UBC Social Ecological Economic Development Studies (SEEDS) Sustainability Program

Student Research Report

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University of British Columbia

CIVL ппрк446

Themes: Water, Climate, Land

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1.0 EXECUTIVE SUMMARY

Our team has been retained by UBC to develop a multi-use stormwater retention system reflecting the need to address the event of a 100 year return period storm. This call to action is as result of of a need to address and prevent cliff erosion off the Southwest Marine Drive and Point Grey area. The system shall be situated adjacent to the UBC Center for Comparative Medicine (CCM) and shall encompass key design criteria as laid out by Mr. Doyle while adhering to UBC SEEDS Department's criteria to sustainability at UBC.

As result, our team is proposing a multi-use Velodrome design to combat the 100 year return period storm whilst also providing an excellent cornerstone for growth within the UBC community. The Velodrome will also be encompassing a park within it as to further push UBC SEEDS Department's criteria to sustainability and a greener image. The system will limit the outflow to approximately 1.2 m3/s. Additionally, the volumetric capacity will contain 3,400 cubic meters of water and fulfills the BC Water Quality Guidelines for the discharge of water.

Given the provided geological data, soil conditions and borehole data, our team has developed a design structure and ensuing calculations to support the development of the UBC Velodrome. Additionally, Issued for Construction (IFC) drawings are enclosed for the construction of this project.

Utilizing UBC, Metro Vancouver, Canadian, and other applicable guidelines, the construction processes are identified and a proposed schedule of the entire project is enclosed. Using RSMeans, other notable municipal and federal projects information, and finalized details in our service life and maintenance plan including the time value of money and interest rates, our Class C cost estimate has been updated to a Class B cost estimate. Additionally, our team will include considerations for the service life and maintenance of the UBC Velodrome as well as recommendations for its design.

2.0 DESIGN CRITERIA & ASSUMPTIONS

The key standards and software packages used in the design process include:

- National Building Code of Canada
- Canadian Foundation Engineering Manual (FEM)
- AASHTO
- ASTM
- Vancouver by-laws
- American Concrete Institute (ACI)
- CSA A23.3-14 (design of concrete structures)
- CSA A23.2-14 (test methods and standard practices for concrete)
- CSA A23.1-14 (concrete materials and methods for construction)
- CAC - Concrete Design Handbook
- Software: AutoCAD, Civil 3D

Key Design Issues:

The major design issues that were foreseen, and successfully addressed, are the design of the retaining wall and the mechanism to lay the slab (bicycle-track) on the retaining wall. Since there are no readily available codes and standards, specifically catering to the design of velodromes, a thorough analysis was required to ensure that all safeguards are in place. For this, the team referred to all standards and codes applicable referenced above.

Technical considerations associated with the design:

- Sizing of inlet and outlet stormwater pipes to control discharge
- Final design calculations
- Final cost estimate
- Final project schedule
- Detailed engineering drawings

Design criteria:

- Limited Flow Capacity: For the UBC south campus catchment, the storm-water retainment structure to be located at Westbrook Mall and Marine Drive requires a limited 1.2 m3/s [1] output to avoid inundating the culverts crossing Marine Drive, and as such this was worked into our design via the size of the piping for the water leaving the site. The quantity and quality of stormwater leaving campus was considered to be an important factor in our design, and was addressed by our multi-layer rain garden design which removes 90% of nutrients and chemicals and 80% of sediments from rainfall catchment prior to release.

- Volume Control: With the current moderate storm incidents (1 in 10 year), water can currently flood the roadways, and in a major storm event (1 in 100 year), severe flooding could cause overland flows with the existing system in place. As such, the UBC Integrated Stormwater Management Plans recommend storage capacity able to contain 2,500 to 3,000 cubic meters [1], which our team met and exceeded with a capacity of over 3,400 cubic meters.
- Erosion and Environmental Protection: Protection of the geotechnically and environmentally sensitive surrounding cliffs in Point Grey was a vital consideration. Even with the limited flow capacity of 1.2 m3/s, the discharge of the water all the way to the ocean being safe and not deteriorating the sandy cliffs was considered high priority.
- Social Impact: The project is in close proximity to extensive green areas and the UBC farm, and as such our design aims to have the aesthetics and use for a smooth integration between the environment and infrastructure which could be desirable for the surrounding community.
- Multi-Usability: Being a key design criteria, multi-usability was high priority item for the development of our design, and as such the Velodrome and park design has been engineered to encourage a functional multi-purpose facility and physical activity.
- Economic Impact: In order to facilitate UBC's promotion of greener stormwater management strategies, our team strived to create an affordable project through efficient construction time, labor, and material costs.
- Design Life: The design life for this project has been established to be 100 years. This was selected on the basis that our design needed to account for a 1 in 100 year storm, and as such, it was designed to be equipped to withstand that duration.
- Design Loadings: The loadings selected for our final detailed design were used to determine the design of the foundation, thickness of concrete slabs, design slopes, and amount of required steel rebar reinforcement.

3.0 DESIGN COMPONENTS

The multi-use storm-water detention system used is divided into separate components to simplify the analysis and design of each individual component. In this regard, the detention system is split into the main velodrome structure, and the rain garden components. The analysis and design of these components is presented below.

3.1 Velodrome structure

The main velodrome structure is broken down into following design components for ease of design: *the bicycle tracks*, *the retaining wall* and *the footing*. These components are discussed individually as follows.

3.1.1 Bicycle Tracks

The bicycle tracks are designed using two different design techniques: as slab-on-grade for straight sections and as simply supported one-way slab for end sections, as shown in Appendix D. NBC 2015 specifications as well as CSA A23.3-14 were used in all design considerations, especially with provisions for concrete exposure to soil and chlorides.

The straight sections of the tracks are designed as slab-on-grade since a relatively mild slope of 17° does not pose any challenges in regards to the stability of the excavation. Designing the straight sections of the tracks as slab on grade is also cost effective and relatively easy to construct compared with the end sections.

Live loads were calculated assuming six bicycle riders side-by-side each weighing 80 Kg. Snow-loads were determined per Cl.4.1.6.2 of NBCC 2015. The relation that specifies the calculations of snow loads is reproduced here to elaborate on the different variables listed within it, since these governed the design of the structure:

$$\boldsymbol{S} = \boldsymbol{I_s}\,[\boldsymbol{S_s}\,(\boldsymbol{C_b}\,\boldsymbol{C_w}\,\boldsymbol{C_s}\,\boldsymbol{C_a}\,) + \boldsymbol{S_r} \qquad \textit{[NBCC 2015 CL.4.1.6.2]}$$

$$\begin{aligned} where\ \ S &\rightarrow Specified\ load\ due\ to\ snow\ and\ associated\ rain \\ \boldsymbol{I_s} &\rightarrow Importance\ factor\ for\ snow\ load \\ \boldsymbol{S_s} &\rightarrow 1 - in\ - 50\ year\ ground\ snow\ load \\ \boldsymbol{S_r} &\rightarrow 1 - in - 50\ year\ associated\ rain \\ \boldsymbol{C_*} &\rightarrow wind, slope\ and\ accumulation\ factors \end{aligned}$$

As prescribed by *NBCC 2015 - Appendix B*, the ground snow load for the Vancouver (Granville & 41 Ave.) was used since that is the area closest to the site of the proposed project. The relevant table of of specified loads is shown in Appendix B. Since the structure is not designed as a habitable structure, and is outdoors, away from residential buildings, the importance factor I_s was chosen as 0.8. This ensures that the structure is not over-designed and remains economical to construct while adhering to the safety limits allowed per NBCC.

Load Combinations Without Crane Loads for Ultimate Limit States
Forming Part of Sentences 4.1.3.2.(2) and (5) to (10)

Case	Load Combination[1]	
	Principal Loads	Companion Loads
1	1.4**D**[2]	—
2	(1.25**D**[3] or 0.9**D**[4]) + 1.5**L**[5]	1.0**S**[6] or 0.4**W**
3	(1.25**D**[3] or 0.9**D**[4]) + 1.5**S**	1.0**L**[6][7] or 0.4**W**
4	(1.25**D**[3] or 0.9**D**[4]) + 1.4**W**	0.5**L**[7] or 0.5**S**
5	1.0**D**[4] + 1.0**E**[8]	0.5**L**[6][7] + 0.25**S**[6]

Table 1: Load Combinations per NBCC 2015

Table 1 above lists the load combinations prescribed by the NBCC. Cases 2 and 3 indicate scenarios where a combination of live loads (cyclists) and snow loads may be combined to determine the factored design loads. The scenario where the maximum snow load and cyclists being on the tracks at the same time is not realistic and unlikely. For this reason, load combination case 3 was chosen without adding the companion live loads. This ensures that the structure is not over-designed and remains economical to construct. Thus, the governing load combination was $1.25D + 1.5S$ and the factored load for the design of the structure was determined to be 11 kPa. The detailed calculations are attached in Appendix C.

The 30.8 m (x2) straight sections will be cast in place. These sections are inclined at a 17° gradient with the horizontal. The site will need to be excavated to a depth of 1.75 m below existing grade with a slope of 17° to allow for the tracks to be cast. Since the site predominantly consists of sandy soils, as confirmed by the geotechnical reports, and the friction angle of the sandy deposits is assumed to be in the range of 35° - 40° the slope of the excavation does not pose any stability issues. The reason is that any excavation slope smaller than the friction angle of the soil is deemed stable. After compacting the excavation with suitable base material, the straight sections will be cast in place.

Since the slab-on-grade section is exposed to soil, CSA A23.3 prescribes that a larger cover depth of 75 mm be used.

The end sections are inclined at a slope of 47° with the horizontal. Should the end sections be excavated at a 47° slope, additional measures of slope stability would need to be in place for safety of workers and equipment. This would add to the cost of operations, and casting on granular soils at steep slopes poses additional challenges. An easier option is to excavate the site at the end section at a 1V:2H slope. This means that the angle of excavation will be 27° with the horizontal. Being that this is much below the friction angle of the sand, the slope will be stable.

The retaining wall, which is discussed in the next section, will be cast at the base of the excavation. Consequently, the tracks, designed for the end sections as a simply supported, one-way slab, will be placed on top of the retaining wall.

The part of the slab placed on top of the retaining wall was considered a roller joint in designing the slab, whereas the bottom part resting on the footing was considered pinned. This is a safe assumption to make since the bottom end is prevented from any horizontal movement, while being free to rotate. The top end is not a rigid joint and therefore transfers no moment to the retaining wall.

Design criteria laid out by CSA A23.3 was followed and all relevant checks were made to ensure a safe design. The *Direct Procedure* outlined by Brzev, Pao [1] to determine the area of tension reinforcement required was used. The following checks were performed for the tracks, which were designed as one-way-slabs:

> *7.8.1 A minimum area of reinforcement of 0.002Ag shall be provided in each direction.*
> *7.8.2 For exposure conditions where crack control is essential, reinforcement exceeding that required by Clause 7.8.1 shall be provided.*
> *7.8.3 Minimum reinforcement shall not be spaced farther apart than the smaller of five times the slab thickness or 500 mm.*
> *7.8.4 At all sections where it is required, minimum reinforcement shall be developed in tension for its specified yield strength in compliance with Clause 12.*

In addition, the maximum tension reinforcement requirement specified in Cl.10.5.2 was also checked to ensure that the steel ratio is below the balanced steel ratio so that any failure is steel controlled.

The load combinations used in the design of the end sections of the tracks was the same as that followed for slab-on-grade for the straight sections. The snow loads governed the design. The main difference in the design of the straight sections and end sections of the tracks was the prescribed concrete cover. Since the slab-on-grade section is exposed to soil, a 75 mm cover is used whereas the end sections need only a 60 mm cover since it is not cast against earth.

In all sections, however, the classification C-XL was used since the structure is expected to be exposed to chlorides owing to runoff from roads and ditches and the structure as a whole will also be exposed to freeze-thaw cycles. The CSA A23.3 [2] defines the C-XL class as follows:

> ***C-XL:*** *Structurally reinforced concrete exposed to chlorides or other severe environments with or without freezing and thawing conditions, with higher durability performance expectations than the C-1 or A-1 classes.*

3.1.2 Retaining wall

As was mentioned in the previous section, a slope of 47° of the bicycle tracks necessitated using retaining walls. The site predominantly contains sandy soils, and assuming an angle of friction of 30° - 35°, any slope over 30° would be unstable and require special measures to stabilize the slope. In the current design, the site will be excavated at a 1:2 gradient (~26°), and after the retaining wall is cast, the portion behind the retaining wall will be filled and compacted.

The type of retaining wall chosen is a free-standing cantilever wall. To ensure safety, it is checked for the overturning, sliding and bearing capacity failure modes. The respective factors of safety are 9.6, 1.56, and 160. The results are acceptable factors of safety (FOS), all exceeding their minimum requirements (2, 1.5 & 3). Calculations are provided in Appendix C.

A wall thickness of 300 mm was selected for the retaining wall. Design calculations yielded that 200 mm thickness was adequate; however, good practice per CSA A23.3 dictates that for wall heights greater than 4m, a 300 mm thick wall be used.

In the design of the retaining wall, the bottom end was assumed rigid. This resulted in designing for negative moment at the bottom end as well as special considerations for an inflection point. Providing reinforcement for the full length of both the inner and outer faces would be unnecessary and result in cost overruns. Therefore, development lengths were calculated and the bars on the side facing soil can be safely terminated at a distance of 1930 mm from the top of the footing. This takes into account the required minimum length past the inflection point required by CSA A23.3.

3.1.3 Footing

The footing was designed as a continuous, combined footing per CSA A23.3 specifications. Per NBCC 2015, an 'allowable bearing capacity' of 150 kPa was used in the design. The site contains predominantly sandy soils with some traces of silt in the upper 3 m. However, since the top silty layers will be excavated, the silty layers were ignored in design calculations.

The concrete cover for the retaining wall and the footing was set as 75 mm since it is cast against earth.. This fits the condition set by CSA A23.3 that any structure “cast against and permanently exposed to earth” have a 75 mm cover.

3.2 Rain Garden

Construction of the UBC Velodrome will require the removal of pervious forest area, replaced with over 2300 m2 of impervious concrete. This eliminates the ability for water to infiltrate into the soil and instead adds to the burden on the Westbrook main. The solution is the rain garden center piece of the UBC Velodrome. The rain garden will not only serve as a decorative feature but also a rainwater capture and filtration tool.

It is designed to be a down sloping area with plants to add to the overall aesthetics of the velodrome facility. The rain garden will be 12 meters wide and 24 meters long with a 6 meter curved radius on both ends. The dimensions will result in a surface area of 401 m2 and be capable of capturing all the runoff from the velodrome surface for a 6-month 24-hour rainfall event, which accounts for 90% of the storms in the Vancouver area. The design overcompensated for future influxes in storm intensities as the capture capacity of the rain garden approaches that of a 5 year event. Any storm larger than that will result in water reaching the perforated pipe at the bottom of the garden and working its way back to the Westbrook main.

The rain garden will feature a top layer of bioretention soil which allows water to permeate easily while capturing 90% of nutrients and chemicals as well as 80% of sediments. The water will be much cleaner than typical rainwater runoff once it reach the perforated pipe. Under the bioretention soil will be a rock trench where the perforated pipe will run. The rock allows the water to trickle freely to the pipe without getting backed up. A main summary of the rain garden components are shown in Table 2 and the design calculations can be found in Appendix C.

Paved Area (m2)	2305
Rain Garden Area (m2)	401
Topsoil Depth (m)	0.6
Rock Trench Depth	0.8
Input Volume (m3)	112

Capture Capacity (m3)	175

Table 2: Rain Garden Components

Inflow/Outflow:

A diversion pipe will be connected to the existing Westbrook storm main and connect to the UBC Velodrome site to allow for the flow of stormwater into the velodrome detention area during severe storm events. The diversion system is designed to allow normal storm events to continue on their usual paths while only severe flows will be diverted. The weir controlled system can be seen below in Figure 1.

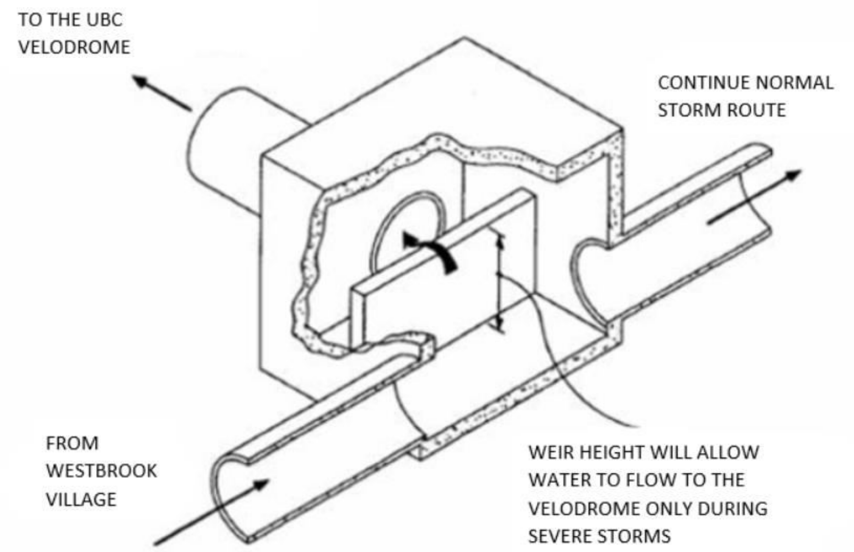


Figure 1: Weir Controlled System (City of Sacramento, 2000)

As the inflow pipe approaches the velodrome detention area it will start to fan out to disperse the energy of the flow. The water will be released into the velodrome via a long thin opening near the top of the northernmost straightaway. The inflow opening will be 8 meters long by 0.3 meter high. Images of the inflow opening and how the velodrome will fill with water can be seen in Appendix E. Cyclists do not ride near the top of the straightaways, so the inflow opening will not interfere with riders.

The rock pit under the rain garden will have a 0.45 meter perforated pipe in the middle, laid at a 2.0% slope towards Westbrook. The pipe will take effluent water away from the site at a controlled rate of around 0.40 m^3/s. The discharge rate is well under the 1.2 m^3/s maximum recommended by the UBC Integrated Stormwater Management Plan.

For storms larger than what the rain garden is designed to handle, two elevated catch basins will be in the rain garden to transport water directly to the outflow pipe. The overflow catch basin will be 0.5 meters above the surface of the rain garden at the center level.

3.3 Concrete Mix Design & Concrete Specifications

The concrete mix design for this structure will be coordinated between the contractor and the concrete supplier to meet the requirements outlined in Table 3 below which outline the requirements specified in CSA A23.1 and CSA A23.2 for concrete Mix Proportions. Some of the parameters that should be noted are:

- Maximum aggregate size for the mix design will be 30 mm.
- Air content for the mix will be 4-7% for the hardened concrete.
- The specified 28-day strength of the concrete will be 25MPa.
- The exposure class is C-1, structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions (Cl.4.1.1).
- The concrete shall be designed to have a finished density of approximately $2400\frac{kg}{m3}$(Cl. 4.3.4.1).

