UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Corridor Redesign of Chancellor Boulevard - Team 21

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CIVL 445

Themes: Transportation, Community, Land

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Executive Summary

MTT Consulting has been tasked with redesigning Chancellor Boulevard between Acadia Road and Drummond Drive. The existing corridor has been assessed and significant issues noted, including: deteriorating road surfaces, a lack of defined bike lanes, vehicles speeding, and traffic congestion near Hamber Road. The preferred design promotes safety and active transportation on the corridor which are in line with the community and client's goals. The finalized design is defined by the following aspects:

- Multi-modal transportation infrastructure: a two-way bike path and wide pedestrian path on the south side and a multi-use pathway on the north side,
- Four lanes are maintained for vehicle traffic: The roadway has been developed to lower driving speeds including narrowing the lanes and median.
- Pedestrian underpass: Located at Hamber Road near the bus stops and Hamber Elementary School to accommodate the high pedestrian traffic at that intersection and allow for the removal of the existing signal light.

The underpass was analyzed and designed in accordance to CSA standards. Synchro analysis software was used for the intersection design, concluding that the intersection of Chancellor Boulevard and Hamber Road will be reconfigured to a protected-T intersection from the existing pedestrian-controlled half signal. Corridor traffic analysis and design was completed in accordance with the *Highway Capacity Manual and TAC and AASHTO Standards*.

Construction is scheduled for May, 2018 with expected completion in August 2018. Based on a Class A cost estimate, the expected total cost for the project will be $4.75 million with an annual maintenance cost of $48,000, including the repair and remediation and preventative maintenance costs.

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01 Introduction

1.1 Background

As one of five major routes connecting the City of Vancouver to the UBC campus, Chancellor Boulevard is the fourth most utilized route as of 2016. The route comprises roughly 18% of daily traffic to the campus, accommodating cyclists, vehicle traffic, and transit users [12]. This project area begins just west of Acadia Road and terminates west of Drummond Drive, as depicted by the red boundary in Figure 1.

It includes two intersections on Chancellor Boulevard, at Acadia Road and at Hamber Road. In addition to vehicle traffic, two Translink bus lines use the corridor, the #44 and #84 routes, traveling to and from UBC. Within the study area, there is one bus stop per direction, located near the intersection with Hamber Road and University Hill Elementary school, as seen below in Figure 1.

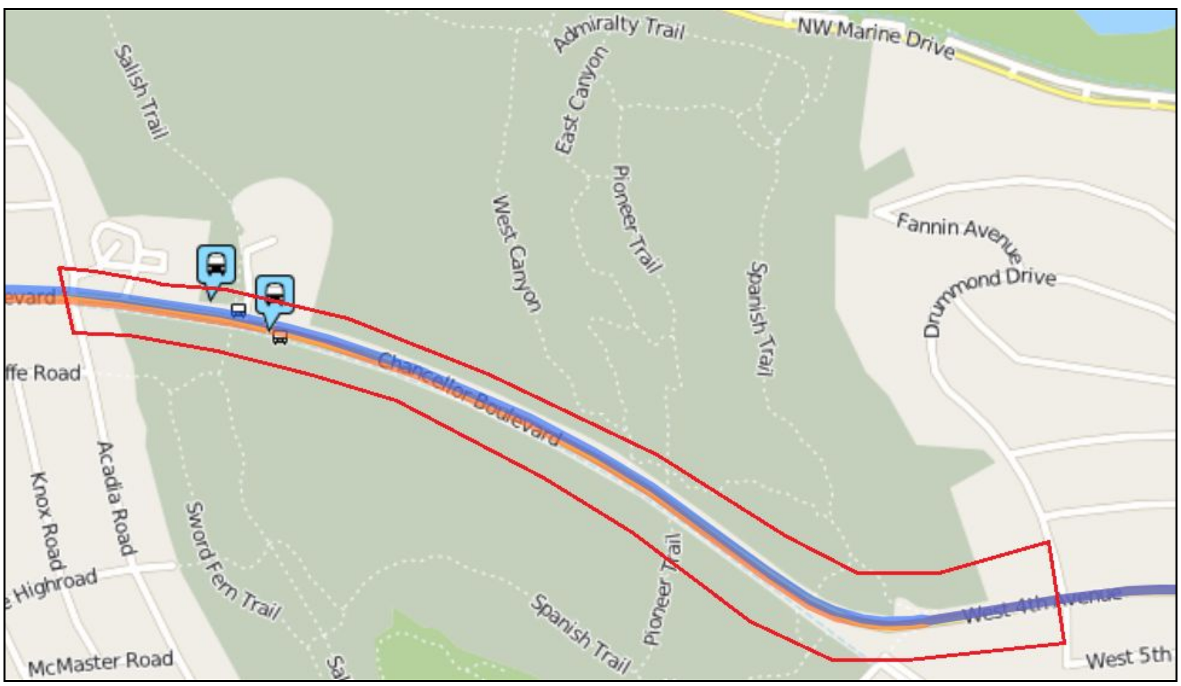


Figure 1. Project Area

Many cyclists and pedestrians also travel through this corridor. Two major bike routes - the Off-Broadway and the West 4th cycle routes - merge onto Chancellor Boulevard near the east end of the corridor, bringing significant volume of cyclists to the region. There is also considerable pedestrian traffic in the area due to the proximity of park space and the nearby elementary school. As seen in Figure 1, Chancellor Boulevard is flanked on both sides by Pacific Spirit Park which boasts many popular trails frequented by runners, walkers, and trail bikers.

1.2 Project Objectives

The objectives guided the project, ensuring appropriate considerations are given to each of the design variables, and that each design decision optimizes the overall project performance. The following five objectives were identified as imperative to the overall success of the project:

1. Prioritization of Active Transportation Modes
2. Introduction of Traffic Calming Measures
3. Improved Safety and Serviceability
4. Minimized Environmental and Social Impacts
5. Constructibility and Economic Feasibility

In addition to the project objectives, a triple bottom line approach was followed in the design, construction, and operation of the corridor.

1.3 Scope of Work

The project area is illustrated above in Figure 1 and described in Section 1.1. The redesign was completed for the entire right-of-way within the study area in addition to a pedestrian crossing; a pedestrian underpass at Hamber Road.. Hamber Road was not included in the redesign, aside from the changes to the intersection with Chancellor Boulevard. All modes of transportation were addressed and prioritized appropriately in the final design.

The project consisted of background research clearly defining and analyzing the existing conditions, developing feasible options to align with the project objectives, and assessing those options to determine the best overall design. The finalized design is presented in this report. Details of the previous phases in the project were communicated in the Conceptual and Preliminary Design Reports.

A high-level drainage plan, a stakeholder and community engagement plan, and environmental considerations were also completed as part of this project. The team did not assess utilities along the corridor in terms of replacement and/or upgrades. Additionally, multiple site visits were conducted to assess the current status of Chancellor Boulevard and collect turning movement count data.

1.4 Design Criteria

The final design was established by referencing many engineering and design guidelines and standards. The following table, Table 1, summarizes those references and the various software that was used for the analysis and design.

Table 1. Design Software, Standards and Guidelines

Standard / Software	Applied to...
AutoCAD	All drawings
Google SketchUp	Underpass 3D model and renderings
Trafficware Synchro 6	Intersection traffic analysis
Highway Capacity Manual	Corridor and intersection analysis and design criteria
Pedestrian Crossing Control Manual for British Columbia	Pedestrian crossing signage and specifications
Geometric Design Guide For Canadian Roads (TAC)	Road and intersection design
A Policy on Geometric Design of Highways and Streets (AASHTO)	Road and intersection design
Microsoft Project	Project scheduling
CSA A23.3-14 Design of Concrete Structures	Underpass structural design
CSA S16-14 Design of Steel Structures	Underpass connections design
CSA S6-14 Canadian Highway Bridge Design	Underpass structural design
CSA B651-12 Accessible Design for the Built Environment	Underpass design

1.5 Team Composition

The table below summarizes the roles and key responsibilities each team member took on over the course of this design project.

Table 2. Team Composition

Member	Primary Role(s)	Key Tasks & Outputs
Erik Frankson	Transportation engineering Municipal engineering	Road Geometric Design, Intersection Design, Corridor Drawings (*AutoCAD*), Drainage Plan
Winnie Miao	Structural engineering	Underpass Structural Analysis & Design, Underpass Drawings (*AutoCAD*)
Victor Mironenko	Project management	Project Cost Estimate, Project Schedule, Maintenance Plan
Kevin Parrish	Structural engineering	Underpass Structural Analysis & Design, Underpass Drawings (*AutoCAD*), Underpass 3D Modelling (*Sketchup*)
Jasmine Smith	Transportation engineering Stakeholder engagement	Traffic Analysis (*Synchro*), Road Geometric Design, Intersection Design, Stakeholder Engagement, Drainage Plan
Daniel Vandervelden	Project management	Project Cost Estimate, Project Schedule, Construction Specifications

02 Geometric Road Design

2.1 Road Cross-Section

The finalized design for the road cross-section, shown below in Figure 2, features:

- Four lanes for vehicle traffic;
- A greenway, including paved designated pedestrian path and two-way cycle path; and
- A gravel multi-use pathway.

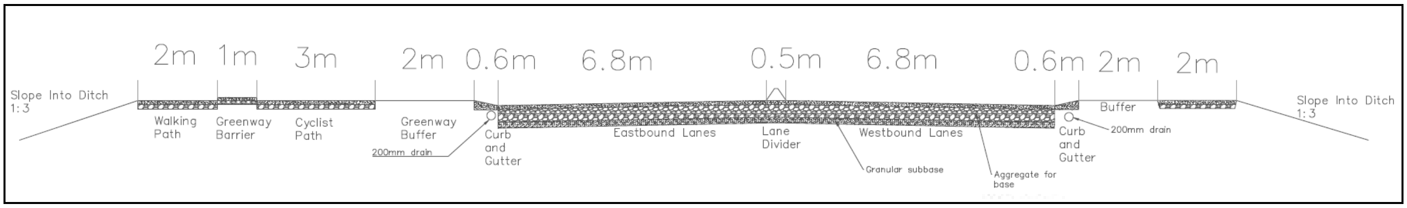


Figure 2. Road Cross-Section

The vehicles lanes have been narrowed to 3.4 m in width per lane, which is adequate to accommodate transit buses. This is a significant decrease from the existing 4 m width for the majority of the corridor. Another change from the current cross-section is the narrowing of the median to 0.5 m from the current median width of 6 m, at the widest point. These two changes were implemented to promote traffic calming along the corridor, and assist with the desired speed limit decrease. It should be noted that since only two lanes are required with the current traffic volumes to maintain an acceptable level of service, the two outer lanes may be assigned to HOV and / or transit only until future traffic volumes require the full 4-lanes.

2.2 Road Alignment

The greenway is located on the south side of the road, and the multi-use pathway is located on the north side of the road. The full alignment is shown below with station 0+000 located at the west end of the corridor at Acadia Road (Figure 3). The current alignment remains unchanged until Hamber Road (STN: 0+265) where the roadway narrows significantly, the westbound lanes shifting south to close the gap for the remainder of the study area.

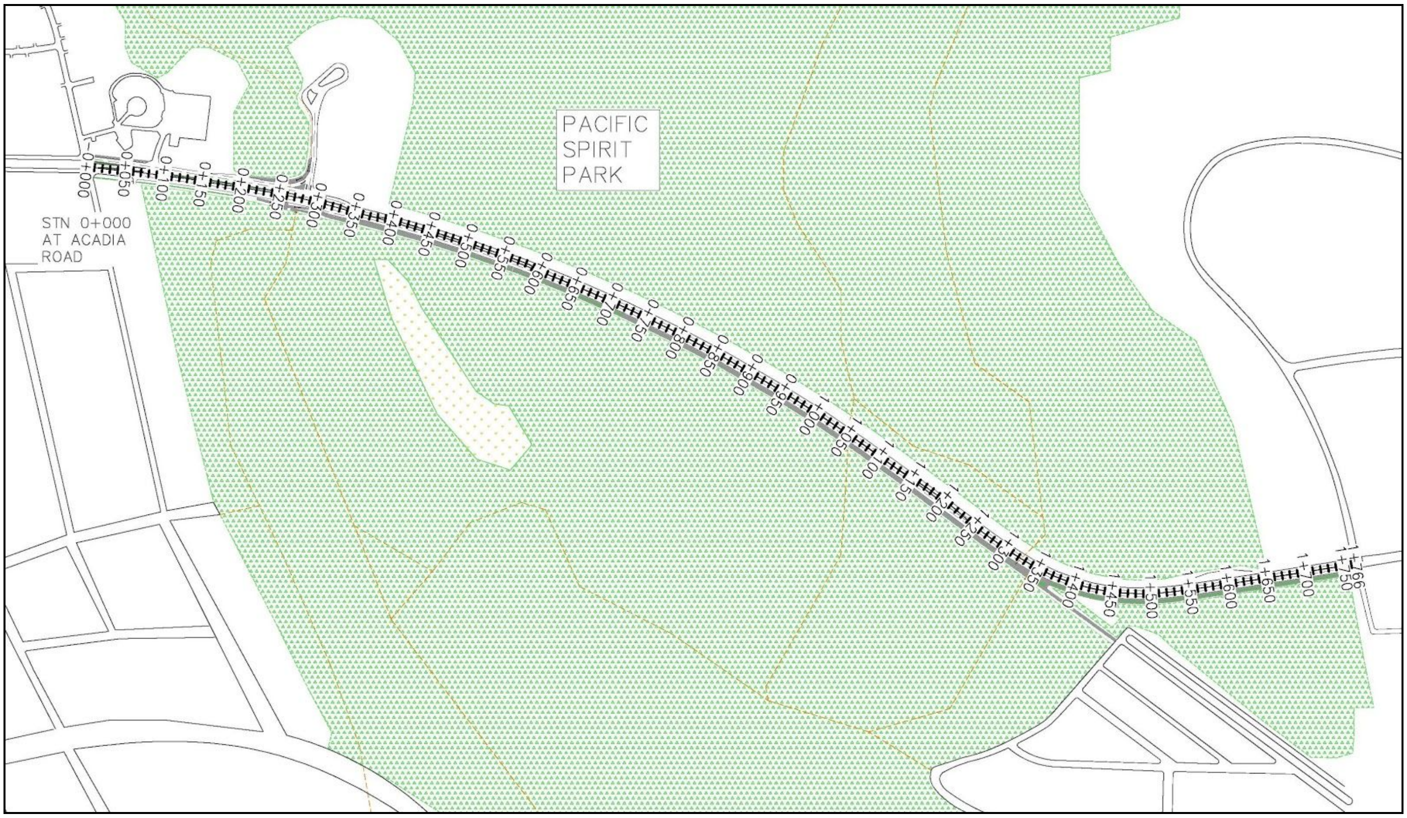


Figure 3. Corridor Plan View

03 Intersections & Trail Crossings

3.1 Hamber Road Intersection

Hamber Road accesses the University Hill Elementary School to the north. The final design includes an underpass at the intersection of Chancellor Boulevard and Hamber Road, making the existing pedestrian half-signal obsolete. The new intersection will be redeveloped to a protected-T intersection and the existing signal will be removed. A plan view of the final intersection design is shown below on Figure 5 and a satellite image of the existing configuration is shown on Figure 4 for comparison.

Figure 4. Existing Hamber Road Intersection

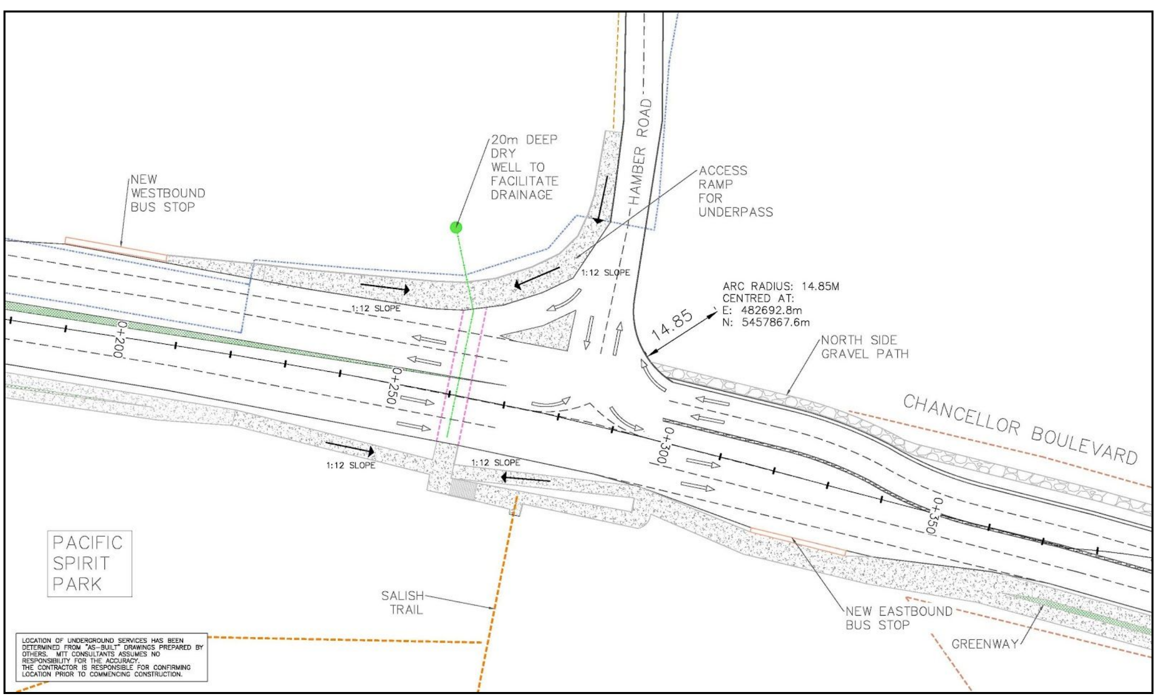


Figure 5. New Hamber Road Intersection Design

As illustrated above, the two bus stops are relocated slightly away from the intersection, for both directions, to accommodate the underpass structure and accesses. Also, the westbound lanes are shifted south, east of the intersection, to allow for a narrowed median for the remainder of the corridor to the east.

3.2 Acadia Road Intersection

Acadia Road provides access to residential properties to the north and south of Chancellor Boulevard. Turning movement volumes were not obtained for this intersection, however, based on the number of properties that are accessed via this road, the volumes are assumed to be very low. No changes were considered for this intersection for two reasons:

1. No safety concerns or issues have been identified by the community or stakeholders, or through on-site investigation and research.
2. Turning movement traffic volumes are expected to be very low. Therefore, this intersection is not expected to negatively impact traffic mobility for either Acadia Road or Chancellor Boulevard traffic.

3.3 Drummond Road Intersection

Bicycles approaching the study area from the east along the 4th Avenue bike route are required to cross Chancellor Boulevard to continue onto the bike paths located on the south side of the corridor. To facilitate this, the design includes a cyclist controlled crossing at Drummond Drive, as shown next page on Figure 6. When activated, the light will stop traffic on Chancellor Boulevard, allowing cyclists to cross diagonally. Eastbound cyclists will not need to cross the street as the greenway will direct them seamlessly to the existing on-street bike lane.

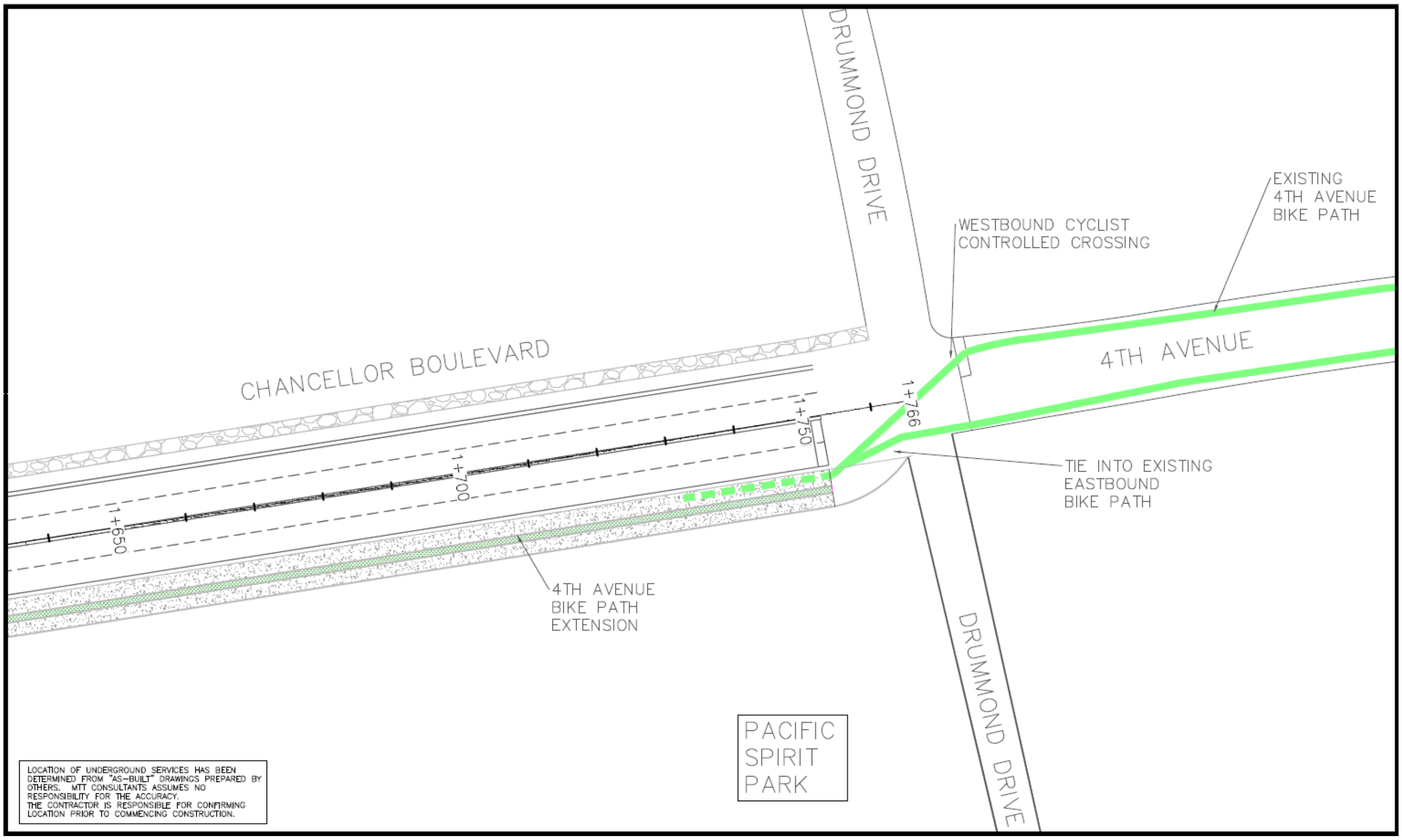


Figure 6. Drummond Drive Intersection Plan View

3.4 Bike Route Intersection

The Off-Broadway path will continue westbound across Blanca Street and onto Chancellor Boulevard (south). Entering the corridor from the east, cyclists will link up with the greenway and continue towards campus along Chancellor Boulevard. A three-way intersection will facilitate a smooth transition on the greenway where these two bike paths intersect, as shown next page on Figure 7. Additionally, ample signage will be provided for cyclists for clear wayfinding.

