University of British Columbia

Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Wesbrook Mall Redesign – Phase 4

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Executive Summary

Team 10 has been contacted by the UBC SEEDS (Social Ecological Economic Development Studies) Sustainability Program to develop a design for Phase 4 of the Wesbrook Mall Redesign project. The Phase 4 design must address the failing road structure and improve the transportation experience between Thunderbird Boulevard and W 16th Avenue. The following report summarizes Team 10's detailed design.

Team 10's detailed design is estimated to cost $7.52 Million CAD and will take seven months to complete from project start. Key features of the design consist of rebuilding the roadway, introducing protected unidirectional cycle lanes on both sides of the road, adding a dedicated northbound bus lane, and constructing a protected pedestrian overpass. The asphalt roadway will be replaced by completing a full road rebuild that will provide a strong base and subbase underlying the freshly paved road surface. To tie in with the existing infrastructure, unidirectional cycle tracks will be installed on either side of the roadway. These cycle tracks will be raised above the roadway, and placed between the on-street parking lanes and the sidewalk for additional protection from road users. The dedicated northbound bus lane will begin on the north end of the pedestrian overpass, located over the crosswalk between Gerald McGavin Rugby Centre and Panhellenic House, and tie in with the bus lane at Thunderbird Boulevard. Additionally, the bus pullout bay adjacent to the Doug Mitchell Thunderbird Sports Centre will be removed and filled in with new green infrastructure, creating an in lane bus stop and reducing impermeable surface area. The pedestrian overpass is a steel girder bridge with a timber and glass roof structure that preserves the natural campus aesthetic while providing a safe means of crossing the Wesbrook corridor.

Team 10 is confident in this design and is excited to collaborate with the UBC SEEDS Sustainability Program to ensure the optimal solution for this vital UBC corridor is delivered.

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1.0 Project Background

The Wesbrook Mall corridor is a quintessential component of the University of British Columbia (UBC) roadway system, providing safe and reliable access for students, faculty, and staff to commute to the UBC campus. The Wesbrook Mall Redesign project has been ongoing over recent years to address a failing road structure and evolving transportation patterns and demands. The Wesbrook Mall Redesign project is split into four primary phases. Phase 1 and 2, which have previously been completed, focused on improving the transportation experience between Student Union Boulevard and Thunderbird Boulevard. Phase 3, which is planned to start in spring of 2022, intends to revise the north end of Wesbrook Mall from Student Union Boulevard to Chancellor Boulevard. The detailed design of Phase 4 has been completed and addresses the congestion and failing road structure between Thunderbird Boulevard and W 16th Avenue. In addition, the Phase 4 design alleviates issues related to cyclist and pedestrian safety while improving traffic flow along the corridor. Team 10 is excited to collaborate with the UBC SEEDS Sustainability Program to further discuss this design and ensure the optimal solution for this vital UBC corridor is delivered.

1.1 Site Overview

Team 10 completed a site visit and identified the following site specific issues and constraints. The maximum available width or right of way (ROW) is approximately 35m. There are currently three bus stops along the Wesbrook Mall corridor within the Phase 4 design area. There are two southbound bus stops located at Doug Mitchell Thunderbird Sports Centre and at Hampton Place. The one northbound bus stop is located at 2900 Block. The west sidewalk and a portion of the east sidewalk are damaged due to nearby tree root growth and there are four distinct rows of trees along the Wesbrook Mall corridor. The proposed location of the protected pedestrian crossing is above the existing crosswalk between the Gerald McGavin Rugby Centre and Panhellenic House, which has minimal space and must be designed accordingly. The bus stop at the Doug Mitchell Thunderbird Sports Centre, poor sidewalk conditions, and existing crosswalk at the proposed protected pedestrian crossing location are shown in Figure 2 on page 6.

A BIM Revit model of the site was created to depict the existing conditions and be used as a base to showcase the redesigned roadway and pedestrian overpass. The model was based off of the provided Autocad file and is shown in Figure 1.

Figure 1: Model of existing site conditions

Figure 2: Annotated map of site location

1.2 Project Objectives

The overall objective of the design is to deliver the optimal solution for the Wesbrook Mall Phase 4 Redesign. A breakdown of the design objectives is provided in the following list.

- Tie in with Phase 2 at Thunderbird Boulevard and the roundabout at W 16th Avenue;
- Improve the safety and transportation experience for buses, cyclists, and pedestrians;
- Design a pedestrian overpass above the Wesbrook Mall crosswalk between the Gerald McGavin Rugby Centre and the Panhellenic House;
- Incorporate protected cycle tracks and dedicated bus lanes;
- Ensure the design is cost effective and time efficient;
- Include green infrastructure to maximize rainwater retention capacity;
- Minimize removal of trees and on-street parking.

Team 10 consistently referenced the design criteria in Table 1 to ensure that the design met the project constraints. Non-negotiable criteria were met using regulatory codes and standards while negotiable criteria satisfaction was gauged through stakeholder consultation.

Table 1: Project design criteria

Non-Negotiable Criteria	Negotiable Criteria
Tie in with existing infrastructure	Cost
Safety of users	Schedule
Rainwater retention capacity	Pedestrian overpass design
Geometric constraints	Tree and on-street parking removal
Construction start date	Design aesthetics
Regulatory constraints	Infrastructure upgrades

An upcoming project that impacts the above design considerations is the extension of the Broadway Subway to UBC. This extension will have significant impacts on traffic volumes, as the use of certain transportation modes will either increase or decrease with the addition of a direct subway line to campus. Team 10 considered this extension in our analyses, as the lifespan of the Phase 4 design extends to the year 2050 and the subway line is planned to be in place by the year 2030.

Table 2 summarizes each team member's contributions relevant to the development of this report.

Table 2: Team member contributions

Team Member	Contributions
Member 1	- Executive Summary - 4.1 Roadway - 6.0 Cost Estimate
Member 2	- 3.0 Project Criteria - 5.0 Schedule - 6.0 Cost Estimate
Member 3	- 1.1 Site Overview - 4.1.2 Software (Synchro analysis) - Roadway drawings
Member 4	- 3.0 Project Criteria - 5.0 Schedule - 6.0 Cost Estimate - Asphalt pavement section of the general notes and specifications page in drawing set
Member 5	- 1.0 Introduction - 2.0 Design Overview - 4.2 Pedestrian Overpass - 7.0 Conclusion - 8.0 References - Reviewed, edited, and formatted report - Detailed design of overpass - General notes and specifications page in drawing set
Member 6	- 4.2 Pedestrian Overpass - Detailed design of overpass - Overpass drawings - General notes and specifications page in drawing set - BIM Revit model

2.0 Design Overview

An overview of Team 10's final detailed design is provided below.

Summary of roadway features:

- Removal and replacement of failing road structure by completing a full road rebuild;
- Removal of east side on street parking from the north end of the crosswalk between the Gerald McGavin Rugby Centre and Panhellenic House to Thunderbird Boulevard to accommodate a dedicated northbound bus lane starting on the north side of the pedestrian overpass, located over the crosswalk mentioned above;
- Protected unidirectional, elevated cycle tracks on both sides of the roadway;
- Removal of damaged sidewalk sections and replacement with concrete panels utilizing crack prevention construction techniques;
- Removal of bus pullout bay outside the Doug Mitchell Thunderbird Sports Centre and replacement with green infrastructure, creating an in lane bus stop and reducing impermeable surface area;
- Additional vegetation planted along the median and buffers between the parking and cycle lanes to increase rainwater retention.

Summary of pedestrian overpass features:

- Steel girder bridge with timber beams and glass roof structure that is stairway accessible;
- Stairways with bicycle access ramps located at the Gerald McGavin Rugby Centre and Panhellenic House;
- Curved glulam beams supporting the glass roof structure are aesthetic architectural features;
- Indigenous art incorporated in the stairways and crosswalk below the overpass;
- Five tree removals to accommodate structural components.

This design achieves the project objective of addressing the failing road structure and improving the transportation experience along Wesbrook Mall. A full road rebuild addresses the failing road structure by providing a strong base for the paved surface. Introducing protected unidirectional cycle tracks, replacing damaged sidewalk sections, providing a dedicated northbound bus lane, and constructing a pedestrian overpass improves the transportation experience.

There are two key updates from the preliminary design to the detailed design. After receiving client feedback, the road replacement technique has changed from mill and fill to a full road rebuild. Additionally, due to right of way constraints, the start of the northbound bus lane has been moved from 2900 Block to the north side of the pedestrian overpass.

3.0 Project Criteria

Team 10 used the criteria and policies listed in the following sections to ensure that non-negotiable constraints were met. Additionally, the criteria aided in prioritizing negotiable constraints requested by stakeholders.

3.1 Technical Issues

Upon reviewing the project criteria and requirements provided by the UBC SEEDS Sustainability Program, Team 10 identified the following areas where technical issues may arise:

- Determining future traffic demands due to potential growth in the campus and/or in surrounding areas (if applicable);
- Determining if traffic capacity meets the demand along Wesbrook Mall and at intersections of Thunderbird Boulevard and W 16th Avenue;
- Determining changes in intersection lane configurations to address future traffic volumes and if these changes can be accomodated;

- Incorporating a cost effective and conflict free protected pedestrian overpass design for vulnerable road users;
- Maintaining the local environment and the natural UBC campus aesthetic;
- Incorporating green infrastructure to maximize rainwater retention;
- Tying in to the existing infrastructure at Thunderbird Boulevard and W 16th Avenue;
- Maximizing parking retention and minimizing tree removal.

3.2 Economic Impact

Project costs have been minimized where applicable through achieving both negotiable and non-negotiable constraints in a cost effective manner. This has been achieved through:

- A well defined scope that minimizes changes to the project budget;
- Contingency plans for delays in project development;
- A required record of predicted versus actual spending to control project costs;
- Strong understanding of non-negotiable criteria to minimize delays and added expenses;
- Development of risk assessments to prepare for additional costs that may occur.

3.3 Societal Impact

It is a priority to minimize any social implications that project construction may have on students and faculty. Additionally, Team 10's design strives to maximize the positive societal impacts of the completed project. These societal goals will be achieved during construction through:

- Undergoing construction in phases that minimize road closure and impedance on vehicles, cyclists, and pedestrians;
- Conducting disruptive tasks during non-peak university hours;
- Providing ample notice before required road closures.

These societal goals will be achieved post construction through:

- Prioritizing a safe and accessible roadway that ties into the existing infrastructure at Thunderbird Boulevard and W 16th Avenue;
- Creating a roadway and overpass that are resilient to harsh weather conditions and capable of accommodating heavy use during peak hours;
- The inclusion of Indiginous artwork on the overpass and crosswalks.

3.4 Environmental Impact

Environmental stewardship is crucial to the successful completion of a project and Team 10 is committed to minimizing the environmental impacts associated with this project through:

- Incorporating green infrastructure to maximize on site rainwater retention;
- Minimizing tree removal and adding additional vegetation (green infrastructure);
- Incorporating environmentally friendly construction practices such as minimizing tree and green infrastructure removal and if tree removal is necessary then attempting tree relocation;
- Creating dedicated cycle and bus lanes to encourage sustainable modes of transportation.

3.5 Stakeholder Consultation and Community Engagement

Prior to construction, Team 10 will utilize the various consultation formats outlined in Table 3 to acquire feedback that will be utilized to optimize the design.

Table 3: Stakeholder consultation and community engagement plan

Consultation Format	Relevant Stakeholder(s)	Feedback Usage	Outcome Communication Method(s)
Client website	Users of Wesbrook Mall, Residents, First Nations Groups	Compile the feedback from the website and attempt to address any major concerns.	Make updates to the project information on the website.
Public displays (i.e. electronic boards)	Users of Wesbrook Mall, Residents	If there is feedback, it can be used to minimize disruption to the users and residents.	The outcomes can be relayed via updating and adding/moving the public displays.
Online and other surveys	Users of Wesbrook Mall, Residents, First Nations Groups	The results of the surveys will be compiled to analyze the concerns of the stakeholders and potentially apply them to the design.	The outcomes can be communicated by sending newsletters or emails to the survey participants.
Public meetings	UBC, Translink, Users of Wesbrook Mall, Residents, First Nations Groups	Relay the results of the meeting to the client to determine if any project changes are necessary based on stakeholder concerns.	The outcomes can be communicated through another set of public meetings to effectively address any comments.
Charrette	UBC, Translink	Make necessary amendments to the design based on the received feedback in order to receive approvals.	The outcomes can be communicated through online/in person meetings and presentations.
Focus groups	UBC, Translink, First Nations Groups	Update the project to address the concerns brought up in the focus groups to ensure the stakeholders are satisfied with the design.	Re-meet with the focus groups to go through updated design and incorporate additional changes if needed.
Advertisements, flyers, posters, letters	Users of Wesbrook Mall, Residents	If concerns are brought up, address them to minimize disruption to the local residents.	Send new advertisements, flyers, posters, or letters with updated project information.

3.6 Construction Planning

The construction planning and execution for this project will align with the following steps:

- Create the project via a Project Initiation Document (PID) that generally describes:
    - Man-power: Number of workers needed (contractors and/or subcontractors);
    - Resources: Outlining the necessary materials for the design and building plans;
    - Budget: Budget accordingly to the cost estimate for the project.
- Come up with an initial plan using the S.M.A.R.T technique to set clear goals:
    - Specific: Outline specific goals, milestones, and deadlines;
    - Measurable: Collaborate with the team on how specific goals will be measured;
    - Attainable: Ensure and outline how the team will achieve stated goals;
    - Realistic: Create realistic goals and deadlines;
    - Timely: Create a realistic and attainable schedule with room for potential delays.
- Begin executing the plan:
    - Go over the construction plan as a group to ensure that each member knows their expectations and to raise any concerns. This often provides insightful discussions and effective problem solving.
- Track Progress:
    - Gather information on key performance indicators (KPI's) such as:
        - Project objectives - are the outlined goals, budget, etc. still on track?
            - i.e. Monthly budget reports.
        - Quality - Is the quality of work being completed up to standards?
            - i.e. Field Review Reports written and signed by a professional engineer, Quality Control, etc.

3.7 Regulatory Policies

Regulatory policies will ensure the project stays on schedule by providing a framework for management and acquiring permits. Additionally, these policies have assisted with design decisions, such as lane widths and road markings. The regulatory policies consist of those outlined in:

- The 2014 UBC Transportation Plan;
- MOTI's manual of "Standard Traffic Signs & Pavement Markings";
- B.C. Governments "Bridge Standards & Procedures Manual";
- 2021 AASHTO Materials Standards;
- AASHTO's Roadside Design Guide;
- UBC SEED's Sustainability Plans.

4.0 Detailed Design

The detailed design of the roadway and pedestrian overpass are described in the following sections.

4.1 Roadway

The roadway design is summarized in the detailed design drawings in Appendix A. The roadway design drawings detail the design of facilities and changes from existing conditions. A detailed description of each facility and design decision is provided below. The minimum and design widths for various lane types are shown in Table 4.

Table 4: Design lane widths

Lane Type	Minimum Width	Design Width
Travel Lane	3.0m	3.1m
Bus Lane	3.2m	3.3m (excluding gutter)
Cycle Track	1.5m	1.5m - 1.8m
Sidewalk	1.5m	1.8m

North and southbound unidirectional cycle tracks are included along the entire corridor. These facilities are raised 200mm from the road surface, with a 400mm at-grade green vegetation strip separating the cycle track from travel lanes. Where parking facilities exist, the cycle tracks will be placed between the sidewalk and parking lane with a raised median to prevent incidents of door openings on cyclists. Where cycle tracks encounter intersections or driveways, there will be letdowns marked with green paint to facilitate vehicle access. A key component of the cycle track is the interaction near bus stops. When reiterating the preliminary design, the cycle track and bus stop interaction was refined to create a more safe and consistent infrastructure system. As shown in Figure 3, the cycle track continues straight between the sidewalk and roadway, with an allowed area for pedestrians to cross and dismount from buses. In total, there will be 675m of unidirectional cycle track per side of the roadway. A model of the cycle track is shown in Figure 4.

Figure 3: Cycle track and bus stop interaction

Figure 4: Unidirectional cycle track

Through traffic modeling software, Team 10 determined the necessity of a dedicated northbound bus lane starting at the north end of the crosswalk between the Gerald McGavin Rugby Centre and Panhellenic House. This lane will begin just north of the pedestrian overpass, located over the crosswalk mentioned above, and continue until Thunderbird Boulevard, where it will tie into existing facilities. Additionally, the design includes the removal of the bus pullout bay outside Doug Mitchell Thunderbird Sports Centre, creating an in lane bus stop. This area will be replaced with green infrastructure, which will reduce impermeable surface area and create additional room for the sidewalk and cycle track.

Upon site inspection, Team 10 identified that 650m of sidewalk is damaged and needs to be replaced with new 1.8m wide concrete panels. On the west side of the road, 500m of the existing asphalt sidewalk from the Gerald McGavin Rugby Centre to W 16th Avenue will be replaced. On the east side of the road, 150m of existing asphalt sidewalk from W 16th Avenue and traveling north will be replaced.

The failing road structure will be removed and replaced by completing a full road rebuild. After consulting the Master Municipal Construction Document (MMCD), Team 10's design includes the full road rebuild that is shown in Figure 5. It is important to note that if unknown utilities are encountered that some utility relocation may be required, which is why the road rebuild diagram includes a typical pipe/utility to depict the necessary requirements. The existing paved road surface and the soil beneath it will be removed in order to construct the new road structure to meet the specifications shown in Figure 5.

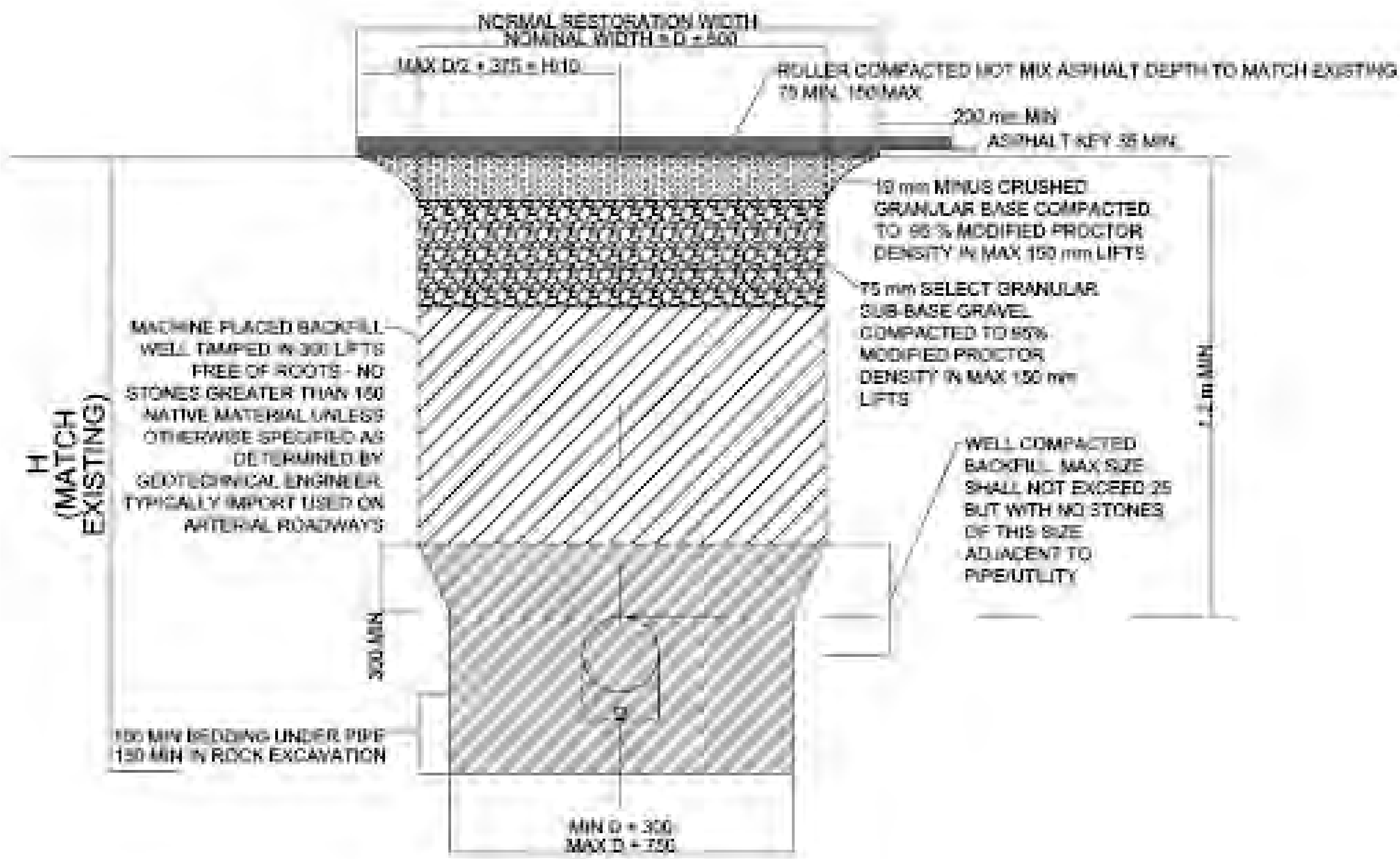

Figure 5: Full road rebuild diagram

4.1.1 Justification

Team 10's design decisions are heavily influenced by several factors: connectivity with surrounding facilities, safety, promoting multi-modal travel, and ease-of-use. The detailed justifications for design specifics are described below.

The unidirectional cycle tracks ensure that conflict points between cyclists and other road users are minimized by elevating the cycle track, separating the track from the roadway with on-street parking whenever possible, providing a green median buffer, and the exclusion of intersection crossovers. These strategies will ensure cyclists are able to utilize these facilities in the safest and easiest way possible.

Inclusion of the northbound bus lane was supported by the traffic analysis software results summarized in section 4.1.2. Additionally, Team 10 implemented the dedicated bus lane to further encourage the use of sustainable transport on the UBC campus. The analysis determined that the intersection at Thunderbird Boulevard and Wesbrook Mall is Class B, which indicates a high level of service. However, to design for future demands and further promote transit use, Team 10 decided to implement a northbound bus lane, starting at the north end of the pedestrian overpass, located above the crosswalk between the Gerald McGavin Rugby Centre and Panhellenic House. The Synchro analysis determined the longest queue was 56m, thus Team 10 ensured the bus lane began at least 60m back. With limited road width along the corridor and below the pedestrian overpass, the bus lane was prioritized north of the overpass to maximize positive benefits to travel time and use of a dedicated lane.