Concrete Mix Proportions in accordance with CSA A23.1 (4.3.1). Mix proportions were selected to provide material properties that meet requirements (a)-(h).	
<u>Requirement (a)</u> **Workable concrete** [Clause 4.3.2]	<u>4.3.2.2 Nominal maximum size of aggregate</u> MSA less than or equal to (a)-(d) (a) ⅕ of the narrowest dimension between side forms = 60mm (b) ¾ of minimum clear spacing between rebars = 214mm (c) ⅓ of the depth of the slabs = 100mm (d) The specified concrete cover not exposed to earth or weather = 60mm (e) ⅔ of the specified cover for concrete exposed to earth or weather = 50mm (f) ½ of the specified cover for concrete exposed to chlorides = **30mm MSA [governs]** <u>4.3.2.3 Slump or Slump Flow</u> Slump requirements shall be identified and reviewed by the contractor and concrete supplier prior to construction. When the slump is specified, the acceptance of the concrete in the field shall be subject to the tolerances specified in Clause 4.3.3.2

Requirement (b) **Concrete Durability** [Clause 4.1.1]	All of clauses 4.1.1.1 to 4.1.1.10 should be adhered to. Placing of concrete will be conducted by the contractor in accordance with clause 7.4: Placing of Concrete, to ensure durability requirements are met. Table 1 Classes of exposure C-1 - Structurally reinforced concrete exposed to chlorides with or without freezing and thawing conditions. Table 2 requirements [C-1] ● Maximum water-to-cementing materials ratio = 0.4 ● Air content category as per *table 4* = 4-7% for hardened concrete and 3-6% at the point of discharge from delivery equipment. ● Curing type as per *table 19*, additional curing (7 days >10 degrees celsius should be provided).
Requirement (c) **Air Content** [Clause 4.3.3]	As per table 4 For freshly delivered concrete: AC = 3-6% For hardened concrete: AC = 4-7%
Requirement (d) **Required density** [Clause 4.3.4]	4.3.4.1 Normal-density concrete The concrete used for this structure will be Normal Density concrete which will be measured in accordance with CSA A23.2-6C for fresh concrete.
Requirement (e) **Specified Strength** [Clause 4.3.5]	4.3.5 Strength The 28 day strength of the concrete must be greater than or equal to 25MPa.
Requirement (f) **Volume Stability** [Clause 4.3.6]	4.3.6 Volume stability considerations Creep and drying shrinkage can be minimized by: (a) Maximizing the nominal aggregate size = 30mm (b) Minimizing water content (c) Has a grading of fine and coarse aggregates that allow for the required workability while minimizing water content.
Requirement (g) **Prevent Concrete Expansion** [Clause 4.2.3.6]	4.2.3.6 Deleterious reactions of aggregates Considering the nature of the structure, only aggregate sources that are confirmed to be clear of alkali materials and other reactive materials that could crack the concrete and make this structure unfit for service.

Requirement (h) **Special Properties specified by owner**	The concrete mix design is subject to change should the owner decided on changing any of the properties that may affect requirements (a)-(g). These include density, stability, water-cement ratio, air content, and SCM's.

Table 3: Concrete Mix Proportions (CSA A23.1):

3.4 Concrete formwork

The simplicity of the concrete forms permits the contractor to select one of their common methods for constructing formwork for a retaining wall and footing system in accordance with CSA A23.1 Clause 6.5. The fabrication and erection of the formwork must be approved by the Engineer of Record and constructed in accordance with CSA-S269.3.

The formwork selected by the contractor shall be determined by the dimensions outlined in the drawings in Appendix D, D.1.

4.0 CONSTRUCTION METHOD

4.1 Construction Requirements

In accordance with the contractual terms of the project, our team will undertake the construction of the project as per the specified design. In doing so, certain requirements are to be met in the construction of the UBC Velodrome. Listed below are key considerations regarding general construction requirements. These requirements may pertain to not only the constructing party (our team), but the owners of the project (UBC):

- Work on site shall abide by our team's approved Health and Safety (H&S) work guidelines. These guidelines are to abide by WorkSafe BC's general guidelines and may include:
  - Company specific daily work sign-offs;
  - Machine pre-use inspection checklists;
  - Proper confined space operations;
  - Work requiring certifications with procedures or machinery will require verification of certifications (fall protection, due diligence, crane, etc);
  - A zero drug or alcohol policy on site.
- Material used for the construction of the UBC Velodrome must abide by Canadian / design guidelines. The conformity of these materials shall be checked on site and logged with a Material Reception Inspection (MRI) sheet;
- Work processes are to abide by either contractual terms or general industry practices. The work shall be undertaken with due diligence and any practice not in compliance with these standards shall be terminated and the practicing party will face liability with regards to the work;
- Subcontractors undertaking jobs shall conform to the same work and H&S policies as the sub-contracting party;
- Change orders must first be specified and approved upon method and cost before work can be undertaken;
- Certain work or processes shall be checked at interval or completion to ensure conformity (concrete tests, soil compaction tests, leak tests, etc).

4.2 Work Breakdown Structure

In the construction of the UBC Velodrome, milestones care attributed to the completion at each major tasks or part. These tasks are defined by its governance over smaller tasks and its independency to ensuing tasks. As such, these tasks are also use as a measure in the completeness of the project which in turn is used as a benchmark for contractual payments. The complete list of tasks can be seen in the work breakdown structure below.

Phase of Project	Task Number	Description	Additional Classification
1.0 Preconstruction	1-001	Environmental Assessment (EA) collection of information, submissions and actions.	
	1-002	Public Notifications and Consultation meetings.	
	1-003	Follow up with EA to receive permitting,	
	1-004	Geotechnical Consulting	
	1-005	Environmental Consulting (Work by Biologists applies here as well)	
	1-006	Original Ground (OG survey) tied up with survey control in place. Survey control to be used for construction survey and as-built.	
	1-007	Measurements, marking and staking for first phases of construction.	
2.0 Construction	2-001	Removal of trees as required for access and construction.	**Site Preparation & Earthworks**
	2-002	Access path construction from Westbrook Mall, entrance and exit to site.	
	2-003	Procurement of materials. (note: certain materials will require weeks or even months of advanced notice before they can be delivered).	
	2-004	Area for onsite office, muster point and outhouse facilities established. Storage areas for new aggregates, crush, soils established. Storage areas for waste materials established.	
	2-005	Excavation earthworks for upstream piping, the containment area, and downstream piping.	
	2-006	Engineering controls for slope stability during construction installed (e.g.) sheet piles. Engineered controls for drainage during construction installed (e.g.)	

2.0 Construction		pump and hose system.	
	2-007	Placement of material for subgrade placed and compacted. Specifications for placement and compaction will be provided for the pipe trenches and the Velodrome location.	
	2-008	Underground piping placement for influent and effluent pipe.	
	2-009	Backfill and compaction for pipe trenches.	
	2-010	Rebar Placement: Bottom of Velodrome	**Main Concrete Work for Velodrome Structure**
	2-011	Formwork: Bottom of Velodrome	
	2-012	Concrete Pouring: Bottom of Velodrome	
	2-013	Removal-Formwork: Bottom of Velodrome	
	2-014	Concrete Curing: Bottom of Velodrome	
	2-015	Rebar Placement: Straight Segments of Velodrome	
	2-016	Formwork: Straight Segments of Velodrome	
	2-017	Structures for shoring: Straight Segments of Velodrome	
	2-018	Concrete Pouring: Straight Segments of Velodrome	
	2-019	Removal-Formwork: Straight Segments of Velodrome	
	2-020	Concrete Curing: Straight Segments of Velodrome	
	2-021	Rebar Placement: East side arched Section of Velodrome	
	2-022	Formwork: East side arched Section of Velodrome	
	2-023	Structures for shoring: East side arched Section of Velodrome	
	2-024	Concrete Pouring: East side arched Section of Velodrome	
	2-025	Removal-Formwork: East side arched Section of Velodrome	
	2-026	Concrete Curing: East side arched Section of Velodrome	
	2-027	Rebar Placement: West side arched Section of Velodrome	
	2-028	Formwork: West side arched Section of Velodrome	
	2-029	Structures for shoring: West side arched Section of Velodrome	
	2-030	Concrete Pouring: West side arched Section of Velodrome	
	2-031	Removal-Formwork: West side arched Section of	

2.0 Construction		Velodrome	
	2-032	Concrete Curing: West side arched Section of Velodrome	
	2-033	Rebar Placement: Periphery of the Velodrome	
	2-034	Formwork: Periphery of the Velodrome	
	2-035	Concrete Pouring: Periphery of the Velodrome	
	2-036	Removal-Formwork: Periphery of the Velodrome	
	2-037	Concrete Curing: Periphery of the Velodrome	
	2-038	Fill in any minor imperfections as directed by the Engineers representative on site.	
	2-039	Seal coating Concrete	
	2-040	Attach influent pipe to inlet at the North East side of the Velodrome. Attach the effluent pipe to the outlet of the Velodrome at the base in the middle of the structure.	
	2-041	In combination with task 2-039, construct the designed water quality systems including: a large debris and small debris filter.	
	2-042	Install shut off valves and diversion valves at specified locations.	
	2-043	Complete the infilling of granular fill and soils around the periphery of the Velodrome, compact the fill and soils to the specified standard proctor density and up to the elevation specified in the plans.	
	2-044	Place permeable asphalt in the middle of the velodrome, surrounding the outlet.	
	2-045	Place top soils between the concrete track and the permeable asphalt. Grade the soils and seed the surface as specified in the plan drawings	
3.0 Site Finishing & Demobilization	3-001	Landscape the turf area inside the Velodrome and the area outside of the Velodrome according to the landscape architecture plans.	
	3-002	Install and construct the specified benches, decorative structures, curbs, bike racks, and the permanent entrance sign and post board.	
	3-003	Remove debris piles from site and ensure that any excess stockpile material is accounted for and stockpiled in a different location.	
	3-004	Deconstruct and remove the site office, outhouse facilities and any other temporary structures.	

Table 4: Work Breakdown Structure

4.3 Construction Schedule

In the scheduling of work for the UBC Velodrome, several factors are considered when developing the timeline of work. First, it is expected that the turnaround for reports, requests for information (RFIs), submittals and approvals to be a maximum of 14 days. This value is obtained from general Metro Vancouver construction standards and practices. Secondly, the scheduled timeline assumes that work will be done with a crew of 5 laborers overseen by 1 foreman, 1 superintendent, and 1 project coordinator. However, this is subjected to change for activities that requires heavy man-hours and that are on the critical path. An example of this would be the slab formwork, rebar, and pour of the side segments of the velodrome: given that the this slab pour shall include the piping system for the filtered water removal (which is needed due to the high amount of debris expected in a 100 year return period storm), a crew of 10 is anticipated in such instance. Furthermore, items such as landscaping and piping install may be subcontracted out to other companies. However, the timeline shall remain the same in the instances that it does. With regards to man-hours, the values are accurate and reflect RSMeans standards for construction work. Lastly, the schedule takes into account all statutory holidays as well as a two week Christmas break. As the project is set to begin on April 29th, 2019 and finished June 12th, 2020 with a total of 276 working days. The complete schedule can be seen below; a full size version can also be found in the appendices.

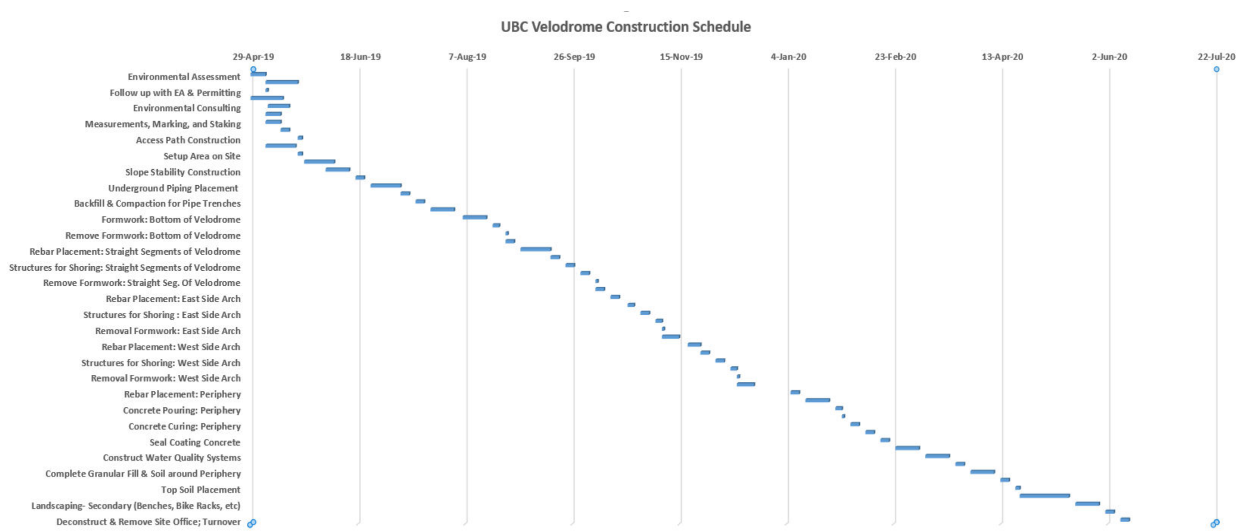


Figure 2: UBC Velodrome Construction Schedule Gantt Chart

4.4 Quality Assurance

The on-site work, both done by our crew members and through our subcontractors, are to be overseen by our team. As previously mentioned in 4.1 Construction Requirements, site work will follow certain guidelines and are subjected to inspection by not only our team's engineers, but UBC's as well. Summarized below are recurring inspections to ensure the adequacy of the project.

- Bi-weekly Environmental Assessments (EA) reports are to be conducted with respect to site cleanliness, quality of water runoffs, debris, and trailing;
- Compaction tests are to be completed and logged following soil placements to ensure design compactions (90% compaction on untraveled walkways, 95% on traveled walkways)
- Concrete tests are to be conducted for each batch of concrete poured to ensure that they meet the design strength;
- Rebar ties and formwork are to be inspected by a structural engineer to ensure its conformity;
- Leakage and drain rates shall be checked by a Building Science Consultancy to ensure standards are met;
- Water run offs are to be check and approved prior to the commissioning of the UBC Velodrome to ensure that standards are met.

4.5 Anticipated Issues

There are several anticipated on-site issues regarding the logistics of this project. These issues pertain to either an environmental, weather, by-law or geographical consideration. They are expanded upon more below with actions our team plan to take in addressing them.

4.5.1 Traffic Interruptions

Given that the construction site exists adjacent to two-lane Wesbrook Mall, it can be observed that there will be significant traffic interruptions during the period of construction. This is because Wesbrook Mall acts as the main connector between the Wesbrook Village community and South West (SW) Marine Drive, which in is one of the major roads that connects UBC to the rest of Vancouver, Richmond, and Surrey. Furthermore, the traffic interruptions will be especially disruptive during school seasons give that Wesbrook Mall is a connecting road for various bus routes entering UBC. Another thing to consider is that the traffic of construction vehicles entering the job site will be especially high during concrete pours. With a total volume of 830 cubic meters of concrete that will need to be poured and the average concrete truck carrying 10 cubic meters during the period of August 20th, 2019 and January 30th, 2020, it can be seen that there will be at least 83 visits (and thus, instances of disruption) between that period.

To address these issues, a traffic permit must first be applied for before construction can proceed. Then, adequate steps will need to be taken to warn stakeholders of the area of the impending disruptions. This can be done through stakeholder meetings, mail updates, and road signs warning of the impending construction. Steps will also be taken by our team to manage the traffic when total lane closures are required. Lastly, our team will look to consult Translink on whether there is a need for changes to the bus schedules and routes for any buses passing through the area.

4.5.2 Winter Productivity

Given the unpredictable circumstances of Vancouver climate over the past few years, there may lie a possibility for weather to be a detrimental factor in the construction of the UBC Velodrome. It is understood that unfavourable weather conditions impacts the productivity of workers from both a psychological and physiological standpoint (Ibbs & Sun, 2007). In addition to this, however, there may lie a possibility for weather to interfere with the concrete pours of the project. Given that concrete pours are to take place largely in the Winter months (August 20th, 2019 to January 30th, 2020), extreme weather conditions may make it such that extra precautions will need to be undertaken to ensure that the concrete pours will proceed without hiccup. These precautions may include adequate concrete cover after pours or introducing methods to heat the concrete such that the concrete will cure properly. However, this is already reflected in the scheduling of the project. The development of the concrete pours (rebar, formwork, etc) are assigned a 50% time contingency to allow for disruptions should as these. However, this is also be an indicator that the project can finish ahead of schedule given favourable conditions. In cases of extreme weather such as a snow storm, it can be observed that work may have to stop altogether.

4.5.3 Specialized Design

Given that there have been only 12 velodromes ever constructed in Canada, two of which reside in British Columbia, it can be understood that there may be a learning curve associated with its construction and design. In addition to that, the UBC Velodrome will be the first of its kind in Canada wherein it serves as a multi-use water detention facility for a 100- year return period storm. Thus, we have reached out to prior constructors and consultancies of Velodromes and water retention systems for advice and our team plans to retain a consultancy specializing in hydro-retention to oversee our force calculations.

5.0 COST ESTIMATE

Given the development stage of this project, this report includes an updated Class B Cost Estimate as per EGBC's Classification Definition:

"*Class B estimate (estimate (±15-25%): An estimate prepared after site investigations and studies have been completed and the major systems defined. It is based on a project brief and preliminary design. It is used for obtaining effective project approval and for budgetary control*." (EGBC, 2009).

Our Cost Estimate depicting work to be performed has the following categories: environmental and permitting, civil, mobilization, man hours, site finishing and demobilization, and annual operating and maintenance. Contingency is applied as per the EGBC Class B definition above, using the upper limit of 25% due to the size and potential for unknowns in the project. Further, project design and construction management fees are included as 15% of the total cost. The detailed Class B Estimate is as shown below.

Some key features in this estimate have been able to be updated due to the completion of the detailed design and calculations, enabling a higher level of accuracy and precision. Some of these include the following. Concrete and rebar quantities were increased as per RSMeans recommendations. Due to the over year-long duration of the project, the potential need for ongoing smaller environmental assessments in addition to one large one at the end of the project construction the was identified. Additionally, more testing of products were accounted for, including concrete strength testing for each truckload and concrete leak testing upon placement and curing. As the scheduling has been updated, the man hours have been as well in accordance, and a site surveyor and project coordinator were added to the crew. The cost of site cleanup was increased again to acknowledge the duration of the project, and that site clean up may need to occur routinely, rather than just once at the end of the project.

The largest change to this estimate was the finalization of service life operating and maintenance plan. The design life of the project has been established to be 100 years as per the 1 in 100 year storm event, which enabled durations to be applied to our existing annual operating and maintenance costs. Further needs that were identified and addressed were annual concrete seal coating, concrete resurfacing every 3 years to ensure rider safety, and an allocation for the clean up and landscaping of a 1 in 100 year storm event. A key feature of the service life operation and maintenance costs section is that economic analysis was performed to bring the costs over the duration of the 100 year project to present worth costs. The current interest rate was taken to be

1.75% which was found from the Bank of Canada database. The rest of the costs were considered to be within an immediate enough time period (i.e. take place over approximately the next 1 year) so as to be reasonably already in present worth.

Class B Cost Estimate

Item Description	Unit of Measure	Quantity	Unit Cost	Total Cost
Environmental & Permitting				
Permitting	lsum	1	$20,000.00	$20,000.00
Environmental Assessment Initial (EA)	lsum	1	$5,000.00	$5,000.00
Environmental Assessment Ongoing (EA)	hr	54	$150.00	$8,100.00
Water Quality Testing & Geotechnical Reports	lsum	2	$1,000.00	$2,000.00
Total	-	-	-	**$15,100.00**
Civil				
Site Surveying	ea	1	$500.00	$500.00
Site Access Paths	lsum	1	$750.00	$750.00
Tree Removal	ea	90	$304.67	$27,420.30
Excavation	m3	23504	$14.68	$345,041.66
Subbase Material (Coarse Granular Aggregate) & Placement	m3	540	$100.00	$54,000.00
Base Material (Fine Granular Aggregate) Supply & Placement	m2	270	$19.74	$5,329.49
Influent & Effluent Piping, Valves, and Tie-Ins Supply & Install	lsum	1	$20,000.00	$20,000.00
Catch Basin	ea	2	$5,000.00	$10,000.00
3/4" Clear Crush for Drain Rock	m3	576	$21.74	$12,521.84
Rebar Supply & Placement	tnne	97	$650.00	$63,349.00
Formwork Supply & Placement & Removal	lm	501	$7.87	$3,942.30
Supply & Install Concrete	m3	855	$1,637.00	$1,399,471.30
Water Quality System: Mulch Supply & Placement	m3	140	$40.03	$5,621.36
Water Quality System: Bioswale Supply & Placement	m3	2808	$94.46	$265,272.92
Topsoils Supply & Placement	m2	6767	$21.14	$143,054.38
Concrete Testing (per ea 10 cu.m. truck)	ea	83	$250.00	$20,750.00
Leak Testing	lsum	1	$400.00	$400.00
Total	-	-	-	**$2,377,424.54**
Mobilization				
Excavator 45T	hr	1560	$276.00	$430,560.00
Tandem Truck	hr	1560	$120.00	$187,200.00
Loader (3 - yd3)	hr	1560	$119.00	$185,640.00
Concrete Truck	m3	83	$150.00	$12,450.00
Compactor	hr	1560	$178.00	$277,680.00
Dozer	hr	1560	$157.00	$244,920.00
Total	-	-	-	**$1,338,450.00**
Manhours				
Superintendant	hr	2160	$150.00	$324,000.00
Foreman	hr	2160	$75.00	$162,000.00
Lead Hand	hr	2160	$62.00	$133,920.00
Labourer	hr	10800	$52.00	$561,600.00
Surveyor	hr	162	$90.00	$14,580.00
Project Coordinator	hr	2160	$50.00	$108,000.00
Total	-	-	-	**$1,196,100.00**

Site Finishing & Demobilizing				
Landscaping as per Architectural Plans	ea	150	$91.67	$13,750.50
Benches, Decorative Structures, Bike Racks	ea	20	$400.00	$8,000.00
Signage (Entrance + Post Board)	ea	2	$340.67	$681.34
Site Clean-up	lsum	1	$15,000.00	$15,000.00
Total	-	-	-	**$37,431.84**
Annual Operating & Maintenance				
Power Washing	yrs	100	$800.00	$37,649.18
Annual Seal Coating	yrs	100	$71,368.07	$3,358,686.29
Concrete Resurfacing (every 3 years)	yrs	34	$82,193.14	$1,276,329.96
Horiticulture Maintenance	yrs	100	$800.00	$37,649.18
100-Year Storm Relandscaping	lsum	1	$10,000.00	$10,000.00
Total	-			**$4,720,314.61**
Subtotal	**-**			**$9,684,821**
Project Design & Construction Management	**15%**			**$1,452,723**
Contingency	**25%**			**$2,421,205**
Grand Total	**-**			**$12,106,026**

Table 5: Class B Cost Estimate

6.0 CONCLUSION

This facility will be an excellent way of providing a stormwater detention site, which will alleviate the risks of 10 and 100 year rainfall events, while serving a dual purpose as a public Velodrome which is centred by a Rain Garden. The total capacity of the detention facility is over 3,400 cubic metres which allows the discharge of water to the ocean to be below the maximum of 1.2 cu.m/s. The project will begin April 29th, 2019 and will be concluded on June 12th, 2020, totalling 276 work days. Finally, the all-included cost of the project is estimated at $12,106,026 and is designed for a 100-year lifespan.