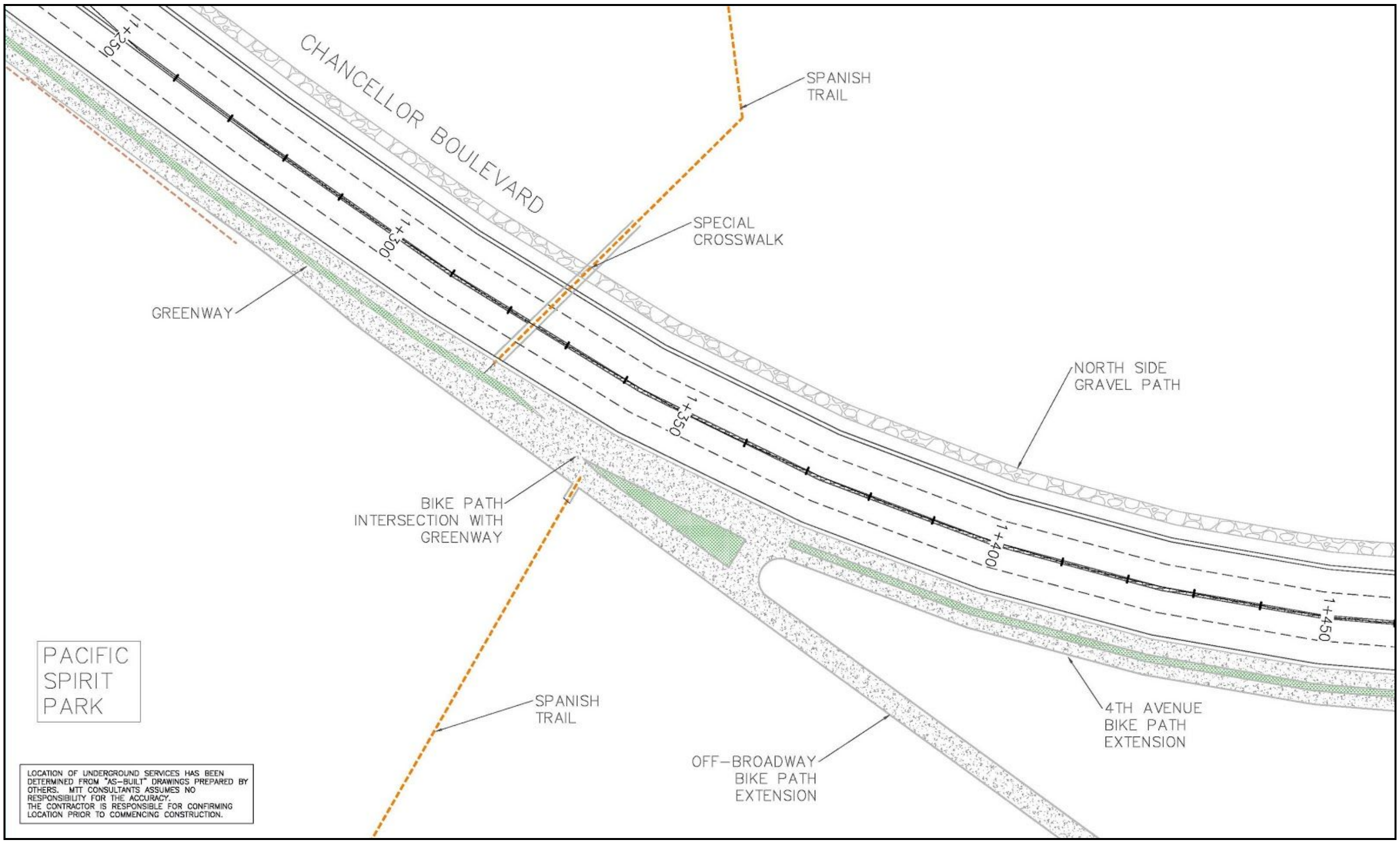


Figure 7. Bike Intersection Plan View

3.5 Trail Crossings

There are currently two trail crossings on Chancellor Boulevard to accommodate Pacific Spirit Park users: Pioneer Trail and Spanish Trail, as seen in Figure 8. Both crossings will be maintained and upgraded to resemble Special Crosswalks, defined as marked crossings with pedestrian-activated amber flashers, zebra crosswalk markings, and warning signs placed in accordance with the *Pedestrian Crossing Control Manual for British Columbia* [11]. The standard infrastructure for Special Crosswalks is illustrated below in Figure 9.

Figure 8. Trail Crossing Locations

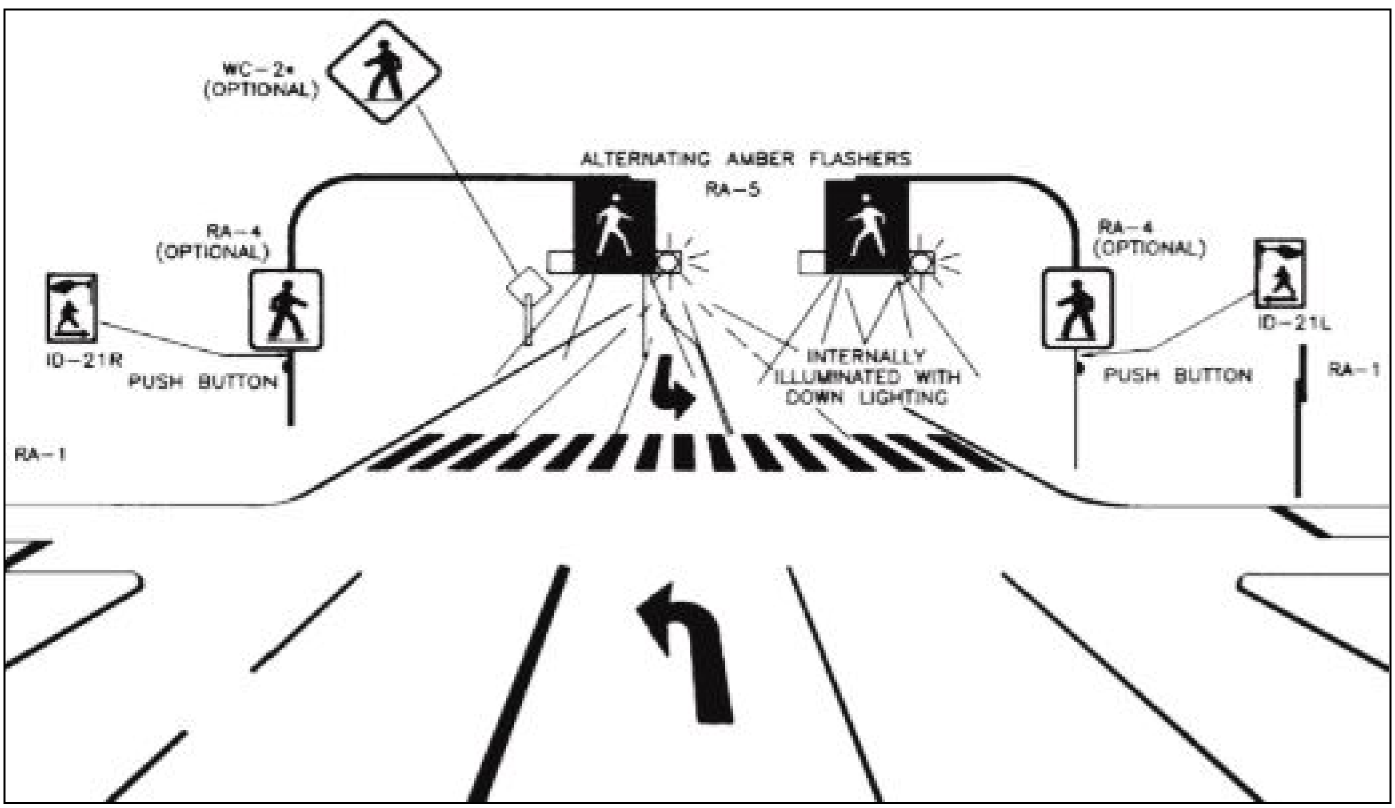


Figure 9. Special Crosswalk Standard Configuration

04 Pedestrian Underpass

4.1 Background

4.1.1 Design Criteria

The client has identified the following specifications for the design of the underpass [13], all of which were met by MTT Consulting Engineers in this proposed design:

Regarding the Substructure Design

- The maximum depth for the underpass below street level should be roughly 3.5 m, and the grade of the underpass shall allow pedestrians to see along the length of the underpass.
- Barriers shall be be placed on the approaches to the underpass directing pedestrians and cyclist to use the underpass and discouraging them from crossing through traffic.

Regarding User Comfort

- Head space within the structure must be high enough to provide safe pedestrian and cyclist passage; and will be at least 2.5 m.
- Underpasses shall be designed to promote a sense of security for all users; a well-lit and open structure with no possible concealment areas is required.
- Lighting will be provided in the underpass with a minimum point horizontal and vertical illuminance of 17.5 lux. Since this design will be greater than 20m length, lighting will provided 24-7.
- Design considerations include accessibility for pedestrians with disability.
- The aesthetics of the design must be considered.

Regarding Drainage

- Particular care should be put towards the design of proper drainage from all areas in and around the underpass and drainage systems in the underpass should be vandal proof.
- Gratings for sump openings should be installed flush with the concrete and set in locations where they will not negatively affect the safety of users
- The capacity of the drainage system shall be capable of handling 1 in 20 year design storm conditions.

4.1.2 Location of Underpass

The decision to construct an underpass at the Hamber Road intersection was mainly driven by the high demand for pedestrian and cyclists crossings there. The use of a signalized pedestrian crossing at this intersection disrupts the flow of traffic greatly, especially during peak school drop-off and pick-up hours of the nearby University Hill Elementary School. Having pedestrians, many of which are school children, crossing the road was seen as a risk that could be easily mitigated with the implementation of a pedestrian underpass. With this, the on-road crossing can then be removed and the through traffic can flow more smoothly.

4.2 The Proposed Design

The 25 m long underpass stretches across Chancellor Boulevard corridor at Hamber Road, slightly offset to the west from the current signalized crossing, allowing for a more direct and shorter length. On the south side of the underpass, access ramps approach the underpass entrance from both east and west, in addition to a westbound staircase access. On the north side of the underpass, access ramps approach the underpass entrance from both the east and west direction as well.

The following renderings illustrate how the Hamber Road underpass will look upon completion; meanwhile, the key aspects of the underpass design will be expanded upon in the subsequent subsections.

Figure 10. Hamber Road Intersection - Looking Northwest

Figure 11. Pedestrian Underpass - South Access

Figure 12. Pedestrian Underpass - South Entrance

Figure 13. Pedestrian Underpass - Interior

4.2.1 Underpass Substructure

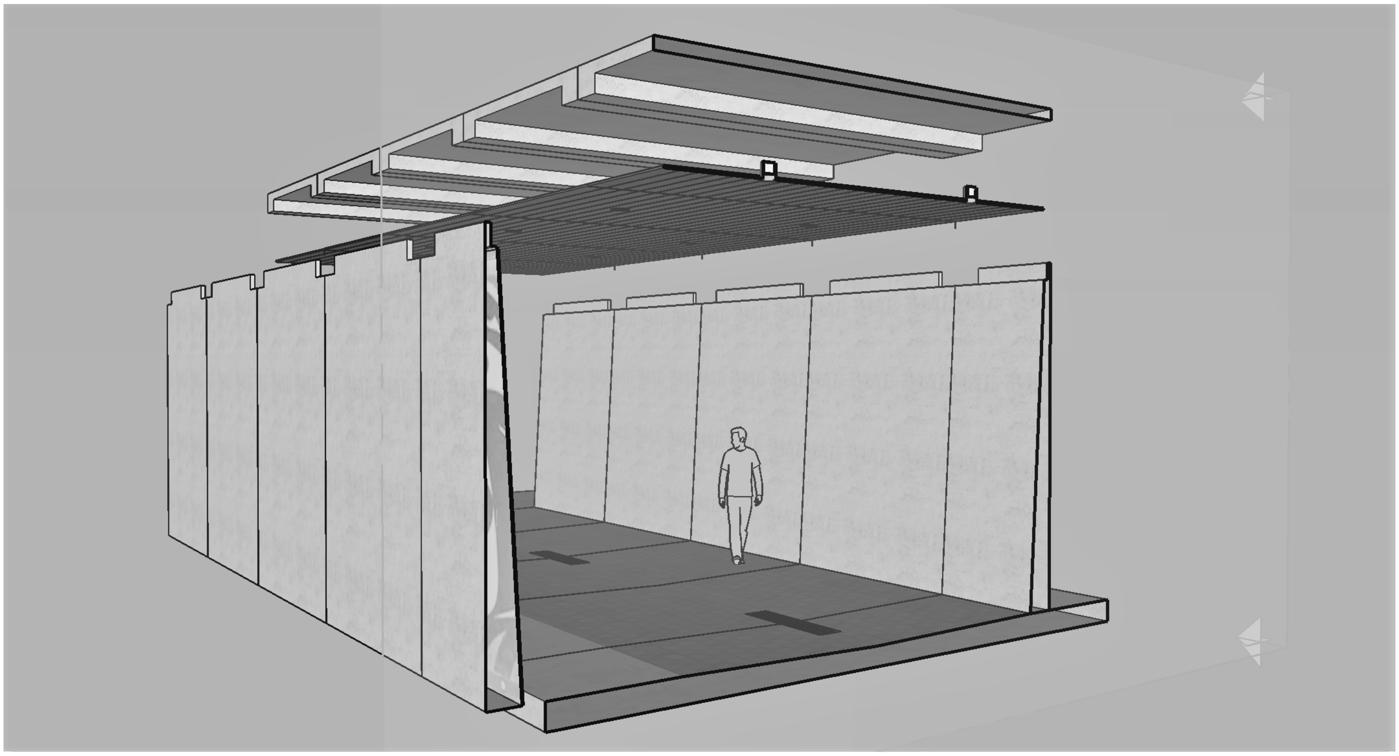


Figure 14. Pedestrian Underpass - Modular Substructure

The design developed for the underpass is composed of ten identical 2.5 m modular sections, amounting to the 25 m long underpass when assembled during construction. Each of these modules is structurally comprised of a base slab, two earth-retaining walls, and a top slab. All structural members are made of reinforced concrete, precast off-site to expedite the on-site construction timeline. Detailed underpass drawings issued for construction can be found in Appendix B, whereas detailed calculations for (and any assumptions made during) the structural analysis can be located in Appendix E.

4.2.1.1 Top Slabs

The top slab of the underpass is an inverted U-shape, 2.5 m by 5 m. The slab is 300 mm at its thickest and 120 mm at its thin sections. Clear cover on the exterior sides and the interior sides are 60 mm and 40 mm respectively. The slab is reinforced to account for moment and shear in both the long and short span directions, and includes additional steel for the required temperature reinforcement.

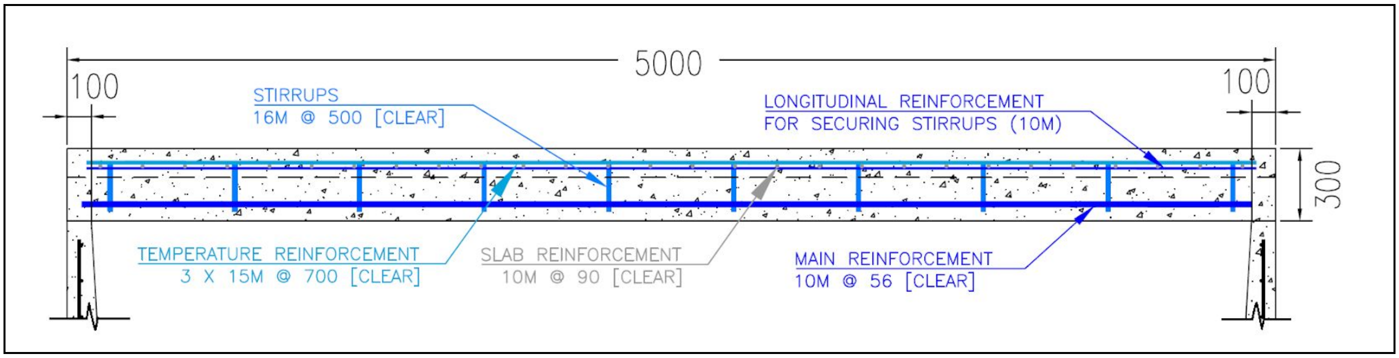


Figure 15. Underpass Detail - Top Slab Cross-Section (North-South)

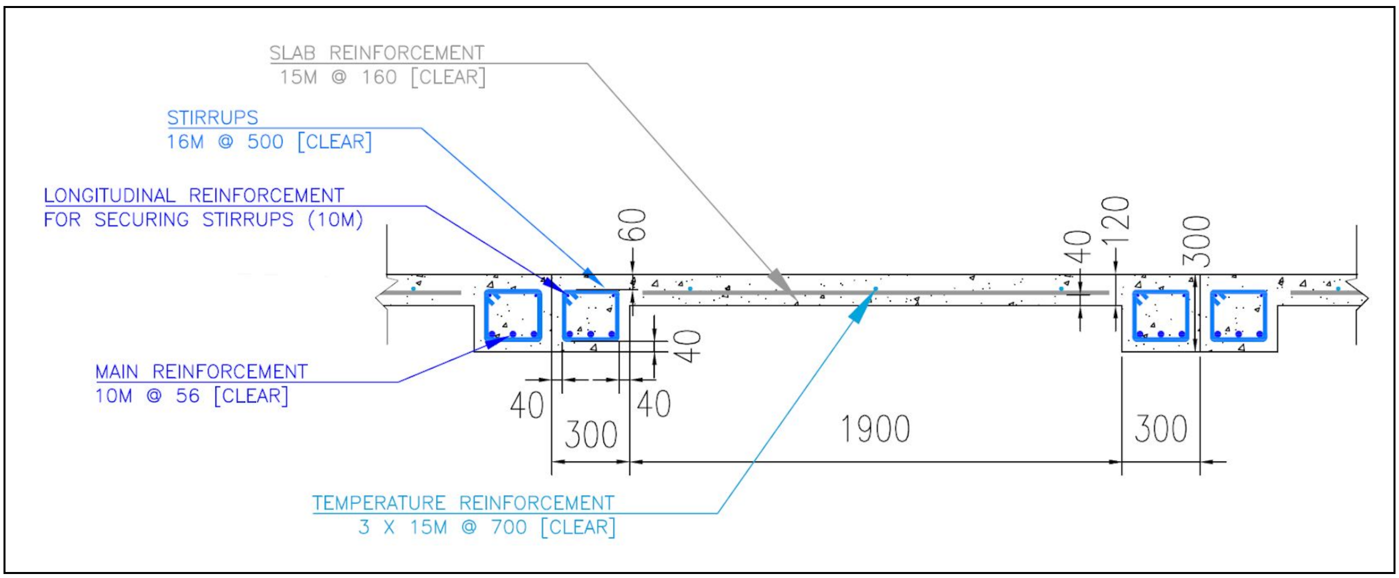


Figure 16. Underpass Detail - Top Slab Cross-Section (East-West)

4.2.1.2 Earth Retaining Walls

The retaining walls are 3.5 m tall, 300 mm thick at the base, and 100 mm thick at the top (see Figure 17). These walls were designed and reinforced for flexure, shear, bearing, shrinkage and temperature changes. Behind the retaining walls are layers of free draining aggregate, structural backfill, and undisturbed native soil at an excavation slope angle of 1:2, as shown in Figure 18.

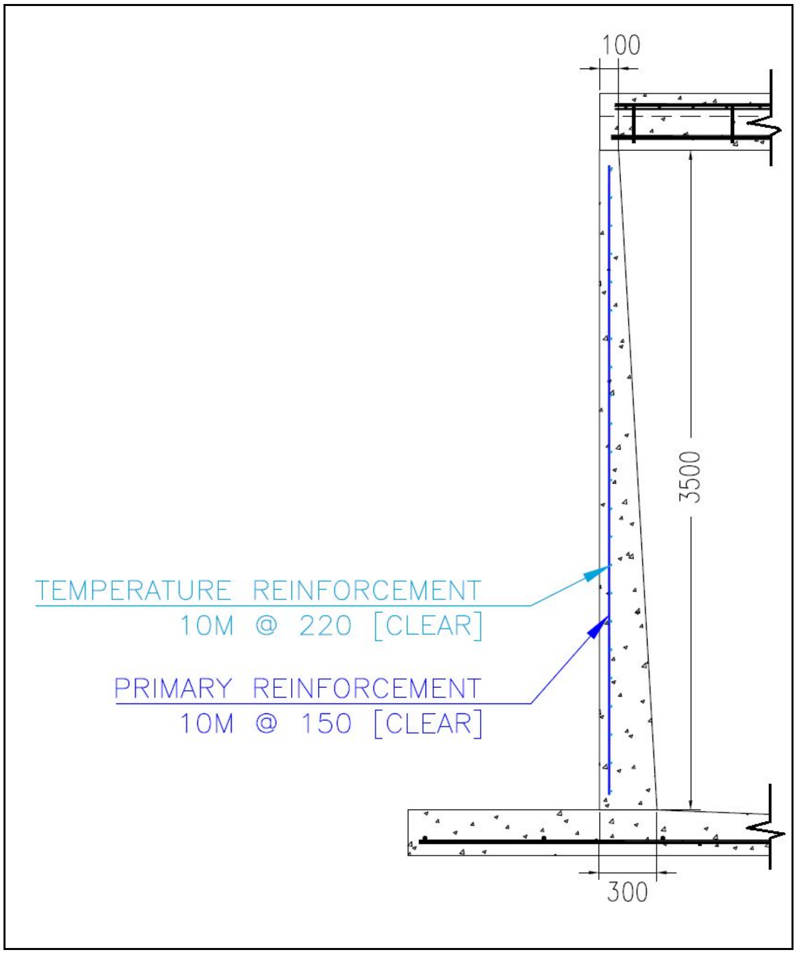


Figure 17. Underpass Detail - Wall Cross-Section (North-South)

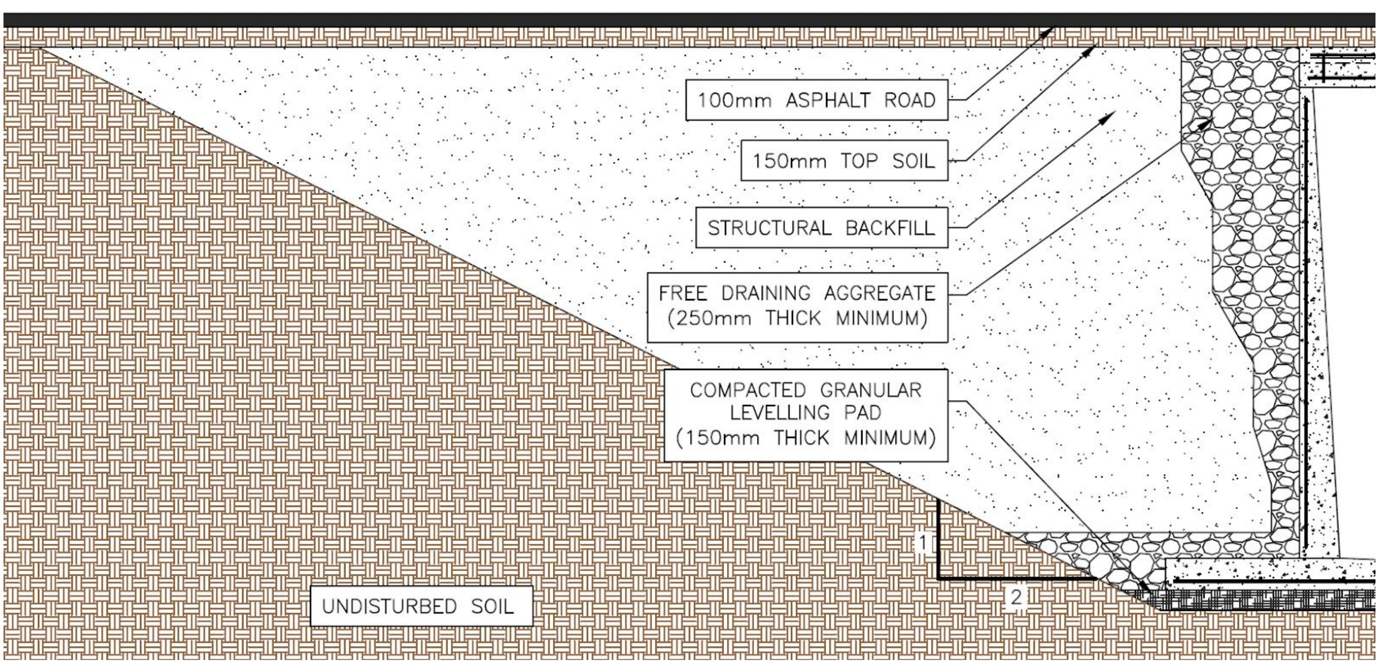


Figure 18. Retaining Wall Backfill Details

4.2.1.3 Floor Slabs

The floor slabs, acting as cantilevered footings, are 7 m wide and 240 mm thick, designed as one-way slabs and reinforced against major flexure, shear, axial, shrinkage and temperature forces. Clear covers to rebar range from 60-80 mm. As depicted earlier in Figure 18, immediately underneath the footing slab is a compacted granular levelling pad, followed then by native soil. The cross-sectional views of the floor slab structure are shown below in Figure 19 and Figure 20.

