For the detailed sizing and structural design calculations, see Appendix E arranged using MathCAD 20.

3.0 Design Criteria

3.1 Design Loadings

Team 11 completed thorough research to ensure that all design criterion used for the project was up to date and correct. To better organize this criterion it was broken up into two main components of project disciplines, Transportation and Structural.

3.1.1 Transportation

For the road design, the main design loadings considered are the roadway and the multi-use path loadings. These loadings for the roadway are specified in the City of Vancouver Engineering Design Guidelines (2019). Roadway loadings to are to be designed to the standard of "Higher Zoned Collector" which is greater than 100,000 trips per year. The loadings for the multi-use path are specified in the BC Active Transportation Design Guidelines (2019). Multi-use path loadings are to be designed to meet greater than 4000 motor vehicles a day. Other safety considerations were met by Suleman & Alhassan (2015) where Rapid Rectangular Flashing Beacons (RRFBs) will be designed to meet greater than 800 peak vehicle volumes, 30-75 crossings per hour.

3.1.2 Structural

For the canopy structures, the primary design loads considered are the dead load D, snow load S, wind load W, and seismic load E(see values in the table below). The dead load includes both the structural self-weight and the permanent weight of the objects on the canopy roof, such as the plants (see in section 3.1.2.1) and drainage conduits. The snow load, wind load and seismic load are calculated based on National Building Code of Canada (2015) Division B – Section 4.1 – Structural Loads and Procedures. The snow load and wind load are calculated manually considering all the parameters mentioned in the NBCC-2015 codes. The seismic load, previously estimated using Earthquake Load Calculator 2020 during preliminary design stage, was now calculated in detail based on NBCC Earthquake loads during detailed design stage.

3.1.2.1 Green Roof Modules

With the addition of new weathering canopies to the UBC campus, it provides the opportunity for a green and sustainable design. The ‘Tree Canopy Project’ is a research project by multiple faculty members at UBC to incorporate green storm water infrastructure into high density urban spaces. Our canopy design can integrate the “Sedum Roof” with Fixodrain ® XD 20 to capture stormwater runoff (Tree Canopy Project 2018). This roof module is still in the prototype phase to research the effectiveness, but the end goal is to incorporate these into UBC's Sustainability and Green Policy. The impact of these modules to the structural integrity of the canopy is minimal as it has an estimated superimposed dead load of less than 2 kPa.

3.1.2.2 Load Combinations

According to NBCC Division B Section 4.1 Structural Loads and Procedures, the load combinations considered for structural analysis are:

Table 8: Design Loads

Dead Load, D (kN)	SW+2.25kPa
Snow Load, S (kPa)	1.8
Wind Load, W (kPa)	1.38
Seismic Load, E (%DL)	40%

For the detailed sizing and structural design calculations, see Appendix E arranged using MathCAD 20.

- 1.4D
- 1.25D + 1.0S
- 1.25D + 0.4W
- 1.25D + 1.5S
- 1.25D + 1.5S + 0.4W
- 1.25D + 1.4W
- 1.25D + 1.4W + 1.5S
- 1.0D + 1.0E
- 1.0D + 1.0E +0.25S

Where D is the dead load of the structure, S is the snow load, W is the wind load, and E is the earthquake load, all calculated in accordance with the NBCC.

3.2 Adopted Design Life

3.2.1 Transportation

The guiding criteria was design life of road which is referenced in the UBC Technical Guidelines. It states that the minimum design life for all classifications of roads must be 20 years.

3.2.2 Structural

The guiding criteria was design life of all structural elements are also referenced in the UBC Technical Guidelines. It states that the minimum design life for all structural elements must be 100 years.

3.3 Standards and Software Packages

The following codes and standards primarily referenced in this design are:

- City of Vancouver Engineering Design Guidelines (2019) + Standard Details
- UBC Vancouver Campus Plan Part 3: Design Guidelines (2010)
- BC Active Transportation Design Guidelines (2019)
- CSA A23.3 (2014), CSA S16 (2019), Handbook of Steel Construction – 11th Edition
- Manual of Standard Traffic Signs & Pavement Markings, MoTI (2000)
- UBC Exterior Signage Standards and Guidelines

The following software's used to complete this design are:

- AutoCAD: Drawing Preparation, AutoTurn Roundabout Analysis
- Synchro 11: Traffic Modelling, Intersection Design (see Figure 12)
- SAP 2000: Structural Analysis

Figure 12: Sample of Existing Synchro Model

3.4 Other Design Aspects

3.4.1 Economic

One of the main project objectives are to minimize costs and maximize safety for all roadway users. To enhance this criterion our team has created a versatile cost estimate found in Section 4.6. Following this cost estimate, a Benefit Cost Analysis was completed by BC Ministry of Transportation's (MOTI) shortben.xls spread sheet. This spreadsheet considers a comparison of the proposed project and a 'do-nothing' scenario. Some of the key considerations in this spreadsheet to calculate a benefit cost ratio are safety, travel times, project costs, maintenance, and discount rates. The benefit cost ratio outputted from the sheet is 1.16 which indicates this project should proceed from an economic standpoint, and that the user benefits outweigh the total project costs. The Net Present Value, using a conservative interest rate of 6%, was determined to be ~$ 500,000. The full benefit cost analysis spreadsheet developed for the East Mall Redesign can be found alongside the Class C cost estimate in Appendix C.

3.4.2 Environmental

An environmental impact assessment should be undertaken to ensure that over this projects lifetime any potential harmful effects will be analyzed. Aligning with UBC's sustainability goals, this project main environmental design criteria is to increase user mode shift, incorporate green infrastructure and enhance stormwater management. We assume that there will be opportunities for environmental impact mitigation throughout the construction period; this is defined in Section 4.1.2 Waste Disposal + Recycling Plan. Environmental sustainability will be completed by following the Environmental Mitigation Procedures provided by the Government of BC. These steps include:

- Establish the team involved in identifying environmental values;
- Identify the boundaries of the assessment area;
- Identify the impacts associated with the proposed activity and the corresponding impact boundary;
- Identify a comprehensive set of environmental values and associated components for the assessment area;
- Identify a relevant subset of environmental values and associated components for the assessment area;
- Provide a rationale;
- Submit information to the Province.

3.4.3 Societal

Since UBC lays on the unseated grounds of the Musqueam territory, there is a potential for societal issues during permitting and designing. All measures must be taken with the respective parties to ensure that appropriate measures are conducted during these stages of the project. Furthermore, the staff and students of UBC must be considered as they are the primary users of the campus. It is a top priority to design a functional corridor that will serve the UBC community for years to come.

3.4.4 Regulatory

There are multiple regulatory bodies within the scope of this project. For the East Mall Redesign Project, the primary regulatory bodies are listed below, and an expanded list is available in 4.1.1 Permitting.

1. **Federal:** Transport Canada
2. **Provincial:** Ministry of Transportation and Infrastructure
3. **Municipal:** City of Vancouver
4. **Local:** UBC and the University Endowment Lands

3.4.5 Risk Management

Team 11 completed a risk management workshop in March 2021 to create a risk register for the project. This workshop outlined the potential risks of the project along with the magnitude of risk, likelihood, and consequence rating. Afterwards, control systems were brainstormed to minimize these risks. An excerpt of the developed sheet is shown in the figure below.

Risk Name	Risk Description	Likelihood	Consequence	Risk Rating	Control Measures
New GHG Emissions	New road generates emissions from vehicular traffic	Rare	Moderate	Low	Follow air quality management criteria
Road Safety	Potential for increased crashes due to changing road conditions during construction phase	Possible	Moderate	Medium	Traffic Management Plan followed and road safety audit possibly to be completed
Habitat Disruption	Potential for habitat disruption due to added noise, light and vibration during construction activities	Minor	Possible	Low	Guidance from Qualified Enviromental Professional possibly needed

Figure 13: Excerpt from Risk Register

4.0 Construction Planning

There are multiple stages needed before construction can start. The following sections detail the duties required by the Project Manager such as construction requirements, permits, methods, schedule, and costs.

4.1 Construction Requirements

4.1.1 Permitting

Permits will need to be created and sent off to the Authority Having Jurisdiction (AHJ) six to twelve months before build start; but must not exceed 12 months due to expiry. The redesign of East Mall will require permits at different stages of the build project. The required permits are shown in Table 9.

Table 9: Breakdown of Required Permits and Justifications

Permit	Key Stakeholder Group	Rationale
Archaeological Impact Assessment	• Government of BC • Musqueam Indian Band	Earth removal on indigenous soil (Musqueam Territory) has potential for unburying indigenous artifacts.
Underground Conduit Extension	• UBC and other AHJs • BC Hydro • TELUS • FortisBC	Conduit Extension for electrical wiring to Rectangular Rapid Flashing Beacons
Tree and Root Removal/Relocation	• UBC and other AHJs • Local Arborist Companies	Removal of boulevard along East Mall
Multiple Traffic Control Permits	• UBC and other AHJs • Local Flagging companies	Removal of boulevard, road realignment, underground conduit extension, construction of round-a-bout.
Civil Permit	• UBC and other AHJs • Contracted construction company	Roundabout Construction
Civil Permit	• UBC and other AHJs • Contracted construction company	Curb-line Construction
Civil Permit	• UBC and other AHJs • Contracted construction company • BC Hydro • TELUS • FortisBC	Excavation, removal, and restoration of boulevard.

Permit designs will need to be prioritized as permit approvals are needed before the detailed design can be Issued for Construction (IFC).

4.1.2 Waste Disposal + Recycling Plan

The nature of the upgrade of the corridor along East Mall requires the disposal of significant amounts of concrete, asphalt, and timber. Integrating the removal of these materials with the construction plan and ensuring facilities can take the material in a timely manner help both keep the project on track and uphold our commitment to sustainability.

The asphalt and concrete to be removed are largely recyclable, and municipalities are actively requesting used asphalt and concrete for reuse in new road paving efforts. Per the City of Vancouver's "*Expression of Interest for Select Waste Concrete and Asphalt Disposal*" (2020), loads of asphalt and concrete greater than 100 tons will be accepted at $0 per ton to fill this demand.

The Government of British Columbia has guidelines laid out for the potential uses of waste wood products, which is of interest to the East Mall project due to the boulevard street trees that will be removed. Waste wood products can be transformed into 'hog fuel' or wood pellets, and then incinerated for power generation at energy plants. This becomes a particularly appealing option for this project, given that the Bioenergy Research Demonstration Facility on UBC's campus accepts such products, and is mere minutes away. So long as the material is appropriately ground down, it can be used to heat buildings on the UBC campus.

With these measures in place, we are able to significantly reduce our environmental footprint while disposing of waste in a timely manner, all while decreasing the cost of the project.

4.1.3 Traffic Management Plan

The 2020 Traffic Management Manual for Work on Roadways (TMM) was used to categorize the East Mall Redesign project into an Initial Assessment Category and a Project Risk Analysis Category. These rankings provide an overall project category that influences what required Traffic Management is required. The project scored a 24 on the initial assessment and a 26 on the risk analysis, categorizing the project as "Category 2". The required measures have been integrated into the construction sequencing described in **Section 4.2**; refer to the 2020 TMM for a full list of Category 2 requirements.

4.2 Construction Sequence

The Construction Plan will be broken up into 3 Phases: South Bound Lane Construction, North Bound Lane Construction, and Roundabout Installation at the Thunderbird Intersection. The Construction Schedule is expected to take a total of 69 days.

4.2.1 Phase 1 – South Bound Lane Construction

The first phase will commence with 2-way traffic set-up in the north bound lane and the closure of the south bound lane. Construction will first be completed on the south bound lane. Any tree removal will be completed and then the asphalt and median will be removed. Levelling and subgrade will be completed, followed by paving, then painting and landscaping. Streetlights, signage, and RRFB units will be installed as the final step.

4.2.2 Phase 2 – Greenspace Construction on Northbound Lane

In the second phase, the newly completed south bound lane will be reopened as 2-way traffic and the north bound lane will be closed. The second phase ends with the completion of the bike path and greenspace. The asphalt as well as existing bike path will be removed and the landscaping for the median and subgrade for the multi-use path will be completed. This will be followed by electrical work for the path lighting. Finally, paving for the pullout lane, bike path, and greenspace will be completed and the north bound lane will be reopened.

4.2.3 Phase 3 – Roundabout Construction at Intersection of Thunderbird Boulevard

For Phase Three, the intersection will be closed at Thunderbird Boulevard. South bound and North bound traffic will be re-routed, and the roundabout will be installed, finishing construction via Stadium Road and Eagles Drive and north bound traffic via Agronomy. Traffic lights will be removed at thunderbird intersection and the roundabout will be installed. The intersection will then be reopened.

4.3 Service Life Maintenance Plan

For the maintenance plan, there are 6 key actions. The list below details the components of these key actions, and what must be considered for maintaining the proposed East Mall Corridor.

1. **Winter Maintenance**
   - Sidewalk Snow Clearing
   - Bicycle & Pathway Network Snow Clearing
   - Bicycle Route De-Icing Considerations
   - Snow Clearing Vehicle
2. **Facility Sweeping**
   - Sidewalk Facilities
   - Bicycle & Multi-Use Path Facilities
3. **Surface Conditions & Quality**
   - Sidewalk Facilities
   - Bicycle Facilities
4. **Landscaping & Vegetation Management**
   - Overgrown Grass
   - Bushes
   - Tree Branches
   - Debree Management After Major Storms
   - Root Barriers to Mitigate Surface Damage
5. **Signage & Pavement Markings**
   - Paint
   - Epoxy
   - Thermoplastic and Tape
6. **Temporary & Special Event Considerations**
   - Route Closures & Major Detours
   - Proper Signage
   - Facility Use & Hoarding Management
   - Provide Fire and Police Dept w/ map route system, along with access points to gates/bollards
   - Enforce speed limits and other rules of the road
   - Enforce all trespassing laws for people attempting to enter adjacent private properties

4.4 Anticipated Issues

Our main concern is Safety. This is due to heavy machinery and a high density of vehicular and pedestrian traffic. For Traffic management active modes along the corridor must be maintained as well as access to residential, business, and recreation facilities, especially during peak hours. Striking underground utilities is also a cause for concern during excavation. Other issues are complaints that may arise from residents of the area.

4.5 Construction Schedule

The anticipated timeline for the completion of this project is just under 70 days from the first closure to the final intersection opening. It was important to consider the context under which the project was being built, and as such concessions for crew size and productivity were made in accordance with proper social distancing during the ongoing Covid-19 pandemic. The sequencing of the construction schedule is described in detail in Section 4.2 above. A full Gantt chart of the proposed project schedule can be found in Appendix B.

4.6 Class C Cost Estimate

The Class C cost estimate considered multiple aspects of the construction build, including installation, major and minor material costs including but not limited to asphalt, steel, and conduit. Arborist costs for brushing and tree removal, traffic accommodation, and maintenance costs were also included. The final cost estimate breakdown, showing the major categories of each cost, is shown in Table 10.

Table 10: Class C Cost Breakdown

Final Estimates:		**Costs**
RRFB Units and Civil Work		$ 84,000.00
Multi-Modal Path		$ 854,000.00
Boulevard Excavation/Fill and Paving		$ 639,000.00
Installation of Roundabout		$ 161,000.00
Asphalt Road Paving of East Mall Corridor		$ 1,023,000.00
Pedestrian Canopy		$ 33,000.00
Bicycle Canopy		$ 6,000.00
Drainage Network		$ 276,000.00
Arborist		$ 65,000.00
Traffic Accommodation		$ 87,000.00
Maintenance Plan		$ 323,000.00
10% Contingency		$ 355,100.00
	Total Cost:	**$ 3,906,100.00**

With an added 10% contingency of $355,00.00, the final cost estimate is $3.9 million. Appendix C highlights the full detailed cost estimate breakdown.

5.0 Next Steps

This design report represents the final step before construction, and as such the next steps would be to begin applying for the necessary permits for the work required. Notably, many of the required permits have long leads times, and so this should be done in a timely manner to ensure that construction commences swiftly.

Additionally, further stakeholder consultation and education can be undertaken to ensure that the community fully understands the context in which this project is being build. Integration with the future development in the Stadium neighbourhood will be important, as will managing the expectations of residents along East Mall for the construction process. Proactive engagement with these individuals can help to smooth over points of conflict that otherwise may arise due to the ongoing construction.

While this report represents the conclusion of Team 11's scope of work, we would be willing to work further with the client to oversee stakeholder consultation or overcome construction challenges that may arise. It should be noted, however, that many of engineers who have acted as points of contact over the duration of this project will be moving on.

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Appendix A: Issued for Construction Drawings

EAST MALL RE-DESIGN PROJECT

PRODUCED BY AN AUTODESK STUDENT VERSION

PRODUCED BY AN AUTODESK STUDENT VERSION

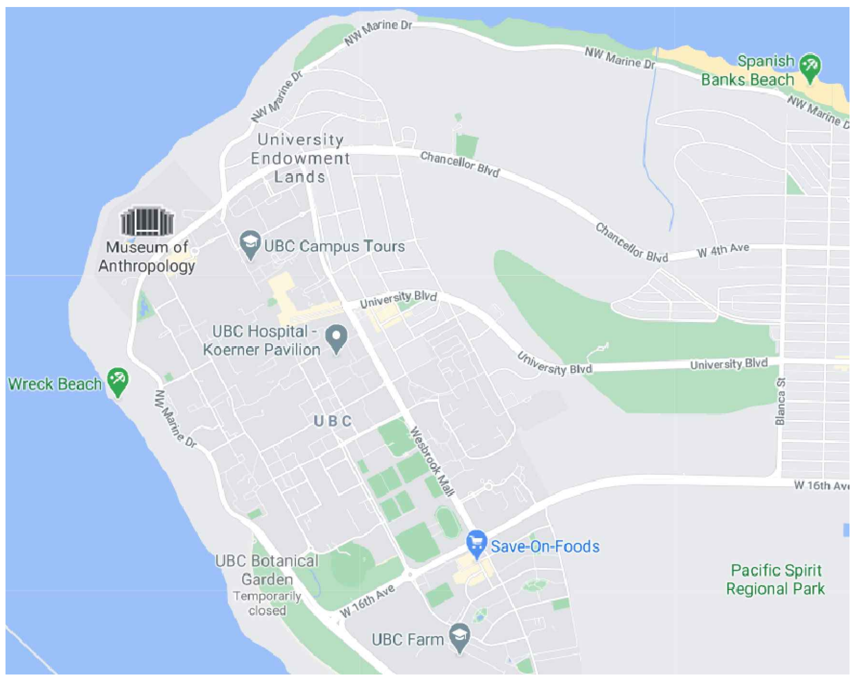
Corona Consulting

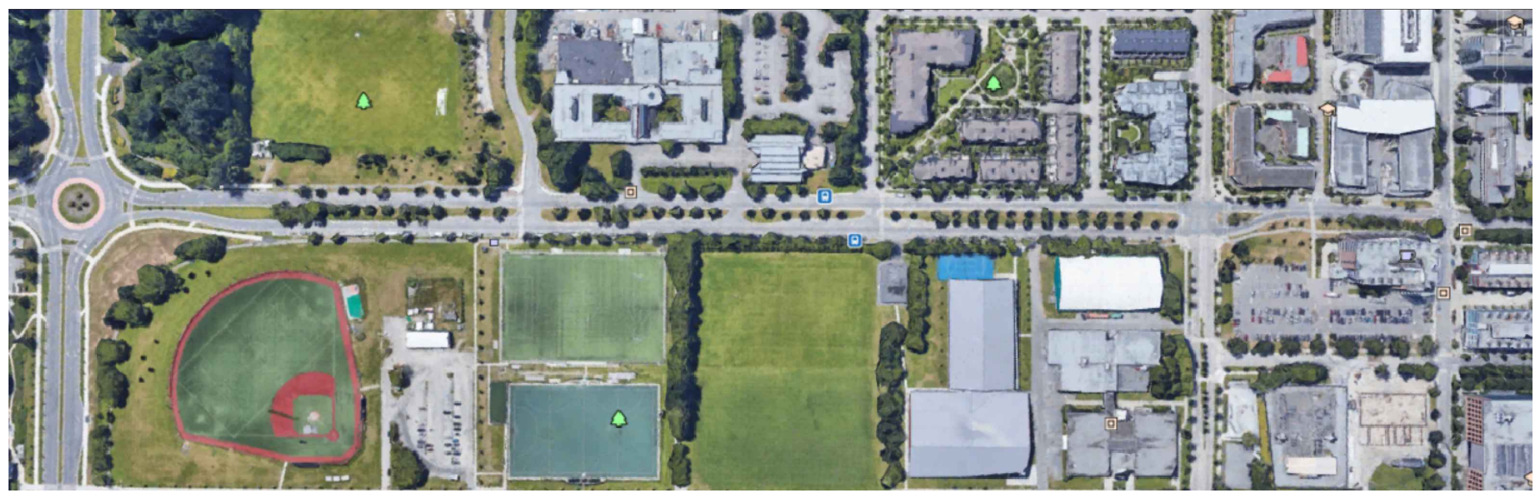
520 Bates Road, Richmond, BC

PREPARED FOR:

University of British Columbia – UBC SEEDS (Social Ecological Economic Development Studies) Sustainability Program
2210 West Mall
Vancouver, BC V6T 1Z4

DRAWINGS SHEETS





PRODUCED BY AN AUTODESK STUDENT VERSION

GENERAL NOTES

1. READ ALL STRUCTURAL/CIVIL DRAWINGS IN CONJUNCTION WITH ALL CONTRACT DOCUMENTS, INCLUDING REFERENCED ELECTRICAL, MECHANICAL, VENDOR DRAWINGS, AND SPECIFICATIONS.
2. THE CONTRACTOR FOR ANY PORTION OF WORK SHALL VISIT THE SITE AND SHALL BE THOROGHLY FAMILIAR WITH ALL THE PHYSICAL FEATURES THAT MAY AFFECT THE WORK IN ANY WAY
3. FIELD MEASURE AND MAKE ADJUSTMENTS TO SUIT EXISTING CONDTIONS
4. THE CONTRACTOR SHALL KEEP THE SITE CLEAN AND FREE OF ALL CONSTRUCTION DEBRIS DURING THE PROCESS OF CONSTRUCTION AND LEAVE THE SITE CLEAN UPON COMPLETION OF WORK OR PORTIONS OF THE WORK.
5. CONSULTANT MUST APPROVE ALL DEVIATIONS FROM THE WORKING DRAWINGS. THE CONTRACTOR MUST KEEP AN ACCURATE RECORD OF ALL CHANGES FROM THE ORIGINAL INFORMATION SHOWN ON THE CONSTRUCTION DRAWINGS.
6. IF DISCREPANCIES EXIST BETWEEN DRAWINGS AND SPECIFICATIONS, CONTACT THE ENGINEER FOR REVIEW AND APPROVAL PRIOR TO PROCEEDING.
7. CONTACT BC 1 CALL (604-257-1900) TO OBTAIN UTILITY LOCATION INFORMATION 1-2 WEEKS PRIOR TO CONSTRUCTION.
8. CONSTRUCTION TO BE COMPLETED IN ACCORDANCE WITH THE REQUIREMENTS AND SPECIFICATIONS OF THE MOST RECENT VERSION OF THE CITY OF VANCOUVER'S ENGINEERING DESIGN MANUAL, COV STANDARD DETAIL DRAWINGS, COV ENGINEERING CONSTRUCTION SPECIFICATIONS, AND THE MASTER MUNICIPAL CONSTRUCTION DOCUMENT (MMCD) UNLESS OTHERWISE NOTED.
9. MAINTAIN ON-SITE COPIES OF THE MOST CURRENT SET OF DESIGN DRAWINGS AT ALL TIMES MARK UP IN RED ANY FIELD REVISIONS OR APPROVED DEVIATIONS FROM THE DESIGN. COPIES OF THE MARKED UP DRAWINGS TO BE SUBMITTED TO THE ENGINEER PRIOR TO COMPLETION OF CONSTRUCTION.
10. OBTAIN ALL PERMITS AND LICENSES PRIOR TO CONSTRUCTION AND ENSURE THAT ALL APPROVALS REQUIRED FOR THE WORK HAVE BEEN OBTAINED.
11. USE EXTREME CARE WHEN WORKING NEAR EXISTING SERVICES AND INFRASTRUCTURE. ALL SERVICES AND INFRASTRUCTURE DISTURBED DURING CONSTRUCTION SHALL BE RESTORED THE ORIGINAL OR BETTER CONDITION AND TO THE SATISFACTION OF THE OWNER OF THE SERVICE, ENGINEER OF RECORD, AND THE CITY ENGINEER.
12. 18. EXISTING ROADWAY NOT INCLUDED IN THESE PROPOSED WORKS SHALL BE KEPT CLEAN AND CLEAR FOR THE DURATION OF CONSTRUCTION AND LEFT IN SAME CONDITION AS PRIOR TO CONSTRUCTION. SURROUNDING STREETS SHALL BE SWEPT DAILY IF NECESSARY.
13. PEDESTRIANS AND THE GENERAL PUBLIC SHALL BE PROTECTED AT ALL TIMES. ANY STREET OR SIDEWALK CLOSURE SHALL BE COORDINATED WITH THE CITY AT LEAST FIVE WORKING DAYS PRIOR TO COMMENCING WORK
14. THE ENGINEER IS RESPONSIBLE TO DIRECT THE CONTRACTOR IF REQUIRED, FOR THE DAY TO DAY OPERATION OF THE PROJECT.
15. THE ENGINEER OF RECORD MUST NOTIFY THE ENGINEERING, PARKS AND ENVIRONMENT DEPARTMENT NOT LESS THAN FIVE WORKING DAYS BEFORE COMMENCING WORK ON MUNICIPAL RIGHTS-OF-WAY. A MINIMUM OF TWO WORKING DAYS NOTIFICATION IS REQUIRED PRIOR TO ANY CITY INSPECTION.
16. TRAFFIC CONTROL IS TO BE IMPLEMENTED IN ACCORDANCE WITH THE MINISTRY OF TRANSPORTATION AND HIGHWAYS 'TRAFFIC CONTROL MANUAL OR WORK ON ROADWAYS.
17. 20. THE ENGINEER OF RECORD SHALL PROVIDE CERTIFIED RECORD DRAWINGS.

