UBC Spiral Drain Capacity Upgrade

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CIVL 446

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1.0 Executive Summary

The Spiral Drain near the Museum of Anthropology on the Vancouver campus of the University of British Columbia is the last of its kind in North America, and drains a large portion of the campus' north catchment. It has also been established that in the event of a 1/100-year storm event the drain will be over capacity, resulting in flooding of key UBC infrastructure. ONE7 Engineering was tasked with a design exercise to upgrade the capacity of this system to withstand such a storm.

Through a preliminary design process involving optimization analysis, the selection of two underground detention tanks was chosen; the technical details of which are enclosed in this report. The structural and hydraulic design of the tanks are provided herein, as well as a proposed construction schedule, engineer's cost estimate and considerations towards project risks and benefits.

The underground detention tanks operate using an overflow design concept; a predetermined flow passes through the tanks, with overflow into the tanks as this flow is exceeded. Once the water level in the tank is sufficient, a pump will activate and pump water out of the tank, returning it to the storm sewer system. This will equalize the flow entering the storm sewer and distribute it over a longer time period, resulting in a higher overall system capacity. The flow will then reach the historic spiral drain, and exit to the ocean below, upholding its original operation.

The underground detention tanks have been designed with consideration to surface land uses and the sensitivities of the surrounding environment, in addition to incorporating the triple bottom line and the values of the Musqueam First Nations. The estimated project costs are $5.5 million.

Table of Contents

List of Figures

List of Tables

2.0 Introduction

UBC's Integrated Stormwater Management Plan (ISMP) has identified significant risks regarding campus flooding. Stormwater collected on campus migrates through the storm sewer network and is released to the ocean at several discharge points, and UBC's north catchment is serviced by the spiral drain discharge point. The spiral drain is unable to withstand more than a 1/100-year rain event without causing upstream flooding. ONE7 Engineering has provided upgrade solutions that will improve the north catchment capacity, allowing the spiral drain to function properly up to a 1/100-year rain event.

2.1 Project Background

In 2016, ONE7 Engineering produced a conceptual design report for the spiral drain upgrade project. The report involved identifying and assessing three potential solutions: an artificial wetland, a naturalized discharge creek, and a pair of underground detention tanks. Through a number of objective and subjective comparisons, the underground detention tanks were chosen as the optimal solution.

With UBC approval of the chosen solution, ONE7 Engineering has worked through 2017 to produce this technical design report.

2.2 Project Scope

The scope of this technical design report includes the following:

- Description of key components
- Technical considerations
- Design outputs
- Draft construction plans, including schedule
- Requirements and recommendations
- Engineer's cost estimate

It should be noted that other strategies for reducing the overall flow of stormwater also exist. These include methods such as: constructing rain gardens, reducing impermeable surfaces, and encouraging water re-use activities. However, there strategies were not within the scope of this project; the report focuses solely on the installation of underground detention tanks to directly and immediately improve the performance of the existing stormwater infrastructure and spiral drain discharge unit.

2.3 Summary Table

Table 1: Team member roles and responsibilities.

Team Member	Roles and Responsibilities
Christian Brandl	Concrete Specifications, Additional Design Considerations, Permitting, Environment, Stakeholders & Risks, Final Editing, Executive Summary
Kit Caufield	Hydraulics, Tank Design, Triple Bottom Line, Chief Editor, Report Creation and Formatting, Introduction, Conclusion
Tyler Dickens	Construction Schedule, Alternative Land Uses, Executive Summary, Conclusion
Soohyung Lee	3D Design, Concrete Structure Design, Load Calculations
Genrui Li	Concrete Structure Design, Load Calculations
Qing Liu	Concrete Structure Design, Load Calculations
Terence To Tok Shau	Pump Design, Cost Estimate, Location

3.0 Design

The project design involves the installation of two underground detention tanks in-line with the existing storm sewer infrastructure. These tanks will intercept storm water, store it, and release it in a controlled manner. The tanks (Figure 1) will be concrete structures and will have a combined detention capacity of nearly 4000 m^3. Detailed drawings of structural components described in this section may all be found in Appendix B.