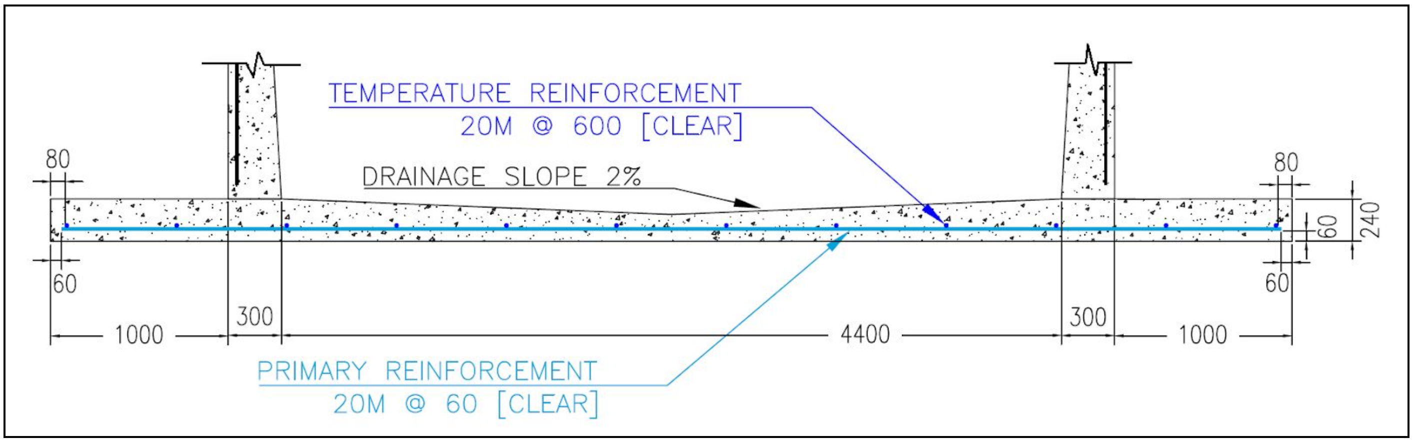


Figure 19. Underpass Detail - Floor Slab Cross-Section (North-South)

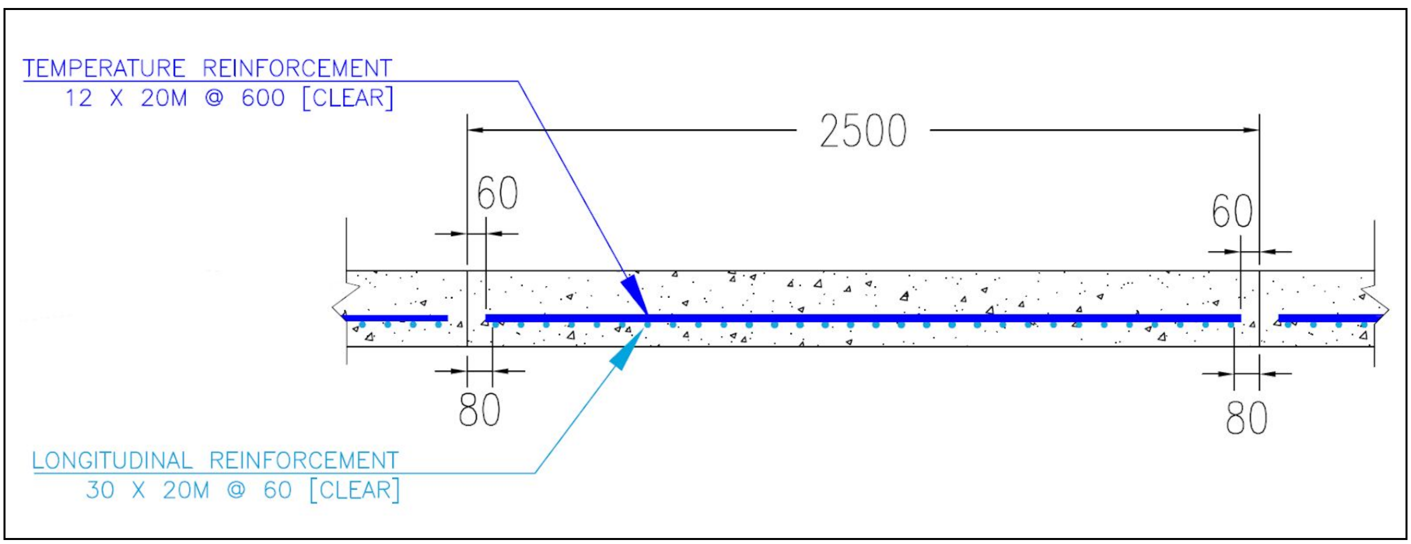


Figure 20. Underpass Detail - Floor Slab Cross-Section (East-West)

4.2.1.4 Connection Details

All connections between sections have been designed to be integrated into the precast slabs and panels, minimizing the amount of on-site pouring required for the underpass. Exposed rebar will be cast into the sections off site, with portions of the slabs cut out that allow the rebar to overlap. These cut out portions will be poured on site, joining the sections. Specifically, the following four locations have been given special attention to design the connections.

1. Between Floor Slabs

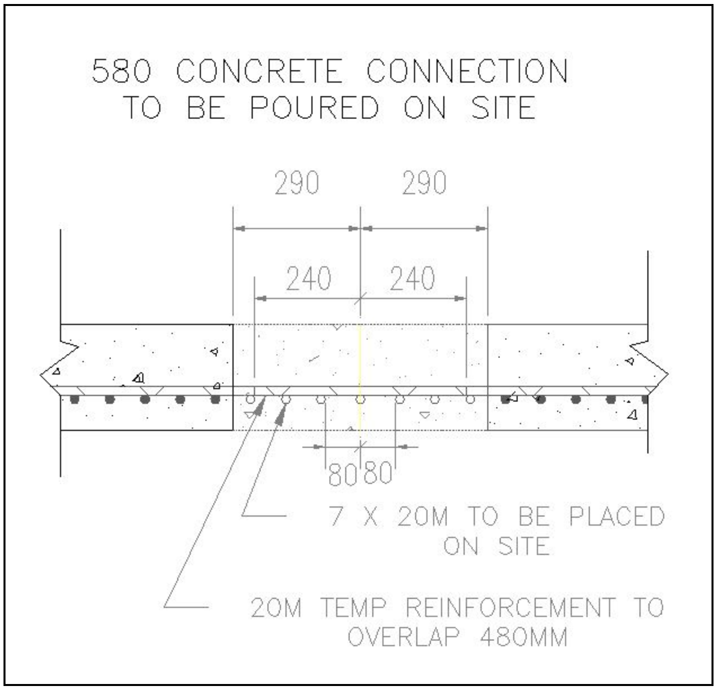


Figure 21. Connection Detail Between Floor Slabs

2. Between Top Slabs

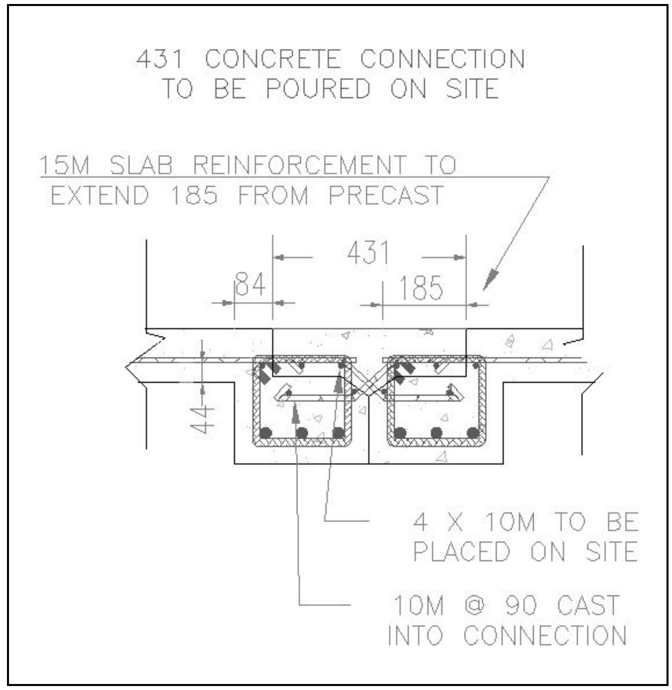


Figure 22. Connection Detail Between Top Slabs

3. Wall to Floor Slab

For this connection, the slab and panel will be connected by a steel L-bracket, bolted to the exterior of the underpass to resist overturning moment caused by the lateral earth pressure. Bolt anchors will be precast into the sections to provide a strong connection for the L-bracket, and an elastomeric bearing pad will be placed between the floor slab and the wall panel. The L-bracket will be covered with a corrosion resistant finish to provide protection and avoid loss of strength while exposed to the soil, and a sealant will be used to close all gaps at the base of the panel to stop water ingress.

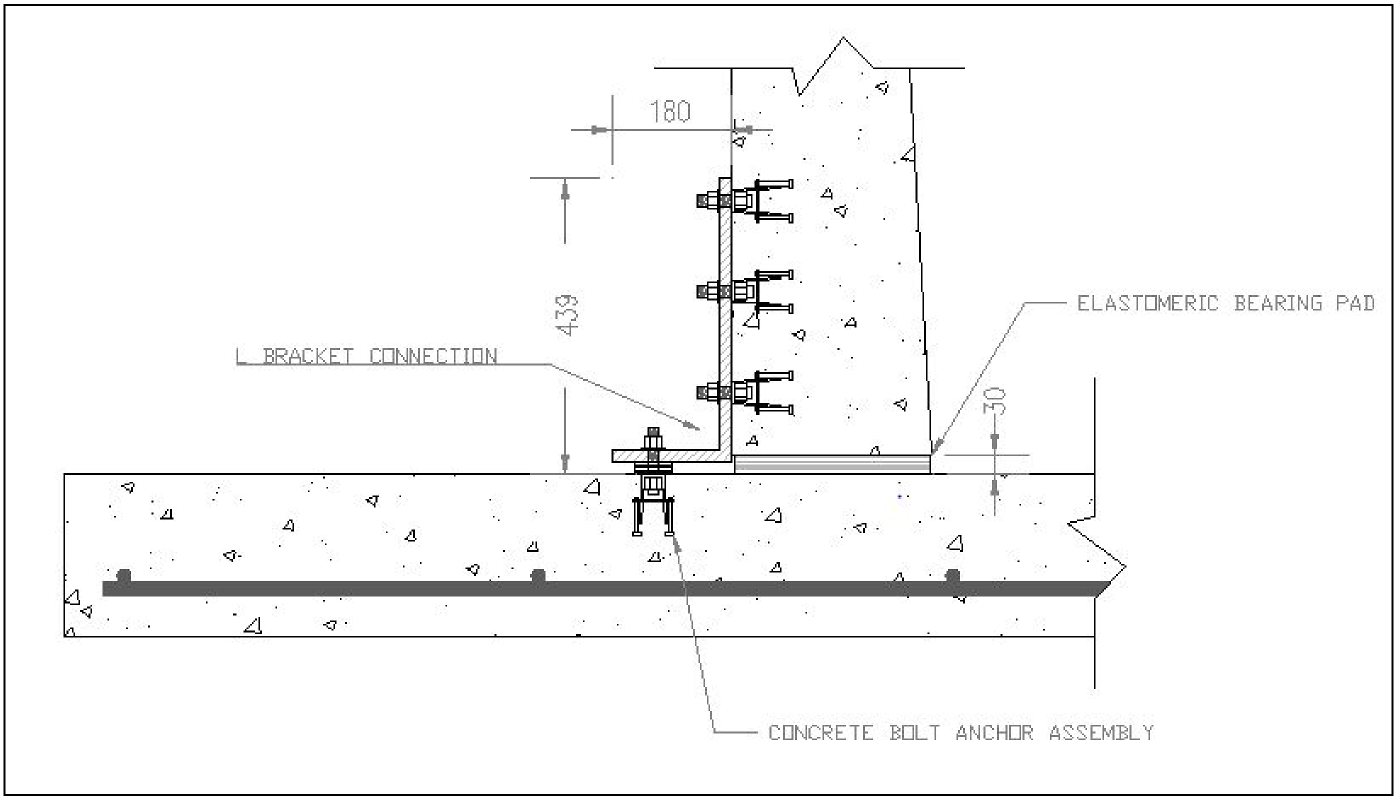


Figure 23. Wall Panel to Floor Slab Connection

4. Wall Panel to Roof Slab

The bearing point of the top slab on the wall panel will be held in place by the weight of the top slab, essentially acting as a pin connection. Between the panel and slab a bearing pad will be placed, and sealant will be used along the seam to protect the underpass' interior.

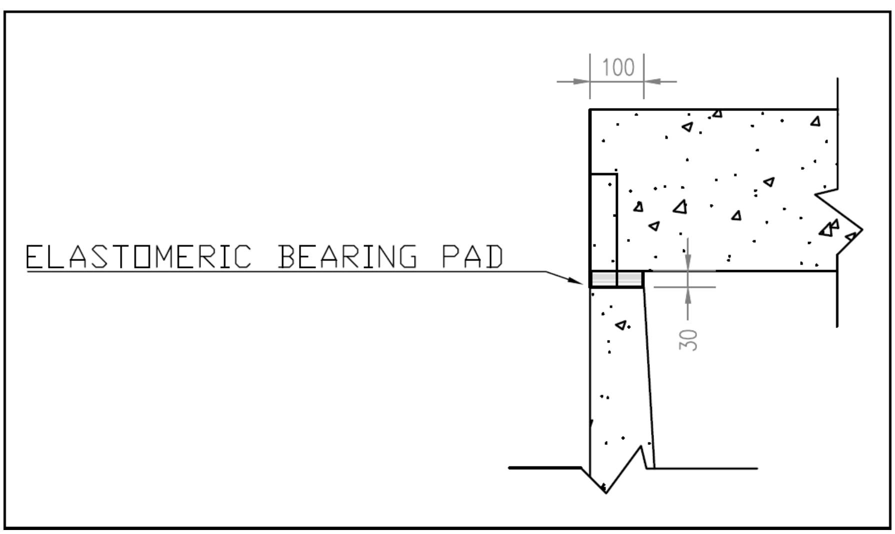


Figure 24. Wall Panel to Roof Slab Connection

4.2.2 Approaches to the Underpass

The underpass approaches feature ramps for both the north and south entries, with slopes of 1:12 as specified in Clause 5.5.1 in CSA B651-12 [6]. These ramps will extend east and west from the south entry, tieing into the road grade pedestrian and cycle paths. At the start point of the ramps on the south side of the corridor, the separated pathways become a single multi-use path, and remains this way through the underpass and on to the north side. In addition to the ramp access, a stairway will also be available for users coming from the Salish Trail in Pacific Spirit Park.

4.2.3 Drainage Facilities

Drains at the top of the ramps will be connected to the existing road outfall pipes while floor drains in the underpass will be connected to storm mains and emptied into a dry well installed north-west of the underpass. These underpass drains are placed every 5 meters along the floor of the underpass, in the middle of the path, as shown in Figure 25 below.

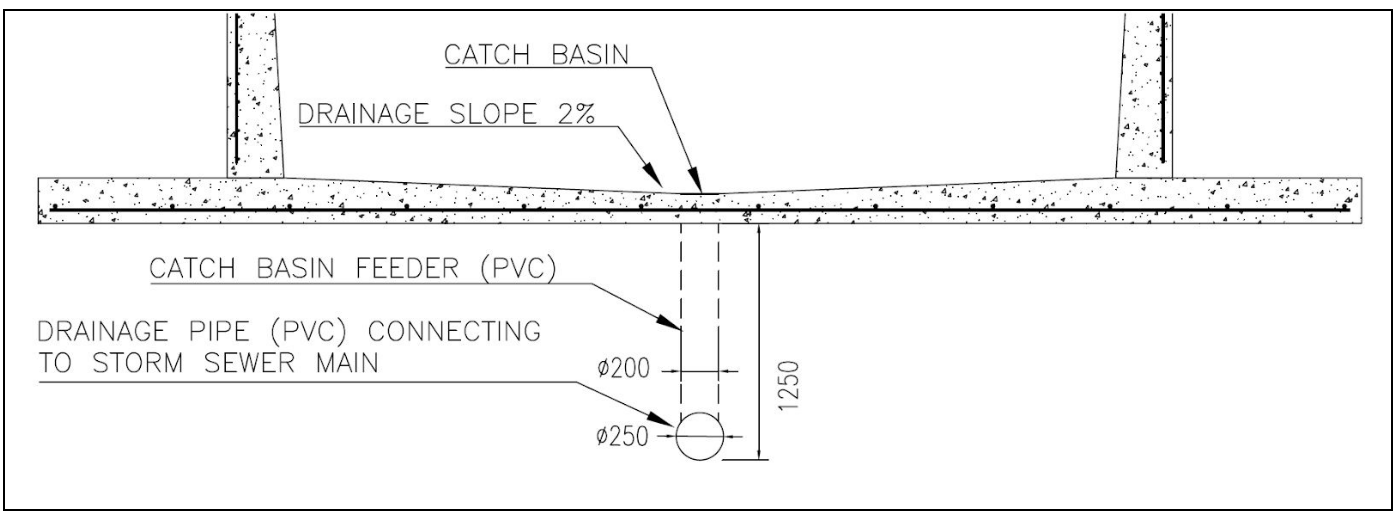


Figure 25. Underpass Floor Drainage Cross-Section

The dry well system will include a sump pump which will be triggered in the case of overfilling and will pump the excess water up to the existing storm water drainage pipes at the intersection. The dry well will be 2 m wide and 14 m deep with a total capacity of approximately 44 m^3, which is designed to accommodate a one hour, one in 100-year rain event.

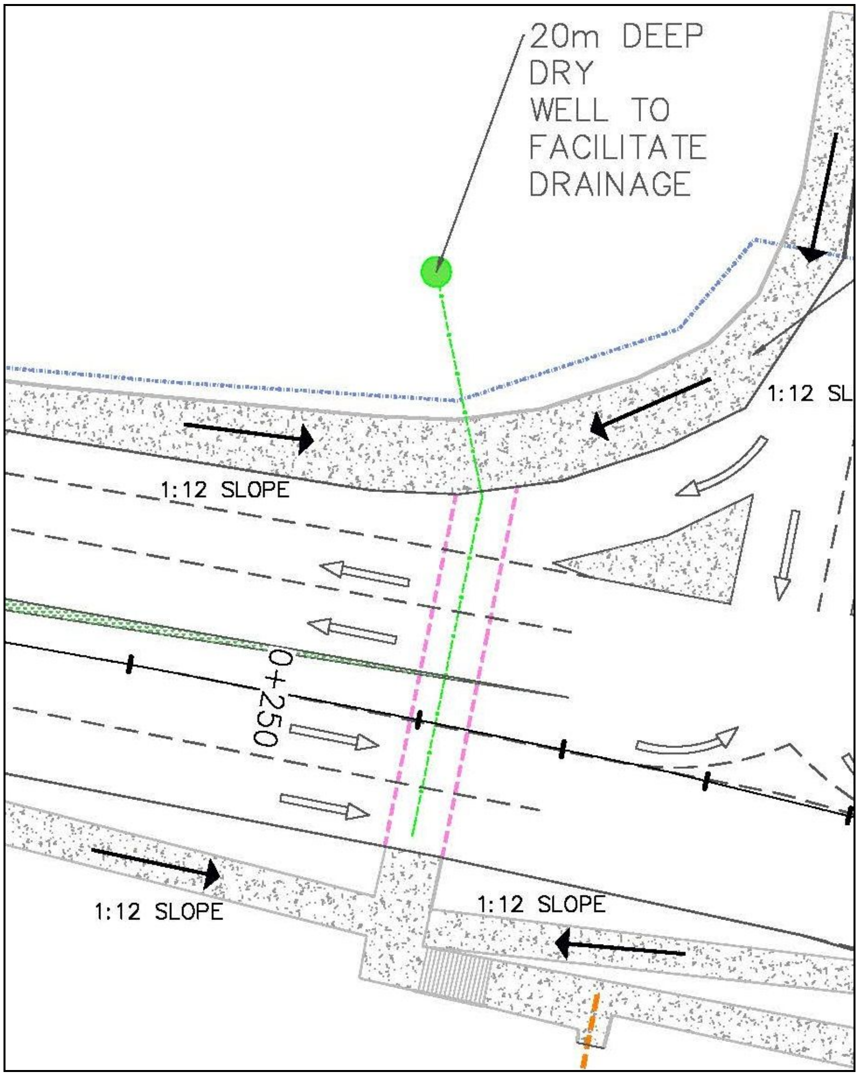


Figure 26. Underpass Drainage Pipes and Location of Dry Well

4.3 User Safety & Satisfaction

All decisions related to the underpass have been made with the intent to offer accessibility, safety, and satisfaction for all users. This meant creating an inviting and safe environment for users through the dimensions and space, the lighting and aesthetics, and the accessibility and accommodation of all.

4.3.1 Accessibility Considerations

To accommodate all underpass users, both ramps and stairs have been incorporated into the design.

4.3.1.1 Ramps

The ramp accesses shall be 1.2 m in width, 1:12 in slope, and provide handrails and edge protections (in the form of a 100 mm high curb) as per Clauses 5.5.1, 5.5.3, and 5.5.6 in [6].

4.3.1.2 Stairs

As for the stairs, they will have solid risers 150 mm high, treads 280 mm deep, 25 mm nosing, and have a horizontal strip at the edge of each tread that is colour-contrasted. Furthermore, tactile attention indicator surface will be provided at the top of the stairs and at landings. Continuous handrails will be installed on both sides of the stairs to a uniform height of 860 mm (Clause 5.4.4, [6]).

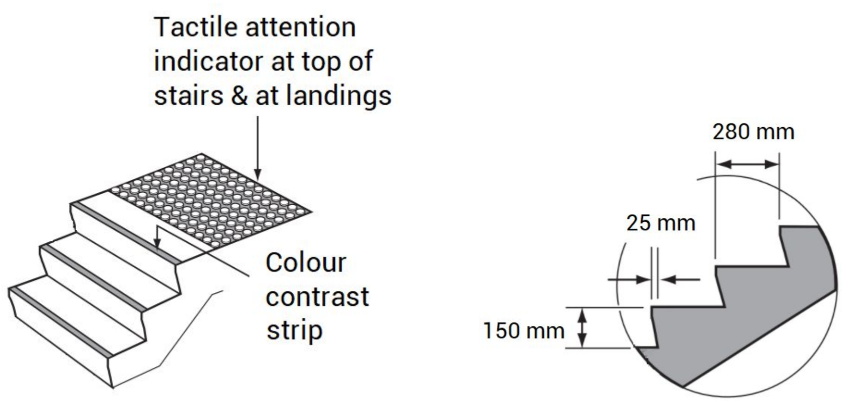


Figure 27. Stair Details

4.3.1.3 Underpass Walkway

The underpass walkway is 4.4 m in width, a deliberate choice made in order to accommodate larger wheeled mobility aids, pedestrians, and cyclists. The floor of the underpass walkway is lined with smooth concrete pavers, which serves as a reminder for cyclists to slow their speeds. Lastly, the type of catch basin covers used will be bike and wheelchair friendly.

