UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

Stadium Neighborhood Underground Parkade and Water Storage

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CIVL 446

Themes: Water, Climate, Land

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***Figure 1**: Stadium Neighbourhood Concept Art.*

Source: Adapted from UBC Campus and Community Planning, 2018

E. Executive Summary

As part of the University of British Columbia's (UBC) Stadium Neighbourhood water storage and mixed-use parkade project, we developed a three-part solution seeking to uphold the goals of sustainability at UBC while managing stormwater in the new Stadium Neighbourhood development. Following approval of the preliminary design components by the client in late 2018, detailed design has progressed in anticipation of construction ground-breaking in May 2019.

E.1 Mixed-Use Parkade

The parkade facility will not only provide parking for the rebuilt Thunderbird Stadium, but also will detain stormwater beneath the parking to protect the neighbourhood against flooding during events as big as the 100-year storm. These tanks have been designed for the climate-change-induced magnitude of the 100-year design storm. The aboveground levels of the parkade feature both parking and commercial use and are designed with the flexibility of being completely repurposed into commercial, communal, or housing space as UBC seeks to decrease future car usage on campus. This component of the project is estimated to have a construction cost of $10,532,000 and will last, to contain the critical path for construction duration, an estimated 410 working days (82 weeks).

E.2 Bioswale on Southern Carriageway of West 16th Avenue

The bioswale is an important element in treating stormwater, as plants and soil will help remove toxins from the water. The swale is designed to keep water moving such that the hazard of mosquito eggs is mitigated while increasing the dissolved oxygen content. To keep from destabilizing the cliffs to the west of the site, the water from the bioswale will not be allowed to infiltrate into the soil, but will be collected and sent to the existing catchment outfall. This component of the project is estimated to have a construction cost of $439,000.

E.3 Redesign of the Southwest Marine Drive and West 16th Avenue Intersection

The redesign of this intersection will significantly reduce impervious area and make room for the aforementioned bioswale while accommodating predicted traffic volumes. It addresses safety issues with the current intersection and promotes active modes (e.g. cycling or walking). This component of the project is estimated to have a construction cost of $1,464,000.

In total, we predict that the entire solution will have a construction cost of $24,936,000, will require 20 months of active construction time, and will require $400,000 per year in maintenance and operational costs.

Contents

E. Executive Summary iii

E.1 Mixed-Use Parkade iii

E.2 Bioswale on Southern Carriageway of West 16th Avenue iii

E.3 Redesign of the Southwest Marine Drive and West 16th Avenue Intersection iii

Contents iv

List of Figures vii

List of Exhibits viii

List of Tables ix

1. Introduction 1

1.1 Client Objectives 1

1.2 Scope of Work 1

1.2.1 Research 2

1.2.2 Analysis 2

1.2.3 Design 2

1.3 Project Team 2

2 Project Overview 4

2.1 Background and Project Objectives 4

2.2 Hydrological Conditions 4

2.3 Data and Information Constraints 6

3 Detailed Design Outputs 9

3.1 Mixed-Use Parkade and Stormwater Management System 9

3.1.1 Design Vision ... 9

3.1.2 Technical Guidance ... 10

3.1.3 Discussion of Analysis ... 10

3.2 Stormwater Management System ... 20

3.2.1 Design Vision ... 20

3.2.2 Technical Guidance ... 21

3.2.3 Discussion of Analysis ... 21

3.3 Intersection Redesign ... 26

3.3.1 Design Vision ... 26

3.3.2 Technical Guidance ... 27

3.3.3 Discussion of Analysis ... 28

4 Project Management Items ... 30

4.1 Methodology ... 30

4.2 Cost Estimate ... 31

4.2.1 Construction Costs ... 31

4.3 Annual Operating Costs and Maintenance Plan ... 33

4.4 Schedule ... 34

4.5 Site Constraints ... 35

5 Conclusion and Recommendations ... 38

Appendix A: Project Management Documents ... 1

A.1. Schedule ... 1

A.2. Work Breakdown Structure ... 18

Appendix B: Design Calculations 23
B.1. Mixed-Use Parkade 23
B.1.1. Tank Volume Sample Calculation........ 23
B.1.2. Raft Foundation Calculations 24
B.1.3. Parkade Structural Calculations 28
B.2. Bioswale........ 33
B.2.1. BMP Verification Calculations 33
B.2.2. Flow Calculations........ 38
B.2.3. Bioswale Infiltration Calculations 41
B.3. Intersection........ 45
Appendix C: Detailed Design Drawings........ 46
C.1. Mixed-Use Parkade........ 46
C.2. Bioswale 58
C.3. Intersection 61
Appendix D: References and Documentation........ 67

List of Figures

Figure 1: Stadium Neighbourhood Concept Art. ii

Figure 2: Project Location and Construction Areas 1

Figure 3: Catchments at UBC 5

Figure 4: Parkade Rendering 9

Figure 5: Detention Tank Inflows and Outflows 11

Figure 6: Parking Space Layout 13

Figure 7: Parking Space Dimensions 13

Figure 8: AutoTURN Ramp Design 14

Figure 9: P-TAC Design Vehicle 14

Figure 10: Summary of Loads on Strip of Foundation 16

Figure 11: A-A Cross-Section of Foundation 17

Figure 12: Bioswale Design Detail: SW Marine Dr / W 16th Ave 22

Figure 13: Ponding Area 22

Figure 14: Bioswale Plan View 23

Figure 15: Row 5 of Foundation 24

Figure 16: Dimensions and Loads from Foundation and Water 25

Figure 17: Summary of Column Loads 25

Figure 18: Total Loads Imposed 26

Figure 19: Soil Bearing Capacity 26

Figure 20: Shear and Bending Moment Diagrams 27

Figure 21: Existing Culvert Tributary Area Example 34

Figure 22: Bioswale Inflows and Outflows 38

Figure 23: Trapezoidal Calculation Cross-Section 39

Figure 24: Culvert Calculation Cross-Section 40

Figure 25: Coefficient of Permeability Values 41

Figure 26: Hydraulic Conductivity vs Infiltration Rate 42

Figure 27: Ponding Area 44

List of Exhibits

Exhibit 1: Schedule of Major Task Groups 37

List of Tables

Table 1: Roles and Responsibilities 3

Table 2: Unadjusted Total Rainfall (mm) Given Duration and Frequency 5

Table 3: Adjusted Total Rainfall (mm) Given Duration and Frequency 6

Table 4: Parkade Technical Considerations and Governing Specifications 10

Table 5: Summary of Assumptions and Unfactored Magnitudes for Loads 18

Table 6: Bioswale Design Criteria CVC BMP [11] Check with Discussion 24

Table 7: Relevant Intersection Specifications 27

Table 8 Crew breakdown 31

Table 9: Construction Cost Breakdown 31

Table 10: Annual Operation Costs and Maintenance Timing 33

Table 11: Total Bioswale Footprint 33

Table 12: Existing Culvert Tributary Area 34

Table 13: LEED Channel Tributary Area 34

Table 14: Bioswale Runoff Tributary Area 34

Table 15: Total Tributary Area 35

Table 16: Bioswale Area vs Tributary Area Results 35

Table 17: Infiltration Rate vs Coefficient of Permeability (Hydraulic Conductivity) [36] 42

1. Introduction

1.1 Client Objectives

As requested by The University of British Columbia Campus + Community Planning (UBC C+CP), we have progressed with the detailed design of the Stadium Neighbourhood Mixed-Use Parkade Project. This project consists of two mutually compatible design areas: the parkade/water storage design and the redesign of the SW Marine Dr / W 16th Ave intersection. The final design aligns with the vision of UBC C+CP and the UBC SEEDS Sustainability program, and successfully meets the following objectives set by UBC:

1. Contribute to the sustainability goals of UBC,
2. Feature an Integrated Stormwater Management Plan for the neighbourhood that includes both water quantity and water quality control components,
3. Cater to projected future traffic, parking, and water storage demands, and
4. Contribute to the community of the Stadium Neighbourhood.

1.2 Scope of Work

The geographic solution designed by us comprises three main construction areas as shown in **Figure 2**. Design of the intersection and bioswale was considered in tandem due to their overlapping areas of influence.

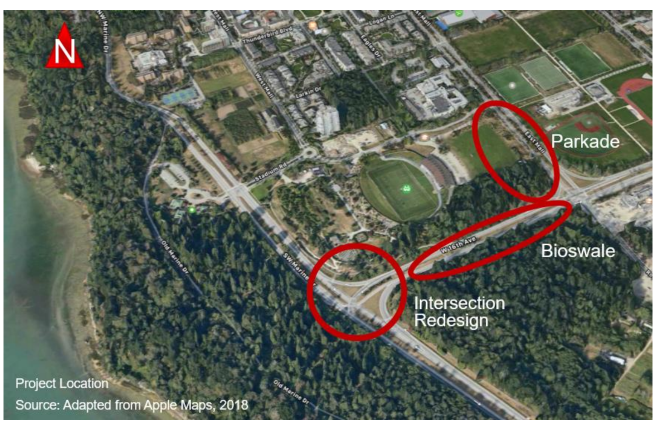


Figure 2: *Project Location and Construction Areas*

1.2.1 Research

In addition to the objectives and data laid out by UBC C+CP, we have conducted further investigation into the project. The scope of this investigation took the form of site investigation, research into previous reports on the area, determination of relevant codes, examination of the existing infrastructure, consideration of precedent solutions, and collection of relevant (hydrological, soil, traffic, and parking) data.

1.2.2 Analysis

The collected research has been analyzed to the level required to produce design criteria for the final design. Hydrological intensities and volumes have been analysed in the standard rational method, with future intensities adjusted for predicted climatic changes. The flows from these volumes and their effects on the infrastructure of the site were predicted using the EPA Storm Water Management Model (SWMM) software. For the parkade structure, loads were determined from the 2015 edition of the National Building Code of Canada (NBCC) and structural elements have been analysed against conservative simplifying assumptions [1]. The parkade will be further analysed by a structural subconsultant. Traffic and parking volumes have been extrapolated from given data and observations, and Synchro modelling was undertaken to ensure suitability of the designed solution.

1.2.3 Design

The designs offered in this report represent a construction-ready level of detail for many components. However, we have subcontracted various specific design elements out to specialized design firms. As such, some elements that are clearly indicated throughout the three main construction areas will not yet exhibit ready-for-construction plans. These additions will be provided to the client once they are completed by the subcontractors, such that a complete construction package will be assembled prior to ground breaking. The anticipated construction commencement date is May 1, 2019.

1.3 Project Team

Our team for this project consists of a small group of specialized engineers and analysts. **Table 1** states their roles and contributions.

***Table 1**: Roles and Responsibilities*

Name	Role	Main Contributions
JB	Project Manager & Structural Lead	• Structural Analysis • Team Organization • Overall Scheduling and Costing
HL	Hydrological Engineer	• Hydrological Analysis • Traffic Modelling • Structural Design Review
GL	Geotechnical Engineer	• Geotechnical Analysis • Floor Plan Development
NM	Transportation Engineer	• Intersection Design • Intersection Drafting • Primary Report Writing and Editing
KU	Transportation Engineer	• Intersection Analysis • Bioswale Detailed Design Drafting • Intersection Scheduling and Costing
CW	Hydrotechnical Engineer	• Hydrotechnical Analysis • Open Channel Flow Design • Bioswale Design

2 Project Overview

2.1 Background and Project Objectives

The stormwater management, mixed-use parkade, and intersection redesign presented in this report are all parts of UBC C+CP's larger Stadium Neighbourhood development project. As such, the design presented in the report needs to not only fulfill the technical boundary conditions of the site, but must also uphold the goals and objectives of the Stadium Neighbourhood Project in general. Some of these goals are similar to overall UBC goals: the solution engineered by us will need to be sustainable against social, environmental, economic, and academic bottom lines. As UBC strives to become a global leader in sustainability research, projects like the mixed-use parkade serve as valuable living labs to implement the sustainability academia being produced at UBC [2]. The redesign of the Stadium Neighbourhood is also part of UBC's "Game Plan" strategy to build the UBC Athletic program, and as such, we recognize that any solution implemented in the Stadium Neighbourhood will be representing UBC to a wider athletic community outside of the day-to-day campus population [3]. However, the main objective of the Stadium Neighbourhood, and therefore a guiding objective for this project, is to build a long-term, affordable, comfortable, new community for UBC [4]. This main goal is tied with the goals for sustainability, academic research, and athletic representation mentioned above, but it also means that preferred designs are ones that promote the formation of a community through measures such as flexible, resilient, accessible spaces, and intercommunity planning.

2.2 Hydrological Conditions

The proposed Stadium Neighbourhood will be mainly situated within the 16th Avenue Catchment, one of four catchments on the UBC Campus, as shown in **Figure 3** [5]. The 16th Avenue Catchment is 34.46 ha, with a current impervious coverage of 33% [6]. The catchment outfall is Botanical Garden Creek [7]. According to a 2012 GeoAdvice study, the existing system is capable of managing a 200-year event in the catchment in its current state with minimal flooding [6] [8].

Figure 3: *Catchments at UBC*

Intensity-duration-frequency (IDF) relations for UBC are available from Environment Canada [9], developed using rainfall records from 1958 to 1990.

Table 2 shows the total rainfall corresponding to different durations and frequencies. IDF relations adjusted for climate change under different Representative Concentration Pathways (RCPs) are available from the IDF_CC Tool developed by Western University [10]. **Table 3** shows rainfall for scenario RCP 4.

Table 2: *Unadjusted Total Rainfall (mm) Given Duration and Frequency*

	2-year	5-year	10-year	25-year	50-year	100-year	200-year
5 min	2.84	4.11	4.94	6.00	6.79	7.57	8.2
10 min	4.19	5.86	6.96	8.35	9.38	10.40	11.3
15 min	5.18	7.16	8.47	10.13	11.36	12.58	13.5
30 min	7.08	9.40	10.94	12.88	14.32	15.75	17

	2-year	5-year	10-year	25-year	50-year	100-year	200-year
1 h	9.76	12.65	14.57	17.00	18.80	20.58	22.3
2 h	13.64	16.36	18.16	20.43	22.12	23.80	25.2
6 h	26.42	31.17	34.31	38.27	41.22	44.14	47
12 h	40.37	49.88	56.18	64.15	70.05	75.91	81
24 h	55.70	71.03	81.18	94.00	103.51	112.96	122

Table 3: *Adjusted Total Rainfall (mm) Given Duration and Frequency*

	2-year	5-year	10-year	25-year	50-year	100-year
5 min	3.09	4.66	5.83	7.66	9.78	11.69
10 min	4.66	6.91	8.50	10.93	13.64	15.96
15 min	5.81	8.46	10.30	13.07	16.18	18.77
30 min	8.00	11.27	13.48	16.72	20.47	23.43
1 h	10.78	14.67	17.55	21.51	27.22	31.81
2 h	15.45	19.45	22.17	25.35	31.03	34.72
6 h	30.44	37.82	42.30	47.85	56.70	61.91
12 h	46.53	60.37	69.05	80.74	96.17	106.36
24 h	62.69	83.81	98.52	118.56	146.17	166.92

The 200-year values were only available from Environment Canada and had to be visually estimated from extrapolation. It is significant that the 100-year adjusted values are larger than the 200-year unadjusted values, as this affects the validity of the assumption of minimal flooding based on the GeoAdvice study [8].

2.3 Data and Information Constraints

Due to the ongoing nature of the Stadium Neighbourhood project, some aspects of the plans for the mixed-use parkade and intersection redesign presented in this report are necessarily subject to change. Similarly, data constraints also led to some conservative assumptions and simplifications in order to produce a final design for UBC C+CP's consideration. These constraints are presented in this section, with the recommendation that such data be collected prior to construction, and that the general contractor for construction ensures that they feel the data collected and provided to them adequately aligns with the level of risk they are willing to take on.

For the parkade area, the most critical data about which various assumptions had to be made was the soil composition. Three borehole results were provided to us at the outset of the project, but their location is approximately 0.5 km from the Stadium Neighbourhood site. As assumptions on geological conditions require significant assumptions even from onsite boreholes, we recommend additional core samples on site to confirm ground conditions. The parkade design was also completed without detailed information on the future Thunderbird Stadium. Only the approximate location of the stadium footprint was available as part of the Stadium Neighbourhood consultation plans, so it was assumed that our proposed parkade will be compatible with the stadium. This assumption will need to be revisited as design of the stadium progresses.

For the bioswale area, design has been conducted based on assumptions about the total building footprint of the completed Stadium Neighbourhood area. As the neighbourhood plan is still under review and has not yet been approved, this total impervious area may still change drastically. Follow-up calculations should be conducted as the plan progresses to ensure compatibility with our detention tank volume. It should also be noted that there are no universally (or even nationally or locally) accepted bioswale design guidelines. Our design is derived from the "Low Impact Development Stormwater Management Planning and Design Guide", which is used by the Ministry of Environment and by Fisheries and Oceans Canada [11]. We are confident that following this design guidance ensures the proposed bioswale design fulfills its objectives for the project, but notes that future developments in bioswale policy may provide more applicable guidance for large swales.

For the intersection area, three key datasets were unavailable throughout design: a survey of the topography of the area, a survey/as-built diagram of existing utilities, and traffic volume data at the intersection of SW Marine Dr / W 16th Ave. Relying on approximate contours from orthophotos means the vertical curve designs, cut and fill volumes, and vertical cross sections for the intersection and its approaches are approximate, and would need significant on-site clarification if construction were to proceed without hiring a certified BC Land Surveyor. Lack of knowledge on existing utilities, especially underground conduits, puts contractors at substantial risk to damaging critical infrastructure during construction and does not allow for the utilities to be relocated along the new road. Traffic volume data is available to intersections neighbouring the one in question, so volumes for analysis were extrapolated from nearby locations. While this provides a reasonable estimate of link volumes, turning movements at SW Marine Dr / W 16th Ave were approximated based only on experience. This means that traffic simulation results, which are highly sensitive to some turning movements, are approximate. Overall, we recommend the collection of these three important datasets in order to ensure the intersection redesign is successful over the long term.

3 Detailed Design Outputs

The following three sections describe the design process with the mixed-use parkade, stormwater management system, and intersection redesign. Each section discusses the overarching design vision, the technical guidance, and the analysis methodology.

3.1 Mixed-Use Parkade and Stormwater Management System

The proposed parkade is a four-level structure (two underground levels and two aboveground levels), as shown in **Figure 4**. A stormwater detention tank will occupy the entirety of the lowest level, while parking will occupy the three levels above. Commercial and plaza space will be also be present on the ground floor. Detailed drawings for the parkade can be found in **Appendix C.1.**

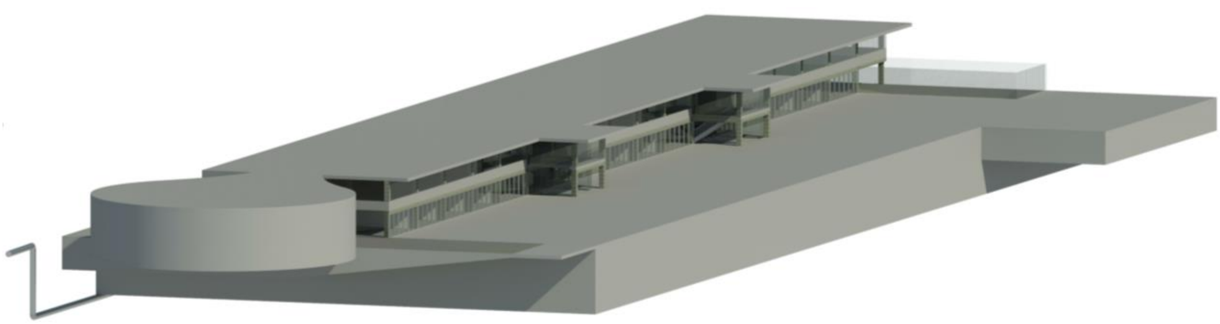


***Figure 4**: Parkade Rendering*

3.1.1 Design Vision

Stadium Neighbourhood's new mixed-use parkade will serve as a transportation hub for drivers, cyclists, and Broadway Extension riders. Commercial storefronts and a bustling plaza activate the streetscape, providing a vibrant gathering place for residents of the community and beyond. Two storeys below, the stormwater detention system is in consistent operation, contributing to the neighbourhood's resilience against significant rainfall events amidst a changing climate.

The design process for the parkade is broken down into three separate elements: the stormwater system, the parking, and the structural system. The stormwater system is to detain all storms up to and including the 100-year event with sufficient reservoir capacity. The provided parking is to satisfy the parking demand induced from the neighbourhood's proposed trip generators, while the lot layout is to ensure safe vehicle movement and circulation. Finally, the structural system is to support the axial, shear, and bending stresses created by the various loading combinations, transferring these loads from superstructure to foundation.

3.1.2 Technical Guidance

Table 4 discusses the technical considerations involved in the design of the stormwater system, parking, and structural system, along with their associated sources for governing specifications.

***Table 4**: Parkade Technical Considerations and Governing Specifications*

	Technical Consideration	Governing Specification(s)
Stormwater System	Stormwater inflow	• Environment Canada IDF relations [9] • Western University IDF_CC tool [10]
	Tank water outflow	• LEED Gold performance standards [7]
Parking	Parking supply vs. demand	• Current parking supply/demand ratio [12]
	Proportion and dimensions of parking space types (normal, small car, handicap)	• City of Vancouver Parking Bylaw [13]
	Dimensions of drive aisles and ramps	• Boise Parking Structure Design Guidelines [14] • AutoTURN ○ TAC 2017 Passenger Car [15]
Structural System	Load magnitudes, directions, and combinations	• NBCC 2015 [1]
	Strength (bending, shear, axial) of structural components	• NBCC 2015 [1] • CSA A23 [16] • Canadian Foundation Engineering Manual [17]
	Site specific parameters (seismic, geotechnical, climatic)	• NBCC 2015 [1] • CSA A23 [16] • GeoPacific borehole samples [18]

3.1.3 Discussion of Analysis

3.1.3.1 Stormwater System

Designing the stormwater detention system requires analysis of the magnitude of water inflows and outflows. Most of this analysis was discussed in the Preliminary Design Report [19], and is repeated below.

UBC's ISMP requires that new developments adhere to the LEED Gold standard of discharging at a maximum of the two-year, 24-hour predevelopment rate [7]. This rate is determined as the product of the rainfall rate of the two-year, 24-hour storm (2.32 mm/hr, based on **Table 3** in **Section 2.2**), the runoff ratio in the predevelopment state (assumed to be 0.2 based on geotechnical conditions), and the area to be developed (49,000 m^2 based on scaled measurements from UBC C+CP Option 2 Site Plan [20]). The output rate based on these parameters is 0.00632 m^3/s.

The inflow rate into the stormwater tank is based on the 100-year storm, which has a specific intensity and duration. Intensity is inversely related to duration, so given the output rate calculated above, there is a specific storm that will govern the required tank capacity. Short duration / high intensity storms will not govern, as the total volume of water that falls within the short period of rainfall is low. Long duration / low intensity storms also will not govern, as the input rate is low and may even be lower than the output rate (in which case no storage is required at all). With the climate-adjusted rainfall-duration relation for the 100-year storm shown in**Table 3** in **Section 2.2**, the governing medium duration / medium intensity storm can be determined. This storm duration is 500 hours, with a rainfall intensity of 1.04 mm/hr. With the tank outputting at the LEED Gold governed rate during this event, and conservatively assuming that all the rainfall within the newly developed area will enter the tank, the required tank capacity is 14,216 m^3. **Figure 5** illustrates the inflows and outflows involved in this storm and the design calculations can be found in **Appendix B.1.** Mixed-Use Parkade

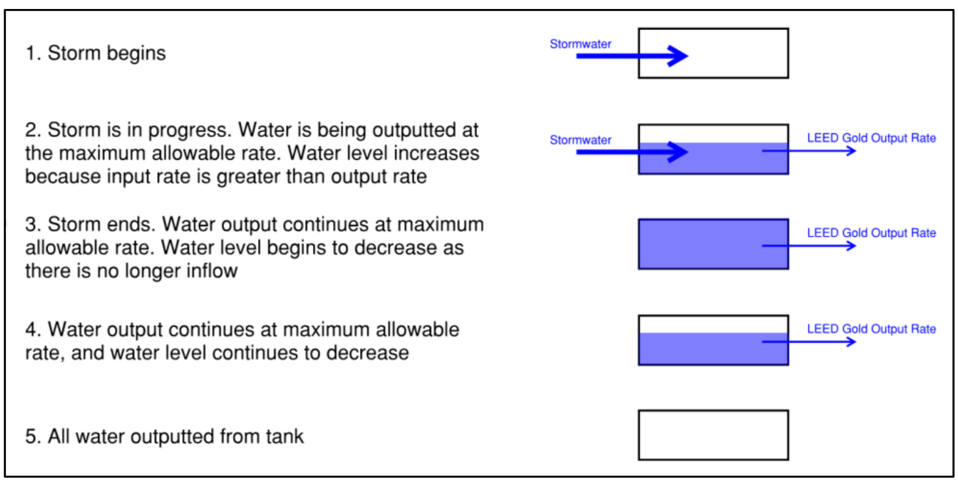


Figure 5: *Detention Tank Inflows and Outflows*

Because the storage tank lies two stories underground, the outflow will need to be pumped back to ground level to flow into the bioswale. Based on the outflow rate (as discussed above) and a 6 m operating head (from the tank base to ground level), a PumpWorks 2x3x6 PWA ANSI/ASME 73.1 Process Pump will satisfy pumping demands with a 73% efficiency [21].

3.1.3.2 Parking

Design of the parking components requires considering the supply and demand of parking spaces; the proportions and dimensions of parking space types; and the dimensions of drive aisles and ramps that facilitate safe circulation within the building.

The current parking lot serving the 5000-person stadium has 186 spaces [12]. We established that doubling this current parking supply, plus 25 extra spaces, would be adequate for the new neighbourhood and 10000-person stadium. While there is more seating at the new stadium, many spectators will be coming in directly from the nearby residences and thus will not require parking. Other trip generators will be built in the neighbourhood (e.g. community spaces, retail shops) but these are minor and would likely only attract people within the University Endowment Lands. With good bike network connectivity and good transit connectivity (along with a potential rapid transit connection) throughout the university, it is also more likely that visitors would not be arriving by car.

With 397 spaces intended for the parking supply, we then sought to maximize the proportion of these as small car spaces in order to conserve floor area. A minimum number of handicap parking spaces must also be provided. Applying the regulations in the City of Vancouver's Parking Bylaw [13], the 397 spaces will include 291 normal spaces, 96 small car spaces, and 10 handicap spaces. **Figure 6** illustrates the layout of these spaces within the building. **Figure 7** illustrates the required dimensions of these spaces.

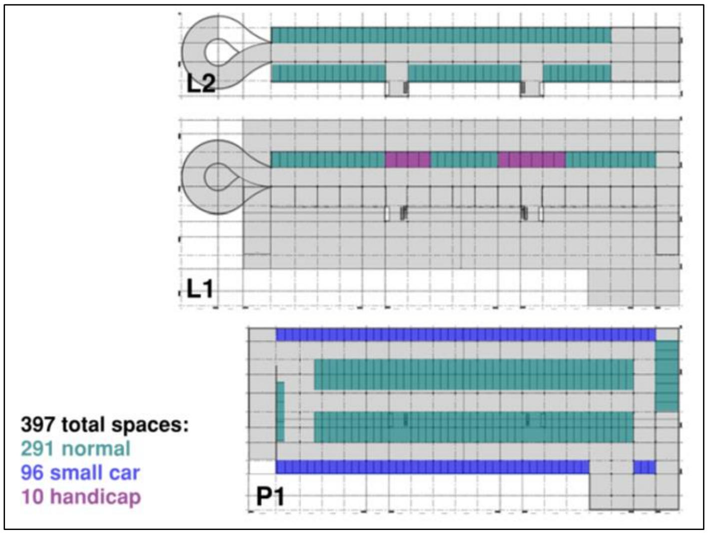


Figure 6: Parking Space Layout

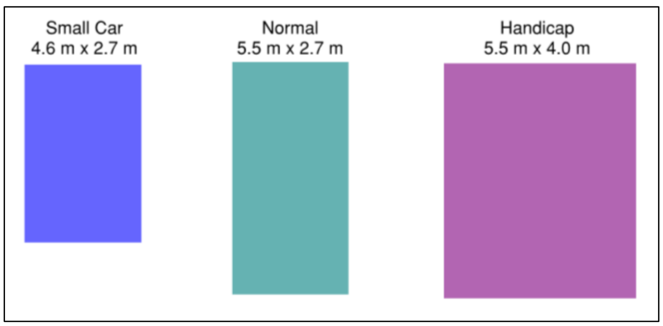


Figure 7: Parking Space Dimensions

We configured drive aisles to have a width of 6.6 m, based on the City of Vancouver's Parking Bylaw [12]. Ramps had their slopes configured up to a maximum of 12.5%, per recommendations in the Boise Parking Structure Design Guidelines [14], which was used due to its comprehensive nature. Ramps had their widths individually configured using AutoTURN, as illustrated in **Figure 8**. AutoTURN was also used to verify that drive aisle dimensions permit unconflicted movement and parking maneuvers.

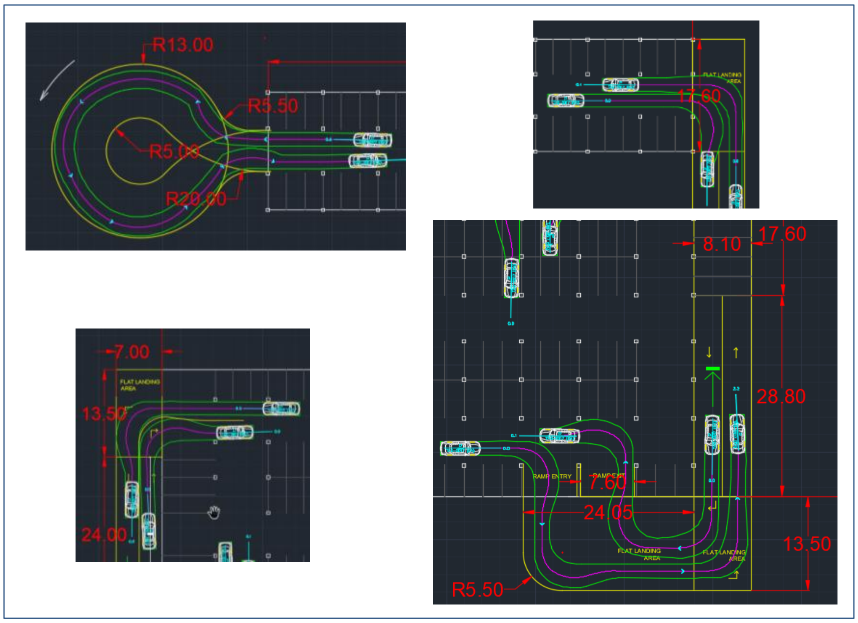


***Figure 8**: AutoTURN Ramp Design*

The design vehicle used in AutoTURN is a Passenger Car from TAC-2017 (P-TAC) [15] and is shown in **Figure 9**. This was chosen over the SU9 (similar to a commercial delivery truck) commonly used in geometric design codes as only private vehicles are expected inside the parkade. Steering from stop (dry-steering) was enabled in our analysis, as this is a reality in parkades.

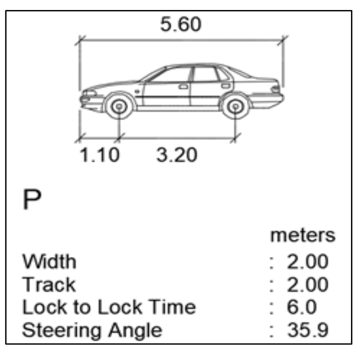


***Figure 9:** P-TAC Design Vehicle*

The P-TAC represents a vehicle that is larger than most passenger cars in North America, with a rather wide turning radius. The AutoTURN analysis thus tends to yield conservative designs. Since all tested movements successfully clear the structure in AutoTURN, little difficulty in traversing this parkade is expected.

3.1.3.3 Structural System

The structural system for the parkade begins with the foundation. Due to limited geotechnical data available from off-site borehole samples from GeoPacific [18], we recommend a raft foundation to ensure that the loads imposed from the columns can be sustained with the soil. A raft foundation is also advantageous in this project due to the proximity between columns, and a significant portion of the parkade being underground. As noted in the GeoPacific report [18], the project site is situated on glacial till, and an allowable design bearing capacity of 300 kPa is assumed as per the Canadian Foundation Engineering Manual [17]. The imposed loads on the foundation have factors applied in their design (Load and Resistance Factor Design, or LRFD).

The design of the raft foundation must be able to withstand shear and bending moment forces imposed by both the soil below it and the columns that it supports above. The loads on the foundation were analyzed as strips along each load of columns, with the halfway distance between adjacent columns as the tributary area. The loads imposed by the columns were modeled as point loads, while the dead weight of the concrete and the water were modeled as a uniformly distributed load (assuming 2400 kg/m^3 density for concrete, and 1000 kg/m^3 density for water). These loads are resisted by an upwards, uniformly distributed load provided by the soil. An inverted roof structure is an appropriate analogy to this design. **Figure 10**: Summary of Loads on Strip of Foundation shows a free body diagram of the imposed loads.