References

[1] Brzev, S. and Pao, J. (n.d.). *Reinforced Concrete Design: A Practical Approach*. 3rd ed. Toronto: Pearson Custom Publishing.

[2] *Design of concrete structures* : CAN/CSA-A23.3-14 : National Standard of Canada. Mississauga, Ont. : Canadian Standards Association, 2014.

[3] *Concrete materials and methods of concrete construction* : CAN/CSA-A23.1-14: National Standard of Canada, Mississauga, Ont. : Canadian Standards Association, 2014.

[4] *Test methods and standard practices for concrete* : CAN/CSA-A23.2-14: National Standard of Canada, Mississauga, Ont. : Canadian Standards Association, 2014.

[5] *Concrete Formwork* : CAN/CSA-S269.3-14: National Standard of Canada, Mississauga, Ont. : Canadian Standards Association, 2014.

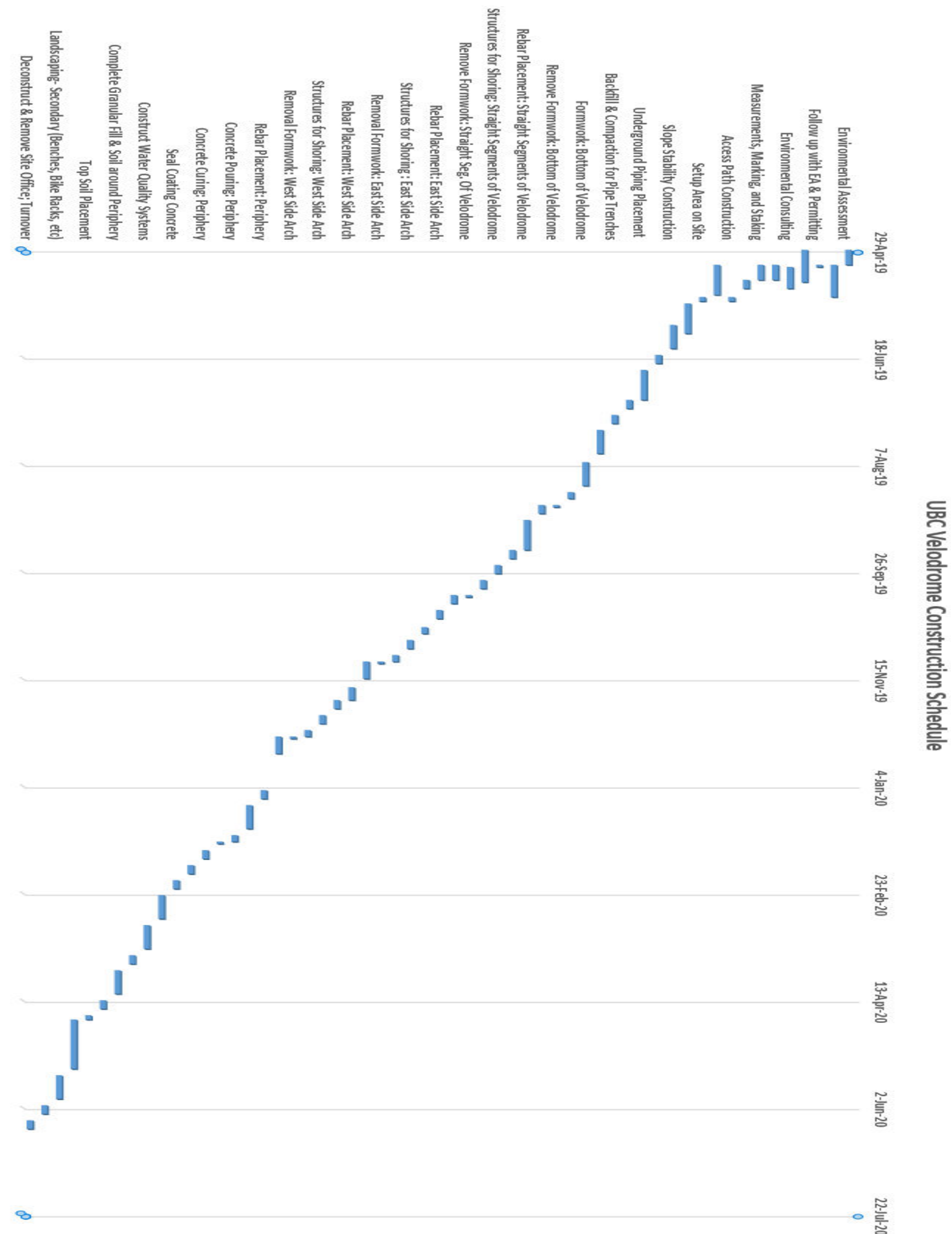
APPENDICES

APPENDIX A: CONSTRUCTION SCHEDULE

Construction Schedule:

Task Number:	Description	Start Date:	End Date:	Number of Days
1-001	Environmental Assessment	29-Apr-19	6-May-19	7
1-002	Public Notifications & Consultation Meetings	6-May-19	20-May-19	15
1-003	Follow up with EA & Permitting	6-May-19	7-May-19	1
1-004	Geotech Consulting	29-Apr-19	14-May-19	15
1-005	Environmental Consulting	7-May-19	17-May-19	10
1-006	Original Ground Surey	6-May-19	13-May-19	7
1-007	Measurements, Marking, and Staking	6-May-19	13-May-19	7
2-001	Removal of Trees	13-May-19	17-May-19	4
2-002	Access Path Construction	21-May-19	23-May-19	2
2-003	Procurement of Materials	6-May-19	20-May-19	14
2-004	Setup Area on Site	21-May-19	23-May-19	2
2-005	Excavation Earth Works (Piping, Containment, etc	24-May-19	7-Jun-19	14
2-006	Slope Stability Construction	3-Jun-19	14-Jun-19	11
2-007	Subgrade Material Placement	17-Jun-19	21-Jun-19	4
2-008	Underground Piping Placement	24-Jun-19	8-Jul-19	14
2-009	Bioswale Install	8-Jul-19	12-Jul-19	4
2-010	Backfill & Compaction for Pipe Trenches	15-Jul-19	19-Jul-19	4
2-011	Rebar Placement: Bottom of Velodrome	22-Jul-19	2-Aug-19	11
2-012	Formwork: Bottom of Velodrome	6-Aug-19	17-Aug-19	11
2-013	Concrete Pouring: Bottom of Velodrome	20-Aug-19	23-Aug-19	3
2-014	Remove Formwork: Bottom of Velodrome	26-Aug-19	27-Aug-19	1
2-015	Concrete Curing: Bottom of Velodrome	26-Aug-19	30-Aug-19	4
2-016	Rebar Placement: Straight Segments of Velodrom	2-Sep-19	16-Sep-19	14
2-017	Formwork: Straight Segments of Velodrome	16-Sep-19	20-Sep-19	4
2-018	Structures for Shoring: Straight Segments of Velo	23-Sep-19	27-Sep-19	4
2-019	Concrete Pouring: Straight Seg. Of Velodrome	30-Sep-19	4-Oct-19	4
2-020	Remove Formwork: Straight Seg. Of Velodrome	7-Oct-19	8-Oct-19	1
2-021	Concrete Curing: Straight Seg. Of Velodrome	7-Oct-19	11-Oct-19	4
2-022	Rebar Placement: East Side Arch	14-Oct-19	18-Oct-19	4
2-023	Formwork: East Side Arch	22-Oct-19	25-Oct-19	3
2-024	Structures for Shoring : East Side Arch	28-Oct-19	1-Nov-19	4
2-025	Concrete Pouring: East Side Arch	4-Nov-19	7-Nov-19	3
2-026	Removal Formwork: East Side Arch	7-Nov-19	8-Nov-19	1
2-027	Concrete Curing: East Side Arch	7-Nov-19	15-Nov-19	8
2-028	Rebar Placement: West Side Arch	19-Nov-19	25-Nov-19	6
2-029	Formwork: West Side Arch	25-Nov-19	29-Nov-19	4
2-030	Structures for Shoring: West Side Arch	2-Dec-19	6-Dec-19	4
2-031	Concrete Pouring: West Side Arch	9-Dec-19	12-Dec-19	3
2-032	Removal Formwork: West Side Arch	12-Dec-19	13-Dec-19	1
2-033	Concrete Curing: West Side Arch	12-Dec-19	20-Dec-19	8
2-034	Rebar Placement: Periphery	6-Jan-20	10-Jan-20	4
2-035	Formwork: Periphery	13-Jan-20	24-Jan-20	11
2-036	Concrete Pouring: Periphery	27-Jan-20	30-Jan-20	3
2-037	Removal Formwork: Periphery	30-Jan-20	31-Jan-20	1
2-038	Concrete Curing: Periphery	3-Feb-20	7-Feb-20	4
2-039	Remedy Imperfections	10-Feb-20	14-Feb-20	4
2-040	Seal Coating Concrete	17-Feb-20	21-Feb-20	4
2-041	Attach Influent & Effluent Pipes to Structure	24-Feb-20	6-Mar-20	11
2-042	Construct Water Quality Systems	9-Mar-20	20-Mar-20	11
2-043	Shut-off & Diversion Valves Install	23-Mar-20	27-Mar-20	4
2-044	Complete Granular Fill & Soil around Periphery	30-Mar-20	10-Apr-20	11
2-045	Asphalt Pour	13-Apr-20	17-Apr-20	4
2-046	Top Soil Placement	20-Apr-20	22-Apr-20	2
3-001	Landscaping- Primary (Tuf, etc)	22-Apr-20	15-May-20	23
3-002	Landscaping- Secondary (Benches, Bike Racks, e	18-May-20	29-May-20	11
3-003	Debris Removation	1-Jun-20	5-Jun-20	4
3-004	Deconstruct & Remove Site Office; Turnover	8-Jun-20	12-Jun-20	4

UBC Velodrome Construction Schedule Gantt Chart:



APPENDIX B: STANDARDS AND CODES

4.1.6.2. Specified Snow Load

(See Note A-4.1.6.2.)

1) The specified load, S, due to snow and associated rain accumulation on a roof or any other *building* surface subject to snow accumulation shall be calculated using the formula

$$S = I_s [S_s (C_b C_w C_s C_a) + S_r]$$

where

I_s = importance factor for snow load as provided in Table 4.1.6.2.-A,

S_s = 1-in-50-year ground snow load, in kPa, determined in accordance with Subsection 1.1.3.,

National Building Code of Canada 2015 Volume 1 *Division B 4-13*

C_b = basic roof snow load factor in Sentence (2),

C_w = wind exposure factor in Sentences (3) and (4),

C_s = slope factor in Sentences (5), (6) and (7),

C_a = accumulation factor in Sentence (8), and

S_r = 1-in-50-year associated rain load, in kPa, determined in accordance with Subsection 1.1.3., but not greater than $S_s(C_b C_w C_s C_a)$.

Table 4.1.6.2.-A
Importance Factor for Snow Load, I_s
Forming Part of Sentence 4.1.6.2.(1)

Importance Category	Importance Factor, I_s	
	ULS	SLS
Low	0.8	0.9
Normal	1	0.9
High	1.15	0.9
Post-disaster	1.25	0.9

Exposure c

Cast against earth, includ

Beams, girde

Slabs, walls, plates

Ratio of cove

Ratio of cove aggregate siz

** This refers on the vapour bar*

† The cover for

‡ The specified

Table C-2 (Continued)

Province and Location	Elev., m	Design Temperature: January 2.5% °C	January 1% °C	July 2.5% Dry °C	July 2.5% Wet °C	Degree-Days Below 18°C	15 Min. Rain, mm	One Day Rain, 1/50, mm	Ann. Rain, mm	Moist. Index	Ann. Tot. Ppn., mm	Driving Rain Wind Pressures, Pa, 1/5	Snow Load, kPa, 1/50 S_s	Snow Load, kPa, 1/50 S_r	Hourly Wind Pressures, kPa 1/10	Hourly Wind Pressures, kPa 1/50
Smithers	500	-29	-31	26	17	5040	13	60	325	0.60	500	120	3.5	0.2	0.31	0.40
Sooke	20	-1	-3	21	16	2900	9	130	1250	1.37	1280	220	1.3	0.3	0.37	0.48
Squamish	5	-9	-11	29	20	2950	10	140	2050	2.12	2200	160	2.8	0.7	0.39	0.50
Stewart	10	-17	-20	25	16	4350	13	135	1300	1.47	1900	180	7.9	0.8	0.28	0.36
Tahsis	25	-4	-6	26	18	3150	13	200	3845	3.91	3900	300	1.1	0.4	0.26	0.34
Taylor	515	-35	-37	26	18	5720	15	72	320	0.49	450	100	2.3	0.1	0.31	0.40
Terrace	60	-19	-21	27	17	4150	13	120	950	1.08	1150	200	5.4	0.6	0.28	0.36
Tofino	10	-2	-4	20	16	3150	13	193	3275	3.36	3300	300	1.1	0.4	0.53	0.68
Trail	440	-14	-17	33	20	3600	10	54	580	0.65	700	60	4.1	0.1	0.27	0.35
Ucluelet	5	-2	-4	18	16	3120	13	180	3175	3.26	3200	280	1.0	0.4	0.53	0.68
Vancouver Region																
Burnaby (Simon Fraser Univ.)	330	-7	-9	25	17	3100	10	150	1850	1.93	1950	160	2.9	0.7	0.36	0.47
Cloverdale	10	-8	-10	29	20	2700	10	112	1350	1.44	1400	160	2.5	0.2	0.34	0.44
Haney	10	-9	-11	30	20	2840	10	134	1800	1.86	1950	160	2.4	0.2	0.34	0.44
Ladner	3	-6	-8	27	19	2600	10	80	1000	1.14	1050	160	1.3	0.2	0.36	0.46
Langley	15	-8	-10	29	20	2700	10	112	1450	1.53	1500	160	2.4	0.2	0.34	0.44
New Westminster	10	-8	-10	29	19	2800	10	134	1500	1.59	1575	160	2.3	0.2	0.34	0.44
North Vancouver	135	-7	-9	26	19	2910	12	150	2000	2.07	2100	160	3.0	0.3	0.35	0.45
Richmond	5	-7	-9	27	19	2800	10	86	1070	1.20	1100	160	1.5	0.2	0.35	0.45
Surrey (88 Ave & 156 St.)	90	-8	-10	29	20	2750	10	128	1500	1.58	1575	160	2.4	0.3	0.34	0.44
Vancouver (City Hall)	40	-7	-9	28	20	2825	10	112	1325	1.44	1400	160	1.8	0.2	0.35	0.45
Vancouver (Granville & 41 Ave)	120	-6	-8	28	20	2925	10	107	1325	1.44	1400	160	1.9	0.3	0.35	0.45
West Vancouver	45	-7	-9	28	19	2950	12	150	1600	1.69	1700	160	2.4	0.2	0.37	0.48
Vernon	405	-20	-23	33	20	3600	13	43	350	0.41	400	80	2.2	0.1	0.31	0.40
Victoria Region																
Victoria (Gonzales Hts)	65	-4	-6	24	17	2700	9	91	600	0.82	625	220	1.5	0.3	0.44	0.57
Victoria (Mt Tolmie)	125	-6	-8	24	16	2700	9	91	775	0.96	800	220	2.1	0.3	0.48	0.63
Victoria	10	-4	-6	24	17	2650	8	91	800	0.98	825	220	1.1	0.2	0.44	0.57
Whistler	665	-17	-20	30	20	4180	10	85	845	0.99	1215	160	9.5	0.9	0.25	0.32

APPENDIX C: CALCULATIONS

UBC Velodrome Rain Garden Design Calculations

(Calcs based on Kerr Wood Leidal Ltd. Rain Garden Design Considerations)

Input Volume

Paved Area (sm)	2305	
2 yr, 24 hr (mm/hr)	2.8	(metrovancouver.org, Estimated 2050)
Period (hrs)	24	

2-yr Rainfall Event
Rainfall Intensity x Period — 67 mm

6-month Rainfall Event (90% of storms in area)
2-yr Rainfall event x 72% — 48 mm

Input Volume:
Paved Area x 6-month Rainfall Event — **112 cm**

Capture Volume:

Rain Garden Area (sm)	401	
Evaporation Rate (mm/day)	1	(Avg for Metro Van. In winter)
Topsoil Depth (m)	0.6	(Bioretention Soils)
Field Capcity	0.25	
Wilting Point - Sandy Soils	0.05	
Typical Trench Depth (m)	0.8	
Voids Ratio - Sandy Soils	0.35	(Range 0.3-0.5)
Infiltration Rate (mm/hr)	1.5	(Glacial Till)

Evaporation Vol. = Rain Garden Area x Evaporation Rate — 0.4 cm

Growing Medium Vol. =
Rain Garden Area x Porosity x (Field Capacity - Wilting Point)
48.1 cm

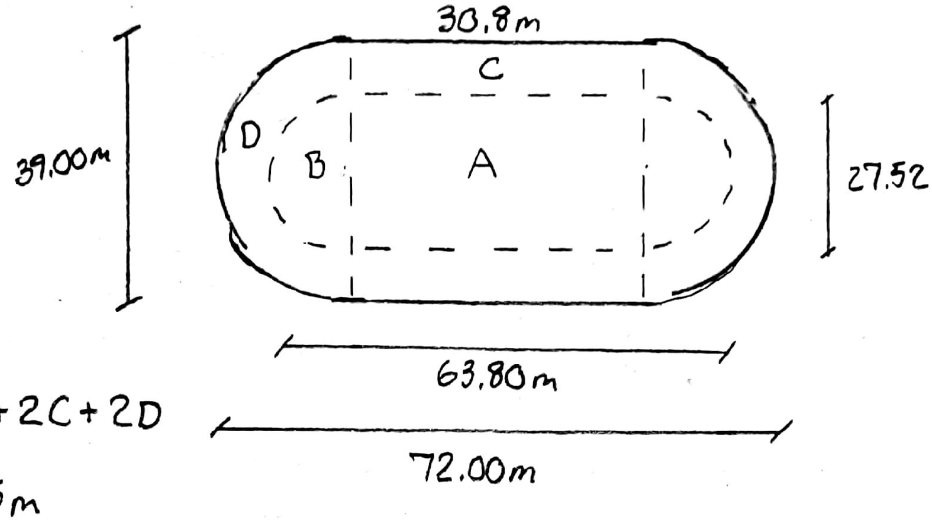
Rock Trench Vol. = RG Area x Trench Depth x Voids Raio — 112.3 cm

Infiltration Rate = Rain Garden Area x Infiltration Rate — 14.4 cm

TOTAL CAPTURE VOLUME	**175.2 CM**

100 % Capture Rate

VOLUME CALCS - UBC VELODROME



TOTAL VOLUME = A + 2B + 2C + 2D

CONSTRAINT : $H_{MAX} = 1.75m$

A

$W * H * l = 30.8m(1.75m)(27.52m)$ $A = 1483.33m^3$

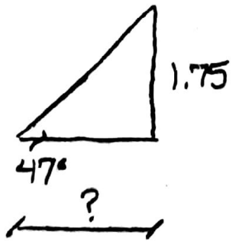
B

$\pi r^2 H = \pi(16.5)^2 1.75m$ $B = 1{,}496.77m^3$

C

$l * W * H = 30.8m * 5.74 * 1.75$ $C = 309.39\ m^3$

D



$\tan 47 = \frac{1.75}{x}$ $x = 1.63m$

$r_1 = 16.5$ $r_2 = 18.13$

$\pi(r_2^2 - r_1^2) * H = \pi(18.13^2 - 16.5^2) * 1.75$ $D = 310.33m^3$

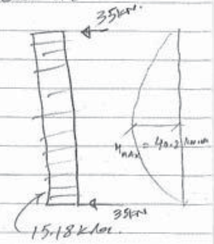
+

$3599.8\ m^3$

→ ~ $3600\ m^3$

WALL 3

THUS, THE AVERAGE SOIL PRESSURE ON THE WALL.