ROADWORKS

1. ALL MANHOLE COVERS, VALVE COVERS, CATCH BASIN RIMS, AND LIDS OF ANY OTHER STRUCTURE OR UTILITY ARE TO BE ADJUSTED TO SUIT FINAL GRADES.
2. ALL LOOSE AND ORGANIC MATERIALS ARE TO BE EXCAVATED AND REMOVED FROM ROADWAY AS APPROVED BY THE ENGINEER PRIOR TO PLACING OF ANY ROAD GRAVELS.
3. ALL SUBGRADES TO BE COMPACTED TO 95% MODIFIED PROCTOR DENSITY.
4. CHANGES IN GRADE TO BE FORMED WITH SMOOTH CURVES.
5. TESTING OF ROAD MATERIALS AND COMPACTION TO BE COMPLETED IN ACCORDANCE WITH THE SDD .
6. SCORING PATTERNS FOR CURB RAMPS SHALL CONFORM TO CITY STANDARD DRAWINGS C8.1 OR C8.2 AND INDICATE DIRECTION OF TRAVEL IN TO CROSSWALK.
7. INSTALL ALL SIGNAGE, PARKING METER, AND BUS ID SLEEVES AS PER CITY STANDARD DRAWING C19.1, C19.2 AND C19.3.
8. BOULEVARDS ARE TO BE CONSTRUCTED TO THE CURRENT EDITION OF THE MASTER MUNICIPAL CONSTRUCTION DOCUMENTS (MMCD) AND CITY OF VANCOUVER SUPPLEMENTARY SPECIFICATIONS AND DETAIL DRAWINGS UNLESS OTHERWISE SHOWN ON CONTRACT DRAWINGS. BOULEVARDS TO BE SLOPED TO ICs WHERE APPLICABLE.
9. ALL CURBS ARE TO BE TYPE A AS PER CoV STD DETAIL DRAWING C4.1

ENVIRONMENTAL NOTES

1. ALL WORKS TO BE IN COMPLIANCE WITH CITY OF VANCOUVER, BC MINISTRY OF ENVIRONMENT AND FEDERAL FISHERIES REQUIREMENTS.
2. IMMEDIATELY STOP WORK AND NOTIFY THE ENGINEER OF ANY SUSPECTED ARCHAEOLOGICAL MATERIALS UNCOVERED DURING EXCAVATION.
3. PROVIDE DITCHING, SILT FENCING, CATCHBASIN SEDIMENT TRAPS, AND CONTAINMENT FACILITIES ARE REQUIRED TO PREVENT DISCHARGE OR SEDIMENT FROM WORK AREA.
4. ALL TEMPORARY FILL SLOPES AND STOCK PILES TO BE PROTECTED FROM WEATHER EROSION.
5. ALL EXPOSED SLOPES TO BE PROTECTED FROM WEATHER EROSION AND SEEDED AS SOON AS PRACTICABLE.

DRAINAGE NOTES

1. ALL CATCH BASINS TO BE RELOCATED AS SHOWN IN DRAWINGS, DAMAGED CATCH BASINS TO BE RECYCLED, AND NEW CATCH BASINS TO BE ORDERED FROM THE THE CITY OF VANCOUVER 4 WEEKS AHEAD OF TIME.
2. LEADS TO BE EXTENDED TO FINAL GRADE, MAINTAINGING 2% GRADE AS PER CoV STD DETAIL DRAWINGS S11.1.
3. ALL DRAINAGE DESIGN CALCULATIONS HAVE BEE COMPLETED USING THE RATIONAL METHOD AS PER CoV AND MMCD STANDARDS.

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR LAYOUT	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 1 OF 23			3		

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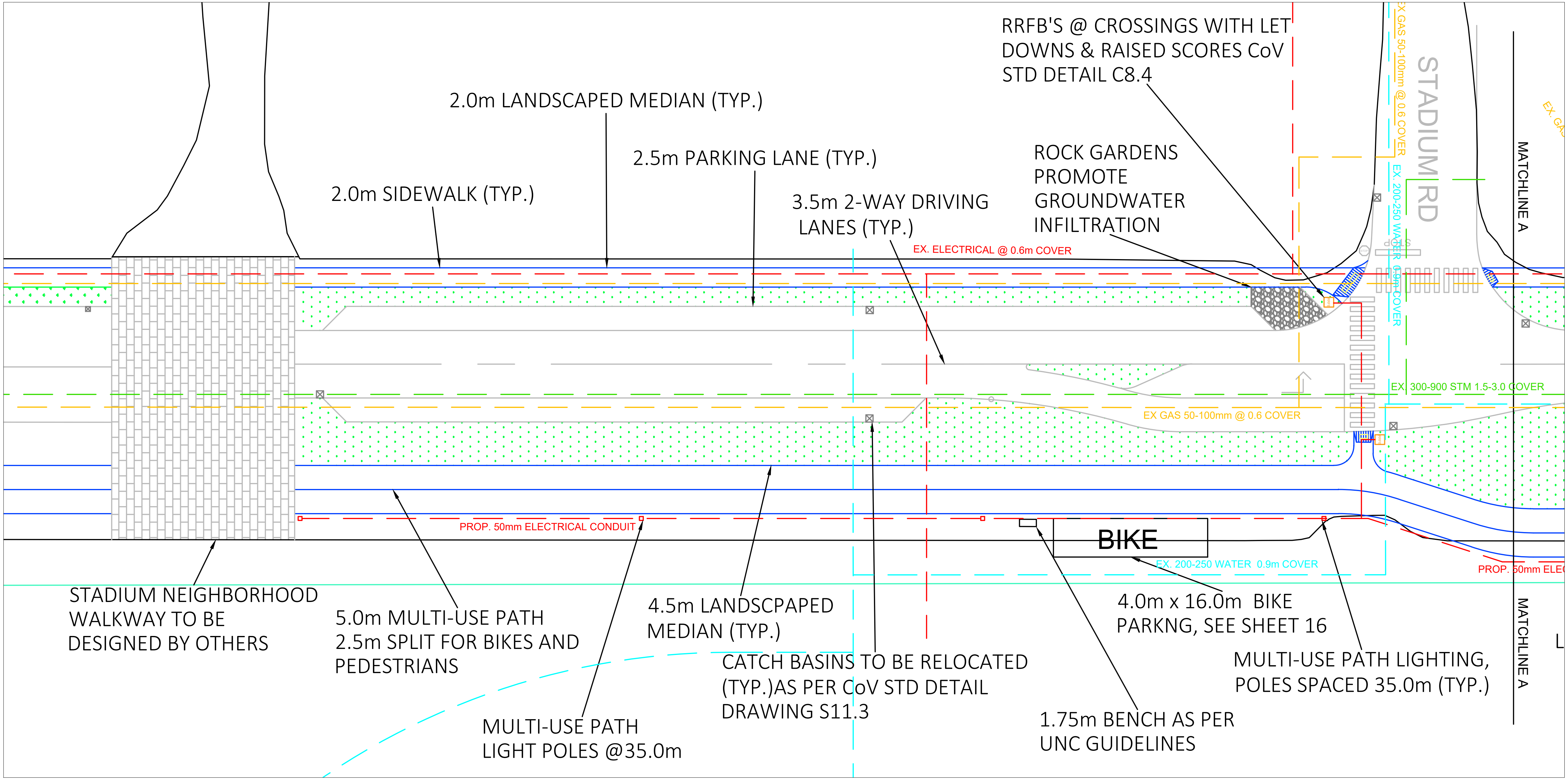
PRODUCED BY AN AUTODESK STUDENT VERSION



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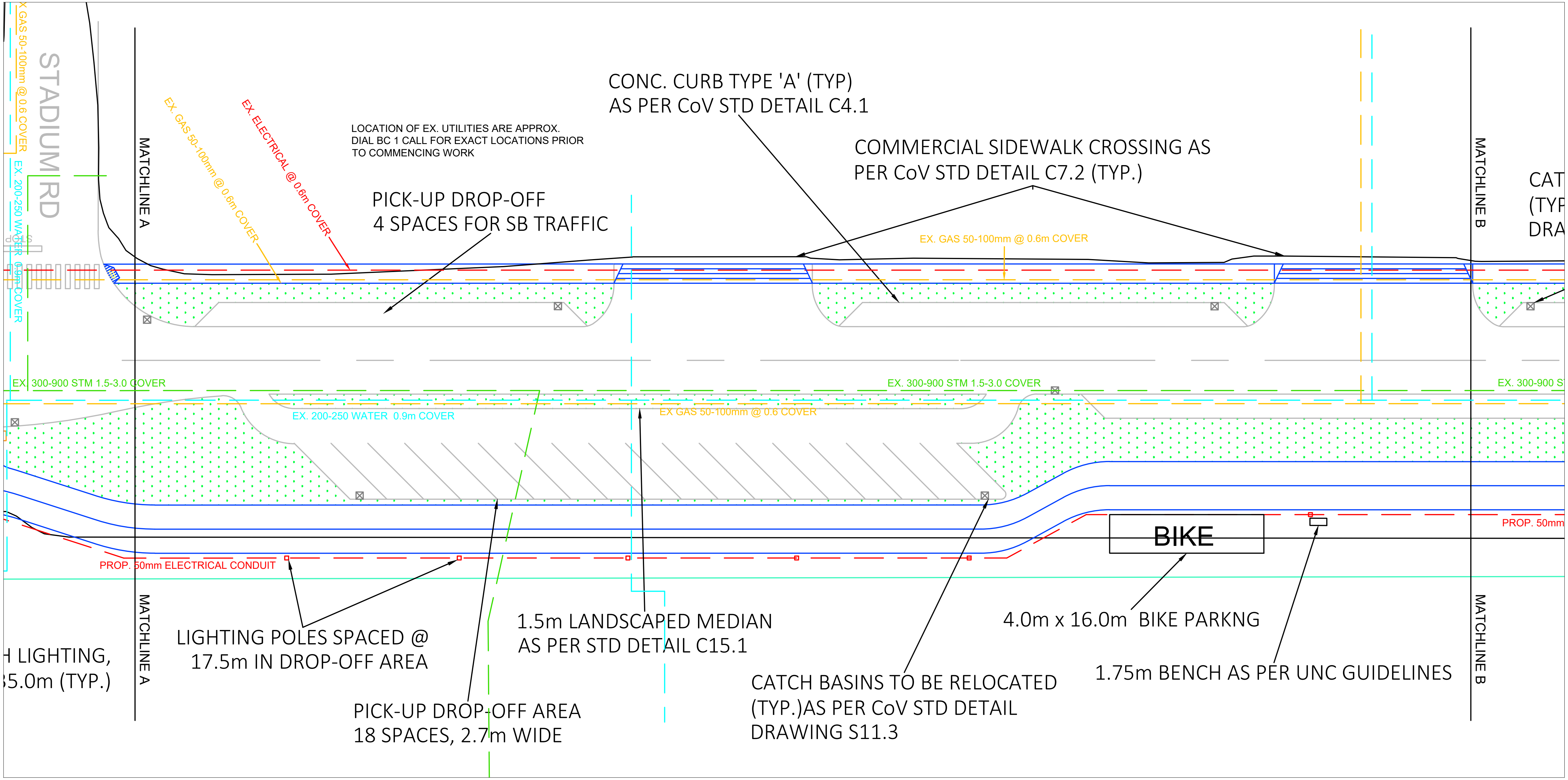
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 2 OF 23	SCALE: 1:500		3		



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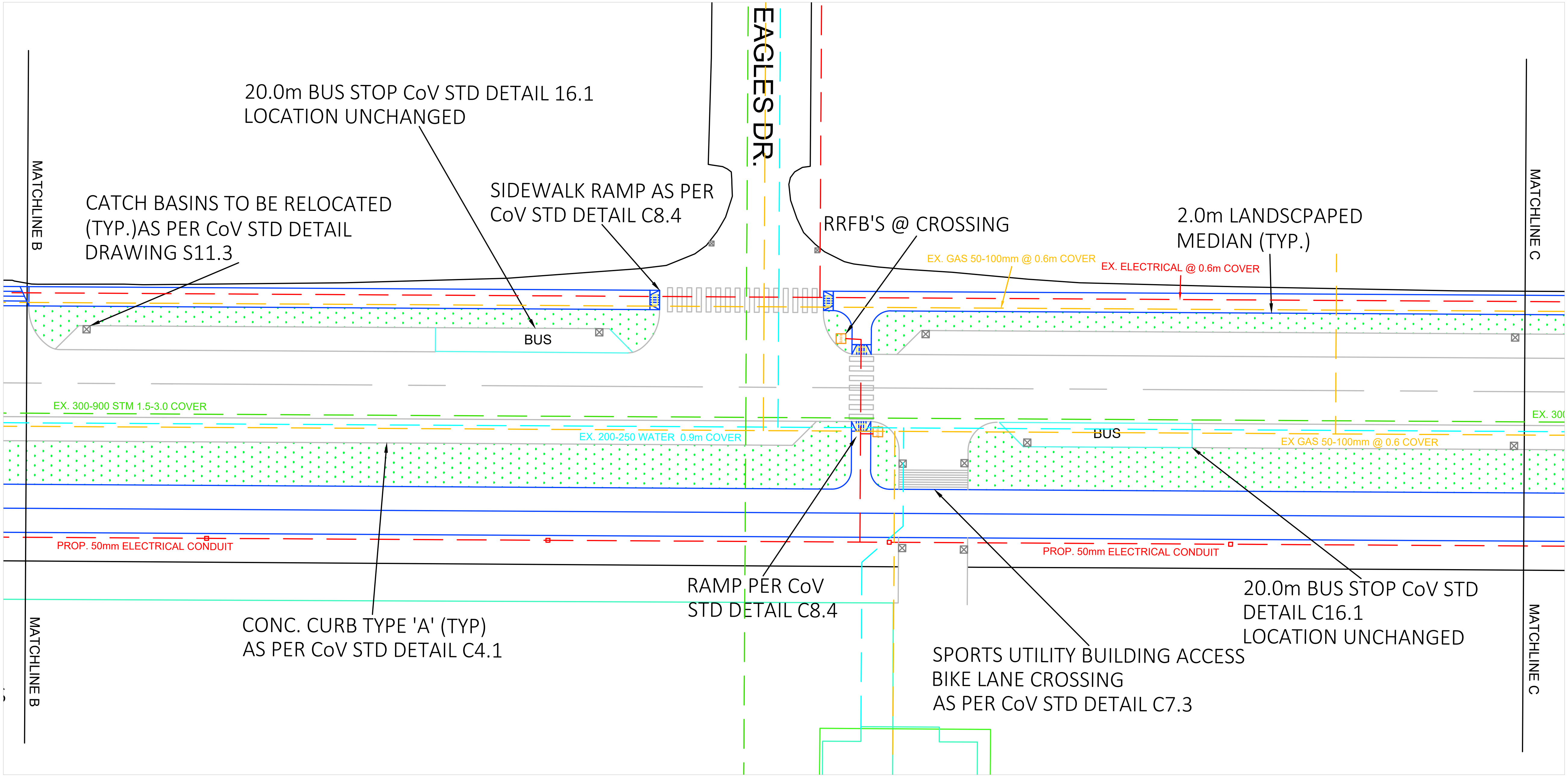
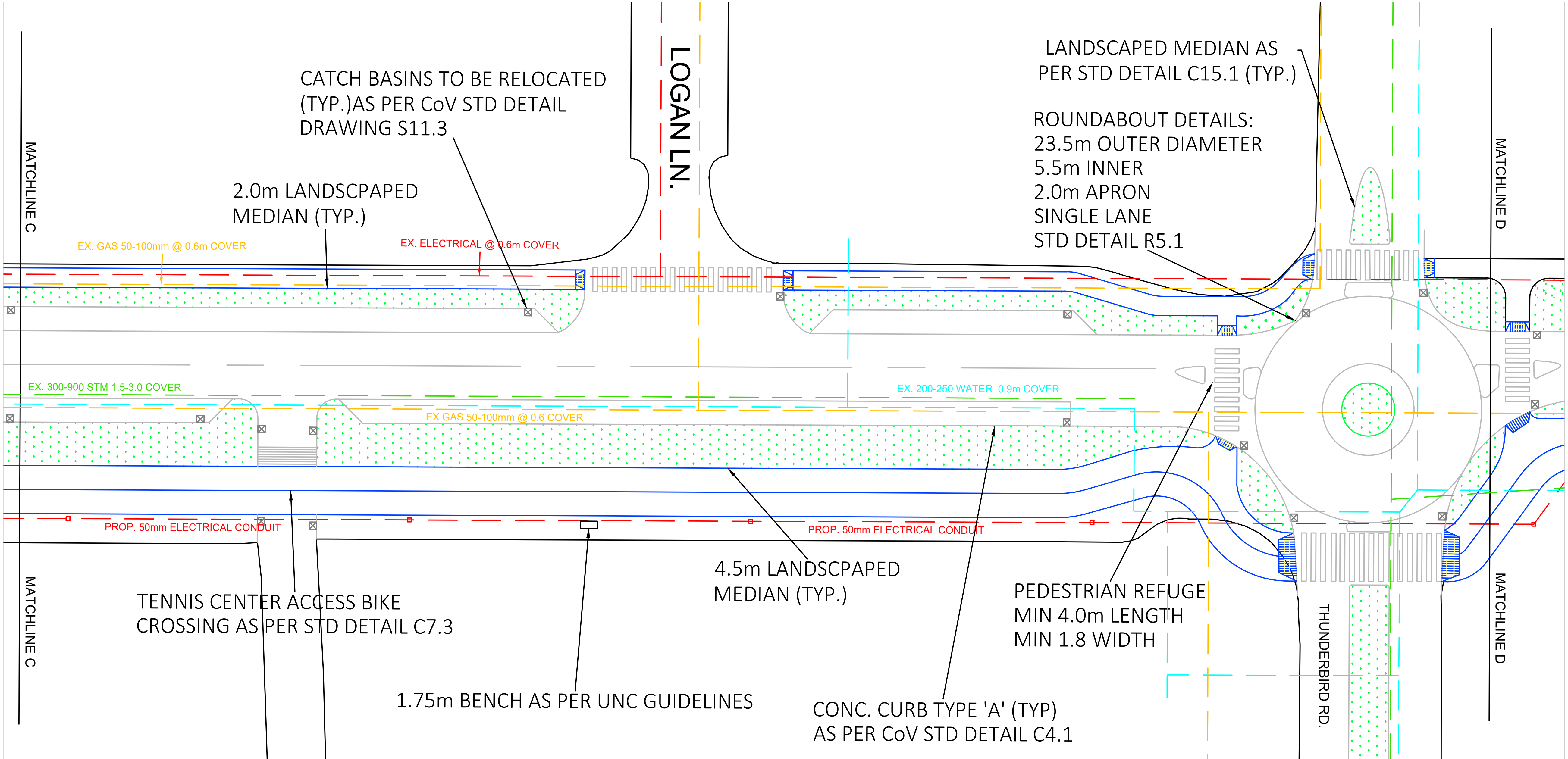
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 3 OF 23	SCALE: 1:500		3		



CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.	
CIVIL 446 - CAPSTONE PROJECT	GROUP 11
DRAFTED BY: KRISTIAN BIELA	
SHEET: 4 OF 23	SCALE: 1:500

EAST MALL CORRIDOR LAYOUT

NO.	SUBMISSION	DATE
1	PRELIMINARY DESIGN	12/6/2020
2	ISSUED FOR CONSTRUCTION	04/16/2021
3		



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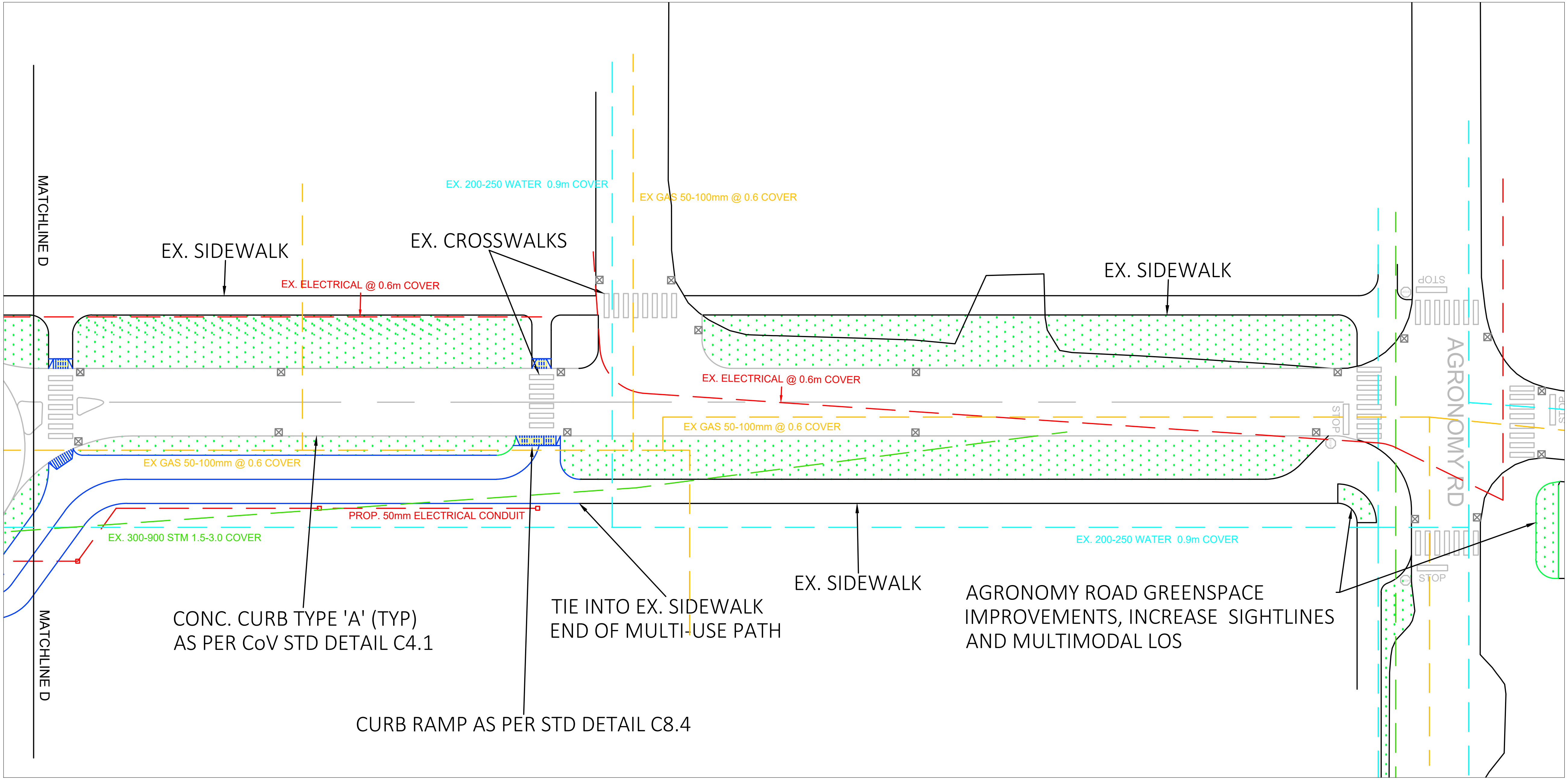

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PRODUCED BY AN AUTODESK STUDENT VERSION

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR LAYOUT	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 6 OF 23	SCALE: 1:500		3		