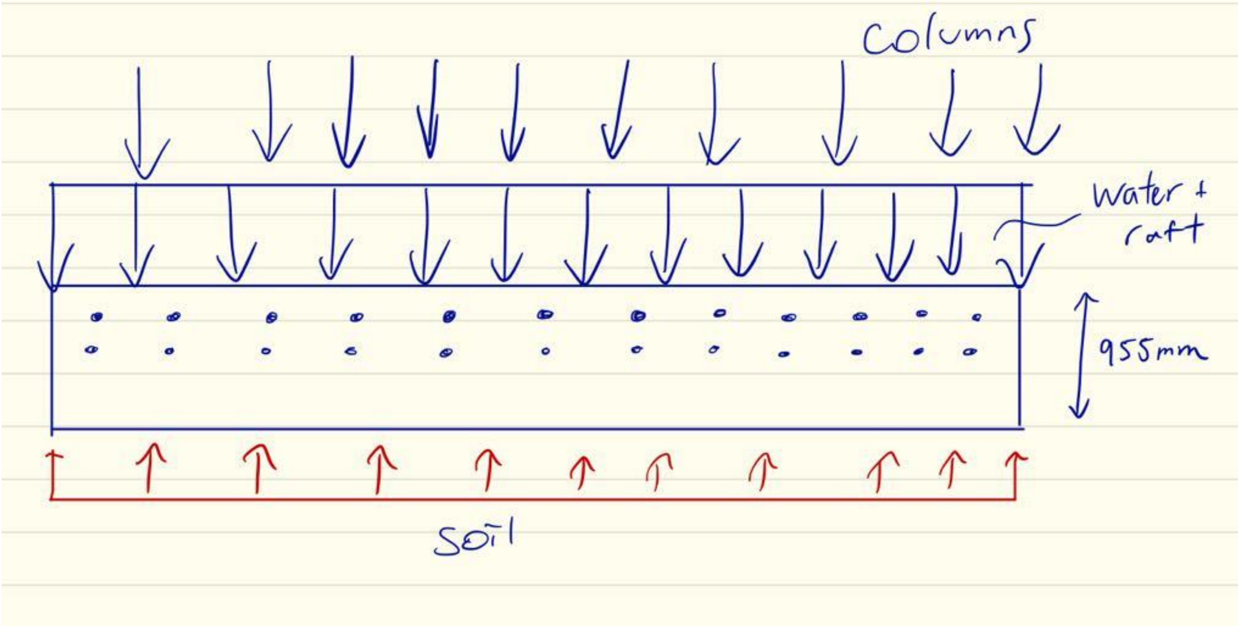


Figure 10: Summary of Loads on Strip of Foundation

The final foundation design calls for a depth of 955 mm directly underneath the stormwater detention tank, measuring 53.2 m by 146.8 m as its footprint. The foundation uses 25 MPa concrete and is reinforced by two layers of 35M rebar (36 mm diameter) running in both the transverse and longitudinal axes. There is 54 mm of clear spacing between the two layers of rebar. Considering that the foundation will be underground and exposed to soil, with the presence of chlorides, a 75 mm cover for the steel reinforcement is maintained to comply with Canadian Standards Association (CSA) A23 [22]. **Figure 11** shows an example of rebar placement and foundation dimensions on the transverse side, specifically the A-A cross section. Full details of the foundation can be found in **Drawing C.1.11.** An example of calculations used in the design progress of the raft foundation is provided in **Appendix B.**

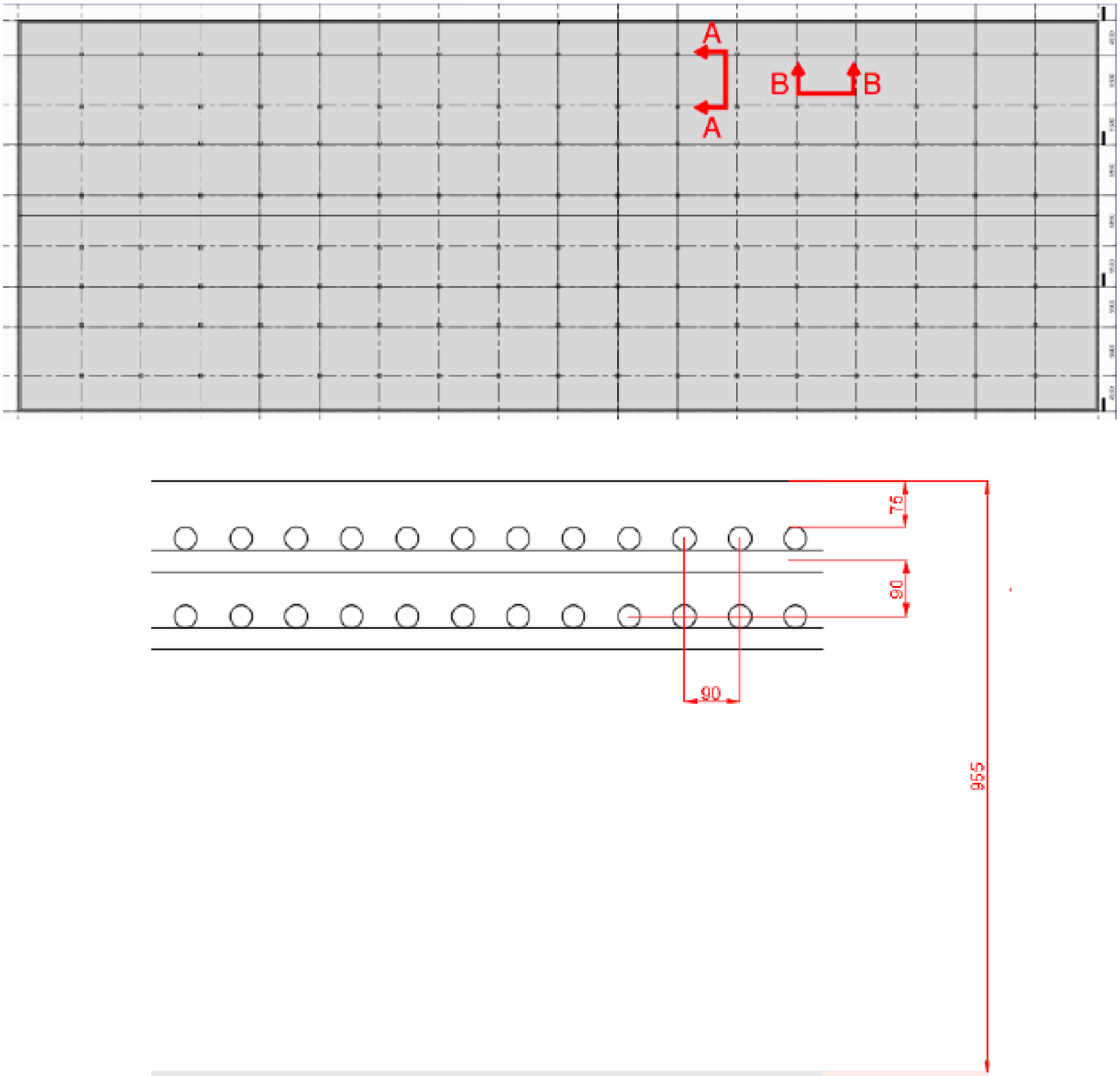


***Figure 11**: A-A Cross-Section of Foundation*

For the loads of the parkade, National Building Code of Canada (NBCC) 2015 is used for governing specifications [1]. Between the different load cases that NBCC 2015 prescribes, the highest of any load case is used as the design load, consistent with LRFD [1]. Additionally, despite plans for Level L2 to be developed from a parking level to living or office space in the future, the structural design must be sufficient to hold the higher of the two loads. The design of structural components must bear all axial, shear, and bending moment forces that are subjected to it. The following assumptions are unchanged from our Preliminary Design Report [19], and are summarized in **Table 5**.

***Table 5**: Summary of Assumptions and Unfactored Magnitudes for Loads*

Load	**Assumptions**	**Unfactored Magnitude**
General	• Flat, green roof • Climatic and soil conditions similar to Vancouver City Hall • Floors are 4 m high, measured from floor to floor	N/A
Dead	• Reinforced Concrete density = 25 kg/m^3 • Multi-use floors designed with extra 1.5 kPa for possible future partitions • The tank is designed to hold 3 m of water	• Roof: 1.0 kPa + (24 kN/m^2)*(depth of floor slab) • Multi-use floors: 1.5 kPa + (24 kN/m^2)*(depth of floor slab) • P1: (24 kN/m^2)*(depth of floor slab) • Tanks: 30 kPa
Live	• Cars are expected to weigh less than 4000 kg, thus design load is 2.4 kPa • Floor load in multi-use floors is governed by office space load (4.8 kPa) • Point load in multi-use floors is governed by parkade load (18 kN)	• Roof: 1.0 kPa • Multi-use floors: Floor = 4.8 kPa, Point = 18 kN • P1: Floor = 2.4 kPa, Point = 18 kN
Snow	• Parkade is in "unexposed terrain" (little snow is blown off)	• 1.7 kPa
Wind	• Parkade is in "exposed terrain" (stronger wing loads) • Parkade is on flat ground (rather than on top of a hill, realistic) • Parkade has "large, non-windproof openings" (stronger internal pressures) • Loads are constant magnitude and equal to edge loads (conservative)	• Roof: -1.22 kPa or 0.31 kPa • Windward wall: 1.07 kPa • Leeward wall: -0.80 kPa
Earthquake	• Parkade is "perfectly attached" to foundation (earthquake loads only act on the structure above grade) • Soil conditions are considered "poor" (stronger accelerations) • "Building weight" is the sum of dead loads above grade	• Magnitude: 2950 kN • Point of action: 4 m above grade (on floor between L1 and L2)

For design of the structural components, all components were modeled as simply supported elements for ease of calculation. This assumption will need to be revisited when completing the final design of the parkade structure. Reinforced concrete is the primary construction material, with a compressive strength of 25 MPa for the concrete and a yield strength of 400 MPa for the rebar. Due to the relative weakness of concrete in tension, it is considered negligible for design purposes, and thus the rebar must be designed and spaced to carry any tensile loads. The rebar has a cover of 60 mm considering corrosion concerns from the chloride environment of the parkade, and has been spaced assuming a 25 mm maximum aggregate size in the concrete. Governing specifications were taken from the CSA A23 [15] and NBCC 2015 [1].

Roof and floor slabs have a depth of 340 mm, and acts as a flange on top of a 500 mm wide web to form a T-beam. The total depth of this T-beam is 650 mm (340 mm floor + 310 mm web). In the flange (floor slab), rebar is specified at 20M at 100 mm, center to center, in the primary loading direction, and 15M at 250 mm, center to center, perpendicular to the primary direction to minimise temperature and shrinkage cracking. Rebar spacing in the web calls for 10-30M rebar spaced 110 mm, center to center, in two rows. Stirrups of 10M spaced at 110 mm are placed in the beams to resist shear forces. **Drawing C.1.11** provides a detailed view of the dimensions and rebar placement.

Above-grade (curtain) walls are 200 mm thick, with sets of 10M at 250 mm center to center rebar in the horizontal direction and 20M at 90 mm center in the vertical to resist bending stresses from wind. **Drawing C.1.10** shows this in greater detail.

Below-grade (foundation) walls are 350 mm thick. (Note, the recommendation of 300mm thick subgrade walls in the Preliminary Design Report was an error). Rebar spacing is 15M at 250 mm center to center in the horizontal direction (temperature and shrinkage steel), and 20M at 75 mm center in the vertical direction do resist earth pressure induced bending **Drawing C.1.10.**

Center columns are 500 mm by 500 mm, reinforced with 12-35M rebar axially and 10M ties spaced at 480 mm (center to center) as shown in **Drawing C.1.10.** Columns abutting perimeter walls are 500 mm by 350 mm and reinforced with 12-35M rebar at a spacing (center to center) of 90 mm in the weak axis and 82.5 mm in the strong axis. The ties for these columns are the same as those for the center columns.

3.2 Stormwater Management System

The Preliminary Design Report [19] summarized the calculations of the detention tanks, the open channel flows, and the bioswale. It began by focusing on volume calculations to determine the size of the tank. Then, it determined both the maximum flow capacity of each feature and compared this to the required demand from the 100-year climate-adjusted storm. Finally, it expanded on the flow characteristics of the bioswale, estimating the drawdown (soil infiltration) times and minimum average residence time in the bioswale. It is understood that there are concerns of insect growth in the channel; this was addressed while also ensuring the appropriate residence time is achieved for water filtration. Please refer to the Preliminary Design Report [19] for the calculations relevant to the above.

As explained in the Design Progress Report, the preliminary design was quite comprehensive. However, the bioswale preliminary design relied on elementary assumptions of key parameters. Most importantly, the coefficient of permeability, which can vary by several orders of magnitude, was assumed based on the geotechnical reports of soils away from the bioswale site. Therefore, this detailed design ultimately focused on refining the bioswale design by designing to a comprehensive a relevant design guideline. In the process, additional accuracy was needed of project components, which required more detailed use of the SWMM model provided.

3.2.1 Design Vision

As a whole, the stormwater management system needs to adequately convey the 100-year storm without any local flooding while complying with the Fisheries Act, Canadian Environmental Protection Act, Water Act, Environmental Management Act, and Integrated Liquid Waste Management and Resource Plan. The proposed design routes the existing road runoff culvert and new detention tank outflow into a 265.29 m long bioswale before reconnecting with the existing infrastructure that channels the stormwater towards the botanical gardens. For a plan view of the whole Stormwater Management System, see **Drawing C.2.1** in **Appendix C.2.**

For the bioswale in particular, the focus of the detailed design, it must "convey, treat, and attenuate stormwater runoff" [23] from the 100-year storm. It does this through dam overtopping, infiltration, and evapotranspiration. However, due to the contaminated nature of the quadra sand underlying the site, and the concerns of slope stability related to the groundwater table near the cliff edges of Point Grey, an impermeable liner will be installed to ensure there is no infiltration into the native soil. Therefore, stormwater will only infiltrate into the bioswale filter media, which leads into the underdrain. Finally, as mentioned in preliminary design, the stormwater should have enough residence time to be adequately filtered, yet not linger for mosquito growth. According to the literature, the ideal residence time is slightly below 24 hours [24]. Taking all of these considerations into account, the final detailed design of the bioswale are illustrated with specification details in **Drawing C.2.2** in **Appendix C.2.**

3.2.2 Technical Guidance

After consulting several different codes and standards online, and getting the opinion of Dr. Keen, the Best Management Practice (BMP) design was based off the Low Impact Development (LID) Stormwater Management Planning and Design Guide [11], which was made with consultation with the Ministry of Environment, Fisheries and Oceans Canada, Greater Toronto Area municipalities, and the development industry. This BMP guide was chosen because it is comprehensive, well cited, and endorsed by relevant Canadian authorities. As a cross check, dimensions were also compared to the Iowa Stormwater Management Manual Chapter 9 [25].

3.2.3 Discussion of Analysis

This section explains all the work undertaken to arrive at a bioswale detailed design. The approach taken to design the bioswale was to first create a design based on best management practices, then to check the capacities against the required inflow demand. **Section 3.2.3.1** explains how the key dimensions were arrived at, while the **Section 3.2.3.2** provides a summary of the BMP checks undertaken to verify the key dimensions.

3.2.3.1 Key Dimensions

Based on the BMPs [11] [25], the initial cross section was chosen as depicted in **Figure 12**, which is further detailed in **Drawing C.2.2** in **Appendix C.2**. Both BMPs [11] [25] indicated that for the bioswale’s 4.7% slope, check dams were required.

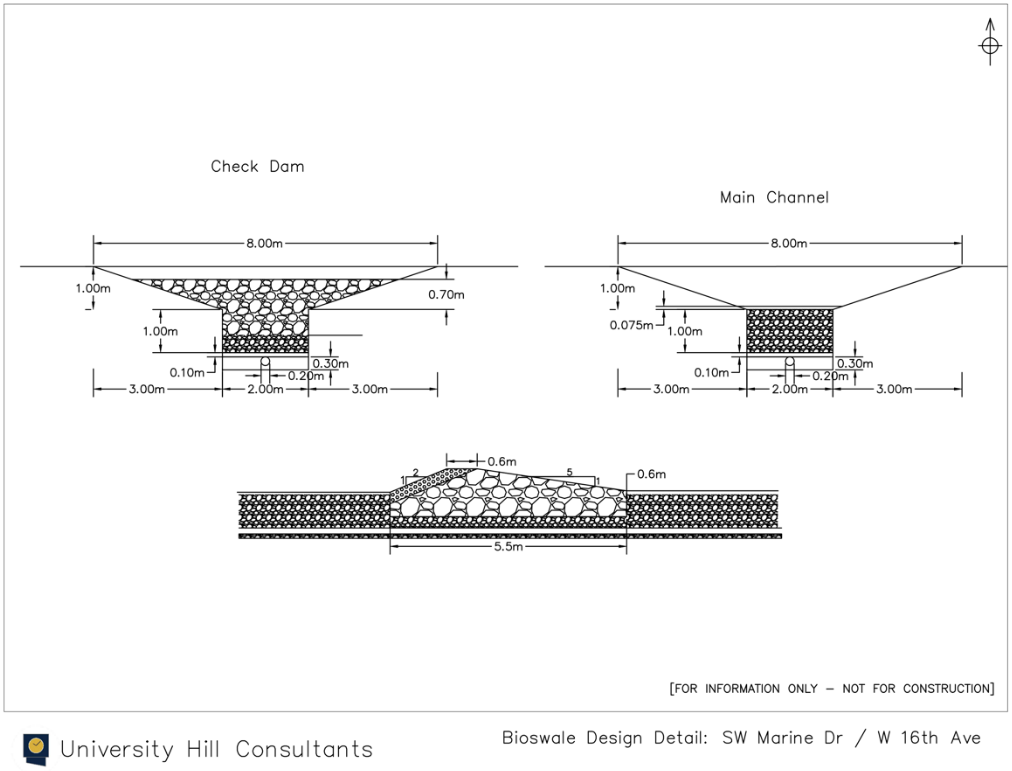


***Figure 12**: Bioswale Design Detail: SW Marine Dr / W 16th Ave*

The length between each check dam was determined by adding the ponding length of 14.9 m (see **Figure 13**) to the check dam length of 5.5 m (see **Figure 12**). To allow maintenance vehicles to pass over the non-ponded portion of the bioswale, a spacing of ~10 m was added. Therefore, each bioswale was about 30 m apart. Dividing the total bioswale length (265.29 m) by the bioswale spacing, it was determined that 9 check dams were needed, see **Figure 14**.

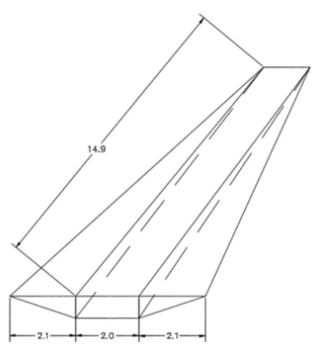


***Figure 13**: Ponding Area*

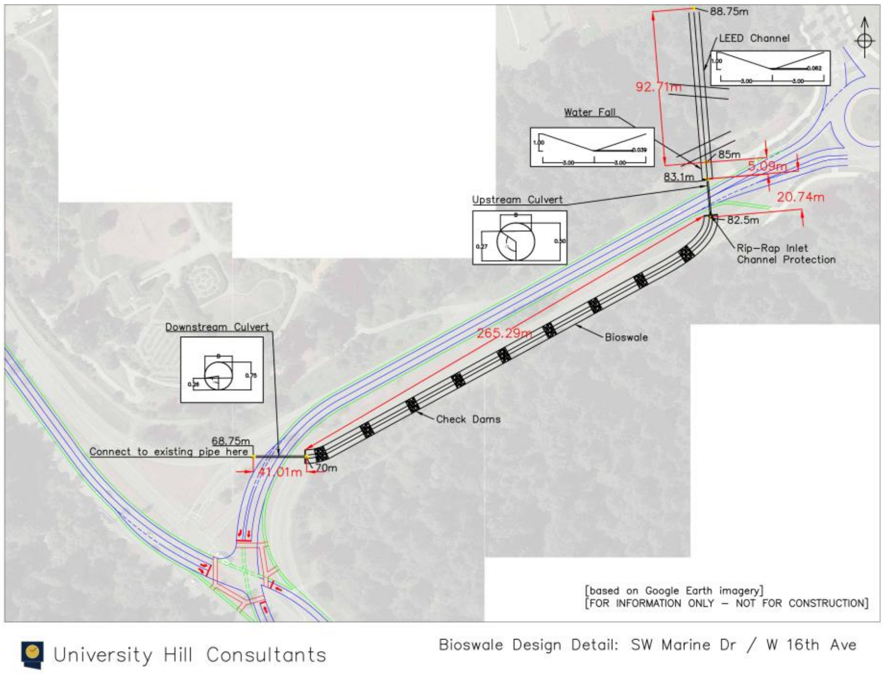


***Figure 14**: Bioswale Plan View*

Note that other water features on UBC Campus use a stainless steel sheet for the “check dams”. While this option was considered to keep a consistent UBC branding look, it was decided that the rock check dams, with the more gradual slope, would be more forgiving for any vehicles that may accidently drive off the road. The rocks also provide a more natural feel that matches Pacific Spirit Regional Park. While this Key Dimensions section provides a general discussion on the channel cross sections, see **Drawing C.2.2** in **Appendix C.2**. for the finalized cross sections including details on soil layer thicknesses and the locations of geotextile liners.

3.2.3.2 BMP Verification Calculations

The Credit Valley Conservation (CVC) BMPs [11] were analyzed in detail to ensure that the detailed bioswale design meets as many of the requirements as possible. This required numerous technical calculations and checks. **Table 6** below summarizes the criteria checked with the results.

Table 6: Bioswale Design Criteria CVC BMP [11] Check with Discussion

No.	Criteria	P/F	Discussion
1	Bioswale Catchment Area	Fail	The bioswale is approximately two times over the recommended BMP [11] for tributary area. The CVC BMP [11] explains that the main concerns with exceeding this ratio are: 1. Sediment buildup, which may create 2. higher flow velocities, which may scour the bioswale. The first concern has been remedied with the inclusion of the sedimentation forebay with riprap immediately after the upstream culvert (which is essentially achieved with the first check dam). It can further be addressed by maintaining the upper region of the bioswale more frequently. The second concern of scour velocity is explored in criteria No. 7 below in this table. If this result further concerns the client, or if the client does not want to commit to additional maintenance measures in the future, we suggests looking into diverting the flow at the LEED Channel/Existing Culvert/Upstream Culvert unction to split flow between the Upstream Culvert and the downstream existing system. The existing system is able to handle lower flow volumes without flooding. It is of our opinion that increasing the size of the bioswale would increase construction costs (as it currently utilizes the removal of the eastbound W16th Ave carriageway effectively), and would be unsightly due to excessive size.
2	Site Topography / Check Dams	Pass	Bioswale has been designed with check dams as recommended.
3	Soils and Underdrain	Pass	Impermeable membrane requires the installation of the 200 mm diameter underdrain, as designed in **Drawing C.2.2.**
4	Pollution Hot Spot Run-Off	Pass	Bioswale takes road runoff.
5	Setbacks from Buildings / Proximity to Underground Utilities	Pass	Designed bioswale is clear of any buildings. Bioswale will use CVC BMP [11] recommended double-casing in the event that utilities crossing the path of the bioswale are discovered.
6	Side Slopes	Pass	Bioswale has been designed with 3:1 (H:V) side slopes.
7	Flow Velocity	Pass	The velocity during the 100-year storm event was determined to be below the CVC BMP [11].
8	Bottom Width	Pass	Bioswale designed with 2 m bottom width.
9	Pre-treatment	Pass	Sedimentation forebay with rip rap included as the first check dam.
10	Monitoring Wells	Pass	Design includes monitoring well.
11	Allowable Depth of Filter Bed	Pass	Bioswale is less than max depth.

All of the detailed calculations to arrive at these results are included in **Appendix B.2.**

3.2.3.3 Infiltration Calculations

One of the main assumptions of the preliminary design was the Coefficient of Permeability. A detailed analysis of this variable is included in **Appendix B.2. Bioswale**. This analysis concluded that, to achieve a residence time of 24 hours, the Coefficient of Permeability should be set to $\boldsymbol{k_{24} \approx 2 \times 10^{-5}}$. As the bioswale is used, sediment will build up and decrease the Coefficient of Permeability. Therefore, we recommend using a soil with a Coefficient of Permeability slightly greater than k_{24}.

3.3 Intersection Redesign

This section of the report discusses the design vision and design processes employed for the redesign of the intersection of SW Marine Dr / W 16th Ave. It also explains the use of technical guidelines and elaborates upon the detailed designs developed.

3.3.1 Design Vision

The SW Marine Drive / West 16th Avenue intersection is redesigned to significantly reduce impervious surfaces while better reflecting the existing and projected traffic demands. The intersection will also accommodate the aforementioned bioswale (Section 3.2), substantially improving the area's stormwater management. The improved intersection will also better fit UBC's goal of increasing traffic safety for all modes of transportation hence promoting active modes of transportation.

The redesign of the intersection essentially turns the existing three-legged T-intersection into a four-legged intersection. This reduces impervious surfaces by approximately 35%. This is achieved by narrowing the intersection's east and north legs from 4 lanes to 2 lanes, which also better reflects the peak traffic volumes. Also, with the removal of the 2 right turn channelized lanes acting like slip ramps, speeding of vehicles will be controlled and space will be freed up to install the bioswale. This design also improves the active modes safety, allowing for separated bike lanes, shorter pedestrian crossing distances, and considerably improved geometric sightlines. On overview drawing of these improvements is illustrated in **Drawing C.3.1** in Appendix C.

The proposed intersection redesign addresses the fact that the largest amount of traffic using the intersection turns from south to east and vice versa. As such, the direction of through traffic will be modified accordingly, and the north leg of the intersection will become the minor leg. All approaches to the intersection will have reductions in the number of vehicle lanes, addressing the overbuilt nature of the intersection, reducing impervious surfaces, and increasing pedestrian and cyclist safety.

The reconfiguration of the existing intersection will consequently create an unexpectancy issue with drivers that initially travel to the new intersection. This is due to how the design turns the 3-leg intersection into a 4-leg intersection. Drivers will have to get past the initial learning curve of approaching the intersection in the left lane in order to continue on W 16th Ave. If the driver chooses to continue on SW Marine Dr, they will have to take the right lane on the approach to the intersection, which becomes a through lane at the intersection, that continues as SW Marine drive. In order to mitigate the issue of unexpectancy and the initial learning curve drivers may face, adequate signage and guidance should be put in place on the approach to the intersection so that drivers have sufficient time and information to make their decision and to respond effectively

3.3.2 Technical Guidance

Where existing conditions did not require deviation from existing standards, geometric design is generally conforming to the Transportation Association of Canada's (TAC's) Geometric Design Guide [15] and the BC Ministry of Transportation and Infrastructure's (MoTI's) supplement to TAC [26].

The primary guideline followed was the BC Supplement to TAC Geometric Design Guide 2007 [15]. Section 330 of this guideline was used in determining the super elevation of the roadway curves and its radii. The TAC Geometric Design Guide for Canadian Roads Chapter 9 [15] – Intersections was used to determine and analyze the stopping sight distance and intersection sight distance for the redesigned intersection. The 2018 BC MoTI Design Build Specifications [27]were followed to design the pavement structure of the intersection. Other resources and guidelines also considered during the process of redesigning the intersection were the 2014 UBC Transportation Plan [28] and the Geometric Design Guidelines for B.C. Roads-Intersections [26].

The specifications used in designing this intersection are highlighted in **Table 7** as per the 2018 Design Build Standard Specifications for Highway Construction from the BC Ministry of Transportation (MoTI) [27].

Table 7*: Relevant Intersection Specifications*

Design Component	**Relevant MoTI Specification**
Site Safety	Section 135
General Requirements	Section 145
Environmental Protection (general)	Section 165
Sediment & Erosion Control	Section 165.04
Clearing	Section 165.05, 200.01-02
Waste Disposal	Section 165.14

Noise & Air Pollution	Section 165.16
Traffic Management	Section 194
Removal of Existing Signs	Section 200.07
Excavation	Section 201
Pavement Surface, Base, and Sub-Base	Section 202
Portland Cement Concrete	Section 211
Culverts	Section 303
Traffic Marking Paint	Section 321
Asphalt Pavement Construction	Section 502
Concrete Curb & Gutter	Section 582
Electrical and Signage	Section 635
Topsoil and Landscape Draining	Section 751
Plantings	Section 754
Revegetation Seeding	Section 757

3.3.3 Discussion of Analysis

3.3.3.1 Super Elevation

Super elevation of the roadway at the intersection and its approaches were necessary in order to reduce the probability of vehicles overturning and skidding due to centrifugal forces. This is carried out by raising the outer edge of the pavement which allows vehicles to maneuver around a curve while counteracting the effects of centrifugal forces. **Drawing C.3.3** illustrates the super elevation profiles of the three key road segments that require super elevation. **Drawing C.3.5** shows the plan view of these segments and their chainage locations. Super elevation sample calculation can be found within **Appendix B.3**.

3.3.3.2 Sight Distance

The sight distances and sight triangles were analyzed and used to maintain adequate sightlines and increase the overall safety of the redesigned intersection. Stopping sight distance is the distance a driver must see in order to stop before a collision. **Drawing C.3.4** illustrates the required stopping sight triangles and intersection sight triangles. As per this drawing, it was determined that no tall plants or trees shall be planted on the center median boulevard close to the intersection as it would obstruct sightlines.

3.3.3.3 Cross-section and Pavement Structure

The redesigned intersection and its approach will match the roadway lane widths to existing conditions which already abide by the existing guidelines for BC MoTI roadways [26] [27]. A shoulder bikeway and bikeway connection at the intersection are also featured in this design.

Existing pavement will be removed for the purpose of re-aligning the intersection as well as increasing pervious area through removal of carriage ways as discussed. Some areas will also require removal of median vegetation. **Drawing C.3.2** showcases infrastructures that are to be removed or relocated. The new pavement structure will comprise of 150 mm Asphalt Pavement (AP) as the top layer, or “wearing course”. This is followed by 150 mm Crushed Base Course (CBC) below it. Followed by 300 mm Select Granular Sub-Base (SGSB). A standard crown of 2% is recommended in locations where super elevation is not specified.

The pavement structure and roadway cross-sections can be found within **Drawing C.3.3** and the plan view can be found in **Drawing C.3.1**.

3.3.3.4 *Traffic Signal and Active Modes of Transportation*

A semi-actuated uncoordinated traffic signal is recommended. This will require an updated timing plan based on turning movement count data to be collected. Buses will be given priority at the intersection using signal pre-emption techniques. This allows high volume and frequency bus lines running along this route such as the 43, 49, and 480 to be given signal priority so that they are able to seamlessly get onto W 16th Ave as they are currently via the existing right turn channelized lanes.

The intersection will be re-designed in a way that heavily promotes UBC’s vision of active modes of transportation such as bicycling. The shoulder bike lane will tie into new, separated bike lanes at the intersection so cyclists are able to cross the intersection safely. The south side of the intersection will feature ramps to transition the bike lane between sidewalk level and road level. It will also include a new gravel path to Botanical Gardens. The north side of the intersection will have the existing asphalt trail tie into new infrastructure. The new intersection will include 3.5m-wide crosswalks at each leg with appropriate curb letdowns for safe pedestrian crossing. The intersection design details can be found in **Drawing C.3.4**.

4 Project Management Items

After reviewing all the project documents, conducting significant research, and compiling information, it is estimated that the project will cost $25 million and will take 20 months to construct. Following construction, yearly maintenance costs of $400,000 are forecasted, some of which are new costs and some of which are pre-existing from the current road alignment. The following subsections describe the details of the cost estimating and construction scheduling process and results.

4.1 Methodology

A cost estimate was developed to match the level of detail of the final design components presented in previous sections. This is intended to be on the detailed side of a Class B cost estimate, which can be taken as accurate within ±15%. A more complete Class A estimate will be available closer to the construction start date once the remaining items discussed have been completed by their respective subcontractors, and once tender documents have been prepared. These items are nonetheless included in the cost estimate provided, but are subject to larger percentage change moving forward.

Construction items were broken down into tasks specific enough that a defined crew of workers given the appropriate design drawings, equipment, and materials would be able to carry out the work. Each task was assigned an associated cost based on its required materials, labour, and resources/equipment. Costs for these different materials and equipment were obtained from suppliers and experience, and labour rates for various skilled and unskilled workers were based on standard industry values in Canada. As such, the cost of each major design area of the project is simply the sum of the costs of its component tasks. On top of these task-specific costs, the following aggregate markups were considered in the overall project cost: project management, engineering, overhead, and contingency.

Scheduling is also based on the defined tasks. Assuming 8-hour work days, crews are assigned to tasks for durations based on experience from past projects and with help from RS Means [29]. Crews have been further broken down into different categories to reflect the different type of work required. For this break down, see **Table 8** below.

Table 8 *Crew breakdown*

Crew	Size (# workers)	Cost/Duration hour ($)
General Construction (low skill)	7	148
General Construction (high skill)	7	182
Trades Crew	7	216
Specialized work	7	250
Engineering	5	225

For tasks that require more than one crew to be working on site at a time, the schedule has been resource leveled in order to minimise short term worker contracts, equipment shortages, and the inefficiency that stems from a crowded work site. There are never more than 5 crews of a single type working on the parkade at any single time and there is never more than 1 crew of a single type working on the intersection/ Bioswale at any given time.

4.2 Cost Estimate

4.2.1 Construction Costs

Construction costs have been broken down into major project elements as shown in **Table 9**, subtotaling to $13 million prior to mark-ups. Mark-ups included 2% of the construction subtotal for project management costs, 10% for overhead costs, and a 50% profit margin recognising that many materials will likely come from sub-consultants. A 20% contingency is then applied to the project subtotal. This contingency not only makes a slight allowance for risk, but also summarises costs that were not directly accounted for, such as traffic redirection, worker training, site security and fences, permits or professional construction checks. A detailed cost listing down to the task level is provided in **Appendix A**.