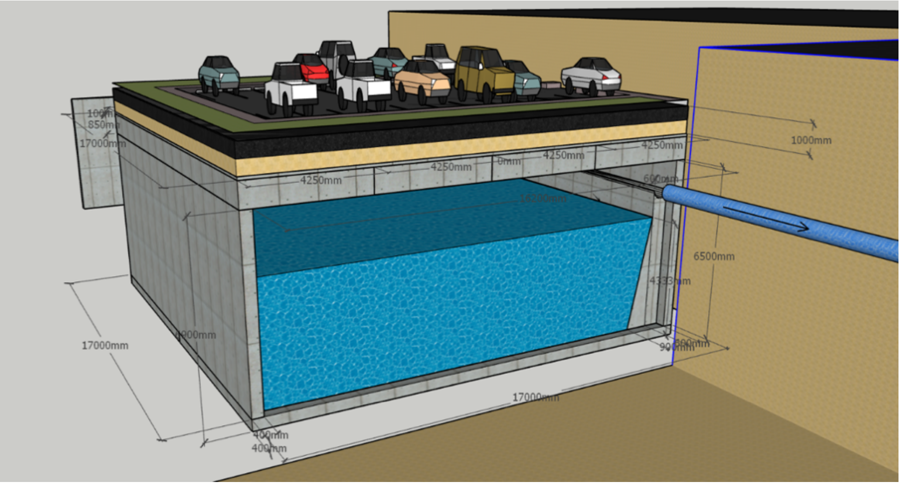


Figure 1: Conceptual tank design

3.1 Locations

Tank locations were chosen based on a number of factors. First, a number of manhole locations susceptible to flooding were identified in a report produced by GeoAdvice Engineering; these areas would naturally benefit the most from additional water storage. Next, using Google Maps and site visits, areas large enough to accommodate tank construction without major disruptions to surrounding buildings and infrastructure were identified. The following two locations (Figure 2) were ultimately chosen:

1. Adjacent to the intersection of Chancellor Boulevard and Northwest Marine Drive. This tank will now be referred to as the “Chancellor Tank”.
2. The southwest lot adjacent to the UBC Museum of Anthropology. This tank will now be referred to as the “MoA Tank”.

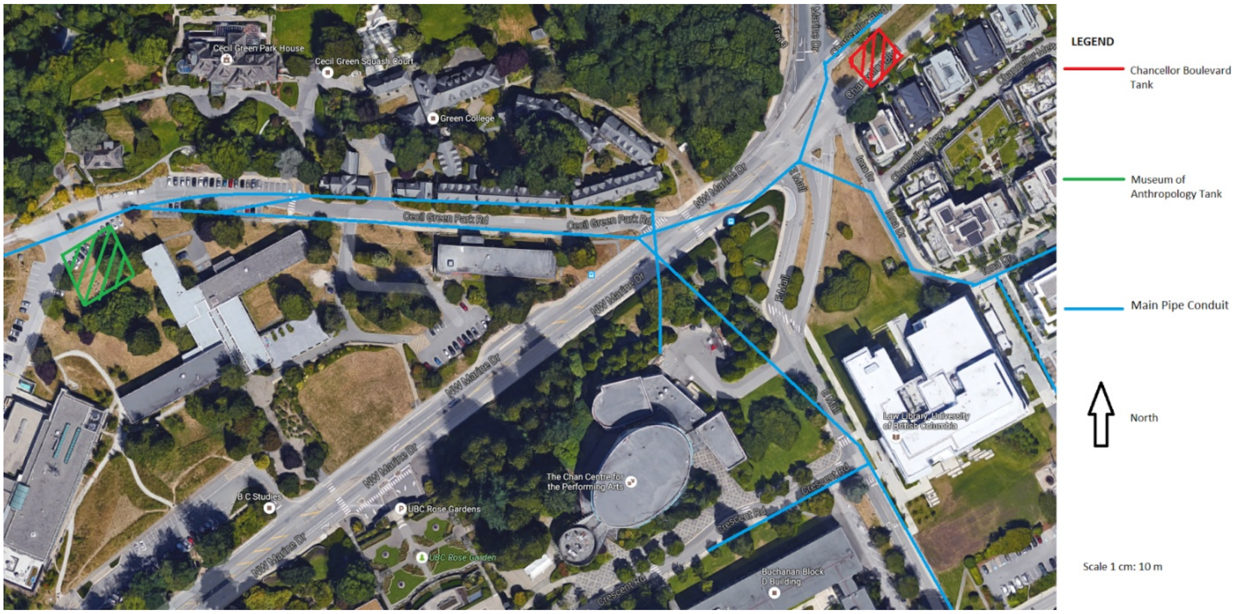


Figure 2: Tank locations.