The decision to remove the bus pullout bay and create an in lane bus stop adjacent to the Doug Mitchell Thunderbird Sports Centre was influenced by Translink BC's Bus Infrastructure Design

Guidelines (BIDG). In this design manual, it is highly recommended to not include bus pullout bays, as they require buses to remegre. This merging creates conflict zones with other road users.

During site inspections, damaged sidewalk facilities on both sides of the roadway were identified as dangerous for pedestrian users. These facilities contained large cracks and uprooting which pose a serious tripping hazard for users. Thus, the design includes the full replacement of the damaged asphalt sidewalk. These damaged facilities will be replaced with durable concrete panels that include a metal mesh, which acts to distribute loads from growing roots and resist damage. An overview of the new sidewalks with crack prevention techniques is shown in Figure 6.

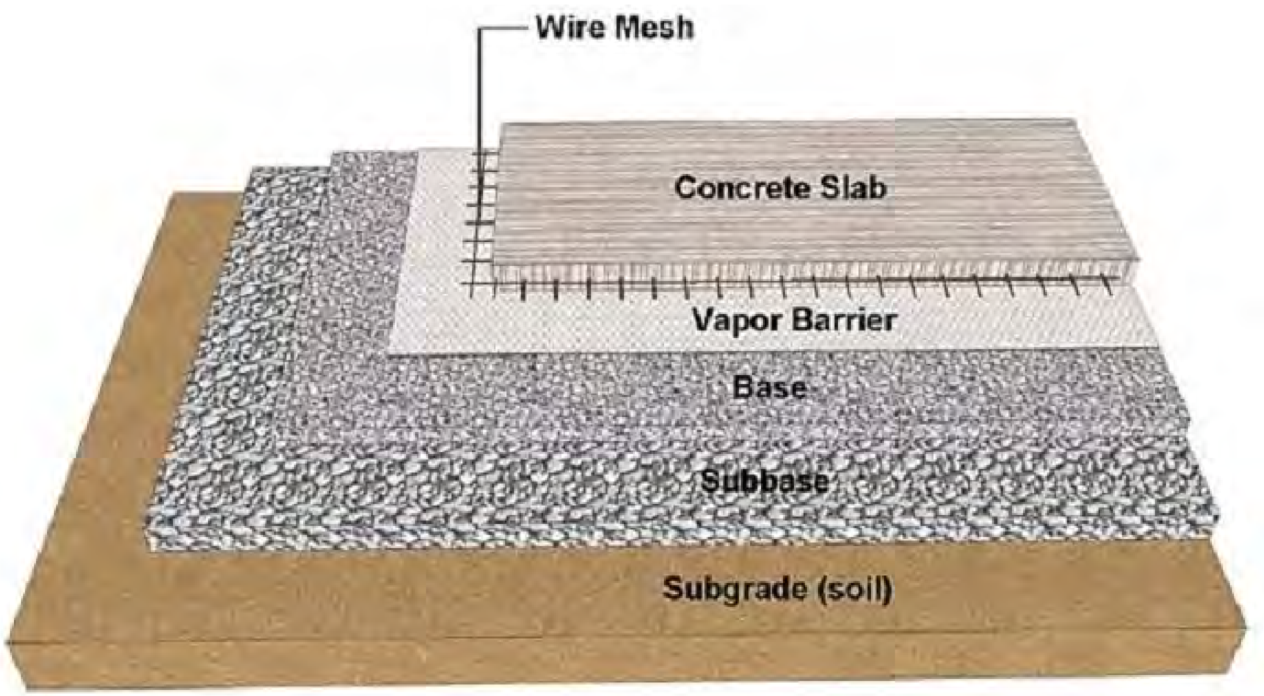

Figure 6: Sidewalk with crack prevention

A full road rebuild of the entire roadway within the Phase 4 area will be completed. While a more costly measure, the full road rebuild increases the road durability and service life as well as reduces maintenance requirements.

4.1.2 Software

Synchro was used to analyze the current conditions of the signalized intersection within the design area at Wesbrook Mall and Thunderbird Boulevard. To complete this analysis, traffic volumes and signal timings provided by the client were used. The results are summarized in Table 5 below and full reports can be found in Appendix E. The intersection received a level of service (LOS) B for the morning (AM) and midday (MD) peak while the afternoon (PM) peak was LOS C. According to the Canadian Capacity Guide for Signalized Intersections, LOS B has slight delays and LOS C has acceptable delays while both have stable flow. Thus, the Thunderbird Boulevard intersection is currently running at an acceptable level and has space for future increases in traffic. The Wesbrook Mall Phase 4 redesign does not need to improve traffic flow and should focus on increasing the multimodal functionality of Wesbrook Mall, making sure to prioritize safety for all users. This will assist in promoting pedestrian, cyclist, and transit travel.

Table 5: Synchro analysis summarized results

	AM Peak	**MD Peak**	**PM Peak**
Intersection	LOS B	LOS B	LOS C
Eastbound	LOS B	LOS B	LOS B
Westbound	LOS C	LOS B	LOS B
Northbound	LOS B	LOS B	LOS C
Southbound	LOS B	LOS B	LOS C

The largest 95th percentile northbound queue length was 56.4m. This led to the decision to begin the bus lane at least 60m south of Thunderbird Boulevard.

4.2 Pedestrian Overpass

The protected pedestrian crossing is a steel girder bridge with a timber and glass roof structure that is accessible via stairways equipped with bike ramps. The design will provide a safe means for pedestrians and cyclists to cross the roadway, without conflict points with road users. The bridge will span 32m above the crosswalk between the Gerald McGavin Rugby Centre and the Panhellenic House. Both access points will be located south of the span on either end. This will require the temporary relocation of two trees, which are highlighted in orange in Figure 7, and the permanent relocation of three trees, which are highlighted in yellow in Figure 7. This will also require the removal of 19m of west and 16m of east on-street parking, which is highlighted green in Figure 7. The detailed design drawings of the overpass are provided in Appendix A.

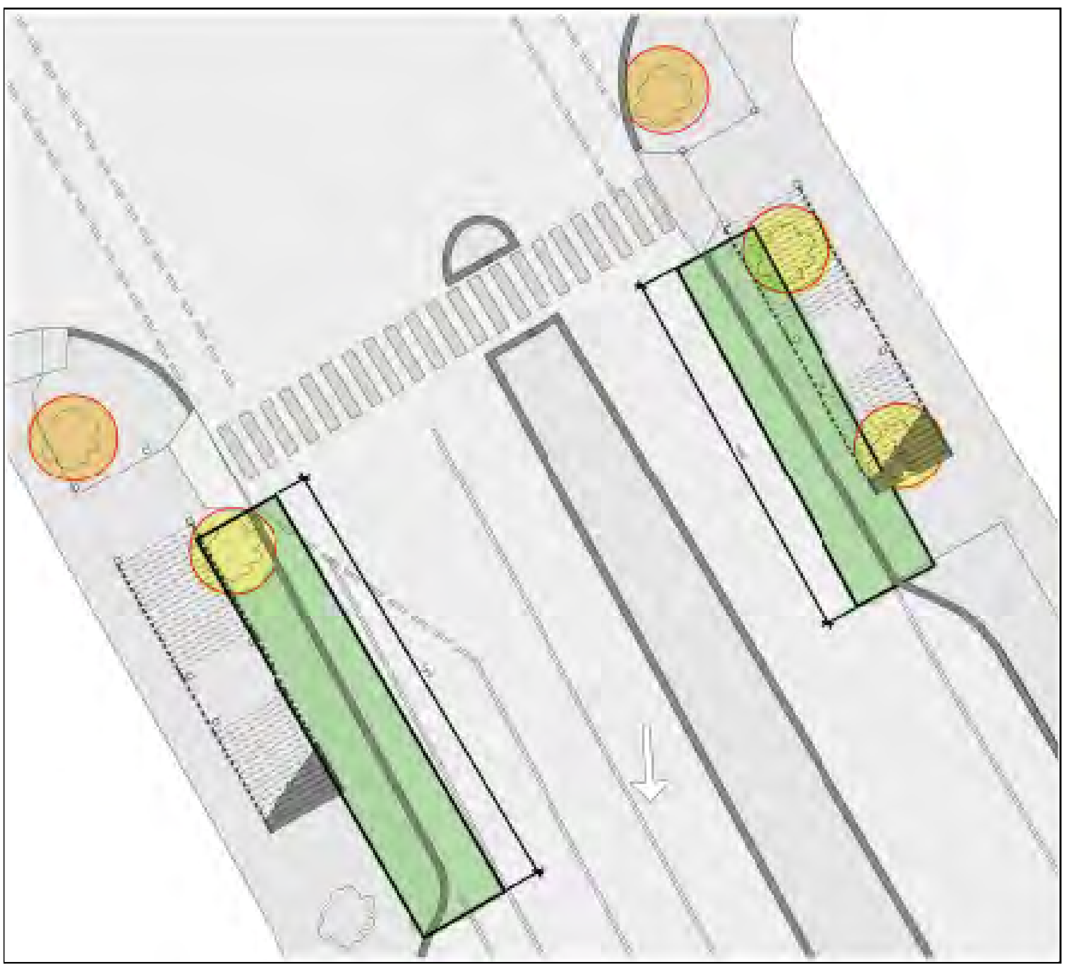

Figure 7: Pedestrian overpass tree and on street parking removal

4.2.1 Architectural Features

The pedestrian overpass is a steel girder bridge with a curved glulam beam and glass roof structure that is the focal point of the bridge's architectural features. The curved glulam beams are 270mm x 380mm and are supported by 270mm x 270mm glulam columns. The roof structure also has 200mm x 200mm diagonal bracing and 270mm x 380mm lateral bracing. All of the timber elements are Douglas Fir Larch 20f-E and are pressure treated with Aluminum Copper Quaternary. The glass roof is made of 6mm thick SGP laminated glass that follows the beam curves to create an innovative and beautiful roof structure. These architectural features are displayed in the model shown in Figure 8 and Figure 9.

Figure 8: Pedestrian overpass looking northbound

Figure 9: Pedestrian overpass looking southbound

4.2.2 Structural Overview

The overpass structure consists of steel members supported by reinforced concrete footings. There are ten steel columns along the span of the overpass and ten isolated concrete footings complete with steel base plates. There are five beams that span the five sets of columns and support the two girders that span the entire length of the overpass. All structural steel is grade 350W. The concrete deck atop of the girders forms a composite beam with a supporting steel deck, which was not considered in preliminary calculations to achieve more conservative section sizes. The deck consists of 30MPa concrete while the footings consist of 25MPa concrete and grade 400W reinforcing steel. The section sizes of the structural elements are summarized in Table 6.

Table 6: Overpass structural element overview

Overpass Member	Section
Girder	W840x176
Beam	W360x79
Column	HSS254x254x7.9
Isolated Footing	2m x 2m x 0.7m

4.2.3 Justification

Team 10 prioritized the architectural design of the pedestrian overpass to ensure the design maintained the existing UBC natural aesthetic. This was achieved by combining a variety of materials including steel, timber, concrete, and glass to create an aesthetically pleasing structure. Effort was put into keeping the structural elements as small as possible to minimize the obstruction of views of the surrounding landscape. The incorporation of the curved glulam beams and glass roof structure was an architectural design decision to ensure that the overpass would be another innovative and beautiful structure on the UBC campus.

The sections of the members discussed in section 4.2.1 and 4.2.2 were determined through a detailed structural analysis. This analysis consisted of using a structural analysis software called S-FRAME to determine the bending, shear, axial, and deflection demands of the different members. The demands were then compared to the capacities of the selected sections and if any of the sections failed (i.e. demand > capacity) they were updated to a larger section. The governing demand was the deflection in the girders, which was expected given the large span. The final demand and capacity comparisons for the steel members and timber members are summarized in Table 7 and Table 8 respectively.

Table 7: Demand versus capacity of steel members in overpass

	Girder (W840x176)	**Beam (W360x79)**	**Column (HSS254x254x7.9)**
Moment (kN*m)	Mr > Mf 3,388.1 > 983.5	Mr > Mf 425.0 > 1.2	Mr > Mf 170.0 > 90.9
Shear (kN)	Vr > Vf 2,180.0 > 315.5	Vr > Vf 620.0 > 568.3	Vr > Vf 782.4 > 23.3
Axial (kN)	-	-	Cr > Cf 1,380.0 > 568.3
Deflection (mm)	$\Delta_{limit} > \Delta$ 53.9 > 42.3	$\Delta_{limit} > \Delta$ 9.7 > 4.0	$\Delta_{limit} > \Delta$ 11.0 > 4.0
Beam - Column	-	-	0.68 < 1.0

Table 8: Demand versus capacity of timber members in overpass

	Curved Glulam Beam (270mm x 380mm)	**Glulam Column (270mm x 270mm)**
Moment (kN*m)	Mr > Mf 107.8 > 1.2	-
Shear (kN)	Wr > Wf 204.7 > 69.8	-
Axial (kN)	-	Pr > Pf 879.8 > 7.0

The foundation design consists of isolated concrete footings with steel base plates located beneath each of the columns. The plan dimensions of the footing are solely based on the allowable bearing stress of a dense to very dense sand as the provided geotechnical report states that the top 5m of soil consists of a dense to very dense sand. Using a typical allowable bearing stress of 150kPa and the worst case axial force in the columns, the plan dimensions of the footings were determined. The footing depth was determined by assigning an initial guess depth and then checking one-way shear and two-way shear. If either of the one-way or two-way shear resistances were less than the shear demand provided by the largest column axial load, the footing depth was changed and rechecked until it was sufficient. The reinforcing steel was determined by setting the flexural capacity of the footing equal to the flexural demand provided by the largest column axial load and solving for the minimum required area of steel. The final demand and capacity comparisons for the footings are summarized in Table 9. The complete structural analysis calculations are provided in Appendix B.

Table 9: Demand versus capacity of concrete footings

Bearing Stress (m)	One-Way Shear (kN)	Two-Way Shear (MPa)	Flexure (mm^2)
Width > Min. Width 2 > 1.8	Vr > Vf 737.1 > 94.6	Vr > Vf 1.2 > 0.2	Area > Min. Area 1,500 > 545.4

4.2.4 Software

The structural analysis software S-FRAME was used to determine the section sizes of the steel overpass members. First, the overpass was modeled and initial guess sections were assigned. Note that the overpass model was done conservatively by only considering three sets of columns instead of the actual five sets. This results in increased spans and therefore is conservative for the design. Then the ultimate limit state (ULS) load combinations of 1.4D and 1.25D + 1.5L as well as the serviceability limit state (SLS) load combination of 1.0D + 1.0L were applied to the model. D represents the dead load, which is equal to the structure's self weight and L represents the live load, which is equal to the pedestrian loading. The structure's self weight was determined by utilizing the self weight option in S-FRAME and by hand calculating the self weight of the deck, railing, and roof structure that were not part of the model. The hand calculation is provided in Appendix C. Once the loads were applied, the model was run using a static analysis and the resulting bending, shear, axial, and deflection demands were analyzed. As previously discussed in section 4.2.3, these demands were compared to the capacities of the chosen sections and if any of the members failed they were updated to a larger section. The model was run again with the updated sections and this process was repeated until the optimal sections sizes were determined. The S-FRAME model is shown in Figure 10.

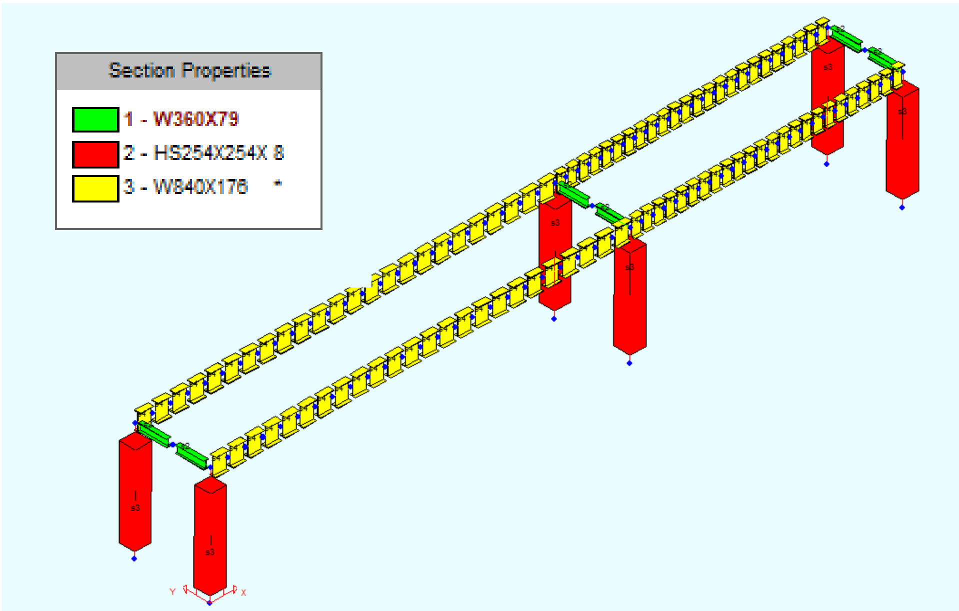

Figure 10: S-FRAME model

5.0 Schedule

Construction will start on the day the site is available, which is May 1, 2022. Prior to this construction start date, Team 10 will begin the bidding process on January 15, 2022 and award the project contract to the most qualified candidate on January 30, 2022. After meeting with the contractor and client, Team 10 will look to obtain all the required development permits and necessary materials for the construction start date. Refined from the preliminary design, activities now include allotment for traffic design plans, permits, and implementation. This refinement has extended the project schedule and the project itself is now anticipated to be complete by August 16, 2022. However, maintenance will be required on an as needed basis throughout the project life. Ongoing maintenance will include replacing damaged concrete sidewalk panels, sealing cracks in the roadway, and conducting structural inspections of the overpass.

5.1 Construction Work Plan

Once the project contract has been awarded and permits are obtained, the first task to be initiated is to acquire building materials. Obtaining building materials will be an ongoing task up until the start of the overpass construction, at which point it's assumed that all materials will be on site. As materials are being delivered to site, about six days will be allocated to construction setup (fencing, equipment mobilization, proper signage, etc.). Once the site is set up safely, a full road rebuild of the northbound lane will commence. The southbound lane will operate as a temporary multi-directional lane of traffic incorporating traffic control personnel where necessary. After approximately eleven days, the northbound lane, its unidirectional cycle track, necessary signs, and pavement markings will be installed. The northbound lane will then act as a temporary multi-directional lane while the southbound full road rebuild is in progress. It is important that these north and southbound lanes undergo their stages of construction separately to ensure that the other lane can be utilized to maintain access to Wesbrook Mall. Next, the bus pullout bay outside of Doug Mitchell Thunderbird Sports Center will be filled in while various tree removals and relocation take place [approx. 11 days]. Lastly, construction of the overpass will commence [approx. 65 days] as the last of the materials become readily available. During this time, landscaping will be done and vegetation buffers for the medians and cycle lanes will be finalized [approx. seven days]. As stated in section 5.0, the project is forecasted to be complete by August 16, 2022. The need for ongoing maintenance will be monitored closely to ensure that the corridor can consistently provide safe and reliable transportation.

5.2 Gantt Chart

The project schedule is summarized in the Gantt chart in Figure 11 below.

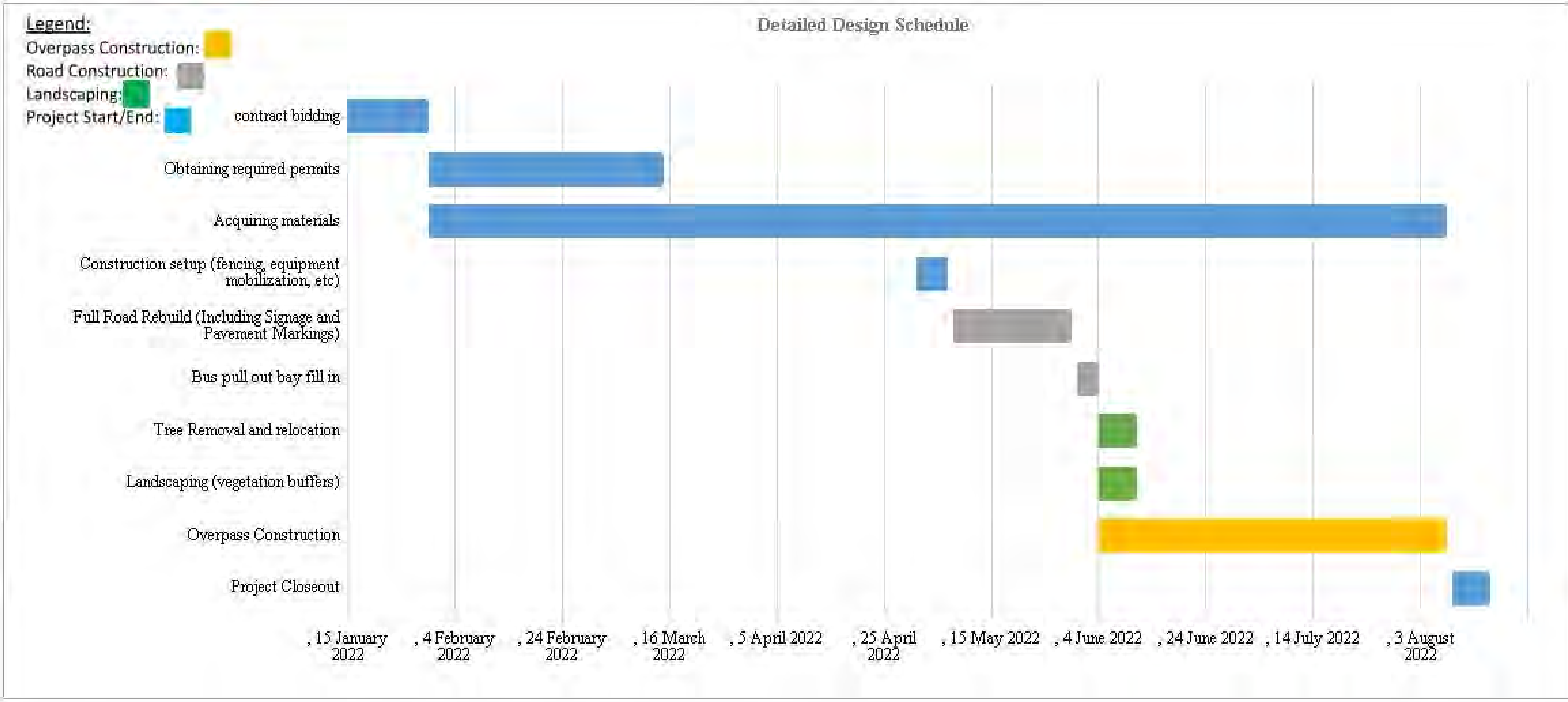

Figure 11: Gantt chart

6.0 Cost Estimate

A Class A cost estimate found that Team 10's design will cost approximately $7.52 Million CAD. Majority of the cost lies in the road upgrade, as it includes the cost for sidewalks, bicycle lanes, relocating trees, and landscaping. This cost estimate has been updated from the preliminary design and now accounts for escalation and contingency. Escalation will compensate for the large uncertainties related to what lies beneath UBC's roadways in terms of unknown infrastructure. Due to this, excavating throughout UBC is often a much more involved process and this is compensated for with escalation. Additionally, contingency has been added to recompense any form of delays that may occur during the construction of this project. Refer to Table 10 for a breakdown of the various components and Appendix D for the cost estimate calculations.