Table 9: *Construction Cost Breakdown*

Project Area	Construction Element	Cost
Parkade	Foundation	$4,278,000
	Tank Level T1	$1,985,000
	Parkade Level P1	$2,197,000
	Parkade Level L1	$847,000

Project Area	Construction Element	Cost
	Parkade Level L2	$1,230,000
Intersection	Utility Work	$709,000
	Site Work	$181,000
	Paving	$478,000
	Signage + Landscaping	$96,000
Open Channel Flow Components	LEED Channel	$54,000
	Bioswale	$335,000
	LEED-Channel-to-Bioswale Culvert	$14,000
	Bioswale-to-Botanical-Garden Culvert	$35,000
Pre and Post Construction Tasks	Pre Construction	$338,000
	Post Construction	$38,000
	Construction Subtotal	*$12,827,000*
	Project management (2%)	$257,000
	Overhead (10%)	$1,283,000
	Profit (50%)	$3,940,000
	Project Subtotal	*$20,780,000*
	Contingency (20%)	$4,160,000
	Total Project Estimate	**$24,936,000**

It should be noted that the final estimate is significantly less than was predicted at earlier stages in the project. Now that the design has been significantly advanced, we are more confident moving away from the many conservative assumptions that were imposed on the conceptual and preliminary cost estimates. For example, the preliminary cost of the underground portion of the parkade at $24,000,000 was based on an expected cost of $145/sq ft, when in fact literature provides that such structures fall into the range of $100-145/sq ft. [30] Furthermore, earlier in the project it was thought that the cost intersection portion of construction may have been overestimated due to lack of data on road narrowing projects as opposed to the road widening projects on which the cost was based. This has also proved to be true after examining the detailed construction procedure. Similarly, it was hypothesized that the bioswale cost may have been overestimated due to potential economies of scale involved in building a large swale, and lack of data on swales of similar size. Detailed costing likewise revealed this to be true, and the current predicted cost of the bioswale has been appropriately reduced.

4.3 Annual Operating Costs and Maintenance Plan

Annual operating and maintenance costs were estimated for all project components with the foreseeable expenditures noted in this section. It should be noted that the roadways being modified already exist, thus some annual roadway expenditures may already be budgeted for outside of the scope of this construction project. Similarly, it is our understanding that following construction, the BC MoTI will continue to hold jurisdiction over the roadway, thus the following maintenance plan will likely be divided between various parties moving forward. **Table 10** lists the ongoing annual maintenance costs necessary to ensure the project lasts its design life, totalling $400,000 per year. In order to facilitate comparisons, costs listed are per year even if the item is expected to take place less frequently. For example, $585,000 is expected to be spent on roadway paving every 15 years, so the table lists an annual cost of $39,000.

Table 10: *Annual Operation Costs and Maintenance Timing*

Maintenance Area	Cost per year	Description
Parkade		
Overall parkade maintenance	$258,000	Includes utilities and preventative maintenance such as deck sealing and re-caulking [31] – timing as necessary to be determined by building manager
Tank maintenance	$5,000	Annual week-long cleaning, and a weekly 1-hour inspection
Green roof maintenance	$6,000	Includes fertilization, irrigation, weed control, and replanting – biannually
Retail building maintenance	$22,900	Only for the ground floor portion set aside for retail, for items such as HVAC, plumbing, etc. [32] – timing as necessary to be determined by building manager
Utilities	$30,200	Only for the ground floor portion set aside for retail [32] – ongoing cost, charged monthly/bimonthly
Janitorial costs	$19,300	Only for the ground floor portion set aside for retail [32] – ongoing cost for salary, equipment, and materials
Subtotal	*$341,400*	
Bioswale		
Landscaping	$900	General fixes, weeding, etc. Biannually, unskilled labour
Dredging	$900	Necessary to ensure subsoils do not get “clogged” – requires backhoe. Likely to happen every 2-5 years.

Maintenance Area	Cost per year	Description
Re-planting	$2,100	As necessary with annual or perennial plants
Mulching	$1,900	Weed prevention and general plant health
Subtotal	*$5,800*	
Intersection		
Paving/surface maintenance	$39,000	Paving of full corridor likely every 15 years. Other surface maintenance (sealing, pothole repair) as needed, determined by MC MoTI [33]
Traffic signal	$4,000	Ongoing utilities cost, manual resets as needed. Similar to existing pre-construction cost [33]
Lighting	$9,000	Ongoing utilities costs; repair and replacing bulbs as needed. Similar to existing pre-construction cost as lineal-km of roadway is not changing [33]
Subtotal	*$52,000*	
Total	**$399,200**	

With proper ongoing maintenance as tabulated above, the parkade structure should last at least 50 years, and may last upwards of 70. While intersection repaving is expected to take place every 15 years, the smaller surface area of asphalt paving reduces this ongoing cost to the province compared to today.

4.4 Schedule

The estimated construction schedule was developed under the assumption that the bioswale and intersection portions of the project are independent from the parkade portion, allowing construction of each section to progress in parallel. However, in order to minimize traffic impacts, construction of the bioswale will not commence until paving of the intersection is complete, allowing the complete closure of one carriageway at a time rather than closing portions of each. A full list of subtasks is included in **Appendix A**; only major task groups are shown here in **Exhibit 1**.

The bioswale and intersection portion of the project are projected to take 138 working days, and the parkade is expected to take 410 working days. Although the proposed start date is May 1, 2019, a number of pre-construction tasks need to be undertaken before ground breaking may occur on June 5, 2019 (See **Appendix A**: Project Management Documents). This places the end of construction of the roadworks on August 30, end of construction for the bioswale on December 13, 2019, and end of construction for the parkade on December 29, 2019. In order to minimize traffic disruptions, it is important to keep the roadworks confined to the summer period before UBC resumes fall session in September. The current project schedule predicts this will happen, but with minimal slack. As such, the project should be considered to have two critical paths: construction of the parkade leading to an overall project duration, and construction of the roadworks in order to ensure uninterrupted traffic by September 2019.

As noted earlier, the parkade's location immediately adjacent to the proposed new stadium means that the construction schedule may be significantly influenced by stadium construction. As no information on construction of the new stadium is available at this time, it was assumed that parkade construction could proceed without knowledge of its integration with the stadium building.

4.5 Site Constraints

There are a number of site-specific constraints that impact both the cost and timeline of the project, which are compiled here for convenience.

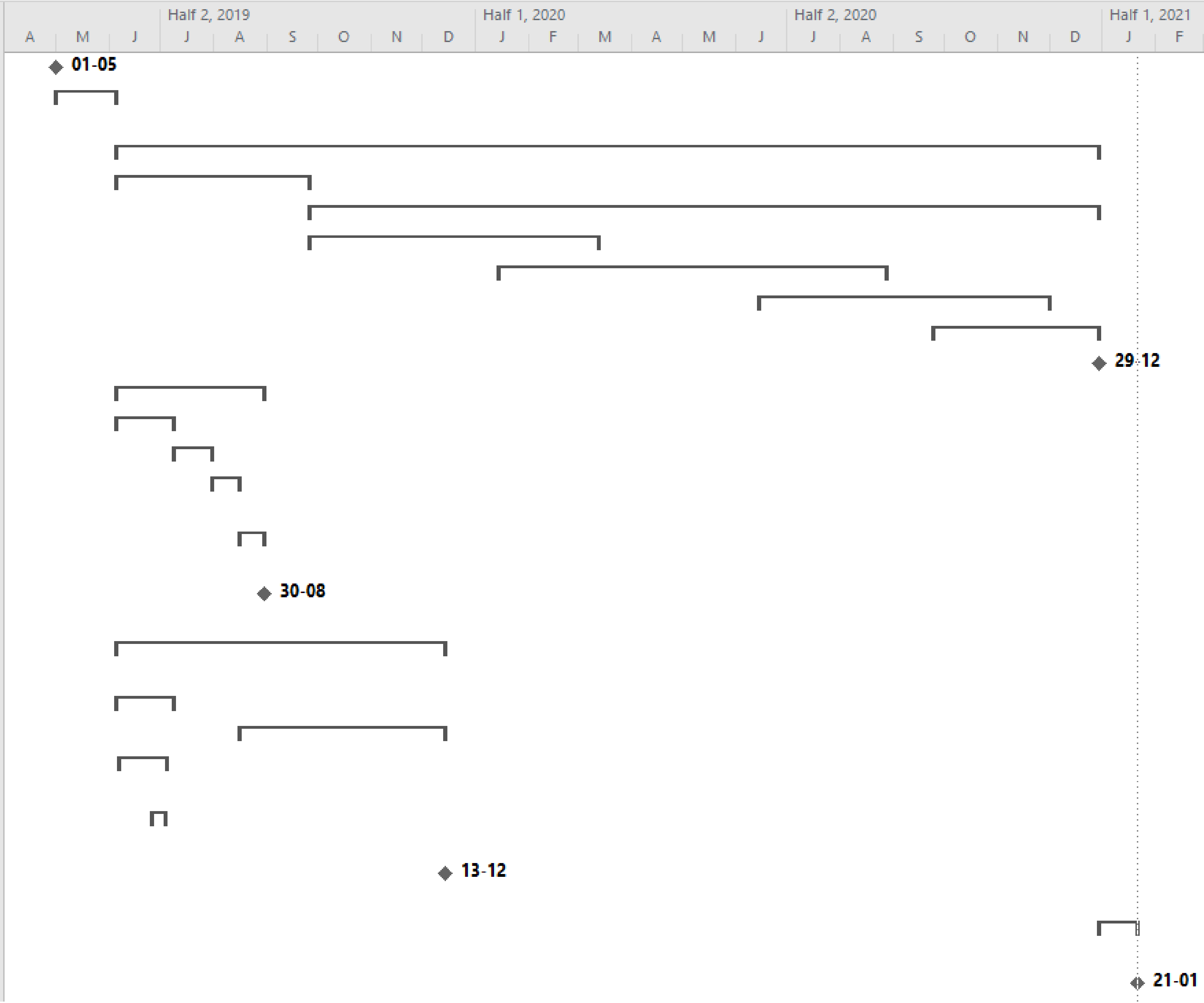
At the parkade site, which lacks any existing structures, the main constraints are the extremely small setback between the parkade structure and East Mall, as well minimizing disruption to the mature forest buffer to the south of the site. The proximity of East Mall means that a sloped trench wall cannot be used when excavating the foundation area, necessitating anchored retaining walls and piles. This expense has been considered in both the cost estimate and the construction schedule. We anticipate that it will be possible to leave traffic on East Mall undisturbed during this process; however, if updated geotechnical information reveals undesirable soil conditions, the general contractor will have a backup option to make use of East Mall's southbound carriageway and temporarily direct all traffic to use the amply wide northbound carriageway.

At the intersection site, as previously mentioned, the main constraint is to maintain access to all turning movements at SW Marine Dr / W 16th Ave throughout construction. This is important as the intersection is UBC's main gateway from the south, and accommodates three bus routes to points south and east. Maintained access is proposed to take place by retaining W 16th Ave's westbound carriageway for as long as possible into construction, so that single lane per direction traffic can proceed along the boundary of construction while the intersection is realigned. There may be times where turning or access to the north leg of SW Marine Drive will have to be restricted, but these restrictions must not happen during the AM or

PM peak periods. The intersection/bioswale site is also bounded on two sides by the UBC Botanical Garden. As such, noise and dust pollution during construction must be kept to an absolute minimum. Similarly, the sediment and erosion control plan to be developed by the prime contractor will ensure to address the impact of potentially increased sediment loads flowing through the Botanical Garden creeks to the existing outfall.

Exhibit 1: Schedule of Major Task Groups

WBS	Task Name	Duration
0	Start Project	0 days
1	**Pre Construction Tasks**	**25 days**
2	**Parkade**	**410 days**
2.1	**Foundation**	**81 days**
2.2	**Structure**	**329 days**
2.2.1	**T1**	**121 days**
2.2.2	**P1**	**162 days**
2.2.3	**L1**	**121 days**
2.2.4	**L2**	**69 days**
2.3	Finish structure	0 days
3	**Intersection**	**63 days**
3.1	**Utility Work**	**24 days**
3.2	**Site Work**	**16 days**
3.3	**Paving**	**12 days**
3.4	**Signage & Landscaping**	**11 days**
3.5	Finish Intersection	0 days
4	**Open Channel Flow components**	**138 days**
4.1	**Leed Channel**	**24 days**
4.2	**Bioswale**	**86 days**
4.3	**Leed-Swale Culvert**	**20 days**
4.4	**Swale-Garden Culvert**	**6 days**
4.5	Finished Open Channel	0 days
5	**Post Construction tasks**	**17 days**
6	Finish Project	0 days



5 Conclusion and Recommendations

Group 25 has proceeded with the detailed design for the University of British Columbia Campus and Community Planning's Stadium Neighbourhood Project, finalizing the combined solution of a mixed-use parkade, a bioswale, and an intersection redesign of SW Marine Drive and W 16th Avenue. The anticipated total cost of this project is $24.9M, with annual operational costs of $400,000.

In order to proceed into the construction phase, various deliverables are needed to build onto the design. Work from subcontractors hired to complete specialized design of parkade structural components will have to be integrated into the design package. Various data will need to be collected, such as an official elevation survey of the site, a survey of existing utilities, and improved geotechnical information in the form of on-site boreholes. Once sufficient information is collected and all design components have been progressed to a "for construction" status, groundbreaking may take place, and construction is expected to last 20 months.

The mixed-use parkade is to serve both as a parking facility for the anticipated demand generated by the new Thunderbird Stadium, and as a stormwater detention facility. As UBC pushes for more sustainable modes of transportation in the upcoming decades, vehicular parking demand is expected to decrease, and the upper floor of the parkade may be converted from parking to commercial space. This approach, combined with the green roof on top of the parkade, is intended to help UBC reach its sustainability goals in the future while balancing current demands. The bioswale is further intended to retain and filter rainfall. As a result, the stormwater is cleaned and prevented from infiltrating into the soil while the strain on stormwater outfalls during storm events is reduced. Finally, the intersection redesign of SW Marine Drive / W 16th Avenue will use the right-of-way more efficiently to accommodate the current and anticipated traffic demand. This extra space allows for the implementation of the bioswale. The redesign has a high emphasis on encouraging sustainable modes of transportation and on significantly reducing impervious surfaces that would otherwise add onto runoff.

We trust this final design report addresses the client's concerns and that the proposed design proves satisfactory to carry forward. Should the client have additional concerns, do not hesitate to reach out and contact us.

Appendix A: Project Management Documents

A.1. Schedule

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
1	0	Start Project	0 days	Wed 01-05-19	Wed 01-05-19			Yes
2	**1**	**Pre Construction Tasks**	**25 days**	**Wed 01-05-19**	**Tue 04-06-19**			**Yes**
3	**1.1**	**Preparation, Human Resources**	**25 days**	**Wed 01-05-19**	**Tue 04-06-19**			**Yes**
4	1.1.1	Contract Negotions	10 days	Wed 01-05-19	Tue 14-05-19	1		Yes
5	1.1.2	Obtain Relevant Permits	10 days	Wed 15-05-19	Tue 28-05-19	4		Yes
6	1.1.3	Kick Off Meeting	1 day	Wed 15-05-19	Wed 15-05-19	4		No
7	1.1.4	Worker Training	5 days	Wed 29-05-19	Tue 04-06-19	5		Yes
8	1.1.5	Secure Site	5 days	Wed 29-05-19	Tue 04-06-19	5		Yes
9	1.1.6	Secure Supplies	5 days	Wed 29-05-19	Tue 04-06-19	5		Yes
10	**1.2**	**Engineering**	**10 days**	**Wed 15-05-19**	**Tue 28-05-19**			**No**
11	1.2.1	Complete Parkade Seconday Analysis	5 days	Wed 15-05-19	Tue 21-05-19	4		No
12	1.2.2	Write Construction Manual	5 days	Wed 22-05-19	Tue 28-05-19	11		No
13	1.2.3	Revise Schedule and Cost Estimate	5 days	Wed 22-05-19	Tue 28-05-19	11		No
14	1.2.4	Demention Remaing Intersection Details	2 days	Wed 15-05-19	Thu 16-05-19	4		No
15	**2**	**Parkade**	**410 days**	**Wed 05-06-19**	**Tue 29-12-20**			**Yes**
16	**2.1**	**Foundation**	**81 days**	**Wed 05-06-19**	**Wed 25-09-19**			**Yes**
17	2.1.1	Site survey and existing utilities	2 days	Wed 05-06-19	Thu 06-06-19	6,7,8,9,12,13	4	Yes
18	2.1.2	Excavate	21 days	Fri 07-06-19	Fri 05-07-19	17	2[300%]	Yes
19	2.1.3	Groundwater Drainage	21 days	Fri 07-06-19	Fri 05-07-19	17	1	No

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
20	2.1.4	Soil compaction	2 days	Mon 08-07-19	Tue 09-07-19	18	4[200%]	Yes
21	2.1.5	Check slope	2 days	Wed 10-07-19	Thu 11-07-19	18,20	1	Yes
22	2.1.6	Installation of anchored retaining walls	4 days	Thu 18-07-19	Tue 23-07-19	21	3[200%]	Yes
23	2.1.7	Installation of anchor piles	4 days	Fri 12-07-19	Wed 17-07-19	21	3[200%]	Yes
24	2.1.8	Install drainage to bioswale	3 days	Fri 12-07-19	Tue 16-07-19	21	2	No
25	2.1.9	Install waterproof membrane	3 days	Fri 12-07-19	Tue 16-07-19	21	1	Yes
26	2.1.10	Tying rebar	5 days	Wed 31-07-19	Tue 06-08-19	22,23,25	1[500%]	Yes
27	2.1.11	Rebar Placement with spacers	5 days	Wed 24-07-19	Tue 30-07-19	22,23,25	1[500%]	Yes
28	2.1.12	Concrete Pour	8 days	Wed 07-08-19	Fri 16-08-19	26,27	2	Yes
29	2.1.13	Concrete Curing	28 days	Mon 19-08-19	Wed 25-09-19	28	1	Yes
30	2.1.14	Concrete Deflection inspection	1 day	Fri 06-09-19	Fri 06-09-19	28FS+14 days	3	No
31	2.1.15	Foundation built	0 days	Wed 25-09-19	Wed 25-09-19	19,24,25,29,30		Yes
32	**2.2**	**Structure**	**329 days**	**Wed 25-09-19**	**Tue 29-12-20**			**Yes**
33	**2.2.1**	**T1**	**121 days**	**Wed 25-09-19**	**Thu 12-03-20**			**Yes**
34	2.2.1.1	Start structure	0 days	Wed 25-09-19	Wed 25-09-19	31		Yes
35	2.2.1.2	Install tank-to-bioswale pump	**1 day**	Thu 26-09-19	Thu 26-09-19	34	1	Yes
36	2.2.1.3	Install T1 column formwork	**16 days**	Fri 27-09-19	Fri 18-10-19	35	1	Yes
37	2.2.1.4	Install T1 wall formwork	**15 days**	Fri 27-09-19	Thu 17-10-19	35	1[200%]	Yes
38	2.2.1.5	Lay T1 column rebar	**12 days**	Fri 27-09-19	Mon 14-10-19	35	1	Yes
39	2.2.1.6	Lay T1 wall rebar	**7 days**	Fri 27-09-19	Mon 07-10-19	35	1	Yes
40	2.2.1.7	Pour T1 column concrete	**2 days**	Mon 21-10-19	Tue 22-10-19	36,38	1[200%]	Yes

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
41	2.2.1.8	Pour T1 wall concrete	2 days	Fri 18-10-19	Mon 21-10-19	37,39	1[300%]	Yes
42	2.2.1.9	Install P1 slab/beam formwor	55 days	Wed 23-10-19	Tue 07-01-20	40,41	1[300%]	Yes
43	2.2.1.10	Lay P1 slab/beam rebar	30 days	Wed 23-10-19	Tue 03-12-19	41,40	1[200%]	No
44	2.2.1.11	Pour P1 slab/beam concrete	5 days	Wed 08-01-20	Tue 14-01-20	42,43	1[500%]	Yes
45	2.2.1.12	Remove P1 slab/beam formwo	17 days	Wed 19-02-20	Thu 12-03-20	44FS+25 days	1	Yes
46	**2.2.2**	**P1**	**162 days**	**Wed 15-01-20**	**Thu 27-08-20**			**No**
47	2.2.2.1	Install P1 MEP components	38 days	Wed 15-01-20	Fri 06-03-20	44	2	No
48	2.2.2.2	Relocate T1 column formwork	18 days	Wed 15-01-20	Fri 07-02-20	44	1	No
49	2.2.2.3	Relocate T1 wall formwork to	15 days	Wed 15-01-20	Tue 04-02-20	44	1[200%]	No
50	2.2.2.4	Lay P1 column rebar	12 days	Wed 15-01-20	Thu 30-01-20	44	1	No
51	2.2.2.5	Lay P1 wall rebar	7 days	Wed 15-01-20	Thu 23-01-20	44	1	No
52	2.2.2.6	Pour P1 column concrete	2 days	Mon 10-02-20	Tue 11-02-20	48,50	1[200%]	No
53	2.2.2.7	Pour P1 wall concrete	2 days	Wed 05-02-20	Thu 06-02-20	49,51	1[300%]	No
54	2.2.2.8	Install L1 slab/beam formwork	60 days	Fri 13-03-20	Thu 04-06-20	45,52,53	1[300%]	Yes
55	2.2.2.9	Lay L1 slab/beam rebar	62 days	Wed 12-02-20	Thu 07-05-20	52,53	1	No
56	2.2.2.10	Pour L1 slab/beam concrete	6 days	Fri 05-06-20	Fri 12-06-20	54,55	1[500%]	Yes
57	2.2.2.11	Remove L1 slab/beam formwo	19 days	Mon 03-08-20	Thu 27-08-20	56FS+35 days	1	Yes
58	**2.2.3**	**L1**	**121 days**	**Mon 15-06-20**	**Mon 30-11-20**			**No**
59	2.2.3.1	Install L1 MEP components	15 days	Mon 15-06-20	Fri 03-07-20	56	2	No
60	2.2.3.2	Install L1 studwalls	3 days	Fri 16-10-20	Tue 20-10-20	71	1	No
61	2.2.3.3	Install L1 glazing	6 days	Mon 23-11-20	Mon 30-11-20	60	1	No
62	2.2.3.4	Relocate P1 column formwork	13 days	Mon 15-06-20	Wed 01-07-20	56	1	No
63	2.2.3.5	Relocate P1 wall formwork to	8 days	Mon 15-06-20	Wed 24-06-20	56	1[200%]	No

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
64	2.2.3.6	Lay L1 column rebar	7 days	Mon 15-06-20	Tue 23-06-20	56	1	No
65	2.2.3.7	Lay L1 wall rebar	4 days	Mon 15-06-20	Thu 18-06-20	56	1	No
66	2.2.3.8	Pour L1 column concrete	1 day	Thu 02-07-20	Thu 02-07-20	62,64	1[200%]	No
67	2.2.3.9	Pour L1 wall concrete	1 day	Thu 25-06-20	Thu 25-06-20	63,65	1[300%]	No
68	2.2.3.10	Install L2 slab/beam formwork	17 days	Fri 28-08-20	Mon 21-09-20	66,67,57	1[400%]	Yes
69	2.2.3.11	Lay L2 slab/beam rebar	22 days	Fri 03-07-20	Mon 03-08-20	66,67	1	No
70	2.2.3.12	Pour L2 slab/beam concrete	2 days	Tue 22-09-20	Wed 23-09-20	69,68	1[500%]	Yes
71	2.2.3.13	Remove L2 slab/beam formwc	7 days	Wed 07-10-20	Thu 15-10-20	70	1	Yes
72	**2.2.4**	**L2**	**69 days**	**Thu 24-09-20**	**Tue 29-12-20**			**Yes**
73	2.2.4.1	Install L2 MEP components	15 days	Thu 24-09-20	Wed 14-10-20	70	2	No
74	2.2.4.2	Install L2 glazing	5 days	Wed 23-12-20	Tue 29-12-20	86	1	Yes
75	2.2.4.3	Relocate L1 column formwork	13 days	Thu 24-09-20	Mon 12-10-20	70	1	Yes
76	2.2.4.4	Relocate L1 wall formwork to l	8 days	Thu 24-09-20	Mon 05-10-20	70	1[200%]	Yes
77	2.2.4.5	Lay L2 column rebar	7 days	Thu 24-09-20	Fri 02-10-20	70	1	Yes
78	2.2.4.6	Lay L2 wall rebar	4 days	Thu 24-09-20	Tue 29-09-20	70	1	Yes
79	2.2.4.7	Pour L2 column concrete	1 day	Tue 13-10-20	Tue 13-10-20	75,77	1[200%]	Yes
80	2.2.4.8	Pour L2 wall concrete	1 day	Tue 06-10-20	Tue 06-10-20	76,78	1[300%]	Yes
81	2.2.4.9	Install Roof slab/beam formwc	18 days	Wed 21-10-20	Fri 13-11-20	79,80,71	1[400%]	Yes
82	2.2.4.10	Lay Roof slab/beam rebar	25 days	Wed 14-10-20	Tue 17-11-20	79,80	1	Yes
83	2.2.4.11	Pour Roof slab/beam concrete	3 days	Wed 18-11-20	Fri 20-11-20	81,82	1[500%]	Yes
84	2.2.4.12	Install elevator	2 days	Mon 23-11-20	Tue 24-11-20	83	4	Yes
85	2.2.4.13	Construct green roof	16 days	Wed 25-11-20	Wed 16-12-20	84	2[200%]	Yes
86	2.2.4.14	Remove Roof slab/beam form	2 days	Mon 21-12-20	Tue 22-12-20	83FS+20 days	1[500%]	Yes

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
87	2.3	Finish structure	0 days	Tue 29-12-20	Tue 29-12-20	61,74,85,73,59,47		Yes
88	**3**	**Intersection**	**63 days**	**Wed 05-06-19**	**Fri 30-08-19**			**No**
89	**3.1**	**Utility Work**	**24 days**	**Wed 05-06-19**	**Mon 08-07-19**			**No**
90	3.1.1	Site Preparation	1 day	Wed 05-06-19	Wed 05-06-19	6,7,8,9,14,13	1.1	No
91	3.1.2	Relocate conflicting poles	1 day	Thu 06-06-19	Thu 06-06-19	90	1.1	No
92	3.1.3	Excavation for new water-main	3 days	Thu 06-06-19	Mon 10-06-19	90	2.1	No
93	3.1.4	Install water mains	3 days	Thu 27-06-19	Mon 01-07-19	92	2.1	No
94	3.1.5	Excavation for new storm-main	3 days	Tue 11-06-19	Thu 13-06-19	90	2.1	No
95	3.1.6	Install storm mains	3 days	Mon 24-06-19	Wed 26-06-19	94	2.1	No
96	3.1.7	Excavation for new sanitary-mair	3 days	Fri 14-06-19	Tue 18-06-19	90	2.1	No
97	3.1.8	Install new sanitary mains	3 days	Wed 19-06-19	Fri 21-06-19	96	2.1	No
98	3.1.9	Connect existing utilities to re-ali	2 days	Fri 05-07-19	Mon 08-07-19	97,93,95,91,155,1	4.1	No
99	**3.2**	**Site Work**	**16 days**	**Tue 09-07-19**	**Tue 30-07-19**			**No**
100	3.2.1	Excavation	6 days	Tue 09-07-19	Tue 16-07-19	98	1.1	No
101	3.2.2	Remove backfill off site	2 days	Wed 17-07-19	Thu 18-07-19	100	1.1	No
102	3.2.3	Transport as-per-code soil on site	2 days	Fri 19-07-19	Mon 22-07-19	101	1.1	No
103	3.2.4	Lay road sub grade	1 day	Tue 23-07-19	Tue 23-07-19	102	2.1	No
104	3.2.5	Compact road sub grade	1 day	Wed 24-07-19	Wed 24-07-19	103	1.1	No
105	3.2.6	Lay road sub base	1 day	Thu 25-07-19	Thu 25-07-19	104	2.1	No
106	3.2.7	Compact road sub base	1 day	Fri 26-07-19	Fri 26-07-19	105	1.1	No
107	3.2.8	Lay road base	1 day	Mon 29-07-19	Mon 29-07-19	106	2.1	No
108	3.2.9	Compact road base	1 day	Tue 30-07-19	Tue 30-07-19	107	1.1	No
109	**3.3**	**Paving**	**12 days**	**Wed 31-07-19**	**Thu 15-08-19**			**No**

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
110	3.3.1	Curb + Gutter	2 days	Wed 31-07-19	Thu 01-08-19	108	2.1	No
111	3.3.2	Base layer asphalt	5 days	Fri 02-08-19	Thu 08-08-19	110	2.1	No
112	3.3.3	Top Layer Asphalt	3 days	Fri 09-08-19	Tue 13-08-19	111	2.1	No
113	3.3.4	Concrete Sidewalk Pouring and C	2 days	Wed 14-08-19	Thu 15-08-19	112	2.1	No
114	3.3.5	Finish paving	0 days	Thu 15-08-19	Thu 15-08-19	113		No
115	**3.4**	**Signage & Landscaping**	**11 days**	**Fri 16-08-19**	**Fri 30-08-19**			**No**
116	3.4.1	Traffic Signal Replacement	1 day	Fri 16-08-19	Fri 16-08-19	114	4.1	No
117	3.4.2	Install New Signage	1 day	Mon 19-08-19	Mon 19-08-19	114	4.1	No
118	3.4.3	Paint Lines	2 days	Tue 20-08-19	Wed 21-08-19	114	4.1	No
119	3.4.4	Street Trees & Landscaping	7 days	Thu 22-08-19	Fri 30-08-19	114	4.1	No
120	3.5	Finish Intersection	0 days	Fri 30-08-19	Fri 30-08-19	116,117,118,119		No
121	**4**	**Open Channel Flow components**	**138 days**	**Tue 04-06-19**	**Fri 13-12-19**			**No**
122	**4.1**	**Leed Channel**	**24 days**	**Tue 04-06-19**	**Mon 08-07-19**			**No**
123	4.1.1	Start Leed Channel	0 days	Tue 04-06-19	Tue 04-06-19	6,7,8,9,13		No
124	4.1.2	Surveying	2 days	Wed 05-06-19	Thu 06-06-19	123	4.2	No
125	4.1.3	Cut trees	2 days	Fri 07-06-19	Mon 10-06-19	124	3.1	No
126	4.1.4	Remove stumps	2 days	Tue 11-06-19	Wed 12-06-19	125	1.1	No
127	4.1.5	Dig channels	4 days	Thu 13-06-19	Tue 18-06-19	126	1.1	No
128	4.1.6	Transport Soil away	1 day	Fri 05-07-19	Fri 05-07-19	127	1.1	No
129	4.1.7	Lay impervious Geotextile	1 day	Wed 19-06-19	Wed 19-06-19	127	1.1	No
130	4.1.8	Place RipRap Lining	2 days	Thu 20-06-19	Fri 21-06-19	129	1.1	No
131	4.1.9	Connect with Parkade and down:	1 day	Mon 08-07-19	Mon 08-07-19	129,154	1.1	No
132	4.1.10	Landscaping and beautificaton	2 days	Mon 24-06-19	Tue 25-06-19	130	1.1	No

Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
133	4.1.11	Finish Leed Channel	0 days	Mon 08-07-19	Mon 08-07-19	128,131,132		No
134	**4.2**	**Bioswale**	**86 days**	**Thu 15-08-19**	**Fri 13-12-19**			**No**
135	4.2.1	Start Bioswale	0 days	Thu 15-08-19	Thu 15-08-19	114		No
136	4.2.2	Survey Site	6 days	Fri 16-08-19	Fri 23-08-19	135	4.2	No
137	4.2.3	Dig Bioswale and Forebay	15 days	Mon 26-08-19	Fri 13-09-19	136	1.1	No
138	4.2.4	Transport Soil away	3 days	Fri 20-09-19	Tue 24-09-19	137	1.1	No
139	4.2.5	Lay impervious Geotextile	2 days	Mon 16-09-19	Tue 17-09-19	137	1.1	No
140	4.2.6	Place Gravel Storage Layer	2 days	Wed 18-09-19	Thu 19-09-19	139	1.1	No
141	4.2.7	Lay Drain Pipe	5 days	Wed 25-09-19	Tue 01-10-19	140	1.1	No
142	4.2.8	Connect Drain to lower Culvert	1 day	Wed 02-10-19	Wed 02-10-19	141,158	1.1	No
143	4.2.9	Place Pea Gravel Choking Layer	1 day	Thu 03-10-19	Thu 03-10-19	141	1.1	No
144	4.2.10	Lay Pervious Geotextile	1 day	Fri 04-10-19	Fri 04-10-19	143	1.1	No
145	4.2.11	Place Filter medium	4 days	Mon 07-10-19	Thu 10-10-19	144	1.1	No
146	4.2.12	Construct Check Dams	9 days	Fri 11-10-19	Wed 23-10-19	145	1.1	No
147	4.2.13	Replace Native Soil Layer	4 days	Thu 24-10-19	Tue 29-10-19	146	1.1	No
148	4.2.14	Connect Upstream Culvert	1 day	Wed 30-10-19	Wed 30-10-19	147,154	1.1	No
149	4.2.15	Landscaping and beautificaton	4 days	Thu 31-10-19	Tue 05-11-19	147	1.1	No
150	4.2.16	Plant plants	28 days	Wed 06-11-19	Fri 13-12-19	149	1.1	No
151	4.2.17	Finish Bioswale	0 days	Fri 13-12-19	Fri 13-12-19	138,142,148,150		No
152	**4.3**	**Leed-Swale Culvert**	**20 days**	**Fri 07-06-19**	**Thu 04-07-19**			**No**
153	4.3.1	Dig Trench	1 day	Fri 07-06-19	Fri 07-06-19	90	1.1	No
154	4.3.2	Install culvert	1 day	Mon 10-06-19	Mon 10-06-19	153	1.1	No
155	4.3.3	Cover Trench	1 day	Thu 04-07-19	Thu 04-07-19	154	1.1	No