$= \frac{1}{2}(P_0) = \frac{1}{2}(Ka \cdot \gamma_{FILL} \cdot H_w)$

$= \frac{1}{2}(0.22)(20\frac{kN}{m^3})(4.6)$

$\boxed{P_{0_{AVG}} = 10.12 \text{ kPa}}$

THIS SOIL PRESSURE NEEDS TO BE FACTORED PER NBC 2015.

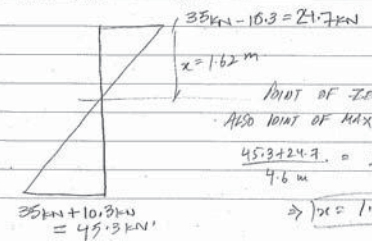
$\Rightarrow P_{0_f} = 1.5 P_{0_{AVG}} = 1.5(10.12 \text{ kPa}) = 15.2 \text{ kPa}.$

$M_f = \frac{P_f \times H^2}{8} = \frac{(15.2 \text{ kPa})(4.6)^2}{8} = 40.2 \text{ kN.m}.$

$\boxed{M_f = 40.2 \text{ kN.m}}$

COMBINED GRAVITY AND LATERAL LOADS.

SHEAR FORCE DIAGRAM IS OBTAINED BY SUPERPOSITION, BY COMBINING CORRESPONDING SHEAR FORCE VALUES FOR GRAVITY AND SOIL PRESSURE LOADS.



$\frac{45.3+24.7}{4.6 \text{ m}} = \frac{24.7}{x}$

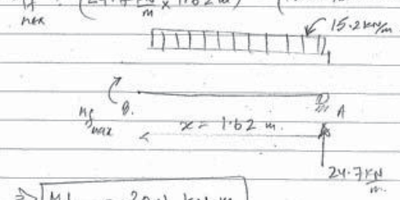
$\Rightarrow \boxed{x = 1.62 \text{ m}}$

WALL 4

MAX BENDING MOMENT DEVELOPS AT POINT OF ZERO SHEAR (DISTANCE OF 1.62 m FROM TOP). THE CORRESPONDING $M_{f_{max}}$ CAN BE OBTAINED AS.

$\Sigma M @ B = 0$ +VE.

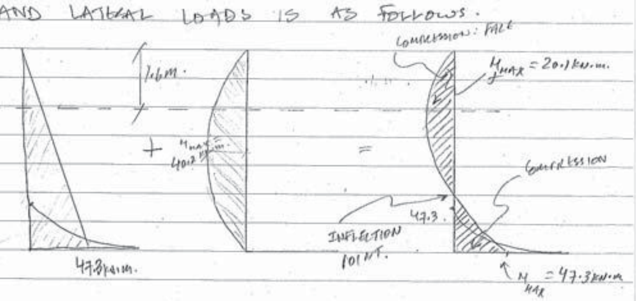
$-M_{f_{max}} + (24.7\frac{kN}{m} \times 1.62 m) - (15.2 kN/m \times 1.62 \times \frac{1.62}{2}) = 0.$



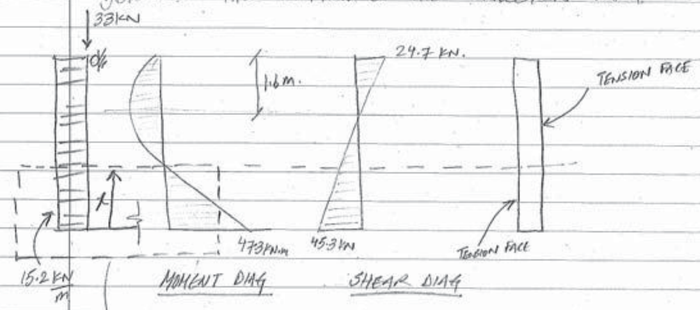
$\Rightarrow \boxed{M_{f_{MAX}} = 20.1 \text{ kN.m/m.}}$

1.62 m FROM TOP

THUS MOMENT DIAGRAM DUE TO COMBINED GRAVITY AND LATERAL LOADS IS AS FOLLOWS.



DETERMINE THE LOCATION OF THE INFLECTION POINT.



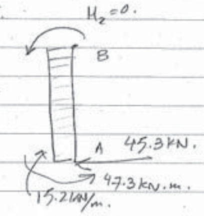
→ ISOLATING THE PART OF THE WALL UP TO THE INFLECTION POINT. $M_z = 0$.

$\Sigma M @ B = 0$ ↻ +ve

$47.3\,kN.m - 45.3\,kN\,(x) + 15.2 \cdot x \cdot \frac{x}{2} = 0.$

$47.3 - 45.3x + 7.6x^2 = 0.$

$\boxed{x = 1.35}$ FROM BOTTOM.



DESIGN THE FLEXURAL REINFORCEMENT FOR THE FOOTING AND EXTERIOR WALL FACE.

FOR THE FOOTING AND WALL, USE 20 M BARS.

EFFECTIVE DEPTH — FOOTING.

COVER = 75 mm ,, PER A23.3 — OUTDOORS, EXPOSED TO EARTH

$t = 300$ mm.

$d = t - \text{COVER} - \frac{d_b}{2}$

$= 300 - 75 - \frac{20}{2}$

$\boxed{d = 215 \text{ mm}}$ FOOTING

EFFECTIVE DEPTH — WALL

COVER = 75 mm — OUTDOORS, EXPOSED TO EARTH

MIN WALL THICKNESS. MAX OF — $\begin{cases} \frac{1}{25} \times h = \frac{1}{25} \times 4600 = 184 \\ 150 \text{ mm} \end{cases}$

MINIMUM WALL $t \Rightarrow 184 \sim 200$ mm.

HOWEVER GOOD PRACTICE DICTATES THAT FOR WALLS EXCEEDING 4m IN HEIGHT, WALL THICKNESS BE 300 m.

$\therefore \boxed{t = 300 \text{ mm.}}$

$d = t - \text{COVER} - \frac{d_b}{2}$

$= 300 - 75\text{mm} - \frac{20}{2}$

$\boxed{d = 215 \text{ mm}}$

WALL 7

THE REQUIRED MOMENT RESISTANCE

$$M_r = M_f = 47.3 \ \frac{kN\text{-}m}{m}.$$

FIND THE REQUIRED AREA OF VERTICAL TENSION REINF

DESIGN THE WALL FOR FLEXURE BASED ON A STRIP OF UNIT WIDTH $b = 1000$ mm.

USING DIRECT METHOD

$$A_s = 0.0015 f_c' b \left(d - \sqrt{d^2 - \frac{3.85 M_r}{f_c' \cdot b}} \right)$$

$$= 0.0015 (25 \tfrac{N}{mm^2}) (1000 \text{ mm}) \left(215 - \sqrt{215^2 - \frac{3.85 (47.3 \times 10^6)}{25 \tfrac{N}{mm^2} \cdot 1000 \text{ mm}}} \right)$$

$A_s = 675.7 \ mm^2$.

USING 20M BARS — $A_b = 300 \ mm^2$.

SPACING $s \le \frac{A_b \cdot 1000}{A_s}$.

$$s \le \frac{300 \text{ mm}^2 \ 1000 \text{ mm}}{675.7}$$

$s \le 443.97$

USE $\boxed{s \approx 400 \text{ mm}.}$

WALL 8

MAX PERMITTED BAR SPACING PER Cl 14.1.8.4

$$S_{max} \le \begin{cases} 3t = 3 \times 300 = 900 \text{ mm}. \\ \underline{500 \text{ mm}}. \end{cases}$$

SINCE $S = 400$ mm $< S_{max} = 500$ mm $\therefore$ ok!

THEREFORE VERTICAL REINFORCEMENT 20M @ 400
FOOTING REINFORCEMENT 20M @ 400

CONFIRM THAT THE CSA A23.3 MAX TENSION REINF REQUIREMENT Cl. 10.5.2 HAS BEEN SATISFIED.

ACTUAL REINF. AREA.

$$A_s = A_b \cdot \frac{1000}{s} = (300 \text{ mm}^2) \frac{1000 \text{ mm}}{400}$$

$A_{s\,(PROVIDED)} = 750 \ mm^2 > A_{s\,REQUIRED} = 676 \ mm^2$

CHECK THAT FAILURE IS STEEL CONTROLLED.

$$\rho = \frac{A_s}{bd} = \frac{750}{(1000 \text{ mm})(215 \text{ mm})}$$

$\rho = 0.0035 < \rho_b = 0.022 \ \therefore$ OK!

(FOR $f_c' = 25$ MPa)

CHECK THE CSA MINIMUM REINF REQUIREMENT PER Cl 14.1.8.5

$A_g = 1000\ mm \times t$
$= 1000\ mm \times 300\ mm$
$A_g = 300{,}000\ mm^2$

$A_{v_{min}} = 0.0015 A_g$
$= 0.0015 (300 \times 10^3\ mm^2)$
$A_{v_{min}} = 450\ mm^2$

SINCE $A_{s_{provided}} = 750\ mm^2 \geq A_{v_{min}} = 450\ mm^2$ ∴ OK!

DETERMINE THE LENGTH OF THE 20M BARS ABOVE FOOTING. (THE DEVELOPMENT LENGTH)

$l_d = 0.45 K_1 K_2 K_3 K_4 \frac{d_b}{\sqrt{f'_c}} f_y$

$K_1 - 1.0$ (BOTTOM BARS)
$K_2 - 1.0$ (UNCOATED BARS)
$K_3 - 1.0$ (NORMAL DENSITY CONCRETE)
$K_4 - 0.8$ (20M BARS)

$l_d = 0.45 (1)(1)(1)(0.8) \frac{20\ mm}{\sqrt{25}} 400\ N/mm^2$

$l_d = 576\ mm$

Cl 12.11.3 APPLIES, WHICH STATES FOR INFLECTION POINTS.

$l_d \leq \frac{M_r}{V_f} + l_a$

$\Rightarrow l_d \leq \frac{47.3\ kN \cdot m}{45.3\ kN} + l_a$

$l_a \rightarrow$ GREATER OF $\begin{cases} d = 215\ mm \\ 12 d_b = 12(20) = 240\ mm \end{cases}$

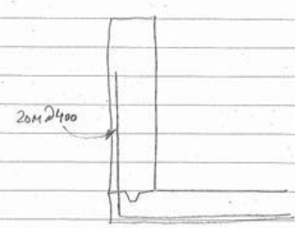
$\Rightarrow l_a = 240\ mm$

∴ $l_d = 576\ mm \leq \frac{47.3\ kN \cdot m}{45.3\ kN} + 0.240\ m$

$l_d = 576\ mm \leq 1.284$ ∴ OK!

THEREFORE, THE TOTAL WALL REINFORCEMENT LENGTH ABOVE THE WALL FOOTING INTERFACE CAN BE OBTAINED AS

$l = 1.35\ m + 0.576\ m$ ← l_d
$l = 1.93\ m$



WALL 11

DESIGN THE VERTICAL AND HORIZONTAL REINFORCEMENT AT THE INTERIOR WALL FACE

- DESIGN THE WALL FOR FLEXURE.

COVER = 60 mm ⟶ OUTDOORS, EXPOSED TO CHLORIDES

$t = 300$ mm

$d = t - COVER - \frac{d_b}{2}$

$= 300 - 60 - \frac{20}{2}$

$d = 230$ mm

- FIND THE REQUIRED MOMENT RESISTANCE.

SET $M_r = M_f = 20.1$ kN·m.

- FIND THE REQUIRED AREA OF VERTICAL TENSION REINFORCEMENT.
- DESIGN THE WALL FOR FLEXURE BASED ON A STRIP OF UNIT WIDTH $b = 1000$ mm.
- USING DIRECT METHOD.

$$A_s = 0.0015\, f'_c \cdot b \left(d - \sqrt{d^2 - \frac{3.85 M_r}{f'_c\, b}} \right)$$

$$= 0.00153 \left(25 \tfrac{N}{mm^2}\right)(1000\,mm)\left(230\,mm - \sqrt{230^2 - \frac{3.85(20.1\times10^6)}{25\times1000}}\right)$$

$A_s = 261.3$ mm².

SINCE AREA IS SMALL USE 15 M BARS. ($A_b = 200$ mm²)

$S \leq A_b \times \frac{1000}{A_s} = 200 \times \frac{1000}{261.3} = 765$

$S \sim 750$ mm

WALL 12.

FIND MAXIMUM PERMITTED BAR SPACING PER Cl. 14.1.8.4

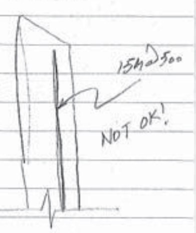
$S_{MAX} \not> \begin{cases} 3t = 3\times300 = 900\text{ mm.} \\ \underline{500\text{ mm.}} \end{cases}$

SINCE $S_{max} = 500 \leq S = 750$

∴ USE $S = 500$ mm

∴ VERTICAL REINFORCEMENT IS 15M@500

CONFIRM THAT THE MAXIMUM REINF REQUIREMENT Cl 10.5.2 IS SATISFIED.



$A_s = A_b \frac{1000}{S} = (200\,mm^2)\frac{1000}{500}$

$A_s = 400$ mm²

$\rho = \frac{A_s}{bd} = \frac{400}{(1000)(230\,mm)} = 0.00174$

$\rho_b = 0.022$ SINCE $\rho = 0.00174 < \rho_b = 0.022$ ∴ OK!

CHECK THAT THE MINIMUM REINF REQUIREMENT IS SATISFIED. Cl 14.1.8.5

$A_g = 1000\,mm \times t = 1000\,mm \times 300\,mm$

$= 300\times10^3$ mm².

$A_{v_{min}} = 0.0015\, A_g = 0.0015\,(300\times10^3)$

$A_{v_{min}} = 450$ m $< A_s = 400$ mm² ∴ NOT OK!

WALL 13.

INCREASE THE AREA OF STEEL THUS.

$$S_{min} = \frac{A_b \, 1000}{A_{s_{MIN}}} = \frac{200\,mm^2 \cdot 1000}{450} = 444\,mm$$

$S \sim 400$ mm.

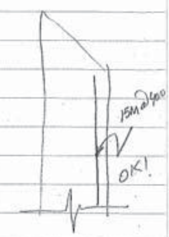
$$A_s = \frac{A_b \, 1000}{S} = \frac{200\,mm^2 \; 1000\,mm}{400\,mm}$$

$A_s = 500\,mm^2$!

CHECK MAX REINF REQUIREMENTS.

$$\rho = \frac{A_s}{bd} = \frac{500}{(1000)(230)} = 0.0022$$

SINCE $\rho = 0.0022 < \rho_b = 0.022$ ∴ OK!



DESIGN THE WALL FOR SHEAR.

DESIGN SHEAR FORCE

$V_f = 45.3$ kN

DETERMINE V_c THE CONCRETE SHEAR RESISTANCE.

$$d_v = \text{LARGER OF} \begin{cases} 0.9d = 0.9(230) = 207\,mm \\ 0.72t = 0.72(300) = \boxed{216\,mm} \end{cases}$$

∴ $d_v = 216$ mm.

WALL 14

$$\beta = \frac{230}{1000 + d_v} = \frac{230}{1000 + 216} = 0.189 \sim 0.19$$

$$\therefore V_c = \phi_c \lambda \beta \sqrt{f'_c} \, b_w d_v.$$

$$= (0.65)(1.0)(0.19)\sqrt{25\,N/mm^2}\,(1000)(216)$$

$V_c = 132.8$ kN.

∴ $V_f = 45.3\,kN < V_c = 132.8\,kN$ ∴ OK!

AND SHEAR REINF IS NOT NECESSARY

HOWEVER A23.3 CODE REQUIREMENTS REQUIRE MINIMUM PROVISIONS FOR HORIZONTAL REINFORCEMENT IN WALLS.

· DETERMINE THE MINIMUM DISTRIBUTED HORIZ REINF.

i) REINFORCEMENT AREA

$$A_g = 1000\,mm \times t = 1000\,mm \times 300 = 300 \times 10^3\,mm^2.$$

$$A_{h_{min}} = 0.002\,A_g = 0.002\,(300 \times 10^3\,mm^2)$$

$A_{h_{min}} = 600\,mm^2$.

ii) DETERMINE THE REQUIRED BAR SPACING.

USING 15M BARS.

$$S \leq A_b \frac{1000}{A_s} = 200 \cdot \frac{1000}{600} = 333 \Rightarrow \boxed{S = 300\,mm}$$

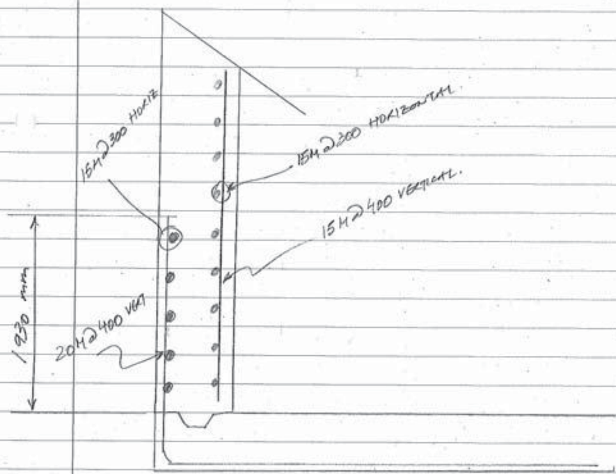
WALL 15

CHECK WHETHER THE SPACING IS WITHIN LIMITS PRESCRIBED BY A23.3 Cl 14.1.8.4

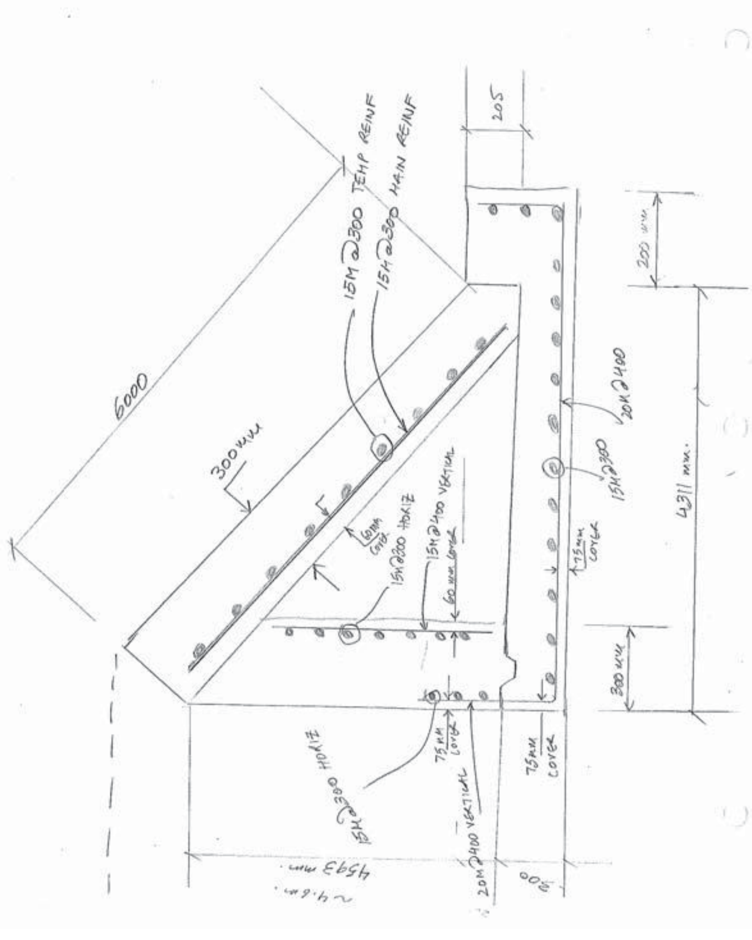
$$S_{max} \text{ is } \begin{cases} 3t = 3 \times 300 = 900\text{ mm.} \\ 500\text{ mm} \end{cases}$$

SINCE $S = 300$ mm $< S_{max} = 500$ mm ∴ OK!