Table 10: Cost estimate breakdown

Class A Cost Estimate		
Note: See Appendix D for Calculations and Justification		
Pedestrian Overpass	Estimated Cost (CAD)	
Girder(W840x176)	$	7,177
Columns (HSS 354x254x8)	$	2,589
Pile Cap Beams (W360x79)	$	956
Glulam Columns	$	23,738
Glulam Beams	$	23,920
Glass Roof (PVB)	$	1,603
Wooden Railing	$	17,958
Concrete Stairs	$	5,920
Foundation	$	1,117
Concrete Deck Slab	$	13,147
Total Overpass	**$**	**98,125**
Road		
Remove/Install Concrete Panels	$	438,000
Full Road Repair	$	2,544,210
Bicycle Lane	$	675,000
Vegetation Buffer	$	32,250
Median Retrofit	$	9,600
Bus Pad Fill in	$	3,010
Curb and Gutter	$	112,000
Tree Removal	$	12,500
Signage	$	4,000
Pavement Lines	$	1,317
Pavement Symbols	$	19,173
Total Road	**$**	**3,851,060**
Other		
Labour	$	790,984
Project Management	$	438,770
Architecture	$	442,760
Engineering	$	843,261
Preconstruction/Permits	$	75,000
Municipal Connection Fees	$	100,000
Traffic Control Personnel	$	13,438
Escalation	$	258,949
Contingency	$	284,413
GST	$	323,856
Total Other	**$**	**3,571,431**
Total Project Cost	**$**	**7,520,616**

7.0 Conclusion

Team 10's detailed design addresses the failing road structure and evolving transportation patterns and demands along the Wesbrook Mall corridor. The design consists of completing a full road rebuild, introducing protected unidirectional cycle tracks on both sides of the road, adding a dedicated northbound bus lane, replacing damaged sections of sidewalk, and constructing a protected pedestrian overpass. The design is estimated to cost $7.52 Million CAD and will take seven months to complete from the start of the project. Team 10 is confident in this design and is excited to collaborate with the UBC SEEDS Sustainability Program to further discuss the design and ensure the optimal solution for this vital UBC corridor is delivered.

8.0 References

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Appendix A: Detailed Design Drawings

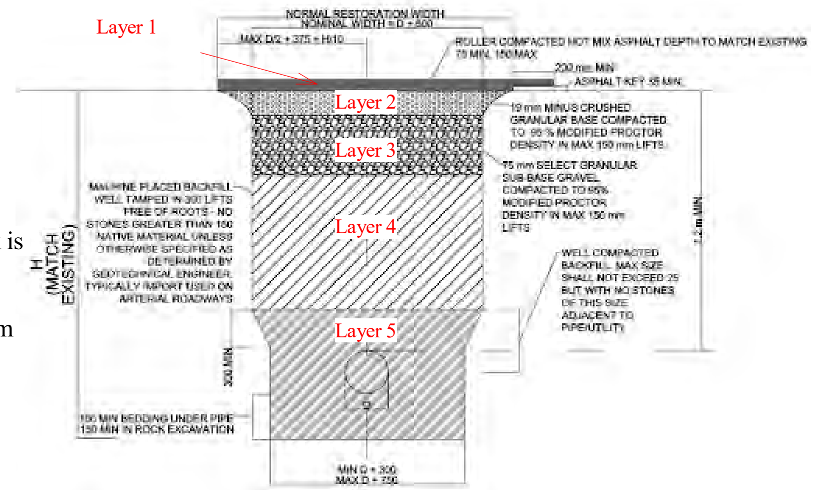
GENERAL NOTES

1. Contractors shall conduct a site visit(s) and become familiar with all the site conidtions that may affect their work
2. Make neccesary on-site adjustments to match exisiting conditions (consult site-engineer prior to making any decisions)
3. Contractor shall keep the site clean during construction and prior to leaving the site after work is completed
4. All codes and standards are to be as referenced from the British Columbia Building Code. In the case where the standards are not referenced, refer to the latest edition of codes and standards
5. If there is a discrepancy between the drawings and specifications, contact the design engineer
6. The strucutral drawings only show the completed structure; The contractor is responsible for any required bracing and shoring
7. These drawings are not to be scaled
8. A lateral and seismic load check on the pedestrian overpass must be completed prior to construction
9. Refer to the steel detailer for connection details

GENERAL MATERIALS

1. Ensure materials are clean and under dry condition during delivery and storage
2. All steel to meet CSA S16:19 Standards
3. All concrete to meet CSA A23.3 Standards
4. All timber to meet CSA O86-19 Standards
5. All fill material to meet the requirements under the Fill Material section
6. The disposal of all excavted material must be done in a pre-approved location
7. Concrete sidewalk panels to be provided by supplier
8. SGP laminated glass to be provided by supplier

FILL MATERIAL



Layer 1	Roller compacted hot mix asphalt to match existing
Layer 2	Crushed granular base compacted to 95% Modified Proctor
Layer 3	Select granular sub-base compacted to 95% Modified Proctor
Layer 4	Machine placed backfill used on arterial roadways
Layer 5	Well compacted backfill in the case utility relocation is required

ASPHALT PAVEMENT

1. Contractor to prepare and review a Quality Control Plan prior to commencing the work
2. Contractor to supply and deliver asphalt cement and spray primer meeting SS 952 requirements
3. Contractor to prepare and produce asphalt mix in accordance with SS 502.08.04 or an accepted variation in accordance with SS 502.08.10
4. Contractor to use approved SUPERPAVE 19mm nominal mix (75 min. depth) as per Section 32 12 17 of the City of Vancouver Construction Specifications

CONCRETE

Foundation

1. Investigation of bearing surfaces shall be completed prior to construction to confirm the material is consistent with the geotechnical assessment report
2. U.N.O center footings below columns
3. Contractor is responsible for constructing the forms and ensuring they are verified by the site engineer
4. Ensure surface below footing is clean and free of loose material prior to casting concrete
5. Concrete mix shall conform to the table below
6. Site engineer must be present prior to and during concrete casting

Deck

1. The steel deck to be provided by the supplier shall have an overall depth of 40 mm and flute spacing of 150mm or verified by design engineer
2. Headed studs to be provided by the supplier and to be verified by the design engineer
3. Concrete mix shall conform to the table below
4. Site engineer must be present prior to and during concrete casting

Description	28 Day Strength (f'c)	Max Aggregate	Max Slump	Air	Exposure
Footings	25 MPa	20 mm	75 mm	5-8 %	E
Deck	30 MPa	20 mm	75 mm	4-7 %	C-1

TIMBER

1. Connections details to be specified by timber supplier
2. Pressure treat all timber with Aluminimum Cooper Quarternary
3. Provide shop drawings from supplier to design engineer to be approved
4. Site engineer to inspect all timber and connections to ensure they are consistent with the design
5. All structural timber shall be Douglas Fir Larch 20f-E

Description	Section	Quantity
Curved Glulam Beam	270mm x 380mm	2
Glulam Column	270mm x 270mm	28
Diagonal Bracing	200mm x 200mm	52
Lateral Bracing	270mm x 380mm	14

STEEL

Structural

1. Connections details to be specified by steel detailer
2. Center the bearing plate on footings U.N.O
3. Treat all steel by cleaning, priming, and painting it to protect against corrosion
4. Do not treat connection surfaces
5. Provide shop drawings from supplier to design engineer to be approved
6. Column base plates shall be 1/2" minimum thickness to satisfy bearing requirements
7. Site engineer to inspect all steel and connections to ensure they are consistent with the design
8. All structural steel shall be grade 350W

Description	Section	Quantity
Girder	W840x176	2
Beam	W360x79	5
Column	HSS254x254x7.9	18

Reinforcement

1. Contractor is responsible for tying intersecting reinforcing steel together and securely placing the steel in the correct location
2. Contractor shall notify the site engineer to conduct an inspection of the placed reinforcing steel prior to concrete casting
3. Minimum cover to reinforcemnet shall be 75 mm
4. All structural reinforcement shall be 25M bars and grade 400W

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Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Final Drawing	04/06/22

General Notes

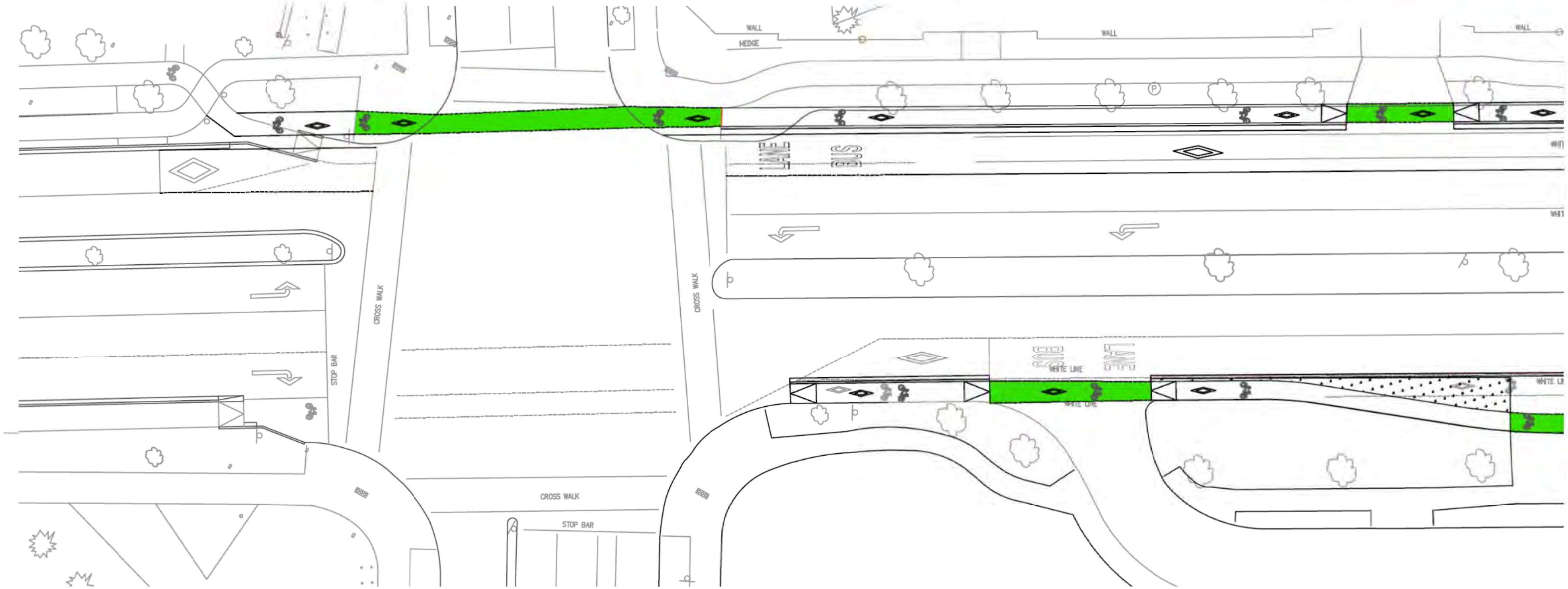
Project number	44610
Date	April 6th, 2022
Drawn by	
Checked by	

G100

Scale

Thunderbird Boulevard to Doug Mitchell Stadium

ISSUED FOR CONSTRUCTION



Legend

New Green Infrastructure

Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Team 10

Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Preliminary Drawing	01/12/21
2	Final Drawing	04/06/22

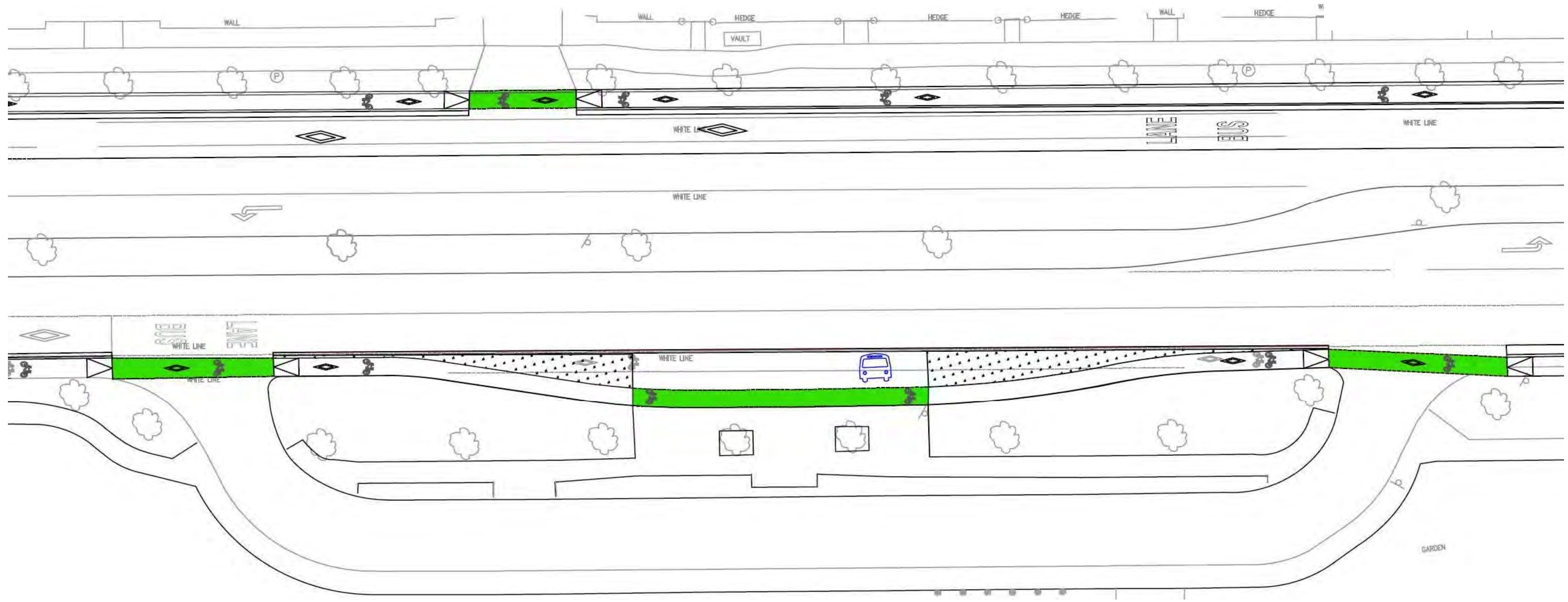
Aerial View 1

Project number	44510
Date	Apr. 6, 2022
Drawn by	
Checked by	

A100

Doug Mitchell Stadium Entry

ISSUED FOR CONSTRUCTION



Legend

- New Green Infrastructure
- Bus Stop

Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Preliminary Drawing	01/12/21
2	Final Drawing	04/06/22

Aerial View 2

Project number 44510

Date Apr. 6, 2022

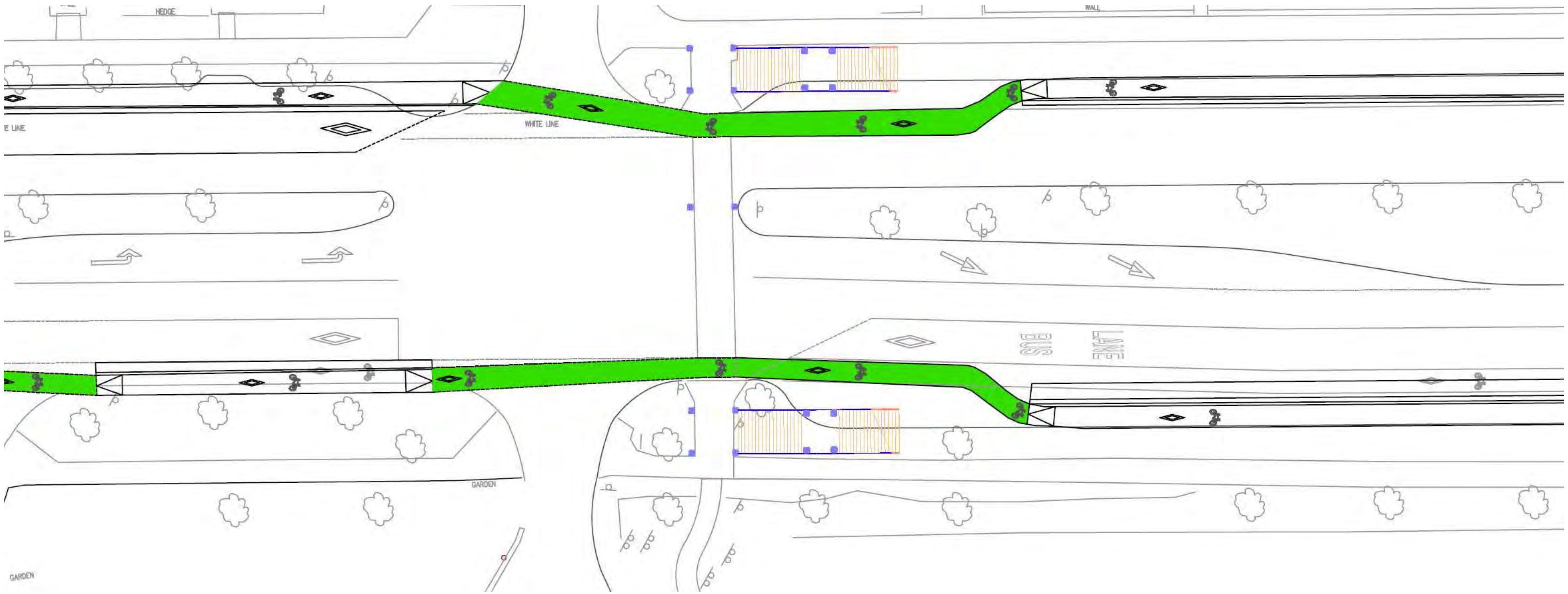
Drawn by

Checked by

A101

Overpass Location

ISSUED FOR CONSTRUCTION



Legend

Overpass Base

Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Preliminary Drawing	01/12/21
2	Final Drawing	04/06/22

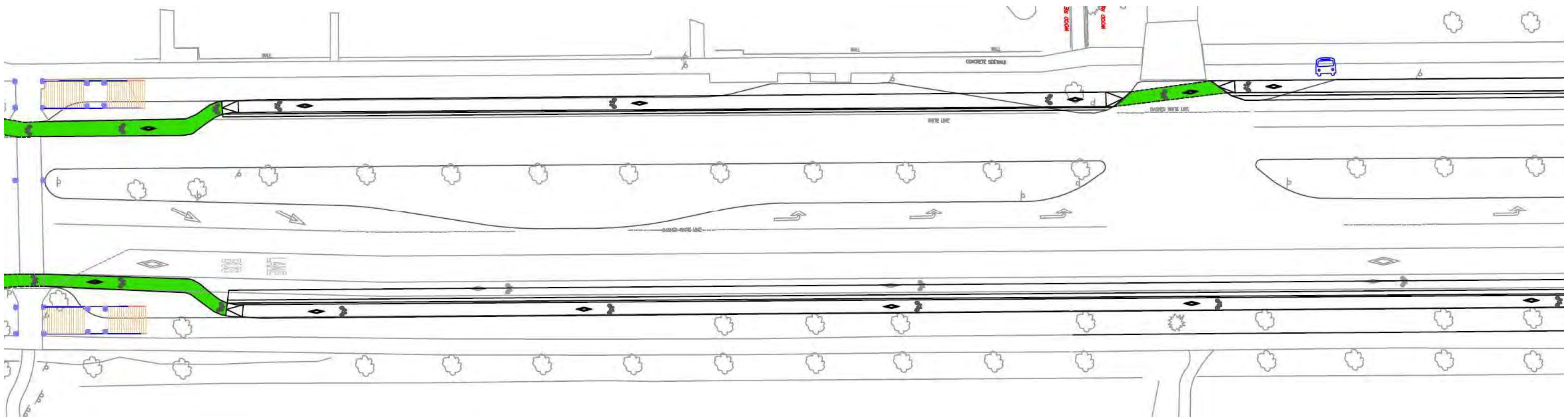
Aerial View 3

Project number	44510
Date	Apr. 6, 2022
Drawn by	
Checked by	

A102

Overpass Base to RCMP Station

ISSUED FOR CONSTRUCTION



Legend

Overpass Base

Bus Stop

Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Team 10

Wesbrook Mall Redesign Phase 4

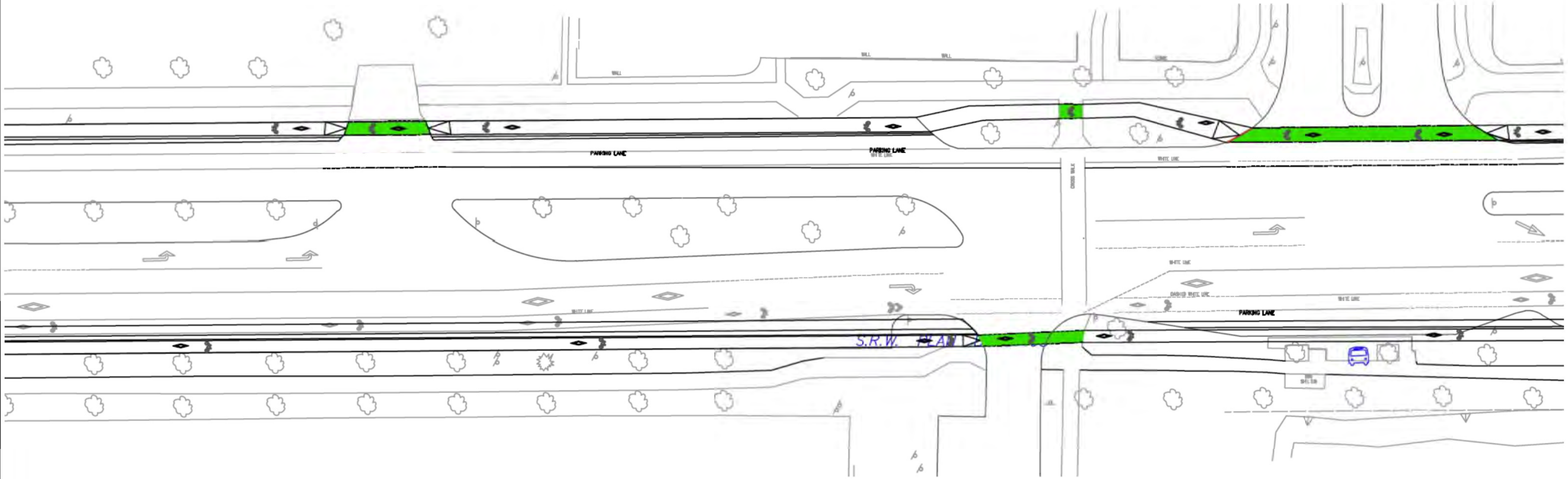
No.	Description	Date
1	Preliminary Drawing	01/12/21
2	Final Drawing	04/06/22