4.3.2 Lighting

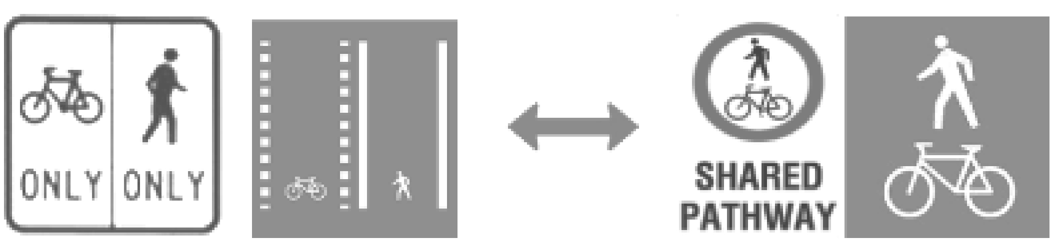
Lighting for both the approaches and within the underpass has been designed to promote the comfort of users. Outside of the underpass, regularly placed light posts will illuminate the the pedestrian and cyclist pathways during late evening and early morning hours, however the lights inside the underpass and on the ramps and stairs will operate at all times for safety precautions, providing illuminance of at least 50 lux

(Clause 8.2.9, [6]). Inside the underpass, two spot lights are placed every 2.5 meters, as depicted in Figure 28, totaling to 20 lights illuminating the underpass' interior.

Figure 28. Pedestrian Underpass - Interior View

4.3.3 Signage & Wayfinding

On the approaches to the underpass, clear signage will be provided to display that the pathway transitions from separated to multi-use, avoiding conflict between users. Specifically for cyclists, additional signage will direct users away from the road as the buffer between the cycle path and roadway becomes thinner at the intersection. A guardrail will begin along the road edge, providing a physical separation and guide for the cyclists to use the underpass and rampway instead of entering vehicle traffic flow. Markings on the pathways will also reinforce the messages displayed on the signs, clearly delineating where the pathway are separated and where they are shared between cyclists and pedestrians.



4.3.4 Acoustics

The design for the underpass specifies enough depth from the roadway to allow the underpass structure to be topped with 150 mm of earth and 100 mm of asphalt. This will act as a sound buffer between the traffic traveling overhead and the open space of the underpass directly below. The interior includes a further would panel layer to diffuse noise, and additional sound barrier material may be placed to reduce the noise levels further to ensure the acoustic comfort of users.

4.3.5 Aesthetics

In addition to the lighting along the length of the underpass, to increase the warmth of the interior the design includes red cedar NLT paneling along the bottom of the top slab components. The cedar will be resistant to decay, ideal for use in an exposed setting such as this, while also adding some colour to the interior of the underpass. The paneling will also enclose a space between itself and the top slab, allowing for lighting conduit and other utilities to be placed. Pending an analysis of the noise levels caused by traffic, this space may also be used for placing additional insulation and sound barrier material. The interior walls of the underpass will be decorated with murals to increase the visual appeal of the bare concrete, with the hope to showcase local indigenous artwork from the Musqueam people upon further community consultation.

05 Roadway Amenities

5.1 Utilities

Utility upgrades or replacements are outside the scope of this project. However, all existing utilities within the right-of-way were identified and considered in the underpass design and construction methodology and scheduling. Further investigation into the condition of the existing utilities is recommended to determine whether upgrading or replacement should be done in conjunction with the construction phase of this project.

5.2 Lighting

The existing lighting at the Hamber Road intersection will be maintained and no additional roadway lighting will be installed. Lighting will be provided for pedestrians and bicyclists along the greenway in the form of bollard lights. These will be spaced approximately 10 meters apart and will be one meter in height, with reference to the *CSA Standards Accessible Design for the Built Environment* (2012, Section 8.2.9). The bollard lights will be on a timer and will turn on at dusk and shut off between 12:00 midnight and 5:00 AM, to come on again from 5:00 AM until dawn. This exception was implemented due to various habitat and wildlife concerns. Many studies have found a link between bright street lighting in urban areas and migration patterns of the surrounding wildlife [9 and 10]. As road user safety is a key project goal, a compromise was reached to provide the desired level of safety while minimizing ecological impacts.

5.3 Signage

All signage along the corridor will be in accordance with the *BC Manual of Standard Traffic Signs & Pavement Markings* and other relevant guides for pedestrians and cyclists as discussed in the applicable sections. Wayfinding signage for Pacific Spirit will also be incorporated along the greenway and pedestrian walkways. As mentioned above, cyclist wayfinding signage will ensure routes are clearly identified. Other guidelines that were referenced in the design include *UBC's Exterior Signage Standards and Guidelines* (2017) and CSA's *Accessible Design for the Built Environment* (2012).

5.4 Greenway Amenities

The greenspace between the bicycle path and walkway will host various pedestrian amenities such as:

- Benches,
- Trash bins,
- Bollard Lighting,
- Wayfinding signage, and
- Educational and informational signage referring to the surrounding wildlife, habitat and ecosystems, and Pacific Spirit Park.

There is also the opportunity to incorporate local art and landscaping features, such as flowers and shrubs, but installation should only be pursued based on budgetary allowances and community desires.

06 Environmental Protection

6.1 Stormwater Management

The existing catch basins locations will be maintained and integrated into the new roadway. Based on the high-level drainage analysis, the storm sewer system adequately meets the minimum flow requirements for a 1:50 year storm. There is one storm sewer pipe that requires relocating due to the underpass design.

6.2 Construction Impacts

Throughout the project construction, measures will be taken to ensure that the construction activities do not result in unreasonable environmental impacts. Forested areas must be delineated off to ensure that the park vegetation is not damaged. If vegetation removal is necessary for any part of the project, proper authorizations will be obtained and bird survey will be completed to ensure that no active nests are being disturbed.

Any equipment working on site will be periodically inspected to ensure that it is free of any leaks. If any contaminated sites are discovered in the process of the construction, work in the area will be stopped immediately and put on hold until inspected by an environmental consultant.

As a part of tender process, it is recommended that contractors include an environmental management plan prepared by a professional environmental engineer with their bid.

07 Construction & Maintenance

7.1 Construction Specifications

The following present the minimum required specifications that the contractor must meet for successful completion of the project elements.

7.1.1 Underpass

The following specifications are required for the construction of the underpass:

- To secure the precast sections together, a 25 MPa quick-curing concrete will be applied to the connection points.
- Concrete applied at connection points must reach 75% of its design strength before backfilling or paving can occur
- The concrete applied at the connection points must reach its design strength within 48 hours of placement
- All backfill must be compacted to 100% of the optimum density
- Optimum backfill density to be determined by the proctor compaction test.
- Requirements for backfill granular distribution as per IFC drawings.
- Backfill grain distribution to be determined by sieve analysis
- Backfill to be placed as per IFC drawings in 200 mm lifts

7.1.2 Dry Well

A dry well will be constructed after the completion of the underpass and during the ramp construction.

- 2 m diameter dry well to be drilled by auger to 14 m depth
- Precast perforated concrete pipe to be placed into dry well
- Emergency sump pump to be placed in the well 2 m below grade

7.1.3 Road

The road must be constructed with the focus to minimize road closures and interruptions. Refer to Section 7.2 for the construction sequencing and schedule.

- Asphalt to be placed in two lifts, at 150 mm per lift
- Each lift must be compacted to required density

- Pavement density to be measured using nuclear density gauge
- Silt fencing is to be used near all waterways

7.2 Construction Schedule

The project is scheduled to commence on May 1, 2018, with expected completion on August 10, 2018. The project implementation schedule has been composed with the goal to accommodate traffic demand while providing a realistic work environment to the contractor. To minimize the impact on the local stakeholders, it also takes into consideration local community milestones, such as the elementary school summer closure.

7.2.1 Construction Sequencing

The project sequencing is as follows:

1. Close the southern (eastbound) lanes and existing multi-use pathway to all traffic, the northern (westbound) lanes remain open to two-way traffic.
2. Re-pave the existing multi-use pathway and re-purpose as the new cycle path.
3. Construct the new pedestrian pathway to the south of the cycle path and add bollard lights between the bike and pedestrian pathways.
4. Pave the median between the existing west and eastbound traffic lanes.
5. Remove the existing southernmost lane and re-vegetate the areas around the new multi-use path.
6. Open the southern lanes for two-way traffic and close the northern lanes and trails for all traffic.
7. Resurface northern lanes and add the gravel multi-use pathway on the north side of the corridor.
8. Close Chancellor Blvd. to all traffic at Hamber Road, after elementary school closes for the summer.
9. Excavate for the new underpass.
10. Place the precast underpass sections and secure all connections.
11. Backfill the underpass.
12. Perform drilling for dry-well.
13. Pave the re-designed intersection.
14. Re-open chancellor boulevard to through traffic

15. Construct the ramps leading up to the underpass.
16. Open the intersection to traffic.
17. Finish the underpass approaches on the north and south sides of Hamber Road.

This construction sequence is based on the design decisions made to date. The contractor awarded the project will provide their own construction schedule subject to approval as per previously discussed stakeholder considerations.

7.2.2 Project Milestones

Table 3 below summarize the project milestones and their expected completion dates.

Table 3. Project Milestones

Milestone	Start	End
Mobilization	May 1	May 3
South Pathway and Lane Construction	May 2	June 15
Remobilize to North, North Lanes and Path	June 15	June 28
Underpass crossing, closed road	June 29	July 6
Underpass Approaches, electrical	July 9	August 6
Drywell Drilling	July 12	July 13
Demobilization	August 6	August 9
Project Completion	**August 10**	**August 10**

Detailed project schedule, complete with dates and detailed task descriptions, can be found in Appendix D.

7.3 Maintenance Plan

To maintain the corridor in optimal condition, preventative maintenance and remediation will be required. A proposed maintenance plan is described in the following section.

7.3.1 Assumptions

It is assumed that the subbase will be constructed as per MoTI standard specifications and, as such, will not lead to major surfacing failures such as alligator cracking. The mix design for the asphalt is assumed to be adequate and issues such as depression in wheel paths and washboarding would not occur. For the purpose of this report, it is assumed that the road surface will deteriorate at a normal rate. The costs are derived from MoTI's construction and rehabilitation cost guide and are assumed to be accurate costs for the study area.

7.3.2 Right of Way Maintenance

The primary goal of the right of way maintenance is to maintain a satisfactory driving surface and to prevent deterioration related to water infiltrating into the subbase below the pavement. The maintenance of the paved surface is divided into three types, as listed below and summarized in Figure 23. The maintenance activities, issues they resolve, frequency, and cost of each of the three maintenance types are discussed further in the following sections.

- **Annual repair and remediation:** Takes care of the normal wear and tear, such as potholes and minor cracking.
- **Preventative maintenance:** Regularly scheduled maintenance activities that prolong the lifetime of the pavement.
- **Major rehabilitation:** When the repair and remediation is no longer practical, replacing the pavement will be required.

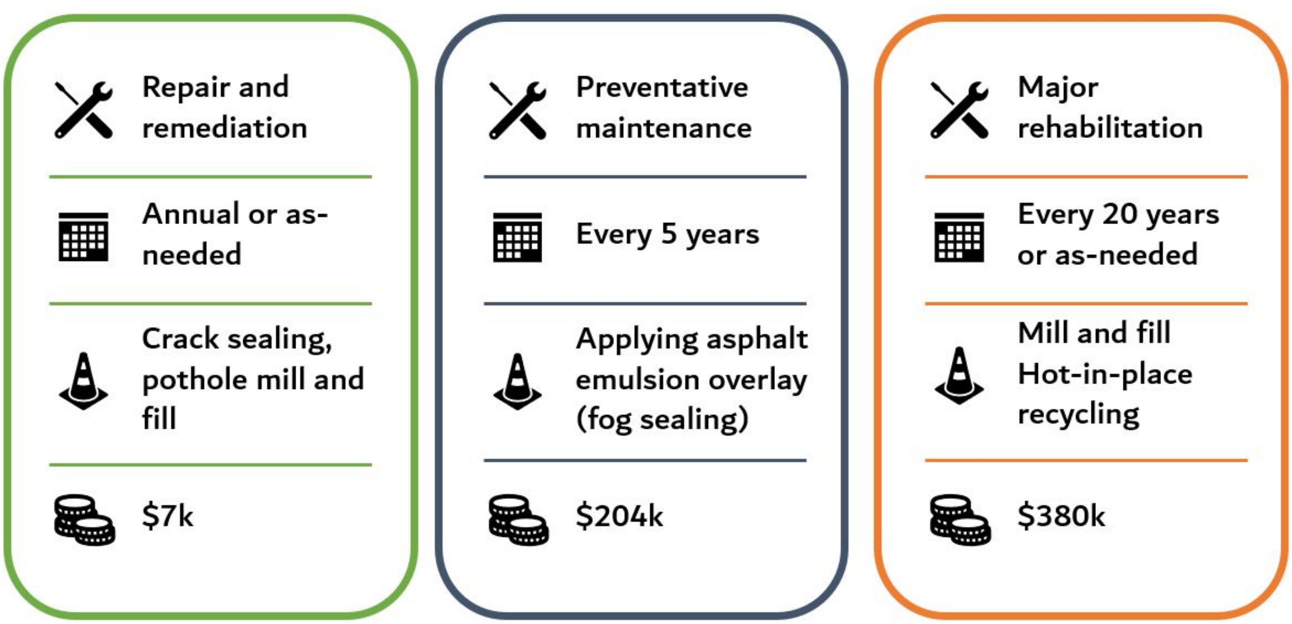


Figure 29. Maintenance Activities Summary

7.3.2.1 Annual Repair and Remediation

Under normal service conditions, defects such as minor cracking and potholes can be expected to occur at a moderate frequency. As they normally do not present an immediate need for repair, those can be remediated on an annual basis. Repair activities to remedy these issues include the following Rubber crack sealing for minor cracking Mill and fill patches for potholes. Expected frequency of this repair and remediation is every year or as needed. On average, it is expected to come at an annual cost of $7,000.

7.3.2.2 Preventative Maintenance

Through the lifetime of the paved surface, microcracks are expected to form. While they are not normally visible and do not pose an immediate deterioration concern, they will still contribute to water infiltration and long-term subbase deterioration. In order to prevent the long term effect of microcracking, maintenance activities such as fog sealing will need to be done approximately every 5 years, or as required. By re-establishing an impervious surface, it will prolong the lifespan of the paved surface and deter the eventual need for complete re-paving. It is expected to cost of approximately $203,800.

If a more durable preventative maintenance option is desired, microsurfacing may be considered. Microsurfacing contains polymers that increase strength and has the life expectancy of up to 11 years. Microsurfacing the corridor would come at a cost of approximately $398,900.

7.3.2.3 Major Rehabilitation

At the end of the service life, repairing and renewing the driving surface would no longer be practical due to the effects of long term deterioration. As such, the driving surface should be replaced entirely. It is recommended that when it is needed to replace the paved surface, it is done via hot in place recycling as it is a much cheaper and a more environmentally friendly option.

The expected cost to repave the corridor using hot in place recycling method is $376’800. Expected frequency of major rehabilitation work is 20 years, but may be later if it is determined that preventative maintenance can extend the lifespan of the pavement.

08 Project Cost

8.1 Methodology

A Class A project cost estimate was developed using precedent project examples and historical unit prices for materials and items. The estimate is based on the finalized road corridor (Section 2), the underpass at Hamber Road (Section 4), and the construction schedule (Section 7.2). As such, it is assumed that the accuracy of this cost estimate will be within ±(25-40)% of the actual project cost. The project cost estimate can be found in the following section, with a more detailed cost breakdown in Appendix C.

8.1.1 Development of Costs

Precedent examples using US dollars were converted to Canadian dollars using a conversion factor of 0.80 USD / CAD. Where precedent examples were taken from older projects located in North Carolina, an additional factor of 1.2 was applied to account for the cost of inflation and location cost differences between North Carolina and Vancouver. Crew sizes, wage rates, and equipment requirements for construction were estimated using RS Means 2009. Labour hours were estimated using past experience, as well as consultation with senior engineers. The estimate for the cost of drilling was based on a quote provided by Henry Drilling.

Engineering fees were assumed to equal 15% of the construction cost (including project management), and divided among the engineering services as follows:

1. Conceptual Design: 10% of engineering fees
2. Preliminary Design: 20% of engineering fees
3. Detailed Design: 50% of engineering fees
4. Construction Services: 20% of engineering fees

Quality Assurance (QA) and Permitting were considered to be separate charges. The assumed cost of QA was $1000 per week of construction, and for permitting a lump sum equal to $15,000.

Project management fees were determined from previous experience, and from the detailed construction schedule.

Costs associated with the maintenance and upkeep of the road can be found in Section 7.3. Mobilization was assumed to be 10% of the construction cost of the project, and is intended to cover the costs of contractor mobilization and site preparation.

8.1.2 Contingencies

A 20% contingency was placed on the project cost, intended to cover:

- Any design changes made in the detailed design resulting in a change of quantities or scope,
- Unforeseen circumstances or acts of god that may occur during construction,
- Potential material price changes that may occur before procurement, and
- Unexpected geotechnical conditions

The same contingency was given to operations and maintenance, which accounts for inflation as well as any unforeseen damage or required maintenance costs.

8.2 Cost Breakdown

The following page shows a breakdown of the costs associated with the project. A more detailed cost estimate can be found in Appendix C.

Cost Estimate
The Chancellor Boulevard Corridor Redesign Project

Summary of Total Project Cost (contingency incl.)

Engineering	$ 557,502.33
Project Management	$ 524,400.00
Construction	$ 2,952,282.23
Mobilization	$ 322,723.52
Traffic Control & Other	$ 396,000.00
Total	**$ 4,752,908.09**

Item	Base Estimate	Contingency %	Contingency $	Total Estimate	Comments
Engineering					
Concept Design	$ 43,458.53	20	$ 8,691.71	$ 52,150.23	15% of construction and management costs
Preliminary Design	$ 86,917.06	20	$ 17,383.41	$ 104,300.47	
Detailed Design	$ 217,292.64	20	$ 43,458.53	$ 260,751.17	
Contsruction Services	$ 86,917.06	20	$ 17,383.41	$ 104,300.47	
Quality Assurance	$ 15,000.00	20	$ 3,000.00	$ 18,000.00	
Permitting	$ 15,000.00	20	$ 3,000.00	$ 18,000.00	
Engineering Total	**$ 464,585.28**	**20**	**$ 92,917.06**	**$ 557,502.33**	
Project Management					
Planning and Scheduling	$ 150,000.00	20	$ 30,000.00	$ 180,000.00	
Construction Supervision	$ 150,000.00	20	$ 30,000.00	$ 180,000.00	
Contract Documents	$ 125,000.00	20	$ 25,000.00	$ 150,000.00	
Tender Services	$ 12,000.00	20	$ 2,400.00	$ 14,400.00	
Project Management Total	**$ 437,000.00**	**20**	**$ 87,400.00**	**$ 524,400.00**	
Roads					
Road Paving	$ 933,105.94	20	$ 186,621.19	$ 1,119,727.13	
Median	$ 71,194.50	20	$ 14,238.90	$ 85,433.40	
Decomission Southern Lanes	$ 23,000.00	20	$ 4,600.00	$ 27,600.00	
Lights, Signage	$ 222,782.99	20	$ 44,556.60	$ 267,339.59	
Roads Total	**$ 1,250,083.43**	**20**	**$ 250,016.69**	**$ 1,500,100.12**	
Underpass					
Dry well	$ 104,320.00	20	$ 20,864.00	$ 125,184.00	
Precast Sections (manufacture)	$ 62,230.00	20	$ 12,446.00	$ 74,676.00	
Excavation & Soil Prep	$ 27,450.00	20	$ 5,490.00	$ 32,940.00	
Precast Section Installation	$ 16,850.00	20	$ 3,370.00	$ 20,220.00	
Approaches	$ 81,976.23	20	$ 16,395.25	$ 98,371.48	
Underpass Total	**$ 292,826.23**	**20**	**$ 58,565.25**	**$ 351,391.48**	
Pedestrian and Bike Paths, Intersections, Crossings					
South Paths	$ 453,870.78	20	$ 90,774.16	$ 544,644.93	
North Paths	$ 105,136.00	20	$ 21,027.20	$ 126,163.20	
Special Crosswalks	$ 350,200.00	20	$ 70,040.00	$ 420,240.00	
Protected - Tee Intersection	$ 8,118.75	20	$ 1,623.75	$ 9,742.50	
Paths, Crossings, Intersections Total	**$ 917,325.53**	**20**	**$ 183,465.11**	**$ 1,100,790.63**	
Other Costs					
Landscaping	$ 250,000.00	20	$ 50,000.00	$ 300,000.00	
Fencing	$ 20,000.00	20	$ 4,000.00	$ 24,000.00	
Flagging	$ 60,000.00	20	$ 12,000.00	$ 72,000.00	
Other Costs Total	**$ 330,000.00**	**20**	**$ 66,000.00**	**$ 396,000.00**	

**This is a Class B cost estimate with assumed project costs developed using the quantity take offs from detailed design drawings and past experience, and may differ from the final project costs by as much as 20%*

09 Conclusion

The team's design of Chancellor Boulevard has some limitation that are outlined in the previous sections. To mitigate any negative impacts that could occur, a risk assessment was completed and can be found in Appendix F. The assessment aims to acknowledge all potential risks involved in the project from a triple bottom line approach. In addition to acknowledging these unknowns, some next steps and recommendations are outlined below.

9.1 Next Steps

9.1.1 Key Stakeholder Engagement

Continued consultation of the key stakeholders identified should be carried out to mitigate any risk posed by backlash to the design. Appropriate stakeholders will be informed of all large decisions and the opinions of those affected will be highly regarded. Consideration and due diligence will be taken to provide the most equitable solution. As progress continues, members of the public, particularly those regularly using the corridor, will be notified in advance of the impacts of the following project phases.

9.1.2 Funding Acquisition

Funding acquisition is crucial for the project success, and is a key consideration when allocating resources and scheduling and sequencing. Various funding avenues will need to be explored and assessed.

9.1.3 Permitting and Licensing

Necessary permitting and licensing required for this project is a key step and will follow shortly after the completion of the environmental assessment and issuance of a certificate for the project. Permits that are likely required include, but are not limited to, authorization under the fisheries act to build new water drainage into fish bearing streams, construction licenses and permits, and building permits for structures along the corridor, specifically the underpass.

9.2 Recommendations for Future Work

Further investigation into upgrading the utilities along the corridor is recommended. If some of the utilities are to be replaced or upgraded within the near future, it would be beneficial to combine the work with this project to minimize cost and repeated traffic disruptions along the corridor.

Another recommendation put forth by MTT is to incorporate local art into the greenway and/or the pedestrian underpass, possibly in the form of a mural or art pieces. This would promote a stronger local community in the area. Indigenous art could also be incorporated and be a positive way to recognize the ancestral and unceded territories of the Musqueam people.

10 References

[1] Bushell, Max A., Poole, Bryan W., Zegeer, Charles V., Rodriguez, Daniel A. *Costs for Pedestrian and Bicyclist Infrastructure Improvements*. UNC Highway Safety Research Center. 2013.

[2] *Budget Guidelines for Consulting Engineering Services*. Association of Professional Engineers and Geoscientists of British Columbia. 2009.

[3] "Chapter 4 – Cross Section Elements." *Geometric Design Guide for Canadian Roads*, 2017th ed., Transportation Association of Canada, 2017. *https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/engineering-standards-guidelines/highway-design-survey/tac-bc*

[4] *Climate Projections for Metro Vancouver*. Metro Vancouver. 2016. *http://www.metrovancouver.org/services/air-quality/AirQualityPublications/ClimateProjectionsForMetroVancouver.pdf*

[5] *Construction and Rehabilitation Cost Guide*. Ministry of Transportation and Infrastructure. 2013.

[6] *CSA B651-12, Accessible Design for the Built Environment*. CSA Group, 2012.

[7] *CSA S6-14, Canadian Highway Bridge Design Code*. CSA Group, 2014.