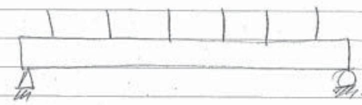
∴ USE [15M@300] HORIZONTAL REINFORCEMENT.



SLAB/RETAINING WALL/FOOTING DEISGN TA 03/05



DESIGN OF SLAB



80 kg × 6 = 480 kg. f = m.a.

= 480 × 9.81

= 4709 ~ 4710 N.

~ 4.7 kN × 1m / 6 m²

LL = 0.8 kN/m.

SNOW LOAD $S = I_s [S_s (C_b C_w C_s C_a) + S_r]$.

$I_s = 0.8$.

$S_s = 1.9$ kPa.

$S_r = 0.3$ kPa

S = 0.8 × 1.9 + 0.3.

S = 1.82 kPa.

= 1.82 kN/m² × 1m.

S = 1.82 kN/m

DEAD LOAD — ASSUME 150 mm THICK SLAB → NOT OK

CHECK THICKNESS TAB 9.3 ln/20 ; ln/20 = 6000/20 = 300 mm

γ_{conc} : 24 kN/m³.

FOR A 1m WIDTH OF SLAB.

6m × 1m × 0.30m × 24 kN/m³ = 7.2 kN/m.

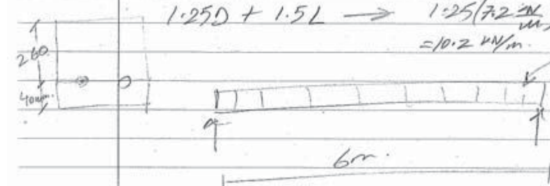
DL = 7.2 kN/m

LOAD COMBINATIONS.

1.4D → 1.4 (7.2 kN/m) = 10.08 kN/m.

1.25D + 1.0S → 1.25 (7.2 kN/m) + 1.0 (1.82 kN/m) = 10.82 kN/m ~ 11 kN/m

1.25D + 1.5L → 1.25 (7.2 kN/m) + 1.5 (0.8 kN/m) = 10.2 kN/m.



$M_{max} = \frac{wL^2}{8}$ = 28 ... kN·m.

$= \frac{(11)(6)^2}{8} = 49.5$ ~ 50 kN·m

• DETERMINE A_s.

d = 110 mm.

$A_s = 0.0015\, b_w f'_c \left(d - \sqrt{d^2 - \frac{3.85\, M_f}{b_w f'_c}}\right)$.

(1000 mm, 25 MPa, 260 ..., 50 kN·m, 25 MPa, 1000 mm)

$A_s = 0.0015 (1000\text{ mm})(25\text{ N/mm}^2)\left(260\text{ m} - \sqrt{(260\text{ m})^2 - \frac{3.85 (50E6)}{1000\text{ mm} \times 25\text{ N/mm}^2}}\right)$

A_s = 583.5 mm²

~584 mm² USING 15M BARS. A_b = 200 mm².

S: SPACING OF REBARS ⇒ $s = \frac{b A_b}{A_s} = \frac{(1000\text{ mm})(200\text{ mm}^2)}{584\text{ mm}^2}$ = 342.5 ~300 mm.

∴ REINF 15@300 mm.

$A_s = A_b \frac{1000}{s}$

$= 200\ mm^2 \cdot \frac{1000}{300\ mm}$

$= 667\ mm^2 > 584\ mm^2$

PROVIDED AREA OF STEEL IS LARGER THAN REQUIRED.

• CONFIRM THAT MAXIMUM TENSION REINF IS SATISFIED (A23.3 Cl 10.5.2)

$\rho = \frac{A_s}{bd} = \frac{667\ mm^2}{(1000)(260\ mm)} = 2.565 \times 10^{-3} = 0.002565$

$\rho = 0.002567 < \rho_b = 0.022$ ∴ OK!

∴ SLAB WOULD FAIL IN STEEL CONTROL MODE.

• CONFIRM THAT THE MINIMUM REINF REQUIREMENTS ARE SATISFIED PER Cl A23.3 Cl 7.8.1

- CALCULATE THE GROSS CROSS SECTIONAL AREA FOR THE UNIT STRIP

$A_g = b \times h$
$= 1000 \times 300$
$A_g = 300\,000\ mm^2$

- DETERMINE MINIMUM REINFORCEMENT AREA

$A_{s_{min}} = 0.002\ A_g$
$= 0.002\ (300{,}000\ mm^2)$
$A_{s_{min}} = 600\ mm^2$.

$A_{s_{PROVIDED}} = 667\ mm^2 > A_{s_{min}} = 600\ mm^2$ ∴ OK!

SLAB 4

• CONFIRM THAT THE MAX BAR SPACING REQUIREMENT IS SATISFIED.

S_{max} = LESSER OF $\begin{cases} 3h = 3(300) = 900\ mm \\ 500\ mm \end{cases}$

$S = 300\ mm < S_{max} = 500\ mm$ ∴ OK!

• CALCULATE M_r

- CALCULATE THE DEPTH OF COMPRESSION STRESS BLOCK

$a = \frac{\phi_s f_y A_s}{\alpha_1 \phi_c f'_c b}$

$= \frac{(0.85)(400\ N/mm^2)(667\ mm^2)}{(0.8)(0.65)(25\ N/mm^2)(1000)}$

$a = 17.4\ mm$

- MOMENT RESISTANCE IS THUS CALCULATED AS

$M_r = T_r \left(d - \frac{a}{2}\right)$

$= \phi A_s f_y \left(d - \frac{a}{2}\right)$

$= (0.85)(667\ mm^2)(400\ N/mm^2)\left(260 - \frac{17.4}{2}\right)$

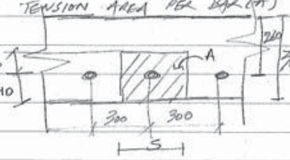
$= 56.989\ kN.m \approx 57\ kN.m$

SINCE $M_r = 57\ kN.m > M_f = 50\ kN.m$ ∴ OK!!

• CHECK THE CRACK CONTROL PARAMETERS.

a) COMPUTE THE EFFECTIVE TENSION AREA PER BAR (A)

- CALCULATE THE DISTANCE d_s FROM THE CENTROID OF THE TENSION REINF TO THE TENSION FACE OF THE CONCRETE SECTION.



$$d_s = d_c = h - d$$
$$= 300 - 260$$
$$= 40 \text{ mm}$$

b) THEREFORE, NET EFFECTIVE AREA A

$$A = S(2d_s)$$
$$= (250\text{ mm})(2 \times 40)$$
$$A = 20{,}000 \text{ mm}^2$$

• DETERMINE THE STRESS IN THE STEEL REINFORCEMENT (f_s) UNDER THE SERVICE LOAD LEVEL.

$f_s = 0.6 f_y$ --- PER Cl.10.6.1
$= 0.6 \times 400$ MPa
$f_s = 240$ MPa

• DETERMINE THE VALUE OF Z

$$Z = f_s \sqrt[3]{d_c \cdot A}$$
$$= 240 \text{ N/mm}^2 \cdot \sqrt[3]{(40\text{ mm})(20{,}000\text{ mm}^2)}$$
$$Z = 22\,279.6 \text{ N/mm}$$

SINCE $Z = 22{,}279.6 < Z = 25000$ FOR EXTERIOR EXPOSURE
THE CSA A23.3 CRACKING CONTROL REQUIREMENTS ARE SATISFIED.

• DETERMINE SHRINKAGE AND TEMPERATURE REINF PER Cl 7.8.1 AND Cl.7.8.3.

• $A_{s\,min} = 600 \text{ mm}^2$ --- FROM BEFORE.

• THE MAXIMUM BAR SPACING (S_{max}) IS LESSER OF

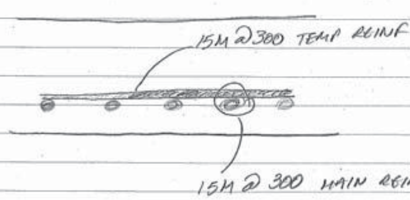
S_{max} → LESSER OF $\begin{cases} 5h = 5 \times 300 = 1500 \text{ mm} \\ \underline{500 \text{ mm}} \end{cases}$

$\therefore S_{max} = 500$ mm

• REQUIRED BAR SPACING.

$$S \leq \frac{A_b\, 1000}{A_s}$$
$$\leq \frac{200 \text{ mm}^2 \times 1000}{600 \text{ mm}^2}$$
$$\leq 333 \approx 300 \text{ mm}.$$

THEREFORE USE 15M @ 300 FOR SHRINKAGE + TEMP. REINF



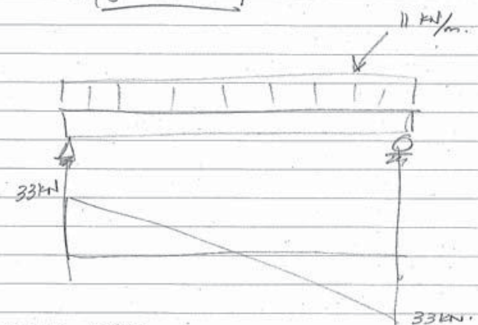
SLAB 7.

· CHECK THE SLAB DESIGN FOR SHEAR.

FIND THE MAX SHEAR FORCE AT SUPPORT.

$V_f = \frac{w_f \times l_n}{2} = \frac{11\ kN/m \times 6m}{2}$.

$\Rightarrow \boxed{V_f = 33\ kN.}$



· FIND EFFECTIVE DEPTH.

$d = h - cover - \frac{d_b}{2}$.

$= 300 - 40 - \frac{15}{2}$

$= 252.5$

· FIND EFFECTIVE SHEAR DEPTH d_v.

$d_v \rightarrow$ GREATER OF $- \begin{cases} 0.9d = 0.9(252.5) = 227.25 \\ 0.72h = 0.72(300) = 216\ mm. \end{cases}$

HENCE $d_v = 227.25 \sim 228\ mm$.

· DETERMINE β

PER Cl 11.3.6.2 FOR SLAB THICKNESS NOT GREATER THAN 350 mm $\beta = 0.21$ CAN BE USED.

SLAB 8

· DETERMINE V_c.

$V_c = \phi_c \lambda \beta \sqrt{f'_c}\ b_w d_v$.

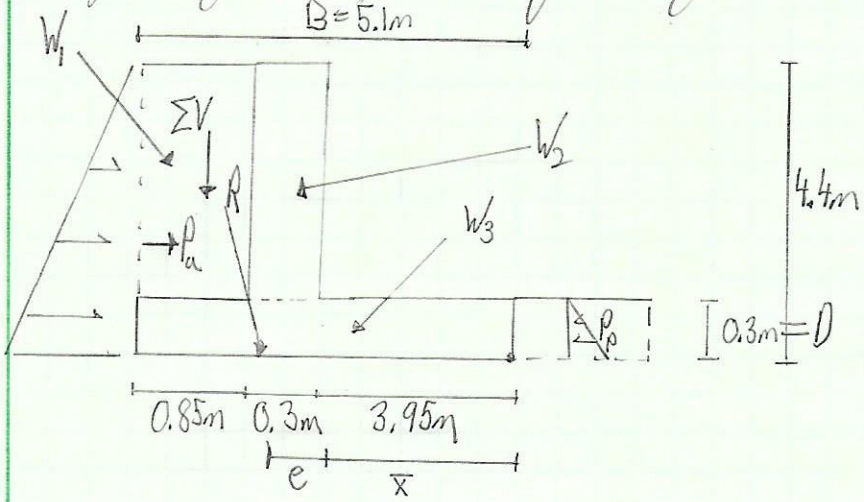
$= (0.65)(1.0)(0.21)\sqrt{25 N/mm^2}\ (1000\ mm)(228\ mm)$

$V_c = 155.6\ kN/m$.

SINCE $V_c = 155.6\ kN > V_f = 33\ kN$

$\therefore$ SHEAR REINF IS NOT REQUIRED.

Design analysis of free-standing retaining wall: Peter Clarke, P.Eng



$\gamma = 20\,kN/m^3$
$\phi = 40°$
$c = 0$

Check for Overturning: (Min FOS: 2-3)

$W_1 = \gamma * A = 69.7\,kN$ $\quad K_a = \tan^2(45 - \frac{\phi}{2}) = 0.217$
$W_2 = \gamma_c * A = 29\,kN$ $\quad K_p = \tan^2(45 + \frac{\phi}{2}) = 4.6$
$W_3 = 36\,kN$

$\Rightarrow P_a = \frac{1}{2} k_a \gamma H^2 = 42.0\,kN/m$
$P_p = 4.14\,kN/m$ $\Rightarrow$

$$\Rightarrow FOS_{(overturning)} = \frac{\Sigma M_R}{M_o} \Rightarrow \Sigma M_R = (4.675m)(W_1) + \left(\frac{1}{3}\right)(0.3m)P_p + (4.1m)(W_2) + (4.1m)(W_3) = 592.8\,kN\cdot m$$

$$M_o = \left(\frac{H}{3}\right)(P_a) = 61.6\,kN\cdot m$$

$$\therefore FOS_{(overturning)} = 9.6\ (>> FOS_{min} = 2)$$ ✓

Check for Sliding: (Min FOS: 1.5)

$\delta = 26°$ (NAVFAC Standards) * Passive Force Ignored
* Adhesion Ignored

W_s = Weight of Sand; W_c = Weight of Concrete

$\Sigma V = W_s + W_c = 134.7\,kN$

$$FOS_{sliding} = \frac{\Sigma F_R}{\Sigma F_d} = \frac{\Sigma V \tan\delta + P_p^{\,0} + B c_a^{\,0}}{P_a} = 1.56\ (> FOS_{min} = 1.5)$$ ✓

Check for Bearing Capacity: (Min FOS = 3) $M_{net} = \Sigma M_R - \Sigma M_o = 592.8 - 61.6 = 531.2\ kN \cdot m$

$\bar{X} = \frac{M_{net}}{\Sigma V} = 3.94m \quad e = 4.25m - \bar{x} = 0.31 \left(< \frac{B}{6} \checkmark\right)$

$q_{max} = q_{toe} = \frac{\Sigma V}{B}\left(1 + \frac{6e}{B}\right) = 36\ kN/m \quad q_{min} = q_{heel} = 22.9\ kN/m$

$q_u = \overset{0}{\cancel{c' N_c F_{cd} F_{ci}}} + q N_q F_{qd} F_{qi} + \frac{1}{2} \gamma B' N_\gamma F_{\gamma d} F_{\gamma i}$

where:

$q = \gamma D = 6;\ D = 0.300m;\ \psi^\circ = \tan^{-1}\left(\frac{P_a}{\Sigma V}\right) = 86.8^\circ$

$B' = B - 2e = 4.48;\ F_{cd} = 1 + 0.4\left(\frac{D}{B'}\right) = 1.027$

$F_{qd} = 1 + 2\tan(\phi)(1 - \sin(\phi))^2\left(\frac{D}{B'}\right) = 1.01$

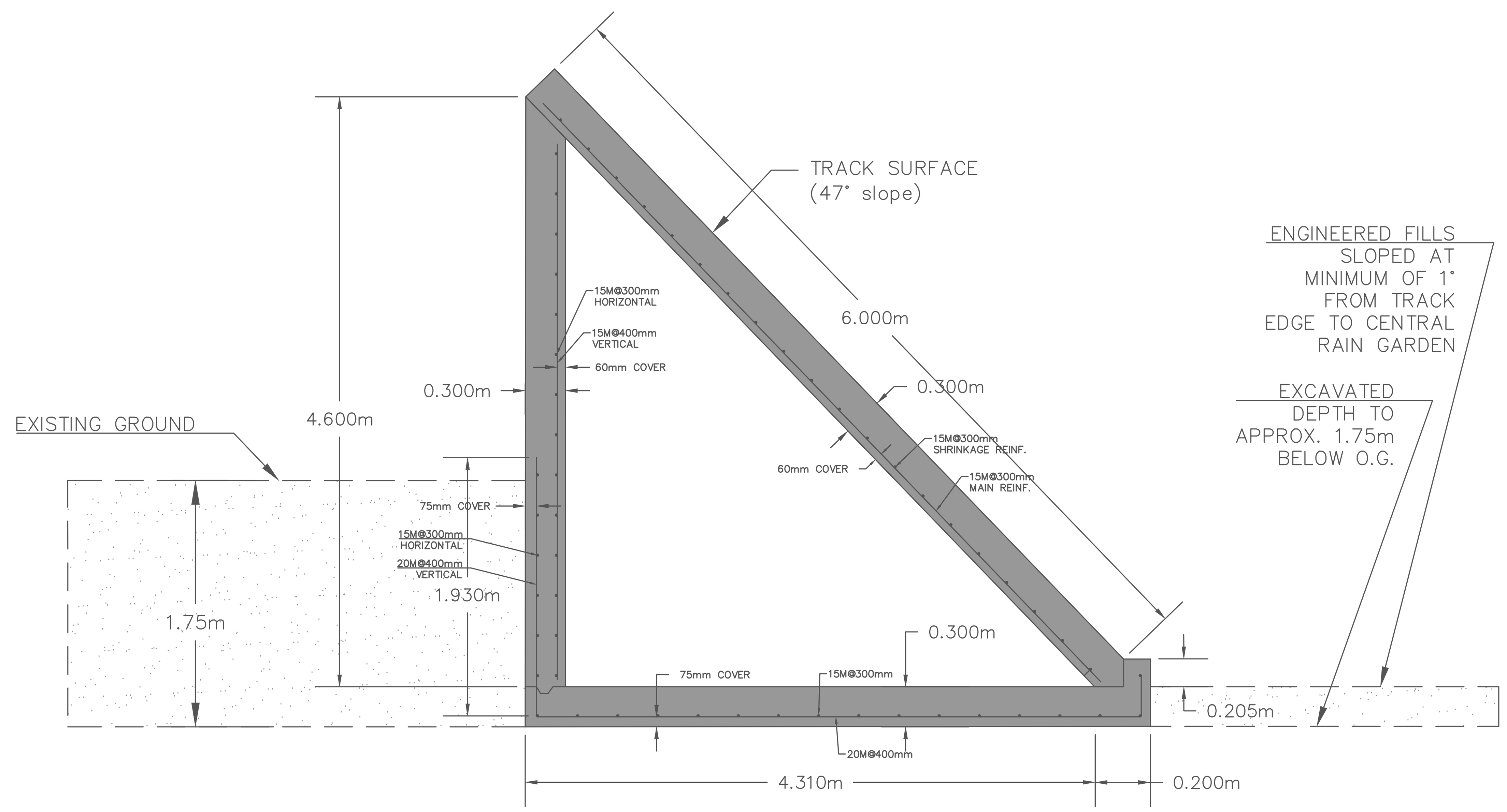
$F_{\gamma d} = 1;\ F_{ci} = F_{qi} = \left(1 - \frac{\psi^\circ}{90^\circ}\right)^2 = 0.0013;\ F_{\gamma i} = \left(1 - \frac{\psi^\circ}{\phi}\right)^2 = 1.37$