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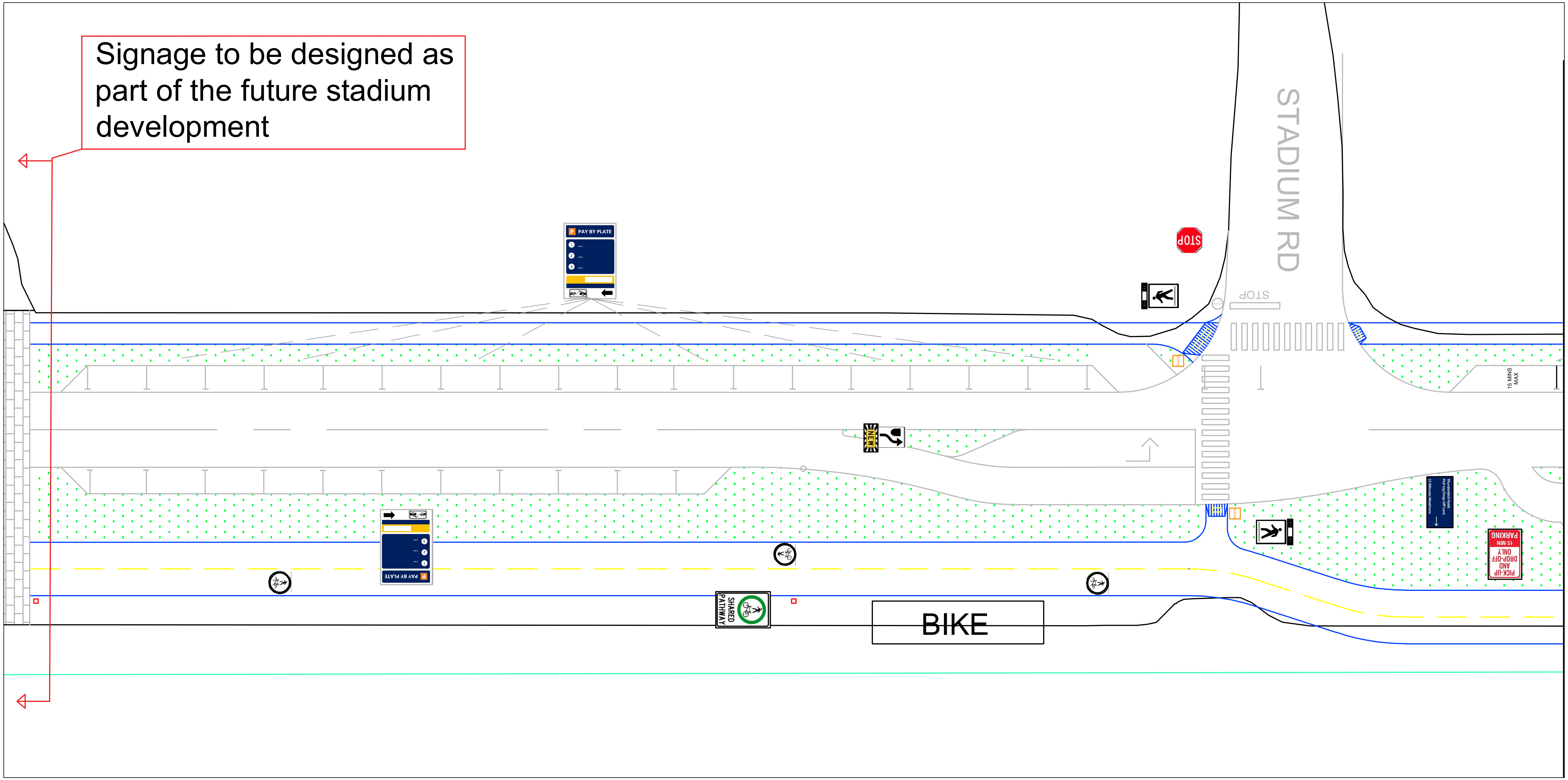

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DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN			2	ISSUED FOR CONSTRUCTION	04/16/2021
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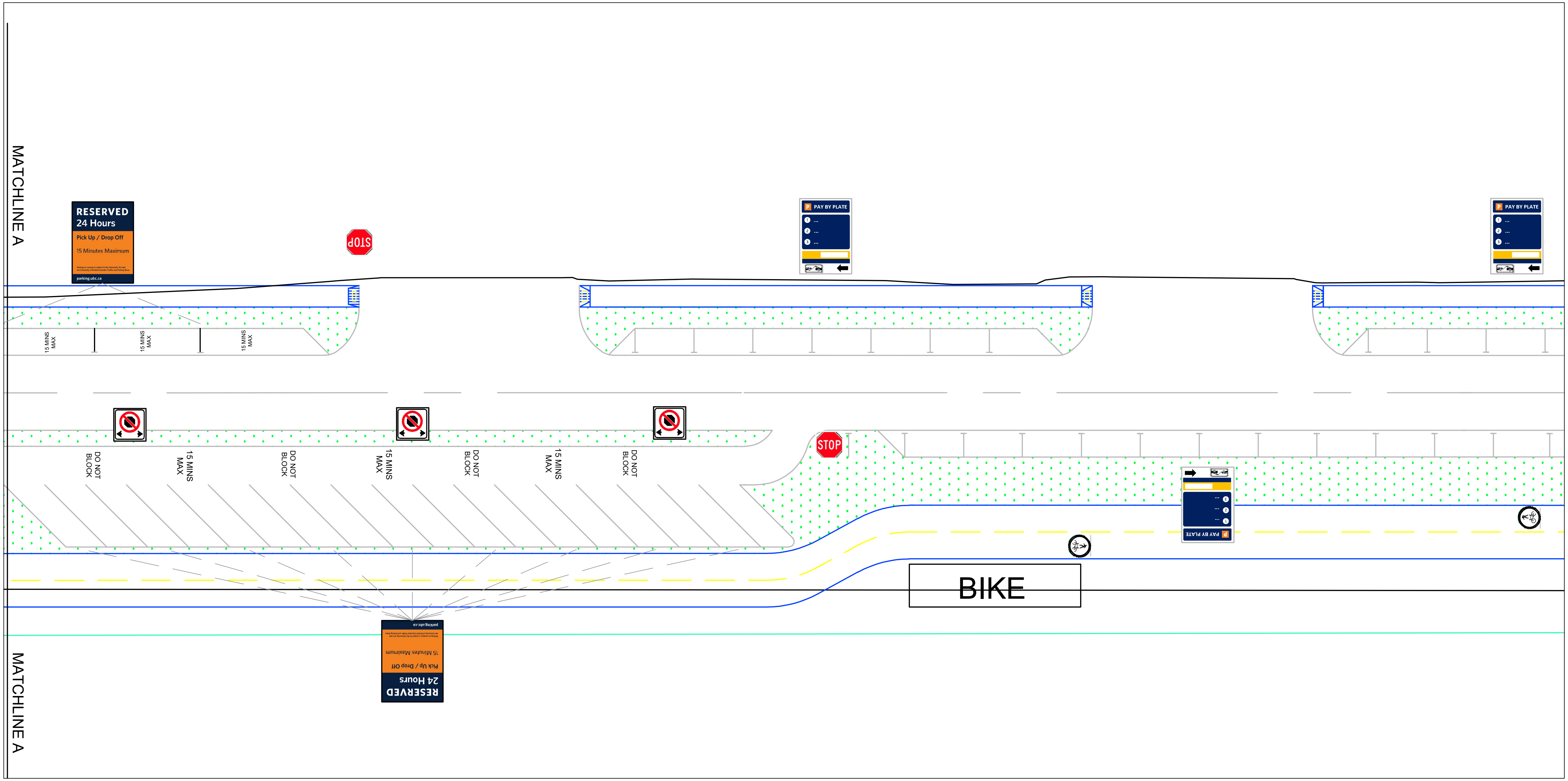

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DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN			2	ISSUED FOR CONSTRUCTION	04/16/2021
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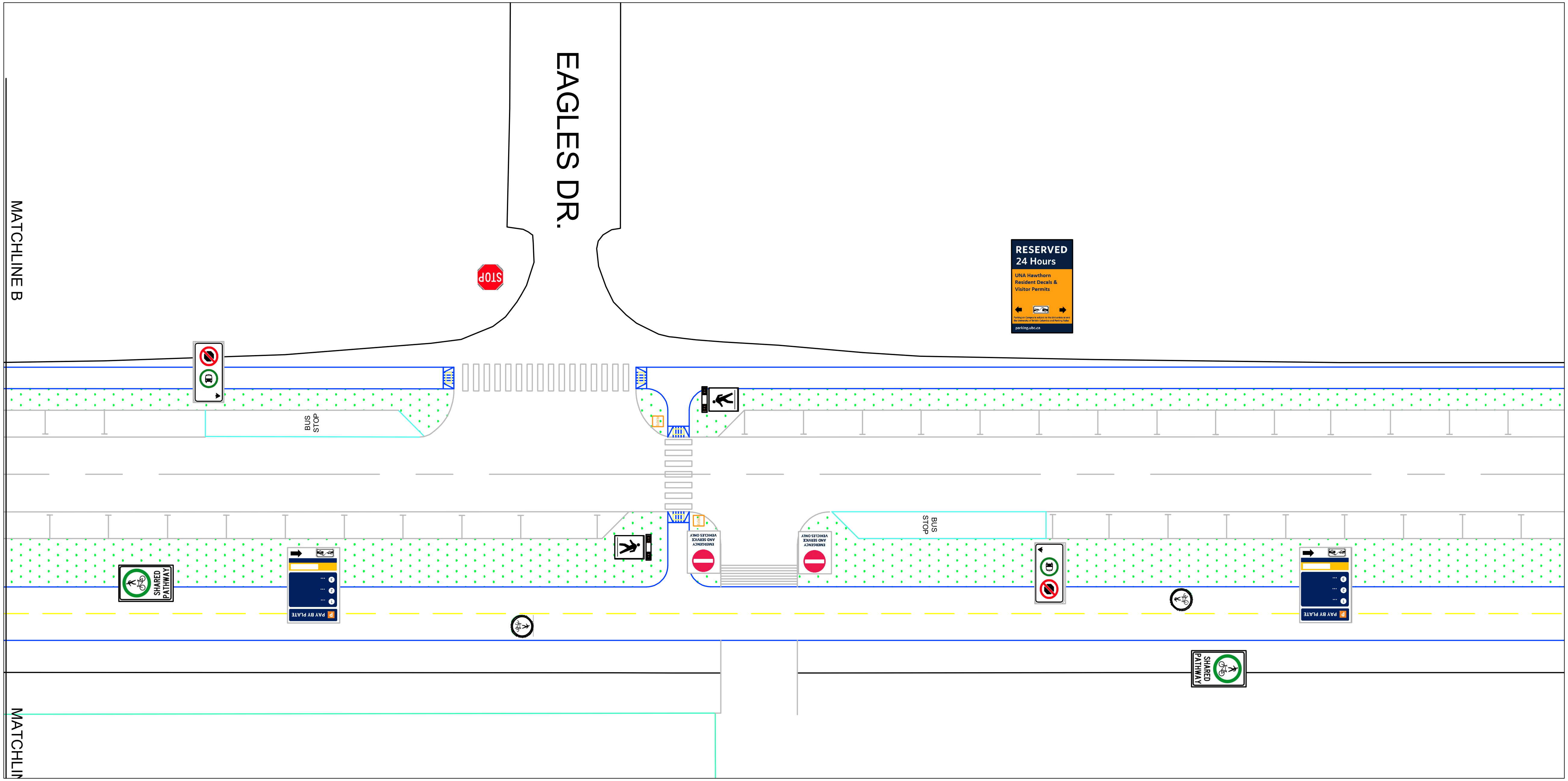

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DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN			2	ISSUED FOR CONSTRUCTION	04/16/2021
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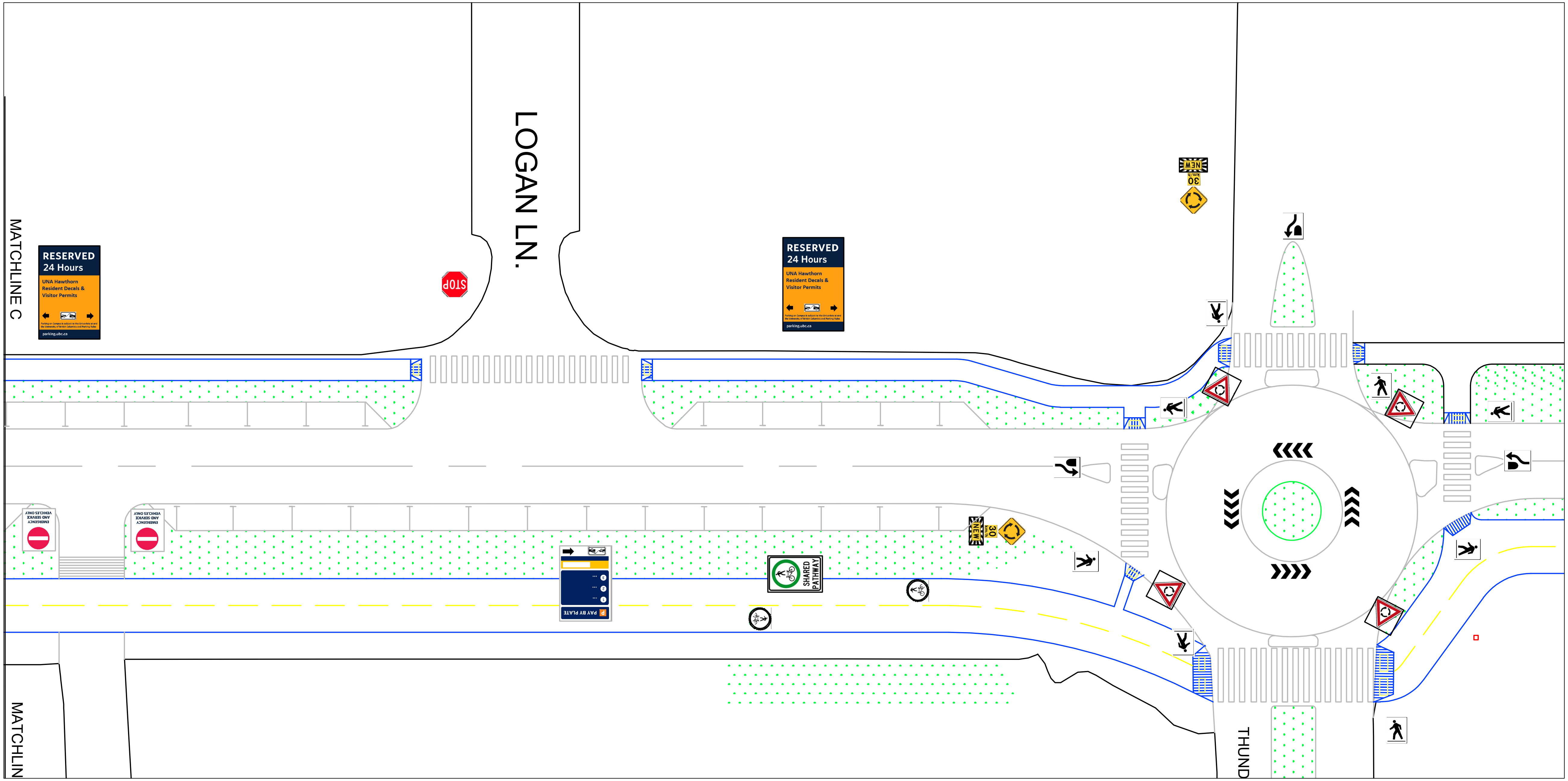

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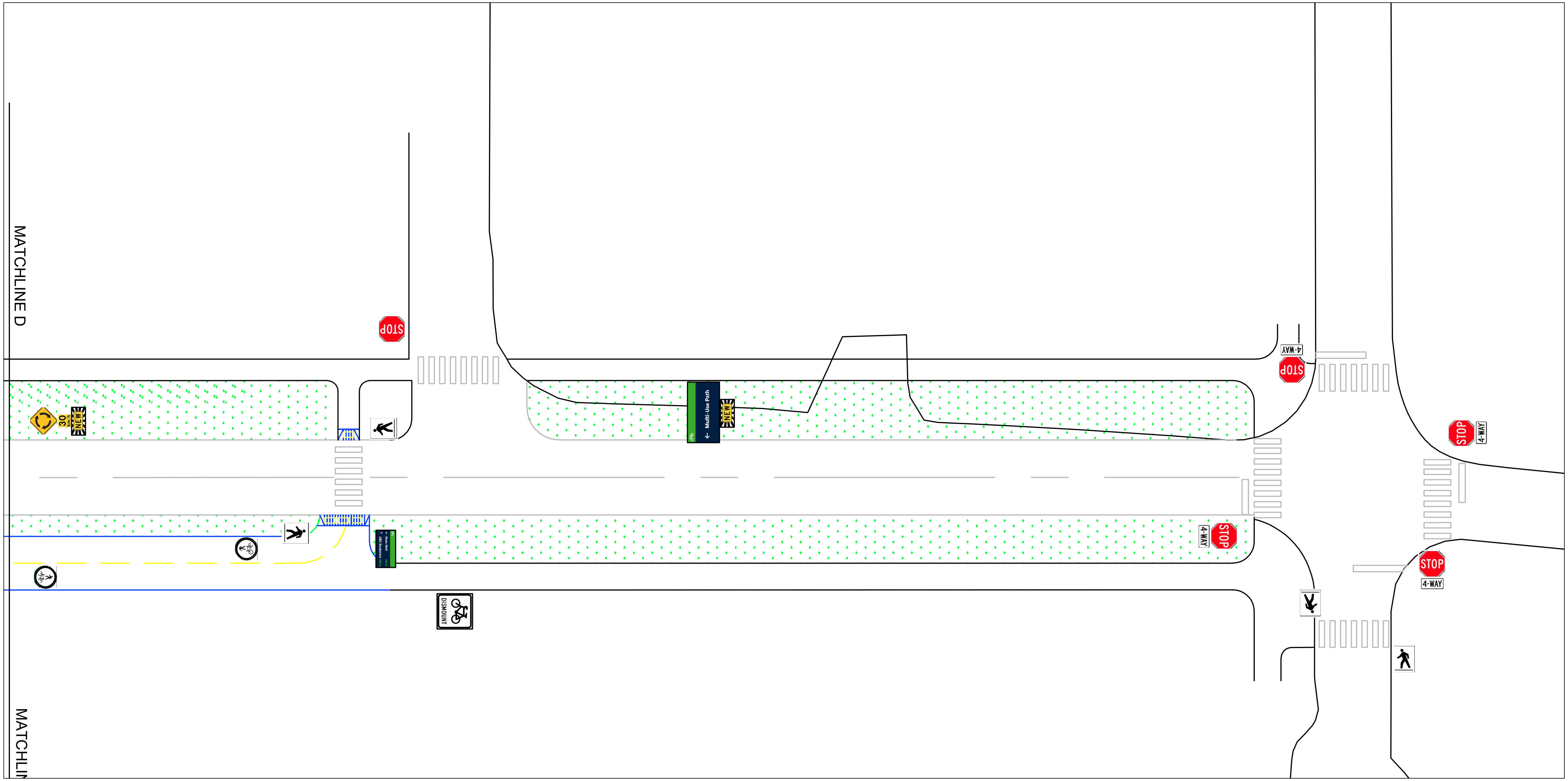

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DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN			2	ISSUED FOR CONSTRUCTION	04/16/2021
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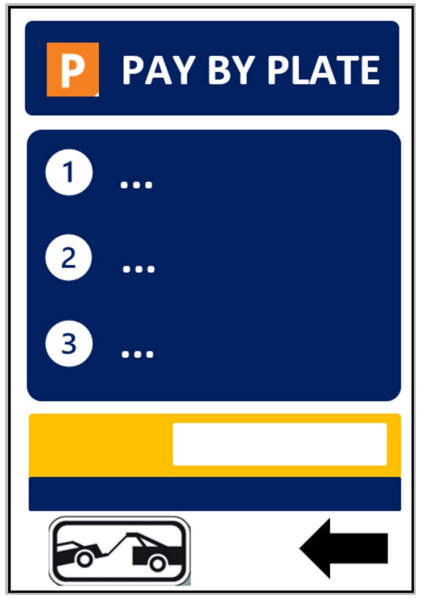
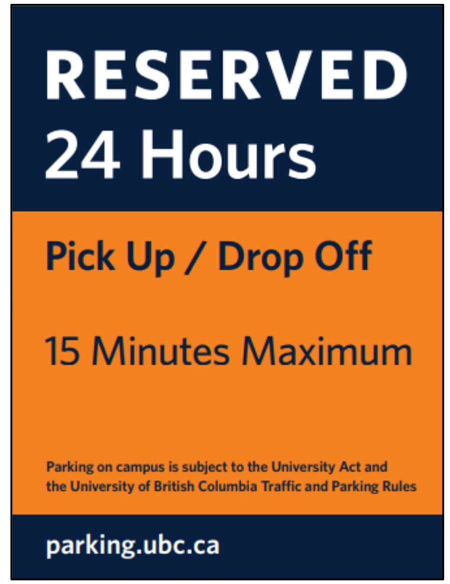


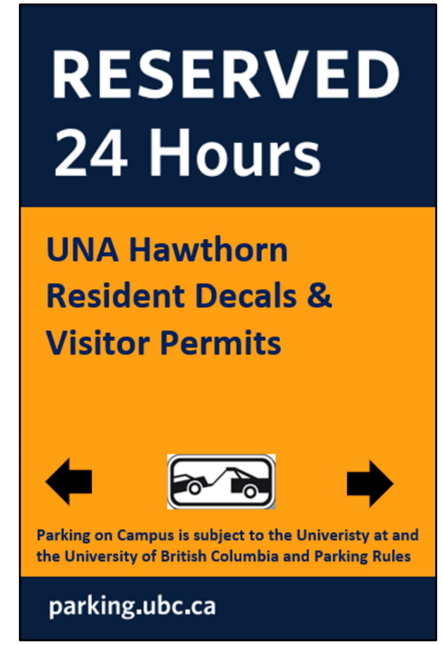
Pay by Plate Template

MUP Shared Pathway



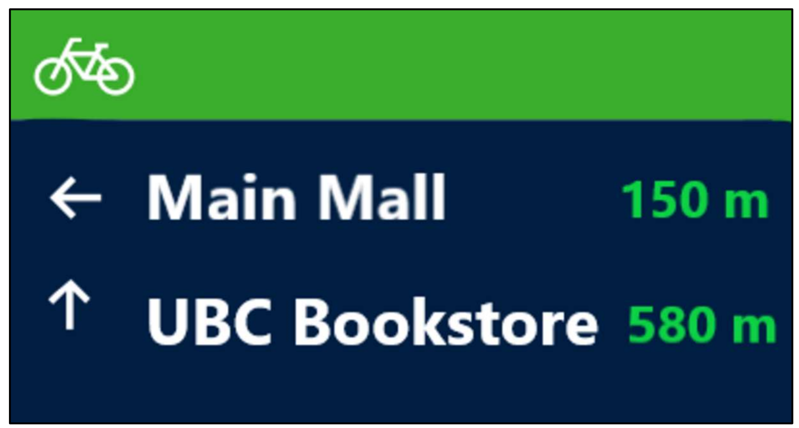
Pick-off/Drop-off Only

Pick-up/Drop-off Only



Hawthorn Place Resident Decal Only

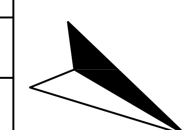
Pick-Up/Drop-off Lane



Multi-use Path Navigation Signage

New Multi-Use Path

			NO.	SUBMISSION	DATE
CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR CUSTOM SIGNAGE			
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 12 of 23	SCALE: N/A		3		