3.2 Structural Design

Based on a conceptual rectangular design, the tanks were analyzed to determine the loads, and an iterative process was used to determine the optimal design. The calculations for the Chancellor Tank are detailed in the following discussion; calculations for the MoA Tank can be found in Appendix C. Throughout the process, a factor of safety of 1.5 was strictly observed.

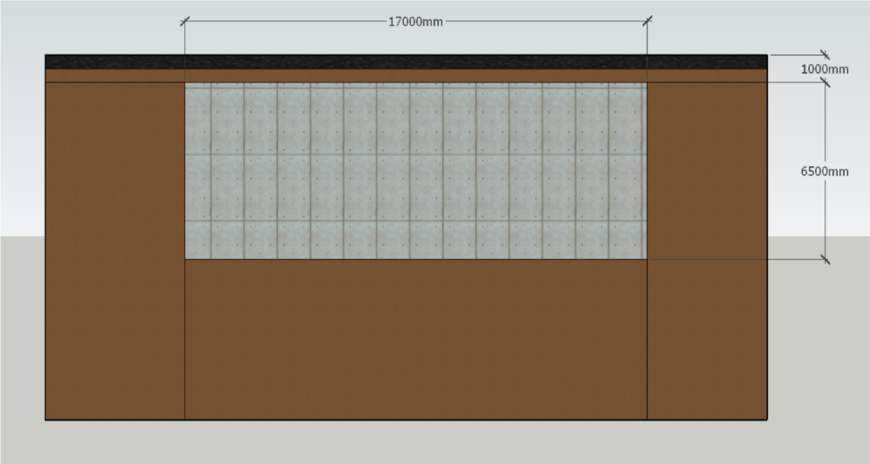


Figure 3: Underground detention tank.

The combined overlying layer of asphalt and soil provides a dead load of 22kN/m^3. This transfers the vertical stress to the tank roof, and the surrounding soil transfers lateral stress to the walls. The design is not heavily affected by moment and torsion, hence these are not considered in the calculations.

Table 2: Tank design dimensions

Tank Dimensions		
	Tank 1 (MoA)	Tank 2 (Chancellor)
Width (m)	20	17
Length (m)	20	17
Height (m)	6.5	6.5

3.2.1 Vertical Loads

Distributed loads on the tanks were determined based on the National Building Code of Canada (NBCC).

Table 3: Distributed loads on tank tops.

Loads (LL, DL, SL, wf)			
Vehicle Load (LL)	2.4	kpa	
Snow Load	1.4	kpa	
Dead Load (22kN/m^3 (unsaturated sand) x 1m(depth of soil) x 1.5 (factor of safety))	33	kpa	
Governing Load Combination wf: 1.25 DL+ 1.5 LL + 0.5 SL			
wf (Area)	45.55	kpa	
wf (Area)	45550	N/m^2	
wf (Area)	0.0456	N/mm^2	

The total factored load (wf) acquired from the above chart was later combined with the self-weight of the roof design, which in turn depended on the tank dimensions. Since the shear stress from the vertical loads has the most significant impact, deflection of the roof must not exceed the calculated allowable limit of 95mm. Table 4 shows the calculation of the failure of a single slab in deflection.

Table 4:Chancellor Tank single-slab deflection failure.

Tank Chancellor (Single Slab)				
L	17000	mm		
Wf	0.0456	N/mm^2		
w (wf * L)	774.35	N/mm		
E (typical modulus of elasticity)	20000	Mpa	N/mm^2	
b (slab width)	17000	mm		
h (typical slab height)	100	mm		
I (bh^3/12)	1.417E+09	mm^4		
(deflection) = 5wl^4/(384EI)	29722	mm		
Deflection Limit (L/180)	94.44	mm		
deflection > limit?	yes			
CANNOT use a single slab				

Since a single slab cannot withstand all of the factored distributed loads, multiple beams were under the slab were considered as an alternative option (Table 5). As can be seen, by using four beams the deflection was found to satisfy the allowable deflection limits; hence four beams and a slab were chosen for the final design.