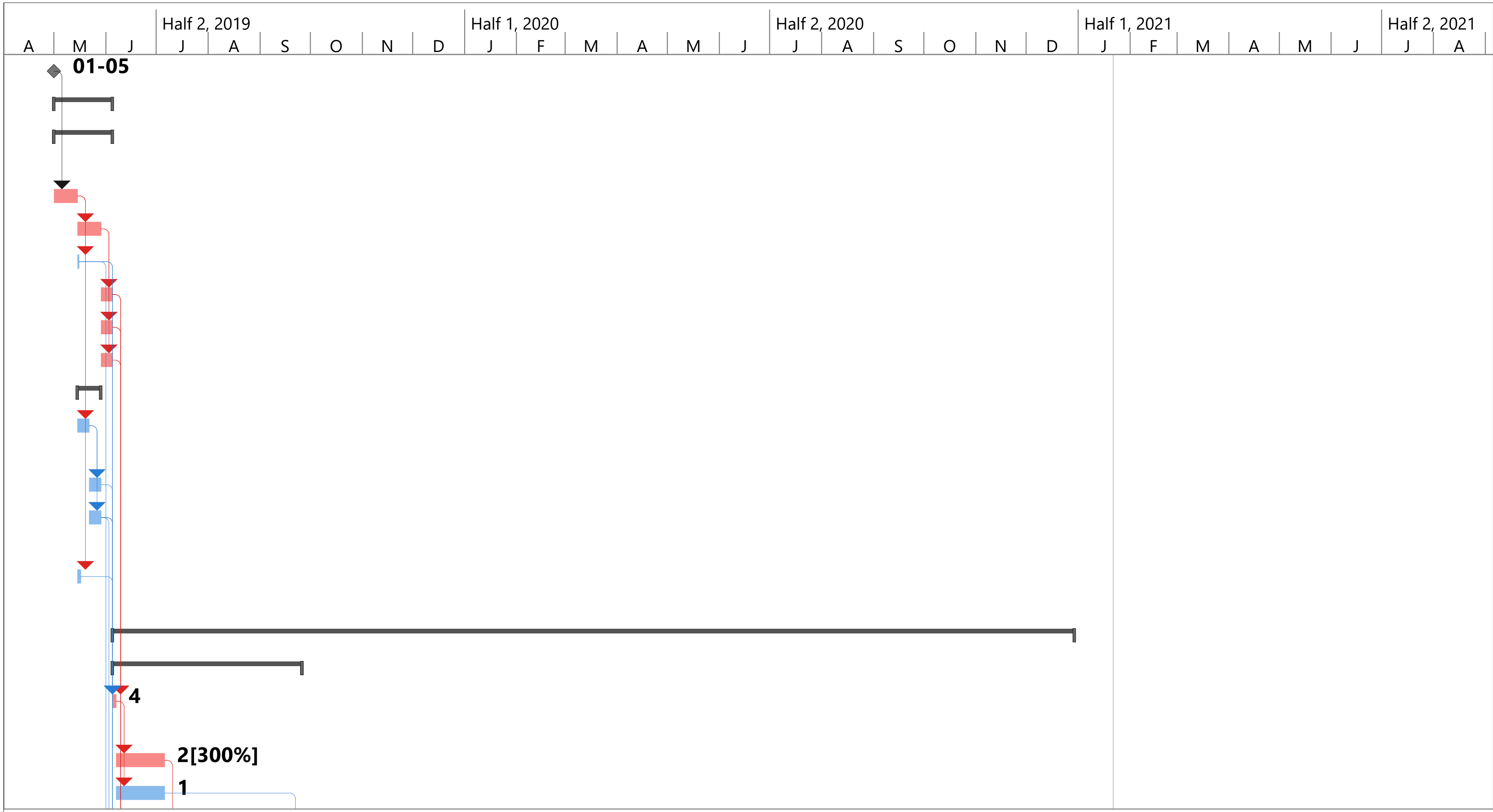
Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

ID	WBS	Task Name	Duration	Start	Finish	Predecessors	Resource Names	Critical
156	**4.4**	**Swale-Garden Culvert**	**6 days**	**Wed 26-06-19**	**Wed 03-07-19**			**No**
157	4.4.1	Dig Trench	2 days	Wed 26-06-19	Thu 27-06-19	90	1.1	No
158	4.4.2	Install culvert	2 days	Fri 28-06-19	Mon 01-07-19	157	1.1	No
159	4.4.3	Cover Trench	2 days	Tue 02-07-19	Wed 03-07-19	158	1.1	No
160	4.5	Finished Open Channel	0 days	Fri 13-12-19	Fri 13-12-19	133,151		No
161	**5**	**Post Construction tasks**	**17 days**	**Wed 30-12-20**	**Thu 21-01-21**			**Yes**
162	5.1	Site Clean-up	8 days	Wed 30-12-20	Fri 08-01-21	87,120,160		Yes
163	5.2	Commisioning	4 days	Wed 30-12-20	Mon 04-01-21	87,120,160		Yes
164	5.3	Final Tasks (Traffic, clean up, etc..)	15 days	Wed 30-12-20	Tue 19-01-21	87,120,160		Yes
165	5.4	Hand Over to Client	2 days	Wed 20-01-21	Thu 21-01-21	163,164,162		Yes
166	6	Finish Project	0 days	Thu 21-01-21	Thu 21-01-21	165		Yes

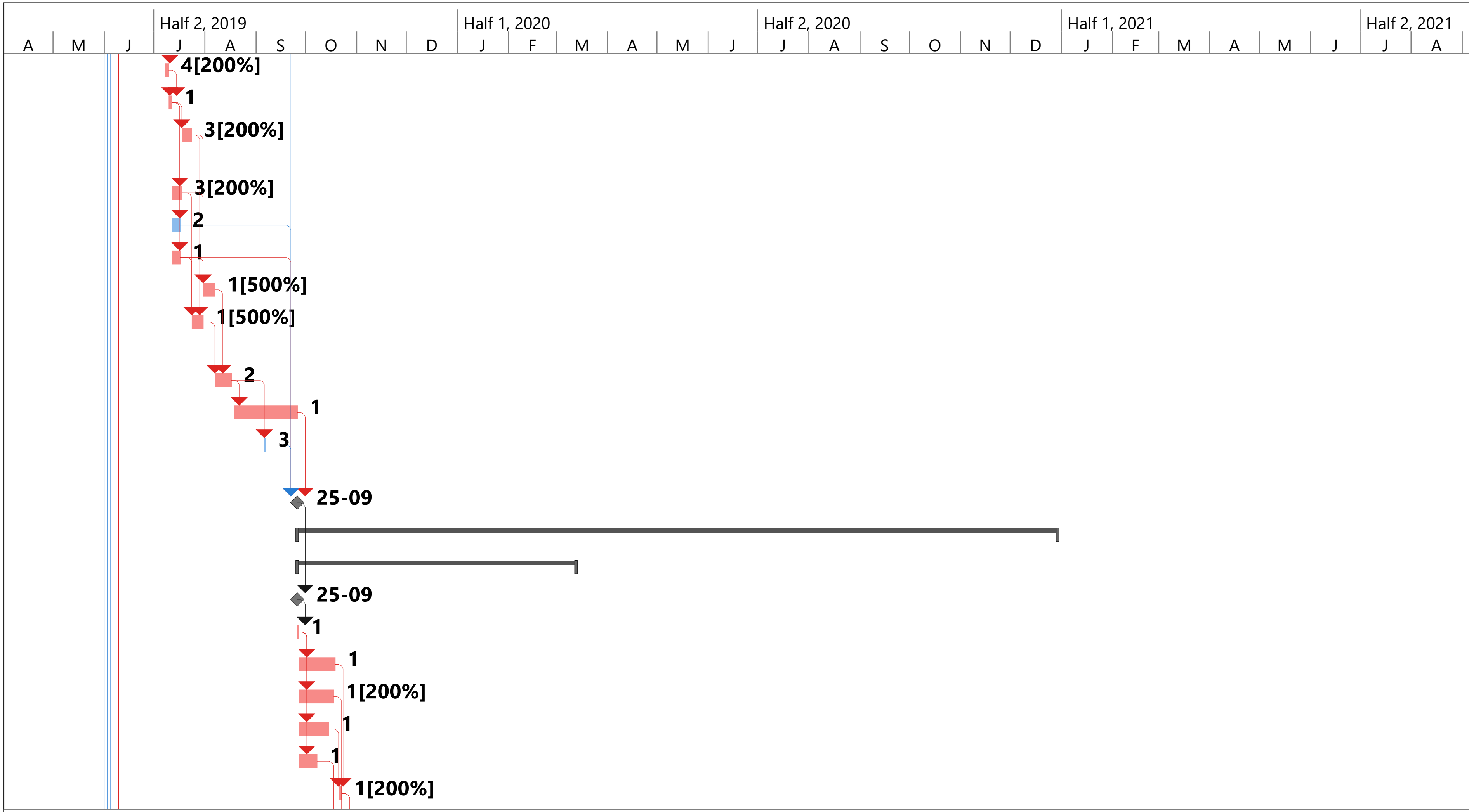
Project: Stadium Neighbourhood
Date: Sun 31-03-19

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



Project: Stadium Neighbourhood
Date: Sun 31-03-19

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



Project: Stadium Neighbourhood
Date: Sun 31-03-19

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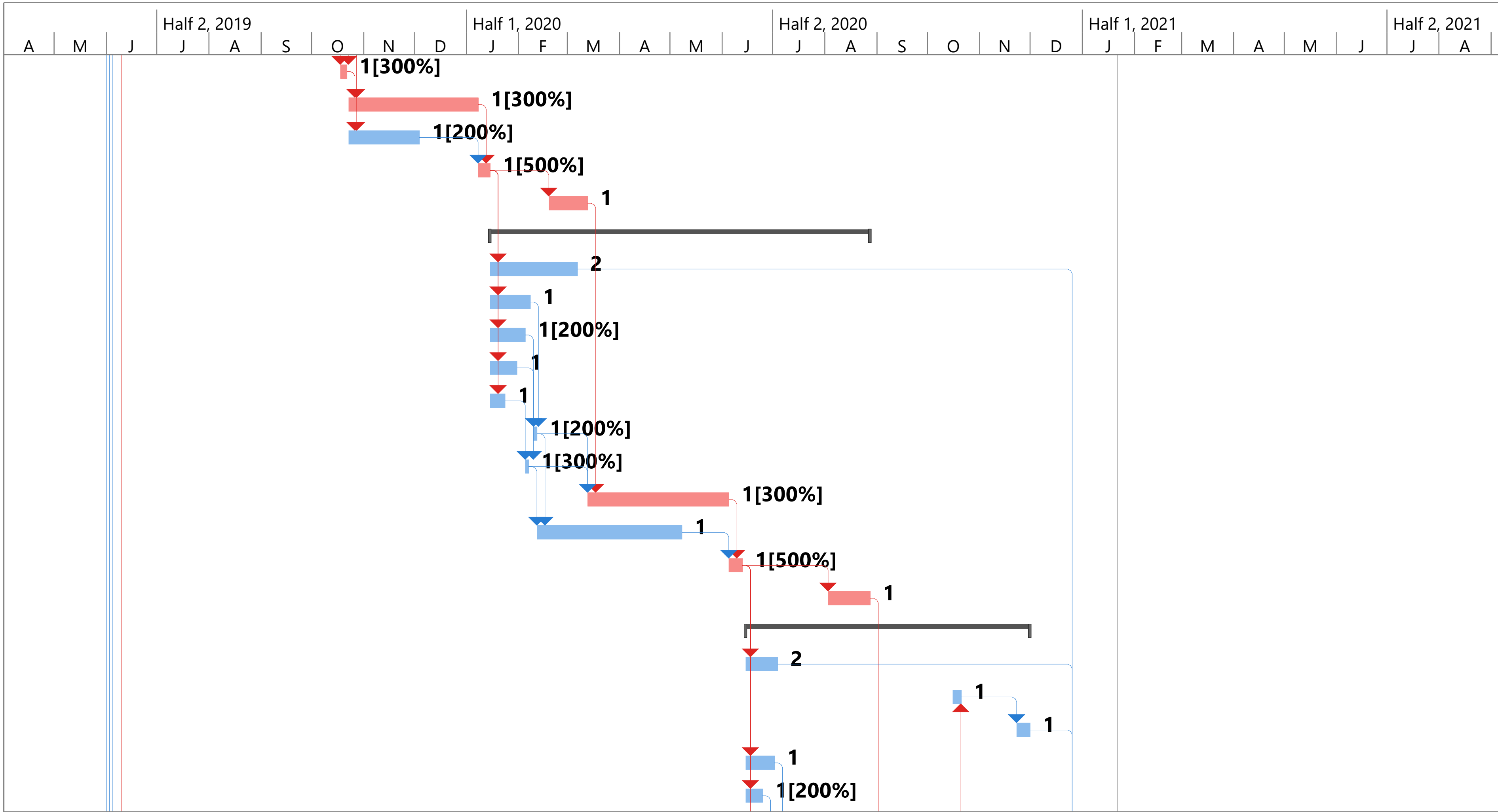
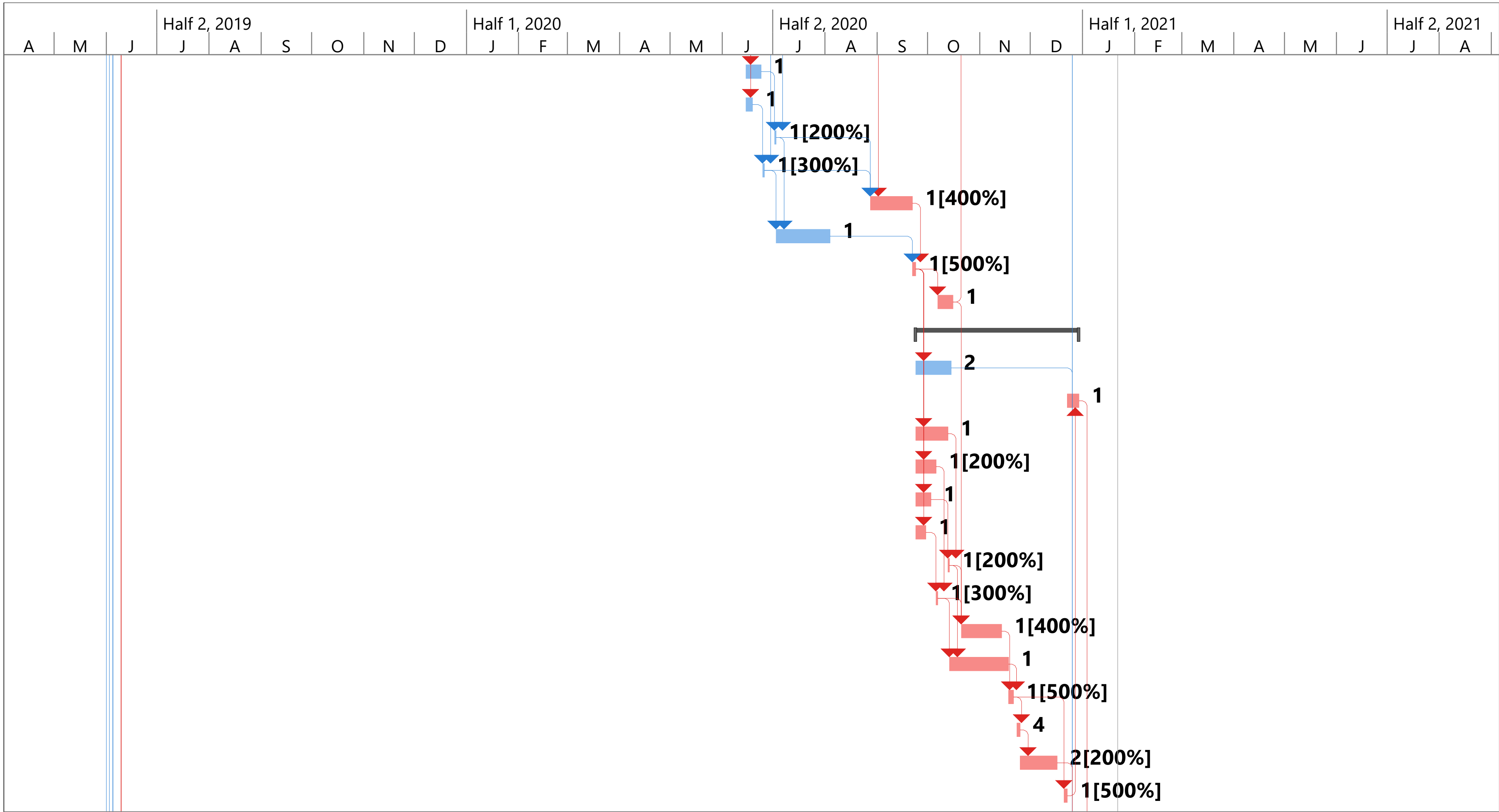
External Tasks
External Milestone
Deadline
Critical
Critical Split
Progress
Manual Progress



Project: Stadium Neighbourhood Date: Sun 31-03-19	Task		Inactive Summary		External Tasks	
	Split		Manual Task		External Milestone	
	Milestone		Duration-only		Deadline	
	Summary		Manual Summary Rollup		Critical	
	Project Summary		Manual Summary		Critical Split	
	Inactive Task		Start-only		Progress	
	Inactive Milestone		Finish-only		Manual Progress	



Project: Stadium Neighbourhood
Date: Sun 31-03-19

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
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Inactive Task	Start-only	Progress
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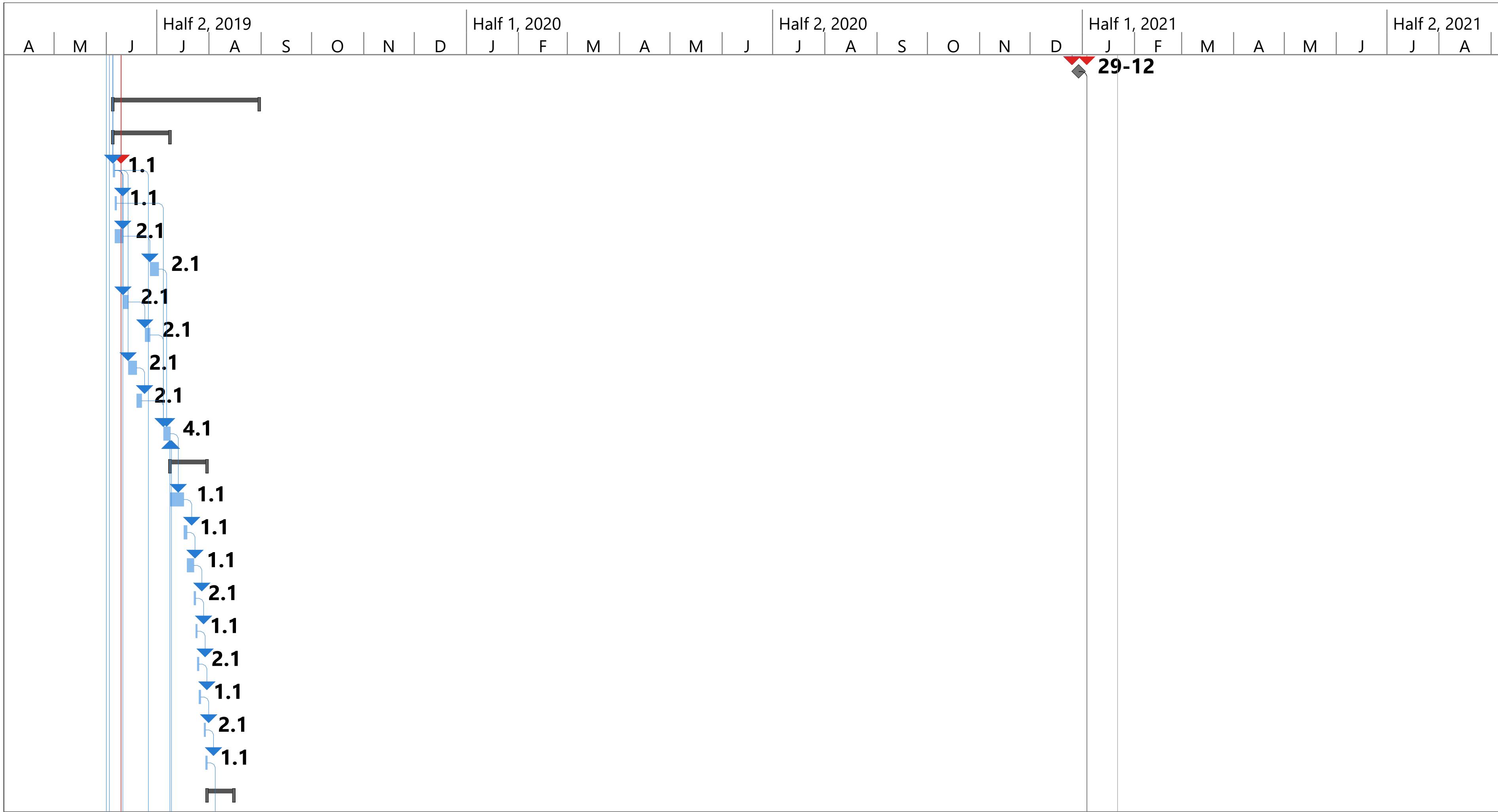

Project: Stadium Neighbourhood
Date: Sun 31-03-19

Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
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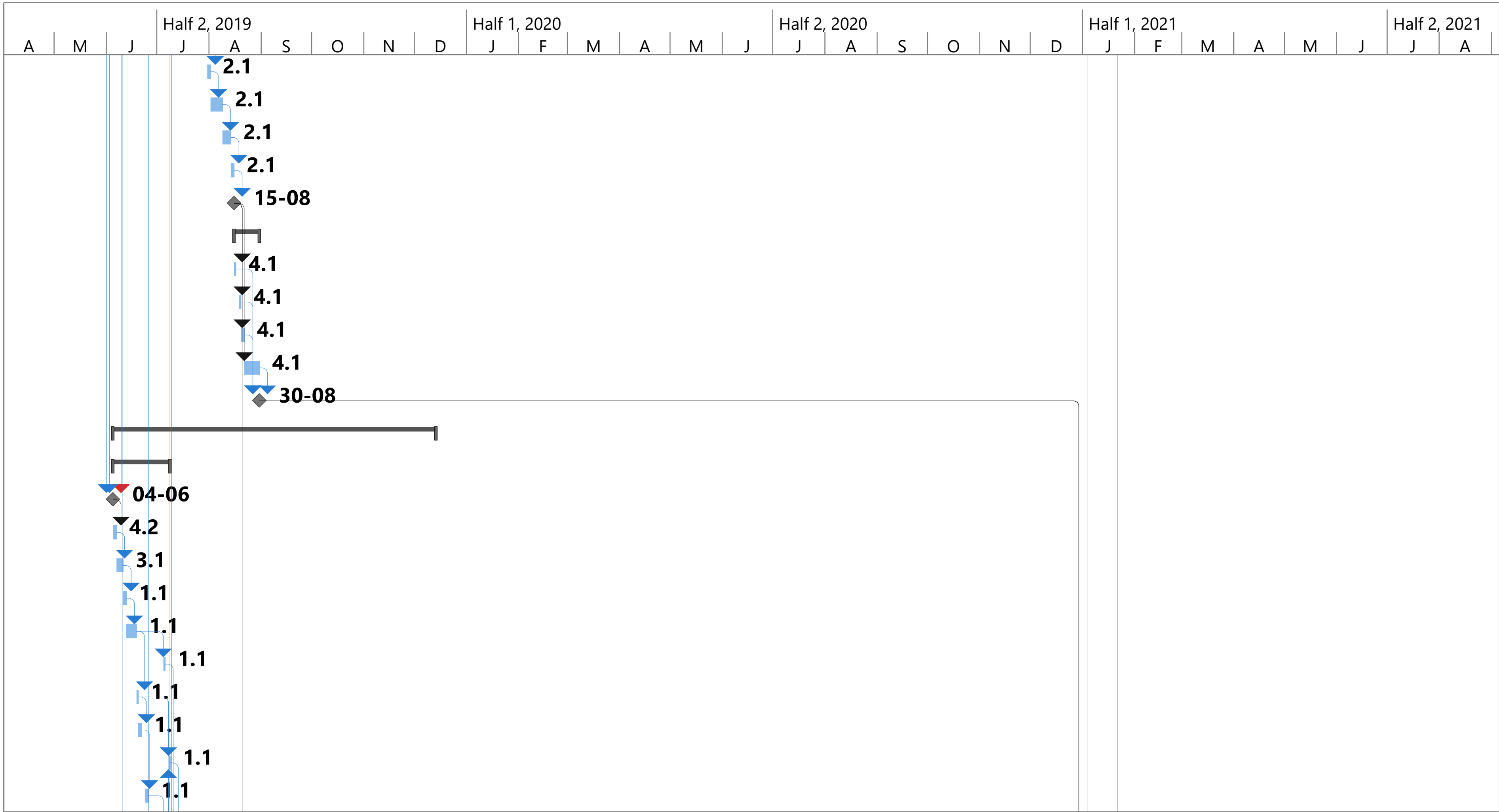

Project: Stadium Neighbourhood
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Task	Inactive Summary	External Tasks
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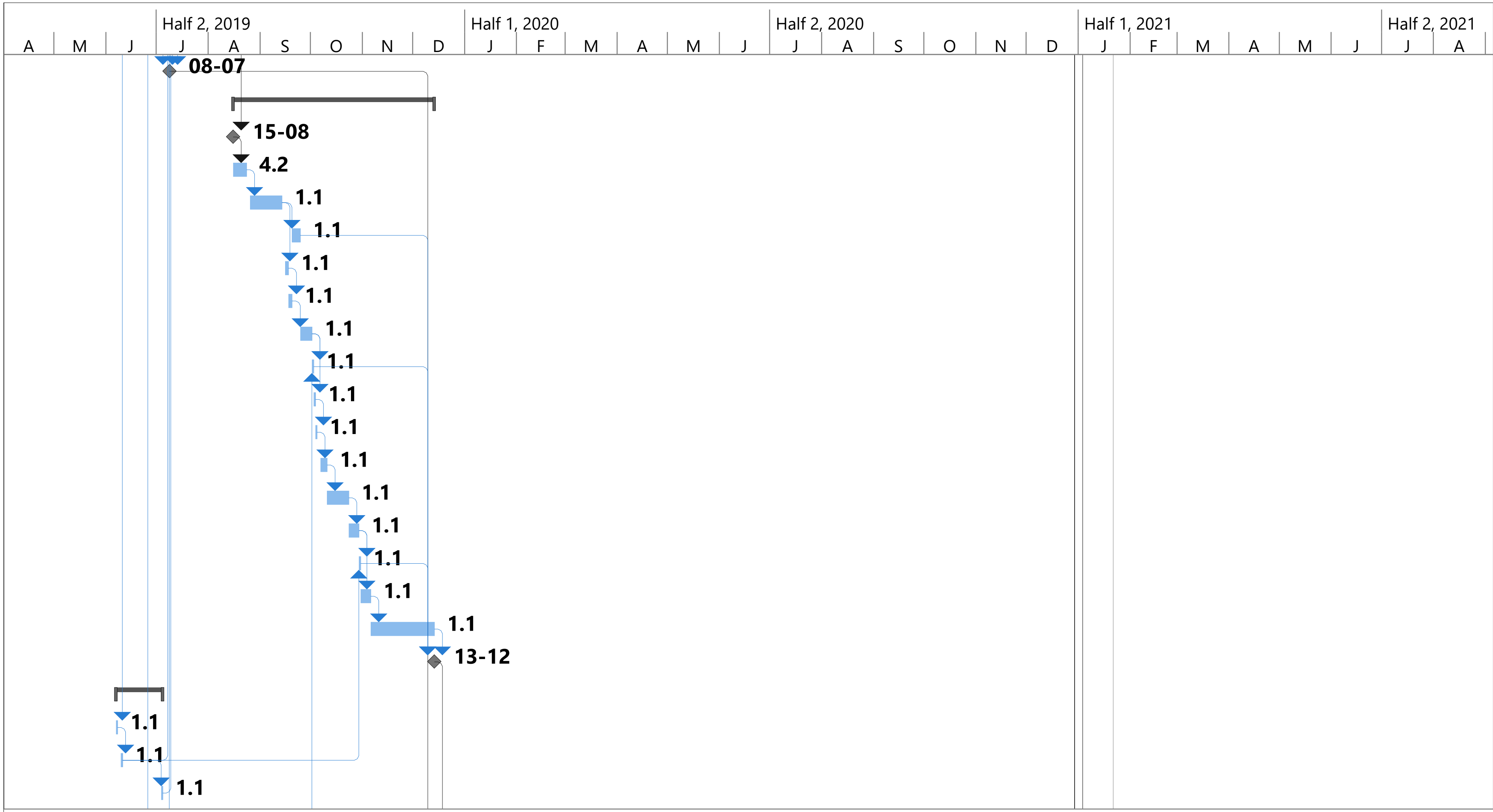

Project: Stadium Neighbourhood
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Task	Inactive Summary	External Tasks
Split	Manual Task	External Milestone
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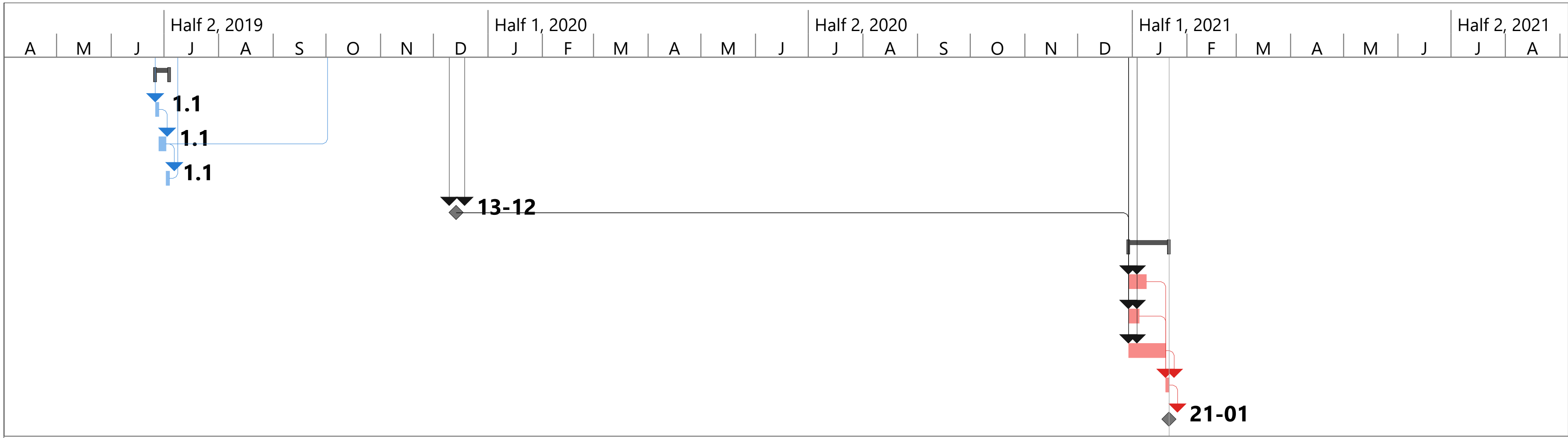
Summary	Manual Summary Rollup	Critical
Project Summary	Manual Summary	Critical Split
Inactive Task	Start-only	Progress
Inactive Milestone	Finish-only	Manual Progress



Project: Stadium Neighbourhood
Date: Sun 31-03-19

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

A.2. Work Breakdown Structure

WBS Number	Task	Magnitude	Unit	Duration (work days)	Cost		
					Materials	Labor	Machinery*
1	**Pre-Construction Tasks**						
1.1	***Preparation, Human Resources***						
1.1.1	Contract Negotiations	1	contract	10	$0	$18,000	$0
1.1.2	Obtain Relevant Permits	10	permits	10	$0	$18,000	$0
1.1.3	Kickoff Meeting	1	meeting	1	$0	$42,224	$0
1.1.4	Worker Training	5	days	5	$0	$211,120	$0
1.1.5	Secure Site	1	site	5	$0	$9,000	$0
1.1.6	Secure Supplies	10	contracts	5	$0	$9,000	$0
1.2	***Engineering***						
1.2.1	Complete Parkade Secondary Analysis	10	drawings	5	$0	$9,000	$0
1.2.2	Write Construction Manual	1	manual	5	$0	$9,000	$0
1.2.3	Revise Schedule and Cost Estimate	1	estimate documents	5	$0	$9,000	$0
1.2.4	Dimension Remaining Intersection Details	3	drawings	2	$0	$3,600	$0
2	**Parkade**						
2.1	***Foundation***						
2.1.1	Site Survey and Existing Utilities	7809.76	m^2	2	$0	$4,000	$0
2.1.2	Excavate	54668.32	m^3	21	$0	$91,728	$233,100
2.1.3	Groundwater Drainage	8200.25	m^3	21	$0	$24,864	$0
2.1.4	Soil Compaction	7809.76	m^2	2	$0	$8,000	$0
2.1.5	Check Slope	7809.76	m^2	2	$0	$2,368	$0
2.1.6	Installation of Anchored Retaining Walls	2800.00	m^2	4	$904,168	$13,824	$0
2.1.7	Installation of Anchor Piles	290	piles	4	$232,000	$13,824	$0
2.1.8	Install Drainage to Bioswale	75.00	linear m	3	$0	$4,368	$0
2.1.9	Install Waterproof Membrane	7809.76	m^2	3	$312,390	$3,552	$0
2.1.10	Tying Rebar	316255.20	linear m	5	$0	$29,600	$0
2.1.11	Rebar Placement with Spacers	316255.20	linear m	5	$778,187	$29,600	$0
2.1.12	Concrete Pour	7458.32	m^3	3	$1,558,789	$4,368	$0
2.1.13	Concrete Curing	7458.32	m^3	9	$0	$10,656	$0
2.1.14	Concrete Deflection Inspection	7809.76	m^2	1	$0	$1,728	$0
2.2	***Structure***						
2.2.1	**T1**						
2.2.1.1	*Start Structure*						
2.2.1.2	*Install Tank-to-Bioswale Pump and Piping*	1	#	1	$10,000	$1,184	
2.2.1.3	*Install T1 Column Formwork*	600	m^2	16	$6,625	$18,944	
2.2.1.4	*Install T1 Wall Formwork*	1200	m^2	15	$24,083	$35,520	
2.2.1.5	*Lay T1 Column Rebar*	41	ton	12	$49,270	$14,208	