Aerial View 4

Project number	44510	A103
Date	Apr. 6, 2022	
Drawn by		
Checked by		

RCMP Station to Hampton Place

ISSUED FOR CONSTRUCTION



Legend


Bus Stop

Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Team 10

Wesbrook Mall Redesign Phase 4

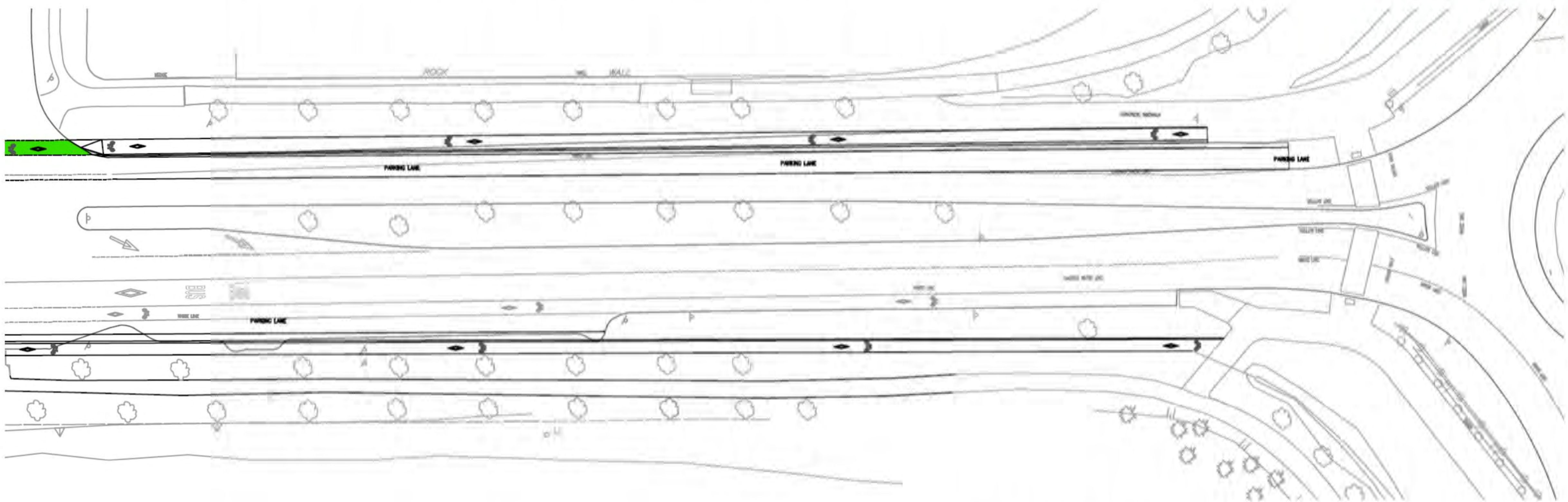
No.	Description	Date
1	Preliminary Drawing	01/12/21
2	Final Drawing	04/06/22

Aerial View 5

Project number	44510	A104
Date	Apr. 6, 2022	
Drawn by		
Checked by		

Hampton Place to W 16th Avenue

ISSUED FOR CONSTRUCTION



Lane Type	Design Width
Travel Lane	3.1 meters
Bus Lane	3.3 meters (excluding gutter)
Cycle Track	1.5 meters to 1.8 meters

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Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Aerial View 6

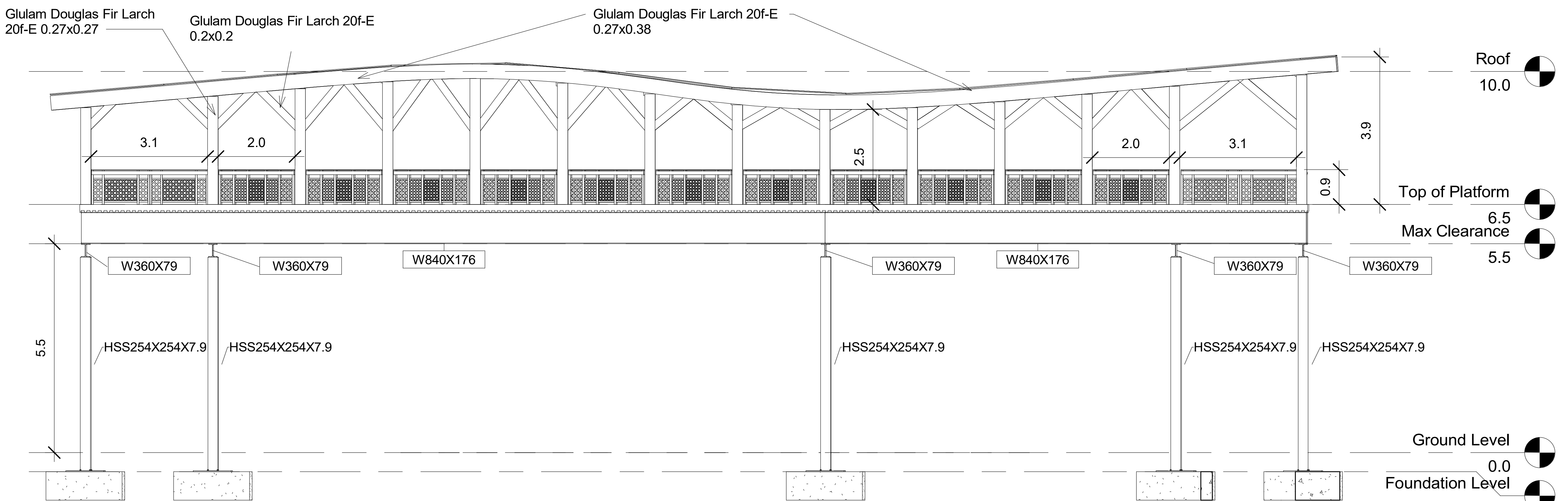
Project number 44510

Date Apr. 6, 2022

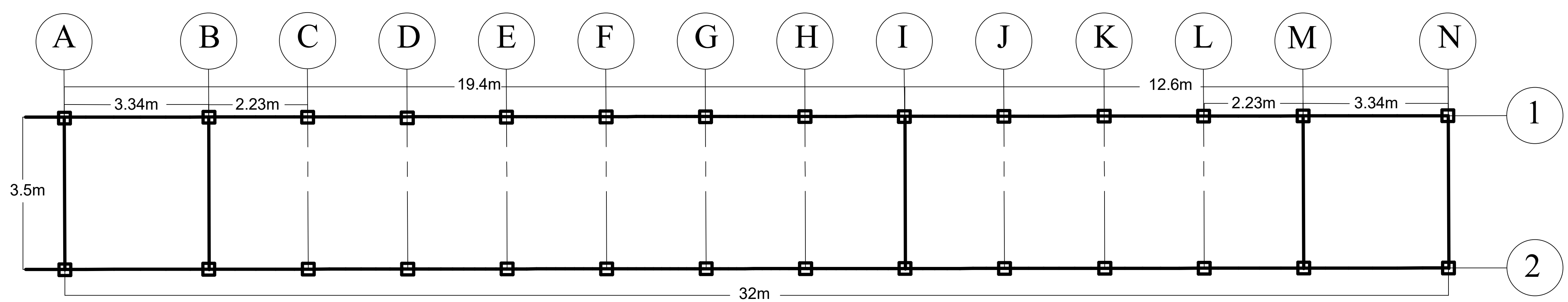
Drawn by

Checked by

A105



SIDE VIEW



PLAN VIEW

All Dimensions expressed in Meters U.N.O

Height Restriction

Min. Clearance Height under the overpass= 5.5 m

Min. Clearance Height for Pedestrians = 2.5m

NOT FOR CONSTRUCTION

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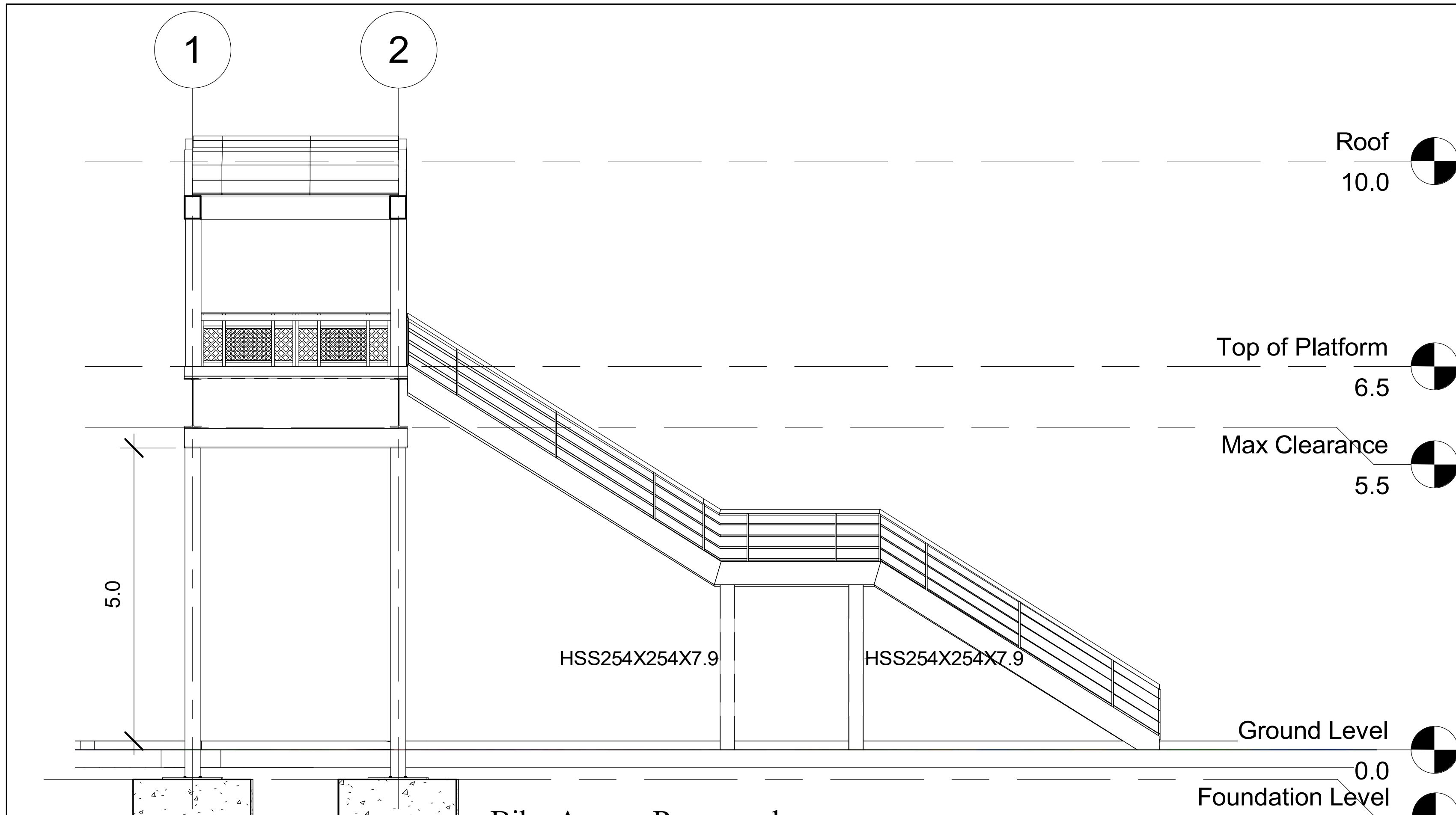
Wesbrook Mall Redesign Phase 4

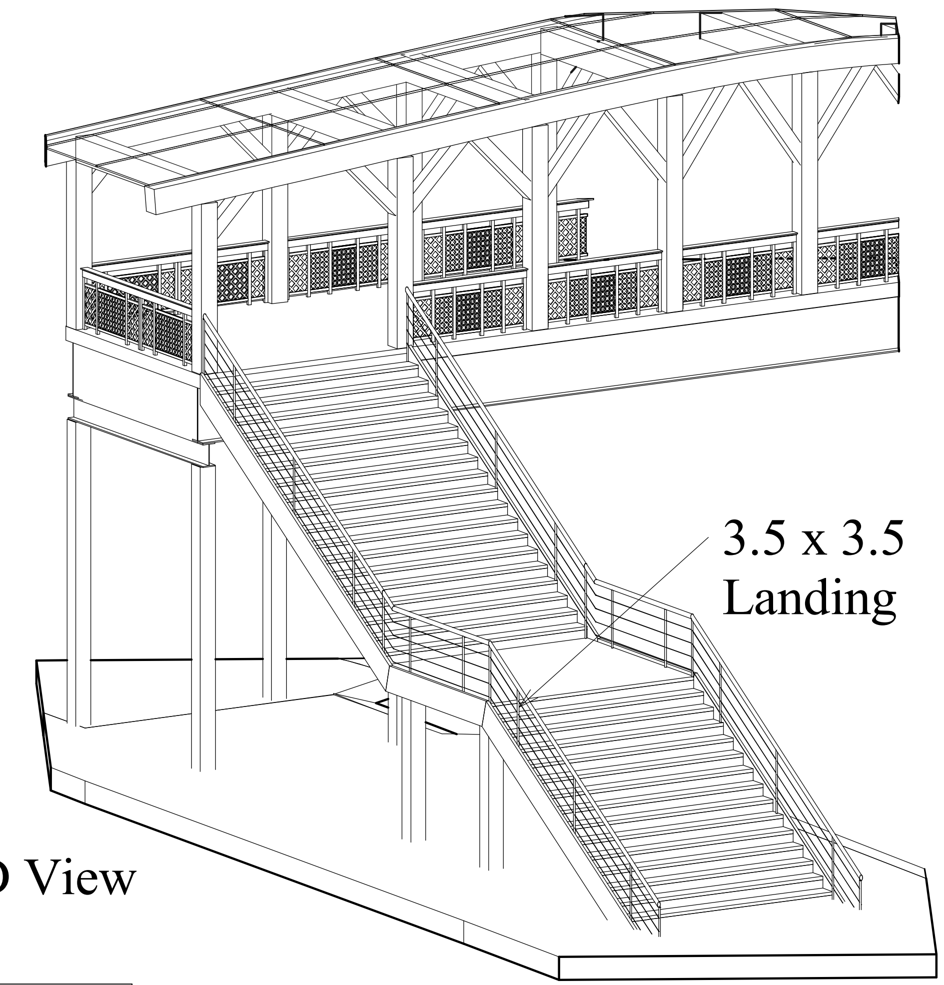
No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Pedesterian Overpass Design

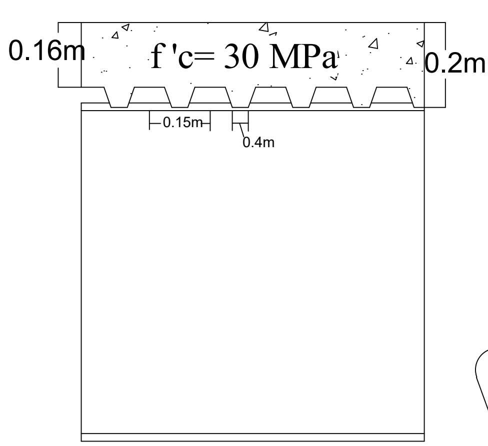
Project number	44610	S100
Date	April 6th, 2022	
Drawn by		
Checked by		Scale 1 : 100



Side View



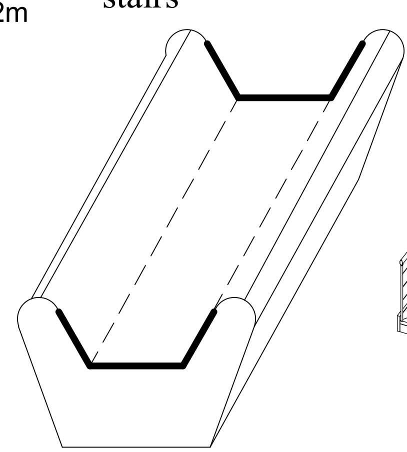
3D View

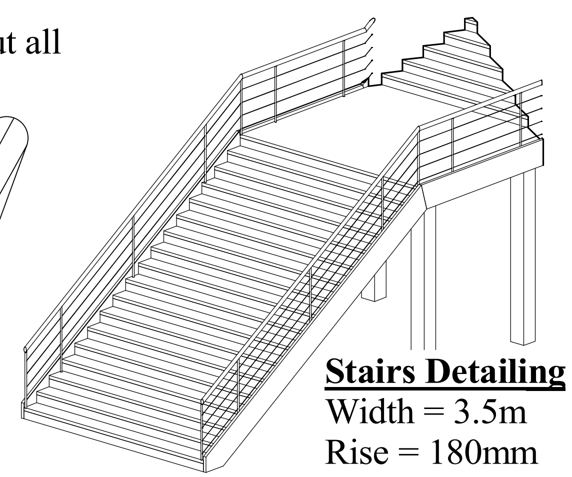


Composite Deck

All Dimensions expressed in Meters U.N.O

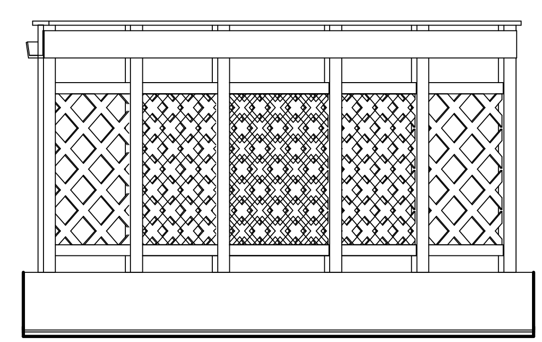
Bike Access Ramp and anti slip tape to be installed throughout all stairs





Stairs

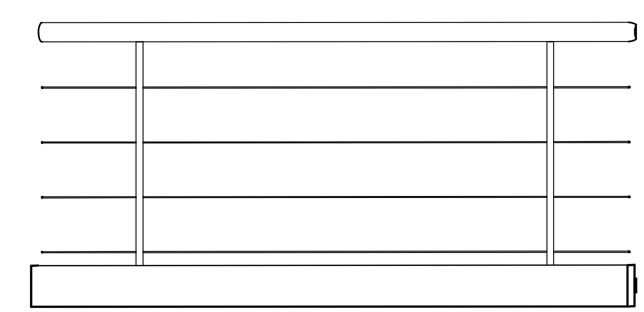
Stairs Detailing
- Width = 3.5m
- Rise = 180mm
- Run = 280mm
- 37 Steps in Total Each Side



Stair Railing Detailing
- -Steel Wire Pipe Railing
- -Height = 900mm
- -48x70 mm Deep Handrail
- -4mm Circular Wire

Deck Railing Detailing
- -Wooden Railing with diagonal hatch design
- -Height = 900mm
- -Material: Legno Pino

NOT FOR CONSTRUCTION



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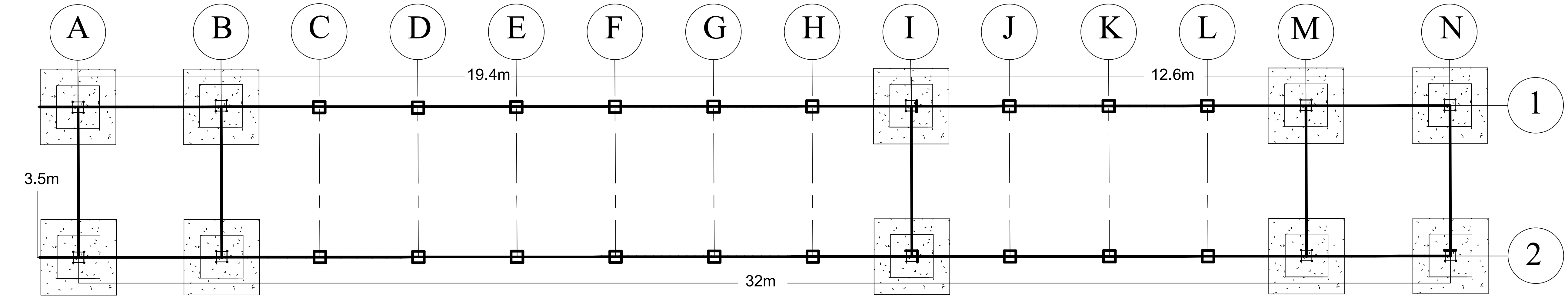
Wesbrook Mall Redesign Phase 4