Table 5: Chancellor tank multiple-beam deflection calculations.

Multiple Beams - Tank Chancellor				
L	17000	mm		
h (minimum thickness L/20)	850	mm		
width (L/4, 4 beams)	4250	mm		
DL of Beams + Slab	22.8	kN/m^2	0.023	N/mm
E (typical modulus of elasticity)	20000	Mpa		
I (bh^3/12)	217502604167	mm^4		
w ((wf+DL*1.25)*width)	314.7	N/mm	1258.9	
(deflection)	78.7	mm		
Deflection Limit (L/120)	141.7	mm		
Is deflection > limit?	no			
Use 4 Beams with Dimension: 850 x 4250 x 17000				

Even though this design satisfies the deflection requirement, it is highly unlikely that the beams could withstand the shear stresses without any reinforcements. Thus, calculations on shear reinforcements were done based on the NBCC and Canadian Standards Association (CSA) codes and typical concrete design parameters (Table 6). Due to the extent of the shear reinforcement calculations, they can be found in Appendix C. Additionally, detailed drawings on the structural components can be found in Appendix B.

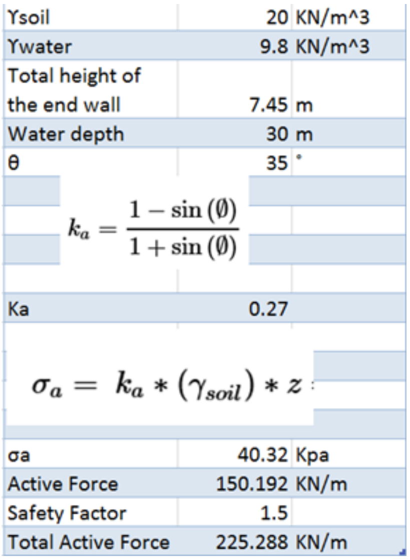
Table 6: Concrete design parameters.

Concrete Design Parameters		
fy	400	Mpa
f'c	30	Mpa
ϕs	0.85	
ϕc	0.65	
α1	0.805	
β1	0.895	

3.2.2 Lateral Loads

Lateral loads on the tanks stem from the surrounding soil and groundwater. Based on the NBCC, the distributed loads on the tanks were determined as follows:

Table 7: Lateral loads applied on tank walls.



Ysoil	20	KN/m^3
Ywater	9.8	KN/m^3
Total height of the end wall	7.45	m
Water depth	30	m
θ	35	°

$$k_a = \frac{1 - \sin(\emptyset)}{1 + \sin(\emptyset)}$$

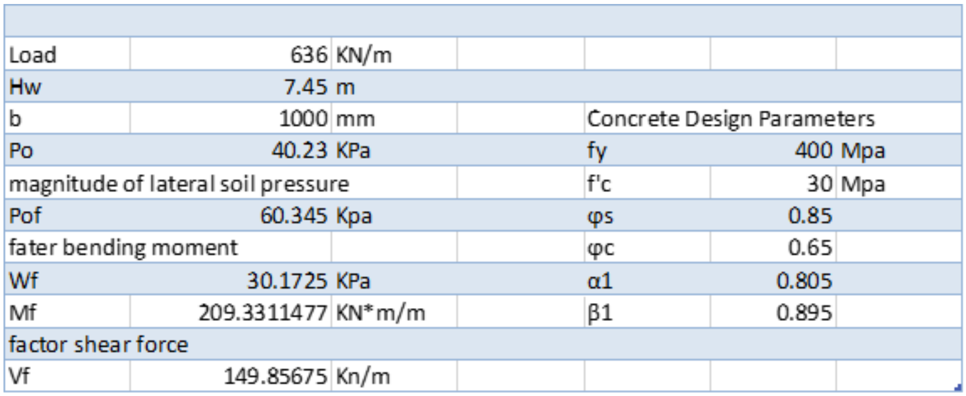
Ka	0.27	

$$\sigma_a = k_a * (\gamma_{soil}) * z$$

σa	40.32	Kpa
Active Force	150.192	KN/m
Safety Factor	1.5	
Total Active Force	225.288	KN/m

Aside from the lateral soil and water loads, the walls also hold the self-weight of the top beams, slab, the soil, and the asphalt road surface. Table 8 details the calculations of the wall dimensions and rebar insulation.