WBS Number	Task	Magnitude	Unit	Duration (work days)	Cost		
					Materials	Labor	Machinery*
2.2.1.6	*Lay T1 Wall Rebar*	30	ton	7	$34,221	$8,288	
2.2.1.7	*Pour T1 Column Concrete*	100	m^3	2	$18,263	$4,736	
2.2.1.8	*Pour T1 Wall Concrete*	420	m^3	2	$75,425	$7,104	
2.2.1.9	*Install P1 Slab/Beam Formwork*	8400	m^2	55	$486,780	$195,360	
2.2.1.10	*Lay P1 Slab/Beam Rebar*	270	ton	30	$345,870	$71,040	
2.2.1.11	*Pour P1 Slab/Beam Concrete*	3000	m^3	5	$528,687	$29,600	
2.2.1.12	*Remove P1 Slab/Beam Formwork*	8400	m^2	17	$0	$20,128	
2.2.2	**P1**						
2.2.2.1	*Install P1 MEP Components*	8400	m^2	38	$42,000	$55,328	
2.2.2.2	*Relocate T1 Column Formwork To P1*	660	m^2	18	$7,287	$21,312	
2.2.2.3	*Relocate T1 Wall Formwork to P1*	1200	m^2	15	$24,083	$35,520	
2.2.2.4	*Lay P1 Column Rebar*	43	ton	12	$51,673	$14,208	
2.2.2.5	*Lay P1 Wall Rebar*	31	ton	7	$35,362	$8,288	
2.2.2.6	*Pour P1 Column Concrete*	110	m^3	2	$20,090	$4,736	
2.2.2.7	*Pour P1 Wall Concrete*	420	m^3	2	$75,425	$7,104	
2.2.2.8	*Install L1 Slab/Beam Formwork*	9100	m^2	60	$527,345	$213,120	
2.2.2.9	*Lay L1 Slab/Beam Rebar*	280	ton	62	$358,680	$73,408	
2.2.2.10	*Pour L1 Slab/Beam Concrete*	3200	m^3	6	$563,933	$35,520	
2.2.2.11	*Remove L1 Slab/Beam Formwork*	9100	m^2	19	$0	$22,496	
2.2.3	**L1**						
2.2.3.1	*Install L1 MEP Components*	3200	m^2	15	$16,000	$21,840	
2.2.3.2	*Install L1 Studwalls*	260	m	3	$2,600	$3,552	
2.2.3.3	*Install L1 Glazing*	600	m^2	6	$6,000	$7,104	
2.2.3.4	*Relocate P1 Column Formwork to L1*	480	m^2	13	$5,300	$15,392	
2.2.3.5	*Relocate P1 Wall Formwork to L1*	600	m^2	8	$12,041	$18,944	
2.2.3.6	*Lay L1 Column Rebar*	24	ton	7	$28,841	$8,288	
2.2.3.7	*Lay L1 Wall Rebar*	16	ton	4	$18,251	$4,736	
2.2.3.8	*Pour L1 Column Concrete*	60	m^3	1	$10,958	$2,368	
2.2.3.9	*Pour L1 Wall Concrete*	150	m^3	1	$27,240	$3,552	
2.2.3.10	*Install L2 Slab/Beam Formwork*	3200	m^2	17	$185,440	$80,512	
2.2.3.11	*Lay L2 Slab/Beam Rebar*	100	ton	22	$128,100	$26,048	
2.2.3.12	*Pour L2 Slab/Beam Concrete*	1100	m^3	2	$193,852	$11,840	
2.2.3.13	*Remove L2 Slab/Beam Formwork*	3200	m^2	7	$0	$8,288	
2.2.4	**L2**						
2.2.4.1	*Install L2 MEP Components*	3200	m^2	15	$16,000	$21,840	
2.2.4.2	*Install L2 Glazing*	500	m^2	5	$5,000	$5,920	
2.2.4.3	*Relocate L1 Column Formwork to L2*	460	m^2	13	$5,079	$15,392	

WBS Number	Task	Magnitude	Unit	Duration (work days)	Cost		
					Materials	Labor	Machinery*
2.2.4.4	*Relocate L1 Wall Formwork to L2*	600	m^2	8	$12,041	$18,944	
2.2.4.5	*Lay L2 Column Rebar*	23	ton	7	$27,639	$8,288	
2.2.4.6	*Lay L2 Wall Rebar*	16	ton	4	$18,251	$4,736	
2.2.4.7	*Pour L2 Column Concrete*	60	m^3	1	$10,958	$2,368	
2.2.4.8	*Pour L2 Wall Concrete*	150	m^3	1	$27,240	$3,552	
2.2.4.9	*Install Roof Slab/Beam Formwork*	3500	m^2	18	$202,825	$85,248	
2.2.4.10	*Lay Roof Slab/Beam Rebar*	110	ton	25	$140,910	$29,600	
2.2.4.11	*Pour Roof Slab/Beam Concrete*	1500	m^3	3	$264,344	$17,760	
2.2.4.12	*Install Elevator*	2	#	2	$60,000	$4,000	
2.2.4.13	*Construct Green Roof*	3500	m^2	16	$175,000	$46,592	
2.2.4.14	*Remove Roof Slab/Beam Formwork*	3500	m^2	2	$0	$11,840	
2.3	***Finish Structure***						
3	**Intersection**						
3.1	***Utility Work***						
3.1.1	Site Preparation	1		1	$0	$1,184	$0
3.1.2	Relocate Conflicting Poles	30	poles	1	$30,000	$1,184	$0
3.1.3	Excavation for New Water-Main	1400	linear ft	3	$72,940	$4,368	$0
3.1.4	Install Water Mains	1400	linear ft	3	$105,000	$4,368	$0
3.1.5	Excavation for New Storm-Main	1400	linear ft	3	$72,940	$4,368	$3,733
3.1.6	Install Storm Mains	1400	linear ft	3	$105,000	$4,368	$0
3.1.7	Excavation for New Sanitary-Main	1400	linear ft	3	$72,940	$4,368	$3,733
3.1.8	Install New Sanitary Mains	1400	linear ft	3	$105,000	$4,368	$0
3.1.9	Connect Existing Utilities to Re-Aligned Utilities	1400	linear ft	2	$105,000	$4,000	$0
3.2	***Site Work***						
3.2.1	Excavation	4000	m^3	6	$20,000	$7,104	$8,000
3.2.2	Remove Backfill Off Site	4000	m^3	2	$20,000	$2,368	$400
3.2.3	Transport As-Per-Code Soil on Site	3000	m^3	2	$15,000	$2,368	$1,982
3.2.4	Lay Road Sub Grade	1500	m^3	1	$45,000	$1,456	$500
3.2.5	Compact Road Sub Grade	1500	linear m	1	$1,200	$1,184	$467
3.2.6	Lay Road Sub Base	1000	m^3	1	$30,000	$1,456	$333
3.2.7	Compact Road Sub Base	1500	linear m	1	$1,200	$1,184	$467
3.2.8	Lay Road Base	500	m^3	1	$15,000	$1,456	$167
3.2.9	Compact Road Base	1500	linear m	1	$1,200	$1,184	$467
3.3	***Pavement***						
3.3.1	Curb + Gutter	30	items	2	$225,000	$2,912	$0
3.3.2	Base Layer Asphalt	10000	sqft	5	$25,000	$7,280	$3,333
3.3.3	Top Layer Asphalt	10000	sqft	3	$30,000	$4,368	$1,600
3.3.4	Concrete Sidewalk Pouring and Casting	175	m^3	2	$175,000	$2,912	$1,050

WBS Number	Task	Magnitude	Unit	Duration (work days)	Cost		
					Materials	Labor	Machinery*
3.3.5	Finish Paving						
3.4	***Signage & Landscaping***						
3.4.1	Traffic Signal Replacement	1	intersection	1	$50,000	$2,000	$360
3.4.2	Install New Signage	8	signs	1	$1,600	$2,000	$0
3.4.3	Paint Lines	5000	linear m	2	$15,000	$4,000	$833
3.4.4	Street Trees & Landscaping	0.25	acre	7	$2,675	$14,000	$3,250
3.5	***Finished Intersection***						
4	**Open Channel Flow Components**						
4.1	***LEED Channel***						
4.1.1	Start LEED Channel						
4.1.2	Surveying	840	m^2	2	$0	$2,000	$0
4.1.3	Cut Trees	30	trees	2	$0	$3,456	$0
4.1.4	Remove Stumps	30	stumps	2	$0	$2,368	$2,000
4.1.5	Dig Channels	480	m^3	4	$0	$4,736	$4,000
4.1.6	Transport Soil Away	280	m^3	1	$0	$1,184	$3,700
4.1.7	Lay Impervious Geotextile	850	m^2	1	$850	$1,184	$0
4.1.8	Replace Native Soil Layer	200	m^3	2	$0	$2,368	$2,000
4.1.9	Connect with Parkade And Downstream Culvert	2	connections	1	$200	$1,184	$1,000
4.1.10	Landscaping and Beautification	840	m^2	2	$7,476	$2,368	$0
4.1.11	Plant Plants	1000	plants	7	$4,000	$8,288	$0
4.1.12	Finish LEED Channel						
4.2	***Bioswale***						
4.2.1	Start Bioswale						
4.2.2	Survey Site	2920	m^2	6	$0	$6,000	$0
4.2.3	Dig Bioswale And Forebay	2750	m^3	15	$0	$17,760	$15,000
4.2.4	Transport Soil Away	2170	m^3	3	$0	$3,552	$11,100
4.2.5	Lay Impervious Geotextile	3600	m^2	2	$3,600	$2,368	$0
4.2.6	Place Gravel Storage Layer	165	m^3	2	$22,275	$2,368	$2,000
4.2.7	Lay Drain Pipe	280	m	5	$2,800	$5,920	$0
4.2.8	Connect Drain to Lower Culvert	1	connection	1	$100	$1,184	$1,000
4.2.9	Place Pea Gravel Choking Layer	60	m^3	1	$8,100	$1,184	$1,000
4.2.10	Lay Pervious Geotextile	570	m^2	1	$570	$1,184	$0
4.2.11	Place Filter Medium	500	m^3	4	$100,000	$4,736	$4,000
4.2.12	Construct Check Dams	81	m^3	9	$4,212	$10,656	$9,000
4.2.13	Replace Native Soil Layer	580	m^3	4	$0	$4,736	$4,000
4.2.14	Connect Upstream Culvert	1	connection	1	$100	$1,184	$1,000
4.2.15	Landscaping and Beautification	2920	m^2	4	$25,988	$4,736	$0
4.2.16	Plant Plants	4600	plants	28	$18,400	$33,152	$0
4.2.17	Finish Bioswale						
4.3	***LEED-Swale Culvert***						

WBS Number	Task	Magnitude	Unit	Duration (work days)	Cost		
					Materials	**Labor**	**Machinery***
4.3.1	Dig Trench	50	m^3	1	$0	$1,184	$1,000
4.3.2	Install Culvert	21	linear m	1	$105	$1,184	$2,000
4.3.3	Cover Trench	50	m^3	1	$6,750	$1,184	$1,000
4.4	***Swale-Garden Culvert***						
4.4.1	Dig Trench	145	m^3	2	$0	$2,368	$2,000
4.4.2	Install culvert	41	linear m	2	$205	$2,368	$4,000
4.4.3	Cover Trench	145	m^3	2	$19,575	$2,368	$2,000
4.5	***Finish Open Channel Flow Elements***						
5	**Post Construction tasks**						
5.1	***Site Clean-up***	1	site	8	$0	$9,472	$0
5.2	***Commissioning***	3	worksites	4	$0	$7,200	$0
5.3	***Final Tasks (Traffic, clean up, etc..)***	20	tasks	15	$0	$17,760	$0
5.4	***Hand Over to Client***	1	handover	2	$0	$3,600	$0

*Machine costs for the Parkade construction (WBS section 2.2) are assumed to be included in the material costs.

Appendix B: Design Calculations

B.1. Mixed-Use Parkade

B.1.1. Tank Volume Sample Calculation

Determine LEED Gold maximum water output rate:

$$Q_{out} = C_{pre-development} i_{2yr,24h} A_{new\ developments} = (0.2)\left(0.00232\frac{m}{hr}\right)(49000\ m^2) = 22.7\frac{m^3}{hr}$$

Perform linear regression on IDF data for 100-year storm to determine relation between storm duration and intensity. Determine intensity for sample duration of 48 hr:

Duration (hr), t	log(t)	Intensity (mm/hr), i	log(i)	Slope	Intercept
0.083	-1.08	140.28	2.15	-0.55504	1.516892
0.167	-0.78	95.76	1.98		
0.250	-0.60	75.08	1.88		
0.500	-0.30	46.86	1.67		
1	0.00	31.81	1.50		
2	0.30	17.36	1.24		
6	0.78	10.32	1.01		
12	1.08	8.86	0.95		
24	1.38	6.96	0.84		

$$\log(i) = -0.555\log(t) + 1.52$$

$$\log(i_{48hr}) = -0.555\log(48) + 1.52 = 0.587 \qquad i_{48hr} = 3.84\frac{mm}{hr} = 0.00383\frac{m}{hr}$$

Determine water input rate for given intensity:

$$Q_{in} = C_{post-development} i_{48h} A_{new\ developments} = (1.0)\left(0.00383\frac{m}{hr}\right)(49000\ m^2) = 187.9\frac{m^3}{hr}$$

Determine volume of water within tank at end of storm:

$$V_{tank} = (Q_{in} - Q_{out})t = \left(187.9\frac{m^3}{hr} - 22.7\frac{m^3}{hr}\right)(48\ hr) = 7928\ m^3$$

Repeat calculations for variety of durations to find critical storm duration that produces highest required tank volume.

B.1.2. Raft Foundation Calculations

The first criteria for design is to check for the maximum bending moment of the structure. Each row of column is modeled as strips of beams. As an example, we will be focusing on row 5, which features the highest loads. This is shown in **Figure 15.**

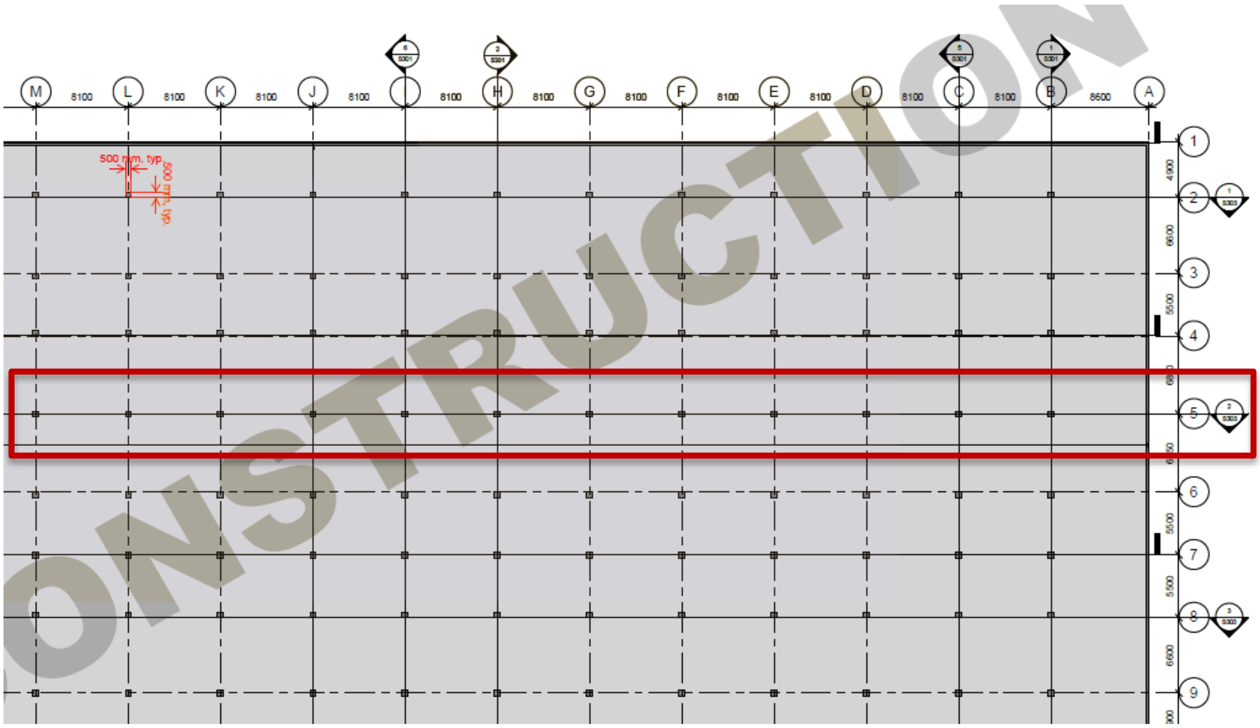


***Figure 15**: Row 5 of Foundation*

Here, the length is 146.8 m, and the width of the strip is 6.85 m, taken halfway between adjacent rows. Water has an assumed specific weight of 9810 N/m^3, and a height of 3 m as that is the height of the water tank at capacity. Thus, the water imposes a uniformly distributed load of (9810 N/m^3)(3 m)(6.85 m [width of strip]) = 201.6 kN/m.

For the raft, a density of 2400 kg/m^3. is assumed, and thus the specific weight is 2400*9.81 = 23544 N/m^3. Using a thickness of 0.955 m, (thickness was first assumed to be around 1m, then through subsequent iterations, reduced to 0.955 m), the raft provides a uniformly distributed load of (23544N/m^3)(6.85m [width of strip])(0.955m) = 154.019 kN/m. This is summarized in **Figure 16.**

	A	B	C	D
1	Dimensions			
2	Length	146.8	m	
3	Width	53.2	m	
4	Width of Strip	6.85	m	
5				
6	Water			
7	Density	9810	N/cubic meter	
8	Height	3	m	
9	q water	201.596	kN/m	
10				
11	Raft			
12	Density	23544	N/cubic meter	
13	Thickness	0.955	m	
14	q raft	154.019	kN/m	
15				

***Figure 16**: Dimensions and Loads from Foundation and Water*

Next, the loads from columns are analyzed from the structure. A factor of 1.4 is applied to dead loads, and 1.25 for live loads. **Figure 17** shows a summary, with the Factored column as a sum after applying the LRFD factors.

16	Columns		
17	Dead	Live	Factored
18	2021	474	3624
19	3186	921	5930
20	3114	893	5788
21	3114	893	5788
22	3114	893	5788
23	3114	893	5788
24	3114	893	5788
25	3114	893	5788
26	3114	893	5788
27	3114	893	5788
28	3114	893	5788
29	3114	893	5788
30	3114	893	5788
31	3114	893	5788
32	3114	893	5788
33	3114	893	5788
34	3114	893	5788
35	3186	921	5930
36	2021	474	3624
37			

***Figure 17**: Summary of Column Loads*

With these components, the total load imposed can be analyzed. The raft imposes (154.019 kN/m)(146.8m [length])(1.4 [dead load factor]) = 31654 kN. The water imposes (201.596kN/m)(146.8m [length])(1.25 [live load factor]) = 36992.8 kN. A total uniformly distributed load is found by dividing the total imposed load of the water and the raft by the length. (31654 kN [raft weight] + 36992.8 kN [water weight]) / 146.8m [length of strip] = 467.6 kN/m. Finally, the columns impose a total of 105923 kN. This brings a total load imposed onto the foundation at 174570 kN. **Figure 18** summarizes this.

37			
38	Total Load imposed		
39	Raft	31654	kN
40	Water	36992.8	kN
41	Combined q	467.621	kN/m
42	Columns	105923	kN
43	Total	174570	kN

***Figure 18**: Total Loads Imposed*

To resist this load, the soil must provide an equal upward force. To determine this, the force is divided by the total area to find the pressure. (174570 kN [total loads])/((146.8 m [length])(6.85 m [width])) = 173.6 kPa. This is under the 200 kPa assumed for our bearing capacity of the soil of glacial till, confirming that this soil can take the imposed loads without deep foundations. The uniformly distributed support from the soil is found as (173.6 kPa [soil bearing capacity])(6.85 m [width]) = 1189.17 kN/m. Compared to the uniformly distributed load (UDL) imposed from above, this results in a net upwards force of 1189.17 [soil UDL] – 467.621 kN/m [water and raft UDL] = 721.546 kN/m, as shown in **Figure 19**.

52	Pressure on soil (Analysis)	
53	173.6009863	kN/meters squared
54	1189.166756	kN/m
55		
56	Net upward force	
57	721.5458345	kN/m

***Figure 19**: Soil Bearing Capacity*

With this net upward uniformly distributed support, and the loads from the columns, all parameters in (**Figure 10,** page 16) can be analyzed with inputs. A bending moment and shear diagram for Row 5 is shown in **Figure 20.**

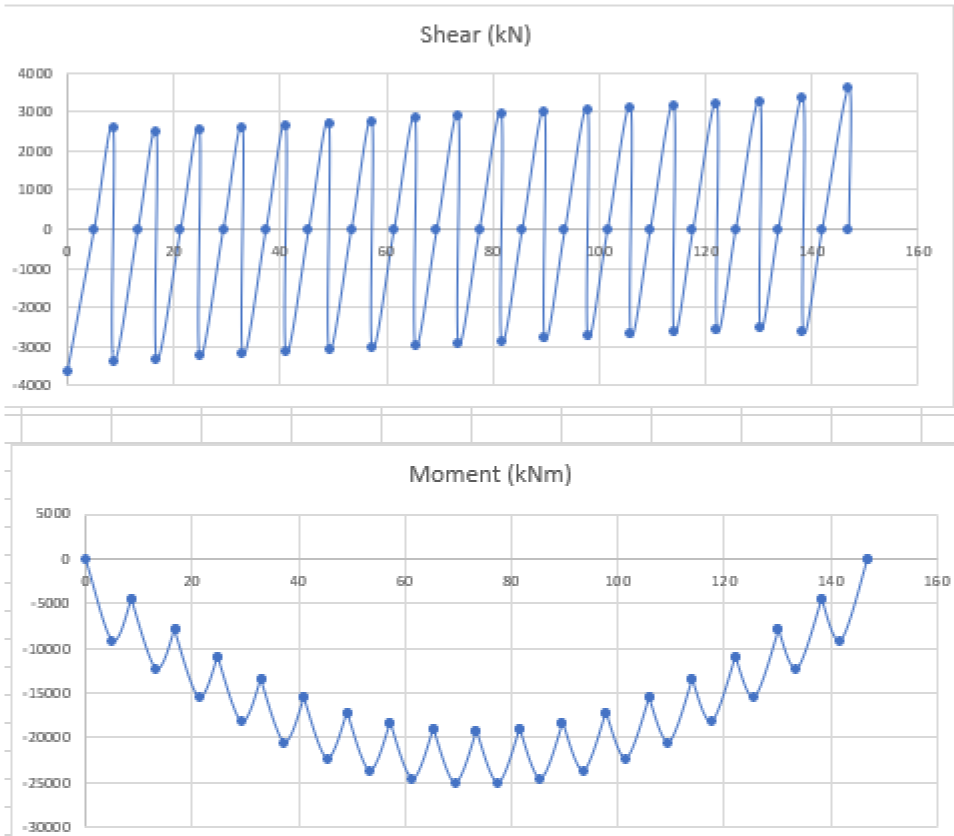


__Figure 20__: Shear and Bending Moment Diagrams

From this, the main focus will be on the maximum moment, which is found to be -26000 kN*m. The negative is expected since it is a uniformly distributed force acting upwards, much like our inverted roof analogy. Thus, rebar is expected to be placed on the top layer. This process is to be repeated for all rows of columns, to be modeled as strips, in each axis. It happens that Row 5 has the highest bending moment and is thus our design bending moment.

To determine the amount of steel area needed as reinforcement, **Equation 1** is used with the following parameters:

__Equation__ 1: Area of steel reinforcement, from S. Brzev and J. Pao, Reinforced Concrete Design: A Practical Approach [21]

$$A_s = \frac{\alpha \phi_c f_c' b}{\phi_s f_y}\left(d - \left(d^2 - 2 * \frac{M_r}{\alpha \phi_c f_c' b}\right)^{0.5}\right)$$

$\alpha = 0.8$ $\phi_c = 0.65$, $f_c' = 25MPa$, b = 6850mm, ϕ_s = 0.85, $f_y = 400MPa$, d = 799mm (this was done through various iterations, but assumed two layers of rebar to begin with), $M_r = 26000 * 10^6\ N * mm$.

The area of steel needed comes out to be 148146 mm^2. For design purposes, this number is rounded up to 150000 mm^2. 35M rebar provides 1000 mm^2 each, so 150 bars are needed. With a width of 6850 mm, it becomes clear two layers are needed. With a center to center spacing of 90 mm (clear spacing of 74 mm) between bars, and leaving 75 mm of cover, two rows of 35M rebar with 94 bars in each row is sufficient to meet the steel requirement (94 bars * 2 rows * 1000 mm^2 = 188000 mm^2, > 150000 mm^2). This process along with subsequent iterations is repeated for all strips modeled on the raft foundation.

To check shear, **Equation 2** provides the shear capacity of concrete. In this design, the following parameters are presented:

***Equation** 2: Shear capacity of concrete, from ACI 318-95 [31]*

$$\varphi V_c = \varphi(0.34)\sqrt{f_C'}b_0 d$$

$\varphi = 0.85$, $f_c' = 25MPa$, $b_0 = 6850mm$, $d_v = 799mm$

With these numbers, the shear capacity from the concrete is 7909 kN, well above the design shear found in **Figure 20**. Thus, no stirrups are needed for diagonal shear resistance as the concrete shear resistance is sufficient.

B.1.3. Parkade Structural Calculations

All calculations are undertaken following CSA A23 as presented in *S. Brzev and J. Pao, Reinforced Concrete Design: A Practical Approach* [22] as well as NBCC 2015 [1].

B.1.3.1 Bending Design Sample Calculation | *Example Structural Component: Slab*

Determine loading demands:

$$q = 1.25q_{DL} + 1.5q_{LL} + 1.0q_{SL} = 19.5\ \frac{kN}{m}$$

$$M_f = \frac{qL^2}{8} = \frac{\left(19.5\frac{kN}{m}\right)(6.8\ m)^2}{8} = 113\ kNm$$

Establish concrete and steel parameters:

$$f_c' = 25\ MPa$$

$$f_y = 400\ MPa$$

$$d_{bar} = 20\ mm$$

Determine section properties:

$$h = \frac{l_n}{20} = \frac{6.8\ m}{20} = 340\ mm$$

$$b = 1000\ mm\ (slab)$$

$$d = h - cover - \frac{d_{bar}}{2} = 340\ mm - 65\ mm - \frac{20\ mm}{2} = \ 265\ mm$$

Determine $A_{s,required}$ for satisfying M_r, while checking $A_{s,min}$ and $A_{s,max}$

$$A_{s,required} = (1.53 * 10^{-3}\ MPa^{-1}) f_c' b \left[d - \sqrt{d^2 - \frac{3.85 M_r}{f_c' b}} \right]$$

$$= (1.53 * 10^{-3}\ MPa^{-1})(25\ MPa)(1000mm) \left[(265\ mm) - \sqrt{(265\ mm)^2 - \frac{3.85(113\ kNm)}{(25\ MPa)(1000mm)}} \right] = 1345\ mm^2$$

$$A_{s,min} = 0.002bh = 0.002(1000\ mm)(340\ mm) = 680\ mm^2$$

$$A_{s,max} = \rho_b bd = (0.022)(1000\ mm)(265\ mm) = 5800\ mm^2$$

$$A_{s,min} < A_{s,required} < A_{s,max}$$

Determine spacing and crack control requirements while selecting A_s, and confirm > $A_{s,required}$

$$A_s = A_{bar}\frac{b}{s} = \frac{(300\ mm^2)(1000\ mm)}{100\ mm} = 3000\ mm^2 > A_{s,required} = 1345\ mm^2$$

$$s \le \min\left(\frac{1000 A_{bar}}{A_s}, 3h, 500\ mm\right) = \min\left(\frac{1000(300\ mm^2)}{3000\ mm^2}, 3(340\ mm), 500\ mm\right) = 100\ mm$$

$$z = 0.6 f_y \sqrt[3]{d_c A} = 0.6\ (400)\sqrt[3]{(75)(15000)} = 25000 \le z_{max} = 25000$$

Use 20M @ 100 mm.

B.1.3.2. Shear Design Sample Calculation | *Example Structural Component: Beam*

Determine shear envelope:

$$V_{f,max} = \frac{(w_{DL} + w_{LL})L}{2} = \frac{(87.4\ kN + 48.2\ kN)(8.1\ m)}{2} = 550\ kN$$

$$V_{midpoint} = \frac{w_{LL}L}{8} = \frac{(48.2\ kN)(8.1\ m)}{8} = \ 50\ kN$$

$$Shear\ envelope\ equation:\ V = V_f - \frac{V_f - V_{midpoint}}{\frac{L}{2}}x = 550\ kN - \frac{550\ kN - 50\ kN}{\frac{(8.1\ m)}{2}}x$$

Establish concrete and steel parameters:

$$f_c' = 25\ MPa$$

$$f_y = 400\ MPa$$

$$A_v = 2 * 100\ mm^2 = 200\ mm^2$$

Note section properties as designed for bending, and determine d_v:

$$h = 650\ mm$$

$$b_w = 500\ mm$$

$$d = 529\ mm$$

$$d_v = \max(0.90d, 0.72h) = 476\ mm$$

Determine shear strength of concrete alone:

$$V_{c,stirrups} = \phi_c \lambda \beta \sqrt{f_c'} b_w d_v = (0.65)(1.0)(0.18)\sqrt{25\ MPa}(500mm)(476\ mm) = 139\ kN$$

$$V_{c,no\ stirrups} = \phi_c \lambda \beta \sqrt{f_c'} b_w d_v = (0.65)(1.0)\left(\frac{230}{1476}\right)\sqrt{25\ MPa}(500mm)(476\ mm) = 120\ kN$$

Design stirrups:

$$V_s = V_{f,max} - V_{c,stirrups} = 550\ kN - 139\ kN = 411\ kN$$

$$s = \frac{\phi_s A_v f_y d_v 1.43}{V_s} = \frac{(0.85)(200\ mm^2)(400\ MPa)(476\ mm)1.43}{411\ kN} \approx 110\ mm$$

Check code limitations and requirements:

$$V_{r,max} = \frac{1}{4}\phi_c f_c' b_w d_v = \frac{1}{4}(0.65)(25\ MPa)(500\ mm)(476\ mm) = 967\ kN > V_f$$

$$s_{max} = \min(600\ mm, 0.35 d_v) = \min\big(600\ mm, 0.35(476\ mm)\big) = 167\ mm > s = 100\ mm$$

$$A_{v,min} = \frac{0.06\sqrt{f_c'} b_w s}{f_y} = \frac{0.06\sqrt{25\ MPa}(500\ mm)(100\ mm)}{400\ MPa} = 37.5\ mm^2 > A_v = 200\ mm^2$$

Determine extent of stirrup placement along beam span:

$$V_{c,no\ stirrups} = 120\ kN = V_f - \frac{V_f - V_{midpoint}}{\frac{L}{2}} x = 550\ kN - \frac{550\ kN - 50\ kN}{\frac{(8.1\ m)}{2}} x$$

$$x = 3.48\ m \quad vs. \quad \frac{L}{2} = 4.05\ m$$

For ease of construction, place stirrups along entire span: 10M @ 110 mm.