Stop Sign

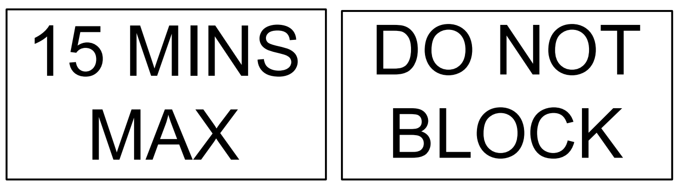
RRFB Pedestrian Crossing

Alignment - Stay Right

30km/h in Roundabout

No Stop - Bus Only

4-Way Tab



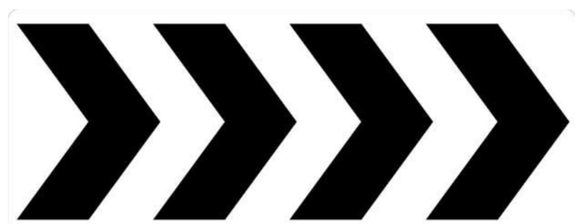
Pick-up Lane Pavement Markings

Pick-up Lane No Stopping/Blocking

Do Not Enter

Yield to Traffic in Roundabout

Multi-Use Path Pavement Marking



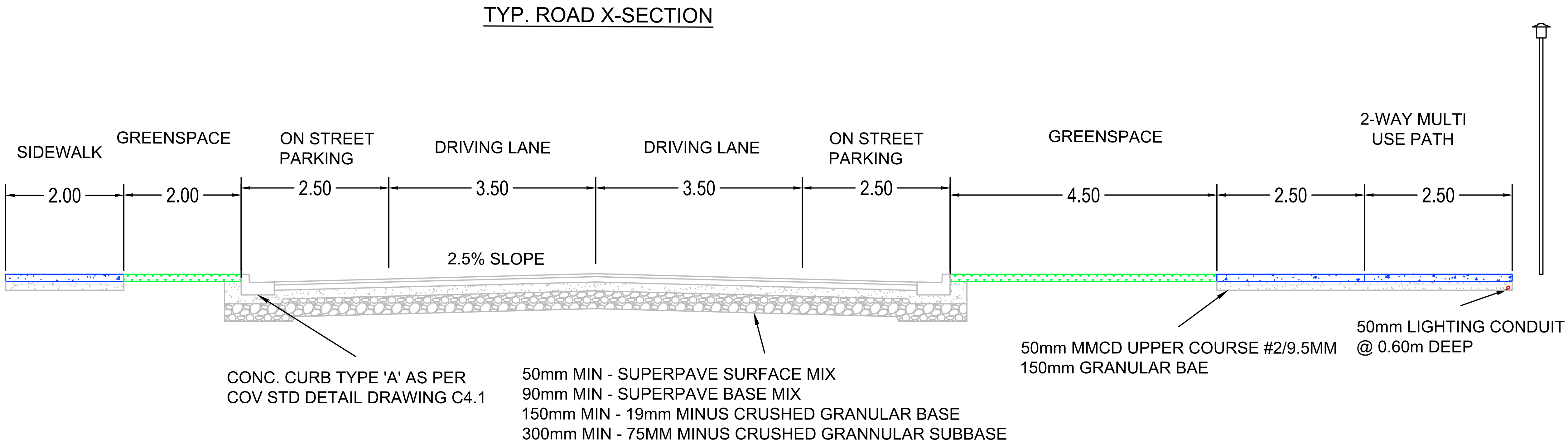
Pick-up Lane No Stopping/Blocking

NEW Tab

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.	
CIVIL 446 - CAPSTONE PROJECT	GROUP 11
DRAFTED BY: KRISTIAN BIELA & STEVE MARTIN	
SHEET: 13 of 23	SCALE: N/A

EAST MALL CORRIDOR
ROAD SIGNAGE

NO.	SUBMISSION	DATE
1	PRELIMINARY DESIGN	12/6/2020
2	ISSUED FOR CONSTRUCTION	04/16/2021
3		



CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR LAYOUT	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
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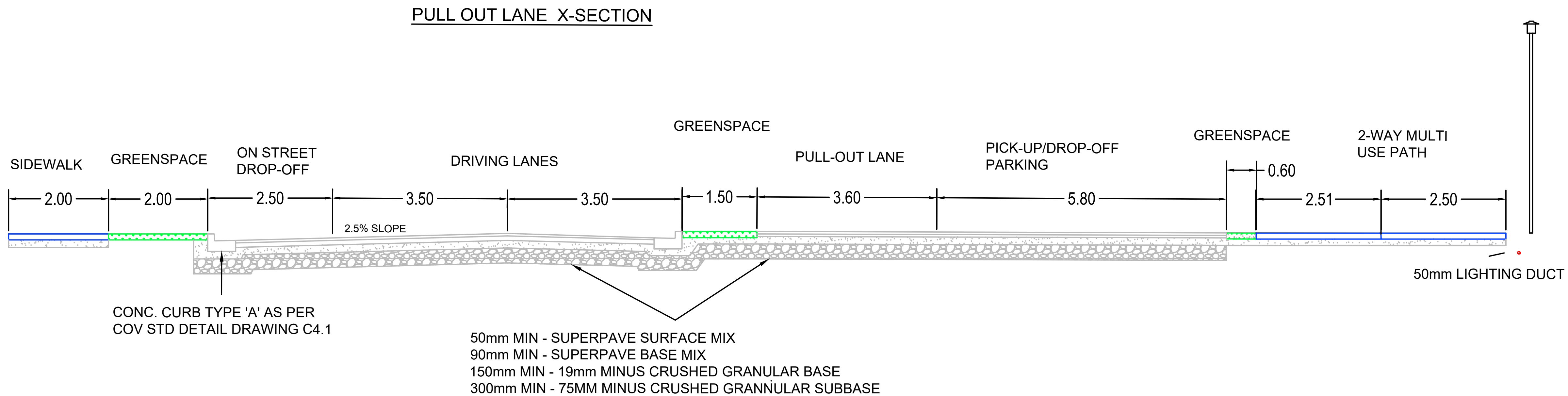
SHEET: 14 OF 23	SCALE: 1:75		3		



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CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
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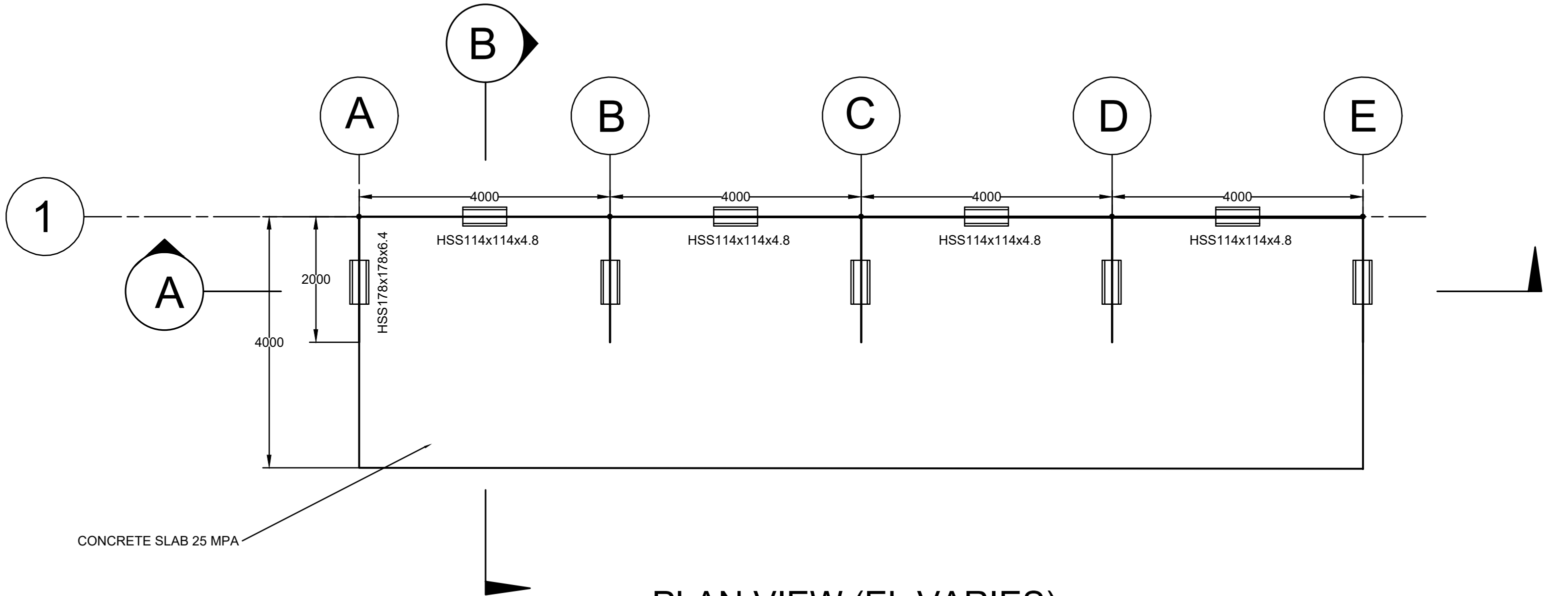
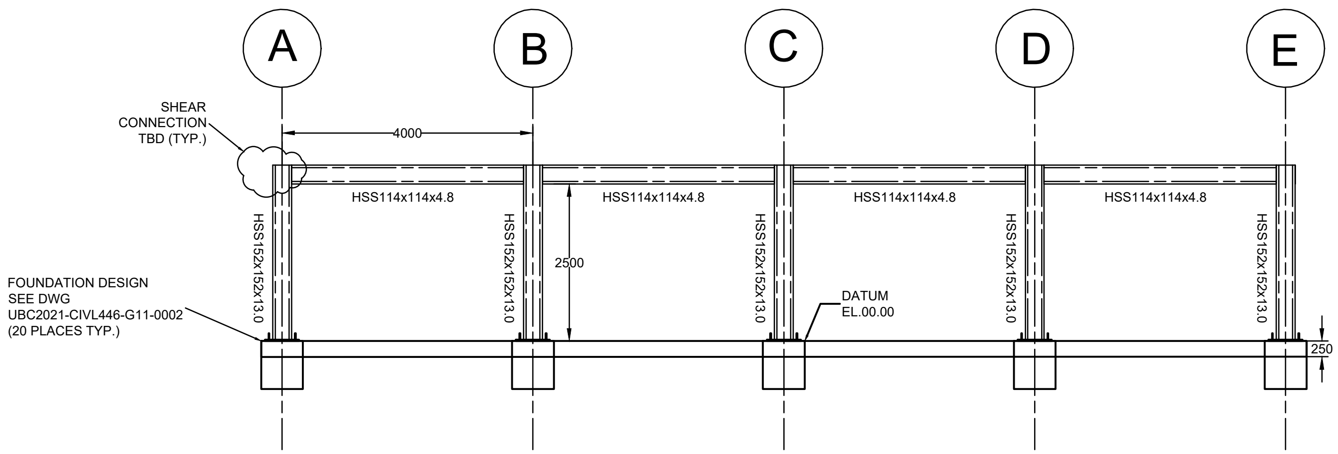
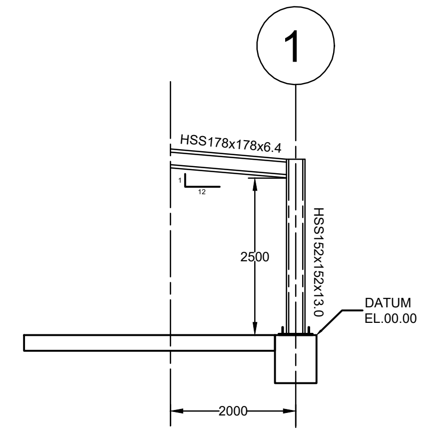
SHEET: 14 OF 23	SCALE: 1:100		3		



PLAN VIEW (EL.VARIES)



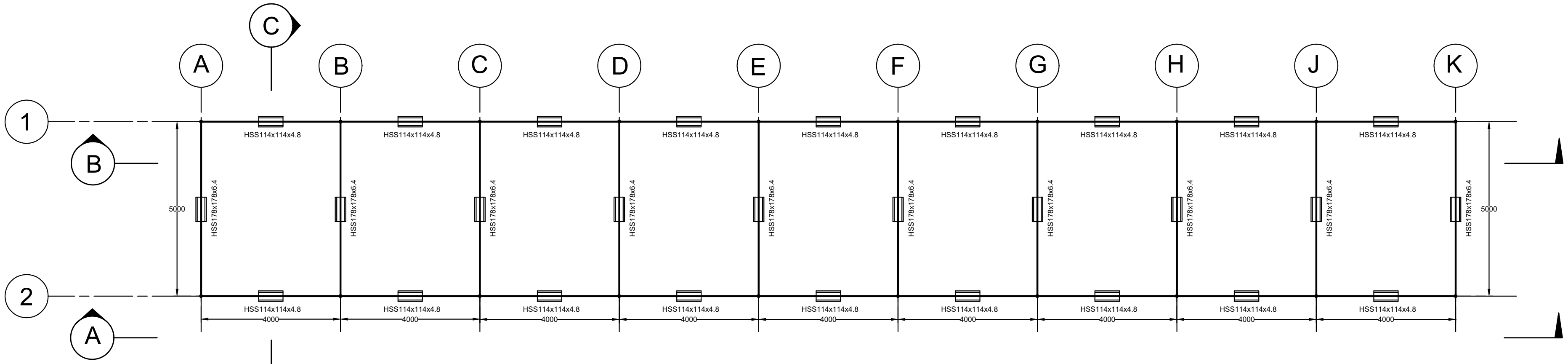
SECTION A



SECTION B

NOTE:
- ALL DIMENSIONS IN MILLIMETERS
- DATUM IS AT THE TOP OF THE CONCRETE PEDESTAL

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		BICYCLE PARKING PLAN VIEW AND ELEVATION DETAILS	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: ROSSI GU			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 16 OF 23			3		



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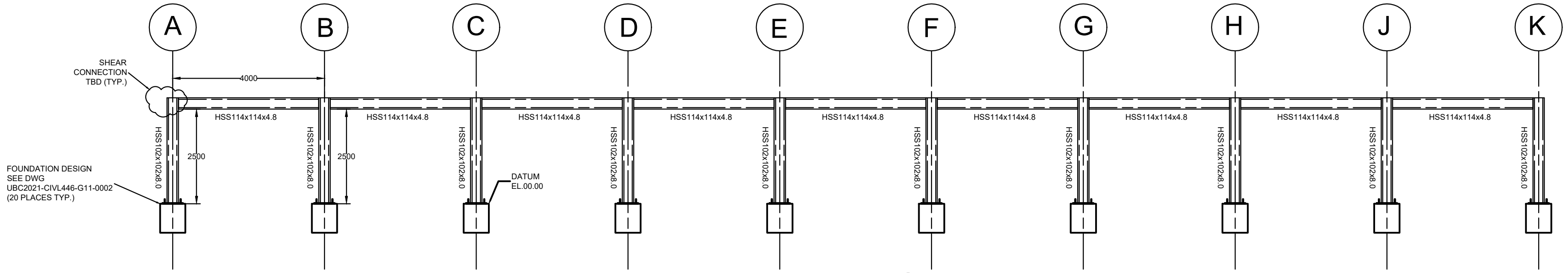
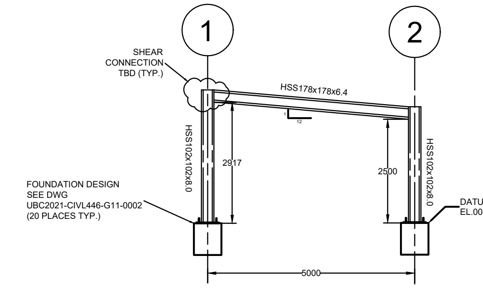
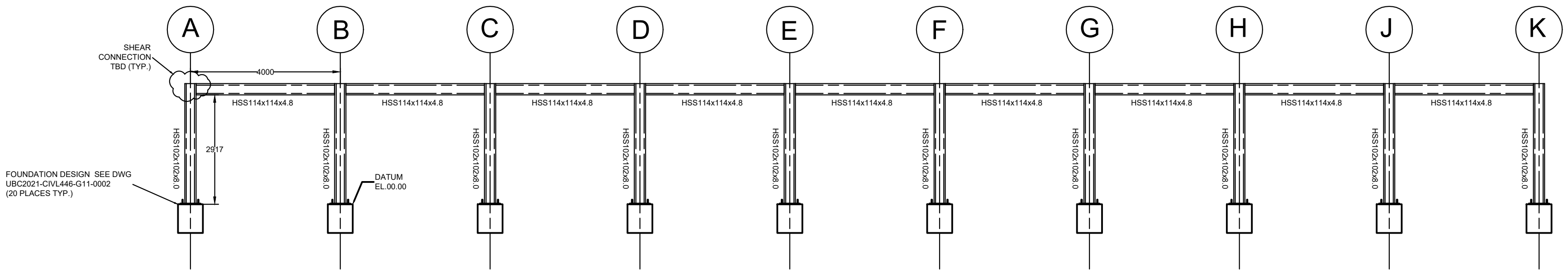


SECTION A



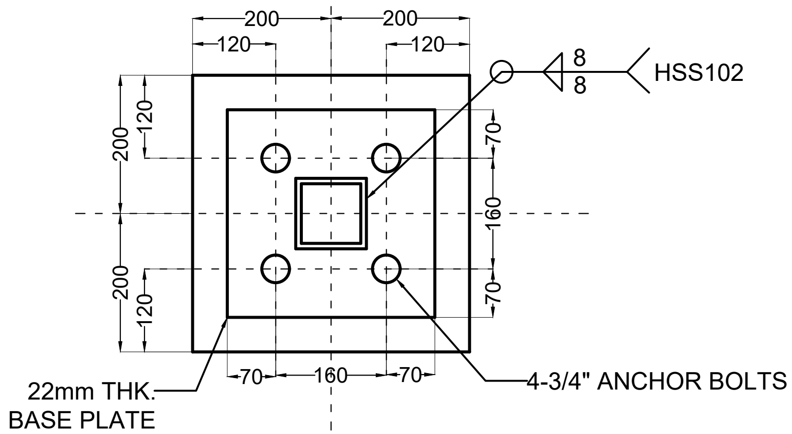
SECTION C



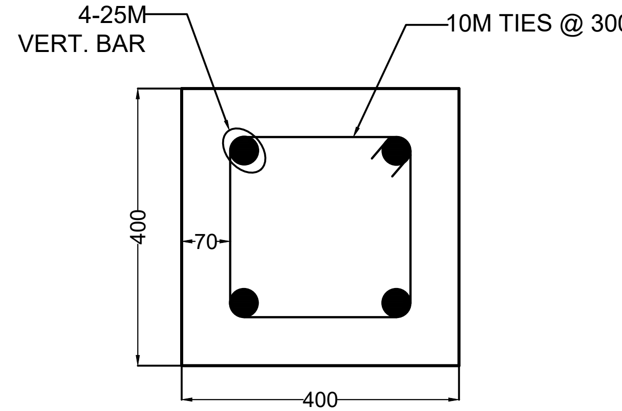
SECTION B

NOTE:
- ALL DIMENSIONS IN MILLIMETERS
- DATUM IS AT THE TOP OF THE CONCRETE PEDESTAL

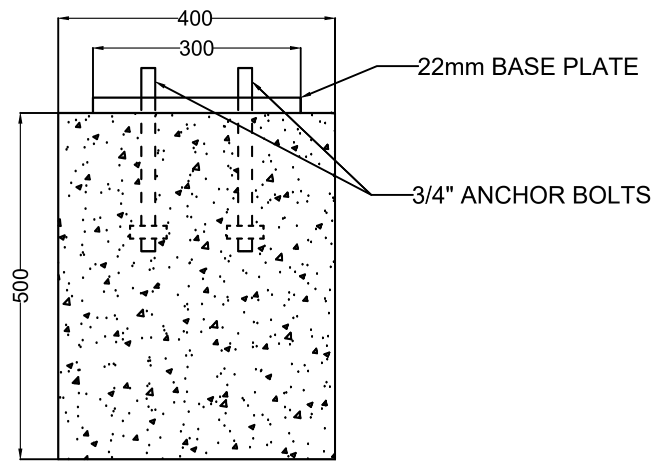
CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CANOPY PLAN AND ELEVATION VIEWS	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: ROSSI GU			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 17 OF 23		DWG. No: UBC2020-CIVL445-G11-S0001	3		



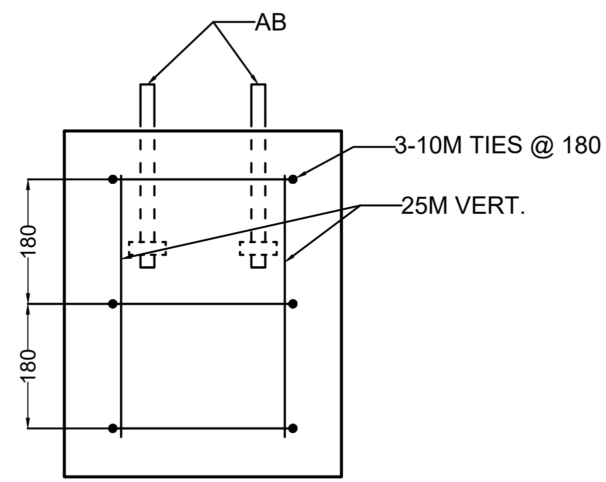
ANCHORAGE
PLAN VIEW



REINFORCEMENT
PLAN VIEW



ANCHORAGE
ELEVATION VIEW



REINFORCEMENT
ELEVATION VIEW

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CANOPY FOUNDATION - PLAN AND ELEVATION VIEWS	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
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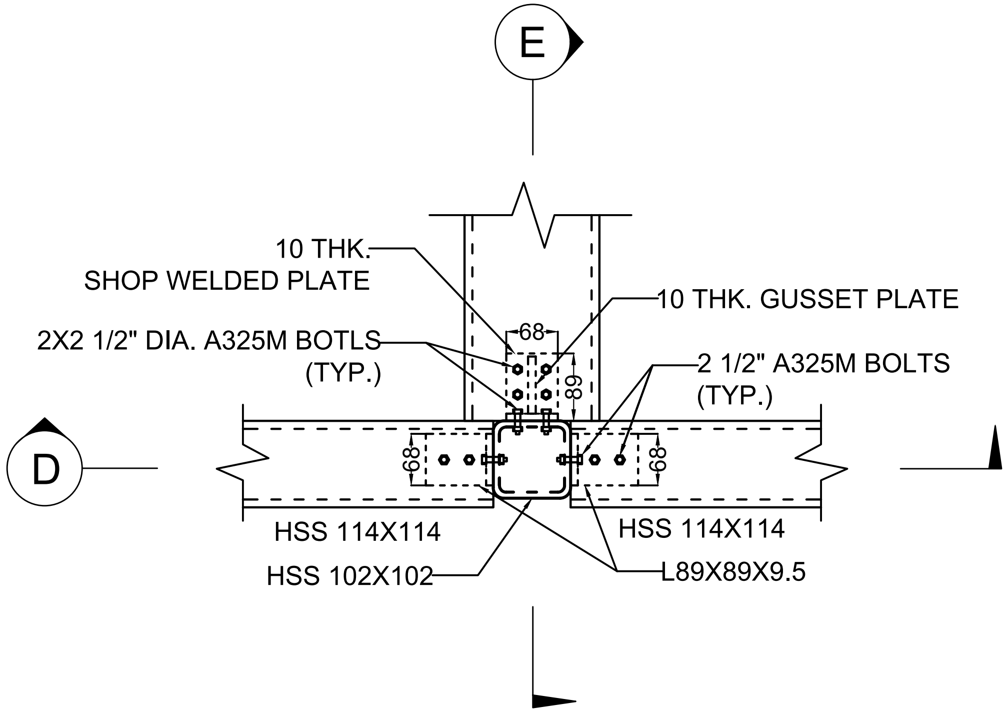
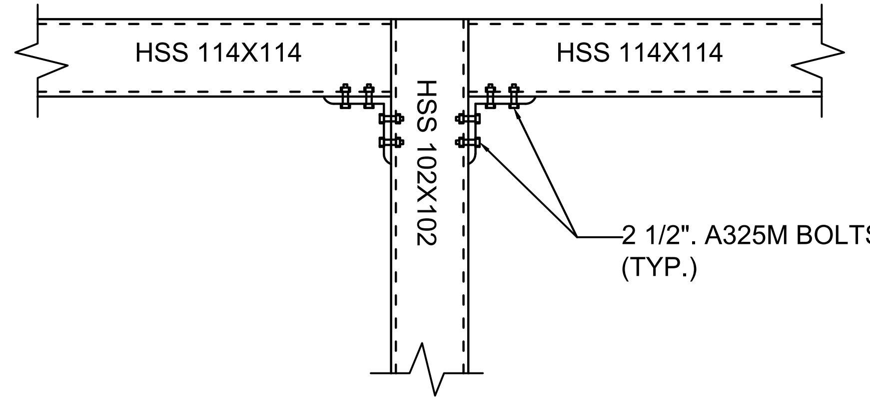
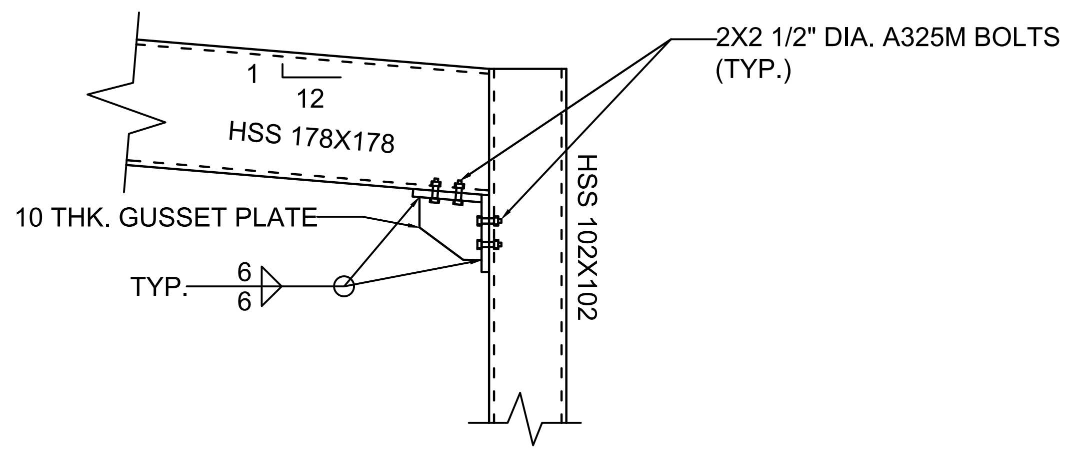
SHEET: 18 OF 23		DWG. No: UBC2021-CIVL446-G11-S0002	3		