Table 8: Wall loads.



Load	636	KN/m				
Hw	7.45	m				
b	1000	mm		Concrete Design Parameters		
Po	40.23	KPa		fy	400	Mpa
magnitude of lateral soil pressure				f'c	30	Mpa
Pof	60.345	Kpa		φs	0.85	
fater bending moment				φc	0.65	
Wf	30.1725	KPa		α1	0.805	
Mf	209.3311477	KN*m/m		β1	0.895	
factor shear force						
Vf	149.85675	Kn/m				

Based on the design parameters given by the CSA 23.3 reinforced concrete structural design code, the following results were obtained:

- Wall Thickness of 400mm
- 30mm clear cover
- 30M rebar installed vertically at 350mm spacing
- 15M rebar installed horizontally at 300mm spacing
- 2 rows of rebar installed parallel at 100mm spacing

3.2.3 Strip Footings

The strip footings were calculated by considering both the dead loads of the soil and the concrete's self-weight, as well as live loads.

Table 9: Loads considered for strip footings.

DL	484.5	KN/m
LL	20.4	KN/m
load	636.225	KN/m
wall thickness	300	mm
allowable soil bhearing pressure	100	Kpa

Based on these loads, the following design parameters were determined for the Chancellor Tank:

- Total load is 636KN/m
- 5.1m long strip footing
- 700mm thickness
- 75mm clear cover at bottom and two sides
- 35M rebar install transversely at 150mm spacing
- 35M rebar install longitudinally at 500mm spacing

And for the MoA Tank:

- Total load is 748KN/m
- 6.0m long strip footing
- 850mm thickness
- 75mm clear cover at bottom and two sides
- 35M rebar install transversely at 100mm spacing
- 35M rebar install longitudinally at 400mm spacing

Finally, the footing dimensions and rebar insulation are shown below in Figure 4.

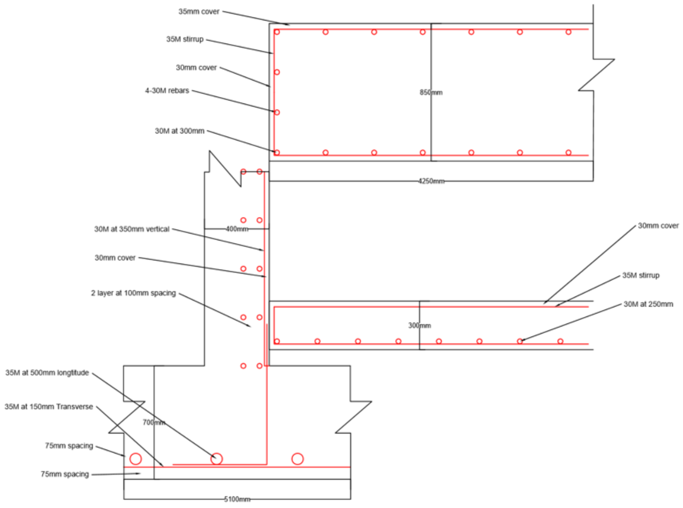


Figure 4: Footing dimensions and rebar cover

3.2.4 Concrete Specifications

As per industry standards for a typical water clarifier design, the walls of the underground detention tanks will not require any form of protective coating. However, it is recommended that consideration be given to more acid resistant concrete mixtures, due to the corrosion risk presented by carbonic acid. One potential mitigation strategy to address this risk could be to lower the water-to-cement ratio, thus reducing the permeability of the concrete and thereby providing fewer pathways for corrosive substances to enter the concrete structure. As a general observation, it is recommended that concrete of type C1 be used; this is classified for potential exposure to chlorides (such as road salt) but minimal exposure to freeze-thaw conditions (McGraw-Hill, 2006. p550). Based on available geological information there has been no indication that sulphates are present in the underlying soil, thus sulphate-resistant concrete is not considered to be essential.