B.1.3.3. Axial Design Sample Calculation | *Example Structural Component: Column*

Determine magnitude of vertical loading based on tributary area (highest expected loads shown):

$$P_{DL} = A_{triburaty} \sum_{P1}^{Roof} q_{DL} = 3114\ kN$$

$$P_{LL} = A_{triburaty} \sum_{P1}^{Roof} q_{LL} = 893\ kN$$

Determine magnitude of bending loading:

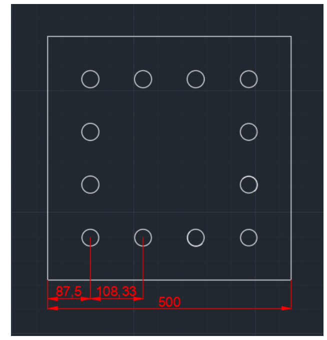
$$M_{WL} = \frac{L_{span}(q_{windward} + q_{leeward})}{N_{columns\ in\ row}} \frac{\left(2H_{storey}\right)^2}{2} = \frac{(8.1\ m)(1.07\ kPa + 0.92\ kPa)}{4} \frac{(2 * 4\ m)^2}{2} = 129\ kNm$$

$$M_{EL} = \frac{P_{EL} H_{storey}}{N_{columns}} = \frac{(2950\ kN)(4\ m)}{68} = 174\ kNm$$

Calculate loading demands for all defining load combinations:

Load Combination	Axial (kN)	Bending (kNm)
1.4DL	4360	0
1.25DL + 1.5LL + 0.4WL	5232	72
1.25DL + 1.4WL + 0.5LL	4339	180

Load Combination	Axial (kN)	Bending (kNm)
1.0DL + 1.0EL + 0.5LL	4339	175



Specify draft design, and develop its moment interaction diagram and failure envelope by investigating column reactions at various placements of the neutral axis:

$f_y = 400\ MPa$

$E_s = 200000\ MPa$

$\varepsilon_y = 0.002$

$Neutral\ axis\ for\ sample\ point = 300\ mm\ from\ left\ edge$

Row	Reinforcing	d = distance from centerline	Ɛ	P = min(AEƐ, Af_y)	M = Pd
1	4-35M	162.5 mm (left)	0.00248	1360 kN (compression)	221 kNm (clockwise)
2	2-35M	54.2 mm (left)	0.00122	413.2 kN (compression)	22.4 kNm (clockwise)
3	2-35M	54.2 mm (right)	0.00005	16.5 kN (tension)	0.90 kNm (clockwise)
4	4-35M	162.5 mm (right)	0.00013	892.5 kN (tension)	145.0 kNm (clockwise)
Concrete		115.0 mm (left)*		1755 kN (compression)**	201.8 kNm (clockwise)
			Σ	2619 kN (compression)	591 kNm (clockwise)

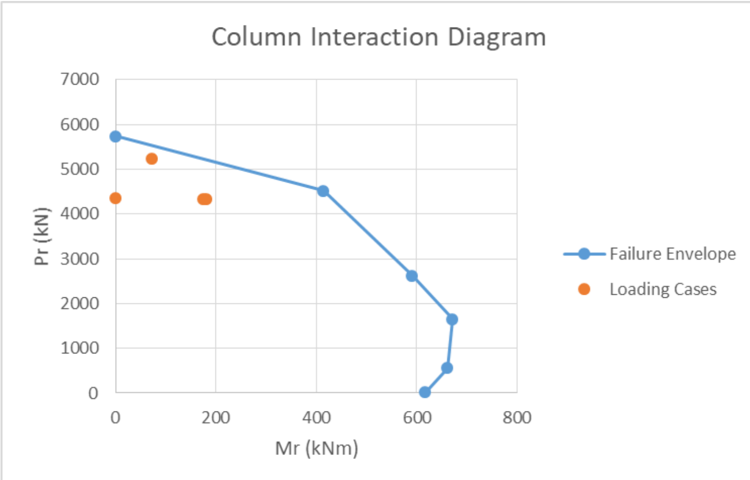
*The concrete compression block works as a single force at the centroid of the block. Therefore the distance from the equivalent force to the centerline is determined by:

$$d_c = \frac{1}{2}(h - c\beta_1) = \frac{1}{2}(500\ mm - 300\ mm * 0.9) = 115\ mm$$

** The compressive force of the concrete is calculated in a similar fashion to the compressive resistance in the slab, except that the column has a width of only 500mm:

$$P_c = (b * c\beta_1) * \left(\varphi_c \alpha_1 f'_c\right) = (500\ mm * 300\ mm * 0.9) * (0.65 * 0.8 * 25\ MPa) = 1755\ kN$$

After moment interaction diagram is complete, verify that loading in all load combinations falls within failure envelope. If so, draft design can be used.



Draft design is acceptable

B.2. Bioswale

B.2.1. BMP Verification Calculations

B.2.1.1. Bioswale Area : Catchment Area (pg 4-151)

According to the CVC [11], the following is recommended:

- Bioswale footprint should be approximately between 5-15% of the catchment tributary area (pg 4-161)
- Impervious drainage area:bioswale footprint should be between 5:1 – 15:1

The bioswale area was determined using the following equation with **Table 11**'s values.

$$Total\ Bioswale\ Footprint\ [m^2] = Length\ \times Width = 265.29\ \times \left(2 + \left(2 \times \sqrt{3^2 + 1^2}\right)\right) = 2{,}208.42\ m^2$$

***Table 11**: Total Bioswale Footprint*

Bioswale Dimensions		
Length	265.29	m
Depth	1.00	m
Slope Length	3.00	m
Bottom Length	2.00	m
"Arc" length	8.32	m
Total Area	2,208.42	m^2

The catchment tributary area was determined using SWMM. First, all SWMM data was extracted to Excel. Then, the ID of each relevant tributary area was manually identified using **Figure 21** into the Existing Culvert, LEED Channel, and Bioswale Runoff inputs. Also available from the SWMM data extraction was the impervious area percentage for each of the catchments. **Table 12**, **Table 13**, and **Table 14** provide the data for the Existing Culvert, LEED Channel, and Bioswale Runoff tributary areas, respectively.

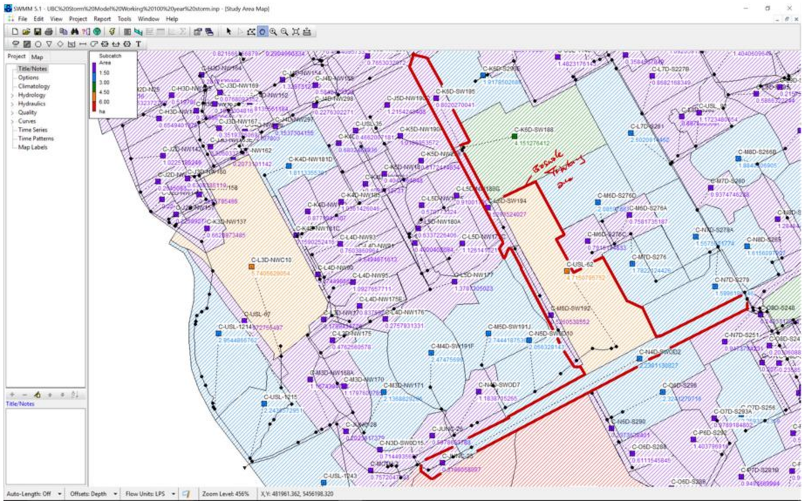


***Figure 21**: Existing Culvert Tributary Area Example*

***Table 12**: Existing Culvert Tributary Area*

Existing Culvert	Ha	Impervious %	Impervious Ha	Pervious Ha
C-K6D-SW195	0.80	73.82%	0.59	0.21
C-L6D-SW194	0.53	75.12%	0.40	0.13
C-M6D-SW192	0.53	66.45%	0.35	0.18
C-USL-62	4.72	65.56%	3.09	1.62
Total	6.57		4.43	2.14

***Table 13**: LEED Channel Tributary Area*

LEED Channel	Ha	Impervious %	Impervious Ha	Pervious Ha
C-M3D-NW171	2.14	35.79%	0.76	1.37
C-M4D-SW191F	2.47	57.34%	1.42	1.06
C-M5D-SW191J	2.74	22.19%	0.61	2.14
C-N5D-SW0D10	2.06	34.07%	0.70	1.36
Total	9.41		3.49	5.92

***Table 14**: Bioswale Runoff Tributary Area*

Bioswale Runoff	Ha	Impervious %	Impervious Ha	Pervious Ha
C-N4D-SWOD2	2.24	53.74%	1.20	1.04
C-JUNC-25	0.32	33.60%	0.11	0.21
Total	2.56		1.31	1.25

Summing the relevant areas (i.e., everything but the LEED Channel, which is addressed with the reduced flow from the detention tanks) and converting, **Table 15** provides the total tributary areas.

Table 15: Total Tributary Area

	Total Area	Impervious Area
Tributary Area [Ha]	9.13	5.74
Tributary Area [m^2]	91,294.32	57,404.14

Finally, comparing **Table 11** with **Table 15**, **Table 16** provides the results.

Table 16: Bioswale Area vs Tributary Area Results

Bioswale Area/Catchment Area	2.42%
Bioswale Area:Impervious Area	26:1

Therefore, the bioswale is approximately two times over the recommended BMP [11] for tributary area in both categories. While this may seem concerning, the CVC BMP [11] goes to explain that the main concern with these ratios would be the buildup of sediment earlier than usual, and the potential for higher flow velocities, which may scour the bioswale. The first concern is easily remedied by increasing the periodic maintenance requirements of the bioswale to remove excess sediment, and by including a sedimentation forebay with riprap immediately after the upstream culvert (which is already achieved with the inclusion of the first check dam). The second concern of scour velocity is explored in Section 0.

If this result is still concerning to the client, or if the client does not want to undertake additional maintenance measures into the future, we suggest looking into diverting the flow at the LEED Channel/Existing Culvert/Upstream Culvert junction to split flow between the Upstream Culvert and the downstream existing system. This is because the existing system is able to handle lower flow volumes without flooding.

It is of our opinion that increasing the size of the bioswale would increase construction costs (as it currently utilizes the removal of the eastbound W 16th Ave carriageway effectively), and would be unsightly due to excessive size.

B.2.1.2. Site Topography and Check Dams (pg 4-151)

According to the CVC BMP [11], bioswale slopes should be between 0.5 to 4%, and no greater than 6% [35]. More specifically:

“Dry swales should be designed with longitudinal slopes generally ranging from 0.5 to 4%. On slopes steeper than 3%, check dams should be used. Dam spacing based on the slope and desired ponding volume.” [11] Dams should be also spaced far enough apart for mowers.

As discussed in Section 3.2.3.1, the bioswale slope is 4.7% and has been adequately designed with check dams spaced far enough apart for mowers.

B.2.1.3. Soils and Underdrain (pg 4-151)

According to the CVC BMP [11], if the native soil infiltration rate is < 15 mm/hr, and underdrain (perforated pipe to collect filtered water beneath the bioswale) is required.

For the bioswale design, a geotextile is being installed that will effectively prevent any infiltration into the native soil as there is a concern for contaminated quadra sand, and a concern for slope stability with the groundwater table. Therefore, the soil infiltration rate at the bioswale is effectively 0 mm/hr, and an underdrain is required. A 200 mm diameter underdrain is installed based on the CVC BMPs [11].

B.2.1.4. Pollution Hot Spot Runoff (pg 4-151)

The CVC BMP [11] notes that groundwater contamination from road runoff (with de-icing salts, vehicle oil/rubber/etc.) should prevented with bioswale infiltration. The current design achieves this through the impermeable geotextile and permeable bioswale. However, in extreme storms that undergo check dam overtopping in the whole bioswale, the result is no worse than the existing condition.

B.2.1.5. Setback from Buildings and Proximity to Underground Utilities

The CVC BMP [11] recommends bioswales to be ≥4 m from building foundations. The designed bioswale is not near any buildings.

For underground utilities, the CVC BMP [11] recommending using double casing for the utility to cross the bioswale. The contractor of this project will be required to use double casing in the event that an underground is encountered, but the QGIS model does not indicate utilities in the path of the bioswale.

B.2.1.6. Side Slopes

The CVC BMP [11] recommends a minimum 3:1 side slope (H:V) for enhance pollutant removal rates and for maintenance considerations. The bioswale has been designed with 3:1 side slopes.

B.2.1.7. Flow Velocity

The CVC BMP [11] recommends that the flow velocity be limited to 0.5 m/s or less during a 4-hour, 25 mm Chicago storm event.

Reviewing the inputs to the SWMM model, it was determined that the 100-year storm water created a higher water demand and therefore velocity for the bioswale. Therefore, the 100-year storm will govern. Using similar methods to Section 0, the velocity through the bioswale during the 100-year storm event was determined to be 0.263518 m/s, and therefore meets the CVC BMP [11] recommendation.

B.2.1.8. Bottom Width

The CVC BMP [11] recommends the bottom width to be between 0.75 – 3 m. The bottom of the designed bioswale is 2 m.

B.2.1.9. Pre-treatment

The CVC BMP [11] recommends using a Sedimentation Forebay to gather sedimentation and slow the water velocity. With the addition of minimal riprap near the outflow of the upstream culvert, the bioswale design's first check dam achieves the purposes and design recommendations of the Sedimentation Forebay.

B.2.1.10. Monitoring Wells

The CVC BMP [11] recommends the installation of a monitoring well at the end of the underdrain to monitor flows through the bioswale. The bioswale design will include this feature.

B.2.1.11. Maximum Allowable Depth of the Filter Bed

The maximum allowable depth of the filter bed, though not governing in this design, was determined using the following equation:

$$d_{b\,max} = i \times \left(t_s - \frac{d_p}{i}\right) / V_r$$

$d_{b\,max}$ = Maximum filter media bed depth (mm)

i = infiltration rate for native soils (mm/hr)

V_r = Void space ratio for filter bed and gravel layer (assume 0.4)

t_s = Time to drain (design for 48-hour time to drain is recommended)

d_p = maximum surface ponding depth

In the design of this bioswale, the following result was

$$300 \times \frac{\left(48 - \frac{700}{300}\right)}{0.4} = 34{,}250\ mm = 34.25\ m = d_{b\ max}$$

This clearly isn't a governing constraint on the bioswale, which has a design filter media depth of 1 m.

B.2.2. Flow Calculations

Once the detailed design was developed according to the CVC BMPs [11], the capacity of the bioswale needed to be checked to ensure that the bioswale met the following design criteria:

- "Convery, treat, and attenuate stormwater runoff" [11] for the 100-year storm
- Reduce stormwater runoff through evapotranspiration
- Prevent infiltration into contaminated soils
- Prevent mosquito growth

As mentioned in the Preliminary Design Report, the bioswale calculations are the most complex of the Stadium Neighbourhood open channel flow system. This is due to the number of inflows and outflows, which include the following two inflows and four outflows:

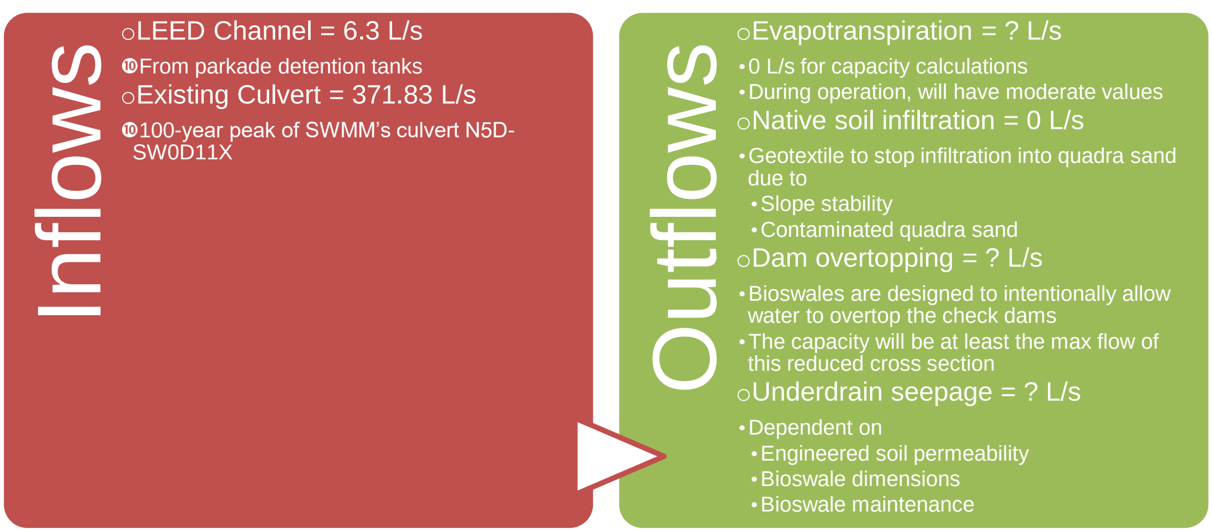


***Figure 22**: Bioswale Inflows and Outflows*

In the calculations to follow, it was assumed that uniform flow was achieved throughout the system for maximum flow calculations. According to Potter & Wiggert, pg 481 "The design of gravity flow … networks is often based on assuming uniform flow and the use of [the Chezy-Manning equation], even though much of the time the flow in such systems may be nonuniform" [33]. For this reason, flow calculations are undertaken using the Chezy-Manning equation:

$$Q = \frac{c_1}{n} A R_h^{\frac{2}{3}} \sqrt{S_o}$$

Where:

c_1 = 1 for SI units
Q = flow [m^3/s]
n = Manning's coefficient
A = Cross-sectional flow area [m^2]
R_h = Hydraulic Radius = A/P, where P is wetted perimeter [m]
S_o = slope of the channel bed = uniform flow slope [m/m]

$$S_o = \frac{Channel\ Bed\ Rise}{Channel\ Bed\ Run} = \frac{Top\ Elevation - Bottom\ Elevation}{Feature\ Length}$$

B.2.2.1. Bioswale Equations

The Channels and Bioswale were modelled as trapezoidal cross sections as is standard practice according to Credit Valley Conservation (CVC) [11] and Iowa [25], while also being consistent with the EPA SWMM model provided by Doug Doyle. The following equations were used for A, P, and B:

$$A = by + \frac{1}{2} y^2 (m_1 + m_2) \qquad P = b + y\left(\sqrt{1 + {m_1}^2} + \sqrt{1 + {m_2}^2}\right) \qquad B = b + y(m_1 + m_2)$$

Variable definitions are visually represented in **Figure 23**.

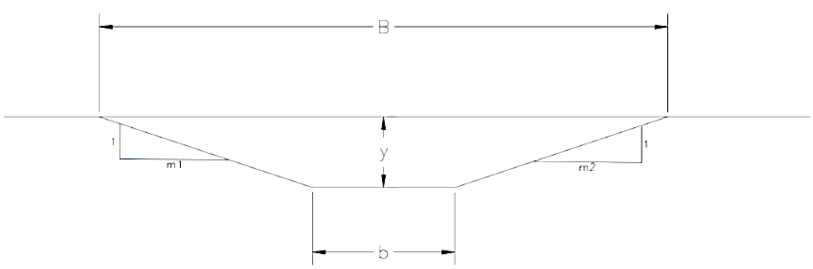


***Figure 23**: Trapezoidal Calculation Cross-Section*

B.2.2.2. Underdrain Equations

The underdrain has circular cross section. The following equations were used:

$$A = \frac{d^2}{4}(\alpha - sin\ sin\ \alpha\ \ cos\ cos\ \alpha\ ) \qquad P = \alpha d \qquad B = d\ sin\ sin\ \alpha$$

Where

$$\alpha = \left(1 - 2\frac{y}{d}\right)$$

Variable definitions are visually represented in **Figure 24**.

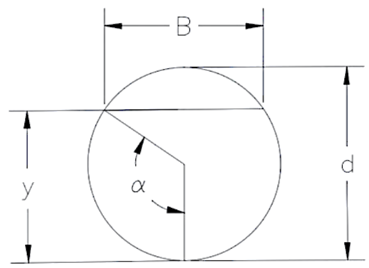


***Figure 24**: Culvert Calculation Cross-Section*

B.2.2.3. Bioswale Capacity Calculations

The most important design criteria is for the bioswale to not flood during the 100 year storm. In the worst case scenario, the only flow through the bioswale will be through dam overtopping. To model these calculations the Chezy-Manning equation is used for the reduced cross section (removing the 0.7 m height form the check dam) and seeing if the maximum flow, $Q_{required}$, of 0.378148 m^3/s can be accommodated. The following calculations illustrate this process.

$$Q = \frac{c_1}{n} A R_h^{\frac{2}{3}} \sqrt{S_o}$$

$$A = by + \frac{1}{2}y^2(m_1 + m_2) = 6.2y_0 + \frac{6}{2}{y_0}^2 = 6.2y_0 + 3{y_0}^2$$

$$P = b + y\left(\sqrt{1 + {m_1}^2} + \sqrt{1 + {m_2}^2}\right) = 6.2 + 2y_0\sqrt{10}$$

$$B = b + y(m_1 + m_2) = 6.2 + y_0 6$$

$$R_h = \frac{A}{P} = \frac{6.2y_0 + 3{y_0}^2}{6.2 + y6}$$

$$0.378148 = \frac{6.2y_0 + 3{y_0}^2}{0.035}\left(\frac{6.2y_0 + 3{y_0}^2}{6.2 + y6}\right)^{\frac{2}{3}} \sqrt{0.04712}$$

Input into Wolfram Alpha or another solver.

$$y_0 = 0.0620759\ m < 0.3\ m$$

Therefore, even with the exclusion of the 0.7 m height, the channel is still considerably below capacity. In fact, if we solve for the maximum flor at y_0 = 0.3 m, Q_{max} = 5.47 m^3/s.

B.2.3. Bioswale Infiltration Calculations

For soil infiltration, typically Darcy's Law is used [25] [34]:

$$q_h = k\frac{\Delta h}{l}A$$

Where:

q_h = flow [m^3/s]
k = coefficient of permeability [m/s]
Δh = change in head from beginning of soil to end of soil [m]
l = length of soil section [m]
A = flow cross section [m^2]

However, since the water reaches atmospheric pressure when it enters the perforated pipe, Δh/l becomes unity [35], and the equation simplifies to Darcy's Law Simplified:

$$q_h = kA$$

One of the main challenges of soil infiltration calculation is the determination of the coefficient of permeability, k. For reference, Figure 25 as provides average k values for different soils [34]. Notice the dramatic range of k values; it has ten orders of magnitude.

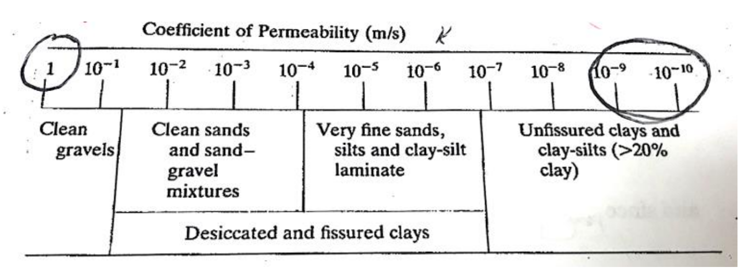


***Figure 25**: Coefficient of Permeability Values*

For detailed design, the CVC BMP [11] specifies that the infiltration rate of the engineered soil must be greater than 25 mm/hr. However, the CVC BMP [11] also explains that the infiltration rate is a different parameter from the coefficient of permeability and cannot be use interchangeably by just using a unit conversion [36]. Therefore, to get the equivalent coefficient of permeability, **Table 17** was used to generate a power trendline (see **Figure 26**) with an R^2 of 0.9888.

***Table 17**: Infiltration Rate vs Coefficient of Permeability (Hydraulic Conductivity) [36]*

Percolation Time, T (min/cm)	Infiltration Rate, 1/T (mm/hr)	Hydraulic Conductivity, K_{fs} (cm/s)	Hydraulic Conductivity, K_{fs} (m/s)
2	300	1.00E-01	1.00E-03
4	150	1.00E-02	1.00E-04
8	75	1.00E-03	1.00E-05
12	50	1.00E-04	1.00E-06
20	30	1.00E-05	1.00E-07
50	12	1.00E-06	1.00E-08

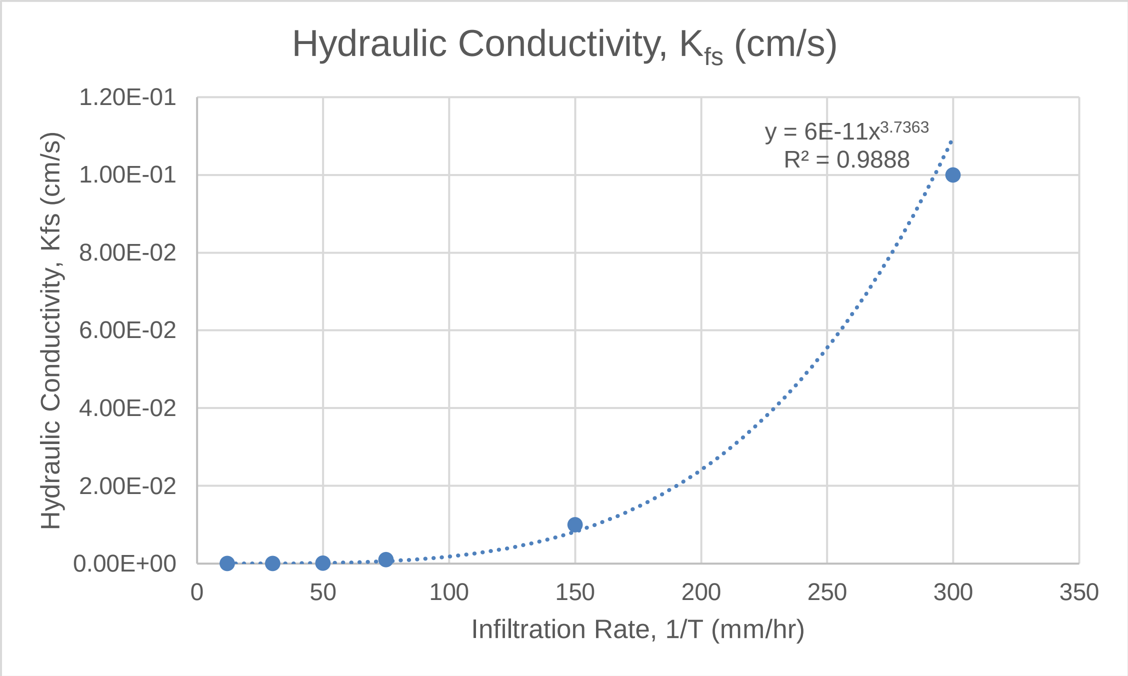


***Figure 26**: Hydraulic Conductivity vs Infiltration Rate*

Therefore, using the power regression equation, we have the following for 25 mm/hr:

$$6 \times 10^{-11} \times 25^{3.7363} = 1.00 \times 10^{-5} \left[\frac{cm}{s}\right] = 1.00 \times 10^{-7} \left[\frac{m}{s}\right]$$

Comparing this number with **Figure 25**'s "clean sands and sand-gravel mixtures", it is interesting to note that the CVC BMP [11] requires a lower coefficient of permeability than the native soil.

However, what we're really interested in is the residence time of the bioswale. Essentially, the coefficient of permeability, k, has to be determined by engineering the soil such that the ideal residence time of 24 – 48 hours is achieved [11]. This ideal residence time is the balance between providing too much time for mosquito growth, and not enough time for water filtration.

To determine the residence time, the following quantities are needed:

- Max quantity of water in each check dam, V
- Flow rate of water out via underdrain infiltration, q
- Coefficient of Permeability, k
- Infiltration area, A
- Residence time, t

As we are setting the coefficient of permeability, k, we want to determine for what values of k is the resident time 24 hours and 48 hours. Therefore:

$$V[m^3] = q\left[\frac{m^3}{sec}\right] \times t[sec]$$

Including Darcy's Law Simplified,

$$V = kA \times t$$

Area was determined using the slope of the bioswale, and the height of the check dam, see **Figure 27**.

$$A = 14.8562 \times 2 = \mathbf{29.71\ m^2}$$

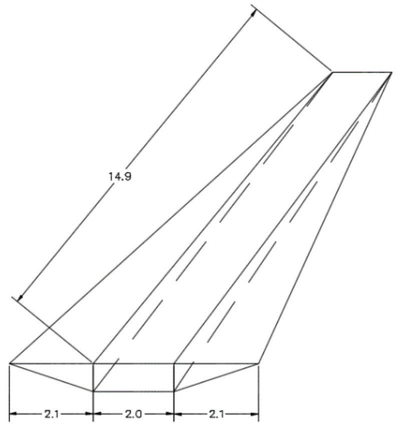


Figure 27: Ponding Area

Volume was determined using simple geometry and integration as follows.

$$\frac{Check\ Dam\ Height \times Pond\ Length}{2} \times Bottom\ Width = Middle\ Section\ Volume$$

$$\frac{0.7 \times 14.8562}{2} \times 2 = 10.3994\ m^2$$

$$\int_0^{Pond\ Length} \frac{(Check\ Dam\ Height - Slope \times x)\left(Check\ Dam\ Side - \frac{Check\ Dam\ Side}{Pond\ Length}x\right)}{2} dx$$

$$\int_0^{14.8562} \frac{(0.7m - 0.04712 \times x)\left(2.1 - \frac{2.1}{14.8562}x\right)}{2} dx = 3.63978m^3$$

$$Total\ Volume = \ 10.3994\ m^2 + 2 \times 3.63978m^3 = \mathbf{17.6789\ m^3/check\ dam}$$

The Coefficient of Permeability for a 24-hour and a 48-hour residence time was determined as follows.

$$17.6789\ m^3 = k_{24} \times 10.3994m^2 \times \left(24\ hours\ \times \frac{3600\ sec}{1\ hour}\right), \boldsymbol{k_{24} \approx 2 \times 10^{-5}}$$

$$17.6789\ m^3 = k_{48} \times 10.3994m^2 \times \left(48\ hours\ \times \frac{3600\ sec}{1\ hour}\right), \boldsymbol{k_{48} \approx 1 \times 10^{-5}}$$

Both of these values satisfy the CVC BMP [11] recommendation. To achieve a residence time of 24 hours, the Coefficient of Permeability should be set to $\boldsymbol{k_{24} \approx 2 \times 10^{-5}}$. As the bioswale is used, sediment will build up and decrease the Coefficient of Permeability. Therefore, we recommend using a Coefficient of Permeability greater than k_{24}.

B.3. Intersection

Tangent runout (Super Elevation Sample Calculations)

Noting design-specific properties for a sample curve

Lane width $w = 3.6\ m$

Design speed $s = 50\ km/h$

Curve radium $r = 96.4\ m$

and noting code-based parameters suggested for this curve

Crown slope $c = 0.02$ as standard suggested by BC Supplement to TAC

Superelevation $e = 0.059$ based on s and r from table in BC Supplement to TAC

then

Spiral length $L_s = 0.035 * s^3 * r = 45.4\ m$

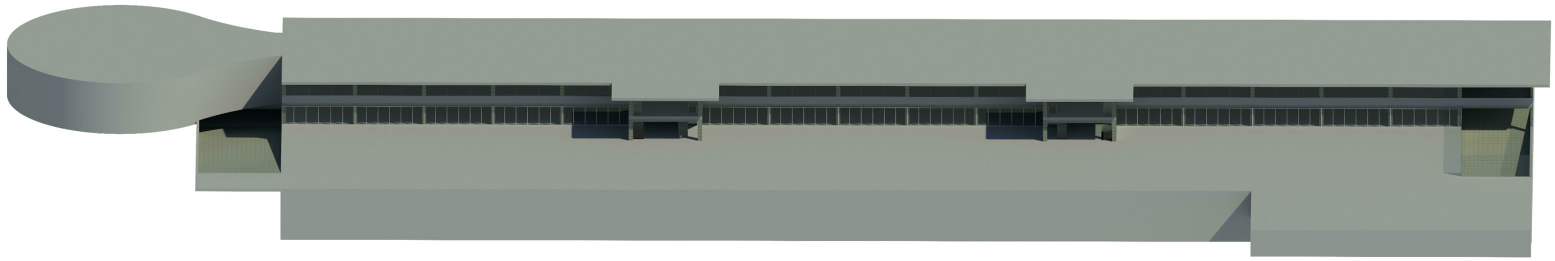
Tangent runout $x = L_s * \frac{c}{e} = 45.4 * \frac{0.02}{0.059} = 15.4\ m$

Recommend $x = 15\ m$ for construction

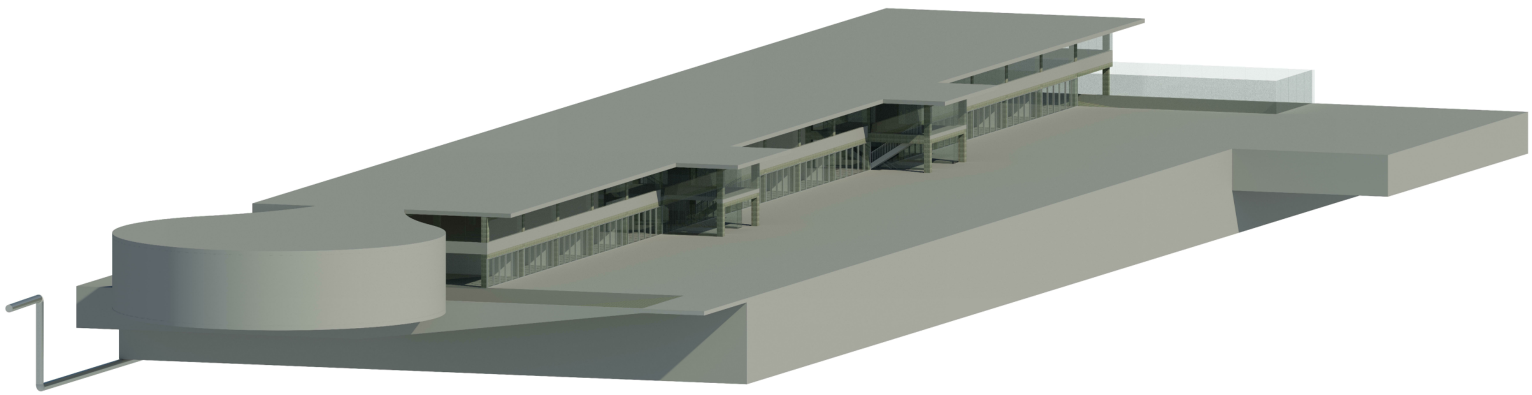
Appendix C: Detailed Design Drawings

C.1. Mixed-Use Parkade

C.1.1



1 Isometric View 1



2 Isometric View 2

Sheet List	
Sheet Number	Sheet Name
S101	Title Sheet
S201	Plan – T1
S202	Plan – P1
S203	Plan – L1
S204	Plan – L2
S205	Plan – Roof
S301	Elevations – North/South
S303	Elevations – West
S302	Elevations – East
S401	Sections
S402	Details

Notes:
- Concrete strength 25 MPa
- Rebar lateral cover 75 mm u.n.o.
- Rebar spacers to be used to ensure accurate placement

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No.	Description	Date
1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Title Sheet