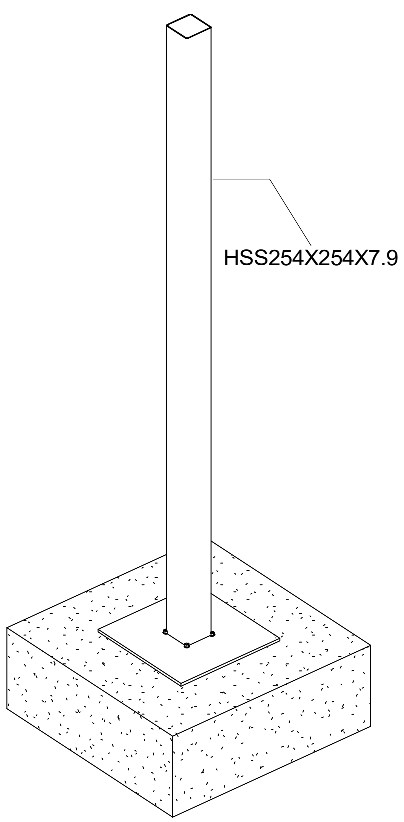
No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Overpass Access Details

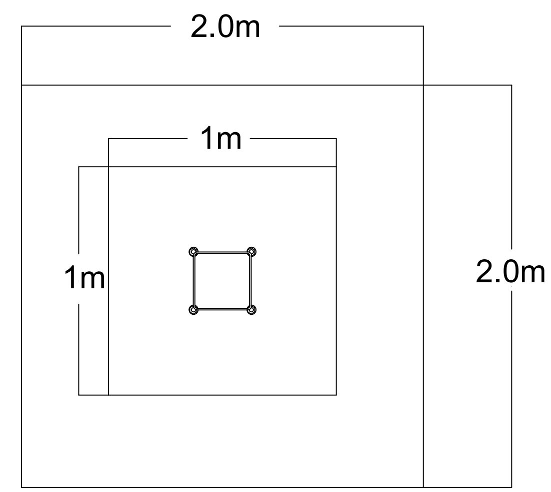
Project number	44610	S101
Date	April 6th, 2022	
Drawn by		
Checked by		Scale 1 : 100



PLAN VIEW

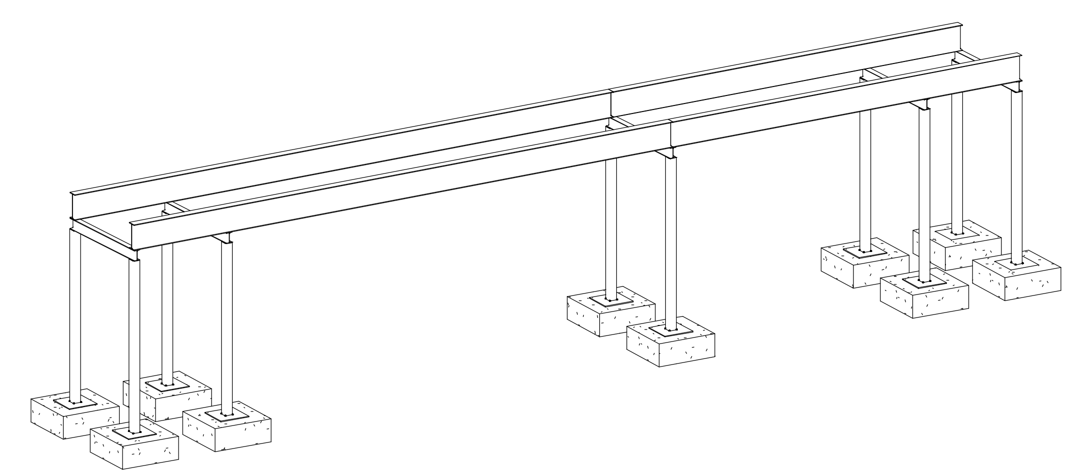


Bearing Plate Geometry
Thickness = 12.7mm
Width = 1.0m
Length = 1.0m
Grade= 350W

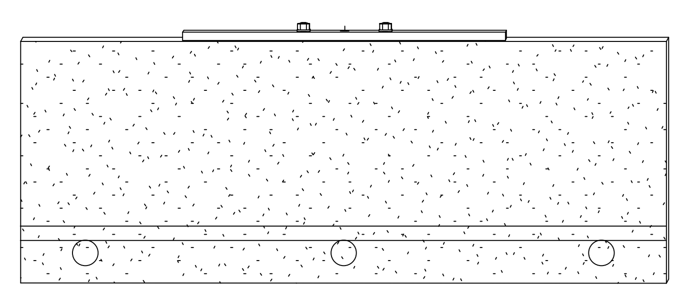


Bearing Plate

3D View



Footing Geometry
Thickness = 0.7m
Width = 2.0 m
Length = 2.0 m



Footing Design
3-25M Bars EW
Cover = 75mm
Spacing = 925 mm C/C
f 'c = 25 MPa

NOT FOR CONSTRUCTION

Footing

All Dimensions expressed in Meters U.N.O

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Team 10

Wesbrook Mall Redesign Phase 4

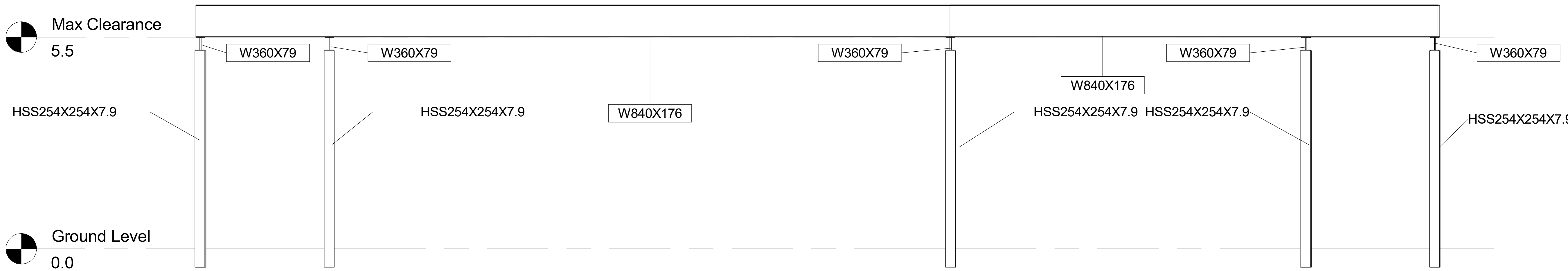
No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Foundation

Project number	44610
Date	April 6th, 2022
Drawn by	
Checked by	

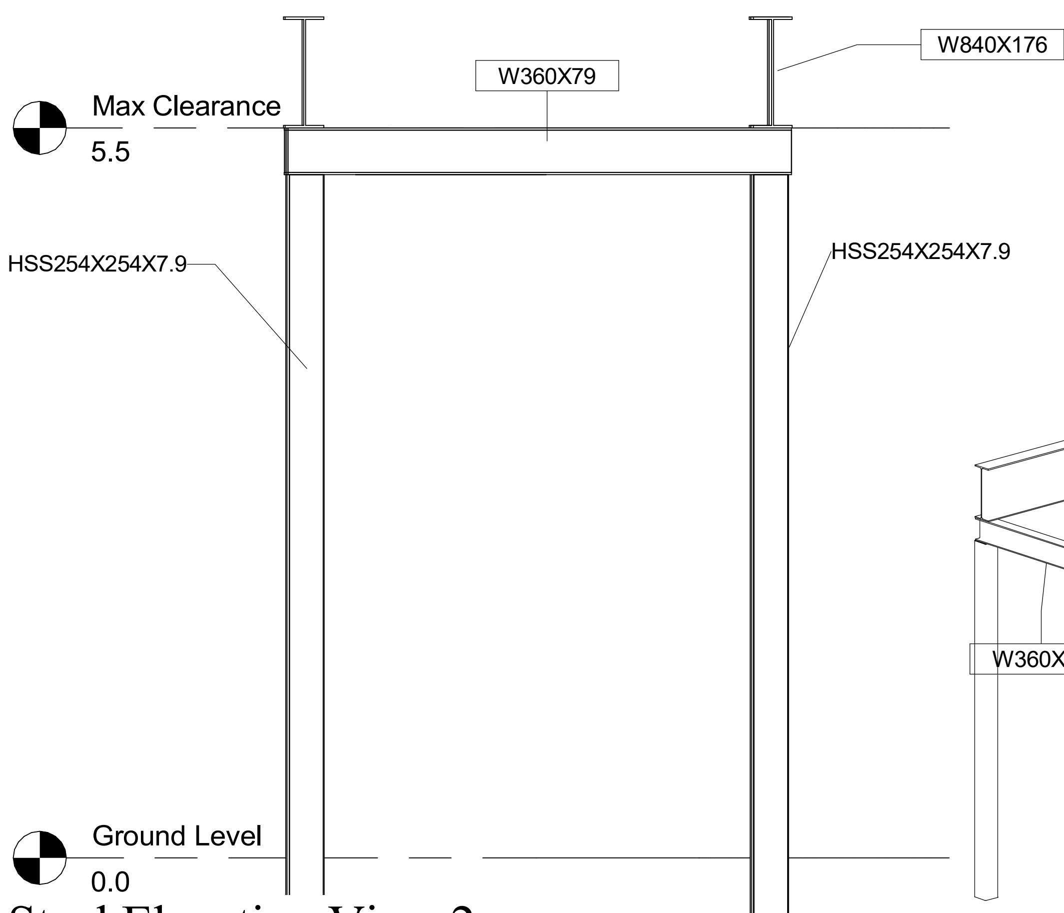
S102

Scale

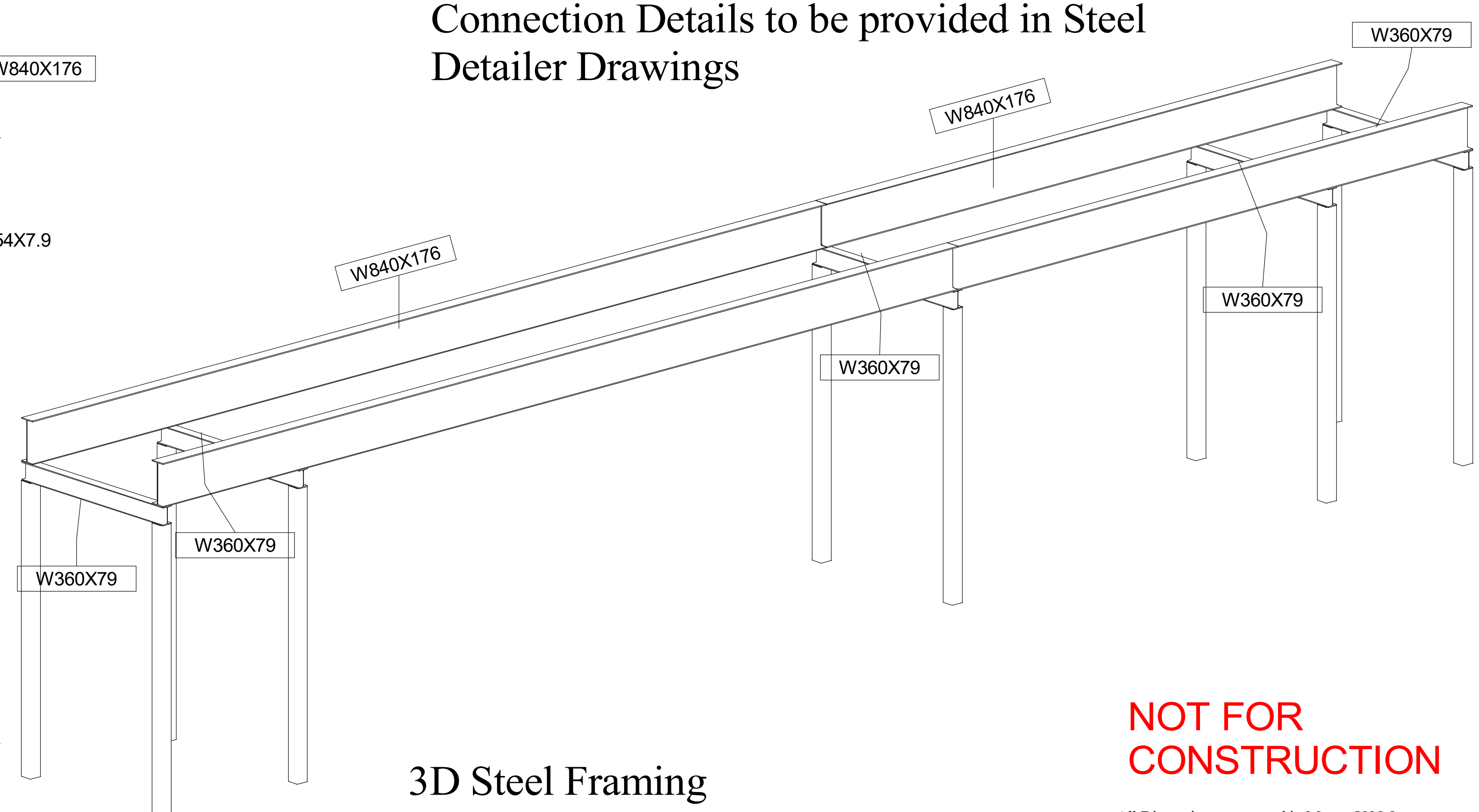


Steel Elevation View 1

Connection Details to be provided in Steel Detailer Drawings



Steel Elevation View 2



3D Steel Framing

NOT FOR CONSTRUCTION

All Dimensions expressed in Meters U.N.O

UBC CIVIL

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Team 10

Wesbrook Mall Redesign Phase 4

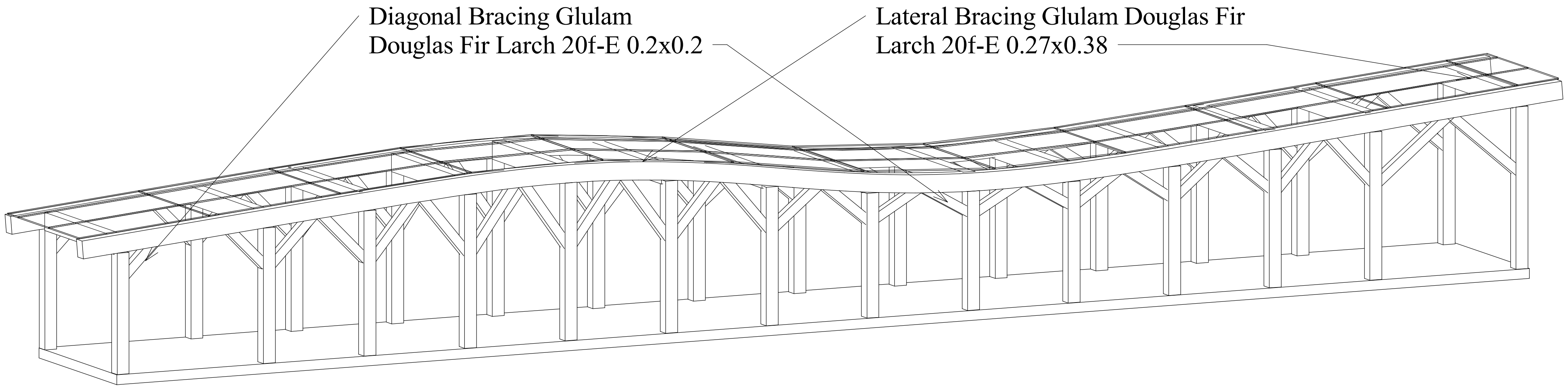
No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Steel Elevation

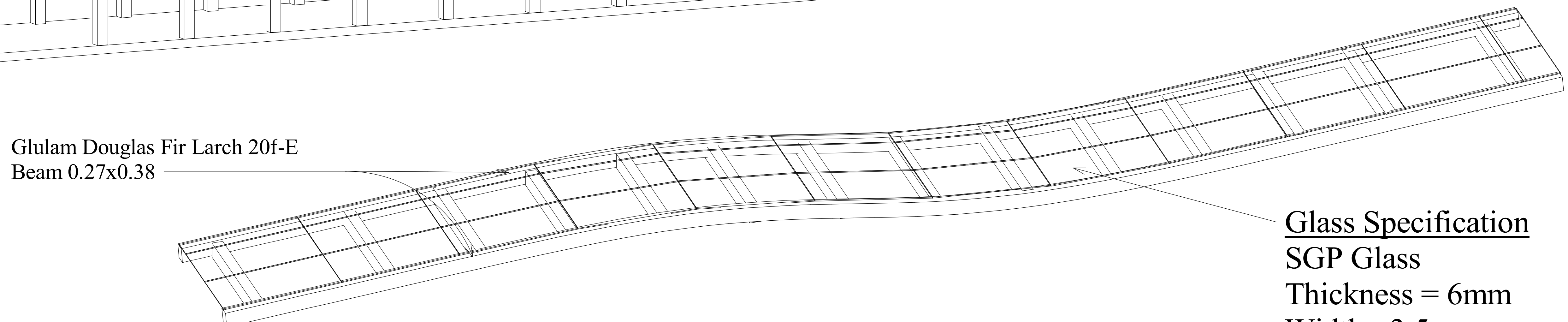
Project number	44610	S103
Date	April 6th, 2022	
Drawn by		
Checked by		Scale

NOT FOR CONSTRUCTION

All Dimensions expressed in Meters U.N.O



3D View



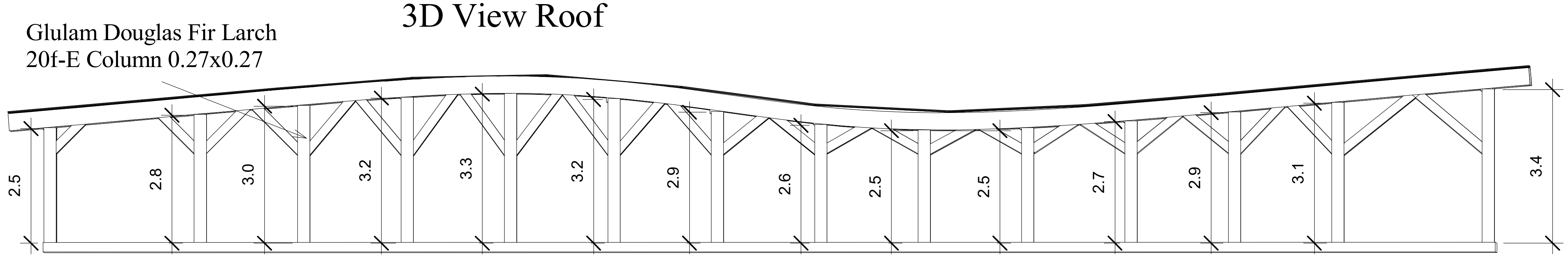
<u>Glass Specification</u>

SGP Glass

Thickness = 6mm

Width= 3.5m

3D View Roof



Min. Clearance Height = 2.5m

Side Profile

UBC Civil Engineering

UBC CIVIL

CIVL 446

Team 10

Wesbrook Mall Redesign Phase 4

No.	Description	Date
1	Preliminary Drawing	26/11/21
2	Final Drawing	04/06/22

Timber & Roof Design

Project number	44610
Date	April 6th, 2022
Drawn by	
Checked by	

S104

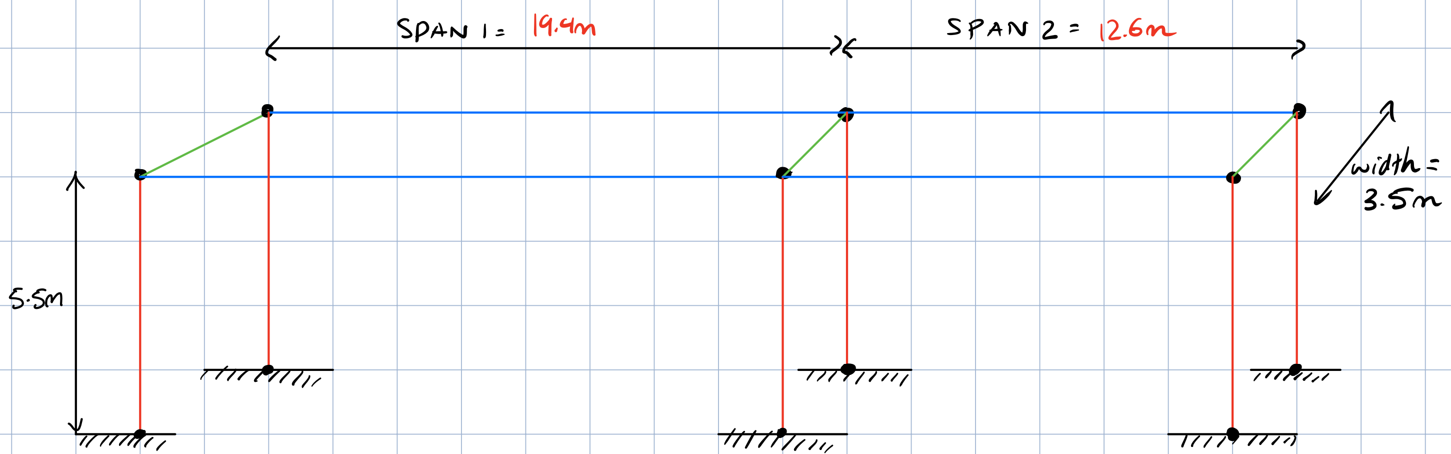
Scale

Appendix B: Pedestrian Overpass Structural Check

Pedestrian overpass Calculation

* To get the moments, shear, axial loads, we modeled our bridge on S-Frame *
* To get the capacity of members, we will use the Steel hand book and perform some hand calcs *
  → CISC HANDBOOK (12th Edition)