$N_q = \left[e^{(\pi \tan 40)}\right]\tan^2\left(45 + \frac{40}{2}\right) = 64.2;\ N_\gamma = (N_q - 1)\tan(1.4\phi_p')$

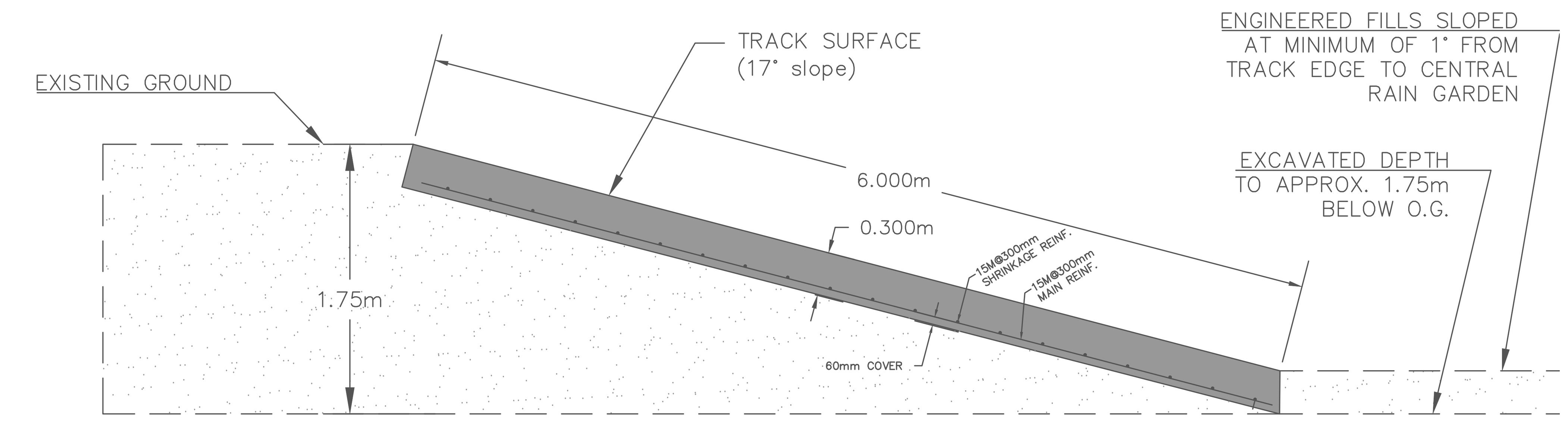
$\therefore q_u = 5751\ kN \Rightarrow$ $FOS_{Bearing} = \frac{q_u}{q_{max}} = \frac{5751}{36} = 160\ (\gg FOS_{min} = 3)$

APPENDIX D: DETAILED DESIGN DRAWINGS

D.1 CONCRETE CONSTRUCTION



1.0 CURVED SECTION REINFORCED CONCRETE LAYOUT
SCALE 1:150



2.0 STRAIGHT SECTION REINFORCED CONCRETE LAYOUT
SCALE 1:150

CONCRETE FORM WORK

1. ALL FORM WORK IS TO BE SELECTED BY THE CONTRACTOR TO MEET THE DIMENSION SPECIFICATIONS FOR CONCRETE REINFORCEMENT AND FINAL CONCRETE DIMENSIONS AS SHOWN IN DWG 445–CIVL–13 SHEETS C–01, C–02 AND C–03
2. THE FABRICATION AND ERECTION OF THE FORM WORK MUST BE APPROVED BY THE FIELD ENGINEER OR ENGINEERS REPRESENTATIVE AND CONSTRUCTED IN ACCORDANCE WITH CSA–S269.3–14..

STEEL REINFORCEMENT

1. ALL STEEL REINFORCEMENT TO BE DONE IN REFERENCE TO DWG 445–CIVL–13 SHEETS C–01, C–02 AND C–03 DIMENSIONS AND IN ACCORDANCE WITH CSA–A23.3–14
2. STEEL REINFORCEMENT WORKS SHALL BE APPROVED BY THE ENGINEER OR ENGINEERS REPRESENTATIVE BEFORE CONCRETE POURS ARE COMMENCED.
3. REINFORCEMENT LAYOUT IN EACH ELEMENT OF THE SECTIONS ARE SHOWN IN DWG 445–CIVL–13 C–02 AND C–03.

CONCRETE

1. ALL CONCRETE WORK IS TO BE DONE IN ACCORDANCE WITH CSA A23.3 DESIGN CODE REQUIREMENTS.
2. BASE STRUCTURE AND RETAINING WALL ARE PLANNED TO BE POURED DURING THE SAME POURING TO FORM A MONOLITHIC BASE AND RETAINING CONCRETE STRUCTURE.
3. THE SLAB SYSTEM WILL BE POURED IN FORM ON LEVEL GROUND ADJACENT TO THE BASE. AFTER HARDENING IT WILL BE CONNECTED AT THE TOP OF THE RETAINING WALL AND AT THE END OF THE BASE.
4. TRACK SURFACE WILL BE SEALED TO PREVENT SEEPAGE.

GENERAL

1. IMPORTANT MILESTONES DURING CONSTRUCTION MUST HAVE THE APPROVAL OF A DESIGNATED ENGINEER WHO HAS CONDUCTED A FIELD VISIT AND INSPECTION.
2. ALL MATERIAL WASTES MUST BE HANDLED ACCORDING TO THE ENVIRONMENTAL MANAGEMENT PLAN.
3. CONSTRUCTION WORKS MUST BE COMPLETED IN SEQUENCE WITH THE WBS AND SCHEDULE SUBMITTED WITH THIS DRAWING SET.

ISSUED FOR CONSTRUCTION

CLIENT
UBC & UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

PROJECT
UBC Velodrome

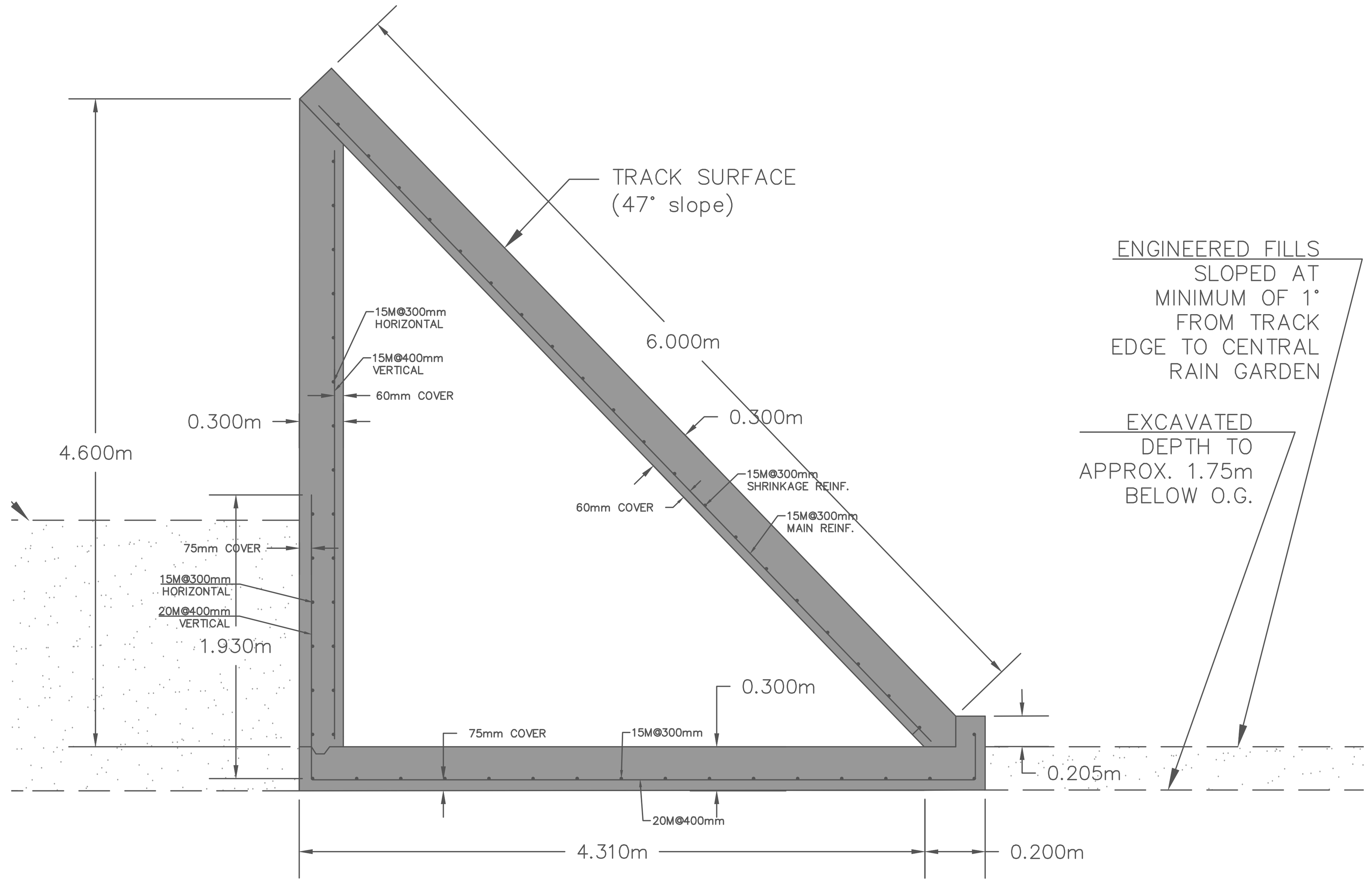
DRAWING NO.
445–CIVL–13

ISSUED FOR CONSTRUCTION
APR.03.2019

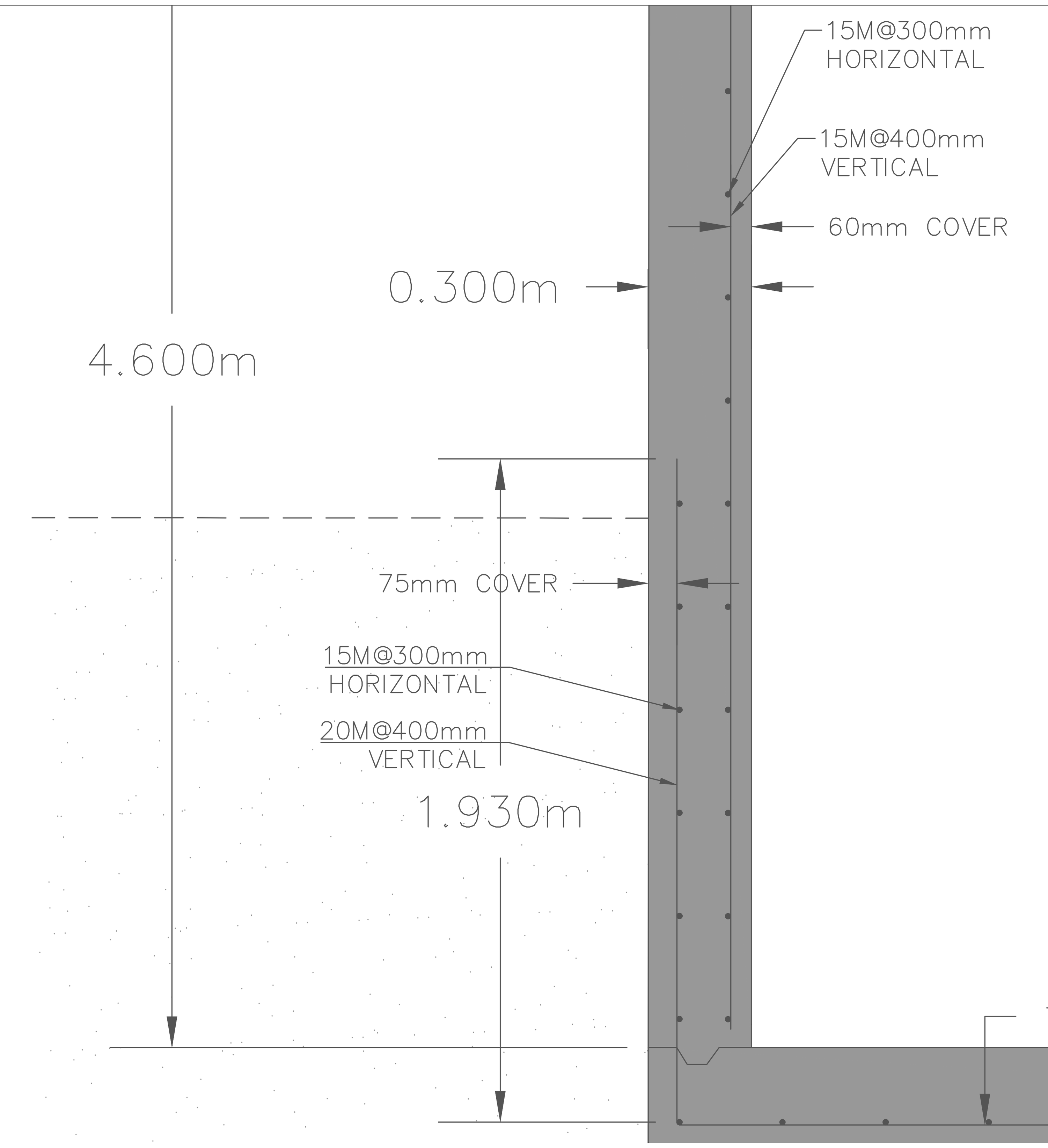
DRAWN BY
EW

SCALE
1:150

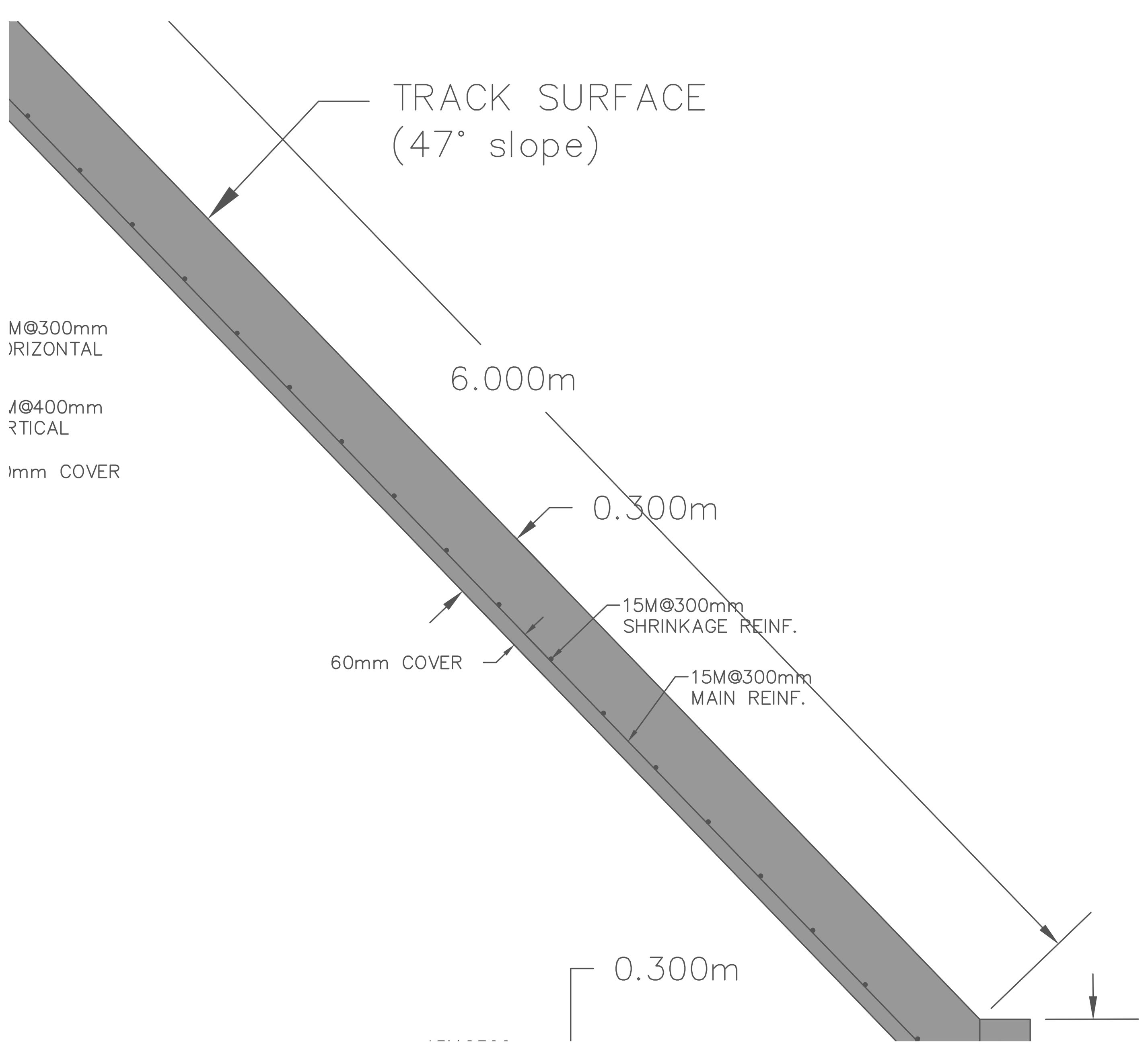
C.01



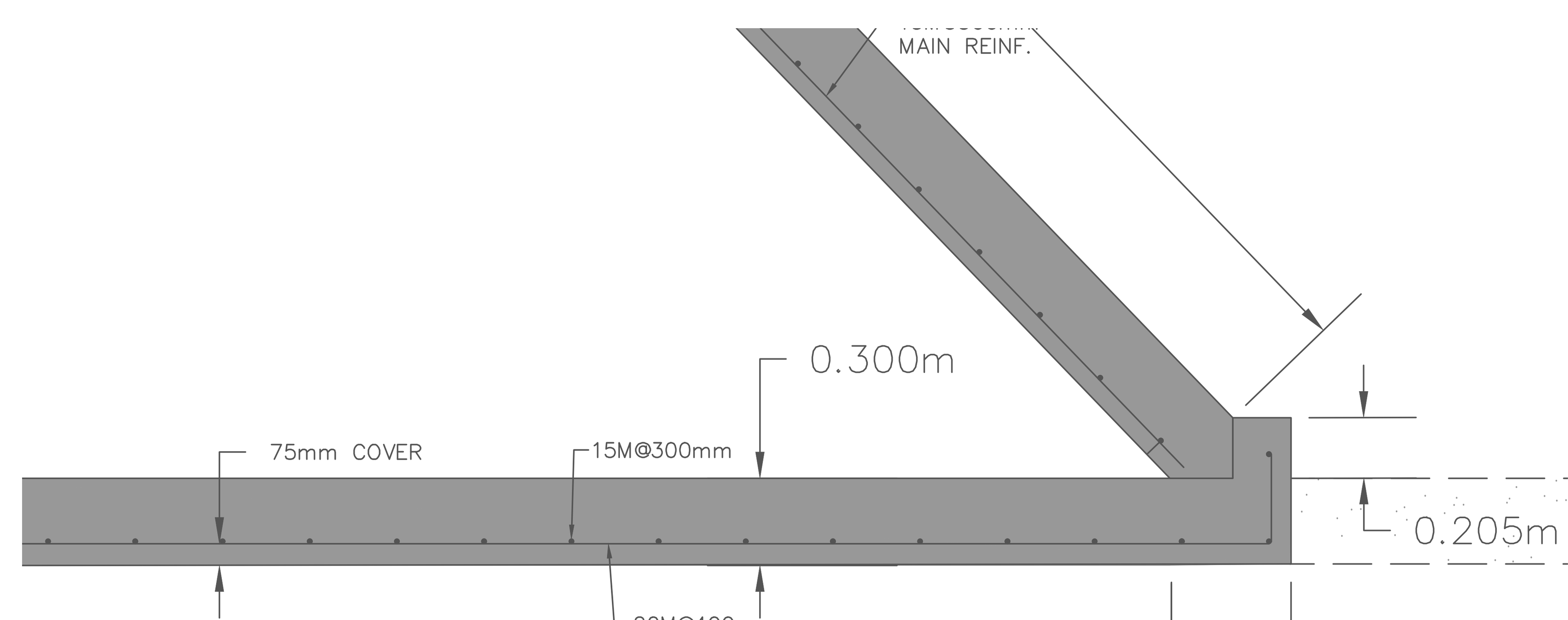
1.0 CURVED SECTION (47° slope)
REINFORCED CONCRETE LAYOUT
SCALE 1:150



2.0 RETAINING WALL
LAYOUT
SCALE 1:50



3.0 TRACK SURFACE
LAYOUT
SCALE 1:75



4.0 FOUNDATION AND TOE
LAYOUT
SCALE 1:75

CONCRETE FORM WORK

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STEEL REINFORCEMENT

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4. TRACK SURFACE WILL BE SEALED TO PREVENT SEEPAGE.