[8] Davies, T. W., Bennie, J., Cruse, D., Blumgart, D., Inger, R. and Gaston, K. J. (2017), "Multiple night-time light-emitting diode lighting strategies impact grassland invertebrate assemblages." *Global Change Biology*, Vol. 23: Pg 2641-2648. http://onlinelibrary.wiley.com/doi/10.1111/gcb.13615/full

[9] "Light Pollution Effects on Wildlife and Ecosystems." *International Dark Sky Association,* http://www.darksky.org/light-pollution/wildlife/

[10] "Light Pollution Harms the Environment." *FAU Astronomical Observatory*, http://cescos.fau.edu/observatory/lightpol-environ.html

[11] "Pedestrian Crossing Control Manual for British Columbia." *Ministry of Transportation and Infrastructure*. Second Edition, April 1994. https://www2.gov.bc.ca/gov/content/transportation/transportation-infrastructure/engineering-standards-guidelines/traffic-engineering-safety

[12] *UBC Vancouver Transportation Status Report Fall 2016*. University of British Columbia, 2017. https://planning.ubc.ca/sites/planning.ubc.ca/files/documents/transportation/reports/UBC2016-TransportationStatusReport-FINAL.pdf

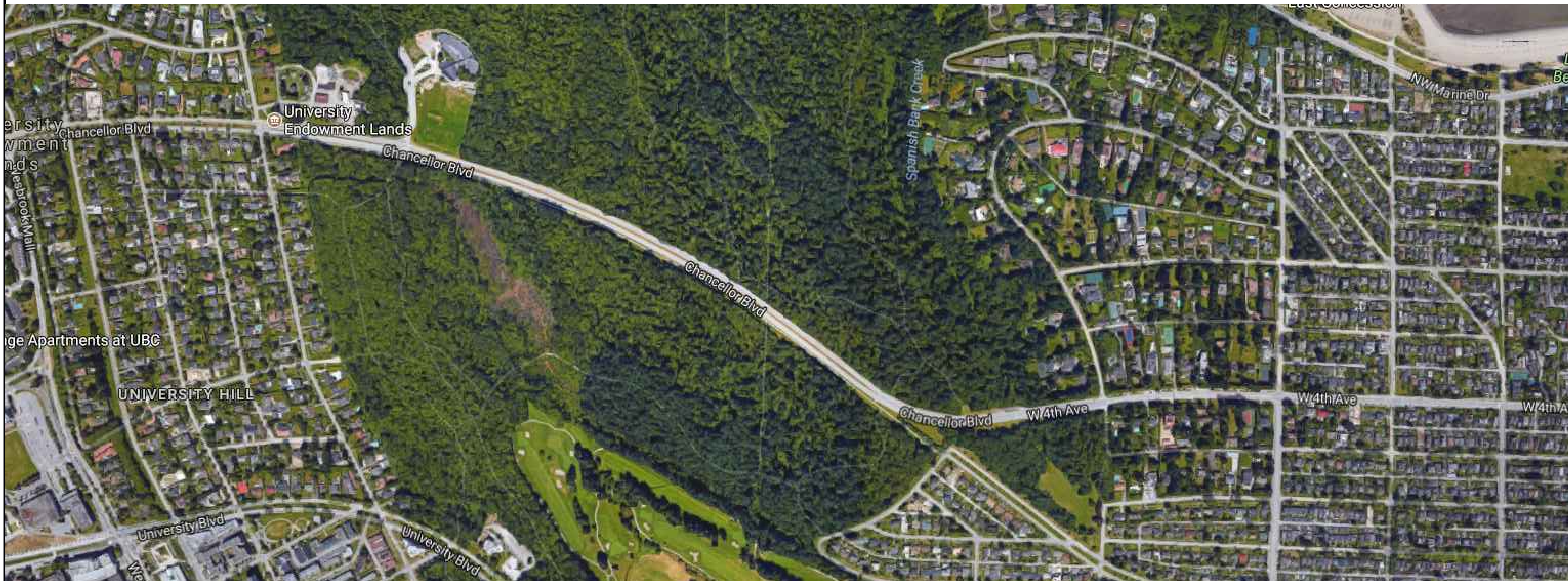
[13] Nazhat, Y. *Specifications for the Pedestrians/Cyclists Underpass*. University of British Columbia - Department of Civil Engineering. 2017.

[14] *CSA A23.3-14, Design of Concrete Structures*. CSA Group, 2014.

Appendix A. Corridor Drawings IFC

CHANCELLOR BOULEVARD REDESIGN

UBC CAMPUS AND COMMUNITY PLANNING

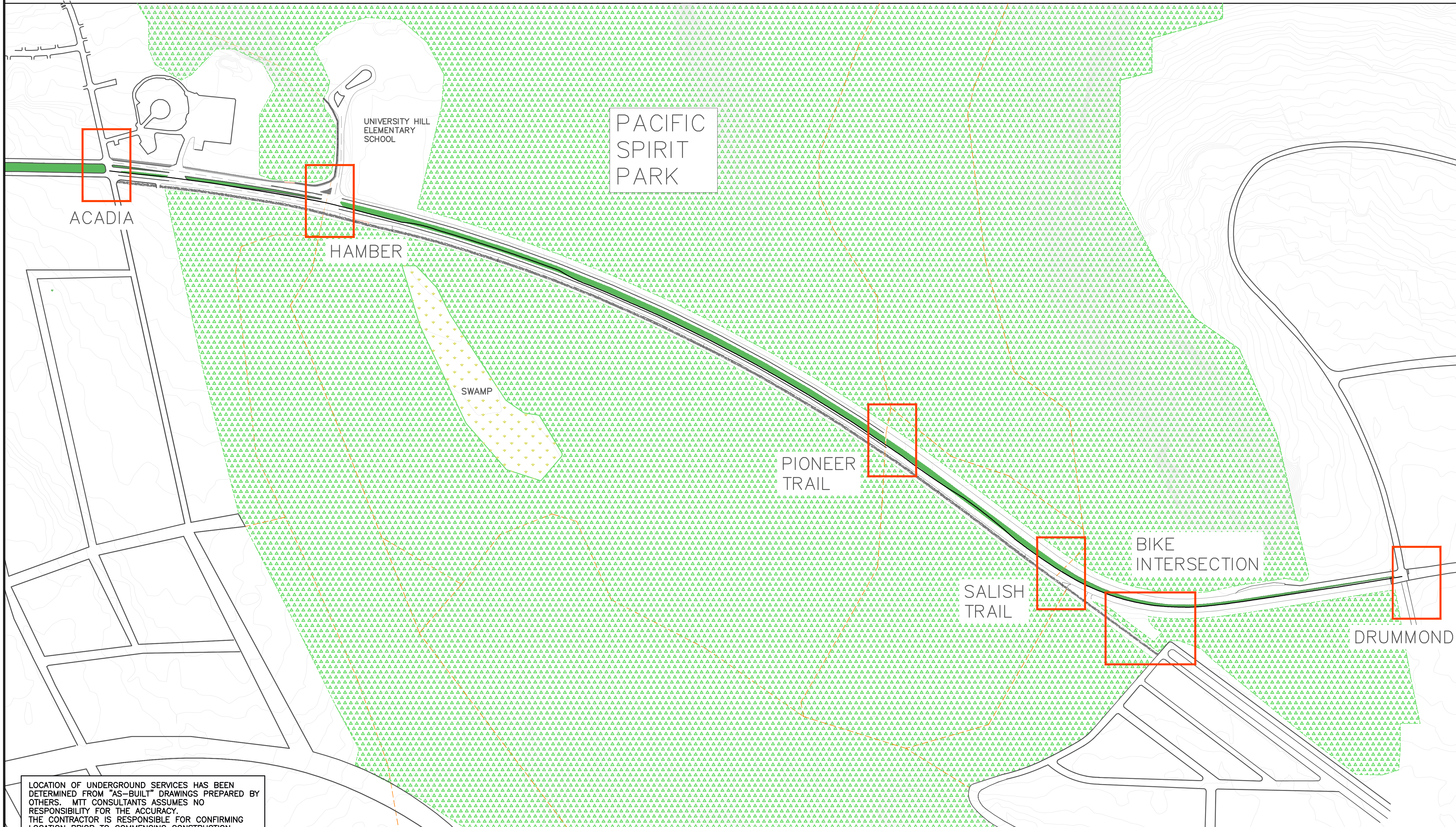


<u>CIVIL DRAWING INDEX</u>

MTT CONSULTING ENGINEERS

ISSUED FOR CONSTRUCTION

PROJECT #: 123-456-78
DATE: APR 2018



LOCATION OF UNDERGROUND SERVICES HAS BEEN DETERMINED FROM "AS-BUILT" DRAWINGS PREPARED BY OTHERS. MTT CONSULTANTS ASSUMES NO RESPONSIBILITY FOR THE ACCURACY.
THE CONTRACTOR IS RESPONSIBLE FOR CONFIRMING LOCATION PRIOR TO COMMENCING CONSTRUCTION.

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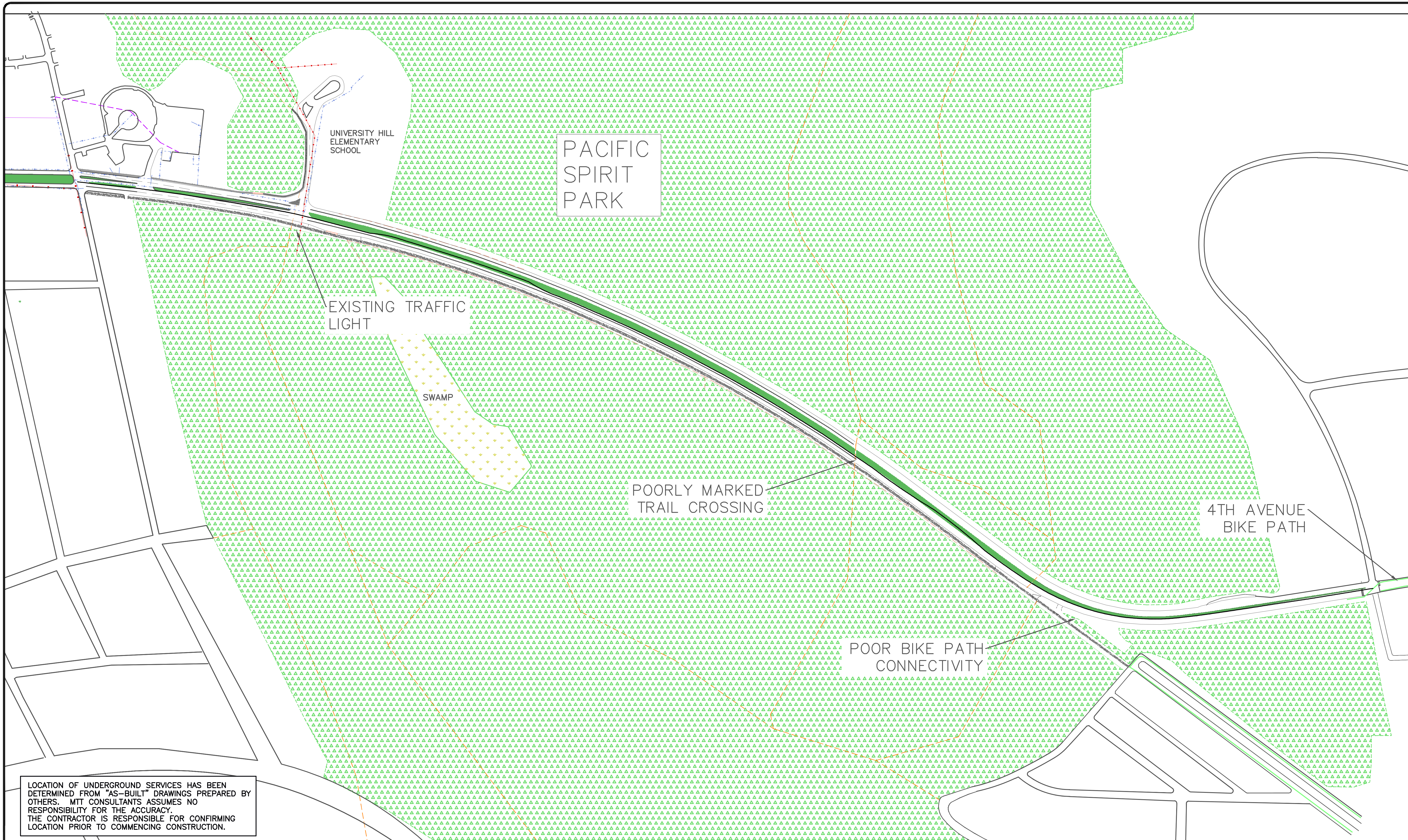
UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

SITE OVERVIEW

SCALE: HOR: NTS VERT:

DESIGNED BY:	FILE#: 610-027-10
DRAWN BY:	DWG.# 610-027-10
CHECKED BY:	SHEET C1 of C7
DATE: APR 2018	REVISION 0



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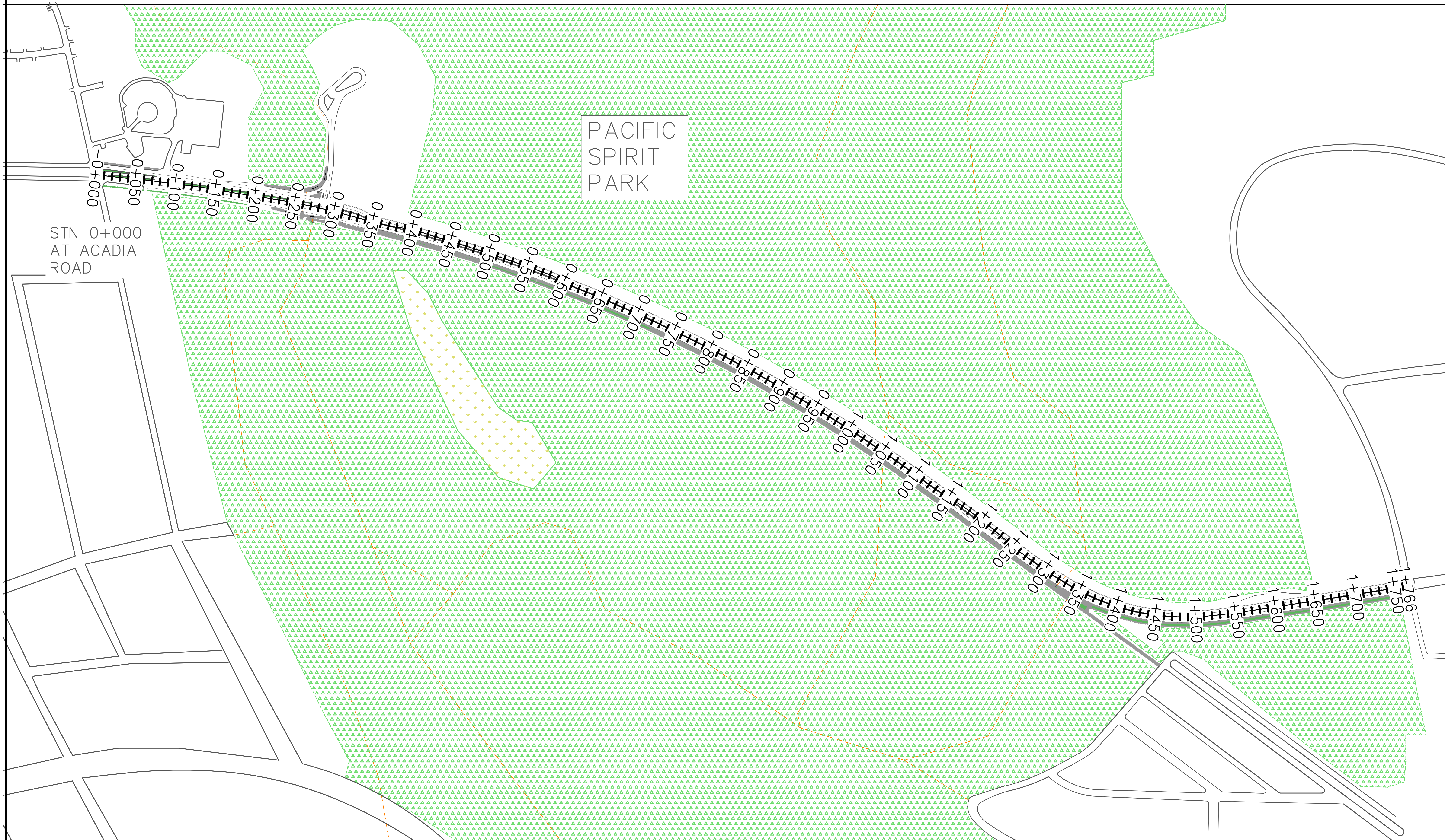

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CHANCELLOR BOULEVARD REDESIGN

ALIGNMENT STATIONS

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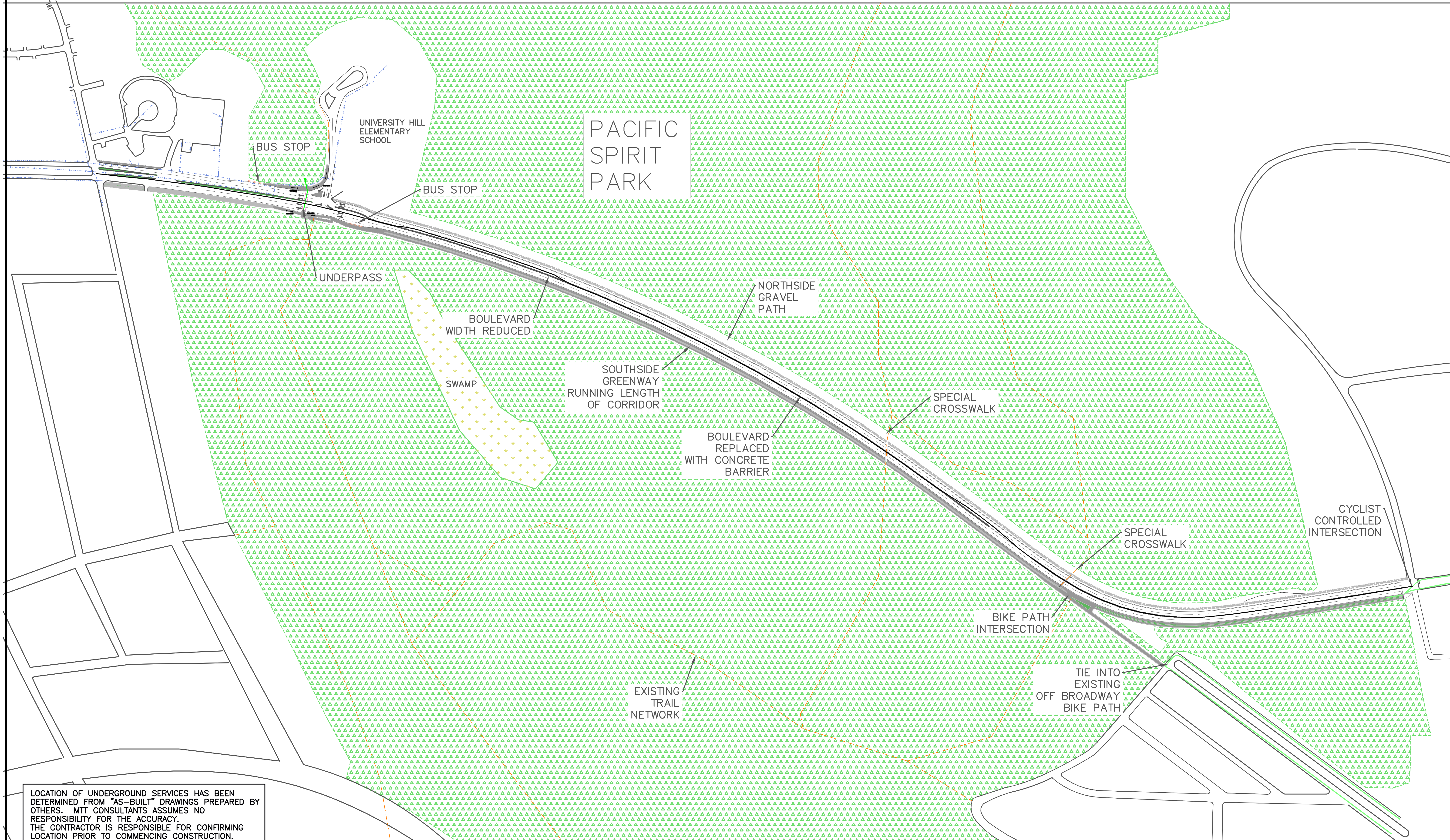

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UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

PROPOSED

SCALE: HOR: NTS VERT:

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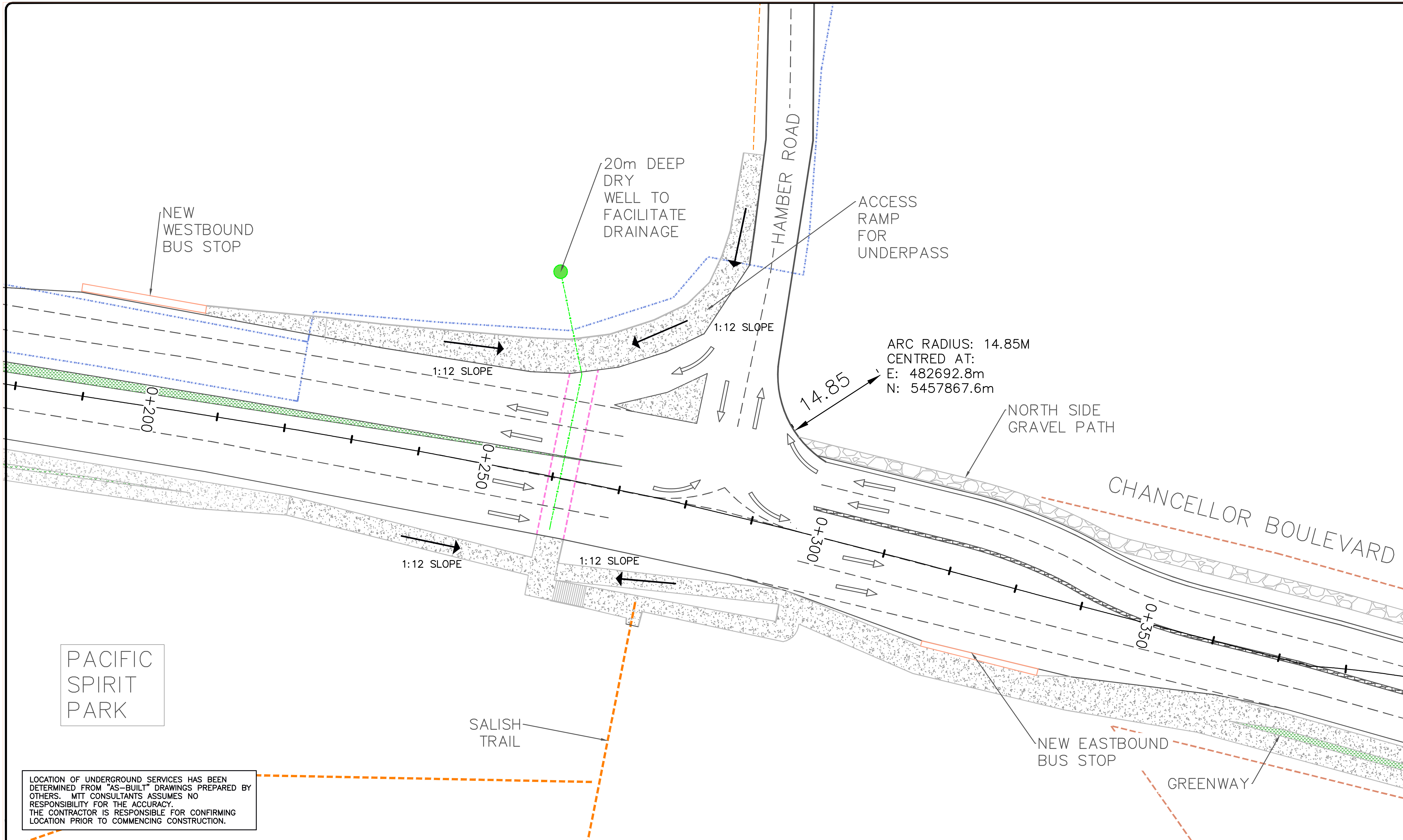
DATE: APR 2018	REVISION 0