① Idealized Model

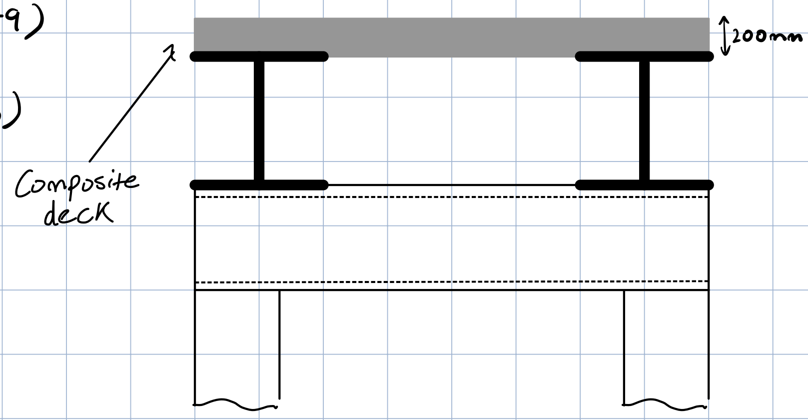


Columns (HSS×254×254×7.9)

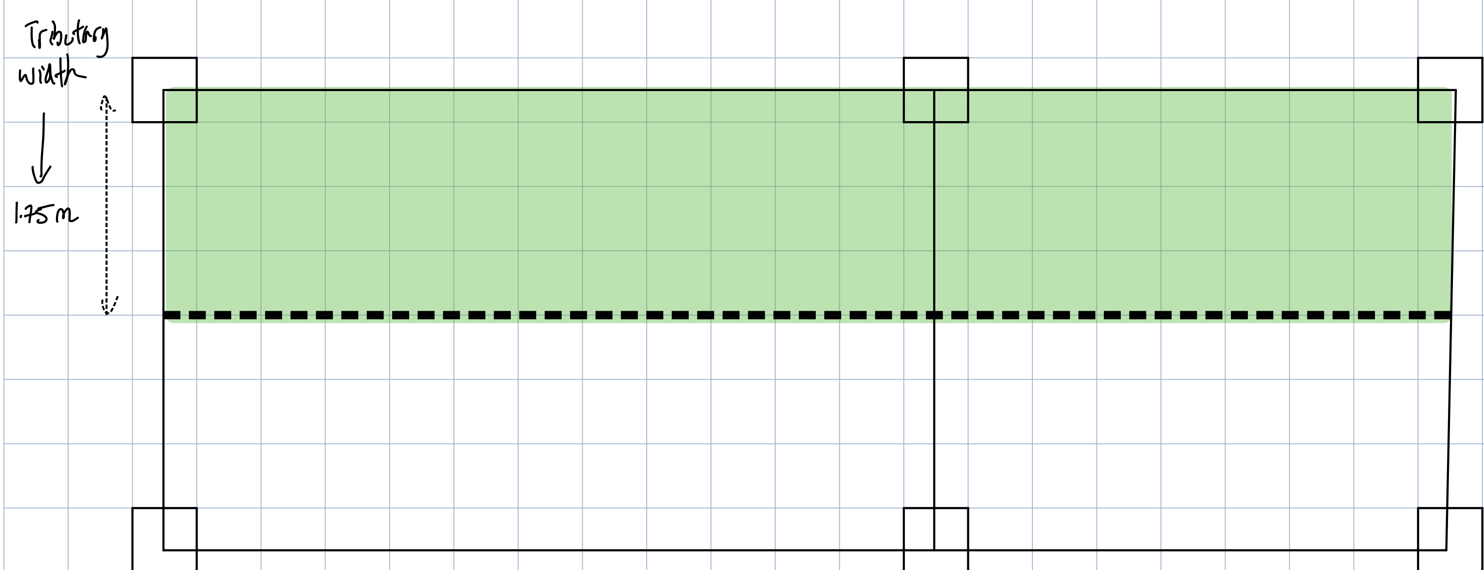
Pile Cap Beams (W360×79)

Girder Beam (W840×176)

Side View



Plan View



② Loading

- Refer to attached Excel sheet for Loading Calc.

LOAD CASES

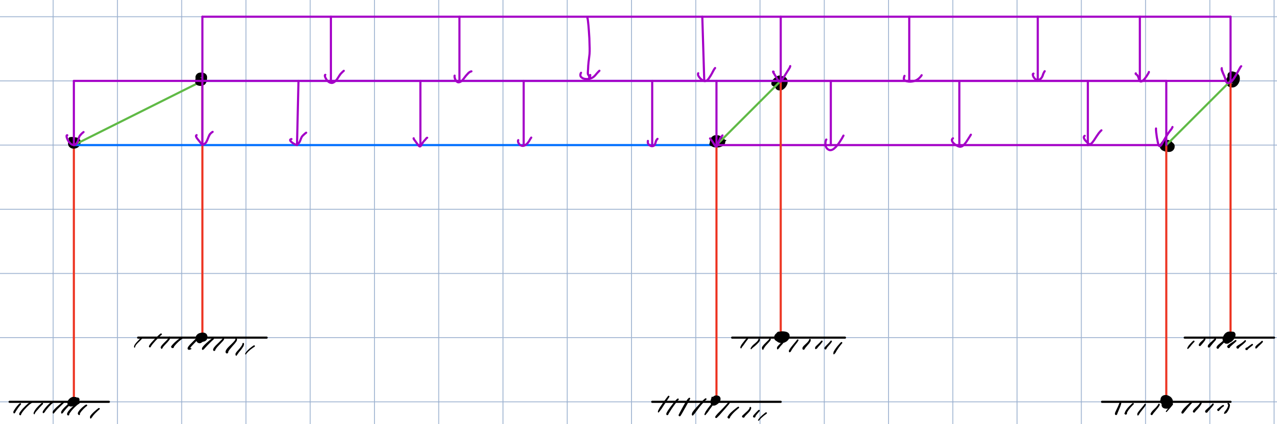
ULS1 = 1.4D
ULS2 = 1.25D + 1.5L
SLS = 1.0D + 1.0L

- Dead Load =
  - Self Weight of Structural members
  - Self weight of Slab (200mm thick)
  - Vertical glulam Columns (0.2731m x 0.2667m)
  - Curved glulam Beams (0.2731m x 0.3810m)
  - Glass on glulam Beam (PVB 6mm thick)
  - Wooden Bracing (0.2m x 0.2m)
  - Railing (Steel pipe railing)

} member sizes are subjected to change in detailed design

SLS must be used for deflection

- Live load =
  - pedestrian live load



Pedestrian Live Load Calculation

Formula: $P = 5 - S/30$ where $1.6kPa \leq P \leq 4.0kPa$
S = span (in m)

$P = 5 - 32/30 = 3.93\ kPa \rightarrow 4.0kPa$ (more conservative)

LL = 4.0kPa x tributary width => 4.0kPa x 1.75m = 7 kN/m

③ Girder Calculation (W840 x 176) ★ Refer to S-Frame results for diagrams ★

SPAN #1.) (CL= 19.4m) (Deflection Controlled) ★ All girders are laterally ★ Supported as it is a composite deck

- Max Deflection = L/360 => 19.4m/360 = 53.9 mm

S-FRAME Results

- Deflection = 42.3 mm
- Max Moment = 983.5 Knm
- Max Shear = 315.5 KN

Steel Book

- Moment Resistance = 2110 Knm
- Shear Resistance = 2180 KN

I) Deflection => 42.3 mm ≤ 53.88mm ✓
II) $M_r > M_{max}$ ✓
III) $V_r > V_{max}$ ✓

SPAN #2.) (CL= 12.6mm) (Deflection Controlled) ★ All girders are laterally ★ Supported as it is a composite deck

- Max Deflection = L/360 => 12.6/360 = 35mm

S-FRAME Results

- Deflection = 4.1 mm
- Max Moment = 930.1 Knm
- Max Shear = 247.1 KN

Steel Book

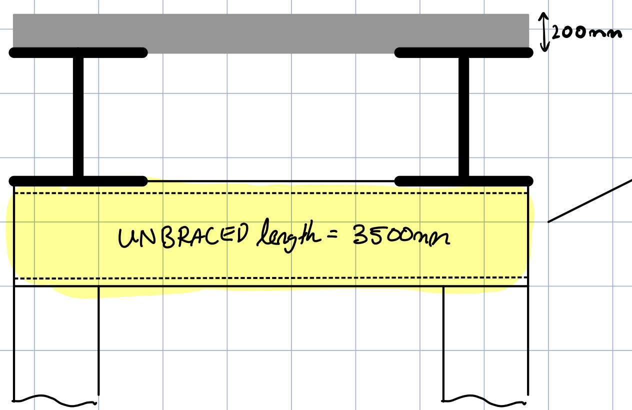
- Moment Resistance = 2110 Knm
- Shear Resistance = 2180 KN

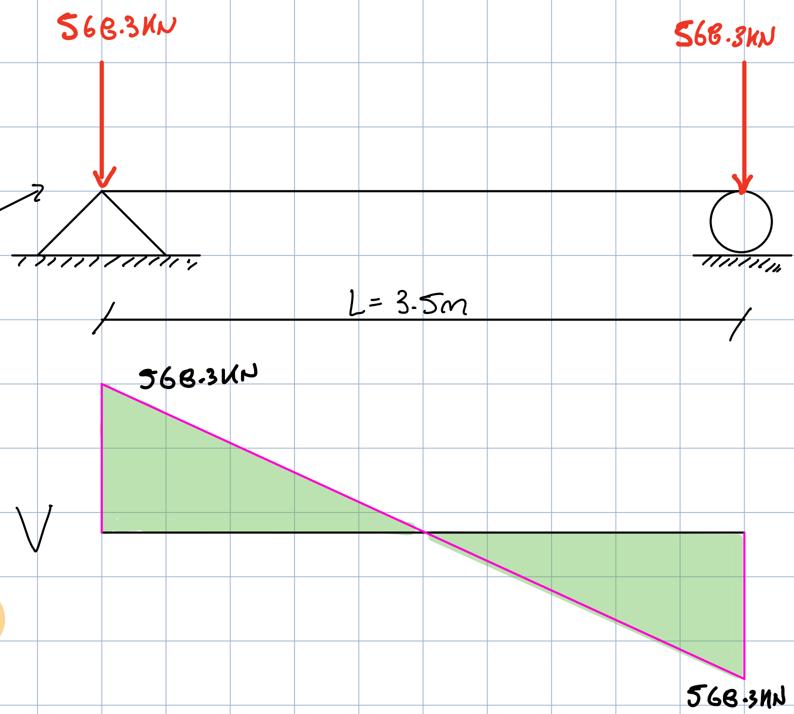
I) Deflection => 4.1 mm ≤ 35 mm ✓
II) $M_r > M_{max}$ ✓
III) $V_r > V_{max}$ ✓

④ Pile Cap Beam (W360×79)

• In our design, we will take the worst case results from S-Frame (In our case, it's the center pile cap beam)

Side View





Max Deflection => L/360 => 3.5m/360
= 9.7mm

S-FRAME Results

- Deflection = 4.0 mm
- Max Moment = 1.2 KNm
- Max Shear = 568.3 KN

Steel Book

(unbraced length of 3500mm)

- Moment Resistance = 425 KNm
- Shear Resistance = 620 KN

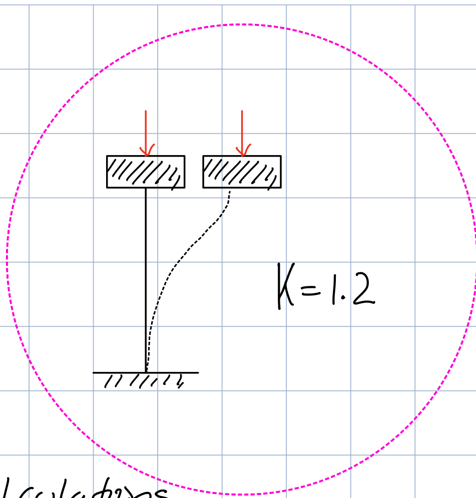
I) Deflection => 4.0 mm ≤ 9.7 mm ✓

II) $M_r > M_{max}$ ✓

III) $V_r > V_{max}$ ✓

⑤ Columns (HSS 254x254x7.9)

Max deflection = $h/500 = 5.5m/500 = 11mm$



S-FRAME Results

- Deflection = 4 mm
- Max Moment = 90.9 kNm
- Max Shear = 23.3 kN

Capacity Calculations

- $V_r = \phi A_w F_s$

$V_r = (0.9)(2(254-2(7.9))(7.9))(0.66 \times 350)$

$V_r = 782.4\ kN$

$\frac{h-2t_f}{t_f} \leq 439\sqrt{\frac{k_v}{F_y}}$

$9.7 \leq 54$

∴ Stocky

$V_r > V_{max}$ ☑

- $M_r = 170$ kNm (From Steel book)

$M_r > M_{max}$ ☑

- $C_f = 568.3\ kN$

$C_r = 1380$ kN (From Steel Book)

$C_r > C_{max}$ ☑

- **Slenderness Check**

$\frac{KL}{r} \leq 200$ (Steel code)

≤ 120 (Bridge code)

$\frac{(1.2)(5550mm)}{99.9mm} \leq 200$ ☑

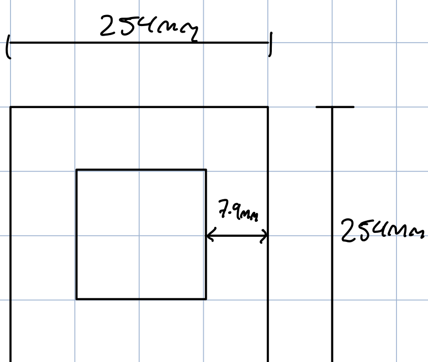
$\frac{(1.2)(5550mm)}{99.9mm} \leq 120$ ☑

- **Local Buckling Check**

$\frac{bel}{t} \leq \frac{670}{\sqrt{F_y}} \Rightarrow \frac{b-4t}{t} \leq \frac{670}{\sqrt{F_y}}$

$\Rightarrow \frac{254-4(7.9)}{7.9} \leq \frac{670}{\sqrt{350}}$

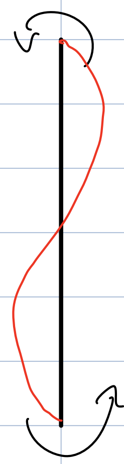
$28.1518 \leq 35.8$ ☑



Deflection

$4mm \leq 11mm$ ☑

Column-Beam Check (HSS 254x254x7.9)



$$\frac{C_f}{C_r} + \frac{0.85 U_{1x} M_{fx}}{M_{rx}} + \frac{0.5 U_{1y} M_{fy}}{M_{ry}} \le 1.0$$

U_{1x}

↗ positive as it is double curvature

$$\omega_1 = 0.6 - 0.4K \ge 0.4$$

$$= 0.6 - 0.4\left(\frac{0.29}{0.29}\right)$$

$$= 0.2 \ge 0.4 \Rightarrow \omega_1 = 0.4$$

$$C_{ex} = \frac{\pi^2 E I_x}{L^2} = \frac{\pi^2 (200E3)(76.5\,E6\,mm^4)}{(5500\,mm)^2}$$

$$C_{ex} = 4991.9\,kN$$

$$\therefore U_{1x} = \left(\frac{\omega_1}{1 - \frac{C_f}{C_{ex}}}\right) = \left(\frac{0.4}{1 - \frac{568.3\,kN}{4991.9\,kN}}\right) = 0.45 \rightarrow 1.0 \text{ (more conservative)}$$

U_{1y}

$$\omega_1 = 0.6 - 0.4K \ge 0.4$$

$$= 0.6 - 0.4\left(\frac{37.3\,kNm}{90.9\,kNm}\right) \Rightarrow \omega_1 = 0.4358$$

$$\hookrightarrow 0.4358 \ge 0.4$$

$$C_{ey} = 4991.9\,kN$$

$$U_{1y} = \left(\frac{0.4358}{1 - \frac{568.3\,kN}{4991.9\,kN}}\right) = 0.49 \rightarrow 1.0 \text{ (more conservative)}$$

$$\frac{568.3}{1380} + \frac{0.85(1.0)(0.29\,kNm)}{170\,kNm} + \frac{0.5(1.0)(90.9\,kNm)}{170\,kNm} \le 1.0$$

$$0.68 \le 1.0$$

✓

Foundation Calcs (shallow foundation)

① Determine required Area

- From the geotechnical report (Appendix E), we know that top 5 meters is composed is dense to very dense sand.
- From our CIVL 430, the allowable bearing pressure is 150 KPa (Assuming a factor safety of 2-3 was used)

② Loading (LL + D.L)

According to our S-Frame model, the unfactored dead or live load is 426.3 KN

③ Find preliminary pad size

$$\text{PAD Area} = \frac{426.3\,KN}{150\,kPa} = 3.1093\,m^2 = B^2$$

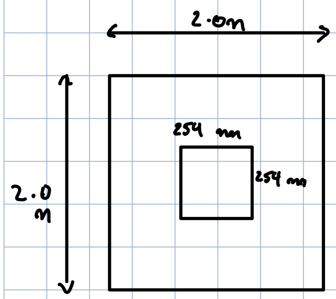
$B^2 = 3.1093\,m^2$ ∴ $B = 1.763\,m$ (preliminary size)

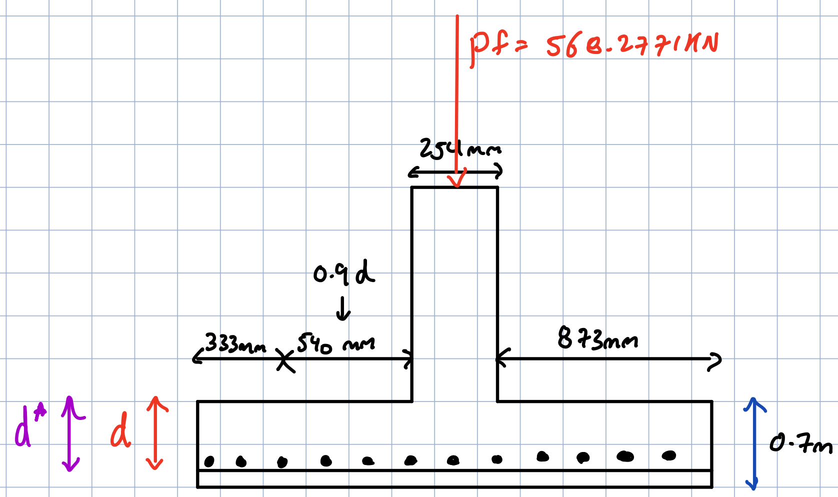
CIVL446 (Detailed Design)

HAND CALCULATIONS (Foundation Design)

- According to our S-FRAME MODEL the factored load is 568.2771KN
- To satisfy the geotechnical requirements, we will update the pad size to 2m x 2m.

① Gather information





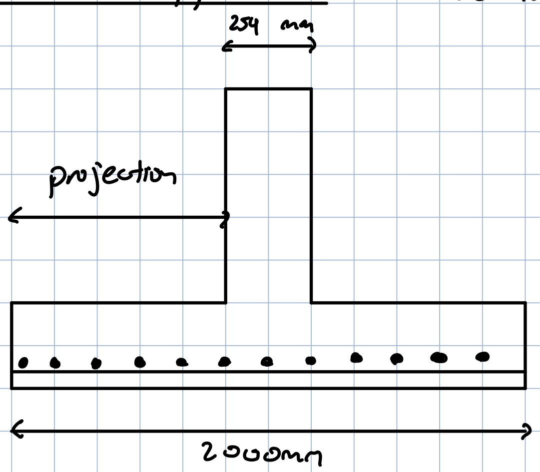
Material info

$f'c = 25MPa$

$fy = 400 MPa$

- $d = 700\ mm - 75mm - (25mm \times 1.5) = 587.5mm$ (used for moments)
- $d^* = 700mm - 75 - 25/2\ mm = 612.5mm$
- $d(shear) = d + d^*/2 = 600mm$ (used for shear)

② Check if $\beta = 0.21$ applicable (Do we need to account for size effect?)



Condition: projection $\leq 2 d_v$ ☑

$873mm \leq 2(0.9)(600mm)$

$873mm \leq 1080mm$

[$\beta = 0.21$ appliable!]