SHEAR CONNECTION PLAN VIEW



SECTION D



SECTION E

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CANOPY SHEAR CONNECTION - PLAN & SECTIONS	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
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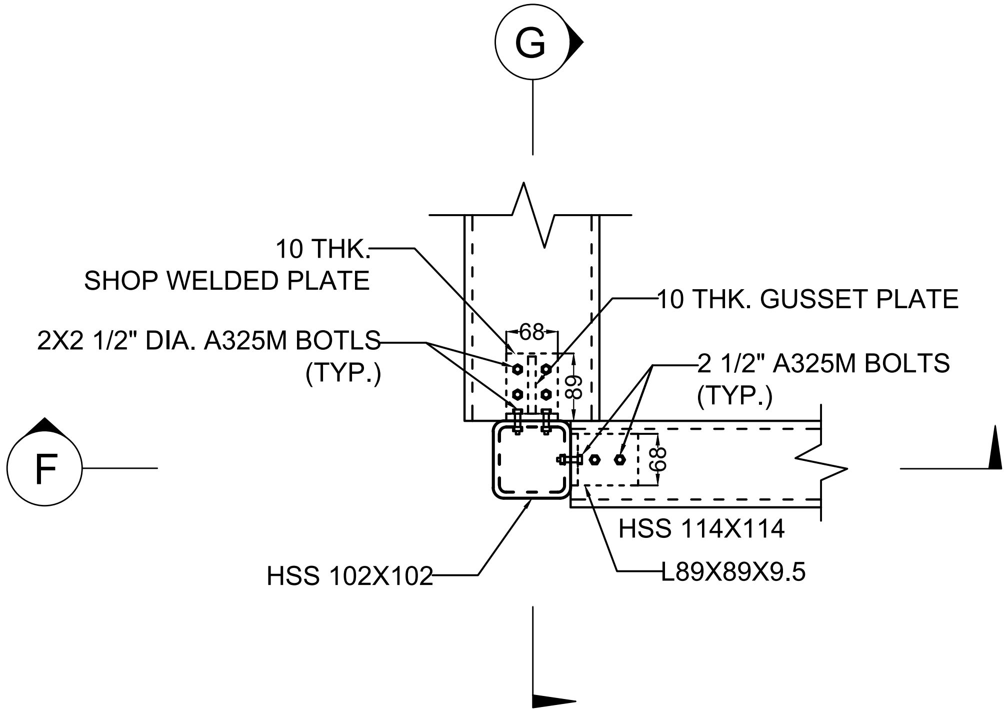
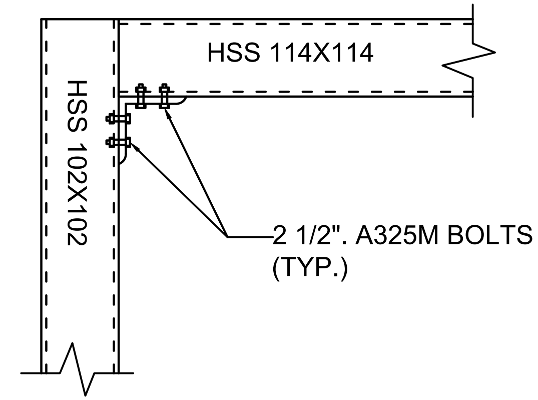


SHEAR CONNECTION PLAN VIEW



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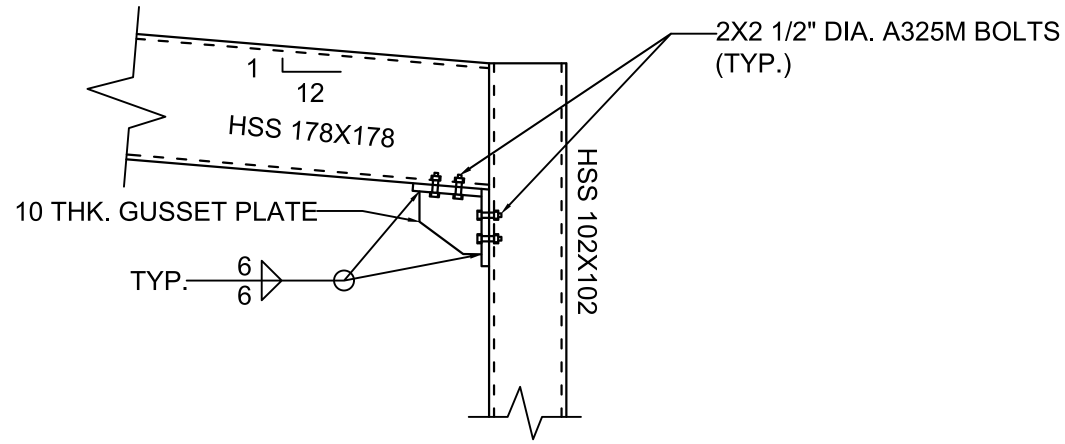

SECTION G

CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CANOPY SHEAR CONNECTION - PLAN & SECTIONS	NO.	SUBMISSION	DATE
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DRAFTED BY: ROSSI GU			2	ISSUED FOR CONSTRUCTION	04/16/2021
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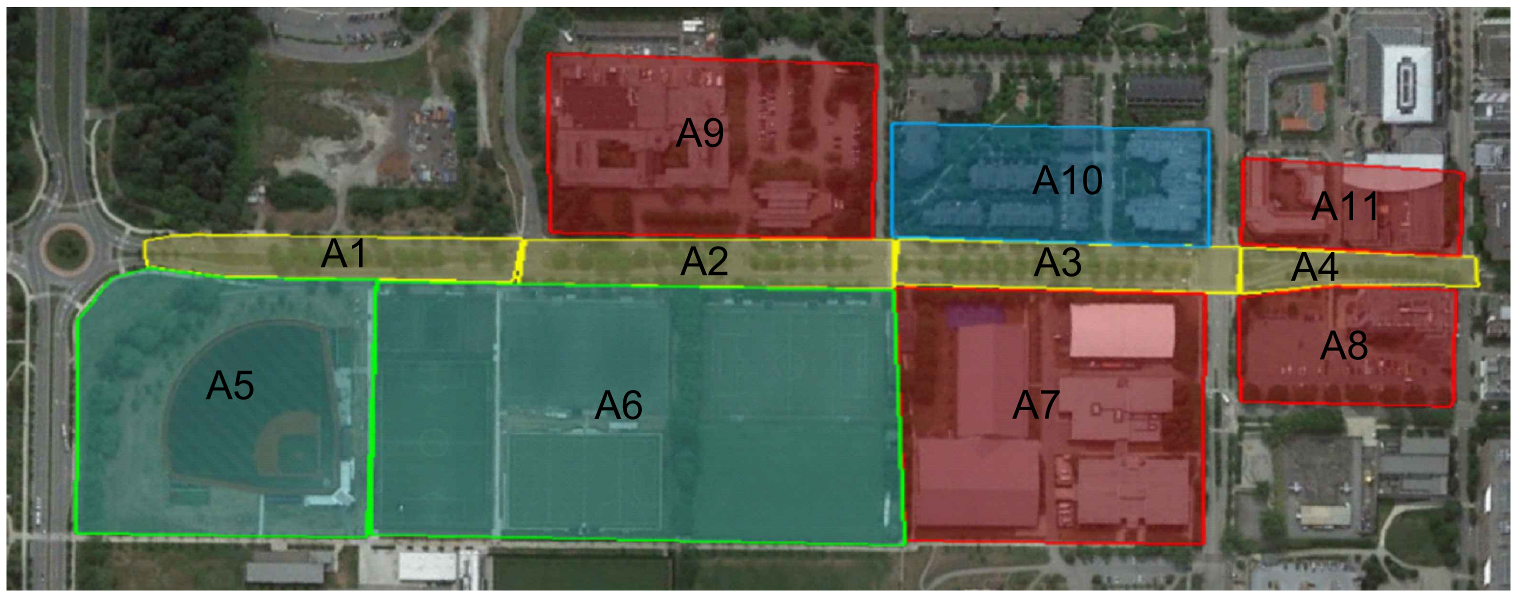
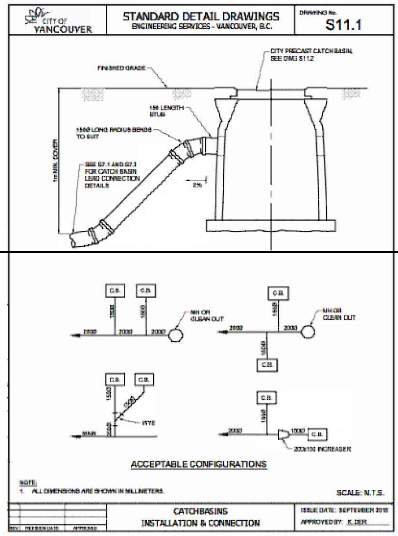
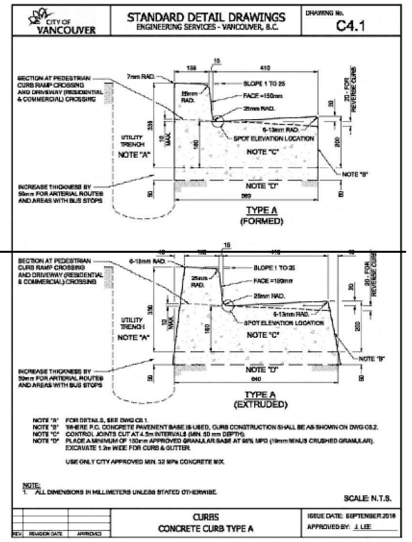
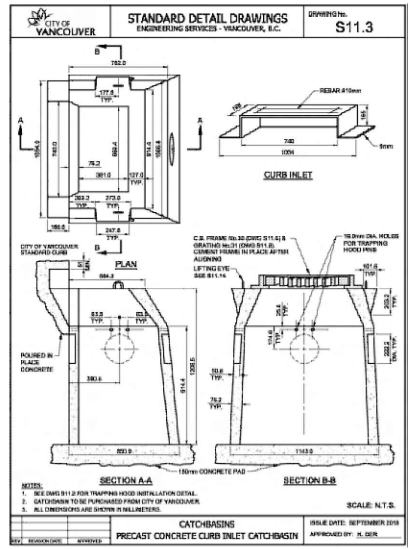
		Catchment Area						IDF Coefficients				
No.	Return Period	Type	Area (ha)	Length (m)	Elev. Diff(m)	Runoff Coefficient C	Slope	a	B	Time of Conc. (hrs)	I (mm/hr)	Q (m^3/s)
1	5 years	Road	0.66	585	5	0.88	0.85%	26.41	-0.54	0.17	69.50	0.11
2	5 years	Road	0.74	480	3	0.88	0.63%	26.41	-0.54	0.17	69.50	0.13
3	5 years	Road	0.67	440	1	0.88	0.23%	26.41	-0.54	0.17	69.50	0.11
4	5 years	Road	0.35	302	1	0.88	0.33%	26.41	-0.54	0.17	69.50	0.06
5	5 years	Baseball Field	3.1	N/A	N/A	0.3	N/A	26.41	-0.54	0.17	69.50	0.18
6	5 years	Sports Fields	5.4	N/A	N/A	0.3	N/A	26.41	-0.54	0.17	69.50	0.31
7	10 years	Tennis Centre	3.15	N/A	N/A	0.95	N/A	31.31	-0.055	0.08	35.90	0.30
8	10 years	Parking	1	N/A	N/A	0.95	N/A	31.31	-0.055	0.08	35.90	0.09
9	10 years	FPInnovations	2.45	N/A	N/A	0.95	N/A	31.31	-0.055	0.08	35.90	0.23
10	5 years	Residential	1.54	N/A	N/A	0.7	N/A	26.41	-0.54	0.17	69.50	0.21
11	5 years	Residential	0.79	N/A	N/A	0.75	N/A	26.41	-0.54	0.17	69.50	0.11
												1.85

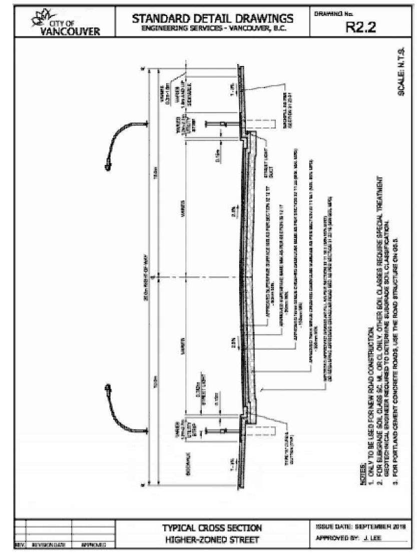


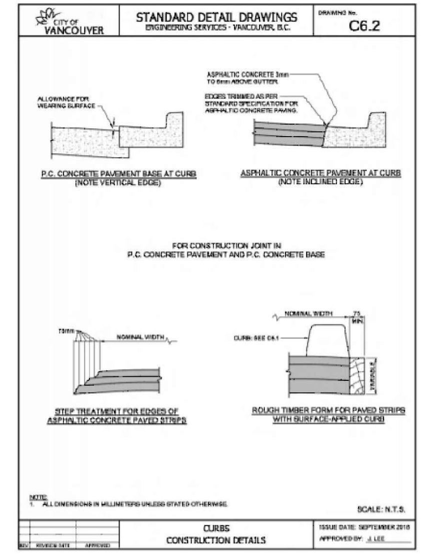
CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR LAYOUT	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 21 OF 23			3		

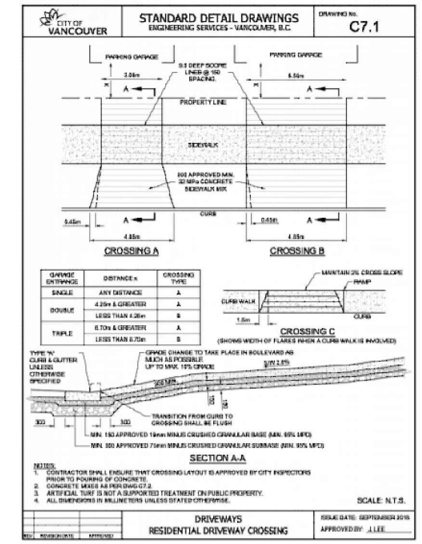


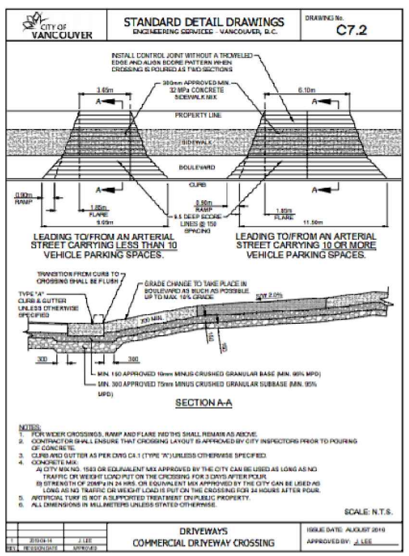


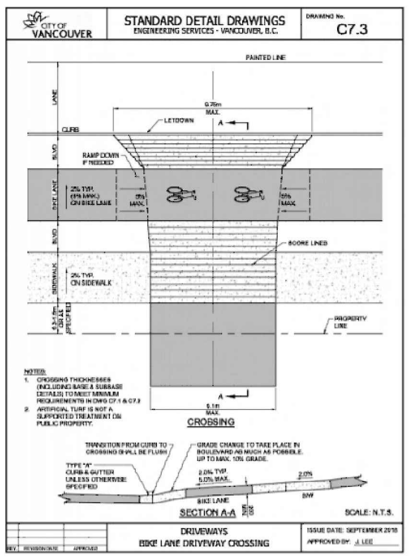


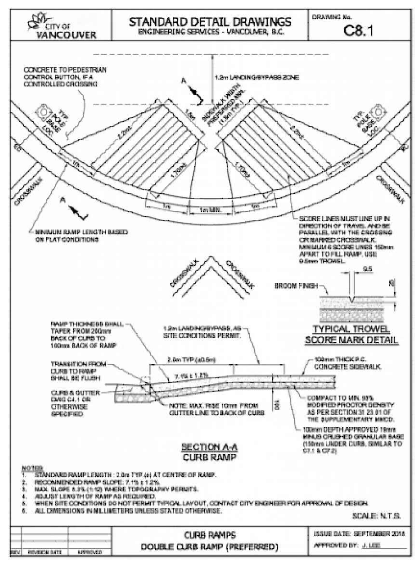


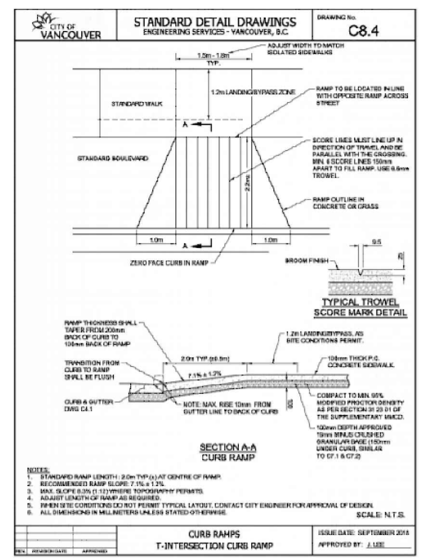


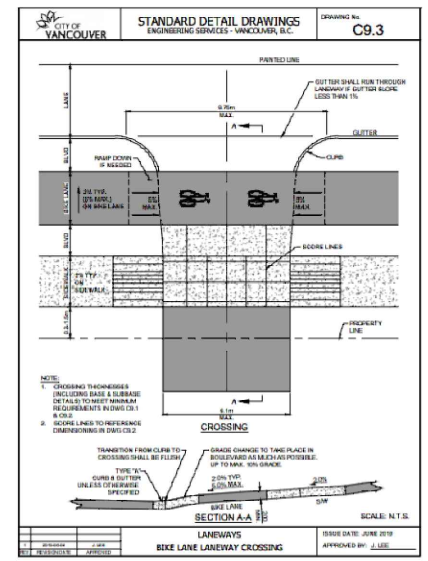


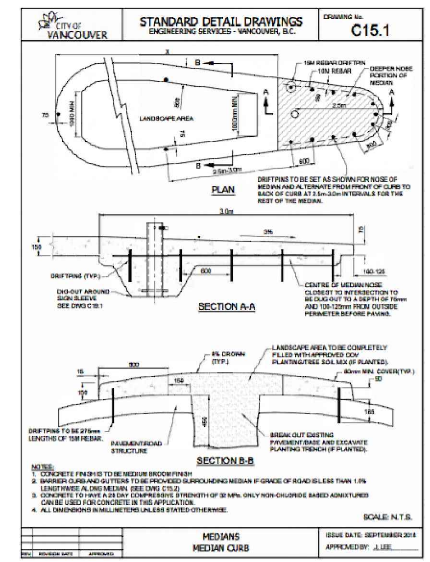




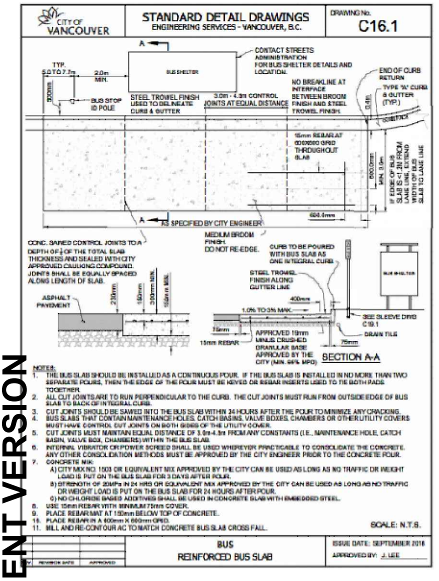


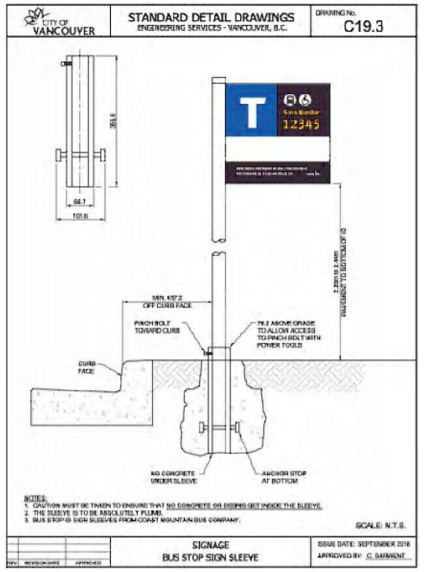


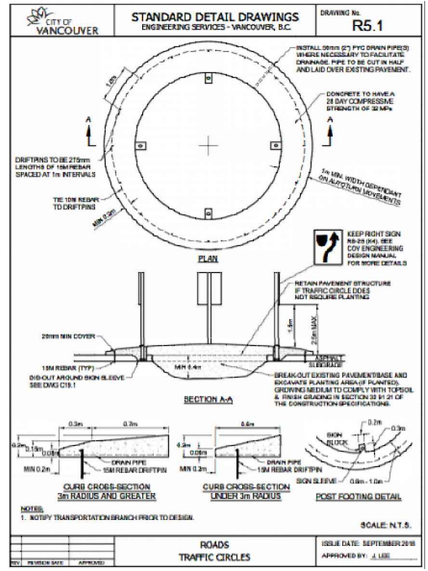


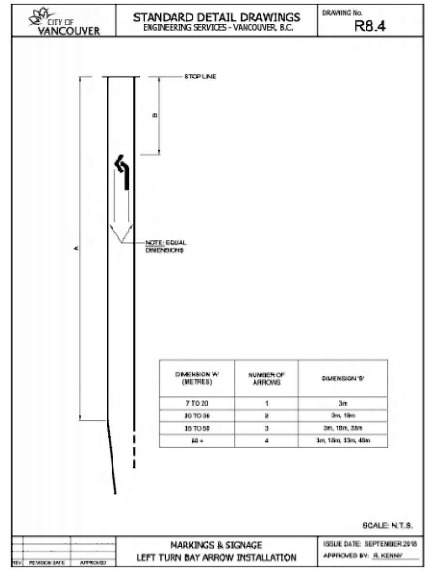


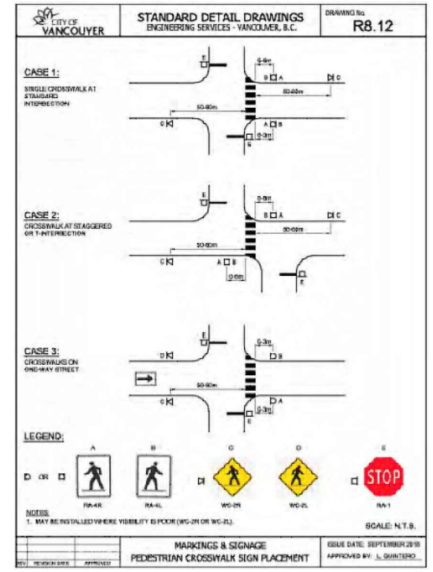
CLIENT: UNIVERSITY OF BRITISH COLUMBIA S.E.E.D.S.		EAST MALL CORRIDOR LAYOUT	NO.	SUBMISSION	DATE
CIVIL 446 - CAPSTONE PROJECT	GROUP 11		1	PRELIMINARY DESIGN	12/6/2020
DRAFTED BY: KRISTIAN BIELA			2	ISSUED FOR CONSTRUCTION	04/16/2021
SHEET: 22 OF 23	SCALE: 1:100		3		