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UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

PROPOSED HAMBER INTERSECTION

SCALE: HOR: NTS VERT:

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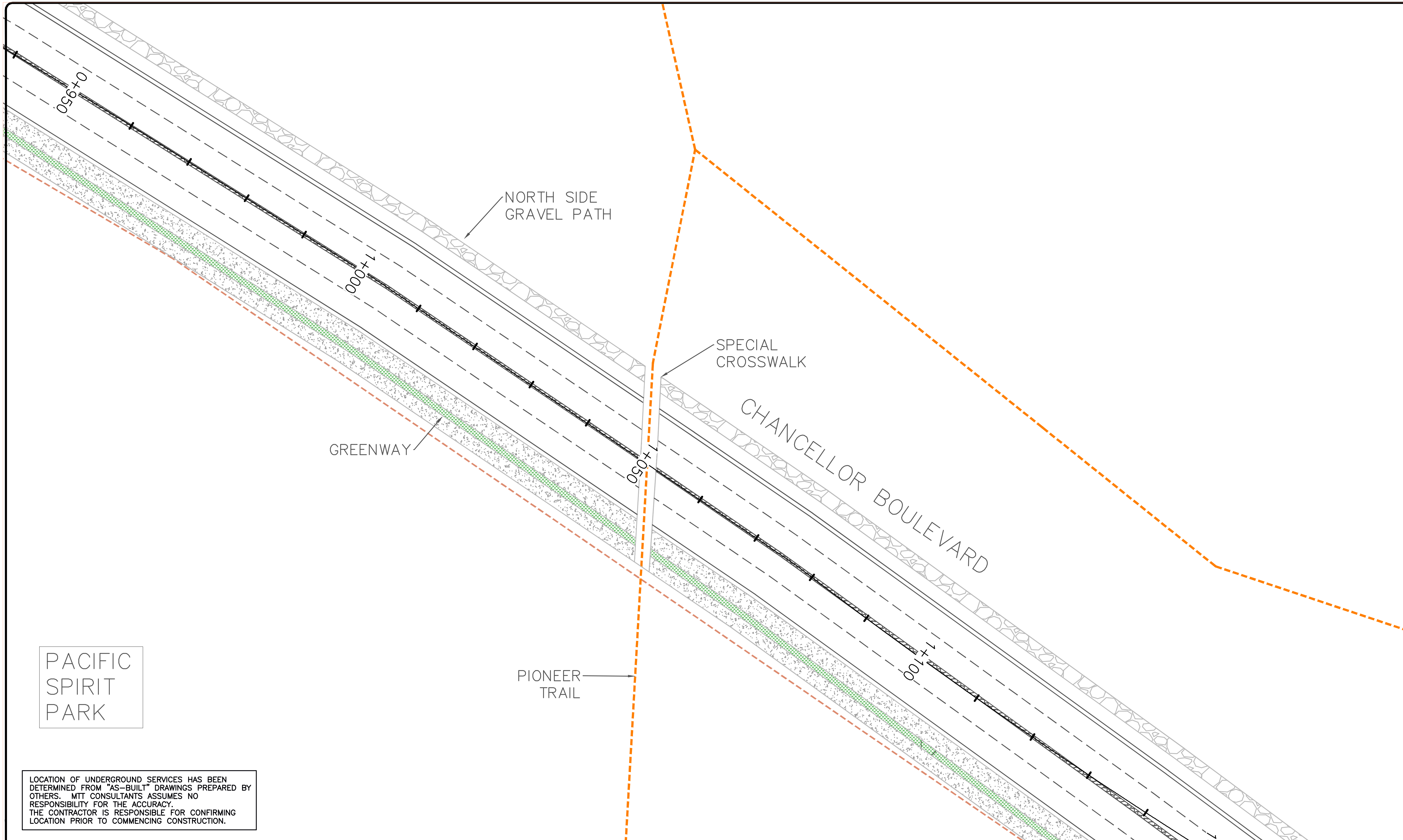

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APR 2018	ISSUED FOR CONSTRUCTION	

NO.	DATE	REVISION	BY	APPROVED

UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

PROPOSED
PIONEER TRAIL CROSSING

SCALE: HOR: NTS VERT:

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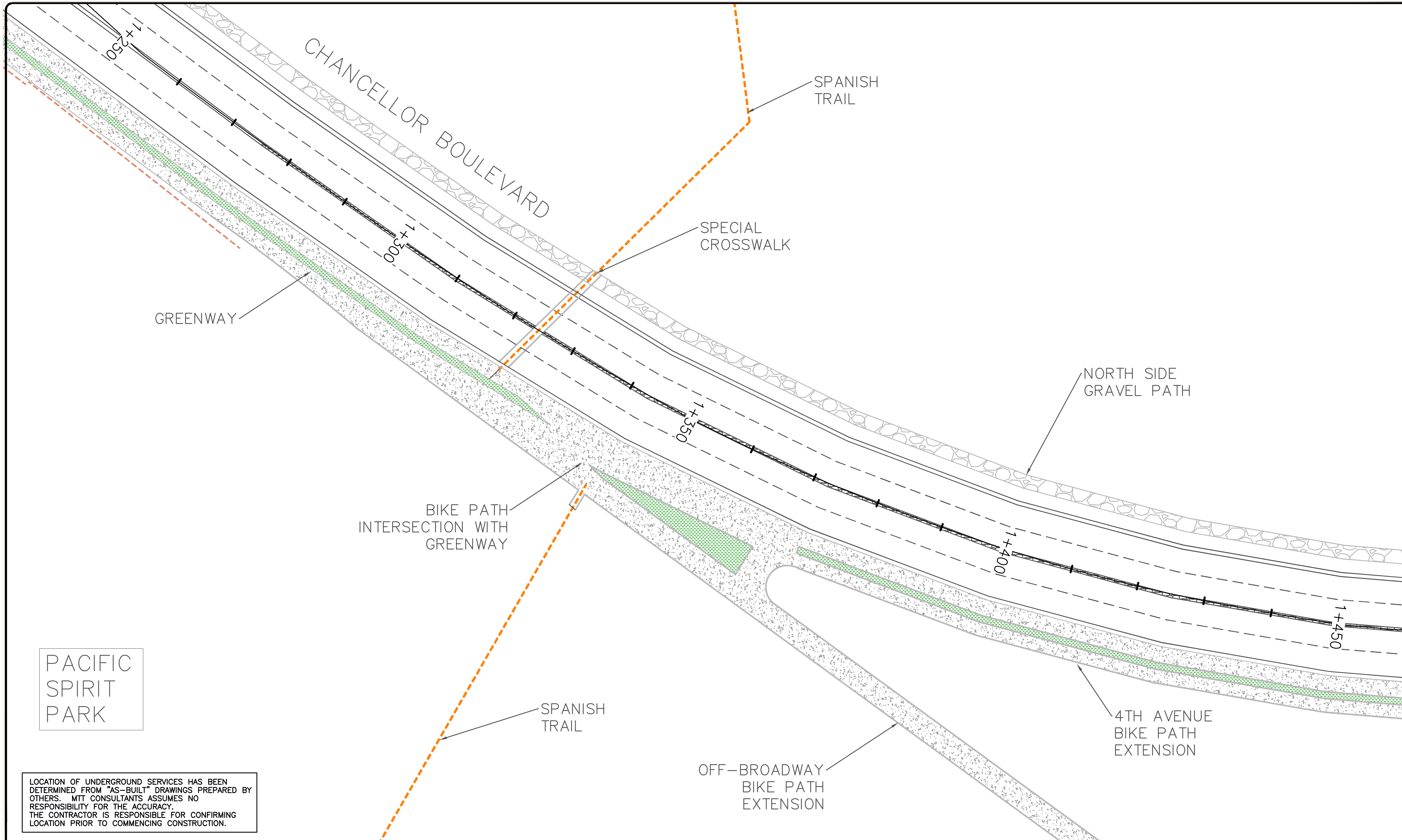
CHECKED BY:	SHEET C5 of C7
DATE: APR 2018	REVISION 0



LOCATION OF UNDERGROUND SERVICES HAS BEEN DETERMINED FROM "AS-BUILT" DRAWINGS PREPARED BY OTHERS. MTT CONSULTANTS ASSUMES NO RESPONSIBILITY FOR THE ACCURACY.
THE CONTRACTOR IS RESPONSIBLE FOR CONFIRMING LOCATION PRIOR TO COMMENCING CONSTRUCTION.

MTT Consultants
Engineering, Planning & Consulting
1234 Fake Street
Phonyville, BC, Canada V6T T8T
Ph: (250) 123-4567, Fax: (250) 111-1111

DATE	DRAWING ISSUE	APPROVED
APR 2018	ISSUED FOR CONSTRUCTION	

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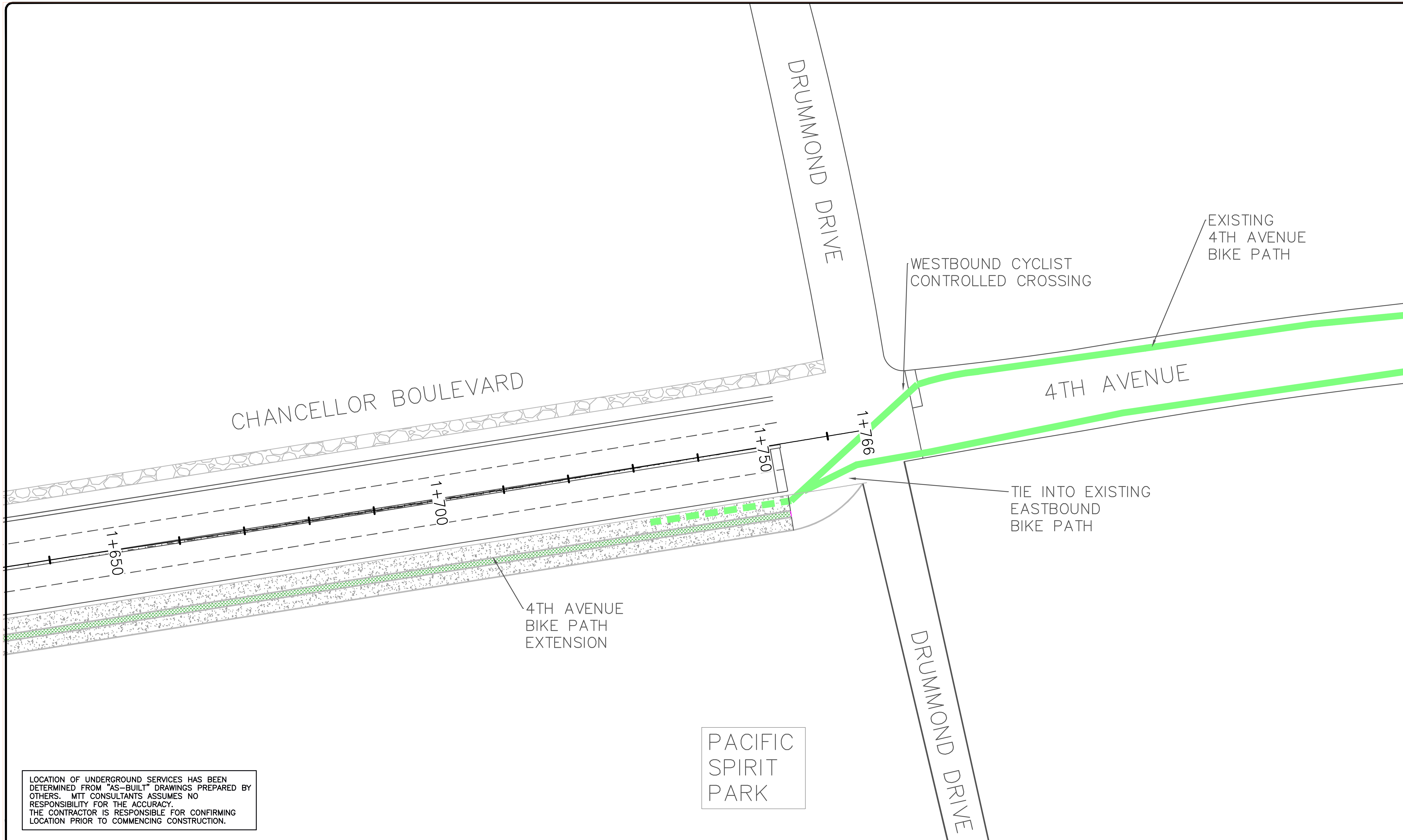
UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

PROPOSED
BIKE PATH INTERSECTION

SCALE: HOR: NTS VERT:

DESIGNED BY:
DRAWN BY:
CHECKED BY:
DATE: APR 2018

FILE#: 610-027-10
DWG.# 610-027-10
SHEET C6 of C7
REVISION 0



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APR 2018	ISSUED FOR CONSTRUCTION	

NO.	DATE	REVISION	BY	APPROVED

UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

PROPOSED
DRUMMOND DRIVE
SCALE: HOR: VERT:

DESIGNED BY:	FILE#: 610-027-10
DRAWN BY:	DWG.# 610-027-10
CHECKED BY:	SHEET C7 of C7
DATE: APR 2018	REVISION 0

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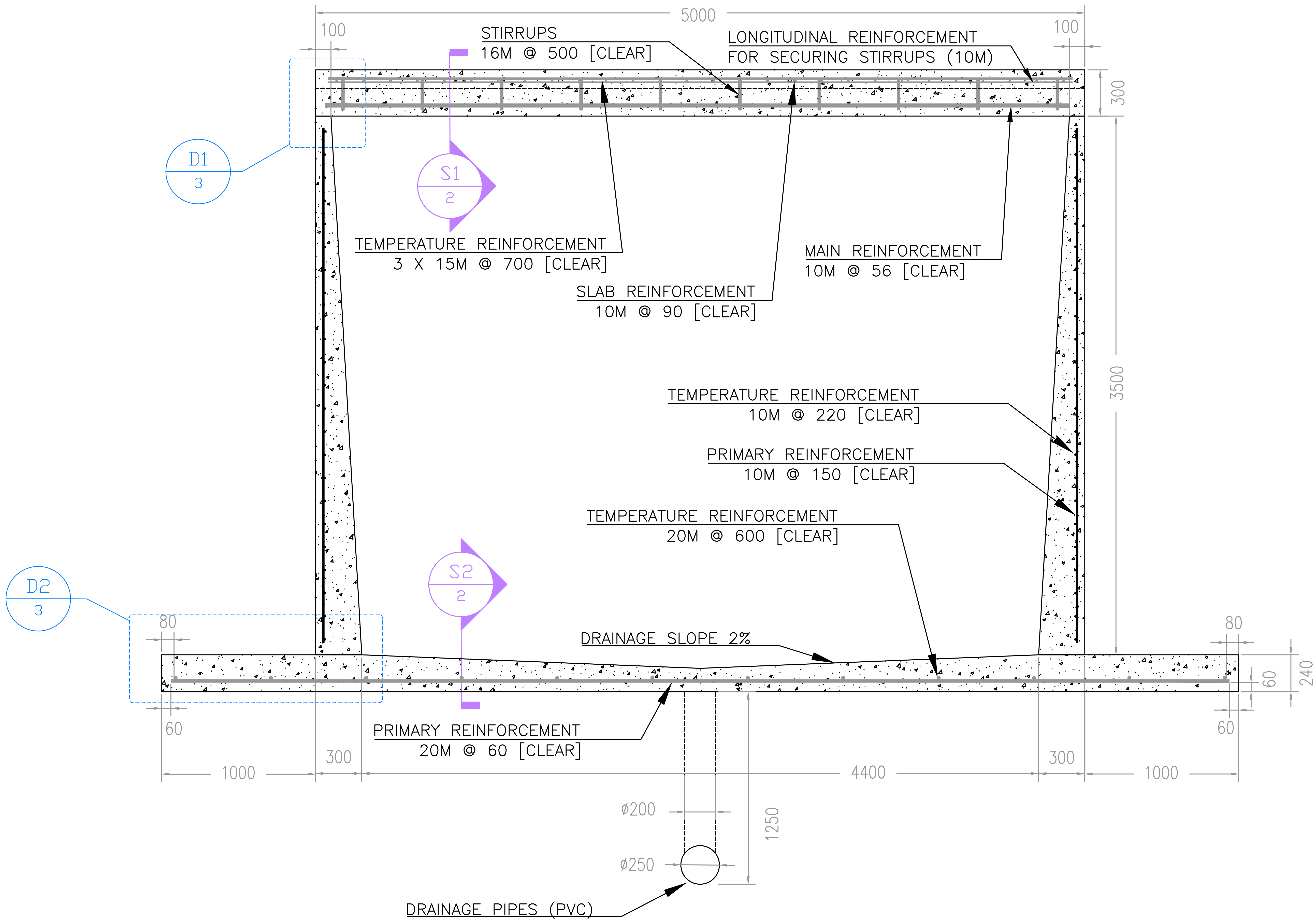
Appendix B. Pedestrian Underpass Drawings IFC



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DATE	DRAWING ISSUE	APPROVED

NOTES: All units shown are in mm unless stated otherwise.

Concrete fc' = 25 MPa
Rebar Steel fy = 400 MPa

NO.	DATE	REVISION	BY	APPROVED

UBC CAMPUS AND COMMUNITY PLANNING

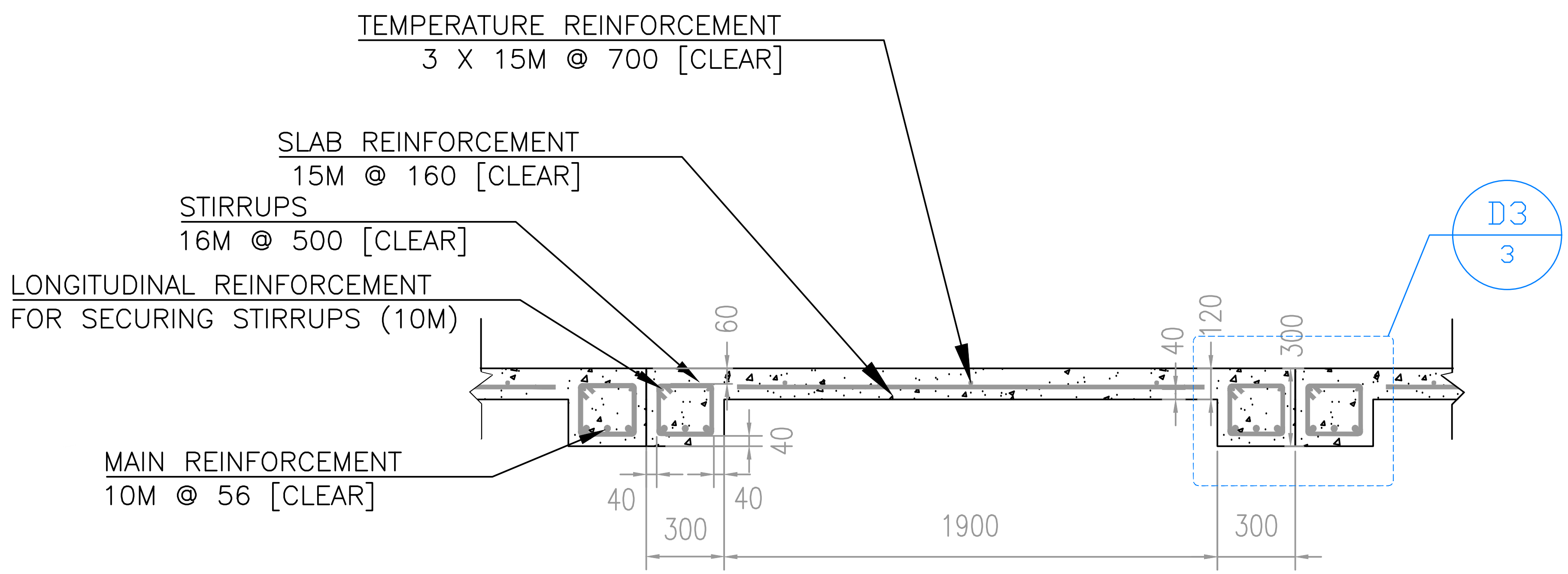
CHANCELLOR BOULEVARD REDESIGN

UNDERPASS CROSS-SECTION
(NORTH-SOUTH VIEW)

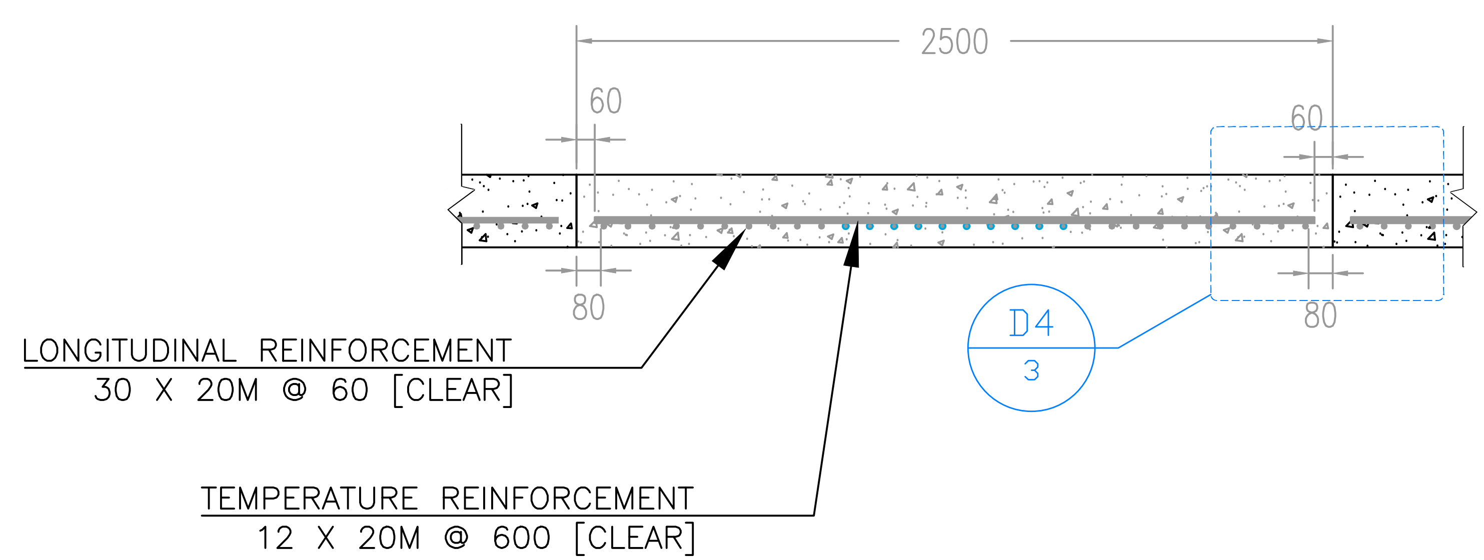
SCALE: HOR: 1:25 VERT: 1:25

DESIGNED BY: KP, WM	FILE#: 610–027–10
DRAWN BY: WM	DWG.# 610–027–10
CHECKED BY: KP	SHEET 1 of 4
DATE: APR 2018	REVISION 0

Section S1



Section S2



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Rebar Steel fy = 400 MPa

NO.	DATE	REVISION	BY	APPROVED

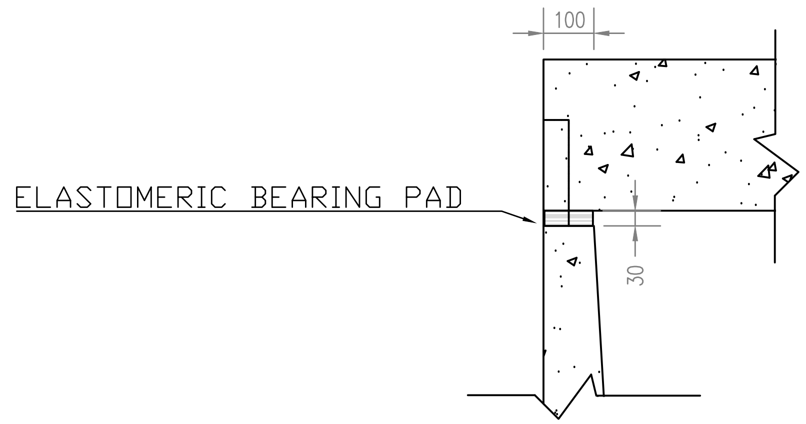
UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