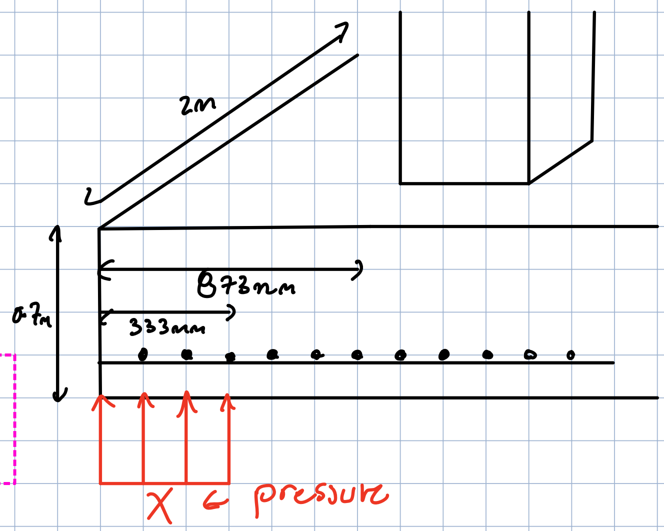
③ Checking one-way shear resistance ($V_r \geq V_f$)

- $V_r = V_c = \phi_c \beta \sqrt{f'_c}\, b_w . d_v = 0.65 \times 0.21 \times \sqrt{25} \times 2000 \times 0.9 \times (600mm) = 737.1 KN$

- $X = \dfrac{568.2771 KN}{2m \times 2m} = 142.1 KPa$

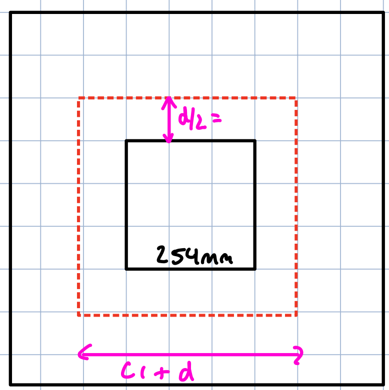
→ V @ d_v from column face = 142.1 kPa × 2m × 0.333

= 94.6 KN



$V_r \geq V_f \rightarrow 737.1 KN \geq 94.6 KN$

④ Checking two-way shear resistance



$b_o = (c_1 + d)(2) + (c_2 + d)(2)$ ($c_1 = c_2$ square)

$= (254mm + 600mm) \times 4$

$b_o = 3416mm$

$d/2 = 300mm$

Two way shear resistance

I) $V_r = (1 + 2/\beta_c)(0.19)\, \phi_c \sqrt{f'_c} \leq 0.38\, \phi_c \sqrt{f'_c}$

$= (1 + 2/1)(0.19)(0.65)(\sqrt{25}) \leq 0.38 \times 0.65 \times \sqrt{25}$

$V_r = 1.8525 MPa \leq 1.235 MPa$

II) $V_r = (\alpha_s d / b_o + 0.19)(\phi_c) \sqrt{f'_c} = \left(\dfrac{2 \times 600}{3416\ mm} + 0.19\right)(0.65) \times \sqrt{25} = 1.76 MPa$

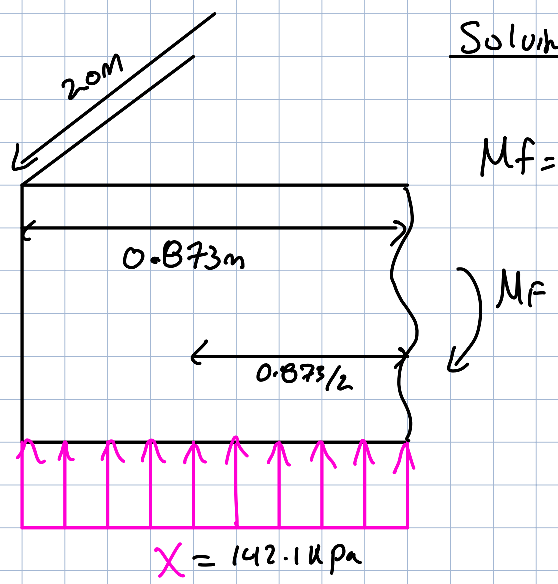
CASE I governs $\therefore V_r = 1.235 MPa$

Vf @ d/2 away from column

$$V_f = \frac{142.1\,kPa\,(2m^2 - 0.854m^2)}{3416\,mm \times 600\,mm} = 0.226\,MPa$$

$$V_r \geq V_f \rightarrow 1.235\,MPa \geq 0.226\,MPa$$

⑤ Ensure flexural capacity of footing is greater than Mf



Solving for Mf @ column face

$$M_f = 142.1\,kPa \times 2.0m \times 0.873m \times \frac{0.873m}{2} = 108.298\,kNm$$

Solving for As

$$M_r = \phi f_y A_s \left(d - \frac{\phi A_s f_y}{2\alpha_1 \phi_c f'_c b}\right)$$

$$108.298\,kNm = 0.85 \times 400\,MPa \times A_s \left(587.5 - \frac{0.85 \times 400\,MPa \times A_s}{2 \times 0.81 \times 0.65 \times 25\,MPa \times 2000\,mm}\right)$$

$$A_s \geq 545.437\,mm^2$$

lets provide 3-25M BARS ($A_s = 3 \times 500 = 1500\,mm^2$)

SAMPLE CALCULATIONS

Composite deck

- For our composite deck, we have W840x176 girder + 200mm ribbed slab

Step ① Calculate effective slab width

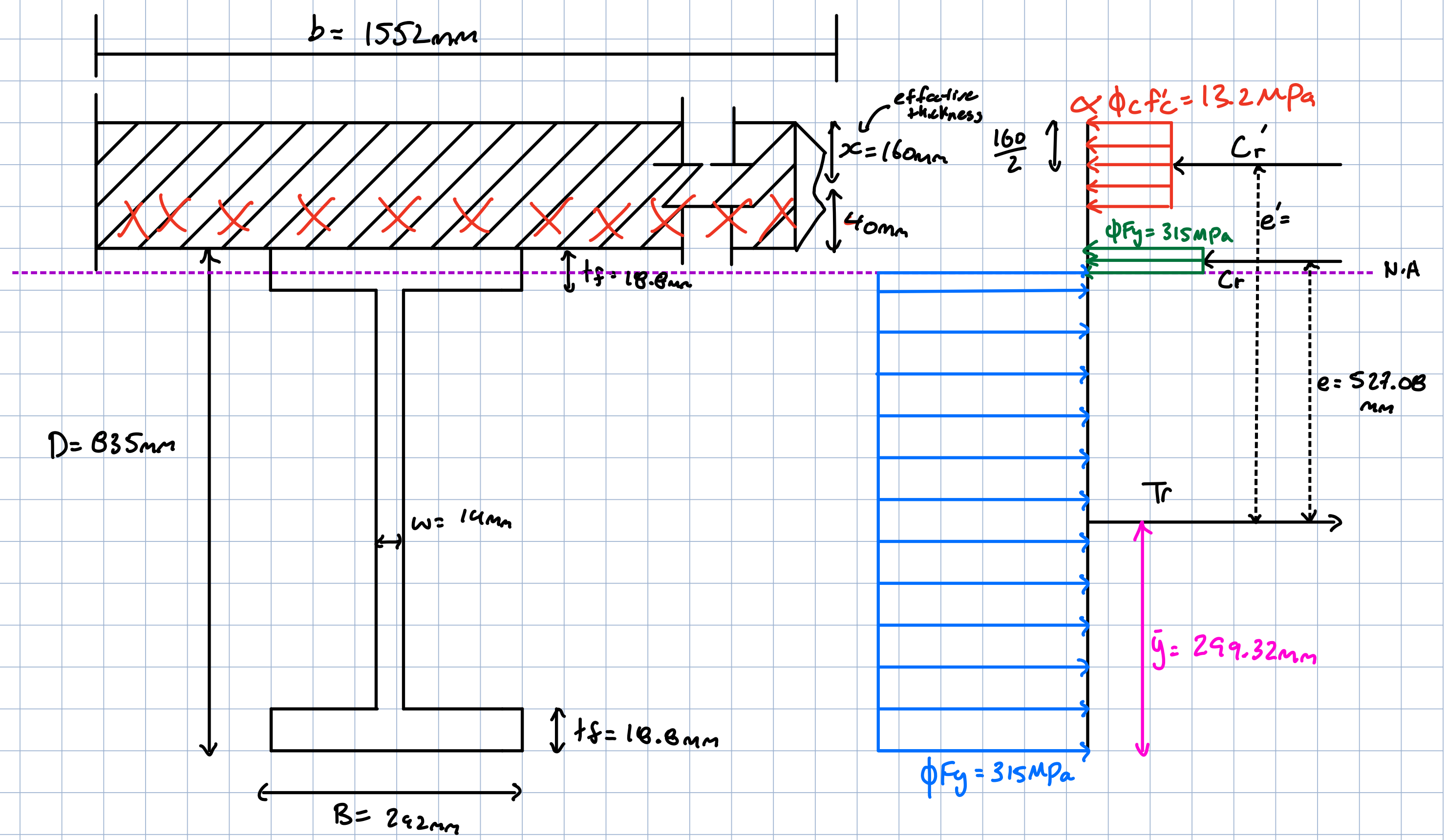
$$b_{effective} = \text{Min.} \begin{cases} \text{i) } 292mm + (0.1 \times 12.6m \times 1000) = 1552mm \\ \text{ii) } 292mm + \frac{1}{2}(3500) = 2042mm \end{cases}$$

$\therefore$ $b_{eff} = 1552mm$

Step ② Assume CASE #1.) (N.A in the slab)

$$a = \frac{\phi A_s F_y}{\alpha_1 \phi_c f'_c b} = \frac{(0.9)(22400mm^2)(350MPa)}{(0.805)(0.65)(30MPa)(1552mm)} = 289.63mm > 200mm$$

$\therefore$ We are in CASE #2.), the N.A is within the steel section



Step ③ Determine Cr' & Cr

$Cr' = \alpha_1 \phi_c f'_c\, b\, t = 0.805 \times 0.65 \times 30 \times 1552mm \times 160mm = 3898.0032 KN$

$Cr = \dfrac{\phi A_s F_y - Cr'}{2} = \dfrac{0.9(22400mm^2)(350MPa) - 3898.0032E3N}{2} = 1579 KN$

Step ④ Solve for df (Assume N.A is in the flange of the steel section)

$Cr = \phi b_f d_f F_y$

$\hookrightarrow d_f = \dfrac{Cr}{\phi F_y b_f} = \dfrac{1579E3N}{0.9 \times 350 \times 292mm} = 17.2mm < 18.8mm$ ✓

Step ⑤ Solve for $\bar{y}$

$\bar{y} = \dfrac{22400(835/2) - 292(17.2m)(835 - 17.2/2)}{22400 - 292 \times 17.2} = 299.32mm$

Step ⑥ Solve for e & e'

- $e = d - \bar{y} - d_f/2 = 835 - 299.32mm - 17.2/2 = 527.08mm$
- $e' = d - \bar{y} + t - \dfrac{x}{2} = 835mm - 299.32mm + 17.2mm - \dfrac{160mm}{2} = 655.68mm$

$\therefore$ $M_r = Cr\,e + Cr'\,e' = 1579KN \times \dfrac{527.08mm}{1000} + 3898.0032KN \times \dfrac{655.68m}{1000}$

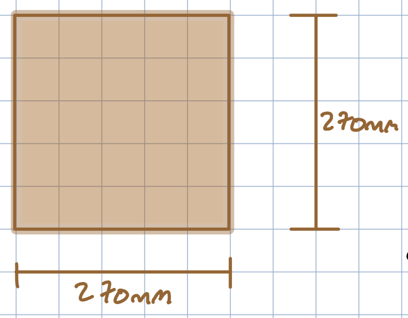
$= 3388.1 KN\,m$ (w/o composite deck $M_r = 2110 KNm$)

$M_r \geq M_f \rightarrow 3388.1 KNm \geq 983.5 KNm$

Sample Calculation for timber structure above (Used CSA O87)

- **Calculation Axial capacity of timber column (taking longest column)**

Step ① Gather Material & Geometric Properties (Column C_{1-1} is Douglas Fir 270mm x 270mm 20f-E)



- AREA = $b \times d$ = 270mm x 270mm = **72900mm²**
- Section Modulus = $bd^2/6$ = $270mm \times 270mm^2/6$ = **3280500mm³**
- Moment of inertia = $\frac{270 \times 270^3}{12}$ = **442867500 mm⁴**
- Volume = $b \times d \times l$ = 0.27m x 0.27m x 3.3m = **0.24057m³**
- Length = **3300 mm**

Material properties

FROM TABLE 7.2 (Douglas Fir LARCH)

- f_c (Compression parallel) = **30.2MPa**
- E = **12400 MPa**

Step 3) Modification factors

1. For glulam modification factors, refer to clause 7.4 in the CSA O86
2. Load duration factor K_D [Clause 7.4.1 TABLE 5.1] → **K_d = 1.0**
3. System factor K_H [Clause 7.4.4]
   ↳ System that consist of three or more essentially parallel members spaced not more than 610mm apart ☒
   K_H = 1.0
4. Service condition factor K_{se} [Clause 7.4.2, Table 7.3] = **K_{se} = 0.75** (Wet Service condition)
5. Treatment factor K_T [Clause 7.4.3] = **K_T = 0.9** (ACQ treatment → Assumed)
6. Size factor K_{Zcg} [Clause 7.5.8.5] $K_{Zcg} = \min[0.68(Z)^{-0.13}, 1.0]$

$$K_{Zcg} = \min[0.68(0.24057)^{-0.13}, 1.0] = 0.818$$

Step 4) Effective length [Clause 7.5.8.1]

$$L_e = K_e L$$

where $K_e = 1.0$

$L = 3300\ mm$

$\therefore L_e = 1.0 \times 3000\ mm = 3300\ mm$

Step 5) Slenderness Ratio C_c [Clause 7.5.8.2]

$$C_c = \max\left[\frac{K_e L_b}{b}, \frac{K_e L_d}{d}\right] \leq 50$$

$$= \max\left[\frac{3300}{270}, \frac{3300}{270}\right] \leq 50 \quad = \text{MAX}\left[12.22, 12.22\right] \leq 50$$

Step 6) Calculate E_{05} [Clause 7.5.8.6]

$$E_{05} = 0.87E$$

$E_{05} = 0.87 \times 12400\ MPa = 10788\ MPa$

Step 7) Compressive Resistance parallel to grain [Clause 7.5.8.5]

$$P_r = \phi F_c A K_{Zcg} K_c$$

① Determine F_c

$F_c = f_c (K_D K_H K_{Sc} K_T) = 30.2\ MPa (1.0 \times 1.0 \times 0.75 \times 0.9)$

$= 20.385\ MPa$

$$K_c = \left[1 + \frac{F_c K_{Zcg} C_c^3}{35 E_{05} K_{SE} K_T}\right]^{-1}$$

② Write P_r (For K_C formula, refer to clause 7.5.8.6)

$$P_r = 0.8 \times 20.385\ MPa \times 270\ mm \times 270\ mm \times 0.818 \times \left[1.0 + \frac{20.385\ MPa \times 0.818 \times 12.22^3}{35 \times 10788\ MPa \times 0.85 \times 0.9}\right]^{-1}$$

$P_r = 879.8\ kN$

• From the excel sheet, each column experiences a load of 7.03 KN.

∴ $P_r \geq P_f \rightarrow 879.8\,KN \geq 7.03\,KN$ ✓

Checking Beam against moment & shear (Assume Beam is straight for simplification)

Douglas Fir Beam 20f-E (270mm x 380mm)

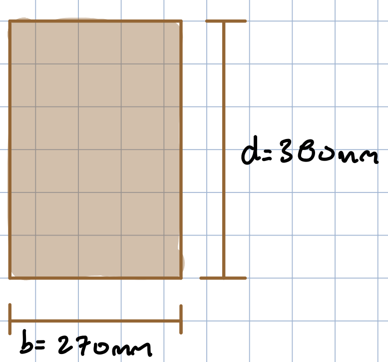
→ glulam Beam: to get material properties, lets refer to Clause 7.3 & Table 7.2

FROM TABLE 7.2 (Douglas Fir-Larch)

- f_b (Bending moment pos.) = 25.6 MPa • E = 12 400 MPa
- f_v (longitudinal shear) = 2.0 MPa

Geometrical properties

20F-E DF (270mm×380mm)



- L = 33.8347 m
- A = 102 600 mm²
- $S = \frac{bd^2}{6} = \frac{270\times380^2}{6} = 6498\,000\,mm^3$
- $I = \frac{bd^3}{12} = \frac{270\times380^3}{12} = 1234620\,000\,mm^4$
- $Z = 0.27\times0.38\times33.8347 = 3.471\,m^3$

STEP 3) MODIFICATION FACTORS

1. For glulam modification factors, refer to clause 7.4 in the CSA O86
2. Load duration factor K_D [Clause 7.4.1 TABLE 5.1] → $K_d = 1.0$
3. System factor K_H [Clause 7.4.4]

↳ System that consist of three or more essentially parallel members spaced not more than 610mm apart ☒

$K_H = 1.0$

4. Service condition factor K_{SB} [Clause 7.4.2, Table 7.3] $K_{SB} = 0.80$ (wet service condition)

5. Treatment factor K_T [Clause 7.4.3] $K_T = 0.9$ (ACQ Treatment → assumed)

6. Curvature factor → $K_X = 1 - 2000\left(\frac{t}{R}\right)^2$ $K_X = 1.0$ [Clause 7.5.6.5.2]

7. size factor for glulam beams K_{zbg} [Clause 7.5.6.5.1]

$$K_{zbg} = \left(\frac{130}{b}\right)^{1/10}\left(\frac{610}{d}\right)^{1/10}\left(\frac{9100}{L}\right)^{1/10} \leq 1.3$$

$$K_{zbg} = \left(\frac{130}{270}\right)^{1/10} \times \left(\frac{610}{380}\right)^{1/10} \times \left(\frac{9100}{3100}\right)^{1/10} \leq 1.3$$

$K_{zbg} = \min[1.08537, 1.3]$ ∴ $K_{zbg} \doteq 1.08537$

8. Lateral stability factor K_L [Clause 7.5.6.4]

L_e [TABLE 7.4] = effective Length → intermediate support? (yes)

↳ 1.92(3.1m) = 5952mm

$L_e = 5952mm$

- Beam slenderness Ratio $C_B = \sqrt{\frac{L_e d}{b^2}}$

$C_B = \sqrt{\frac{5952 \times 380}{270^2}} = 5.57$ Since C_B is less than 10 ∴ $K_L = 1.0$)

↳ $K_L = 1.0$

STEP 4) BENDING MOMENT RESISTANCE OF GLULAM [FROM Clause 7.5.6.5]

$$M_R = \min(M_{r1}, M_{r2}) = \min \begin{cases} \phi F_b S K_{Zbg} K_X \\ \phi F_b S K_L K_X \end{cases}$$

where $\phi = 0.9$

① Calculate Fb

$F_b = f_b(K_D K_H K_{Sb} K_T)$

$= 25.6\text{MPa}(1.0 \times 1.0 \times 0.80 \times 0.9) = 18.432\text{MPa}$

② Calculate M_{r1}

$M_{r1} = \phi F_b S K_{Zbg} K_X$

$= 0.9 \times 18.432\text{MPa} \times 6498000\text{mm}^3 \times 1.08537 \times 1.0$

$M_{r1} = 116.997\text{KNm}$

③ Calculate M_{r2}

$M_{r2} = \phi F_b S K_L K_X$

$= 0.9 \times 18.432\text{MPa} \times 6498000\text{mm}^3 \times 1.0 \times 1.0$

$M_{r2} = 107.8\text{KNm}$

④ Determine Mr

$M_r = \min[116.997\text{KNm}, 107.8\text{KNm}] = 107.8\text{KNm}$

⑤ Checking against Mf (Check Excel)

$M_f = 1.24\text{KNm}$ $M_r = 107.8\text{KNm}$

$M_f <<< M_R$ ✓

$1.24\text{KNm} << 107.8\text{KNm}$

Given that the moment resistance is much larger that the moment demand, the curvature of the Beam shouldn't affect the capacity so much to render the Beam insufficient in Bending

STEP 4 SHEAR RESISTANCE OF GLULAM [CLAUSE 7.5.7.3]

- Recall: Volume of Beam = 3.471m^3

Since members / Beams is more than 2.0m^3 in volume, $W_r = \phi F_v(0.48)(A_g)(C_v)Z^{-0.18}$

① Calculate Ag

$A_g = b \times d = 270\text{mm} \times 380\text{mm} = 102600\text{mm}^2$

② Calculate Fv

- Recall, $f_v = 2.0$ MPa (TABLE 7.2) ($K_{sv} = 0.87$ (longitudinal shear))

- $F_v = f_v(K_D K_H K_{sv} K_T)$

$F_v = 2.0\text{ MPa}(1.0 \times 1.0 \times 0.87 \times 0.9) = 1.566\text{ MPa}$

③ Calculate Cv

$C_v = 3.69$ (TABLE 7.8 clause 7.5.7.6)

③ Calculate Wr

$W_r = 0.9 \times 1.566\text{ MPa} \times 0.48 \times 102600\text{ mm}^2 \times 3.69 \times 3.471^{-0.18} = 204.723\text{ kN}$

④ Checking Wf against Wr ☆

- $W_f = 69.78$ kN (SW from both Beams are included)
- $W_r = 204.723$ kN

$W_f < W_r$

$69.78\text{ kN} < 204.723\text{ kN}$ ✓

Appendix C: Self Weight Calculation

Project: Wesbrook Mall Redesign - Phase 4 (Pedestrian Overpass Load)	Group: 10	Designed By:
Subject: CIVL 445 & CIVL 446 - Civil Engineering Design Project I & II	Date: 2021-11-23 (Updated: 2022-03-31)	Checked By:

References
Bridge Standards and Procedures Manual - Volume 1 - Section 3 - Loads
CSA S6:19, Canadian Highway Bridge Design Code
GIB - LD 08-0909 - Weight of Laminated Architectural Glass

*NOTE: Yellow Highlighted cells are actually 0 but are inputted as 1 in order to use a consistent load calculation formula

*NOTE: 10% Extra is to account for connections, bolts, etc.