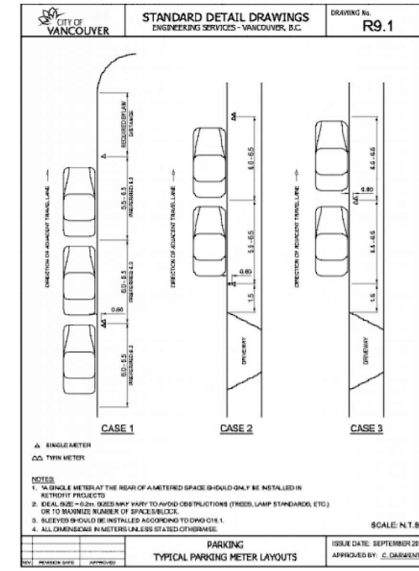


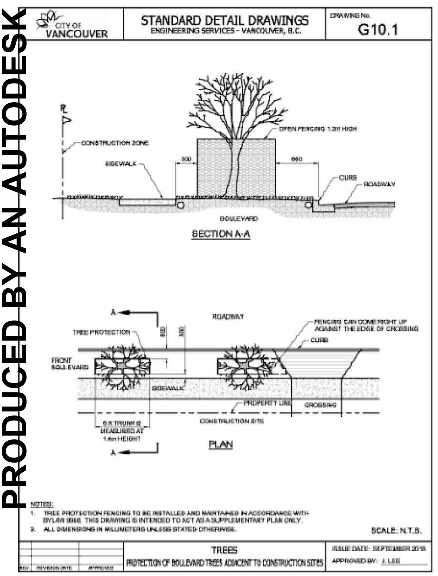


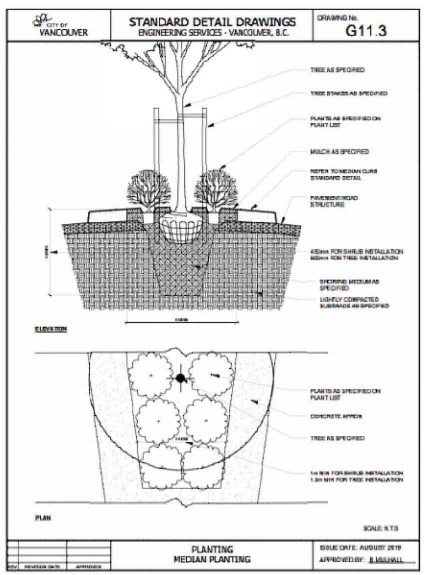


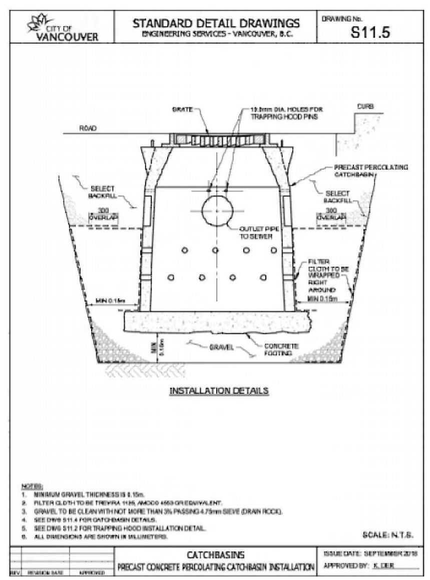


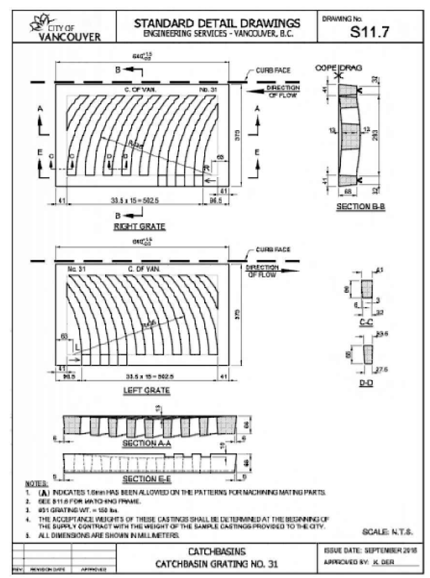


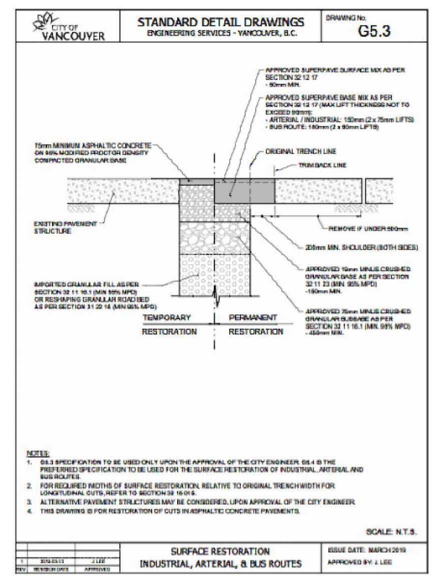












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CIVIL 446 - CAPSTONE PROJECT	GROUP 11	
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SHEET: 23 OF 23		

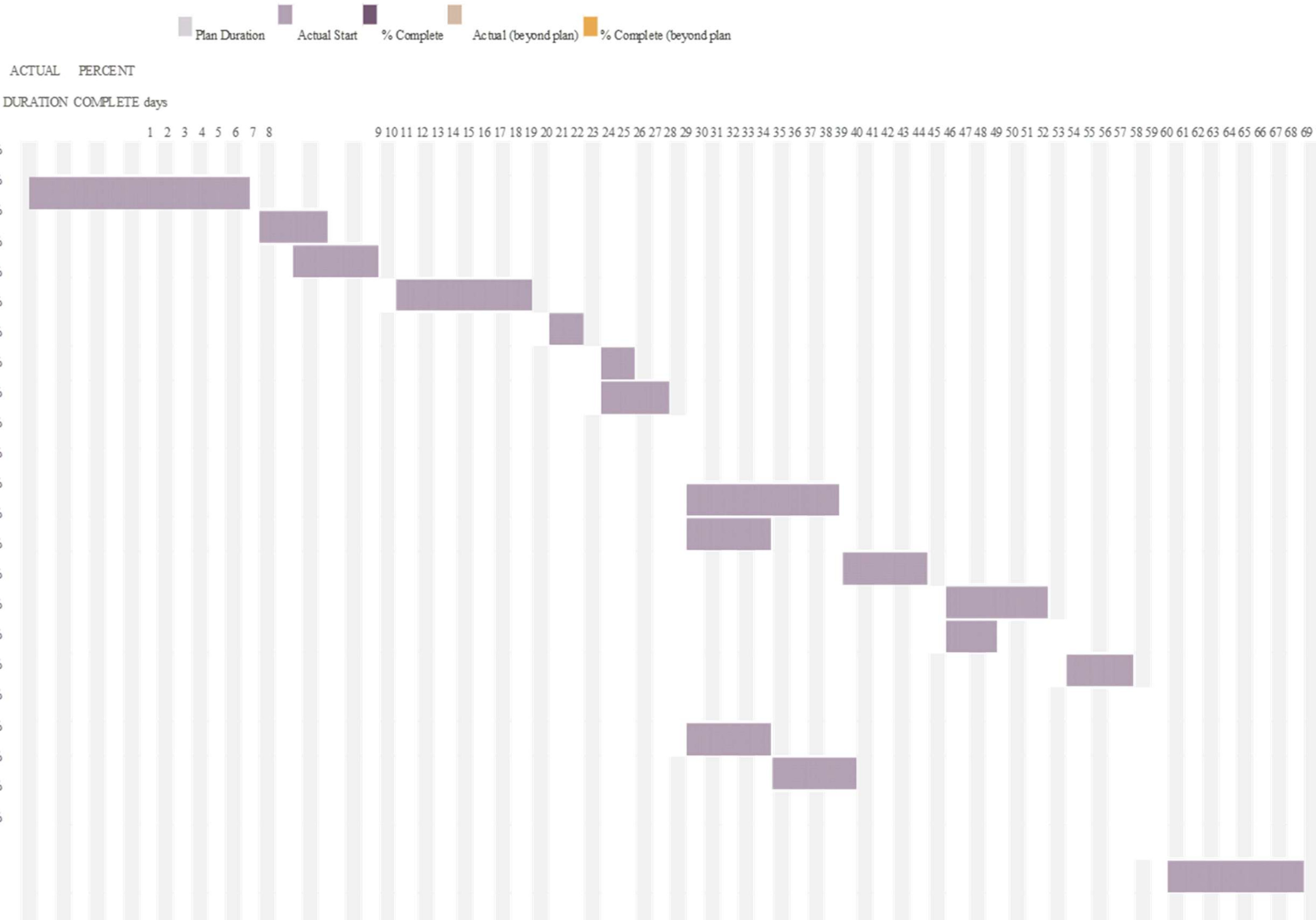
EAST MALL CORRIDOR LAYOUT

NO.	SUBMISSION	DATE
1	PRELIMINARY DESIGN	12/6/2020
2	ISSUED FOR CONSTRUCTION	04/16/2021
3		

Appendix B: Construction Schedule

Project Schedule

ACTIVITY	PLAN START	PLAN DURATION	ACTUAL START	ACTUAL DURATION	PERCENT COMPLETE
	1	1	1	1	0%
Northbound lane 2-way setup	1	14	1	14	0%
Tree removal	15	4	15	4	0%
SB lane from thunderbird to stadium asphalt removal	17	5	17	5	0%
SB lane from thunderbird to Eagle partial substantial median removal	22	8	22	8	0%
SB lane from thunderbird to stadium levelling/elevation and	30	2	30	2	0%
subgrade install	32	2	32	2	0%
SB lane paving	32	4	32	4	0%
SB lane painting and landscaping SB lane	36	1	36	1	0%
RRFB, new street lights, and signage installation	36	1	36	1	0%
	36	9	36	9	0%
SB lane opening to new traffic	36	5	36	5	0%
close NB lane(s) NB lane thunderbird to eagle	45	5	45	5	0%
asphalt removal	50	6	50	6	0%
existing bike path removal	50	3	50	3	0%
landscape for median + subgrade for multi-use path	56	4	56	4	0%
install electrical for lighting	36	1	36	1	0%
on path paving for pull-out	36	5	36	5	0%
paving of bike path	41	5	41	5	0%
closure of east mall from thunderbird to agronomy mill	60	1	60	1	0%
pavement and greenscape repave and install bike paths	60	1	60	1	0%
close intersection @ thunderbird remove traffic	61	8	61	8	0%
lights install roundabout open intersection	69	1	69	1	0%



Appendix C: Cost Estimate & Benefit Cost Analysis

Table C1: RRFB Cost Breakdown

Civil Costs:	Cost per Metre	Total Metres	Total cost
Place Conduit with 100 mm backfill, including excavation	$ 180.00	20	$ 3,600.00
Material Costs:	**Cost**	**Quantity**	**Total Cost**
Hybrid RRFB Unit	$ 40,000.00	2	$ 80,000.00
50mm PVC DB2	$ 1.91	24	$ 45.84
50mm PVC DB2 Coupling	$ 0.34	12	$ 4.08
50mm PVC DB2 90° Bend	$ 9.29	4	$ 37.16
50mm PVC DB2 45° Bend	$ 12.28	4	$ 49.12
		Total Cost:	**$ 84,000.00**

Table C2: Multi-Modal Cost Breakdown

Multi-Modal Path Dimensions:	Meterage, m
Length	700
Width	5
Cost Breakdown:	**Cost**
Removal of Existing Concrete	$ 17,845.70
New Concrete	$ 169,784.08
Gravel Base	$ 55,019.32
Geo-textile base	$ 6,369.32
Landscaping	$ 72,096.59
Paint Making at Intersections	$ 35,227.81
Signalization	$ 487,538.61
Signage	$ 9,678.12
Total Cost:	**$ 854,000.00**

Table C3: Boulevard Excavation/Fill and Paving Cost Breakdown

Labour Day Rates:	**Daily Rate**
1 Equip. Oper.	$ 678.80
Labourer (4)	$ 2,024.00
1 Backhoe Loader, 48 H.P.	$ 235.13
Total Day Rate:	$ 2,937.93
Excavation Day Rates:	**Quantity**
Excavation Rate (m3/hr)	15
Total Excavation Hours	112
Total Excavation Days	12
Total Excavation/Fill Costs:	$ 337,000.00
Paving:	**Quantity**
1 sq.ft	0.092902267 m^2 $ 5.00/sq.ft
Cost/m2 of paving	$ 53.82
Area of Boulevard, m^2 (700m x 8m)	5600
Total Paving Cost:	$ 302,000.00
Total Excavation/Fill and Paving Costs:	**$ 639,000.00**

Table C4: Installation of Roundabout Breakdown

	Cost per m^2	**Area**
Solid Concrete Island	$ 369.50	433.7361357
	Total Cost:	**$ 161,000.00**

Table C5: Asphalt Road Paving of East Mall Corridor

Road Layers and Dimensions:		**Travel Lanes**		
	Depth, m	**Width, m**	**Length, m**	**Volume, m^3**
Asphalt Pavement	0.100	7	770	539
25mm Crush Base Course	0.150	7	770	808.5
25mm Select Granular Sub Base	0.150	7	770	808.5
Road Layers and Dimensions:		**Parking**		
	Depth, m	**Width, m**	**Length, m**	**Volume, m^3**
Asphalt Pavement	0.100	5	833	416.5
25mm Crush Base Course	0.150	5	833	624.75
25mm Select Granular Sub-Base	0.150	5	833	624.75

Cost Breakdown:	Cost per m^3	Cost per m^2	Cost per kg	Unit Weight kg/m^3	Kilograms, kg	Cost
Asphalt Pavement	-	-	$ 0.40	2243	2143186.5	$ 865,416.57
Subgrade Surface (Second Layer)	-	$ 1.42	-	-	-	$ 13,568.10
Granular Fill	$ 100.00	-	-	-	-	$ 143,325.00
					Total Cost:	**$ 1,023,000.00**

Table C6: Pedestrian Canopy Cost Estimate

	Section	Linear Mass (kg/m)	Length (m)	Quantity	Total Length (m)	Total Mass (kg)
Column	HSS102X102X8.0	22.1	2.71	38	102.98	2275.858
Trans. Beam	HSS114X114X4.8	16	5	19	95	1520
Long. Beam	HSS178X178X6.4	33.4	4	34	136	4542.4
					Total:	8338.258

Cost of Steel:

Per kg	**$ 1.33**

Install of Steel:

Per kg	**$ 0.87**

Minor Materials:

Material	Part	Quantity	Total Volume (m^3)	Cost
Concrete	**Concrete Pedestal**	38	3.04	$ 668.80
Steel	**3/4" anchor bolts**	152	-	$ 1,683.70
	22 THK Base Plate	38	0.07524	$ 5,173.47
	L89x89x9.5	68	0.0172448	$ 282.74
	1/2" A325M bolts	576	-	$ 263.50
	10 THK Base Plate	76	0.00798	$ 5,568.24
	10 THK Gusset Plate	38	0.00399	$ 851.31
			Total:	$ 14,491.76
			Total Cost:	**$ 33,000.00**

Table C7: Bicycle Canopy Cost Estimate

	Section	Linear Mass (kg/m)	Length (m)	Quantity	Total Length (m)	Total Mass (kg)
Column	HSS102X102X8.0	52.4	2.71	5	13.55	710.02
Trans. Beam	HSS114X114X4.8	16	4	4	16	256
Long. Beam	HSS178X178X6.4	33.4	2.01	5	10.05	335.67
					Total:	$ 1301.69

Cost of Steel:

Per kg	**$ 1.33**

Install of Steel:

Per kg	**$ 0.87**

Minor Materials:

Material	Part	Quantity	Total Volume (m^3)	Cost
Concrete	**Concrete Pedestal**	5	0.4	$ 88.00
Steel	**3/4" anchor bolts**	64	-	$ 708.93
	22 THK Base Plate	5	0.0099	$ 680.72
	L89x89x9.5	17	0.0043112	$ 282.74
	1/2" A325M bolts	3108	-	$ 263.50
	10 THK Base Plate	10	0.00105	$ 732.66
	10 THK Gusset Plate	5	0.000525	$ 112.01
			Total:	$ 2,868.57
			Total Cost:	**$ 6,000.00**

Table C8: Drainage Network Cost Breakdown

Civil Costs:	Cost per metre	Total meterage, m	Total Cost
Place conduit with 1000mm backfill, including excavation	$ 180.00	900	$ 162,000.00
Material Costs:	**Quantity**	**Cost**	**Total**
Catch Basins	45	$ 2,000.00	$ 112,000.00
200mm PVC SDR35	900	$ 153.00	$ 1,377.00
		Total Cost:	**$ 276,000.00**

Table C9: Arborist Costs

Labour Costs:	Cost	Quantity	Total Cost
Removal of 1 Tree	$ 400.00	100	$ 40,000.00
Permit Costs:	**Quantity**	**Cost**	**Total**
First Tree Costs	$ 75.00	1	$ 75.00
Additional Tree Costs	$ 250.00	99	$ 24,750.00
		Total Cost:	**$ 64,825.00**

Table C10: Traffic Accommodation

Labour Costs:	Cost/day	Number of Days	Total Cost
Flaggers, set-up, mob/demob	$ 1,250.00	69	$ 87,000.00

Table C11: Maintenance Plan

Maintenance Costs:	Total Estimate Cost	Percentage of Total Cost	Total Cost
	$ 3,228,00.00	10%	$ 322,800.00

Table C12: Final Cost Breakdown

Final Estimates:	Costs
RRFB Units and Civil Work	$ 84,000.00
Multi-Modal Path	$ 854,000.00
Boulevard Excavation/Fill and Paving	$ 639,000.00
Installation of Roundabout	$ 161,000.00
Asphalt Road Paving of East Mall Corridor	$ 1,023,000.00
Pedestrian Canopy	$ 33,000.00
Bicycle Canopy	$ 6,000.00
Drainage Network	$ 276,000.00
Arborist	$ 65,000.00
Traffic Accommodation	$ 87,000.00
Maintenance Plan	$ 323,000.00
10% Contingency	$ 355,100.00
Total Cost:	**$ 3,906,100.00**

SHORTBEN.XLS

Version: short_benefit_cost.xlsx

Required Inputs in Yellow

Optional Inputs in Green

Make a workng copyand keep this as the original.

		Existing	Proposed	Notes
General Information				
Segment Length (km)		0.80	0.80	Important to show any differences between base & prop.
Base Year		2020	2020	Should be same for base and proposed.
Base Year AADT		10,000	10,000	Base & Proposed AADT should normally be the same.
Compound Annual Traffic Growth (%)		1.6%	1.6%	Compound growth
% Trucks		20%	20%	
1st Year Benefits Begin		2022	2022	Typically the year after construction is complete
Benefit Period (yrs)		25	25	
Analysis Period (yrs)		27	27	Construction Period + Benefit Period
Horizon Year		2046	2046	
Discount Rate		6%	6%	
Financial Account				
Year	Capital Costs ($)	Existing	Proposed	
2019	Property	$0	$0	
2019	Eng, PM, Site Supv, Plant Insp.	$0	$400,000	Typically 15% to 25% of total construction cost
2020	Grading & Drainage	$0	$1,200,000	
2021	Base & Sub-base	$0	$400,000	
2021	Structures	$0	$20,000	
2021	Surface	$0	$2,000,000	
2030	Other	$0	$0	Rehabilitate an existing bridge for example
	Total ($)	$0	$4,020,000	
	Present Value ($)	$0	$3,907,019	Sum of one time costs discounted back to the base year.
Service Life (yrs)				Typical Values:
	Property	100	100	Property 100 yrs
	Eng, PM, Site Supv, Plant Insp.	0	0	Engineering, Planning & PM 0 yrs
	Grading & Drainage	60	60	Grading & Drainage 60 yrs
	Base & Sub-base	50	50	Base & Sub-base 50 yrs
	Structures	80	80	Structures 80 yrs
	Surface	40	40	Surface 40 yrs
	Other	25	0	or can be a composite of several categories
Residual Value in Horizon Year ($)				
	Property	$0	$0	Residual values account for the value of the asset beyond the
	Eng, PM, Site Supv, Plant Insp.	$0	$0	end of the planning horizon year.
	Grading & Drainage	$0	$1,066,847	
	Base & Sub-base	$0	$324,412	
	Structures	$0	$19,372	
	Surface	$0	$1,290,982	
	Other	$0	$0	
	Horizon Yr Value Total ($)	$0	$2,701,613	
	Present Value ($)	$0	$593,842	
Annual Maintenance				
	Lane-kilometers	0.8	0.8	
	Road Maintenance ($/Ln-km/yr)	$5,099	$5,099	
	Other Mtce ($/yr)	$0	$0	
	PV of Maintenance ($)	$49,194	$49,194	
Periodic Resurfacing				
	Resurfacing Year	2022	2035	Ignored if >= horizon year
	Cost ($/Ln-km)	$70,300	$70,300	Mill and Fill overlay
	Resurfacing Life (yrs)	15	15	Typical Pavement life is 15 yrs from the last resurfacing
	Next Resurfacing Year	2037	2050	Ignored if >= horizon year
	PV of Resurfacing ($)	$70,939	$23,467	Present Value of resurfacings
	PV of Residual ($)	$4,945	$3,297	Residual value in the horizon yr assuming straight line depreciation
Construction Delay		**Existing**	**Proposed**	
	Year in which delay occurs	2022	2021	
	Number of Days	50	150	How many days the restriction is in place
	Hours/day when delay occurs	4	8	and the number of hours per day
	Veh/hr during delay hours	1000	500	What is the flow rate (veh/hr) during times when the restriction is in place
	Delay (sec/veh)	20	10	How many seconds on average, is a vehicle delayed
	Total Veh-Hrs of Delay	1,111	1,667	

PV of Time Cost ($)	$23,734	$37,736	General purpose traffic occupants + truck drivers
PV of Vehicle Operating Cost ($)	$4,165	$6,623	Auto and Truck fuel + Truck time cost
PV Time + VOC ($mill)	$0.03	$0.04	
Net Savings ($mill)		-$0.016	
Reliability			
Closure Duration (Hrs/collision)	**Existing**	**Proposed**	Delay due to collisions.
Fatal	6.0	6.0	May not be applicable in urban areas
Injury	2.0	2.0	where bypass routes are available.
PDO	0.5	0.5	
Collision Weighted Average (hr/coll)	1.36	1.20	
Closure hrs. in Implementation Yr	1.59	1.09	
Traffic Arrival Rate (veh/hr)	800	800	8% of AADT is reasonable for rural locations. Consider 4% or 5% in urban areas
Cost/veh-hr	$30.94	$30.94	
Annual Cost	$39,469	$26,959	
Present Value ($mill)	$0.476	$0.325	
Net Savings ($mill)		$0.151	
Customer Service Account			
Time Costs	**Existing**	**Proposed**	
Value of Travel Time ($/hr)			
Passenger Veh Occupancy	1.2	1.2	Use the same for base and proposed.
Value of Time ($/occupant)	$18.49	$18.49	
Car ($/veh)	$22.19	$22.19	
Truck Driver Payroll Cost($/veh)	$31.25	$31.25	includes drivers wages + payroll expenses & benefits
Travel Time in 1st yr benefits begin			
% of AADT			% of AADT occurring in each period. For example
Peak	30.0%	30.0%	a 3 hr peak period with 10% of AADT per hr = 30% of AADT
Shoulder	35.0%	35.0%	These splits are used to differentiate speed, delay and
Low	35.0%	35.0%	veh. Op. costs during different periods of the day.
Total	100.0%	100.0%	Total must equal 100%
Auto Speed (km/hr)			
Peak	40	40	Representative average speeds in peak and shoulder
Shoulder	60	50	periods are usually not much lower than speeds in
Low	70	50	the low period unless demand is exceeding 80% of capacity.
Truck Speed (km/hr)			
Peak	40	40	
Shoulder	60	50	
Low	70	50	
Avg. Control Delay (sec/veh)			LOS for Signalized I/S (sec/veh)
Peak	35	20	LOS: A, B, C, D, E
Shoulder	35	10	Max Delay: 10, 20, 35, 55, 80
Low	20	5	
% of Vehicles Stopping			% Vehicles Stopping during each period should be 0
Peak	0%	0%	if control delay is 0. Values are used for fuel calculations only
Shoulder	0%	0%	and do not impact delay calculations.
Low	0%	0%	
Travel Time (veh-hrs/yr)			does not include cross street delay
Car	69,117	61,263	
Truck	17,279	15,316	
Value ($/yr)			
Car	$1,533,568	$1,359,311	
Truck	$539,977	$478,620	
Both	$2,073,544	$1,837,931	
Travel Time in Horizon Year	**Existing**	**Proposed**	Horizon year inputs account for changes in operating speeds or delay
AADT Horizon Yr	15,351	15,351	over the planning period.
% of AADT			
Peak	30.0%	30.0%	
Shoulder	35.0%	35.0%	
Low	35.0%	35.0%	
Total	100.0%	100.0%	
Auto Speed (km/hr)			
Peak	40	40	
Shoulder	60	50	
Low	70	50	
Truck Speed (km/hr)			
Peak	40	40	
Shoulder	60	50	