UNDERPASS CROSS-SECTION (EAST-WEST)

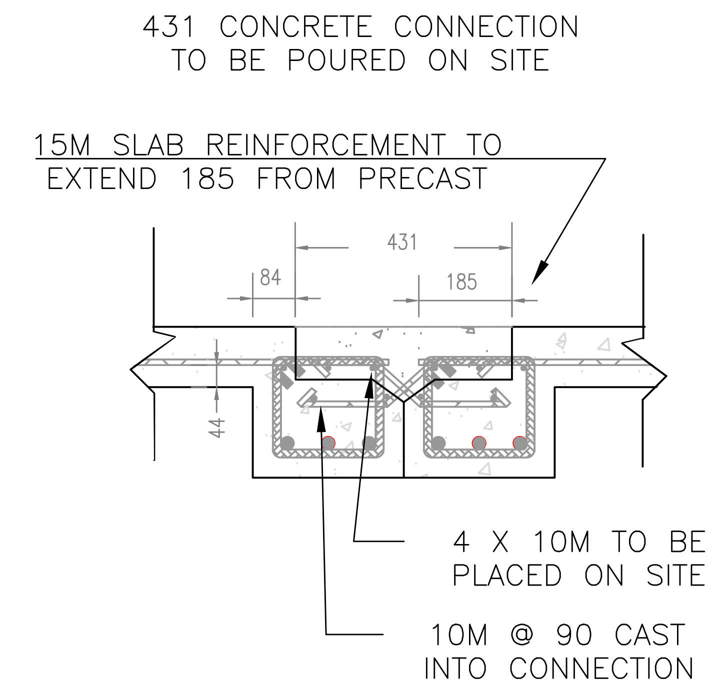
SCALE: HOR: 1:25 VERT: 1:25

DESIGNED BY: KP, WM	FILE#: 610-027-10
DRAWN BY: WM	DWG.# 610-027-10
CHECKED BY: KP	SHEET 2 of 4
DATE: APR 2018	REVISION 0

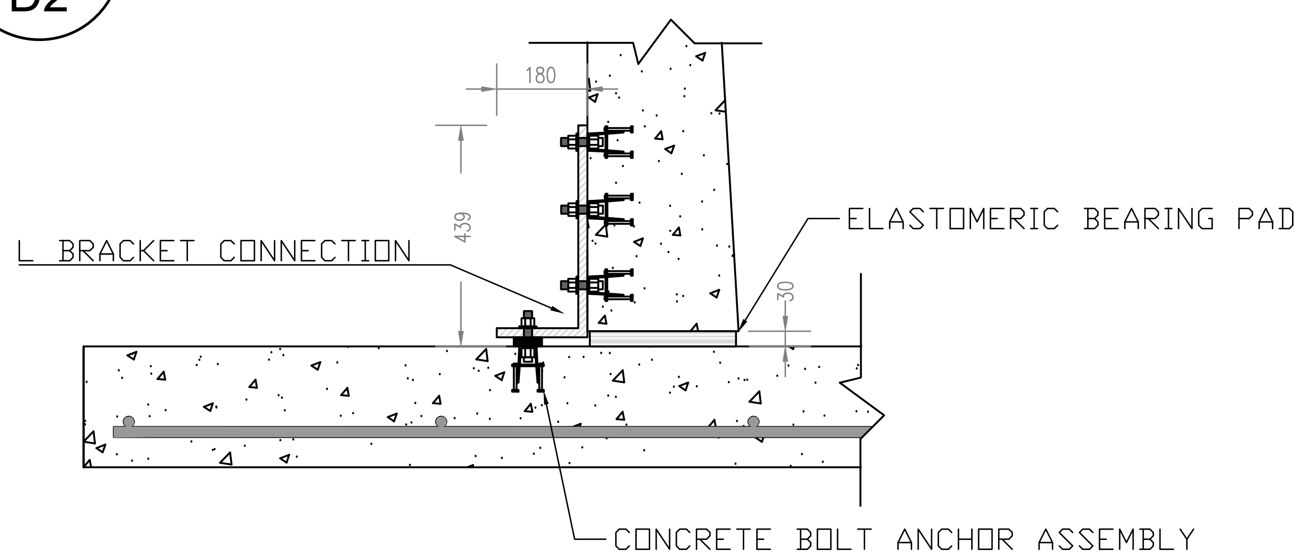
Detail D1



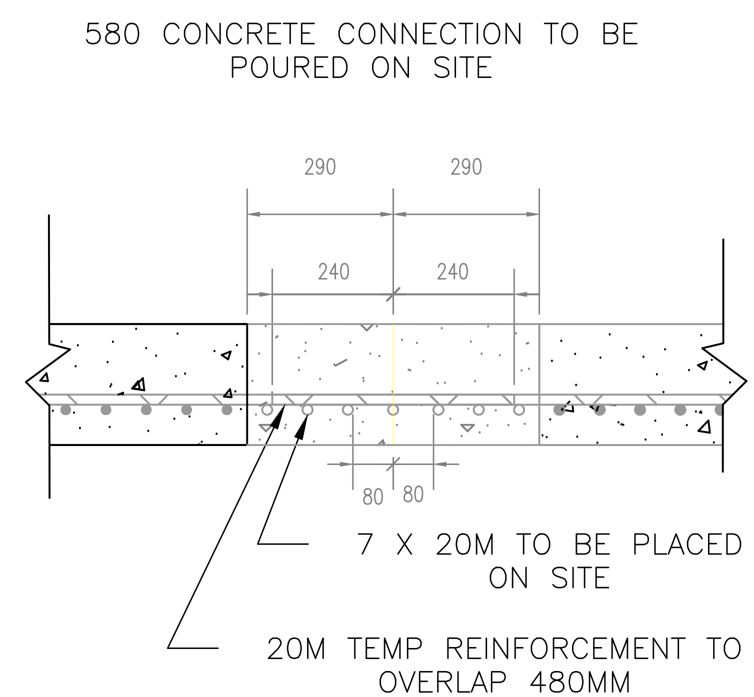
Detail D3



Detail D2



Detail D4



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NO.	DATE	REVISION	BY	APPROVED

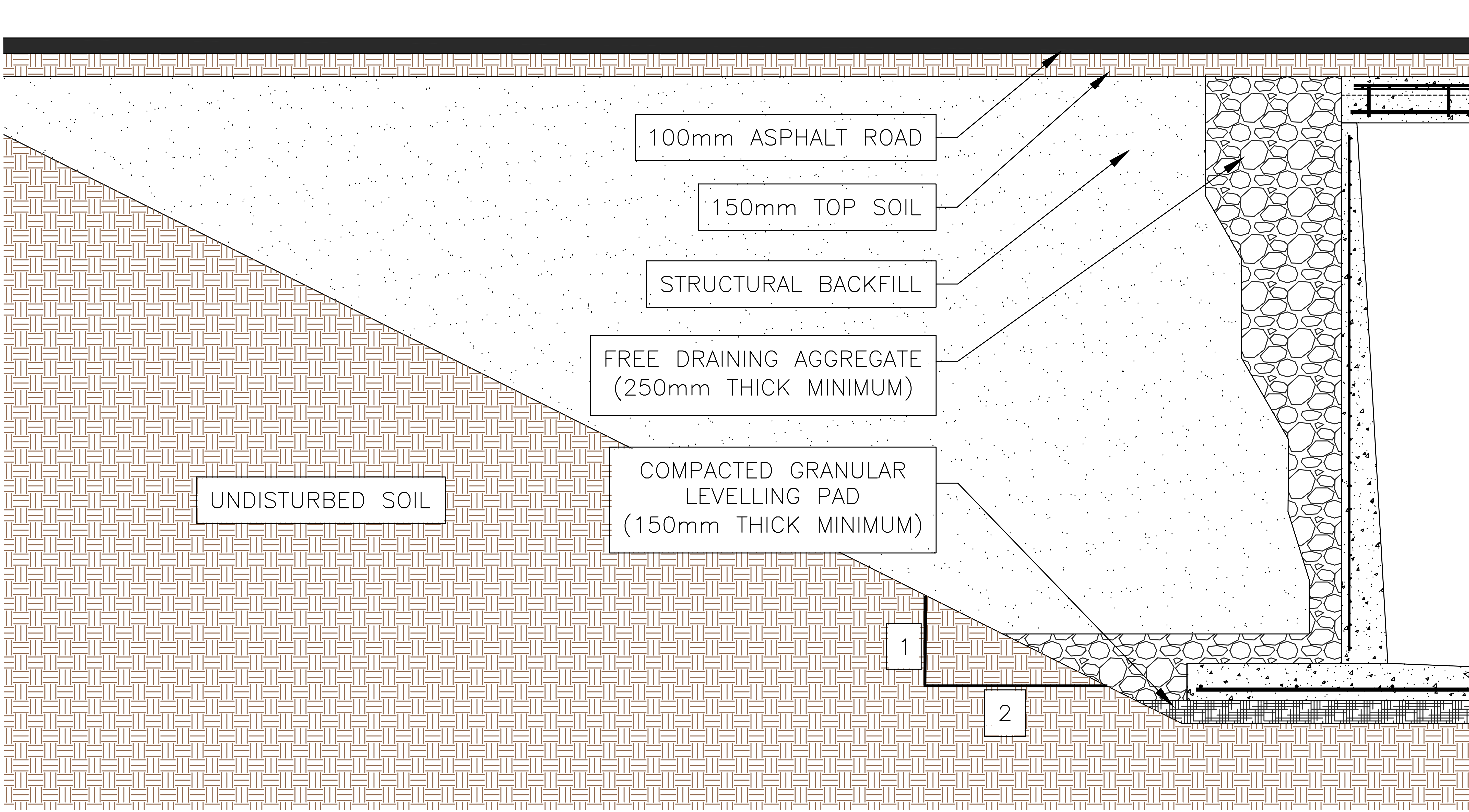
UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

CONNECTION DETAILS

SCALE: HOR: 1:15 VERT: 1:15

DESIGNED BY: KP, WM
DRAWN BY: KP
CHECKED BY: WM
DATE: APR 2018

FILE#: 610-027-10
DWG.# 610-027-10
SHEET 3 of 3
REVISION 0



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DATE	DRAWING ISSUE	APPROVED

NOTES: All units shown are in mm unless stated otherwise.

Concrete fc' = 25 MPa
Rebar Steel fy = 400 MPa

NO.	DATE	REVISION	BY	APPROVED

UBC CAMPUS AND COMMUNITY PLANNING
CHANCELLOR BOULEVARD REDESIGN

BACKFILL DETAIL

SCALE: HOR: 1:25 VERT: 1:25

DESIGNED BY: KP, WM
DRAWN BY: WM
CHECKED BY: KP
DATE: APR 2018

FILE#: 610-027-10
DWG.# 610-027-10
SHEET 4 of 4
REVISION 0

CONSULTING ENGINEERS

Appendix C. Detailed Cost Breakdown

Summary of Costs		
Construction Materials and Labour	$	2,460,235.19
Project Management	$	437,000.00
Engineering	$	464,585.28
Other	$	330,000.00
20% Contingency	$	738,364.09
10% Mobilization	$	322,723.52
Total Project Cost	**$**	**4,752,908.09**

Roads

Item	Notes	Quantity	Unit	Unit Cost	Total Cost
Road Paving					**$ 933,105.94**
Paver		11	Days	$ 3,000.00	$ 33,000.00
Dump Truck	For milled asphalt, 2 trucks	4	Days	$ 800.00	$ 3,200.00
Compactor	For asphalt, and compaction of base materials	21	Days	$ 500.00	$ 10,500.00
Asphalt Miller	For southernmost lane, both north lanes	16	Days	$ 2,500.00	$ 40,000.00
Curb machine	For all curbs, while paving	6	Days	$ 2,000.00	$ 12,000.00
Asphalt	New asphalt for median, assume 6 inch thickness, 5% waste	892.08	m^3	$ 157.01	$ 140,065.48
Asphalt	Asphalt for road resurfacing, 5% waste	1338.12	m^3	$ 157.01	$ 210,098.22
Concrete for curbs	slump < 20 mm	148.68	m^3	$ 200.00	$ 29,736.00
Sub Base	Assume 1 foot thickness, 5% waste	3568.32	m^3	$ 42.00	$ 149,869.44
Base	Assume 1 foot Thickness 5% waste	3746.74	m^3	$ 50.00	$ 187,336.80
Labourer	6 Labourers, 17 days	1020	Hours	$ 75.00	$ 76,500.00
Operators	2 Operators, 17 days	340	Hours	$ 120.00	$ 40,800.00
Median					**$ 71,194.50**
Excavator	For Demolition	10	Days	$ 1,200.00	$ 12,000.00
Concrete	For smaller road median, 5% waste	185.85	m^3	$ 170.00	$ 31,594.50
Forms		1	Each	$ 3,000.00	$ 3,000.00
Labourers	4 labourers, incl. labour foreman	200	Hours	$ 75.00	$ 15,000.00
Operators	One operator for excavator	80	Hours	$ 120.00	$ 9,600.00
Decomissioning of Southern Lane					**$ 23,000.00**
Excavator	CAT 320L Demolition, imported fill	5	Days	$ 1,200.00	$ 6,000.00
Dump Truck	For Greenway	10	Days	$ 800.00	$ 8,000.00
Demo equipment					$ 3,000.00
Operator		50	Days	$ 120.00	$ 6,000.00
Lights, Signage					**$ 222,782.99**
Pedestrian Groundlights	8 m spacing groundlights, incl. electrical to each light	221	Each	$ 850.00	$ 187,850.00
Electrician	2 electricians, install 8 per day	224	Hours	$ 130.00	$ 29,120.00
Road Paint	Incl. material, labour, installation	11614.17	ft	$ 0.07	$ 812.99
Signage	Stop signs, road signs, etc.	20	Each	$ 250.00	$ 5,000.00
				Total	**$ 1,250,083.43**

Underpass

Item	Notes	Quantity	Unit	Unit Cost	Total Cost
Dry well					**$ 104,320.00**
Concrete Dry Well	14 m dry well, custom made, concrete pipes 2 m diameter	14	Each	$ 2,200.00	$ 30,800.00
Drilling	Assume lump sum (incl. labour, equip)	66	Ft	$ 1,000.00	$ 66,000.00
Crane		2	Days	$ 1,600.00	$ 3,200.00
					$ -
Crane Operator		16	Hours	$ 120.00	$ 1,920.00
Labourer	2 labourers for rigging, placement	32		$ 75.00	$ 2,400.00

Precast Sections (manufacture)					**$ 62,230.00**
Concrete	Ocean 25 MPA exposure class F2 (assume 5% waste)	120	m^3	$ 194.00	$ 23,280.00
Rebar	assume $1/ft for all rebar sizes	13000	Ft	$ 1.00	$ 13,000.00
Formwork	Forms for precast section	3	each	$ 1,000.00	$ 3,000.00
Labourer	Rebar, concrete pour, 3 days	30	Hours	$ 75.00	$ 2,250.00
Apprentice Ironworker	Rebar, concrete pour, 3 days x 2 workers	60	Hours	$ 100.00	$ 6,000.00
Journeyman Ironworker	Rebar, concrete pour, 3 days x 2 workers	60	Hours	$ 130.00	$ 7,800.00
Journeyman Carpenter	Forms, pour	30	Hours	$ 130.00	$ 3,900.00
Apprentice Carpenter	Forms, Pour	30	Hours	$ 100.00	$ 3,000.00
Excavation & Soil Prep					**$ 27,450.00**
Track Hoe	Cat 320L Excavation, demolition	4	Days	$ 1,200.00	$ 4,800.00
Dump Truck	2 dump trucks for hauling earth fill	2	Days	$ 1,200.00	$ 2,400.00
Packer	3 packers	6	Days	$ 100.00	$ 600.00
Large Draining Aggregate	1-inch Minus	105	m^3	$ 50.00	$ 5,250.00
Structural backfill	Base/granular material, compacted	105	m^3	$ 50.00	$ 5,250.00
Operators	1 Operator	20	Hours	$ 120.00	$ 2,400.00
Labourers	3 Labourers for compaction	90	Hours	$ 75.00	$ 6,750.00
Precast Section Installation					**$ 16,850.00**
Crane	To lift sections	2	Days	$ 1,600.00	$ 3,200.00
Lights	2 per section	20	Each	$ 100.00	$ 2,000.00
Labourers	2 Labourers	20	Hours	$ 75.00	$ 1,500.00
Journeyman Ironworker	2 Journeymen, one acting as foreman	20	Hours	$ 130.00	$ 2,600.00
Apprentice Ironworker	1 Apprentice	20	Hours	$ 100.00	$ 2,000.00
Journeyman Pipelayer	Reroute watermain	5	Hours	$ 130.00	$ 650.00
Apprentice Pipelayer	2 Apprentices, reroute watermain	10	Hours	$ 100.00	$ 1,000.00
Journeyman Electricians	Install lights	30	Hours	$ 130.00	$ 3,900.00
Approaches					**$ 81,976.23**
Excavator		15	Days	$ 1,200.00	$ 18,000.00
Compactor		4	Days	$ 500.00	$ 2,000.00
Paver		2	Days	$ 3,000.00	$ 6,000.00
Asphalt	For approach ramps	28.35	m^3	$ 157.01	$ 4,451.23
Concrete	For stairs at approach	15	m^3	$ 175.00	$ 2,625.00
Operators	2 operators	200	Hours	$ 120.00	$ 24,000.00
Labourers	For paving, 6 labourers, 4 days	240	Hours	$ 75.00	$ 18,000.00
Journeyman Carpenter	Forms/pour for stairs (3 days)	30	Hours	$ 130.00	$ 3,900.00
Apprentice Carpenter	Forms/pour for stairs (3 days)	30	Hours	$ 100.00	$ 3,000.00
				Total	**$ 292,826.23**

Pedestrian and Bike Paths, Intersections					
Item	**Notes**	**Quantity**	**Unit**	**Unit Cost**	**Total Cost**
South Paths					**$ 453,870.78**
Paver		3	days	3000	$ 9,000.00
Excavator		5	days	1200	$ 6,000.00
Compactor		5	days	400	$ 2,000.00
Dump Trucks	2 dump trucks to import fill materials	7	Days	800	$ 5,600.00
Asphalt	Bike Path, pedestrian path, assume 5% waste	1327.5	m^3	$ 157.01	$ 208,430.78
Sub base	For sidewalks, 8 inch lifts	1770	m^3	$ 42.00	$ 74,340.00
Base	For Sidewalks, 8 inch lifts	1770	m^3	$ 50.00	$ 88,500.00
					$ -
Labourers	4 labourers, labour foreman	480	Hours	$ 75.00	$ 36,000.00
Operators		200	Hours	$ 120.00	$ 24,000.00
North Paths					**$ 105,136.00**
Compactor		5		$ 500.00	$ 2,500.00
Excavator		5		$ 1,200.00	$ 6,000.00
Sub base	Assume 8 Inch lift	708		$ 42.00	$ 29,736.00
Base	Assume 8 Inch lift	708		$ 50.00	$ 35,400.00
Labourers		100	Hours	$ 75.00	$ 7,500.00
Operators		200	Hours	$ 120.00	$ 24,000.00

Special Crosswalks					**$ 350,200.00**
Digger Truck	Multiple axel truck with crane/lift	2	Day	$ 1,500.00	$ 3,000.00
Lights	2 lights at each crossing	4	Each	$ 85,000.00	$ 340,000.00
Painting	Incl. Labour	2	Each	$ 1,000.00	$ 2,000.00
Journeyman Electrician	2 electricians	40	Hours	$ 130.00	$ 5,200.00
Protected - Tee Intersection					**$ 8,118.75**
Bollards	For intersection	20		$ 100.00	$ 2,000.00
Concrete	For protected T	5.25	m^3	$ 175.00	$ 918.75
Forms		1	Each	$ 1,000.00	$ 1,000.00
Labourer	2 labourers for pour	8	Hour	$ 75.00	$ 600.00
Journeyman Carpenter	2 journeymen for forms, pour	20	Hour	$ 130.00	$ 2,600.00
Apprentice Carpents	1 apprentice for forms, pour	10	Hour	$ 100.00	$ 1,000.00
				Total	**$ 917,325.53**

Project Management

Item	Notes	Quantity	Unit	Unit Cost	Base Estimate
Scheduling and Planning					$ 150,000.00
Construction Supervision	Safety, superintendents				$ 150,000.00
Contract Documents	Contract creation				$ 125,000.00
Tender Service	Assisting in contractor selection				$ 12,000.00
					$ 437,000.00

Engineering

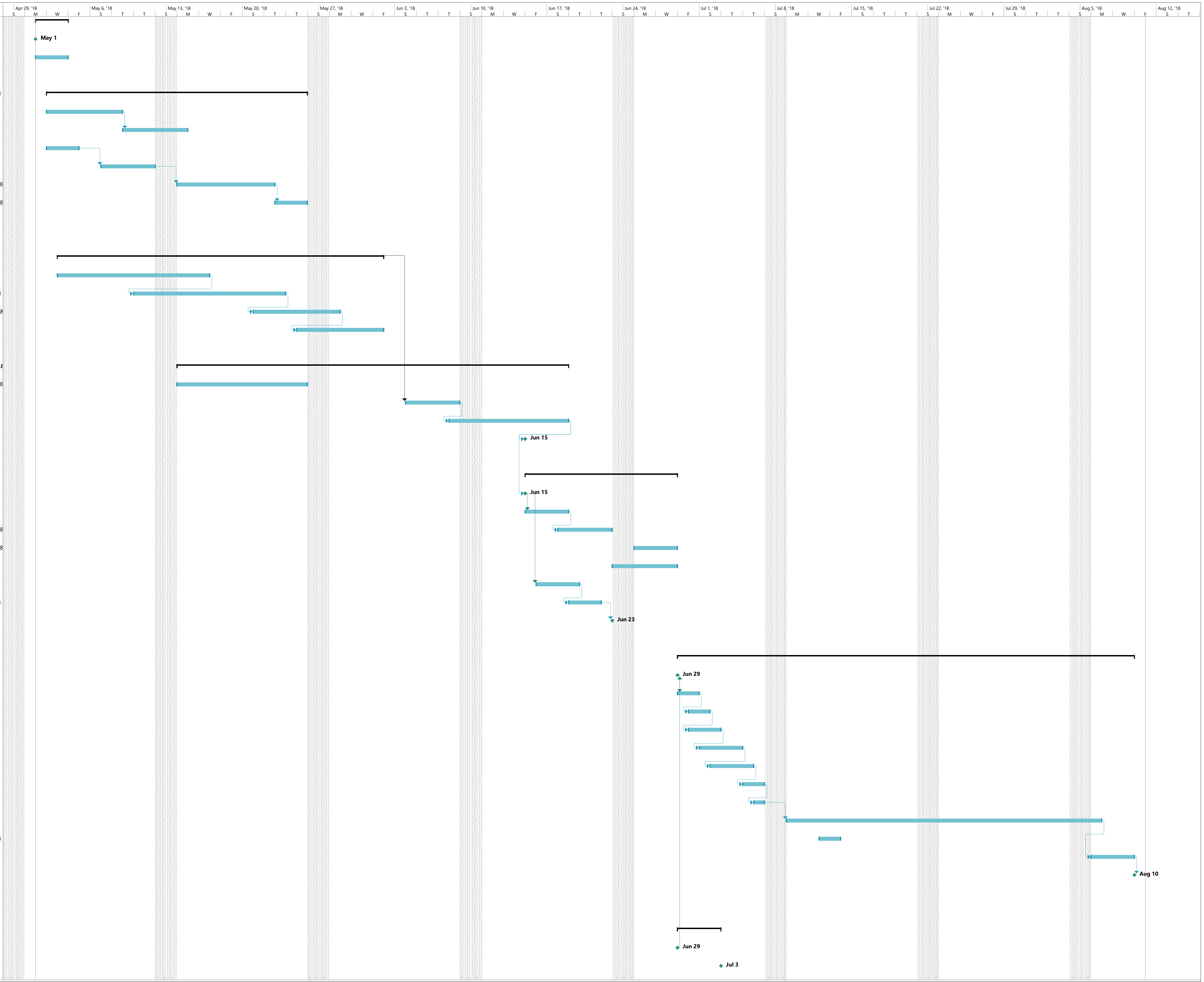
Item	Notes	Quantity	Unit	Unit Cost	Base Estimate
Concept Design	Road Design and cross sections		Lump Sum		$ 43,458.53
Preliminary Design	Road Design, Underpass design, intersection design		Lump Sum		$ 86,917.06
Detailed Design	Road design, Underpass design, intersection design, IFC Drawings		Lump Sum		$ 217,292.64
Construction Service	Inspections, answering RFI's, design changes, etc.		Lump Sum		$ 86,917.06
Quality Assurance		15	week	1000	$ 15,000.00
Permitting			Lump Sum		$ 15,000.00
				Total	**$ 464,585.28**