Assumptions
Load from roof is distributed to columns supporting roof
Load from columns supporting roof are transferred to girders
Load from deck and railing is distributed along girders

Item Loading		
Creosote treated sawn timber and glulam, >114 mm	6.6	kN/m^3
Architectural Flat Glass - 6.0 mm thickness	14.6	kg/m^2
Architectural Flat Glass - 6.0 mm thickness	0.1	kN/m^2
Steel	77.0	kN/m^3
Reinforced concrete	24.0	kN/m^3

Glulam Beam & Glass Roof Structure	Length (m)	x	Width (m)	x	Height (m)	Load per Item (kN/m^3)	Required No. of Items	Total Load (kN)	
Glulam Beam	33.83	x	0.27	x	0.38	6.6	2	46.47	
Glass Roof	33.83	x	3.5	x	1	0.1	1	16.96	
							Subtotal	63.43	kN
							10% Extra	6.34	kN
							Total	69.78	kN

Glulam Columns Supporting Roof	Length (m)	x	Width (m)	x	Volume (m^3)	Load per Item (kN/m^3)	Required No. of Items	Total Load (kN)	
Glulam Column 1	-	x	-	x	0.18	6.6	2	2.39	
Glulam Column 2	-	x	-	x	0.20	6.6	2	2.68	
Glulam Column 3	-	x	-	x	0.22	6.6	2	2.88	
Glulam Column 4	-	x	-	x	0.23	6.6	2	3.05	
Glulam Column 5	-	x	-	x	0.24	6.6	2	3.13	
Glulam Column 6	-	x	-	x	0.23	6.6	2	3.02	
Glulam Column 7	-	x	-	x	0.21	6.6	2	2.75	
Glulam Column 8	-	x	-	x	0.19	6.6	2	2.47	
Glulam Column 9	-	x	-	x	0.18	6.6	2	2.35	
Glulam Column 10	-	x	-	x	0.18	6.6	2	2.39	
Glulam Column 11	-	x	-	x	0.19	6.6	2	2.55	
Glulam Column 12	-	x	-	x	0.21	6.6	2	2.73	
Glulam Column 13	-	x	-	x	0.22	6.6	2	2.93	
Glulam Column 14	-	x	-	x	0.24	6.6	2	3.22	
							Subtotal	38.53	kN
							10% Extra	3.85	kN
							Total	42.38	kN

Concrete Deck and Railing	Length (m)	x	Width (m)	x	Height (m)	Load per Item (kN/m^3)	Required No. of Items	Total Load (kN)	
Concrete Deck	32	x	3.81	x	0.2	24.0	1	584.57	
Top Rail	32	x	0.05	x	0.07	77.0	2	16.56	
Bottom Rails	32	x	1	x	1.26E-05	77.0	8	0.25	
					Area (m^2) ↑		Subtotal	601.38	kN
							10% Extra	60.14	kN
							Total	661.51	kN

Total Load on Girders	**773.67**	kN
Distributed Load on Girders	**24.18**	kN/m
Distributed Load per Girder	**12.09**	kN/m

Total Load on Columns (conservative since both beams are included)	**69.78**	kN
Total Distributed Load on Columns	**2.06**	kN/m
Max Column Tributary Width	**2.55**	m
Max Load on Column	**5.26**	kN
Max Self Weight of Column	**1.77**	kN
Max Load at Column Base, Pf	**7.03**	kN

Total Load on Columns, Wf (conservative since both beams are included)	**69.78**	kN
Total Distiributed Load on Glulam Beams	**2.06**	kN/m
Distributed Load per Glulam Beam	**1.03**	kN/m
Glulam Beam Moment, Mf (conservative since simply supported over largest span)	**1.24**	kN*m
Glulam Beam Shear, Vf (conservative since simply supported over entire length)	**1.60**	kN

Appendix D: Cost Estimate

	Description	Unit Cost ($CAD)	Units	Quantity	Total Cost ($CAD)
Pedestrian Overpass	Cost by weight (W840x176)	0.64	$/kg	11264	$7,177
	Cost by weight (HSS 354x254x8)	0.64	$/kg	4062.76	$2,589
	Cost by weight (W360x79)	0.64	$/kg	1501	$956
	Cost by Volume (Douglas Fir)	3426.88	$/cu.m	6.94	$23,783
	Cost by Volume (Douglas Fir)	3426.88	$/cu.m	6.98	$23,920
	Cost by Area (Glass - PVB)	12.72	$/sq.m	126	$1,603
	Cost per length (Steel)	146	$/m	123	$17,958
	Cost by Area (Concrete)	80	$/step	74	$5,920
	Cost by Area (Concrete)	85.53	$/sq.m	13.06	$1,117
	Cost by Area (Concrete)	85.53	$/sq.m	30.98	$2,649
	Cost by Area (Concrete)	85.53	$/sq.m	122.74	$10,498
Road Rehabilitation	Remove and Install Concrete Panels	1200	$/panel	365	$438,000
	Full Road Repair	1779168	$/km	1.43	$2,544,210
	Bicycle Lane	450	$/km	1500	$675,000
	Vegetation Buffer	43	$/Linear m	750	$32,250
	Median Retrofit	60	$/Sq.m	160	$9,600
	Bus Pad Fill In	3010	$/Fill	1	$3,010
	Curb and Gutter	80	$/m	1400	$112,000
	Tree Removal	2500	$/Tree	5	$12,500
	Signage	200	$/Sign	20	$4,000
	Pavement Lines	351.2	$/Lane-km	3.75	$1,317
	Pavement Symbols	547.8	$/Symbol	35	$19,173
Traffic Control Personnel (TCP)	Traffic Control Signs/Baricades/Delineators	51.12	$/item	30	$1,534
	Personnel	11,904	$/case	1	$11,904
Other	Labour	20% of Materials			$790,984
	Materials	Listed Above			$3,184,460
	Project Management	7-15% of Labour and Materials			$438,771
	Architecture	10% of Labour, Materials, and Project Management			$442,760
	Engineering	15% of Total Cost			$728,545
	Preconstruction/Permits	Assumed Value			$75,000
	Municipal Connection Fees	Assumed Value			$100,000
	Escalation	5% of Materials, Project Management, and Labour			$258,949
	Contingency	6% of Materials and Labour			$284,413
	GST	5% of All Costs			$323,856
		Total Project Cost			**$7,520,661**

Description	Sources
Cost by weight (W840x176)	https://www.focus-economics.com/commodities/base-metals/steel-usa
Cost by weight (HSS 354x254x8)	
Cost by weight (W360x79)	
Cost by Volume (Douglas Fir)	https://www.bucklandtimber.co.uk/glulam-beam-cost-calculator/
Cost by Volume (Douglas Fir)	
Cost by Area (Glass - PVB)	https://tsingglass.en.made-in-china.com/product/sBTQzJhxaqrF/China-6-38mm-8-38mm-8-76mm-PVB-Colored-and-Clear-Tempered-Laminated-Glass-Price-for-Building-Curtain-Wall-Windows-Doors.html
Cost per length (Steel)	https://www.costimates.com/costs/decks-outdoor-living/metal-deck-railing
Cost by Area (Concrete)	https://www.concretenetwork.com/concrete-prices.html
Cost by Area (Concrete)	
Cost by Area (Concrete)	
Cost by Area (Concrete)	
Remove and Install Concrete Panels	https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/contracting-with-the-province/documents/costguide-2013.pdf
Full Road Repair	https://www2.gov.bc.ca/assets/gov/driving-and-transportation/transportation-infrastructure/contracting-with-the-province/documents/costguide-2013.pdf
Bicycle Lane	http://www.transportation.alberta.ca/content/doctype257/production/unitpricelist.pdf
Vegetation Buffer	
Median Retrofit	
Bus Pad Fill In	
Curb and Gutter	*Quoted from City of Surrey Email
Tree Removal	
Signage	http://www.transportation.alberta.ca/content/doctype257/production/unitpricelist.pdf
Pavement Lines	
Pavement Symbols	
Traffic Control Signs/Baricades/Delineators	https://www.columbus.gov/uploadedfiles/Public_Service/Transportation/Mobility/Estimated%20Costs%20FINAL.pdf
Personnel	
Labour	https://clockify.me/blog/business/project-cost-management/#How_to_calculate_project_management_costs
Materials	
Project Management	https://clockify.me/blog/business/project-cost-management/#How_to_calculate_project_management_costs
Architecture	
Engineering	https://www.engineeringdesignresources.com/tag/how-to-estimate-engineering-design-cost-as-percentage-of-construction-cost/
Preconstruction/Permits	
Municipal Connection Fees	
Escalation	https://www.levelset.com/blog/construction-contingency/#:~:text=A%20contractor%20contingency%20is%20an%20amount%20built%20into,contractor.%20Acc
Contingency	
GST	

Appendix E: Traffic Analysis Reports

Synchro Reports

AM Peak

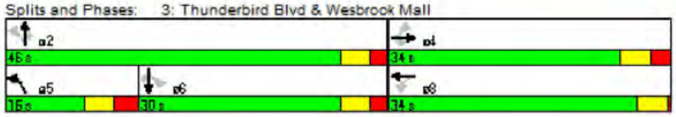
Lanes, Volumes, Timings
3: Thunderbird Blvd & Wesbrook Mall 2021-12-02

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Turning Speed (k/h)	25		15	25		15	25		15	25		15
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	0.78		0.51	0.57	0.96		0.90		0.73	0.84		0.75
Frt			0.850		0.982				0.850			0.850
Flt Protected	0.950			0.950			0.950			0.950		
Satd. Flow (prot)	1770	1863	1583	1770	1752	0	1770	1863	1583	1770	1863	1583
Flt Permitted	0.549			0.700			0.369			0.564		
Satd. Flow (perm)	800	1863	803	747	1752	0	618	1863	1164	883	1863	1195
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)			64		10				186			191
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
Link Speed (k/h)		50			50			50			50	
Link Distance (m)		277.6			392.8			540.3			336.0	
Travel Time (s)		20.0			28.3			38.9			24.2	
Volume (vph)	74	58	38	95	110	24	235	273	150	33	249	155
Confl. Peds. (#/hr)	133		193	193		133	92		100	100		92
Peak Hour Factor	0.69	0.66	0.59	0.64	0.55	0.86	0.86	0.84	0.56	0.75	0.83	0.81
Adj. Flow (vph)	107	88	64	148	200	28	273	325	268	44	300	191
Lane Group Flow (vph)	107	88	64	148	228	0	273	325	268	44	300	191
Turn Type	Perm		Perm	Perm			pm+pt		Perm	Perm		Perm
Protected Phases		4			8		5	2			6	
Permitted Phases	4		4	8			2		2	6		6
Minimum Split (s)	31.3	31.3	31.3	33.3	33.3		12.5	21.9	21.9	28.9	28.9	28.9
Total Split (s)	34.0	34.0	34.0	34.0	34.0	0.0	16.0	46.0	46.0	30.0	30.0	30.0
Total Split (%)	42.5%	42.5%	42.5%	42.5%	42.5%	0.0%	20.0%	57.5%	57.5%	37.5%	37.5%	37.5%
Maximum Green (s)	27.7	27.7	27.7	29.9	29.9		9.5	40.1	40.1	24.1	24.1	24.1
Yellow Time (s)	3.6	3.6	3.6	3.6	3.6		3.4	3.6	3.6	3.6	3.6	3.6
All-Red Time (s)	2.7	2.7	2.7	0.5	0.5		3.1	2.3	2.3	2.3	2.3	2.3
Lead/Lag							Lead			Lag	Lag	Lag
Lead-Lag Optimize?							Yes			Yes	Yes	Yes
Walk Time (s)	5.0	5.0	5.0	5.0	5.0			5.0	5.0	5.0	5.0	5.0
Flash Dont Walk (s)	11.0	11.0	11.0	11.0	11.0			11.0	11.0	11.0	11.0	11.0
Pedestrian Calls (#/hr)	0	0	0	0	0			0	0	0	0	0
Act Effct Green (s)	30.0	30.0	30.0	30.0	30.0		42.0	42.0	42.0	26.0	26.0	26.0
Actuated g/C Ratio	0.38	0.38	0.38	0.38	0.38		0.52	0.52	0.52	0.32	0.32	0.32
v/c Ratio	0.36	0.13	0.19	0.53	0.34		0.55	0.33	0.38	0.15	0.50	0.37
Control Delay	22.4	17.1	6.3	27.9	18.9		15.3	12.1	5.4	21.0	25.2	5.6
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	22.4	17.1	6.3	27.9	18.9		15.3	12.1	5.4	21.0	25.2	5.6
LOS	C	B	A	C	B		B	B	A	C	C	A
Approach Delay		16.6			22.5			11.0			17.8	
Approach LOS		B			C			B			B	
Queue Length 50th (m)	12.1	9.0	0.0	18.0	24.4		23.0	28.0	6.3	5.0	38.2	0.0
Queue Length 95th (m)	18.4	13.3	2.6	23.2	23.0		35.7	41.0	4.9	10.4	55.7	10.1
Internal Link Dist (m)		253.6			368.8			516.3			312.0	
Turn Bay Length (m)												

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Base Capacity (vph)	300	699	341	280	663		497	978	699	287	605	517
Starvation Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Reduced v/c Ratio	0.36	0.13	0.19	0.53	0.34		0.55	0.33	0.38	0.15	0.50	0.37

Intersection Summary	
Area Type: Other	
Cycle Length: 80	
Actuated Cycle Length: 80	
Offset: 0 (0%), Referenced to phase 2:NBTL and 6:SBTL, Start of Green	
Natural Cycle: 75	
Control Type: Pretimed	
Maximum v/c Ratio: 0.55	
Intersection Signal Delay: 15.6	Intersection LOS: B
Intersection Capacity Utilization 58.3%	ICU Level of Service B
Analysis Period (min) 15	

Splits and Phases: 3: Thunderbird Blvd & Wesbrook Mall



MD Peak

Lanes, Volumes, Timings
3: Thunderbird Blvd & Wesbrook Mall 2021-12-02

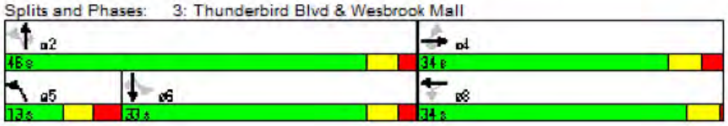
Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Turning Speed (k/h)	25		15	25		15	25		15	25		15
Lane Util. Factor	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	0.89		0.84	0.86	0.91		0.88		0.73	0.84		0.71
Frt			0.850		0.896				0.850			0.850
Flt Protected	0.950			0.950			0.950			0.950		
Satd. Flow (prot)	1770	1863	1583	1770	1516	0	1770	1863	1583	1770	1863	1583
Flt Permitted	0.723			0.742			0.386			0.558		
Satd. Flow (perm)	1203	1863	1323	1185	1516	0	632	1863	1152	872	1863	1117
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)			100		36				48			108
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
Link Speed (k/h)		50			50			50			50	
Link Distance (m)		277.6			392.8			540.3			336.0	
Travel Time (s)		20.0			28.3			38.9			24.2	
Volume (vph)	91	12	66	34	13	28	115	256	34	29	268	91
Confl. Peds. (#/hr)	46		59	59		46	112		103	103		112
Peak Hour Factor	0.84	0.50	0.66	0.77	0.81	0.78	0.82	0.76	0.71	0.66	0.86	0.84
Adj. Flow (vph)	108	24	100	44	16	36	140	337	48	44	312	108
Lane Group Flow (vph)	108	24	100	44	52	0	140	337	48	44	312	108
Turn Type	Perm		Perm	Perm			pm+pt		Perm	Perm		Perm
Protected Phases		4			8		5	2			6	
Permitted Phases	4		4	8			2		2	6		6
Minimum Split (s)	31.3	31.3	31.3	33.3	33.3		12.5	21.9	21.9	28.9	28.9	28.9
Total Split (s)	34.0	34.0	34.0	34.0	34.0	0.0	13.0	46.0	46.0	33.0	33.0	33.0
Total Split (%)	42.5%	42.5%	42.5%	42.5%	42.5%	0.0%	16.3%	57.5%	57.5%	41.3%	41.3%	41.3%
Maximum Green (s)	27.7	27.7	27.7	29.9	29.9		6.5	40.1	40.1	27.1	27.1	27.1
Yellow Time (s)	3.6	3.6	3.6	3.6	3.6		3.4	3.6	3.6	3.6	3.6	3.6
All-Red Time (s)	2.7	2.7	2.7	0.5	0.5		3.1	2.3	2.3	2.3	2.3	2.3
Lead/Lag							Lead			Lag	Lag	Lag
Lead-Lag Optimize?							Yes			Yes	Yes	Yes
Walk Time (s)	5.0	5.0	5.0	5.0	5.0			5.0	5.0	5.0	5.0	5.0
Flash Dont Walk (s)	11.0	11.0	11.0	11.0	11.0			11.0	11.0	11.0	11.0	11.0
Pedestrian Calls (#/hr)	0	0	0	0	0			0	0	0	0	0
Act Effct Green (s)	30.0	30.0	30.0	30.0	30.0		42.0	42.0	42.0	29.0	29.0	29.0
Actuated g/C Ratio	0.38	0.38	0.38	0.38	0.38		0.52	0.52	0.52	0.36	0.36	0.36
v/c Ratio	0.24	0.03	0.18	0.10	0.09		0.30	0.34	0.08	0.14	0.46	0.23
Control Delay	19.0	16.2	4.7	17.1	8.4		11.7	12.3	3.4	18.7	22.3	5.2
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	19.0	16.2	4.7	17.1	8.4		11.7	12.3	3.4	18.7	22.3	5.2
LOS	B	B	A	B	A		B	B	A	B	C	A
Approach Delay		12.5			12.4			11.3			18.0	
Approach LOS		B			B			B			B	
Queue Length 50th (m)	11.6	2.4	0.0	4.5	1.6		10.8	29.3	0.0	4.6	37.5	0.0
Queue Length 95th (m)	21.7	3.9	3.9	9.5	7.3		18.1	37.4	3.0	8.5	56.9	8.5
Internal Link Dist (m)		253.6			368.8			516.3			312.0	
Turn Bay Length (m)												

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Base Capacity (vph)	451	699	559	444	591		460	978	628	316	675	474
Starvation Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Reduced v/c Ratio	0.24	0.03	0.18	0.10	0.09		0.30	0.34	0.08	0.14	0.46	0.23

Intersection Summary

Area Type: Other
Cycle Length: 80
Actuated Cycle Length: 80
Offset: 0 (0%), Referenced to phase 2:NBTL and 6:SBTL, Start of Green
Natural Cycle: 75
Control Type: Pretimed
Maximum v/c Ratio: 0.46
Intersection Signal Delay: 14.0 Intersection LOS: B
Intersection Capacity Utilization 43.8% ICU Level of Service A
Analysis Period (min) 15

Splits and Phases: 3: Thunderbird Blvd & Wesbrook Mall



PM Peak

Lanes, Volumes, Timings
3: Thunderbird Blvd & Wesbrook Mall 2021-12-02

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Lane Configurations												
Ideal Flow (vphpl)	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900	1900
Total Lost Time (s)	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Turning Speed (k/h)	25		15	25		15	25		15	25		15
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	0.77		0.70	0.75	0.91				0.61	0.80		0.51
Frt			0.850		0.956				0.850			0.850
Flt Protected	0.950			0.950			0.950			0.950		
Satd. Flow (prot)	1770	1863	1583	1770	1614	0	1770	1863	1583	1770	1863	1583
Flt Permitted	0.606			0.695			0.206			0.457		
Satd. Flow (perm)	872	1863	1113	975	1614	0	384	1863	974	681	1863	803
Right Turn on Red			Yes			Yes			Yes			Yes
Satd. Flow (RTOR)			34		30				88			120
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
Link Speed (k/h)		50			50			50			50	
Link Distance (m)		277.6			392.8			540.3			336.0	
Travel Time (s)		20.0			28.3			38.9			24.2	
Volume (vph)	239	52	204	81	42	25	81	264	71	38	396	91
Confl. Peds. (#/hr)	121		113	113		121	193		149	149		193
Peak Hour Factor	0.84	0.54	0.85	0.75	0.55	0.78	0.81	0.89	0.81	0.79	0.77	0.76
Adj. Flow (vph)	285	96	240	108	76	32	100	297	88	48	514	120
Lane Group Flow (vph)	285	96	240	108	108	0	100	297	88	48	514	120
Turn Type	pm+pt		Perm	Perm			Perm		Perm	Perm		Perm
Protected Phases	7	4			8			2			6	
Permitted Phases	4		4	8			2		2	6		6
Minimum Split (s)	12.5	31.3	31.3	33.3	33.3		21.9	21.9	21.9	28.9	28.9	28.9
Total Split (s)	13.0	47.0	47.0	34.0	34.0	0.0	33.0	33.0	33.0	33.0	33.0	33.0
Total Split (%)	16.3%	58.8%	58.8%	42.5%	42.5%	0.0%	41.3%	41.3%	41.3%	41.3%	41.3%	41.3%
Maximum Green (s)	9.0	40.7	40.7	29.9	29.9		27.1	27.1	27.1	27.1	27.1	27.1
Yellow Time (s)	3.5	3.6	3.6	3.6	3.6		3.6	3.6	3.6	3.6	3.6	3.6
All-Red Time (s)	0.5	2.7	2.7	0.5	0.5		2.3	2.3	2.3	2.3	2.3	2.3
Lead/Lag	Lead			Lag	Lag							
Lead-Lag Optimize?	Yes			Yes	Yes							
Walk Time (s)		5.0	5.0	5.0	5.0		5.0	5.0	5.0	5.0	5.0	5.0
Flash Dont Walk (s)		11.0	11.0	11.0	11.0		11.0	11.0	11.0	11.0	11.0	11.0
Pedestrian Calls (#/hr)		0	0	0	0		0	0	0	0	0	0
Act Effct Green (s)	43.0	43.0	43.0	30.0	30.0		29.0	29.0	29.0	29.0	29.0	29.0
Actuated g/C Ratio	0.54	0.54	0.54	0.38	0.38		0.36	0.36	0.36	0.36	0.36	0.36
v/c Ratio	0.50	0.10	0.39	0.30	0.17		0.72	0.44	0.22	0.19	0.76	0.33
Control Delay	13.7	9.4	11.5	20.4	13.2		54.2	21.9	5.8	20.2	31.4	6.4
Queue Delay	0.0	0.0	0.0	0.0	0.0		0.0	0.0	0.0	0.0	0.0	0.0
Total Delay	13.7	9.4	11.5	20.4	13.2		54.2	21.9	5.8	20.2	31.4	6.4
LOS	B	A	B	C	B		D	C	A	C	C	A
Approach Delay		12.2			16.8			25.6			26.2	
Approach LOS		B			B			C			C	
Queue Length 50th (m)	23.5	7.0	17.6	11.9	8.0		13.5	35.4	0.0	5.2	71.0	0.0
Queue Length 95th (m)	35.3	8.1	31.0	19.7	9.7		#33.9	56.4	7.3	11.4	86.1	6.9
Internal Link Dist (m)		253.6			368.8			516.3			312.0	
Turn Bay Length (m)												

Lane Group	EBL	EBT	EBR	WBL	WBT	WBR	NBL	NBT	NBR	SBL	SBT	SBR
Base Capacity (vph)	570	1001	614	366	624		139	675	409	247	675	368
Starvation Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Spillback Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Storage Cap Reductn	0	0	0	0	0		0	0	0	0	0	0
Reduced v/c Ratio	0.50	0.10	0.39	0.30	0.17		0.72	0.44	0.22	0.19	0.76	0.33

Intersection Summary

Area Type: Other
Cycle Length: 80
Actuated Cycle Length: 80
Offset: 0 (0%), Referenced to phase 2:NBTL and 6:SBTL, Start of Green
Natural Cycle: 80
Control Type: Pretimed
Maximum v/c Ratio: 0.76
Intersection Signal Delay: 20.7 Intersection LOS: C
Intersection Capacity Utilization 55.2% ICU Level of Service B
Analysis Period (min) 15
\# 95th percentile volume exceeds capacity, queue may be longer.
Queue shown is maximum after two cycles.

Splits and Phases: 3: Thunderbird Blvd & Wesbrook Mall