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	JB

S101

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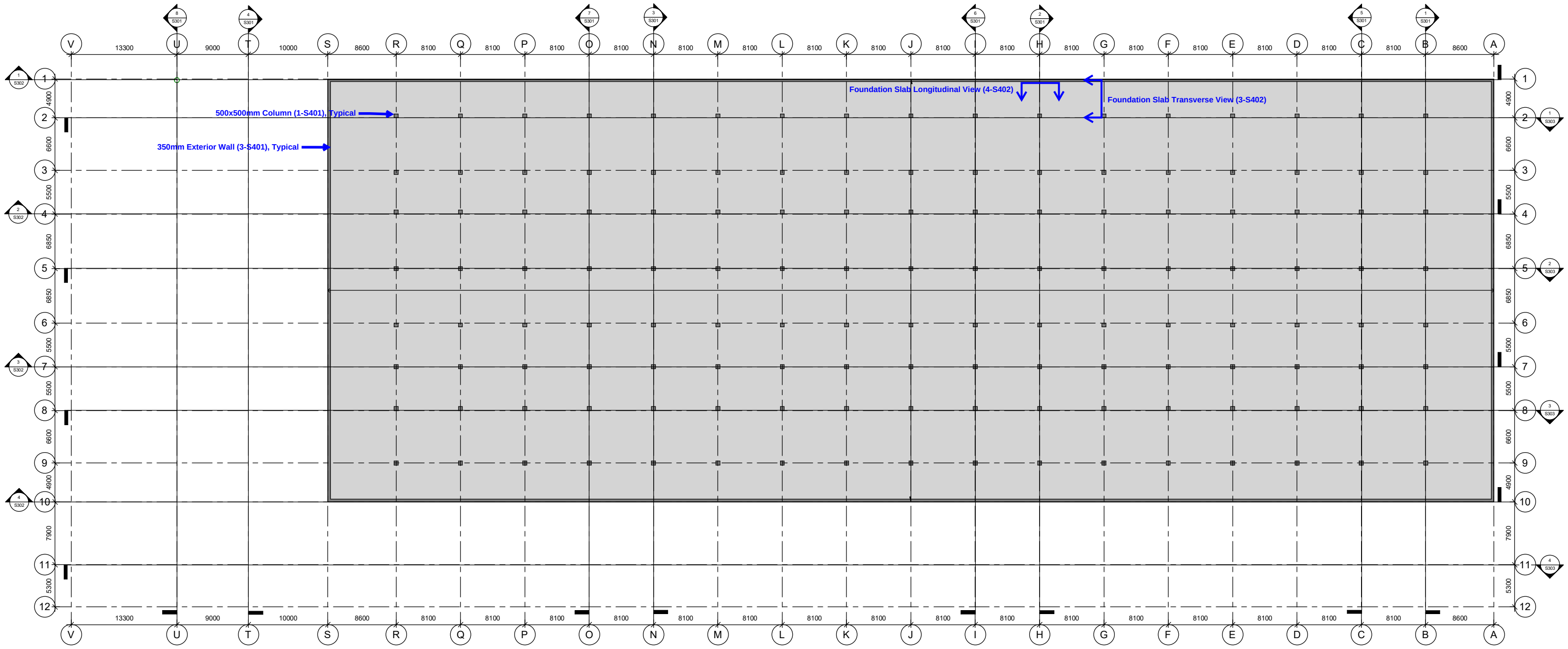
C.1.2



1 T1
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3	Added Sections and Details	2/3/2019

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Plan – T1

Project number	0001
Date	Nov. 15, 2018
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S201

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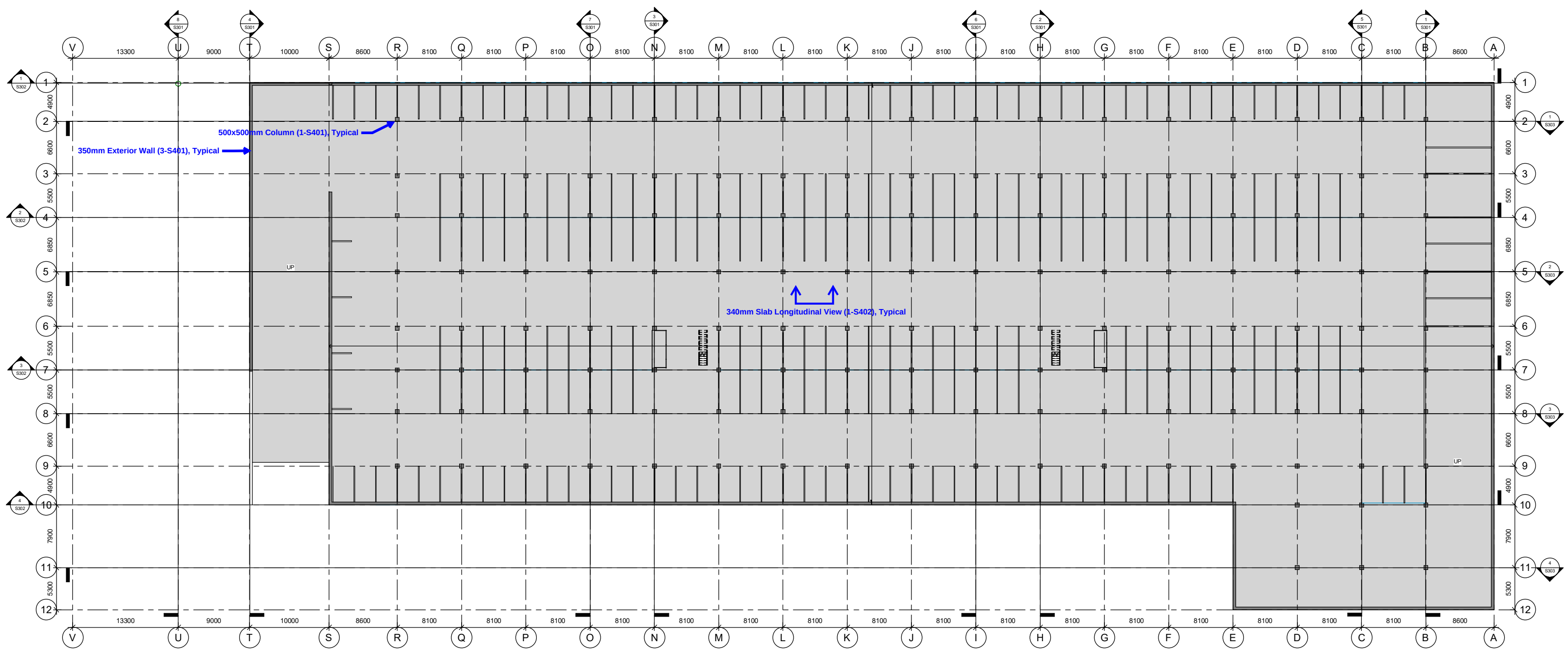
C.1.3



1 P1
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3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Plan – P1

Project number	0001
Date	Nov. 15, 2018
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S202

Scale	1 : 200

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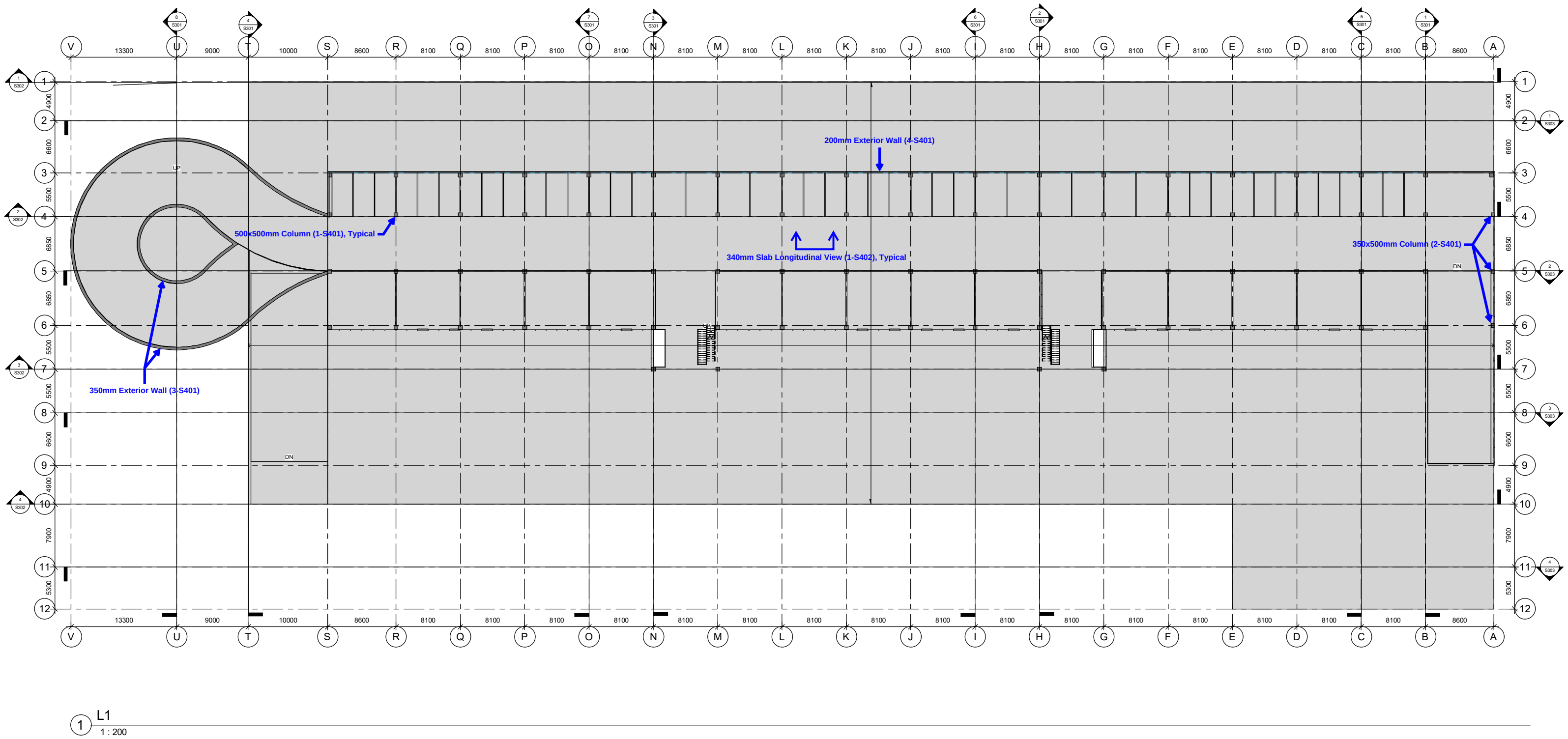
C.1.4



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2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Plan – L1

Project number	0001
Date	Nov. 15, 2018
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Checked by	JB

S203

Scale	1 : 200

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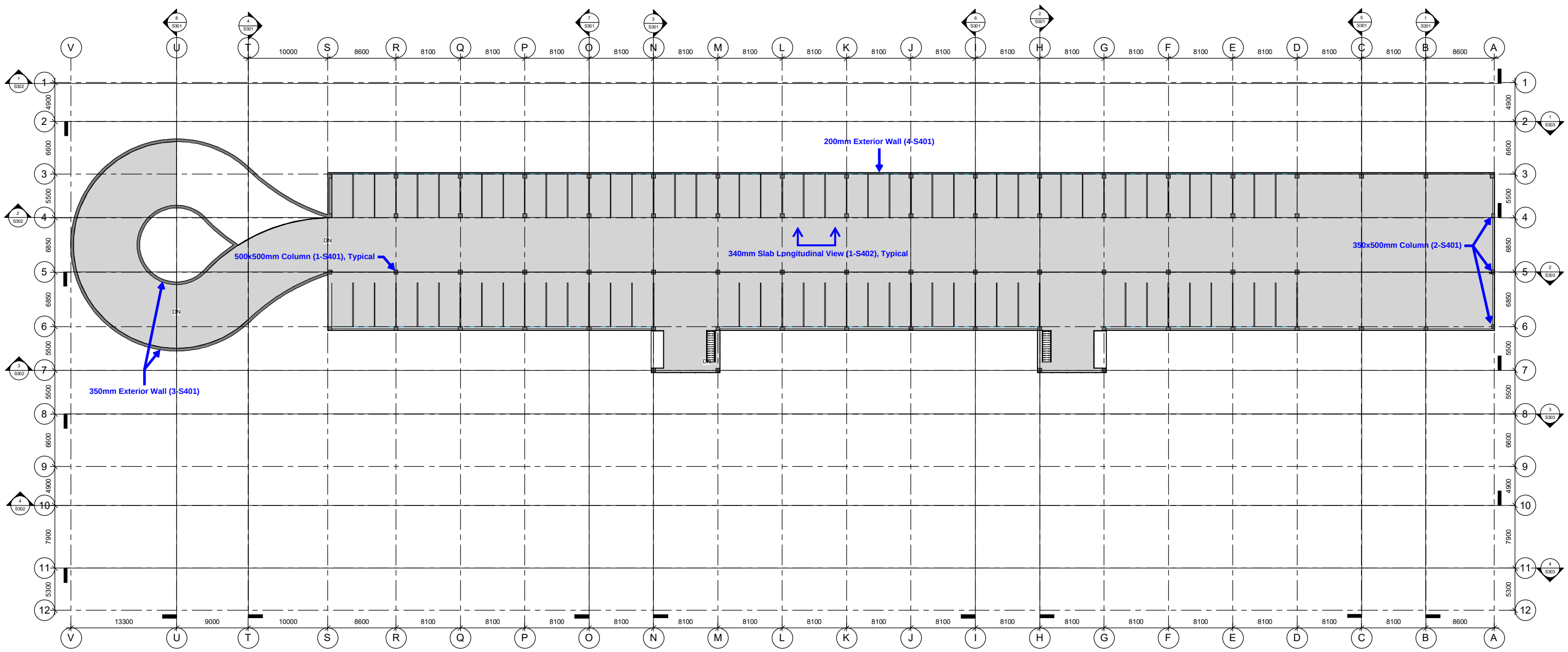

1 L2
1 : 200

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1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Plan – L2

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	JB

S204

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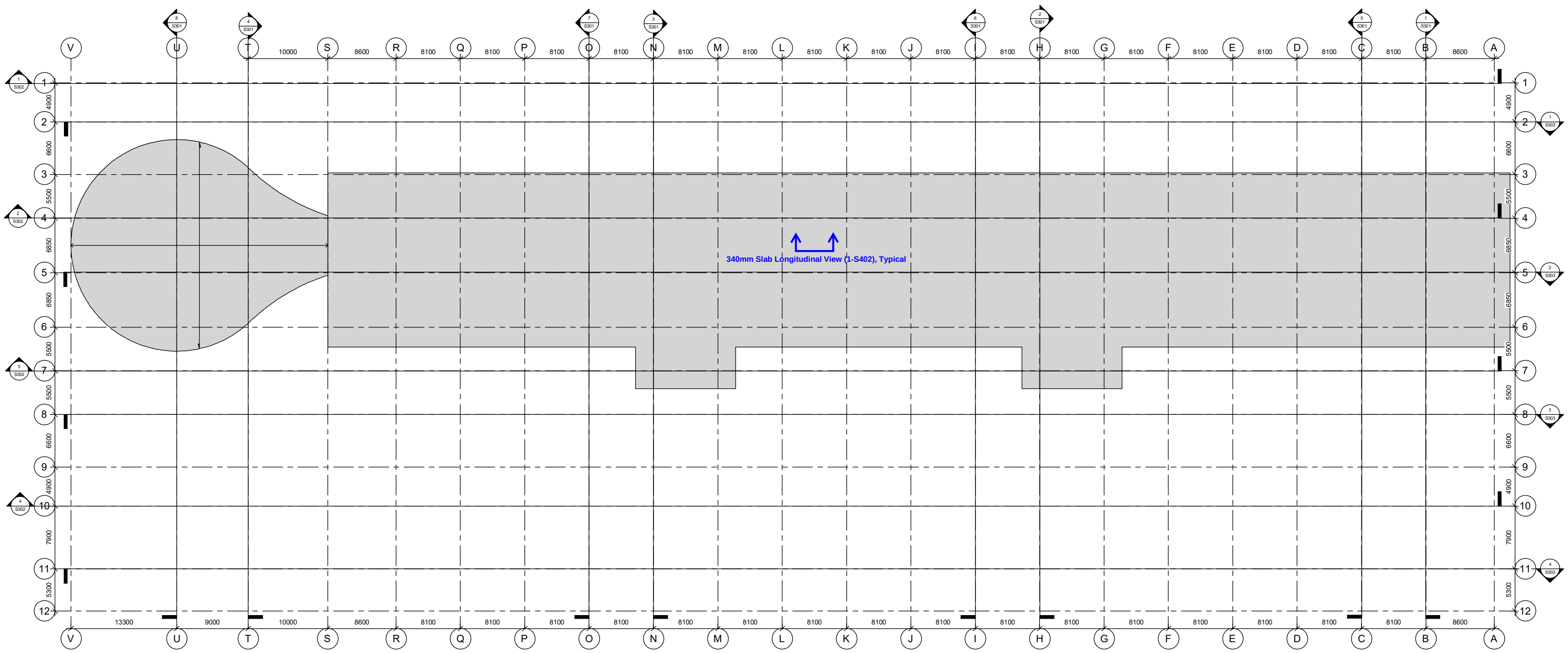
C.1.6



1 Roof
1 : 200

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No.	Description	Date
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2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Plan – Roof

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	JB

S205

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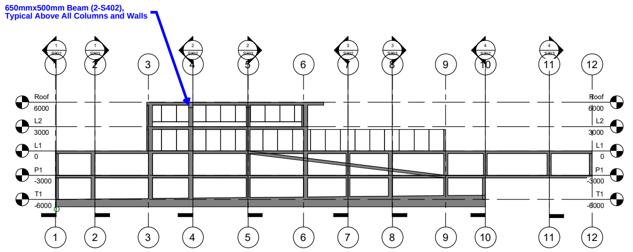

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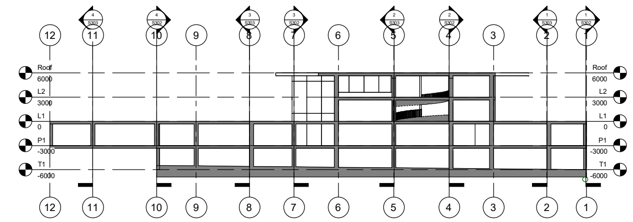

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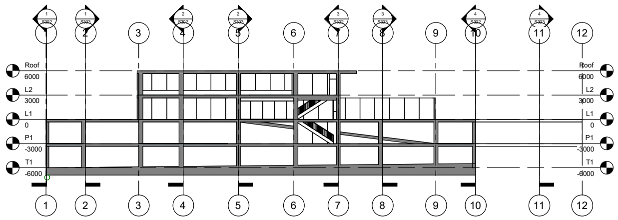

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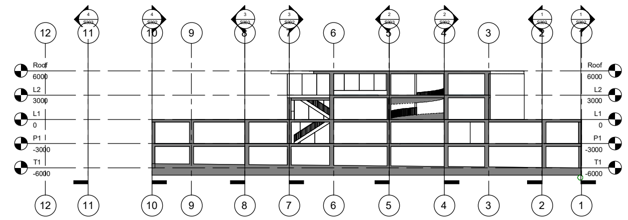

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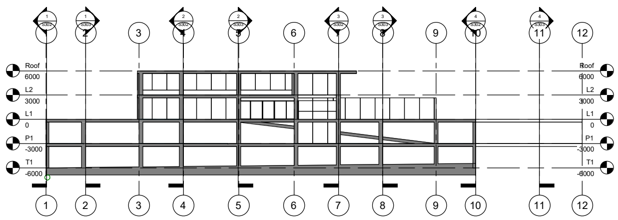

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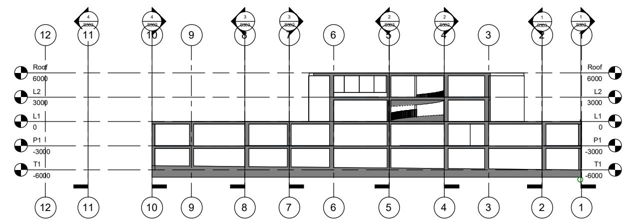

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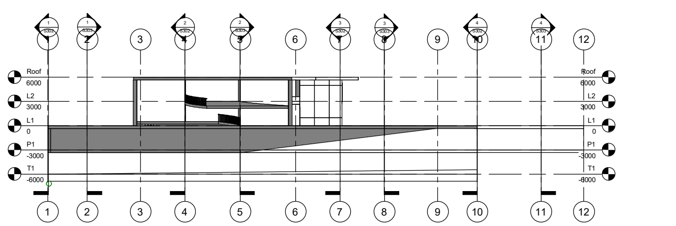

4 S-T
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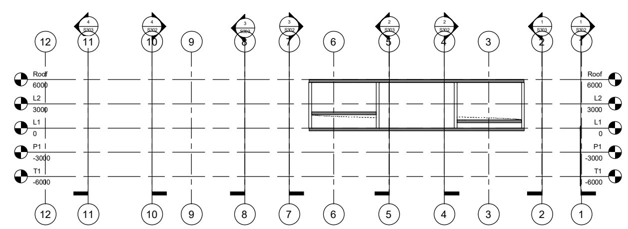

8 N-U
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No.	Description	Date
1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Elevations – North/South

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	JB

S301

Scale 1 : 200

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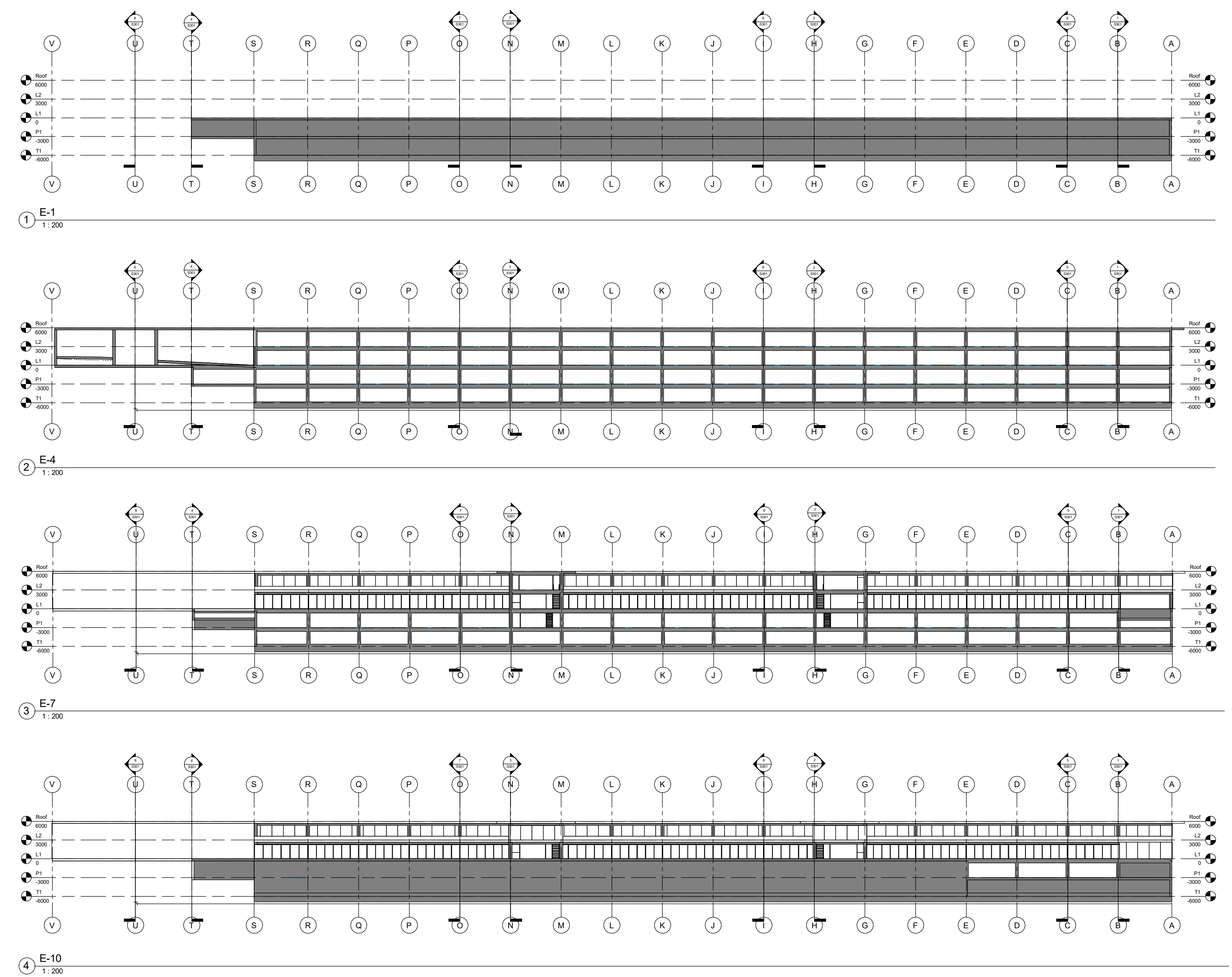
C.1.8



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No.	Description	Date
1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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Stadium Neighbourhood Mixed-Use Parkade

Elevations – East

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	JB

S302

Scale 1 : 200

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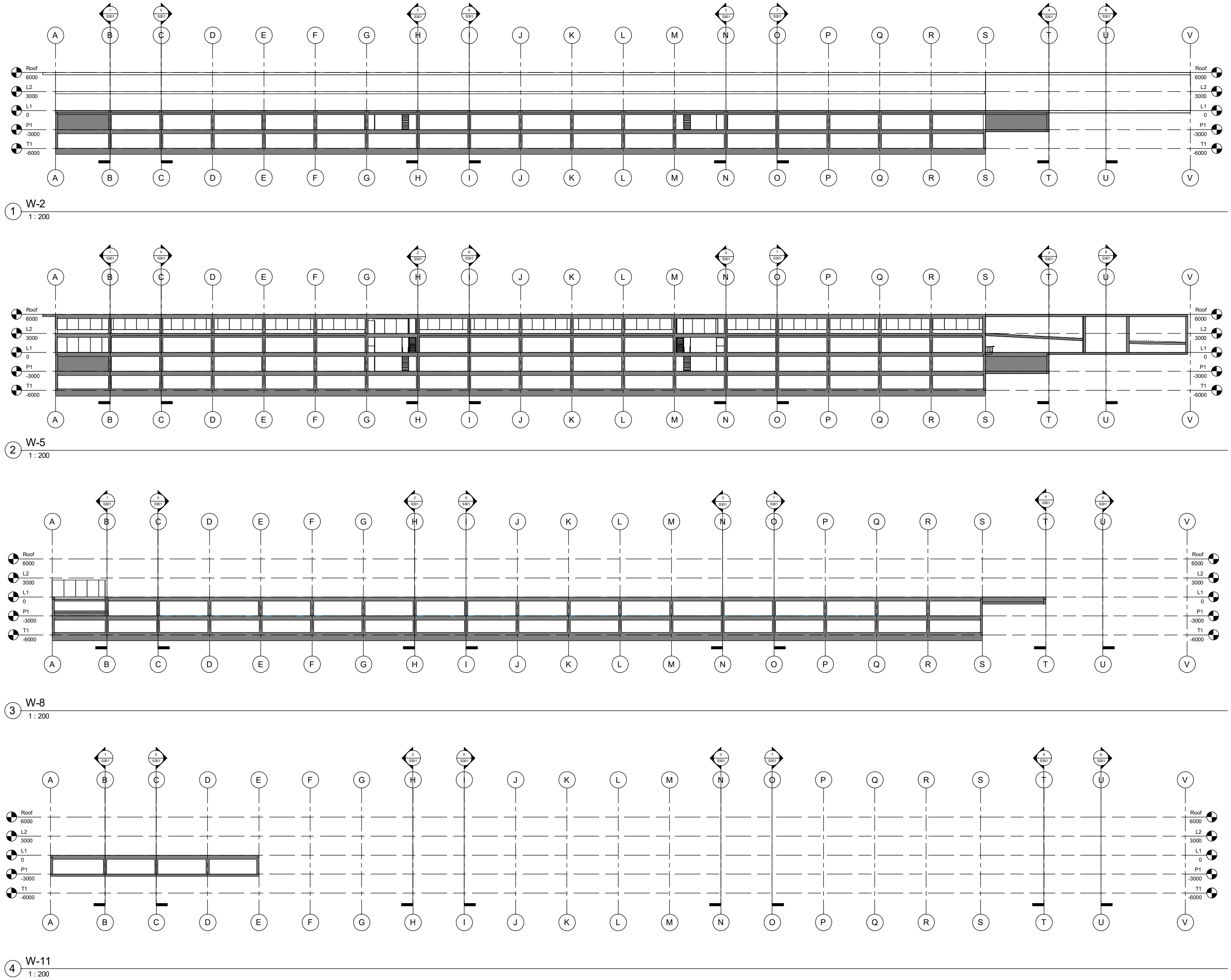

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No.	Description	Date
1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

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UBC SEEDS

Stadium Neighbourhood Mixed-Use Parkade

Elevations – West

Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	Checker

S303

Scale	1 : 200

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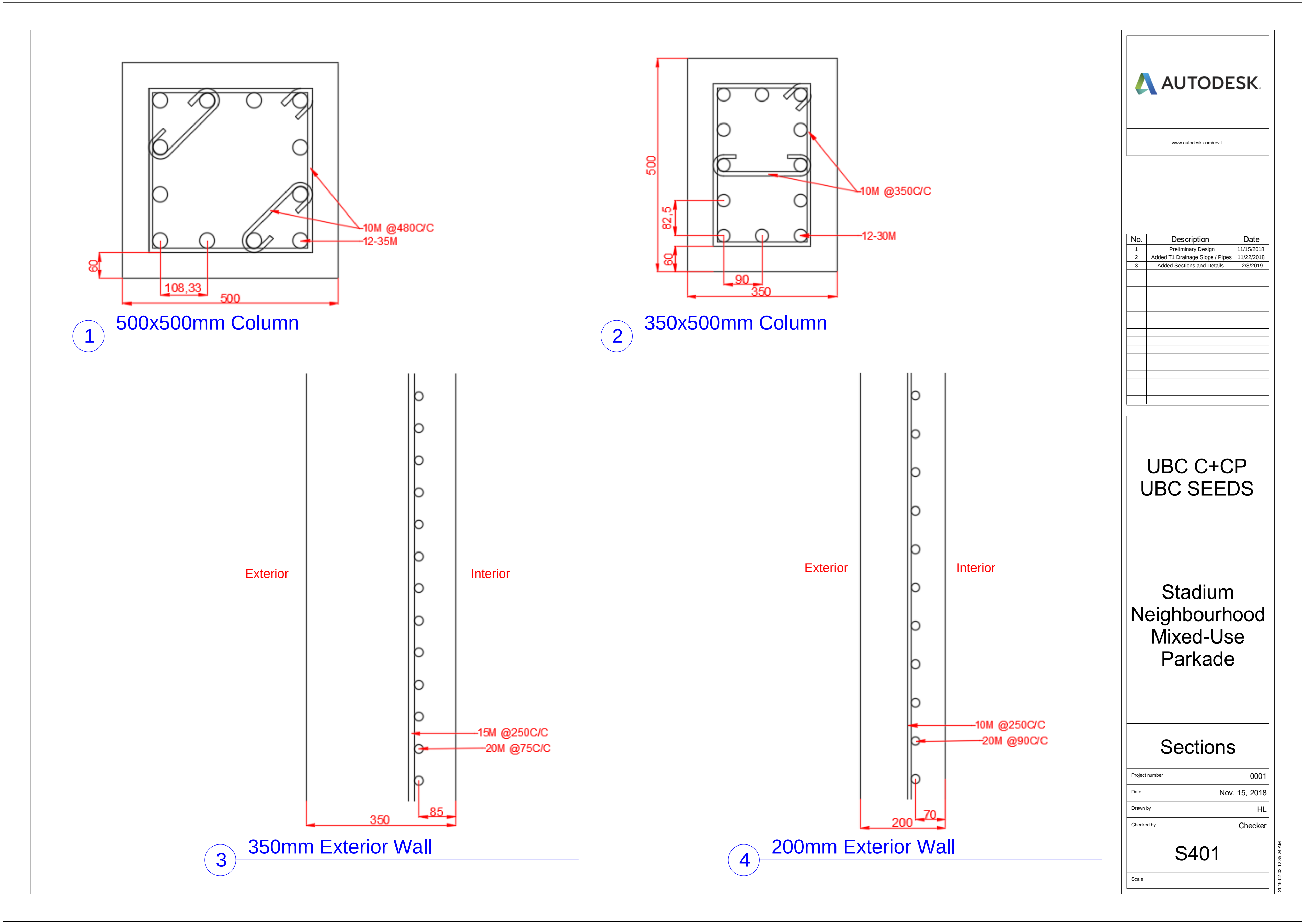
C.1.10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12-35M
60
108.33
500
1 500x500mm Column
500
82.5
60
10M @350C/C
12-30M
90
350
2 350x500mm Column
Exterior
Interior
15M @250C/C
20M @75C/C
350
85
3 350mm Exterior Wall
Exterior
Interior
10M @250C/C
20M @90C/C
200
70
4 200mm Exterior Wall
AUTODESK.
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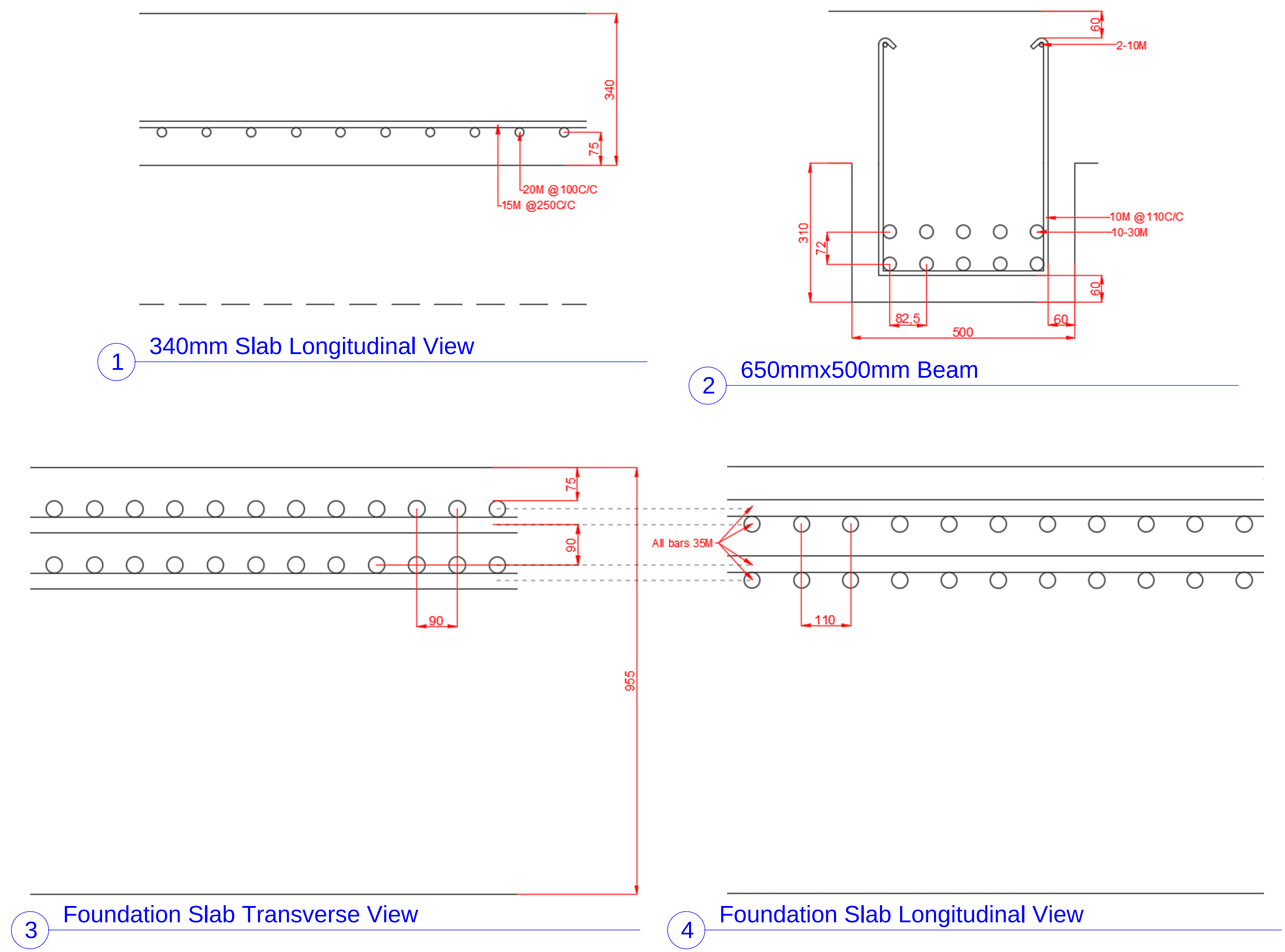
No. Description Date
1 Preliminary Design 11/15/2018
2 Added T1 Drainage Slope / Pipes 11/22/2018
3 Added Sections and Details 2/3/2019
UBC C+CP
UBC SEEDS
Stadium Neighbourhood Mixed-Use Parkade
Sections
Project number 0001
Date Nov. 15, 2018
Drawn by HL
Checked by Checker
S401
Scale