Low	70	50							
Avg. Control Delay (sec/veh)									
Peak	35	20							
Shoulder	35	10							
Low	20	5							
% of Vehicles Stopping									
Peak	0%	0%							
Shoulder	0%	0%							
Low	0%	0%							
Travel Time (veh-hrs/yr)									
Car	102,784	91,105							
Truck	25,696	22,776							
Horizon Year Value ($/yr)									
Car	$2,280,582	$2,021,444							
Truck	$803,004	$711,760							
EquivalentGrowth Rate in Time Costs (%/yr)									
Car	1.48%	1.48%							
Truck	1.48%	1.48%							
Present Value of Time Costs ($mill)									
for Benefit Period									
Car	$21.111	$18.712							
Truck	$7.433	$6.589							
Total	$28.544	$25.301							
			Typical acc. rates and severities by service class (2009 - 2013 data)						
Accident Costs	**Existing**	**Proposed**	Service Class	UAU2	UAU4	UAD4	UED4	UFD4	RAU2
Rate (coll/mvk)	0.78	0.60	Rate (coll/mvk)	0.60	0.76	0.78	0.42	0.29	0.39
Severity				All Collisions					
% Fatal	0.0%	1.30%	Fatal	1.3%	0.0%	0.0%	0.0%	0.0%	3.0%
% Injury	57.1%	42.2%	Injury	42.2%	25.6%	57.1%	37.0%	0.0%	43.9%
% PDO	42.9%	56.5%	PDO	56.5%	74.4%	42.9%	63.0%	0.0%	53.0%
Cost/Collision									
Fatal	$8,087,204	$8,087,204	based on 1.05 fatalities and 0.78 injuries/fat coll.						
Injury	$302,636	$302,636	based on 0.15 major + 1.2 minor injuries/inj coll						
PDO	$13,518	$13,518							
Weighted Average	$178,605	$240,484							
Present Value Coll. Costs ($ mill)	$5.845	$6.054							
Vehicle Operating Costs (VOC)	**Existing**	**Proposed**							
Running Fuel (L/km)			Fuel consumed at running speed, no control delay						
Car	0.091	0.094							
Composite Truck	0.366	0.356	35%SU, semi - 20%empty 30% full, Btrain- 7%empty 8%full						
Idle Fuel (L/hr)									
Car	1.00	1.00							
Composite Truck	2.50	2.50							
Control Delay Fuel (L/veh)			Additional fuel consumed due to control delay.						
Car	0.008	0.003	includes deceleration, stop time and acceleration						
Composite Truck	0.021	0.008							
Fuel (Litres/yr)			Annual Fuel Consumption (L)						
Cars	237,433	227,707							
Composite Truck	228,779	213,893							
Fuel Price ($/L)			Price net of taxes is about 75% of pump price						
Car	$1.014	$1.014							
Composite Truck	$0.942	$0.942							
Fuel Cost ($/yr)									
Car	$240,757	$230,895	Includes excess fuel consumption due to control delay, if any.						
Composite Truck	$215,510	$201,487							
Other Vehicle Costs									
Car ($/km)	$0.135	$0.135	Use-related costs (other than fuel and driver)						
Truck Time ($/hr)	$14.65	$14.65	Combination Truck						
Truck Distance ($/km)	$0.257	$0.257	Excludes fuel and driver						
Annual Cost ($/yr)			Composite values based on peak, shoulder and						
Car	$556,818	$546,955							
Truck Time	$237,171	$215,454							
Truck Distance	$365,598	$351,575							
Present Value of VOC ($millions)									
Car	$7.751	$7.614							
Truck Time	$3.265	$2.966							

Truck Distance	$5.089	$4.894	
Total	$16.106	$15.474	
Summary of Discounted Costs ($millions)	**Existing**	**Proposed**	
Capital	$0.000	$3.907	
Maintenance & Resurf	$0.120	$0.073	
Residual Value	($0.005)	($0.597)	Negative because it it a recoverable
Total	$0.115	$3.383	Sum of discounted Costs
Summary of Discounted Benefits			
Time Savings		$3.243	Savings due to higher speeds or shorter distance
Accident Savings		($0.209)	Savings due to reduced accident rate or severity
Vehicle Operating Savings		$0.631	Often negative with increasing fuel at higher speed
Construction Delay		($0.016)	Construction delay is treated as a negative benefit.
Reliability		$0.151	
Total Benefits		$3.800	
Summary of Results (Present Values in $millions)			
Financial Account	$0.115	$3.383	
Incremental Cost		$3.267	= Proposed - Base
Customer Service Account	$51.00	$47.20	
Incremental Benefit		$3.800	=Base -Proposed
B/C Ratio		1.16	= Incremental benefits/incremental costs
Net Present Value		$0.533	= Incremental Benefits - Incremental Costs

Greenhouse Gas Reduction		Kg/Litre	Gas	Dies	CO2 is 2016 std
Carbon Dioxide	61		2.25	2.62	
Nitrogen Oxide	4		0.262	0.08	
Hydrocarbons	3		0.122	0.12	
Annual Saving (tonnes/yr)	68		2.634	2.824	

Appendix D: Synchro Report Sample

A sample Synchro Report is shown below *(Thunderbird Boulevard Intersection, 2040 PM Volumes, Future Roundabout Configuration).* The full list of synchro reports (2020/2040 AM/PM Existing/Future) can be made available upon request to Steve of Team 11.

Lanes, Volumes, Timings
3: East Mall & Thunderbird Blvd

11-16-2020

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Traffic Volume (vph)	7	95	70	254	90	20	88	37	140	132	320	8
Future Volume (vph)	7	95	70	254	90	20	88	37	140	132	320	8
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Storage Length (m)	0.0		0.0	45.0		0.0	0.0		0.0	0.0		0.0
Storage Lanes	0		0	0		0	0		0	0		0
Taper Length (m)	7.5			7.5			7.5			7.5		
Lane Util. Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Ped Bike Factor												
Frt		0.938			0.992			0.936			0.996	
Flt Protected		0.998			0.967			0.983			0.987	
Satd. Flow (prot)	0	1779	0	0	1810	0	0	1745	0	0	1868	0
Flt Permitted		0.998			0.967			0.983			0.987	
Satd. Flow (perm)	0	1779	0	0	1810	0	0	1745	0	0	1868	0
Link Speed (k/h)		50			50			50			50	
Link Distance (m)		130.1			119.6			72.2			157.3	
Travel Time (s)		9.4			8.6			5.2			11.3	
Confl. Peds. (#/hr)	55		149	149		55	76		51	51		76
Peak Hour Factor	0.75	0.86	0.70	0.83	0.81	0.71	0.77	0.59	0.88	0.93	0.87	0.58
Heavy Vehicles (%)	0%	0%	0%	1%	0%	0%	0%	1%	0%	0%	0%	0%
Adj. Flow (vph)	9	110	100	306	111	28	114	63	159	142	368	14
Shared Lane Traffic (%)												
Lane Group Flow (vph)	0	219	0	0	445	0	0	336	0	0	524	0
Enter Blocked Intersection	No	No	No	No	No	No	No	No	No	No	No	No
Lane Alignment	Left	Left	Right	Left	Left	Right	Left	Left	Right	Left	Left	Right
Median Width(m)		0.0			0.0			0.0			0.0	
Link Offset(m)		0.0			0.0			0.0			0.0	
Crosswalk Width(m)		4.8			4.8			4.8			4.8	
Two way Left Turn Lane												
Headway Factor	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
Turning Speed (k/h)	25		15	25		15	25		15	25		15
Sign Control		Yield			Yield			Yield			Yield	

Intersection Summary	
Area Type: Other	
Control Type: Roundabout	
Intersection Capacity Utilization 74.5%	ICU Level of Service D
Analysis Period (min) 15	

Appendix E: Calculations

Sightline Sample Calculation

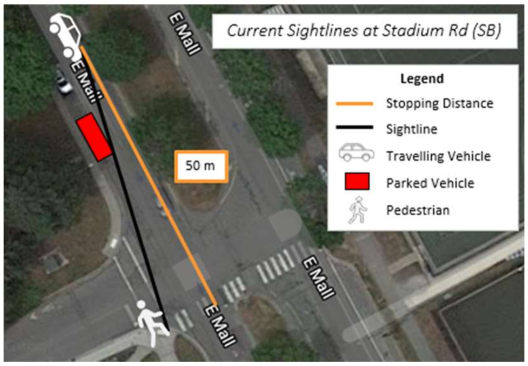
$$SSD = 0.694V + \frac{V^2}{255\left(f + \frac{G}{100}\right)} \quad (5.5.1)$$

Where SSD = stopping sight distance (m)
V = design speed or velocity (km/h)
f = coefficient of friction
G = grade (m/m; % upgrade is positive and downgrade is negative)

V = 85th percentile speeds

G = 2% grade

f = 0.41 (wet pavement conditions)



Current sightlines and required SSD were measured from Google Maps as shown in the adjacent Figure.

A summary of existing vs. required SSD that were used to inform the design and location of parking spaces is shown in the table below.

Crossing Location	85th Percentile Speed	Stopping Sight Distance Required (Wet Pavement)	Current Sightline SSD (NB)	Current Sightline SSD (SB)
Eagles Drive	52.8 km/h	63 m	20 m	30 m
Stadium Road	52.8 km/h	63 m	65 m	50 m

Forecasted Traffic Volumes & Sample Synchro Report

Compounding Growth Rate (1%) = $(1+0.01)^{21}$ = 23% increase in vehicle volumes

Mode Shift of ~8% aligning with the targets set by UBC = 23% - 8% = **15% increase due to population growth.**

1500-unit residential development, via ITE Trip Generation Manual = 400 additional trips to/from Stadium Neighbourhood

These trips were then distributed in accordance with the existing traffic flow patterns in the AM and PM.

Rational Method Calculation and IDF Curves

$$Q = \frac{CIA}{360}$$
$$Q = Design\ Flow\ (\frac{m^3}{s})$$
$$C = Runoff\ Coefficient$$
$$I = Rainfall\ Intensity\ (\frac{mm}{hr})$$
$$A = Tributary\ Drainage\ Area$$

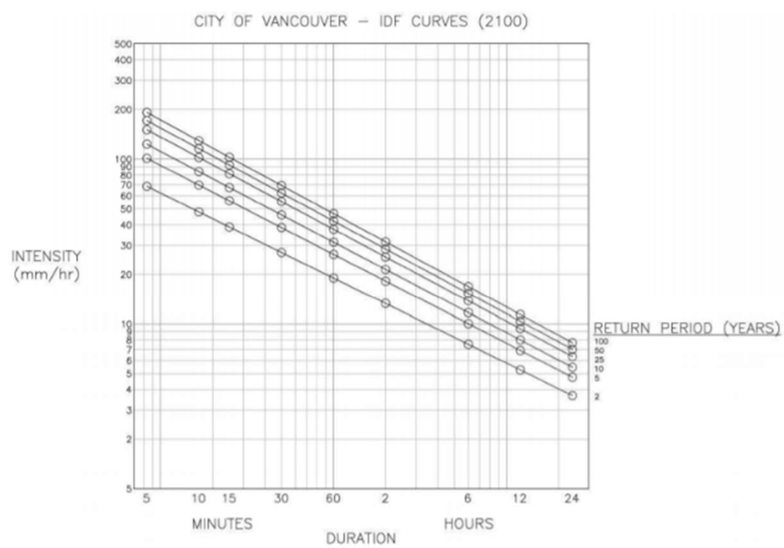
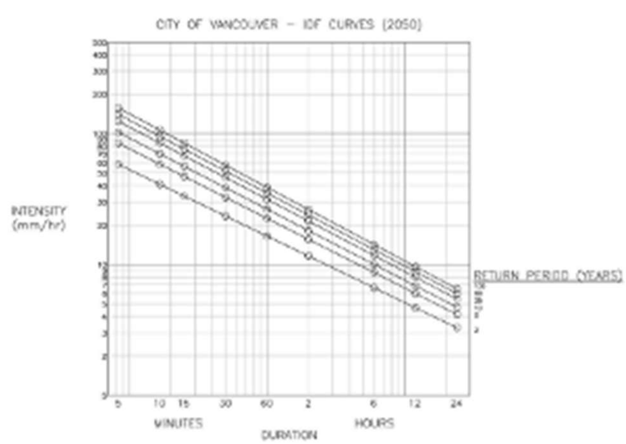
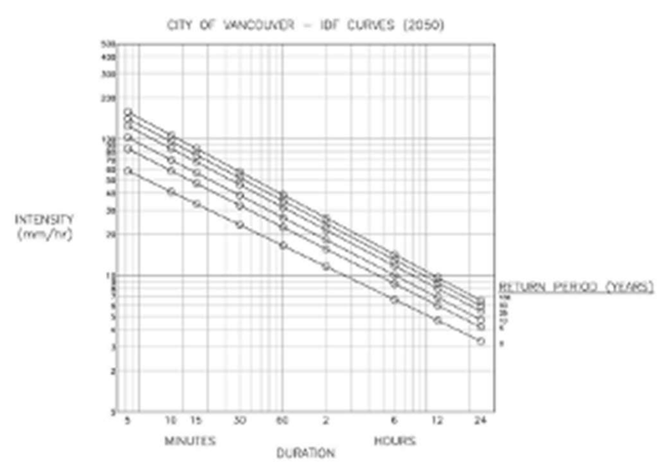


Figure 5-3: 2100 IDF Curve





Max flow to a catch basin (design flow):

Total drainage area = 0.9 ha
No. of catch basins = 45
Drainage area per catch basin = 0.0225ha , round up to min spacing 250m^2
Runoff coefficitent (C): 0.88
Using the 2100 IDF curve and assuming a min concentration time of 5 minutes (max flow)
Rainfall instensity (I) = 122.8 mm/hr
Design flow (Q)= 0.007m^3/s

Pipe Capacity Check:

$$Q_{Full} = \frac{1}{n}\frac{D}{4}^{2/3}\frac{s}{100}^{1/2}\frac{\mu D^2}{4}$$

D = Pipe diameter (200mm)
N = mannings coefficient (0.013)
S = 2%
U (kinematic viscosity) = 1.0E-6
Qfull = 0.017 m^3/s
Qfull > Design flow

Catch Basin Capacity Check

$$Q_{cap} = kCA\sqrt{2gh}$$

Where:

Q_{cap} = Inlet Flow Capacity (m^3/s)

k = Clogging Factor = 0.6

C = Orifice Coefficient = 0.8

A = Open Area (m^2) = 0.080m^2 for City of Vancouver Grate No. 31

g = Acceleration due to Gravity (m/s^2)

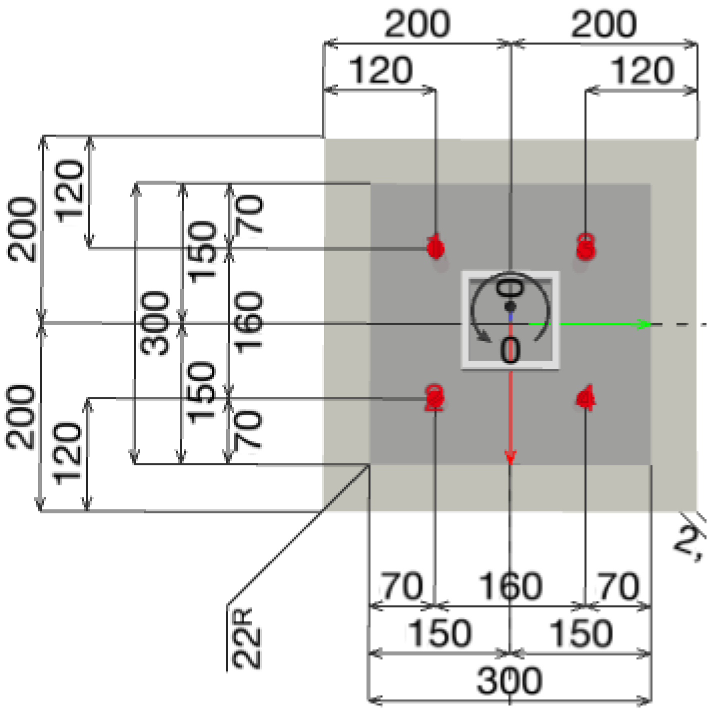
h = Depth of Ponding (m)

H = 1.2m
Qcap = 0.18 m^3/s
Qcap > Design flow

Pedestrian Canopy - Foundation Design

Input   output

The canopy column foundation is a concrete pedestal sitting underground with base plates, anchor bolts and welds connecting the concrete and the steel column. After comparing the reactions in SAP2000 model, the loading difference between the corner columns and the side columns are little. In order to save the effort for designing and construction, only side column foundation will be designed in detail and the corner ones are going to use the same design since the side column foundation is more critical and governs the design.



Design Loads

- Max Tension = 0kN
- Max Compression = 58.8kN
- Max Shear in X dir = 10.3kN
- Max Shear in Y dir = 10.4kN
- Max Moment in X dir = 13.0kNm
- Max Moment in Y dir = 12.9kNm

Pedestal Design Summary

- Length = 400mm
- Width = 400mm
- 4-25M Vertical Reinforcement
- 10M Tie @ 300
- Utilization: 0.13
- Governing Case: Bending

Anchor Design Summary

- 4-20M Dia. Anchor
- Embedment length = 250mm
- Utilization:0.76
- Governing case: Concrete breakout strength

Base Plate Design Summary

- 300mm x 300mm x 22mm thk.

Base Plate Design

Column Geometry

$D := 102mm$ Depth of the member

$B := 102mm$ Width of the flange

Material Properties

$f_c := 25MPa$ Specified concrete compressive strength

$F_{yc} := 400MPa$ Column steel yield strength

$F_{yp} := 400MPa$ Base plate steel yield strength

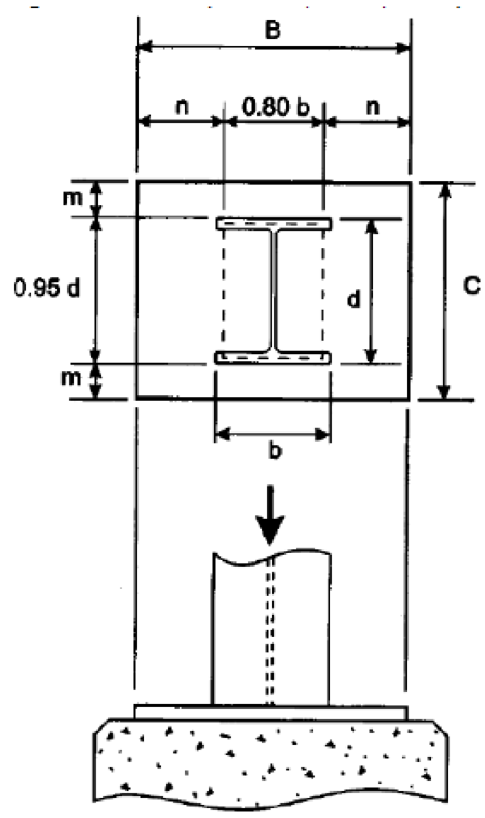
Design Factors

$\phi := 0.9$ Steel resistance factor

$\phi_c := 0.65$ Concrete resistance factor

Factored Load

$C_f := 58.8kN$



$B_r = 0.85\,\phi_c\,f'_c A_1$

Calculate area of base plate required

$A_{bp\_req} := \frac{C_f}{0.85 \cdot \phi_c \cdot f_c}$ Required base plate plan area

$A_{bp\_req} = 4.257 \times 10^3 \cdot mm^2$ $\sqrt{A_{bp\_req}} = 65.246 \cdot mm$

Designed Base Plate Plan Dimensions:

$B_p := 300mm$ $C_p := 300mm$ $A_1 := B_p \cdot C_p = 9 \times 10^4 \cdot mm^2$

$Check_{area\_req} := if(A_1 \geq A_{bp\_req}, "Pass", "Need bigger plan dim.")$ $Check_{area\_req} = "Pass"$

Determine m and n, calculate required plate thickness

$b_{loaded} := 0.8 \cdot B = 81.6 \cdot mm$ Width of the loaded area from column

$d_{loaded} := 0.95 \cdot D = 96.9 \cdot mm$ Depth of the loaded area from column

$n_{edge} := \frac{B_p - b_{loaded}}{2} = 109.2 \cdot mm$ $m_{edge} := \frac{C_p - d_{loaded}}{2} = 101.55 \cdot mm$

$t_{p1\_req} := m_{edge} \cdot \sqrt{\frac{2 \cdot C_f}{B_p \cdot C_p \cdot \phi \cdot F_{yp}}}$ Plate thickness based on m $t_{p1\_req} = 6.118 \cdot mm$

$t_{p2\_req} := n_{edge} \cdot \sqrt{\frac{2 \cdot C_f}{B_p \cdot C_p \cdot \phi \cdot F_{yp}}}$ Plate thickness based on n $t_{p2\_req} = 6.579 \cdot mm$

$t_{p3\_req} := 20\% \cdot max(m_{edge}, n_{edge})$ Plate thickness based on rule of thumb $t_{p3\_req} = 21.84 \cdot mm$

$t_p := 22mm$ Designed base plate thickness

$t_{p\_req} := ceil\left(\frac{max(t_{p1\_req}, t_{p2\_req}, t_{p3\_req})}{mm}\right) mm$ Required plate thickness $t_{p\_req} = 22 \cdot mm$

$Check_{tp} := if(t_p \geq t_{p\_req}, "Pass", "Need thicker plate.")$

$Check_{tp} = "Pass"$

Welded Connection Check

Weld Geometry

$L_{leg1} := 8mm$ Weld size 1 (leg size) $L_{leg2} := 8mm$ Weld size 2 (leg size)

$L_1 := 204mm$ Length of the weld 1 $L_2 := 204mm$ Length of the weld 2

$\theta_1 := 0$ Weld Angle 1 $\theta_2 := \frac{\pi}{2}$ Weld Angle 2

Weld Material

$X_u := 490MPa$ Tensile strength of weld material (E49XX)

Base Plate

$t_1 := 22mm$ Thickness of base plate 1 $t_2 := 8mm$ Thickness of welded plate 2

$w_1 := 300mm$ Width of base plate 1 $w_2 := 102mm$ Width of base plate 2

Base Material

$F_{u\_base} := 450MPa$

Design Constants

$\phi_w := 0.67$

Factored Load

$T_f := 140.5kN$ Factored tension load on the weld connection

Check for Strength of Weld Metal

$A_{w1} := \frac{L_{leg1}}{\sqrt{2}} \cdot L_1$ Effective area of the weld throat 1 $A_{w1} = 1154 \cdot mm^2$

$A_{w2} := \frac{L_{leg2}}{\sqrt{2}} \cdot L_2$ Effective area of the weld throat 2 $A_{w2} = 1154 \cdot mm^2$

$\theta_{1\_deg} := \min(\theta_1, \theta_2) \cdot \frac{180}{\pi}$ $\theta_{2\_deg} := \max(\theta_1, \theta_2) \cdot \frac{180}{\pi}$

$M_w := \dfrac{0.85 + \frac{\theta_{1\_deg}}{600}}{0.85 + \frac{\theta_{2\_deg}}{600}}$ Strength reduction factor for multi-orientation welds $M_w = 0.85$

$V_{r1} := 0.67 \cdot \phi_w \cdot A_{w1} \cdot X_u \cdot \left(1 + 0.5 \cdot \sin(\theta_1)^{1.5}\right) \cdot M_w$ Strength of weld 1 $V_{r1} = 216 \cdot kN$

$V_{r2} := 0.67 \cdot \phi_w \cdot A_{w2} \cdot X_u \cdot \left(1 + 0.5 \cdot \sin(\theta_2)^{1.5}\right) \cdot M_w$ Strength of weld 2 $V_{r2} = 324 \cdot kN$

$V_r := V_{r1} + V_{r2}$ Total weld metal strength $V_r = 539 \cdot kN$

$DesRatio_{Vr} := \frac{T_f}{V_r}$ $DesRatio_{Vr} = 0.26$

$Check_{Vr} := \text{if}(DesRatio_{Vr} \le 1, \text{"Pass"}, \text{"Fail"})$ $Check_{Vr} = \text{"Pass"}$

Check for Strength of Base Metal

Note: if matching electrodes are used, the base metal check is not required

$A_m := L_{leg1} \cdot L_1 + L_{leg2} \cdot L_2 = 3.264 \times 10^{-3} m^2$ Area of the fusion face $A_m = 3264 \cdot mm^2$

$V_{r\_base} := 0.67 \cdot \phi_w \cdot A_m \cdot F_{u\_base}$ Total strength of base plates $V_{r\_base} = 659 \cdot kN$

$DesRatio_{Vrbp} := \frac{T_f}{V_{r\_base}}$ $DesRatio_{Vrbp} = 0.213$

$Check_{Vrbp} := \text{if}(DesRatio_{Vrbp} \le 1, \text{"Pass"}, \text{"Fail"})$ $Check_{Vrbp} = \text{"Pass"}$