ISSUED FOR CONSTRUCTION

CLIENT
UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

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APR.03.2019

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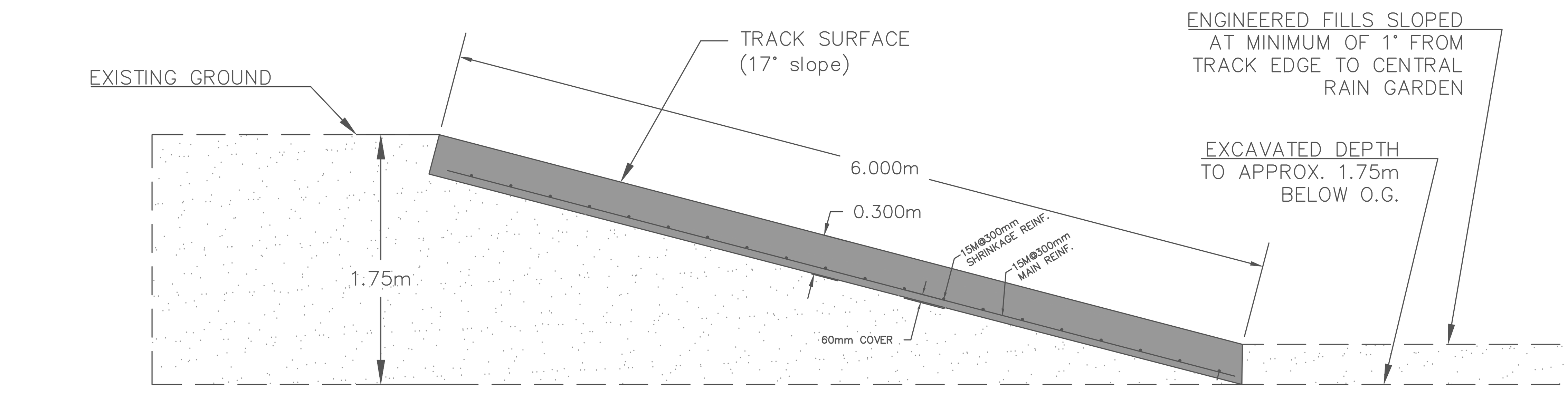
EW

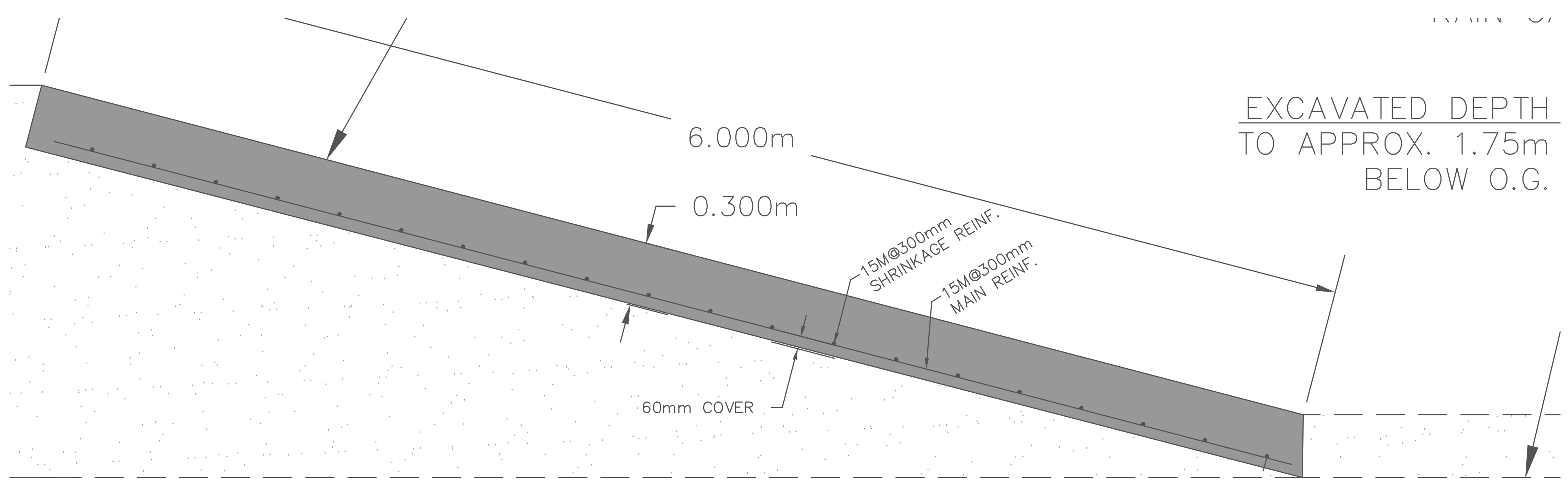
SCALE
VARIES

C.02



1.0 STRAIGHT SECTION REINFORCED CONCRETE LAYOUT

SCALE 1:150



2.0 TRACK SURFACE LAYOUT

SCALE 1:75

ISSUED FOR CONSTRUCTION

CONCRETE FORM WORK

1. ALL FORM WORK IS TO BE SELECTED BY THE CONTRACTOR TO MEET THE DIMENSION SPECIFICATIONS FOR CONCRETE REINFORCEMENT AND FINAL CONCRETE DIMENSIONS AS SHOWN IN DWG 445-CIVL-13 SHEETS C-01, C-02 AND C-03
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4. TRACK SURFACE WILL BE SEALED TO PREVENT SEEPAGE.

CONSTRUCTION METHODS

1. THE SHALLOW SLOPE FOR THE STRAIGHT SECTIONS ALLOWS FOR THE CONFINING FORM WORK TO BE CAST ON FOUR SIDES DIRECTLY ON THE GROUND.
2. AS ALREADY STATED IN THE FORM WORK NOTES, THE FORM WORK METHOD IS NEGOTIABLE DEPENDING ON WHAT THE CONTRACTOR PREFERS. ALL CONSTRUCTION METHODS MUST BE APPROVED BY THE ENGINEER AND MEET CSA-S269.3-14 DESIGN CRITERIA.
3. .SITE PREPARATION WORK FOR THE ENTIRE STRAIGHT SECTION (LENGTH=30.8 METERS) MUST BE COMPLETED BEFORE ANY CONCRETE WORK IS COMMENCED.
4. EXCAVATION WORKS SHALL BE DONE IN ACCORDANCE WITH MMCD AND WORK SAFE BC GUIDELINES AND A CONSTRUCTION SUPERVISOR SHALL BE PRESENT AT ALL TIMES.

GENERAL

1. IMPORTANT MILESTONES DURING CONSTRUCTION MUST HAVE THE APPROVAL OF A DESIGNATED ENGINEER WHO HAS CONDUCTED A FIELD VISIT AND INSPECTION.
2. ALL MATERIAL WASTES MUST BE HANDLED ACCORDING TO THE ENVIRONMENTAL MANAGEMENT PLAN.
3. CONSTRUCTION WORKS MUST BE COMPLETED IN SEQUENCE WITH THE WBS AND SCHEDULE SUBMITTED WITH THIS DRAWING SET.

CLIENT
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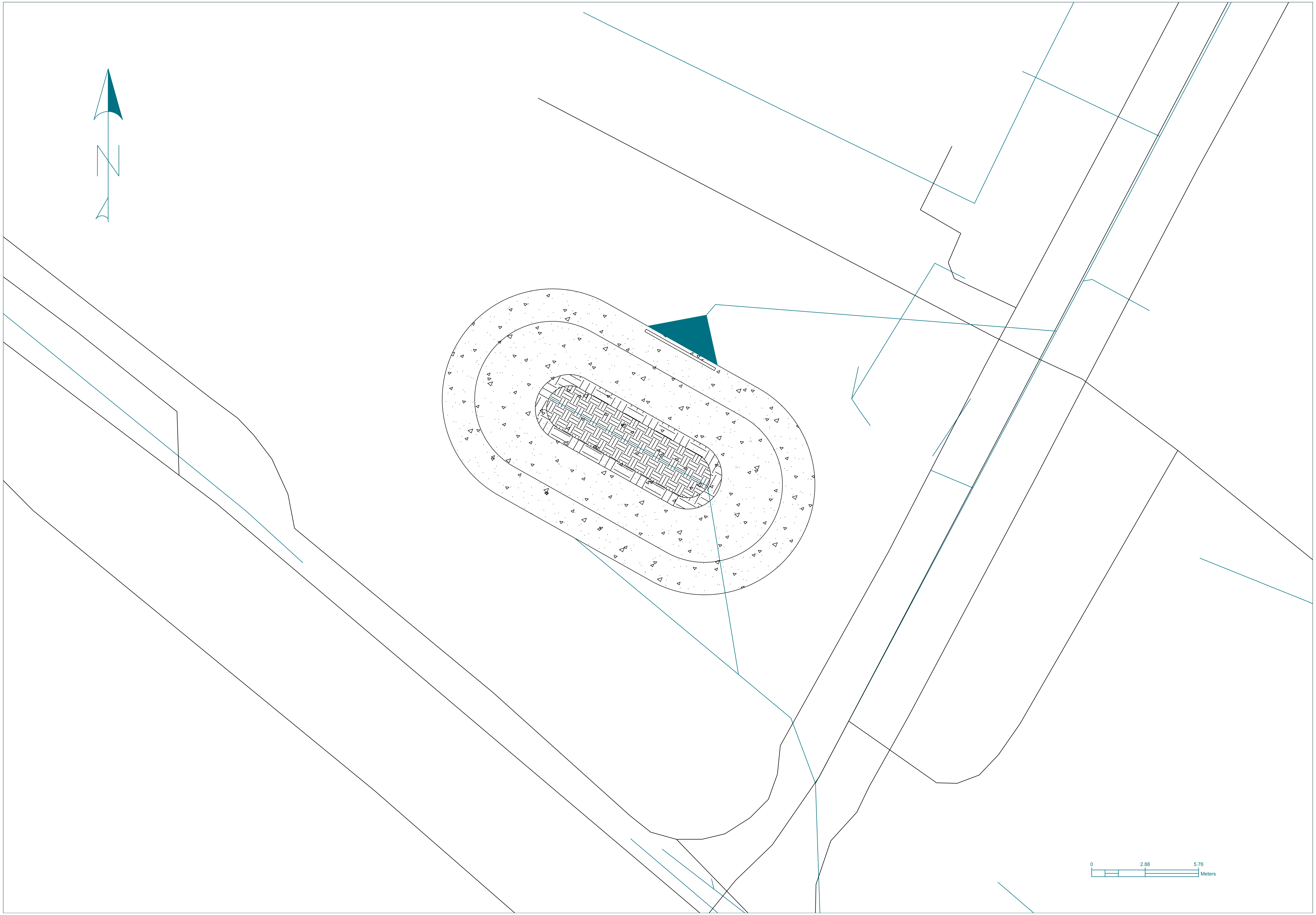
EW

SCALE
VARIES

C.03

D.2 SITE PLANS



COMPANY NAME

CLIENT
UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

PROJECT
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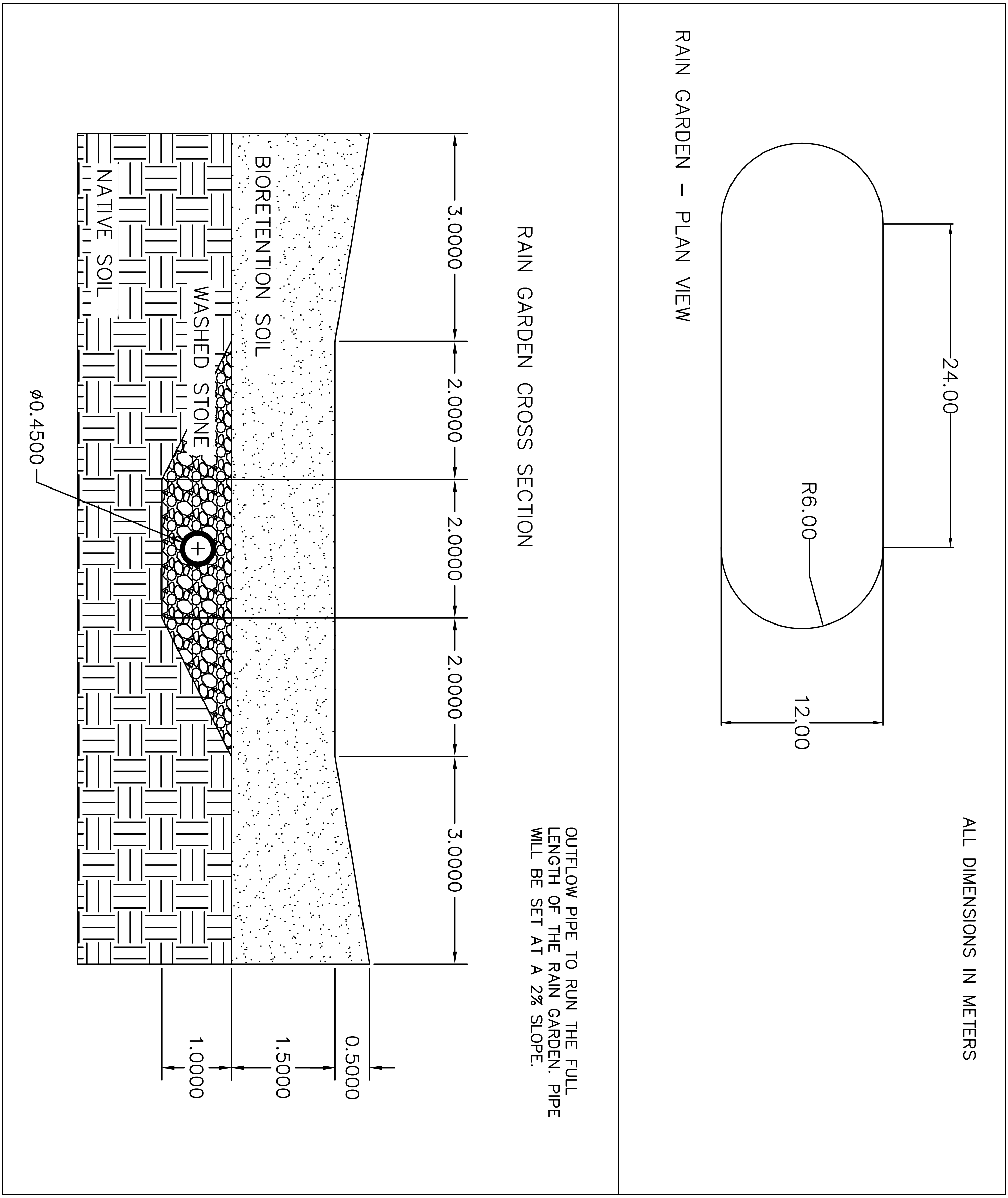
PROJECT NO.
445-CIVL-13

ISSUED FOR REVIEW
APR.01.2019

DRAWN BY
CV

SCALE
NOT TO SCALE

C.02



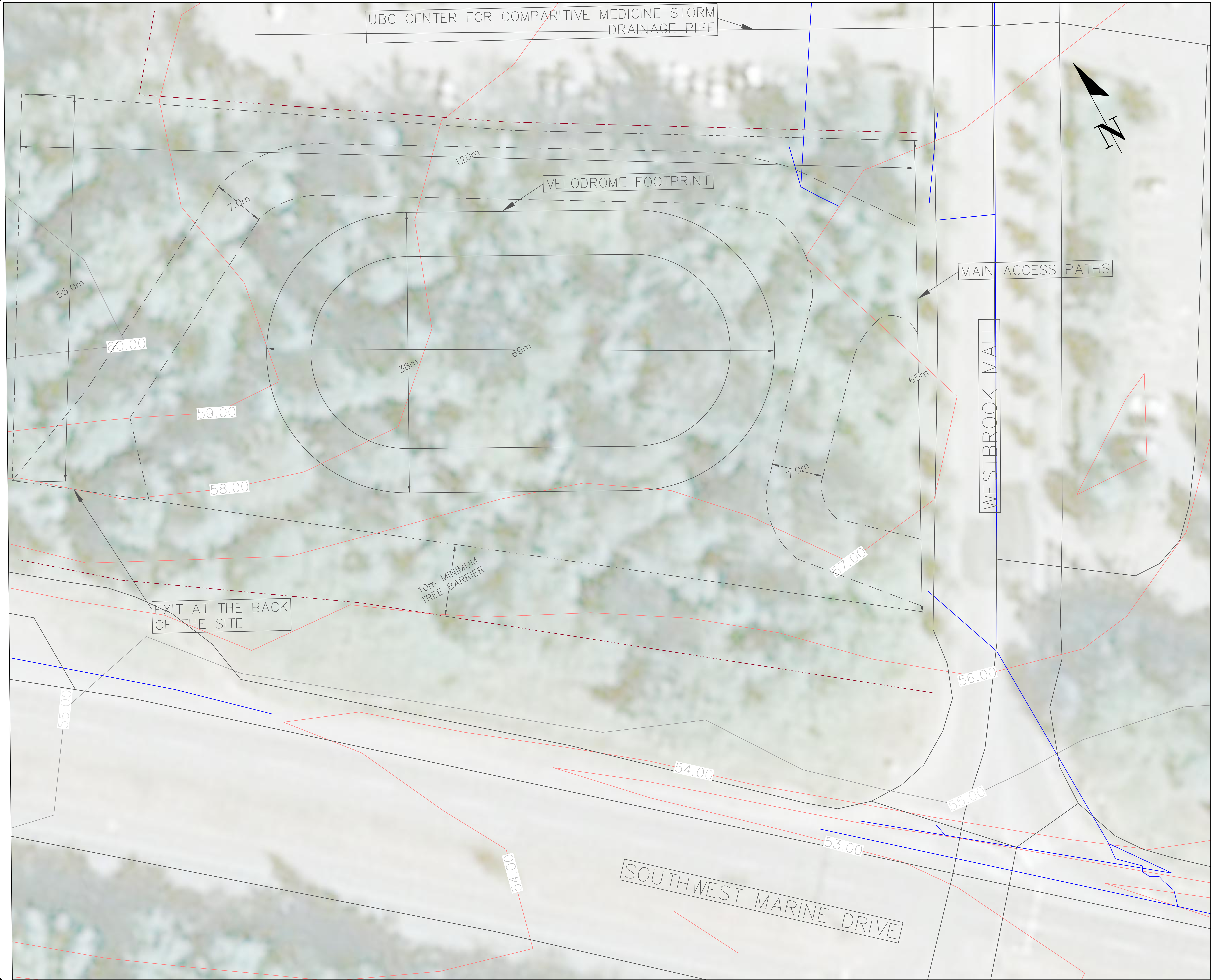
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION

A.04

RAIN GARDEN

ISSUE	PROJECT	CLIENT	COMPANY NAME
11.30.2018	UBC Velodrome	UBC SEEDS 2260 West Mall Vancouver, BC V6T 1Z4	
DRAWN BY	PROJECT NO.		

PRODUCED BY AN AUTODESK STUDENT VERSION



General Notes

GENERAL

1. IMPORTANT MILESTONES DURING CONSTRUCTION MUST HAVE THE APPROVAL OF A DESIGNATED ENGINEER WHO HAS CONDUCTED A FIELD VISIT AND INSPECTION PRIOR.
2. ALL MATERIAL WASTES MUST BE HANDLED ACCORDING TO THE ENVIRONMENTAL MANAGEMENT PLAN.
3. TREES MUST BE CLEARED ONLY WITHIN THE CONFINES OF THE WORK LIMITS. A MINIMUM TREE BARRIER MUST BE MAINTAINED ALONG SW MARINE DRIVE.
4. MAIN ACCESS PATH ENTRANCES SHALL BE PROVIDED FROM WESTBROOK MALL. ACCESS PATHS WILL BE PROVIDED AROUND THE STRUCTURE AS SHOWN.
5. THIS DRAWING, ALONG WITH THE SCHEDULE, WORKPLAN, AND DETAILS SHOULD BE REFERENCED TO HELP THE CONTRACTOR PLAN THE PREFERRED LAY-DOWN AND FACILITY AREAS.