C.1.11



AUTODESK.

www.autodesk.com/revit

No.	Description	Date
1	Preliminary Design	11/15/2018
2	Added T1 Drainage Slope / Pipes	11/22/2018
3	Added Sections and Details	2/3/2019

UBC C+CP
UBC SEEDS

Stadium Neighbourhood Mixed-Use Parkade

Details

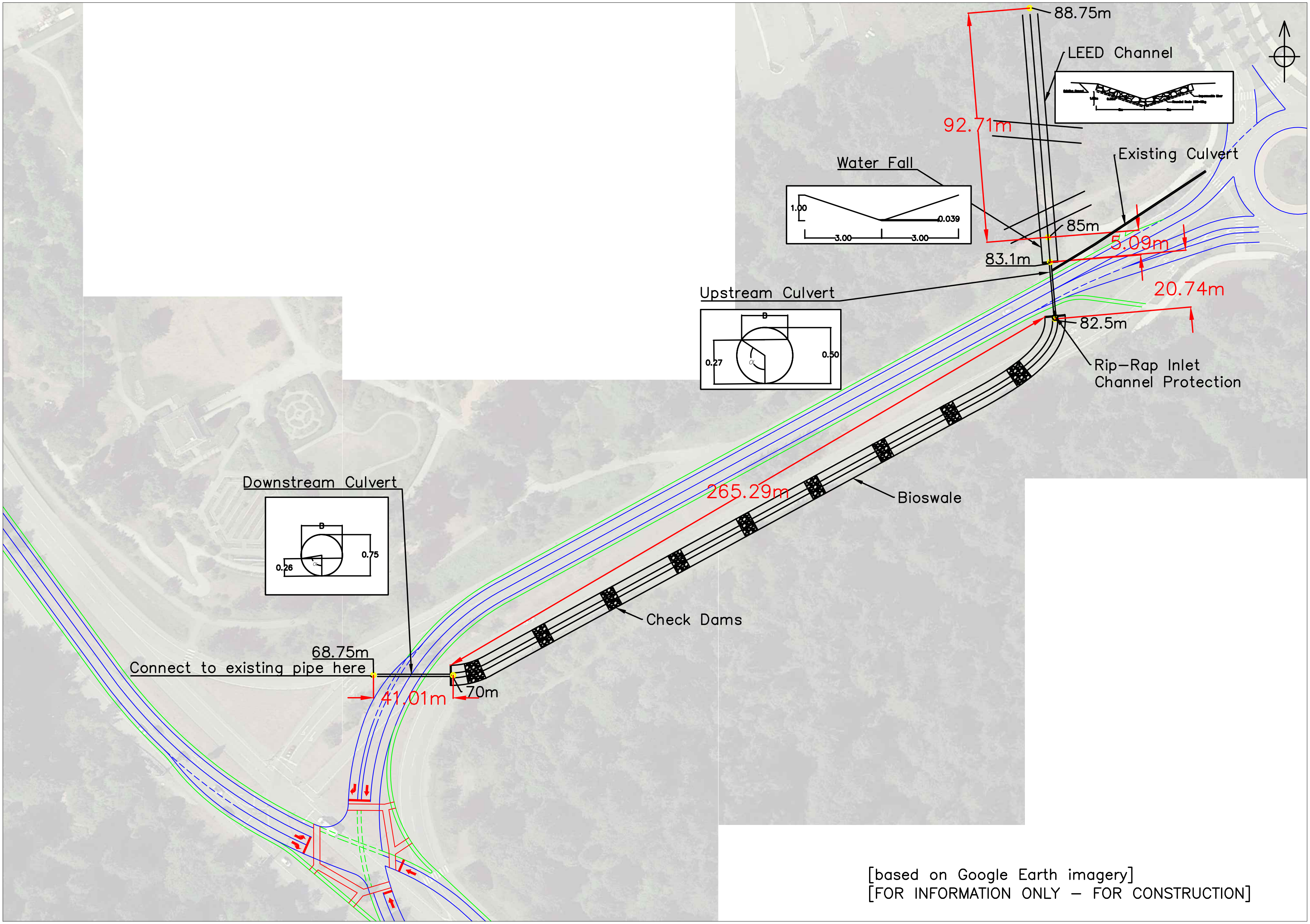
Project number	0001
Date	Nov. 15, 2018
Drawn by	HL
Checked by	Checker

S402

Scale

2019-02-03 12:35:24 AM

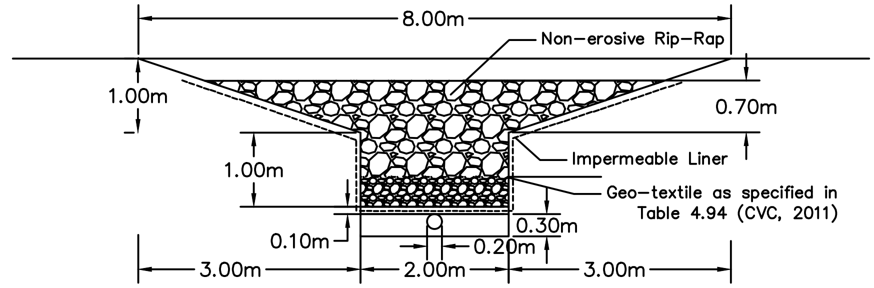
C.2. Bioswale



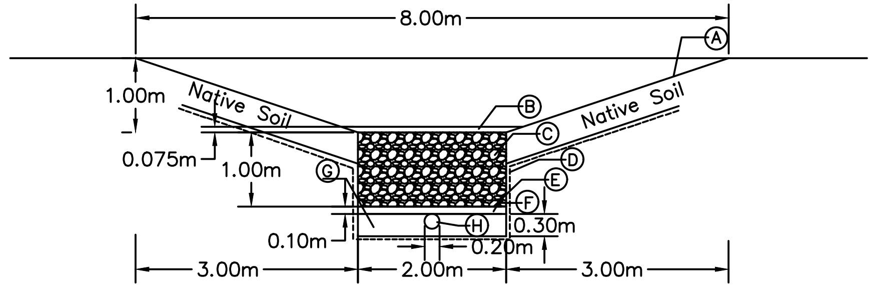
Drawing C.2.1

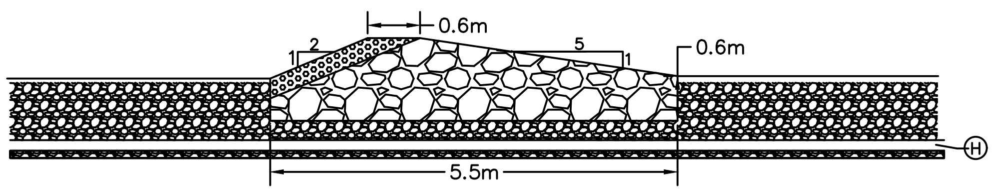
Bioswale Design Detail: SW Marine Dr / W 16th Ave

Check Dam

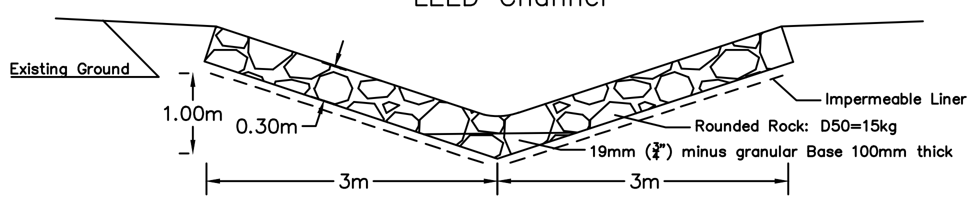


Main Channel





LEED Channel



Ⓐ Choose plants, grasses, or trees that can withstand wet/dry periods and bioswale velocities. A list of recommended plants are available in Appendix B of (CVC, 2011)

Ⓑ Mulch (Shredded Hardwood Bark)

Ⓒ Filter Media refer to pg 4–148 of (CVC, 2011) for more details:

Bioretention Filter Media Soil Mixture	
Component	**% by weight**
Sand (2.0-0.05 mm)	85-88%
Soil Fines (<0.05 mm)	8-12%
Organic Matter (Leaf Compost)	3-5%

Ⓓ Impermeable Filter

Ⓔ Pervious geotextile to prevent fine sediment from entering the perforated underdrain. See Table 4.5.7 of (CVC, 2011) for more details

Ⓕ Pea gravel choking layer (3–10 mm diameter clear stone)

Ⓖ Gravel Storage Layer (50 mm diameter clear stone)

Ⓗ 200 mm diameter
Perforated HDPE or equivalent material
Smooth interior walls
Capped on upstream end
Vertical standpipe used as clean out and monitoring well

For additional Bioswale design specifications, pelase refer to Table 4.9.4 of (CVC, 2011)

AGGREGATE MATERIAL NOTES:

1. ROUNDED ROCK (D50=15 kg) SHALL MEET THE FOLLOWING GRADATION:

MASS (Kg)	% SMALLER (BY WEIGHT) THAN			APPROX. AVE. DIMENSION ± (m)
	TARGET	LOWER LIMIT	UPPER LIMIT	
60	95	95	100	0.28
45	85	70	95	0.26
15	50	40	65	0.18
5	15	5	25	0.12
2	5	0	5	0.09

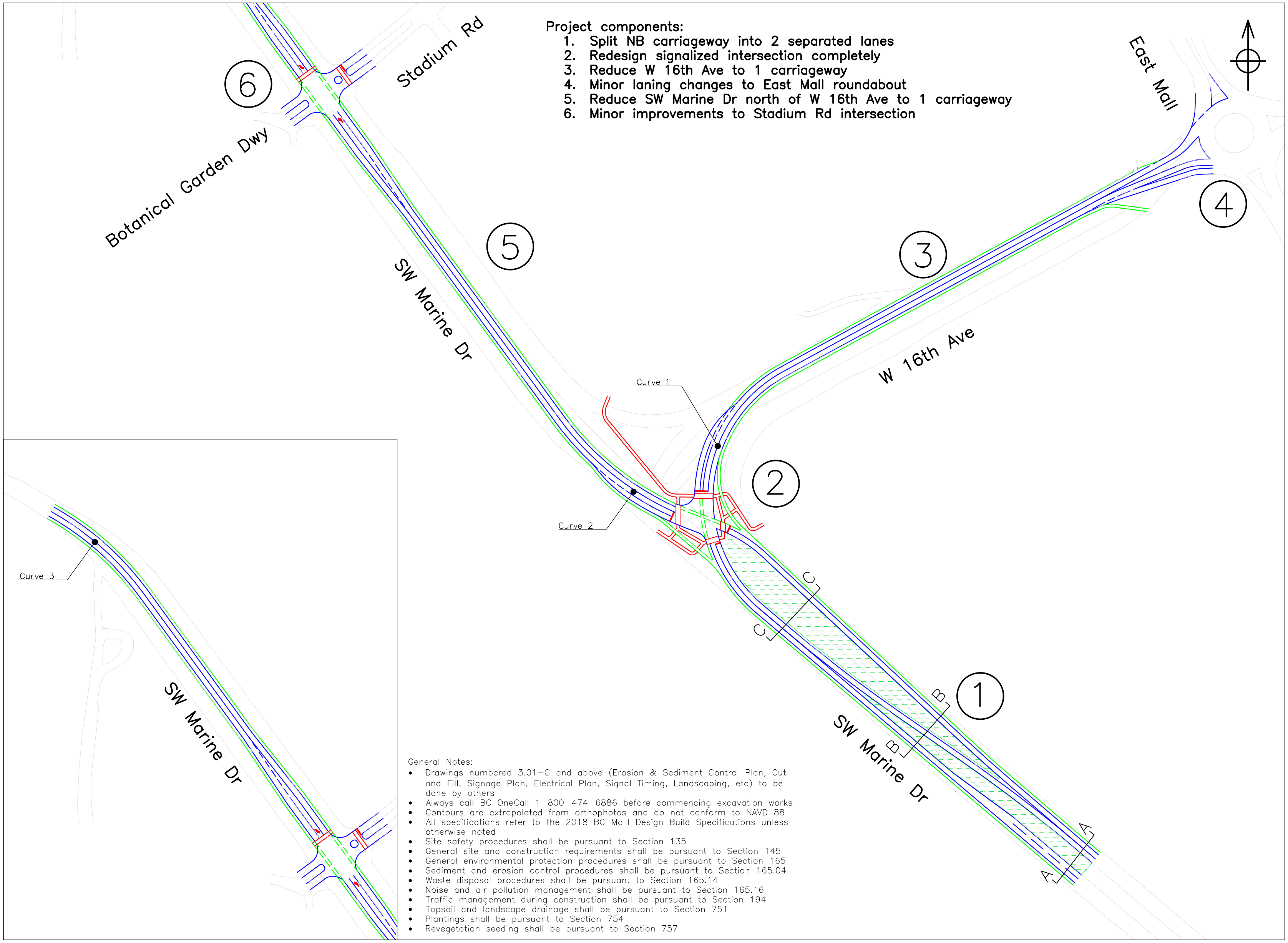
2. 19mm (3/4") MINUS GRANULAR BASE SHALL MEET THE FOLLOWING GRADATION:

SIEVE DESIGNATION	GRADATION LIMITS (% PASSING BY DRY WEIGHT)
19.0 mm	100
12.5 mm	70 - 100
4.75 mm	40 - 70
2.00 mm	23 - 50
0.425 mm	7 - 25
0.075 mm	3 - 8

[FOR INFORMATION ONLY – FOR CONSTRUCTION]

Drawing C.2.2
Bioswale Design Detail: SW Marine Dr / W 16th Ave

C.3. Intersection



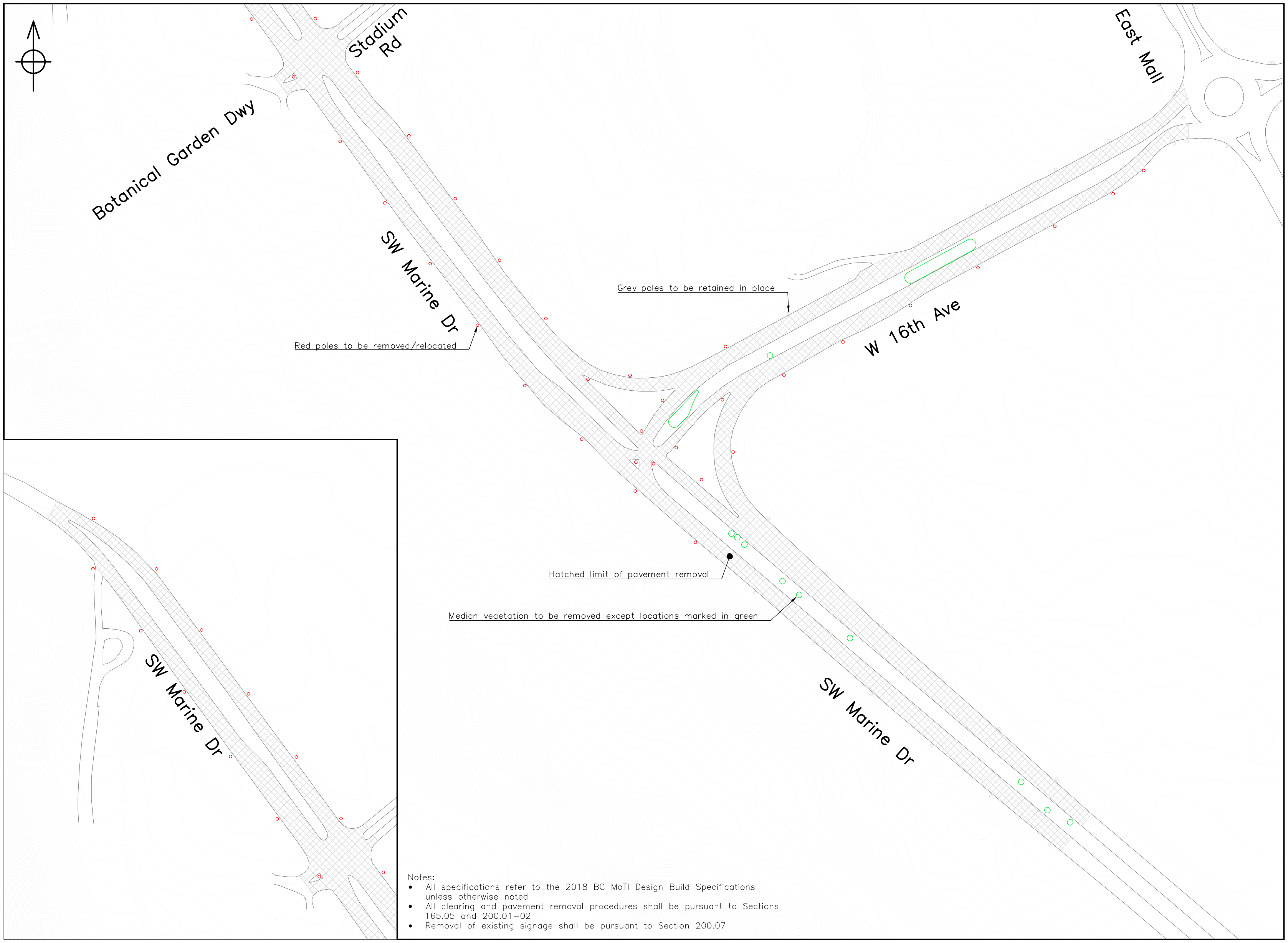
Project components:

1. Split NB carriageway into 2 separated lanes
2. Redesign signalized intersection completely
3. Reduce W 16th Ave to 1 carriageway
4. Minor laning changes to East Mall roundabout
5. Reduce SW Marine Dr north of W 16th Ave to 1 carriageway
6. Minor improvements to Stadium Rd intersection

General Notes:

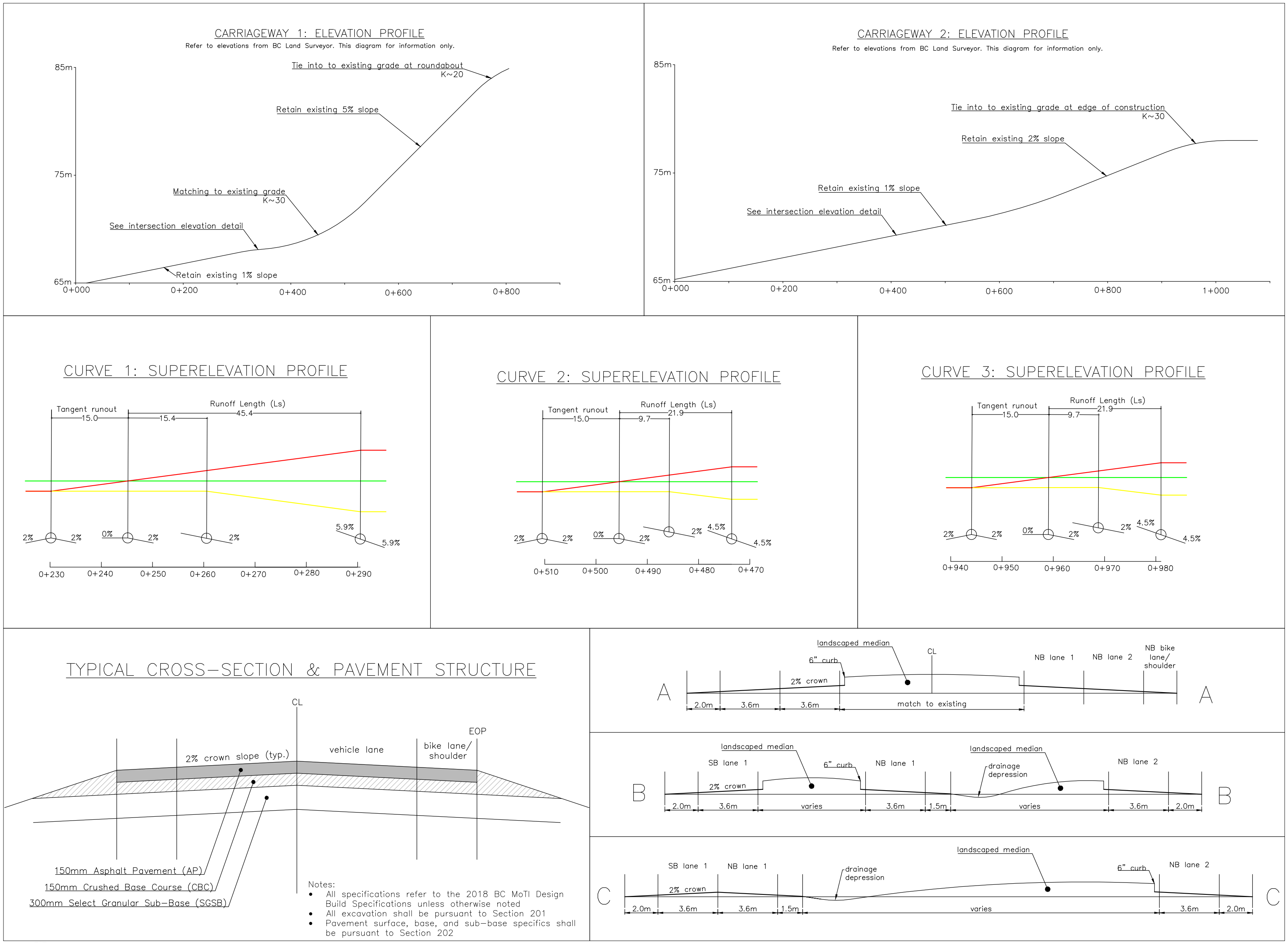
- Drawings numbered 3.01–C and above (Erosion & Sediment Control Plan, Cut and Fill, Signage Plan, Electrical Plan, Signal Timing, Landscaping, etc) to be done by others
- Always call BC OneCall 1–800–474–6886 before commencing excavation works
- Contours are extrapolated from orthophotos and do not conform to NAVD 88
- All specifications refer to the 2018 BC MoTI Design Build Specifications unless otherwise noted
- Site safety procedures shall be pursuant to Section 135
- General site and construction requirements shall be pursuant to Section 145
- General environmental protection procedures shall be pursuant to Section 165
- Sediment and erosion control procedures shall be pursuant to Section 165.04
- Waste disposal procedures shall be pursuant to Section 165.14
- Noise and air pollution management shall be pursuant to Section 165.16
- Traffic management during construction shall be pursuant to Section 194
- Topsoil and landscape drainage shall be pursuant to Section 751
- Plantings shall be pursuant to Section 754
- Revegetation seeding shall be pursuant to Section 757

Drawing C.3.1
Project Overview

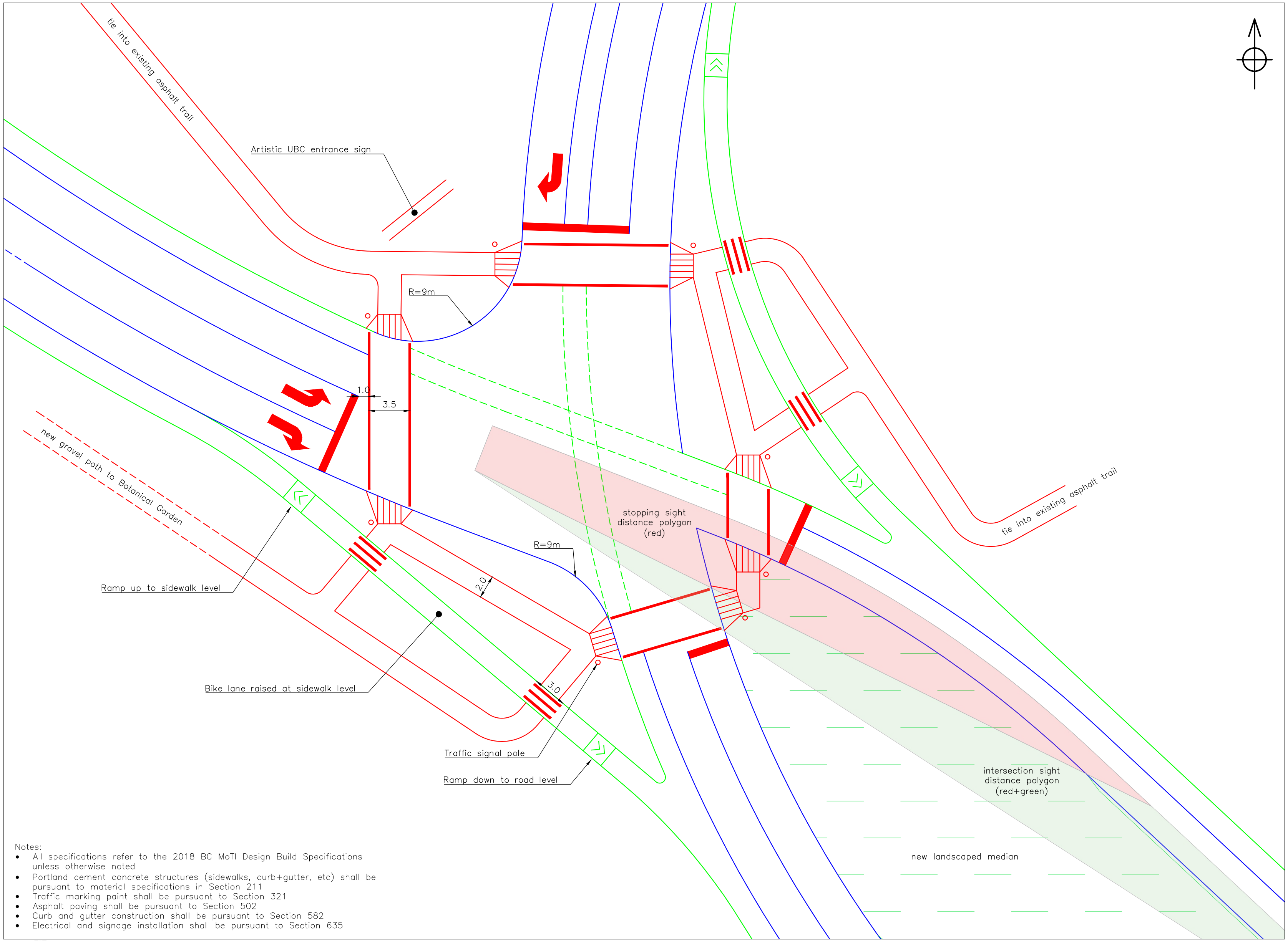


Drawing C.3.2

Existing Conditions and Removal of Existing Infrastructure

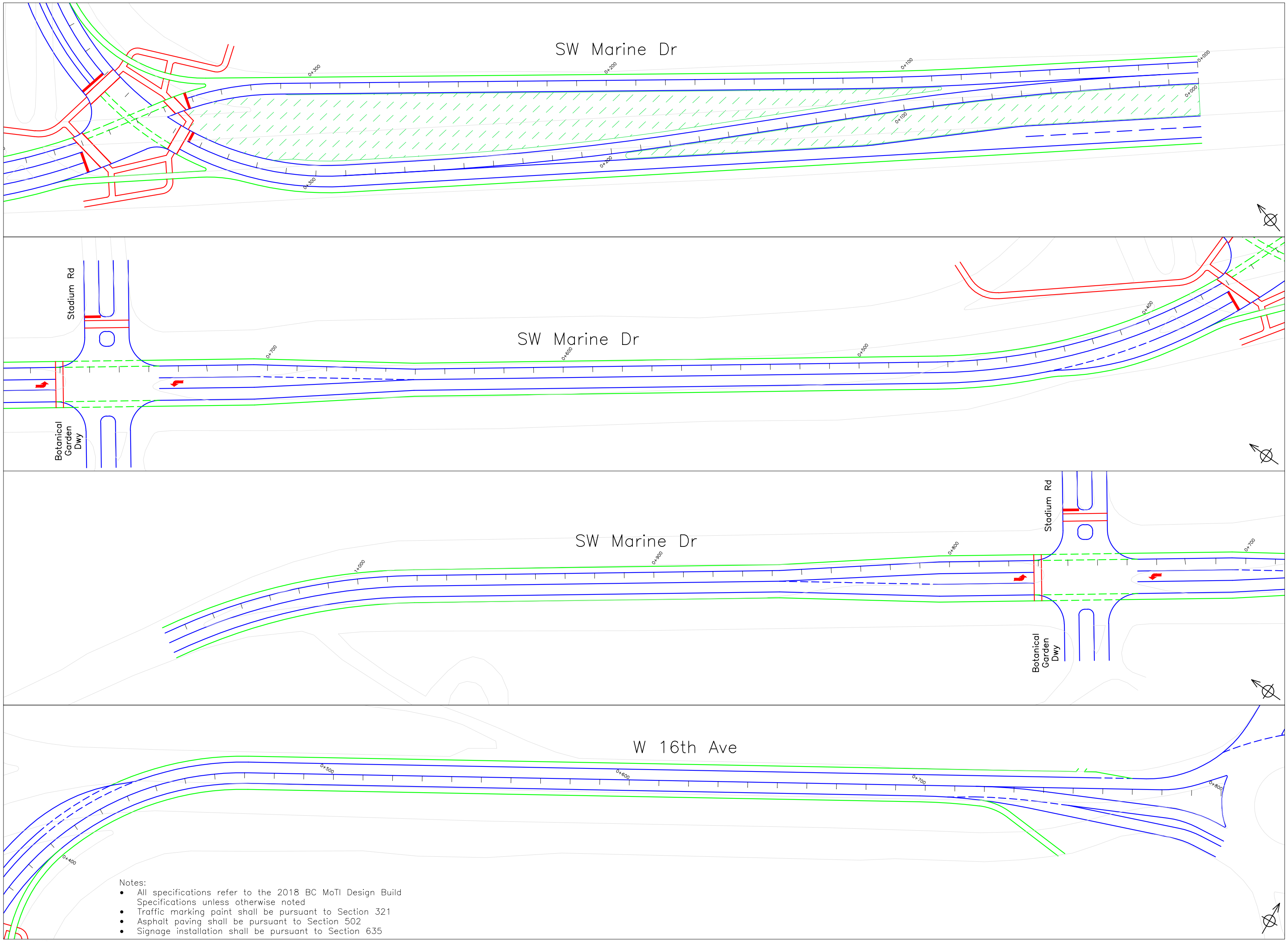


Drawing C.3.3
Elevations and Cross Sections



Drawing C.3.4

Intersection Design Detail: SW Marine Dr / W 16th Ave



Notes:
- All specifications refer to the 2018 BC MoTI Design Build Specifications unless otherwise noted
- Traffic marking paint shall be pursuant to Section 321
- Asphalt paving shall be pursuant to Section 502
- Signage installation shall be pursuant to Section 635

Drawing C.3.5
Plan Detail Segments

Appendix D: References and Documentation

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