Check for Weld Size and Length

Minimum Leg size

$t_{p\_max} := \max(t_1, t_2) = 22 \cdot mm$ Maximum welded plate thickness

$L_{leg\_min} := \begin{cases} 3mm & \text{if } t_{p\_max} \le 6mm \\ 5mm & \text{if } 6mm < t_{p\_max} \le 12mm \\ 6mm & \text{if } 12mm < t_{p\_max} \le 20mm \\ 8mm & \text{otherwise} \end{cases}$ Minimum weld size $L_{leg\_min} = 8 \cdot mm$

$Check_{MinLeg} := \text{if}(L_{leg1} \ge L_{leg\_min} \wedge L_{leg2} \ge L_{leg\_min}, \text{"Pass"}, \text{"Fail"})$

$Check_{MinLeg} = \text{"Pass"}$

Maximum Leg size (recommended only)

$t_{p\_min} := \min(t_1, t_2) = 8 \cdot mm$ Minimum welded plate thickness

$L_{leg\_max} := \min\left(0.75 \cdot t_{p\_min}, \begin{cases} t_{p\_min} & \text{if } t_{p\_min} < 6mm \\ t_{p\_min} - 2mm & \text{otherwise} \end{cases}\right)$ $L_{leg\_max} = 6 \cdot mm$

Minimum weld length

$L_{w\_min} := \max(38mm, 4 \cdot L_{leg1}, 4 \cdot L_{leg2}) = 38 \cdot mm$ Minimum weld length

$Check_{MinWeldL} := \text{if}(L_1 \ge L_{w\_min} \wedge L_2 \ge L_{w\_min}, \text{"Pass"}, \text{"Fail"})$

$Check_{MinWeldL} = \text{"Pass"}$

Resistance of a 4 Cast-in Place Anchor Bolts Group in Unreinforced Concrete to CSA A23.3-14

Reference

- CSA A23.3-14
- Concrete Design Handbook

Input Data

Anchor rod dimensions

$d_a := \frac{3}{4} in$ Anchor rod diameter

$A_{se} := 215mm^2$ Effective area of anchor bolts (Concrete Design Handbook Table 12.3)

$A_{brg} := 422mm^2$ Bearing area of anchor bolts (Concrete Design Handbook Table 12.3)

$h_{efr} := 250mm$ Anchor embedment depth

Concrete pedestal dimensions

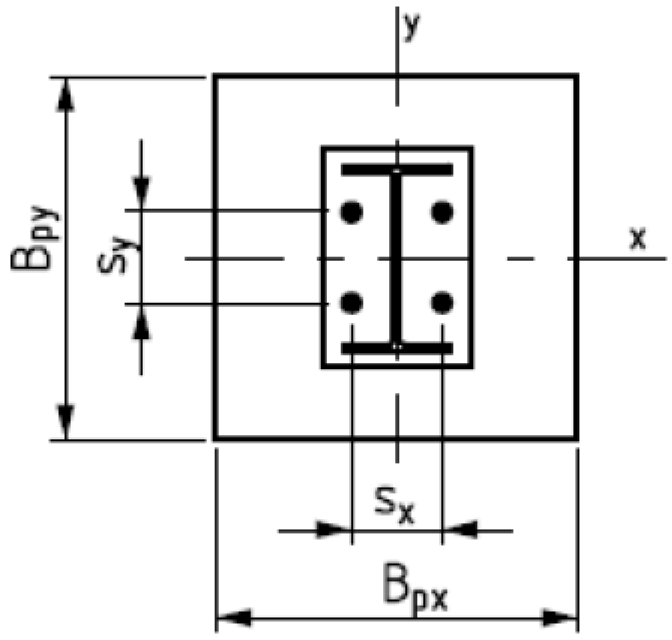
$h_{ped} := 2000mm$ Height of pedestal

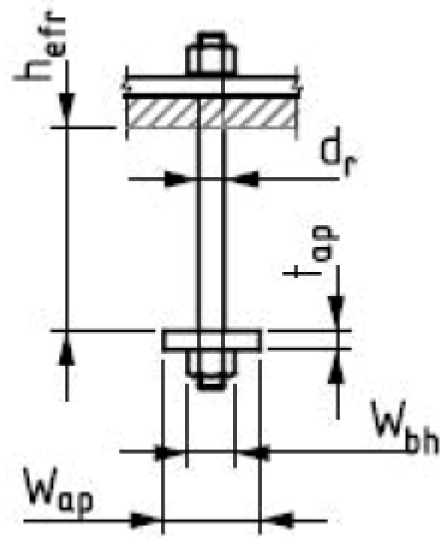
$B_{px} := 400mm$

$B_{py} := 400mm$

$s_x := 160mm$

$s_y := 160mm$





Factored Loads

$F_{zt} := 41kN$ Factored axial tension

$F_{zc} := 0kN$ Factored axial compression

$F_x := 10.3kN$ Factored shear in x-dir

$F_y := 10.4kN$ Factored shear in y-dir

Material Parameters

$f_c := 25MPa$

$f_{ya} := 36ksi = 248.211 \cdot MPa$

$f_{uta} := 58ksi = 399.896 \cdot MPa$

Resistance Design Factors

$\phi_c := 0.65$ $\phi_s := 0.85$ $\phi_g := 0.80$ (CSA A23.3-14 Cl.8.4.2 and D.7.1.3)

$R_{ts} := 0.8$ $R_{tc} := 1.15$ $R_{tp} := 1.15$ (CSA A23.3-14 Cl. D.5.3)

$R_{vs} := 0.75$ $R_{vc} := 1.15$ $R_{vp} := 1.15$ (CSA A23.3-14 Cl. D.5.3)

$V_{res} := \sqrt{F_x^2 + F_y^2} = 14.64 \cdot kN$ Note: the anchor rods are assumed not subject to bending.

Detailed Calculation

Edge distances

$c_x := \frac{B_{px} - s_x}{2}$ Edge distance parallel to x-axis $c_x = 120 \cdot mm$

$c_y := \frac{B_{py} - s_y}{2}$ Edge distance parallel to y-axis $c_y = 120 \cdot mm$

$c_{min} := \min(c_x, c_y) = 120 \cdot mm$

$c_{max} := \max(c_x, c_y) = 120 \cdot mm$

$Check_e := \begin{cases} \text{"Pass"} & \text{if } c_x < 1.5h_{efr} \wedge c_y < 1.5h_{efr} \\ \text{"Fail"} & \text{otherwise} \end{cases}$

$Check_e = \text{"Pass"}$

Check required edge distance and spacing

$s_{r.min} := 4d_a$ Minimum spacing (CSA A23.3-14 Cl.D.9.2)

$c_{r.min} := 6d_a$ Minimum edge distance (CSA A23.3-14 Cl.D.9.2)

$DesRatio_s := \frac{s_{r.min}}{\min(s_x, s_y)} = 0.476$

$DesRatio_c := \frac{c_{r.min}}{c_{min}} = 0.952$

$Check_{cs} := if(DesRatio_s \le 1 \wedge DesRatio_c \le 1, \text{"Pass"}, \text{"Fail"})$

$Check_{cs} = \text{"Pass"}$

Anchor Rods Tension Resistance Check

i) Anchor bolts tensile strengh (Cl. D.6.1.2)

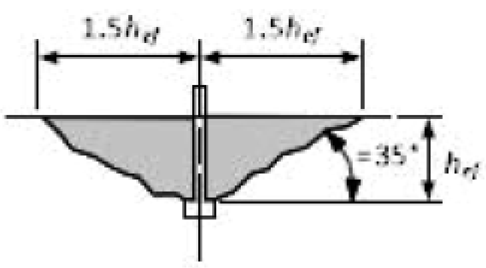
$N_{sar} := A_{se} \cdot \phi_s \cdot f_{uta} \cdot R_{ts}$ Factored tensile resistance $N_{sar} = 58.5 \cdot kN$

$DesRatio_{at} := \frac{F_{zt}}{4.N_{sar}}$ $DesRatio_{at} = 0.18$

$Check_{at} := if(DesRatio_{at} \le 1, \text{"Pass"}, \text{"Fail"})$

$Check_{at} = \text{"Pass"}$

ii) Concrete breakout resistance with anchor reinforcement (D.6.2.2)



$k_c := 10$ For cast in headed anchors as per D.6.2.2

Monify the effective anchorage depth for narrow members (Cl.D.6.2.3):

$h_{ef} := \begin{cases} \max\left(\frac{c_{max}}{1.5}, \frac{\max(s_x, s_y)}{3}\right) & \text{if } c_{max} \le 1.5h_{efr} \wedge Check_e = \text{"Pass"} \\ h_{efr} & \text{otherwise} \end{cases}$

$h_{ef} = 80 \cdot mm$

$a_x := \min(c_x, 1.5h_{ef})$ $a_x = 120 \cdot mm$ $a_y := \min(c_y, 1.5 \cdot h_{ef})$ $a_y = 120 \cdot mm$

Factored concrete breakout resistance for single anchor in tension (Cl.D.6.2.2)

$$N_{br} := \begin{cases} k_c \cdot \phi_c \cdot \sqrt{\frac{f_c}{MPa}} \cdot \left(\frac{h_{ef}}{mm}\right)^{1.5} \cdot R_{tc} \cdot \frac{kN}{1000} & \text{if } h_{ef} \le 275mm \\ 3.9 \cdot \phi_c \cdot \sqrt{\frac{f_c}{MPa}} \cdot \left(\frac{h_{ef}}{mm}\right)^{\frac{5}{3}} \cdot R_{tc} \cdot \frac{kN}{1000} & \text{otherwise} \end{cases}$$

$N_{br} = 26.743 \cdot kN$

Projected area of failure surface for a singel anchor removed from edges (CSA A23.3-14 Figure D.6):

$A_{Nco} := 9 \cdot h_{ef}^2$ $A_{Nco} = 0.06 \cdot m^2$

Projected area of failure surface for a single anchor:

$$A_{Nr} := \begin{cases} A_{Nco} & \text{if } c_{min} \ge 1.5h_{ef} \\ 2a_x \cdot 2a_y & \text{otherwise} \end{cases}$$

$A_{Nr} = 0.06\,m^2$

Projected area of failure surface of anchor group:

$A_{Ngr} := (2a_x + s_x) \cdot (2.a_y + s_y)$ $A_{Ngr} = 0.16\,m^2$

$$\psi_{edN} := \begin{cases} 1.0 & \text{if } c_{min} \ge 1.5h_{ef} \\ 0.7 + 0.3\frac{c_{min}}{1.5h_{ef}} & \text{otherwise} \end{cases}$$

Factor for edge effect (Cl.D.6.2.5)

$\psi_{edN} = 1$

$\psi_{cN} := 1.0$ Factor for resistance in tension to account for cracking. 1.0 being conservative assuming concrete cracked at service loads (Cl.D.6.2.5)

$\psi_{cpN} := 1.0$ Factor for concrete break out resistance which only applies to post-installed anchors. Use 1.0 for cast-in (Cl.D.6.2.7)

$\psi_{ecN} := 1.0$ Factor for eccentrically loaded anchor groups (Cl. D.6.2.4)

$N_{cbr} := \frac{A_{Nr}}{A_{Nco}} \cdot \psi_{ecN} \cdot \psi_{cN} \cdot \psi_{cpN} \cdot N_{br} = 26.743 \cdot kN$ Factored concrete breakout resistance in tension for a single anchor (Cl.6.2.1)

$N_{cbgr} := \frac{A_{Ngr}}{A_{Nco}} \cdot \psi_{ecN} \cdot \psi_{cN} \cdot \psi_{cpN} \cdot N_{br} = 74.287 \cdot kN$ Factored concrete breakout resistance in tension for anchor group (Cl.6.2.1)

$$N_{cb} := \begin{cases} 4N_{cbr} & \text{if } A_{Ngr} > 4 \cdot A_{Nco} \\ N_{cbgr} & \text{otherwise} \end{cases}$$

$N_{cb} = 74.287 \cdot kN$ $DesRatio_{bt} := \frac{F_{zt}}{N_{cb}}$ $DesRatio_{bt} = 0.55$

$Check_{bt} := if(DesRatio_{bt} \le 1, "Pass", "Fail")$

$Check_{bt} = "Pass"$

Pullout resistance of cast-in anchors (Cl. D.6.3.1)

$\psi_{cP} := 1.0$ Modification factor for pullout resistance when ft<fr at service load levels. Use 1.0 for a conservative design (can be up to 1.4, Cl.D.6.3.6)

$N_{pr} := \psi_{cP} \cdot 8 \cdot A_{brg} \cdot \phi_c \cdot f_c \cdot R_{tp}$ Factored pullout resistance in tension fpr a single anchor (cast-in, Cl.D.6.3.4) $N_{pr} = 63.089 \cdot kN$

$N_{prf} := 4 \cdot N_{pr}$ Total resistance $N_{prf} = 252.356 \cdot kN$

$DesRatio_{ctp} := \frac{F_{zt}}{N_{prf}}$ $DesRatio_{ctp} = 0.16$

$Check_{ctp} := if(DesRatio_{ctp} \le 1, "Pass", "Fail")$ $Check_{ctp} = "Pass"$

Concrete Side-face blowout resistance in tension (CSA A23.3-14 Cl.D.6.4)

$N_{sbr\_1} := 13.3c_{min} \cdot \sqrt{A_{brg}} \cdot \phi_c \cdot \sqrt{\frac{f_c}{MPa}} \cdot MPa \cdot R_{tc}$ Resistance for single headed anchor (Cl. D.6.4.1)

$N_{sbr\_1} = 122.538 \cdot kN$

$$N_{sbr} := \begin{cases} \frac{1 + \frac{c_{max}}{c_{min}}}{4} \cdot N_{sbr\_1} & \text{if } 1 \le \frac{c_{max}}{c_{min}} \le 3 \\ N_{sbr\_1} & \text{otherwise} \end{cases}$$

Resistance for single headed anchor, factored by edge distance (Cl. D.6.4.1)

$N_{sbr} = 61.269 \cdot kN$

$N_{sbgr} := \left(1 + \frac{\min(s_x, s_y)}{6c_{min}}\right) \cdot N_{sbr\_1}$ Resistance for multiple headed anchor (Cl..D.6.4.2)

$N_{sbgr} = 149.769 \cdot kN$

$$N_{sbf} := \begin{cases} (4N_{sbr}) & \text{if } \min(s_x, s_y) \ge 6c_{min} \\ N_{sbgr} & \text{otherwise} \end{cases}$$

$N_{sbf} = 149.769 \cdot kN$

$$DesRatio_{cts} := \begin{cases} 0 & \text{if } 2.5c_{min} \ge h_{efr} \\ \frac{F_{zt}}{N_{prf}} & \text{otherwise} \end{cases}$$

$DesRatio_{cts} = 0$

$Check_{cts} := if(DesRatio_{cts} \le 1, "Pass", "Fail")$

$Check_{cts} = "Pass"$

Anchor rods shear resistance

Anchor blot shear strength (Cl.D.7.1.2 b)

For cast-in headed bolts $V_{sar} := A_{se} \cdot \phi_s \cdot 0.6 \cdot f_{uta} \cdot R_{vs} = 32.886 \cdot kN$ Shear resistance for one anchor bolt

$V_{sar.r} := V_{sar} \cdot \phi_g = 26.309 \cdot kN$ Shear resistance reduction built-up grout pad

$DesRatio_{av} := \frac{V_{res}}{4V_{sar.r}} = 0.139$ $Check_{av} := if(DesRatio_{av} \le 1, "Pass", "Fail")$ $Check_{av} = "Pass"$

Concrete breakout resistance (Cl.D.7.2)

$l_s := \min(8d_a, h_{efr})$ Load bearing length for anchor in shear (Cl.D.7.2.2) $l_s = 152.4 \cdot mm$

$\psi_{cV} := 1.4$ Shear resistance modification factor (Cl.D.7.2.7). The anchors are assumed in the cracked concrete with reinforcement of a 15Mbar or greater between the anchor and the edge and with the reinforcement enclosed within stirrups spaced not more than 100mm apart.

$\psi_{ecV} := 1.0$ Modification factor for eccentrically loaded anchor groups. Not applicable to this calculation (Cl. D.7.2.5)

Check shear in x-dir

Projected area for a single anchor (Cl.D.7.2.1)

$c_{a1x} := c_x + s_x$ $\quad c_{a2x} := c_y$ $\quad A_{Vco\_x} := 4.5c_x^2 = 0.065\ m^2$

Factored concrete breakout resistance in shear parallel to x axis for a single anchor (Cl.D.7.2.2):

$$V_{br\_x1} := 0.58\left(\frac{l_s}{d_a}\right)^{0.2}\cdot\sqrt{\frac{d_a}{mm}}\cdot\phi_c\cdot\sqrt{\frac{f_c}{MPa}}\cdot\left(\frac{c_x}{mm}\right)^{1.5}\cdot R_{vc}\cdot\frac{kN}{1000} = 18.852\cdot kN \quad V_{br\_x2} := 3.75\cdot\phi_c\cdot\sqrt{\frac{f_c}{MPa}}\cdot\left(\frac{c_x}{mm}\right)^{1.5}\cdot R_{vc}\cdot\frac{kN}{1000} = 18.424\cdot kN \quad V_{br\_x} := \min(V_{br\_x1}, V_{br\_x2})$$

When anchors are locaed in narrow sections of limited thickness:

$$c_{a1xo} := \begin{cases} c_{a1x} & \text{if } c_{a2x} \ge 1.5c_{a1x} \wedge h_{ped} \ge 1.5c_{a1x} \\ \min\left(c_{a1x}, \frac{c_{a2x}}{1.5}, \frac{h_{ped}}{1.5}, \frac{s_y}{3}\right) & \text{otherwise} \end{cases} \quad c_{a1xo} = 53.333\cdot mm$$

Modification factors for edge effect (Cl.D.7.2.6)

$$\psi_{edV\_x} := \begin{cases} 1.0 & \text{if } c_{a2x} \ge 1.5c_{a1xo} \\ 0.7 + 0.3\frac{c_{a2x}}{1.5c_{a1xo}} & \text{otherwise} \end{cases} \quad \psi_{edV\_x} = 1$$

Projected area fora a single anchor (Figure D.13)

$w_{c2x} := \min(c_y, 1.5c_x)\cdot 2 = 240\cdot mm$ $\quad h_{c2x} := \min(h_{ped}, 1.5c_x) = 180\cdot mm$ $\quad A_{Vc\_x} := w_{c2x}\cdot h_{c2x}$

Projected area for a group of anchors (Figure D.13)

$A_{Vgr\_x} := (w_{c2x} + s_y)h_{c2x} = 0.072\ m^2$

Concrete breakout resistance for a single anchor (Cl.D.7.2.1)

$$V_{cbr\_x} := \frac{A_{Vc\_x}}{A_{Vco\_x}}\cdot\psi_{edV\_x}\cdot\psi_{cV}\cdot V_{br\_x} \quad V_{cbr\_x} = 17.196\cdot kN$$

Concrete breakout resistance for anchor group (Cl.D.7.2.1)

$$V_{cbgr\_x} := \frac{A_{Vgr\_x}}{A_{Vco\_x}}\cdot\psi_{ecV}\cdot\psi_{edV\_x}\cdot\psi_{cV}\cdot V_{br\_x} \quad V_{cbgr\_x} = 28.66\cdot kN$$

Check shear in y-dir

Projected area for a single anchor (Cl.D.7.2.1)

$c_{a1y} := c_y + s_y$ $\quad c_{a2y} := c_x$ $\quad A_{Vco\_y} := 4.5c_y^2$

Factored concrete breakout resistance in shear parallel to y axis for a single anchor (Cl.D.7.2.2):

$$V_{br\_y1} := 0.58\left(\frac{l_s}{d_a}\right)^{0.2}\cdot\sqrt{\frac{d_a}{mm}}\cdot\phi_c\cdot\sqrt{\frac{f_c}{MPa}}\cdot\left(\frac{c_y}{mm}\right)^{1.5}\cdot R_{vc}\cdot\frac{kN}{1000} = 18.852\cdot kN \quad V_{br\_y2} := 3.75\cdot\phi_c\cdot\sqrt{\frac{f_c}{MPa}}\cdot\left(\frac{c_y}{mm}\right)^{1.5}\cdot R_{vc}\cdot\frac{kN}{1000} = 18.424\cdot kN \quad V_{br\_y} := \min(V_{br\_y1}, V_{br\_y2})$$

When anchors are locaed in narrow sections of limited thickness:

$$c_{a1yo} := \begin{cases} c_{a1y} & \text{if } c_{a2y} \ge 1.5c_{a1y} \wedge h_{ped} \ge 1.5c_{a1y} \\ \min\left(c_{a1y}, \frac{c_{a2y}}{1.5}, \frac{h_{ped}}{1.5}, \frac{s_x}{3}\right) & \text{otherwise} \end{cases}$$

Modification factors for edge effect (Cl.D.7.2.6)

$$\psi_{edV\_y} := \begin{cases} 1.0 & \text{if } c_{a2y} \ge 1.5c_{a1yo} \\ 0.7 + 0.3\frac{c_{a2y}}{1.5c_{a1yo}} & \text{otherwise} \end{cases} \quad \psi_{edV\_y} = 1$$

Projected area fora a single anchor (Figure D.13)

$w_{c2y} := \min(c_x, 1.5c_y)\cdot 2 = 0.24\ m$ $\quad h_{c2y} := \min(h_{ped}, 1.5c_y) = 0.18\ m$ $\quad A_{Vc\_y} := w_{c2y}\cdot h_{c2y} = 0.043\ m^2$

Projected area for a group of anchors (Figure D.13)

$A_{Vgr\_y} := (w_{c2y} + s_x)h_{c2y} = 0.072\ m^2$

Concrete breakout resistance for a single anchor (Cl.D.7.2.1)

$$V_{cbr\_y} := \frac{A_{Vc\_y}}{A_{Vco\_y}}\cdot\psi_{edV\_y}\cdot\psi_{cV}\cdot V_{br\_y} \quad V_{cbr\_y} = 17.196\cdot kN$$

Concrete breakout resistance for anchor group (Cl.D.7.2.1)

$$V_{cbgr\_y} := \frac{A_{Vgr\_y}}{A_{Vco\_y}}\cdot\psi_{ecV}\cdot\psi_{edV\_y}\cdot\psi_{cV}\cdot V_{br\_y} \quad V_{cbgr\_y} = 28.66\cdot kN$$

$$DesRatio_{vbx} := \max\left(\frac{|F_x|}{4V_{cbr\_x}}, \frac{|F_x|}{V_{cbgr\_x}}\right) = 0.359 \quad DesRatio_{vby} := \max\left(\frac{|F_y|}{4V_{cbr\_y}}, \frac{|F_y|}{V_{cbgr\_y}}\right) = 0.363$$

$DesRatio_{vb} := \max(DesRatio_{vbx}, DesRatio_{vby})$ $\quad DesRatio_{vb} = 0.36$ $\quad Check_{vb} := \text{if}(DesRatio_{vb} \le 1, \text{"Pass"}, \text{"Fail"})$ $\quad Check_{vb} = \text{"Pass"}$

Concrete pryout resistance of anchor in shear (Cl.D.7.3)

$k_{cp} := \text{if}(h_{ef} < 65mm, 1.2, 2.0)$ Coefficient for prying resistance $\quad k_{cp} = 2$

$V_{cpr} := k_{cp}\cdot N_{cbr}$ Factored pryout resistance for single anchor $\quad V_{cpr} = 53.487\cdot kN$

$V_{cpgr} := k_{cp}\cdot N_{cb}$ Factored pryout resistance for anchor group $\quad V_{cpgr} = 148.574\cdot kN$

$DesRatio_{pr} := \frac{V_{res}}{V_{cpgr}}$ $\quad DesRatio_{pr} = 0.1$

$Check_{pr} := \text{if}(DesRatio_{pr} \le 1, \text{"Pass"}, \text{"Fail"})$ $\quad Check_{pr} = \text{"Pass"}$

Combined Tension and Shear (Cl. D.8)

$DesRatio_n := \max(DesRatio_{at}, DesRatio_{bt}, DesRatio_{ctp}, DesRatio_{cts}) = 0.552$ $\quad DesRatio_v := \max(DesRatio_{av}, DesRatio_{vb}, DesRatio_{pr}) = 0.363$

$$DesRatio_{tv} := \frac{DesRatio_n + DesRatio_v}{1.2} = 0.76$$

$$Check_{tv} := \begin{cases} \text{"Pass"} & \text{if } DesRatio_v \le 0.2 \wedge DesRatio_n \le 1 \\ \text{"Pass"} & \text{if } DesRatio_n \le 0.2 \wedge DesRatio_v \le 1 \\ \text{"Pass"} & \text{if } DesRatio_v + DesRatio_n \le 1.2 \\ \text{"Fail"} & \text{otherwise} \end{cases} \quad Check_{tv} = \text{"Pass"}$$