LEGEND

TOP OF BANK
FENCE LINE
WORK LIMITS
ACCESS PATH

DRAWN BY: E.WIEBE

No.	Revision/Issue	Date
R0	ISSUED FOR CONSTRUCTION	03/04/19

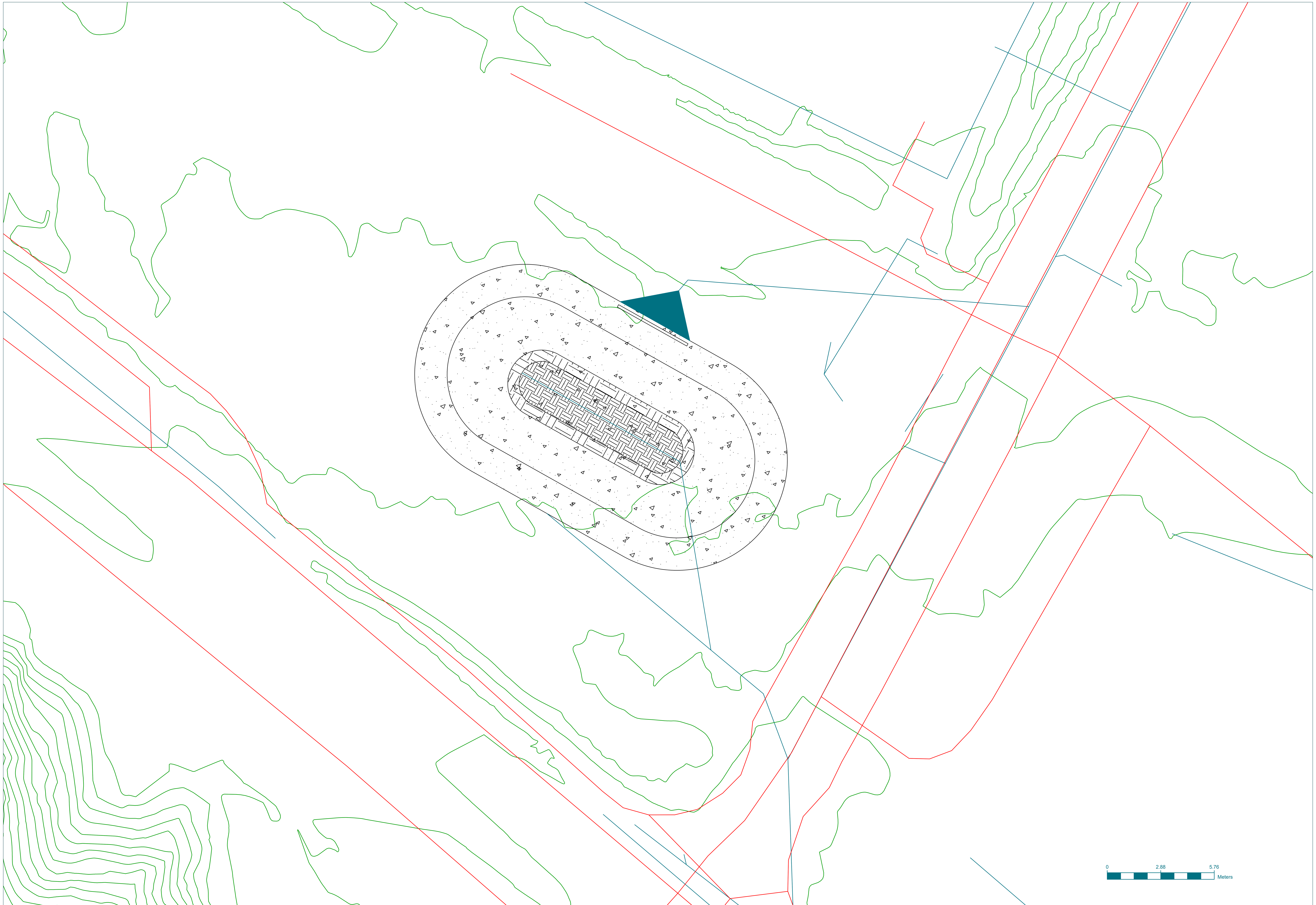
Firm Name and Address
NOT APPLICABLE

HYDRO
WAY, V6T ###,
VANCOUVER, BC

Project Name and Address
UBC MULTI-USE STORM WATER DETENTION FACILITY – ADJACENT TO WESTBROOK MALL

TITLE: CONSTRUCTION BOUNDARIES

Project: 446-CIVIL-13
Date: 03-04-2019
Scale: 1:250
Sheet: C-11



COMPANY NAME

CLIENT
UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

PROJECT
UBC Velodrome

PROJECT NO.
445-CIVL-13

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APR.01.2019

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CV

SCALE
NOT TO SCALE

C.02

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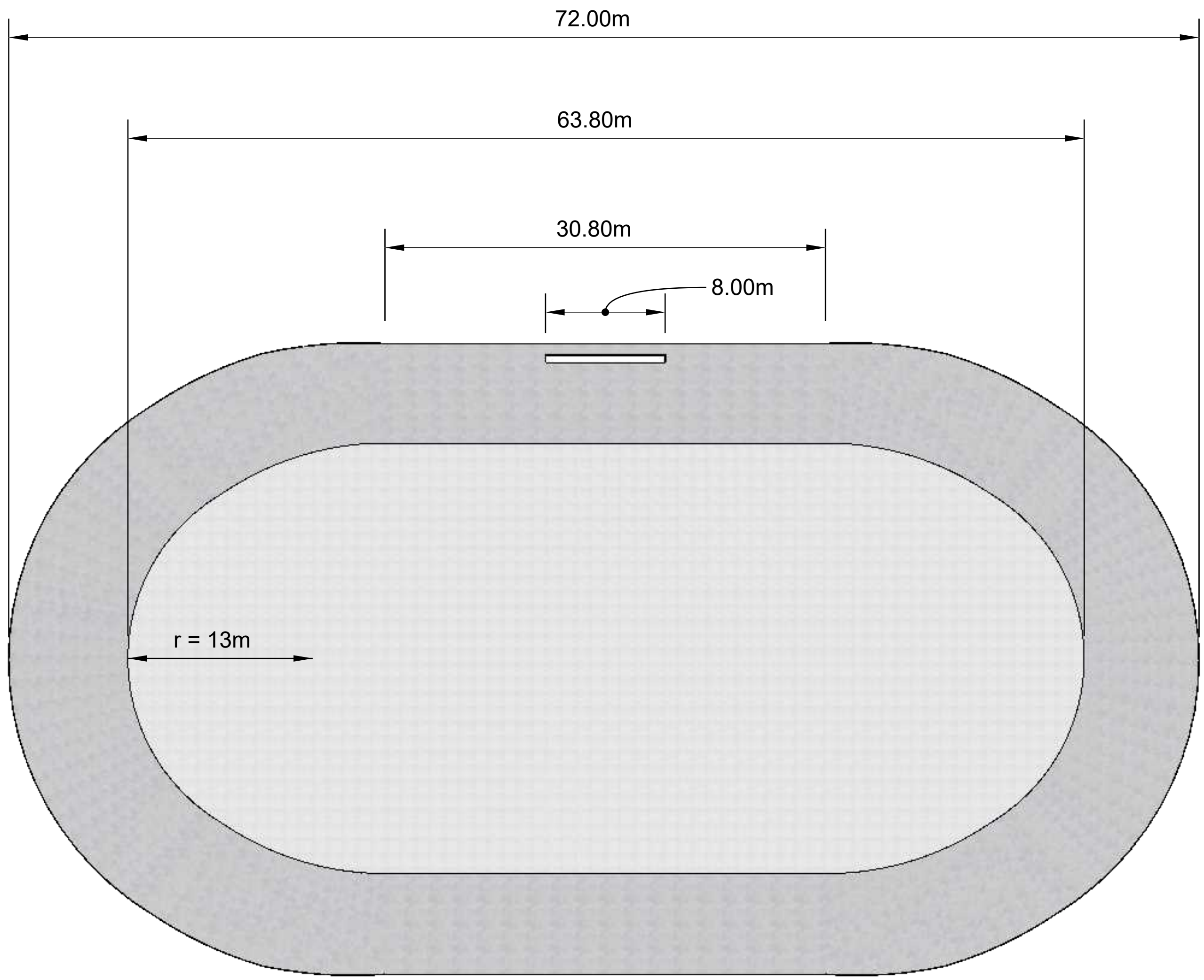
PRODUCED BY AN AUTODESK STUDENT VERSION
PRODUCED BY AN AUTODESK STUDENT VERSION



COMPANY NAME

CLIENT
UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

PROJECT
UBC Velodrome

PROJECT NO.

ISSUE
11.26.2018

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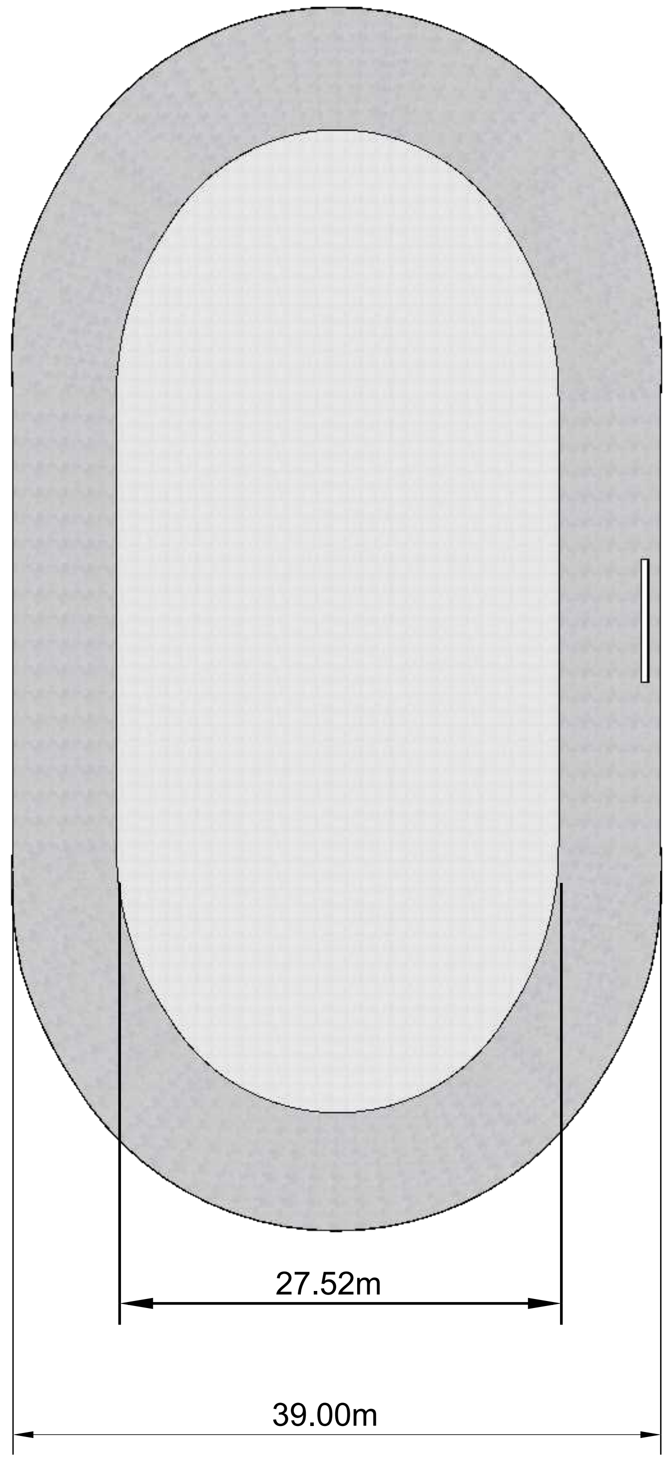
CV

Plan View

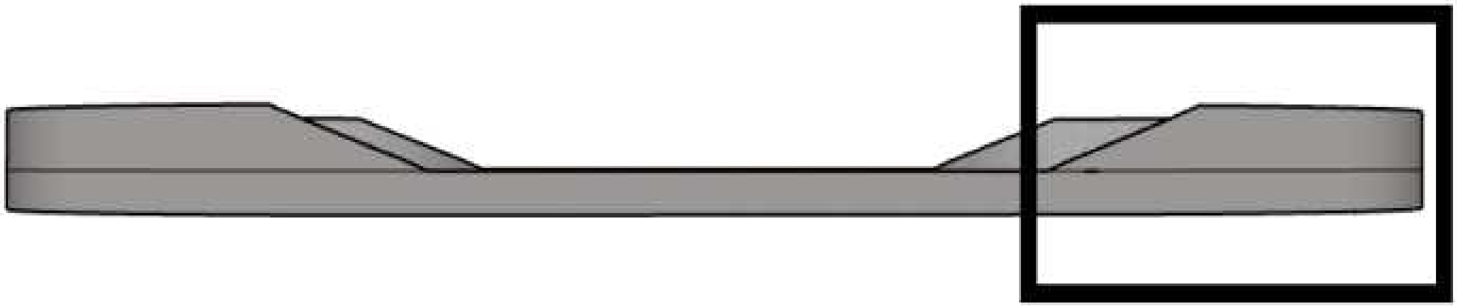
A.01

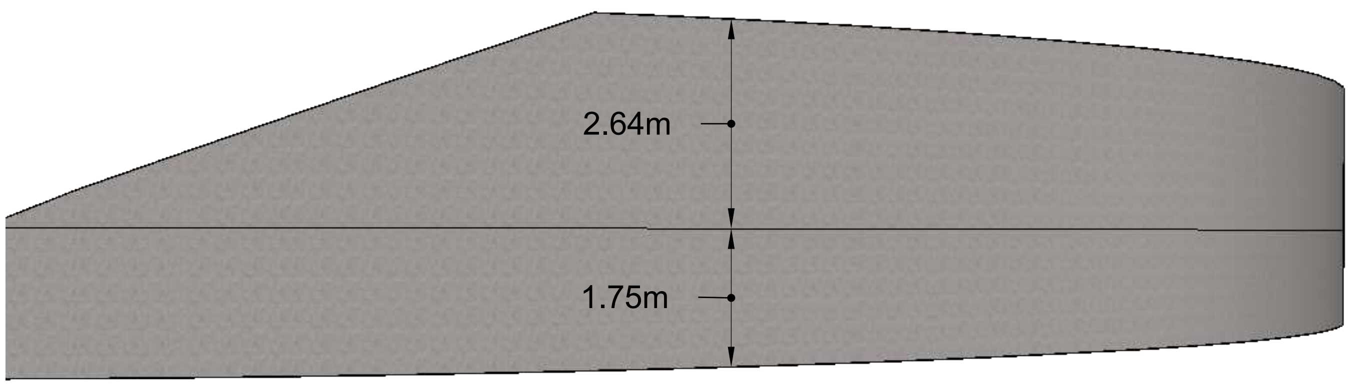


A.02

Plan View 2

ISSUE	PROJECT	CLIENT	DESIGNER
11.26.2018	UBC Velodrome	UBC SEEDS 2260 West Mall Vancouver, BC V6T 1Z4	
DRAWN BY	**PROJECT NO.**		
CV			





COMPANY NAME

CLIENT
UBC SEEDS
2260 West Mall
Vancouver, BC
V6T 1Z4

PROJECT
UBC Velodrome

PROJECT NO.

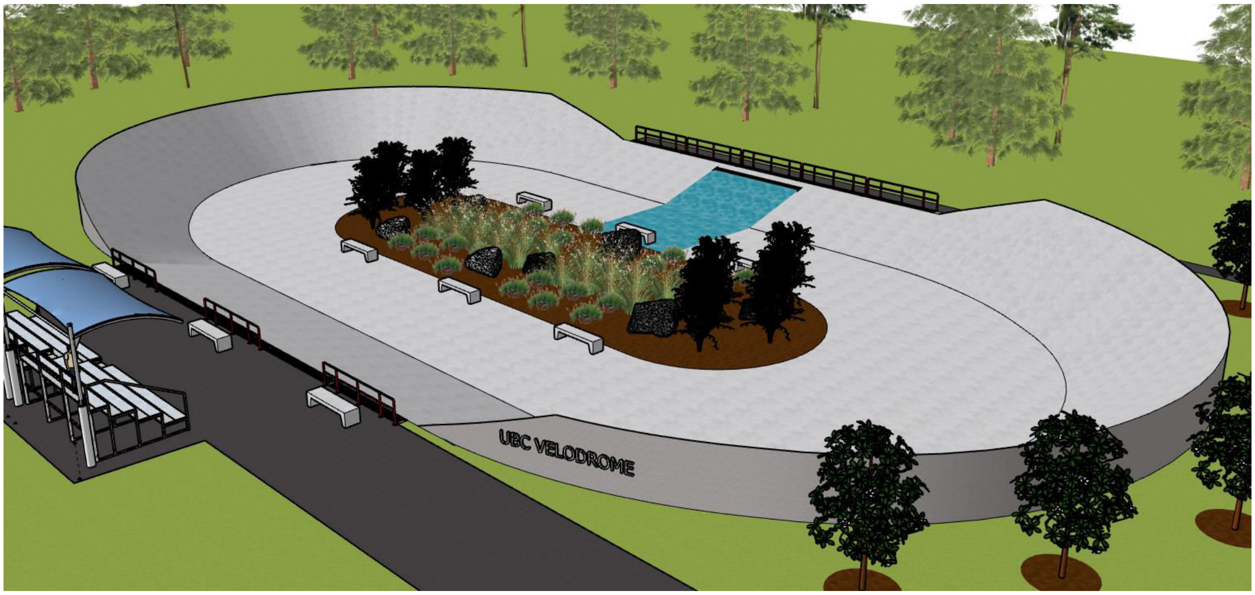
ISSUE
11.26.2018

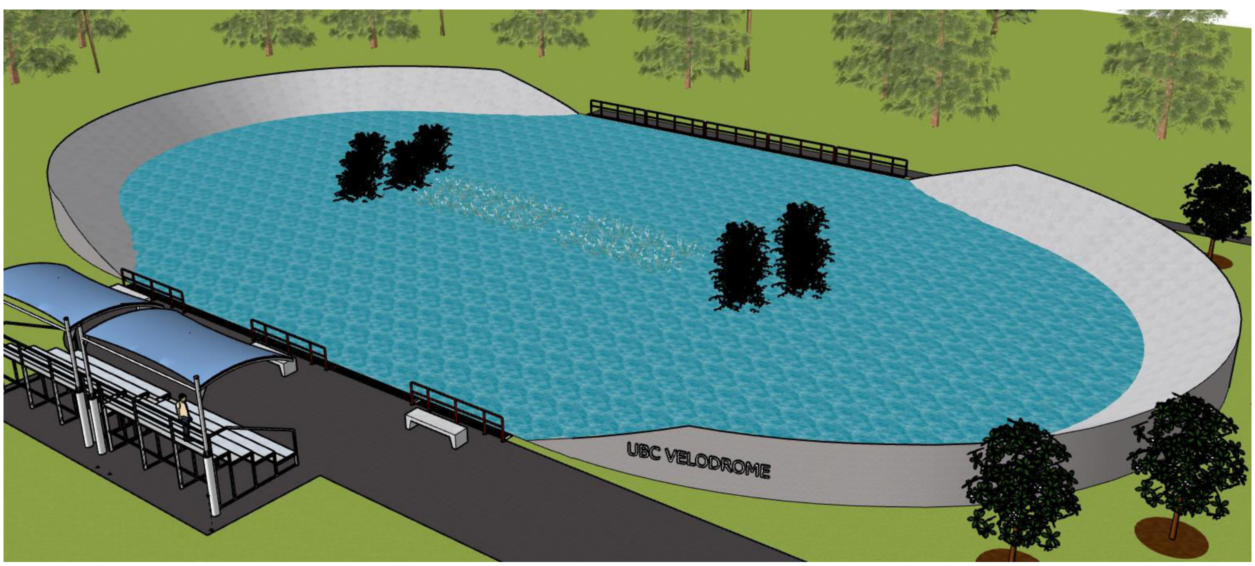
DRAWN BY
CV

Side View

A.03

Appendix E: Artist Renderings of the Facility


UBC VELODROME


UBC VELODROME