Other Costs

Item	Notes	Quantity	Unit	Unit Cost	Total Cost
Flaggers	Traffic Control				$ 60,000.00
Fencing				$ 20,000.00	$ 20,000.00
Landscaping	Lump sum for whole project	1	Lump Sum	$250,000.00	$ 250,000.00
					$ 330,000.00

Appendix D. Detailed Construction Schedule

ID	Task Mode	Task Name	Duration	Start
1		**Project initiation**	**3 days**	**Tue 5/1/18**
2		Close south lanes	0 days	Tue 5/1/18
3		Mobilization and site set up	3 days	Tue 5/1/18
4				
5		**Multi-use pathway construction**	**18 days**	**Wed 5/2/18**
6		Preparing existing multi-use pathway for pavi	5 days	Wed 5/2/18
7		Repaving existing multi-use pathway	4 days	Wed 5/9/18
8		Strip vegetation	3 days	Wed 5/2/18
9		Remove native soil and compact	5 days	Mon 5/7/18
10		Import fill and compact	7 days	Mon 5/14/18
11		Pave new pedestrian pathway	3 days	Wed 5/23/18
12				
13				
14		**Paving over the median**	**22 days**	**Thu 5/3/18**
15		Strip vegetation and native fill	10 days	Thu 5/3/18
16		Import fill and compact	10 days	Thu 5/10/18
17		Pave over the median	6 days	Mon 5/21/18
18		Repave second southernmost lane	6 days	Fri 5/25/18
19				
20		**South lanes reconfiguration**	**26 days**	**Mon 5/14/18**
21		Install street lighting	10 days	Mon 5/14/18
22		Decomission southernmost lane	5 days	Mon 6/4/18
23		Revegetate median between traffic and cyclis	7 days	Fri 6/8/18
24		Open 2 new South lanes to traffic	0 days	Fri 6/15/18
25				
26		**North Lanes Reconfiguration**	**10 days**	**Fri 6/15/18**
27		Close North lanes and trails	0 days	Fri 6/15/18
28		Mobilize to North side	2 days	Fri 6/15/18
29		Resurface left lane	5 days	Mon 6/18/18
30		Pour road median	4 days	Mon 6/25/18
31		Resurface Right Lane	5 days	Sat 6/23/18
32		Stripping native fill and compacting for the new multi-use pathway	3 days	Sat 6/16/18
33		Bring in imported fill and compact for the new multi-use pathway	3 days	Tue 6/19/18
34		Open North lanes to traffic	0 days	Sat 6/23/18
35				
36		**Underpass construction**	**30 days**	**Fri 6/29/18**
37		Close intersection to all traffic	0 days	Fri 6/29/18
38		Strip surfacing from above the new underpas	2 days	Fri 6/29/18
39		Excavate at the new underpass location	2 days	Sat 6/30/18
40		Place precast underpass sections	3 days	Sat 6/30/18
41		Connect underpass sections together	4 days	Sun 7/1/18
42		Backfill	4 days	Mon 7/2/18
43		Repave the intersection	2 days	Thu 7/5/18
44		Reopen intersection to traffic	1 day	Fri 7/6/18
45		Finish underpass approaches and lighting	21 days	Mon 7/9/18
46		Drilling for Dry Well	2 days	Thu 7/12/18
47		Demobilization, site cleanup	4 days	Mon 8/6/18
48		Project complete	0 days	Fri 8/10/18
49				
50				
51		**Community milestones**	**2 days**	**Fri 6/29/18**
52		University Hill elementary closed for the summer	0 days	Fri 6/29/18
53		First day of term 2 of summer semester	0 days	Tue 7/3/18

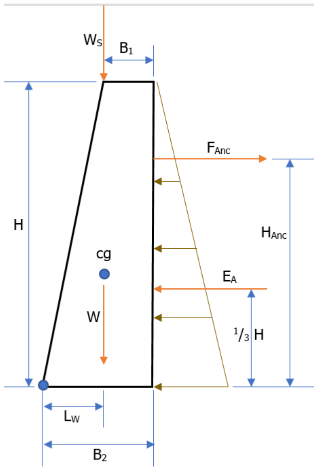


Chancellor Boulevard Redesig
Preliminary Project Schedule

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

Appendix E. Underpass Structural Design Calculations

02 Retaining Wall Analysis



2.5 m Precast Retaining Wall Panels		
Input Values		
Ws	54.914 kN	Ws = half of the weight of the top slab section
W	2.5 m	W = width of wall section
H	3.5 m	H = underpass clearance
B1	0.1 m	
B2	0.3 m	
Soil Unit Weight	18 kN/m3	
Concrete Unit Weight	23.5 kN/m3	
Soil Internal Friction Angle	30 degrees	
HAnc	3.5 m	
Factor of Safety	1.5	
Concrete-Concrete Fric. Factor	0.3	

Output Values	
KA	0.333
Pmaxsoil	21.0 kN/m2
EA	91.9 kN
W	57.575 kN
LW	0.110 m
Fanc or Top Slab Bracing	102.5 kN
Moment reaction @ Base	358.73 kN*m
Friction Force - Top	9.8845 kN
Friction Force - Bottom	84.366 kN/m
Additional Lateral Stabilization	0 kN/m

DIMENSIONS		
Width	2.5	m
Height	3.5	m
Thickness_min	0.1	m
ln	3.5	m
b	2.500	m
h	0.2	m
d'	0.16	m
dc'	0.04	m
f'c	25	MPa
fy	400	MPa
Phi,c	0.65	
Phi,s	0.85	
Lambda	1	
Alpha1	0.8	
Beta1	0.9	
Gamma,c	23.5	kN/m^3
cover	40	mm
stirrup	10	mm
amax	20	mm
Epsilon,c	0.0035	

MOMENT DESIGN			
DL_max	52.50	kN/m	triangularly distributed
Mf	41.26	kN*m	
As	764.01	mm^2	--> use 16 - 10 M with 1600 mm^2
Rho	0.0048		Good
Rho,b	0.0227		
dc	55	mm	
d	145	mm	
s	149.3333333	mm	Good
Asmin	1250	mm^2	Good
a	16.7	mm	Good
Mr	74.3	kN*m	Good
z	23554.3	N/mm	Good
Epsilon,s	0.02379		Good

SHRINKAGE & TEMP REINFORCEMENT			
A_s,min	1000	mm^2	
s_max	500	mm	
s_req	100	mm	
A_s	1000.0	mm^2	--> use 10 - 10 M with 1000 mm^2
s	218.2	mm	

To summarize:

Supports equations: $A_y = \frac{wL}{6}$ $B_y = \frac{wL}{3}$

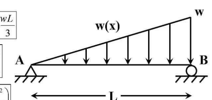
Shear force equation: $V_x = \frac{wL}{2}\left(\frac{1}{3} - \frac{x^2}{L^2}\right)$

Bending moment equation $M_x = \frac{wLx}{6}\left(1 - \frac{x^2}{L^2}\right)$

Maximum shear force at right support $V_{max} = \frac{wL}{3}$

Minimum shear force at $x = \frac{L}{\sqrt{3}}$

Maximum bending moment at zero shear location $x = \frac{L}{\sqrt{3}}$ and equal to $M_{max} = \frac{wL^2}{9\sqrt{3}}$



CSA 14.2

14.2 Structural design of bearing walls

14.2.1

Except as permitted by Clause 14.2.2, bearing walls shall be designed as specified in Clauses 7, 10, and 11.

14.2.2

14.2.2.1

Subject to the requirements specified in Clause 14.2.2.2, bearing walls may be designed using the following equation:

$$P_r = \frac{2}{3} \propto_1 \varphi_c f_c' A_g \left(1 - \left(\frac{kb}{32t}\right)^2\right)$$ **Equation 14.1**

14.2.2.2

Clause 14.2.2.1 shall apply only if the following requirements are met:

a) the wall has a solid rectangular cross-section that is constant over the height of the wall;
b) the principal moments act about a horizontal axis parallel to the plane of the wall;
c) the resultant of all factored axial loads, including the effects of the principal moment, is located within the middle third of the overall wall thickness; and
d) the wall is supported against lateral displacement along at least the top and bottom edges.

14.2.2.3

The effective length factor, *k*, in Equation 14.1 shall have the following values:

For walls restrained against rotation at one or both ends (top, bottom, or both)	0.8
For walls unrestrained against rotation at both ends	1.0

14.2.3

If present, the calculation of the factored resistance of bearing walls shall account for significant strong axis bending moments in accordance with Clause 10.

Note: *Strong axis bending moments may be applied to bearing walls due to the resultant of the axial load not being at the centroid of the section due to in-plane offset of the wall or may be induced by deformation of the lateral force resisting system subjected to the factored lateral loads such as wind and seismic loads.*

∝_1	0.8	
phi_c	0.65	
fc'	25 MPa	
Ag	0.25 m^2	
k	0.8	
b	2.5 m	
t	0.1 m	
Pr =	1320.31 kN	
Prmax =	3453.125 kN	<- *CSA 23.3-14 Cl. 10.8.1*

01 Load Calculations

PERMANENT LOADS

D	100mm of asphalt overlay	0.2243	kN/m2
Load Factor:	150mm of capping material	2.7	kN/m2
1.25	slab self-weight	23.97	kN/m2
	Total Factored Dead Load =	**33.62**	**kN/m**

L	vehicles (max defl.)	88.99632	kN @ midspan
Load Factor:			
1.5			
	Total Factored Live Load =	**133.49448**	**kN @ midspan**

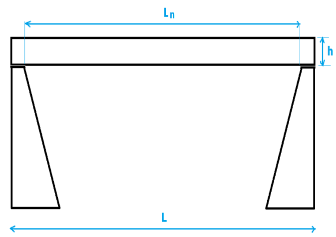
Compression axial caused by retaining wall = 102.5 kN

03 Top Slab Analysis

Slab Dimensions

Total Length (mm) L	Unsupported Length (mm) Ln	Depth (mm) h	Unit Thickness (mm) b	Length of Underpass (North-South) m
5000	4800	900	2500	25

Total Self Weight (kN)
264.375



Design of Slab

Thermal Expansion /deg C	Poisson Ratio	Modulus of Elas.(MPa)
0.0000131	0.3	35000

Load Combinations

Dead Loads	Road Pavement		Temporary Loads	Live Truck Load, AL
(kN/m)	Top Soil Cover			Construction Load, Ac
	Self-Weight	52.875		

DIMENSIONS		
Width	5	**m**
Length	2.5	**m**
Height	0.3	**m**
ln	4.8	**m**
lw	1.9	**m**
bL	0.400	**m**
bw	0.3	**m**
bf	0.700	**m**
hf	0.12	**m**
h	0.3	**m**
d'	0.23	**m**
dc'	0.07	**m**
f'c	25	**MPa**
fy	400	**MPa**
Phi,c	0.65	
Phi,s	0.85	
Lambda	1	
Alpha1	0.8	
Beta1	0.9	
Gamma,c	23.5	**kN/m^3**
cover	40	**mm**
stirrup	16	**mm**
amax	20	**mm**
Epsilon,c	0.0035	

MOMENT DESIGN			
DL	19.30	**kN/m**	distributed
LL	13.35	**kN**	at center
Mf	93.67	**kN*m**	
As	1320.38	**mm^2**	--> use 3 - 25 M with 1500 mm^2
Rho	0.0082		Good
Rho,b	0.0227		
dc	68.5	**mm**	
d	231.5	**mm**	
s	56.5	**mm**	Good
Asmin	300	**mm^2**	Good
a	56.0	**mm**	Good
Mr	103.8	**kN*m**	Good
z	23497.1	**N/mm**	Good
Epsilon,s	0.00951		Good

SHEAR DESIGN		
Vf	27.4570495	**kN**
Vc	36.565425	**kN**
Vs,min	-9.1083755	**kN**
Av	402.1	**mm^2**
dv	208.4	**mm**
theta	35	**degrees**
s,max	-4466.471383	**mm**
Beta	0.18	
s,min	1787.217154	**mm**

Mass of one top slab 88.125 kN

DIMENSIONS		
Width	1	**m**
Length	1.9	**m**
Height	0.12	**m**
ln	1.9	**m**
b	1.000	**m**
h	0.12	**m**
d'	0.06	**m**
dc'	0.06	**m**
f'c	25	**MPa**
fy	400	**MPa**
Phi,c	0.65	
Phi,s	0.85	
Lambda	1	
Alpha1	0.8	
Beta1	0.9	
Gamma,c	23.5	**kN/m^3**
cover	44	**mm**
stirrup	10	**mm**
amax	20	**mm**
Epsilon,c	0.0035	

MOMENT DESIGN			
DL	6.45	**kN/m**	distributed
LL	11.12	**kN**	at center
Mf	13.48	**kN*m**	
As	785.91	**mm^2**	--> use 10 - 10 M with 1000 mm^2
Rho	0.0131		Good
Rho,b	0.0227		
dc	59	**mm**	
d	61	**mm**	
s	88	**mm**	Good
Asmin	300	**mm^2**	Good
a	26.2	**mm**	Good
Mr	16.3	**kN*m**	Good
z	21271.1	**N/mm**	Good
Epsilon,s	0.00385		Good

SHEAR DESIGN		
Vf	11.689105	**kN**
Vc	32.1165	**kN**
Vs,min	-20.427395	**kN**
Av	157.1	**mm^2**
dv	54.9	**mm**
theta	35	**degrees**
s,max	-204.9893837	**mm**
Beta	0.18	
s,min	209.4395102	**mm**

Temp Reinforcement for Slab

s_max	500	mm
Ag	228000	mm^2
As_mi	456	mm^2
s_req ·	1096	mm
Select	700	mm
Select	600	mm^2
Check	YAY	

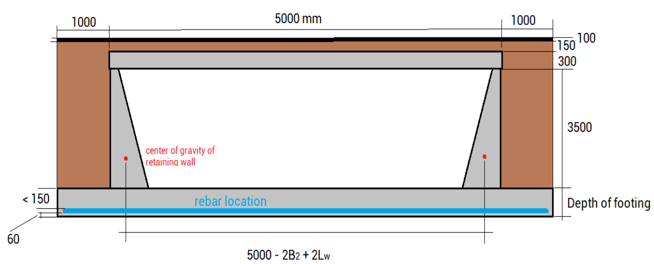
04 Foundation

Cantilevered length of footing	**1.0**	**m**	
Soil weight	9.9	kN/m	
Wt	313.1	kN	*Wt = 1.25 ((2 x retaining wall) + (top slab) + (topping soil)) + (asphalt) + 1.5 LL*
M	358.7	kN.m	
Soil reaction	47.6	kN/m	
Mfmax	**353.8**	**kN.m**	**(tensile on bottom)**
Vfmax	**166.4**	**kN**	
Nfmax	**91.9**	**kN**	**(compressive)**
Depth of footing above bottom-most reinf	160	mm	*<-- CSA A23.3-14 Cl. 15.7*
Longitudinal Reinf, db	20	mm	
Bottom Cover	60	mm	
Total Footing Thickness	**240**	**mm**	

Design Footing Slab for Flexure

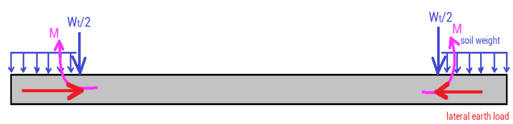
Effective depth, d	170	mm	
As required	8034	mm^2	
Select 30x20M: then, As is:	9000	mm^2	
ρ_b	0.0220		*<-- Table A.4 Balanced Reinf Ratio for f'c=25 MPa, with grade 400 steel*
ρ	0.0212		
Confirm ρ <= ρ_b	YAY		
Confirm As > Asmi = 0.002 Ag	YAY		
s_max	500	mm	
Select spacing, s	**60**	**mm**	
a	94.2	mm	
Mr	376.1	kN.m	
Check that Mr > Mf	YAY		

$$A_{s\,req} = 0.0015 f_c' b \left(d - \sqrt{d^2 - \frac{3.85 \times M_r \times 10^6}{f_c'\, b}}\right)$$



Crack Control Parameters

d_s = d_c	70	mm
b	80	mm
A	11200	mm^2
z	22130.09	
For exterior exposure, need z <= 25000	YAY	



Design for shrinkage/temp

s_max	500	mm
Ag	1680000	mm^2
As_min	3360	mm^2
s_req <=	625	mm
Select spacing, s	600	mm
As	3500	mm^2
Check As > As_min	YAY	
Use 12X20M: As_actual =	3600	mm^2

DESIGN SUMMARY	
Main Tensile Reinforcement:	**30x20M @ 60mm**
Temperature Reinformcement:	**12x20M @ 600mm**

Shear Check

Effective shear depth, dv	172.8	mm	
Max aggregate size	20.0	mm	<-- Assumption
s_ze	172.8	mm	
β	0.2		
Concrete shear resis Vc	275.3	kN	<-- This is our shear resistance Vr
Max allowable Vr	1755.0	kN	
Confirm Vr < Vr_max	YAY		
Confirm Vr > Vf	YAY		

05 Soil Bearing Capacity Calc

$$q_{ult} = \sigma'_D N_q + 0.3\gamma B N_\gamma$$

where:

q_{ult}	- Ultimate bearing capacity
σ'_D	- Vertical effective stress foundation base level
γ	- Total unit weight of soil (below footing underside level)
γ_w	- Unit weight of water
D	- Depth of footing below ground surface
B	- Width/diameter of footing

Nq, Nγ - Bearing capacity factors = f (ϕ') – see Table

sigma'_D	71.1	**kPa**
gamma (soil)	18	**kN/m^3**
D	4.19	**m**
B	2.5	**m**
N_q	22.5	
N_gamma	19.7	
q_ult	1865.7	**kPa**
q_a	5675.78	**kPa**
Safety Factor, F	0.32871	

ϕ	*General shear failure*			*Local shear failure*		
	N_c	N_q	N_γ	N_c'	N_q'	N_γ'
0	5.7	1.0	0.0	5.7	1.0	0.0
5	7.3	1.6	0.5	6.7	1.4	0.2
10	9.6	2.7	1.2	8.0	1.9	0.5
15	12.9	4.4	2.5	9.7	2.7	0.9
20	17.7	7.4	5.0	11.8	3.9	1.7
25	25.1	12.7	9.7	14.8	5.6	3.2
30	37.2	22.5	19.7	19.0	8.3	5.7
34	52.6	36.5	35.0	23.7	11.7	9.0
35	57.8	41.4	42.4	25.2	12.6	10.1
40	95.7	81.3	100.4	34.9	20.5	18.8
45	172.3	173.3	297.5	51.2	35.1	37.7
48	258.3	287.9	780.1	66.8	50.5	60.4
50	347.5	415.1	1153.2	81.3	65.6	87.1

CONSULTING ENGINEERS

Appendix F. Project Risk Assessment

		Risk	Probability	Impact	Severity (1 - 10)	Comments on Weighting	Mitigation Approach
Triple Bottom Line Considerations	Environmental	Animals may be disturbed by lights when they want to cross	Moderately Likely	Negligible	4	Animals in Pacific Spirit Park, such as raccoons, coyotes, and squirrels are familiar with urban lving and effect on animals will not be major	Investigate less impactful lighting options, or consider lower lighting or only using the lights during peak traffic hours
		Impact of construction	Likely	Medium	7	Construction activities may create waste and runoff into surrounding environment. May also have negative impact on noise.	Ensure all construction activities are well managed and all impacts on waste and noise are mitigated through proper planning and construction management.
		Impact of design	Likely	Medium	7		Complete a comprehensive survey of what wildlife is present in which areas of the project route, integrate this knowledge into producing the detailed design
		Natural disaster causing damage to structures (ie. roadway surface, underpass, etc.)	Moderately Likely	Major	8	This is in an earthquake zone, therefore risk is high, also potential for flash flooding	Make sure project design features reliable seismic considerations
		Future hydrological conditions are worse than expected due to climate change, and the new drainage systems are overwhelmed	Moderately Likely	High	7		
	Social	Backlash from first nations opposing new construction on unceded territory	Likely	High	8	new construction requiring possible further use of land and will likely not be recieved well and may lead to isses	Include consultation with musqueam first nations to ensure all need are met and concerns are addressed
		Final Design not accepted by the public	Less Likely	Medium	5	Public users may not apporve of the final design, or may have complaints	Conduct public engagement to hear concerns early on in the project when changes can still be made
		Disruption to public (residential, commuter)	Very Likely	High	9	Project construction will be loud and disrupt the local residential area. Also, there will be some road closures which will affect the commuters using the road.	Consult local stakeholder through a community engagement plan to ensure that the public is well informed about the projet and have an opportunity to provide their input
		Public harrassment of workers on the project	Less Likely	Low	4	Roadway infrastructure projects often cause delays which likely may cause user dissatisfacion and anger	
	Economic	Cost over runs for major project	Moderately Likely	High	7	Large project with lots of variables can lead to cost overruns	Have a large contingency, and place emphasis on effective planning
		Economic downturn cutting funding to the project	Less likely	Medium	5		
			Less Likely	High	6		
	Political	Change of government leading to funding cuts	Unlikely	Medium	4		Ensure all government parties' concerns are heard and addressed early on in the project
		Government stopping project due to public pressure	Unlikely	High	5	Major impact because project will be cancelled completely	Complete public engagement to ensure public is informed and concerns are heard.
		Disagreements between jurisdictions	Unlikely	Medium	4	Since there are many jurisdiction that have key interest in this corridor, namely the University and the City of Vancouver	Encourage and plan meetings and communication between all key stakeholders
		Government opposition	Unlikely	Medium	4	Project may not be in line with current government's platform	Ensure government concerns are heard and addressed early on in the project
	Reputational	People may not want more investment into bike lanes	Moderately Likely	Negligible	4		
		Involved companies have a poor reputation to the public	Unlikely	Low	3	Public may not trust companies and contractors involved in the project	Have an environmental management plan in place that is strictly adhere to in order to provide assurance that environmental considerations are being taken seriously and are incorporated into the project
	Technical	Failed equipment leading to innadequate operation	Unlikely	Medium	4		
		Innadequate workmanship by construction crews	Unlikely	High	5		Invest more time and money into engineering QA
		Human error leading to delays and increased cost	Likely	Medium	7		Invest time and money in training
	Procedural	Work stoppages due to weather (snow, rain)	Less Likely	Medium	5	Snow and rain can affect the paving schedule	Work in the summer
		Work stoppages for unexpected geological conditions	Moderately Likely	Low	5		
		Human error leading to failure or delay	Less Likely	Low	4		
		Loss of productivity or crew shortages	Unlikely	Low	3		
	Project Management	Cost overruns	Likely	Low	6		Include contingency in the cost estimate
		Schedule Overruns	Moderately Likely	High	7		Include float in the project schedule.