3.3 Hydraulic Design

The tanks were designed to accommodate predicted 1/10-year and 1/100-year flows. Based on a 1999 Northwest Hydraulics Consultants report, the 1/100-year flow expected in the spiral drain was roughly 4.5 m^3/s. To confirm this, the Rational Formula was applied, and peak flows for 1/10-year and 1/100-year events were determined to be 3.08 m^3/s and 4.47 m^3/s respectively.

3.3.1 Offline Design

The tanks were designed as an offline system, allowing water up to a certain volume to transit through the tanks unimpeded in a channel. However, when a certain flow is exceeded, the water will be at a height such that it spills over a weir and is stored in the adjacent tank (see Figure 5). This stored water will then be pumped out when it reaches a desired volume; pressure transducers installed in the tank will trigger the pumps. The design of the weir also includes a sluice gate to allow water to spill into the tank even during low flow events. This is desired in order to prevent long idle times for the pumps and to allow suspended solids to settle out of the stormwater. A siphon was considered as an alternative to in-tank pumps; however, due to a lack of sufficient elevation change between the tanks and the spiral drain, it was ultimately deemed unfeasible.

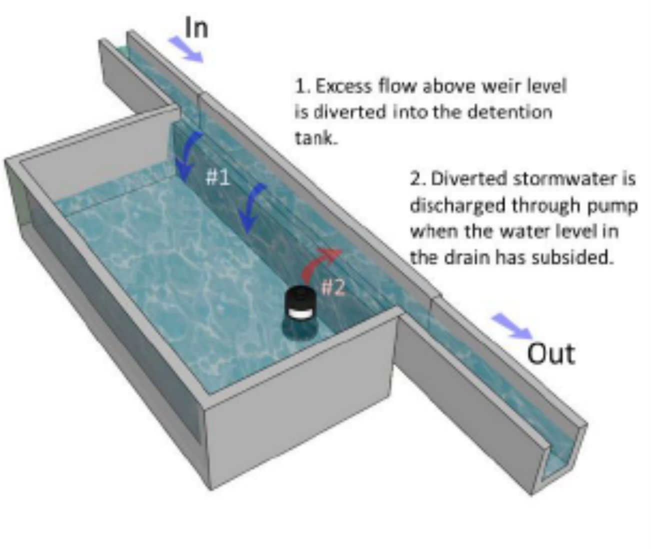


Figure 5: Offline detention system

The Chancellor and MoA tanks will see 65% to 85% of the expected flows in a large storm event. By reducing flows exiting these tanks, the storm water entering the spiral drain will be reduced below 4 m^3/s – the capacity of the drain. The Chancellor tank will begin filling as flows exceed 0.5 m^3/s and the MoA tank at flows exceeding 1.7 m^3/s. At these fill rates, it would take 55 and 75 minutes to fill the Chancellor and MoA tanks respectively. With a combined time of 130 minutes, this exceeds the two hour window desired to accommodate peak flows associated with large storm events. Additionally, pumps in the tanks will help discharge accumulated water, extending the time needed to fill.

3.3.1 Pumps

The proposed design involves the use of pumps inside the tanks to discharge water up into the water trough and eventually through the outlet. The pumps can be used to increase the time needed to fill the tanks as water is continuously discharged, including during storm events. The pumps are also used to pump water out when accumulation is not desired, such as in the event of maintenance checks or emergency repairs. The pumps are to be activated when a certain water level is reached inside the tanks, but can also be manually controlled.

The first pump located in the MoA Tank will be a 7.5’’ diameter pump designed to compensate for a 7m head loss. The second system in the Chancellor Tank features a similar 7.5” diameter pump and is also expected to overcome about 7 m head loss. The corresponding pump curve is found in Appendix C.

Pump stations will be erected aboveground at both locations, 0.5m to the east of each tank. The pump stations will mainly be used to monitor and regulate the pumps. Pump operations can be accessed through a pump house and the pumps can be controlled remotely.

3.4 Additional Considerations

3.4.1 Spiral Drain Air Vents

In 1999, Northwest Hydraulic Consultants constructed a 1:7.38 scale model of the spiral drain in order to model the operation of the drain. One of the key findings of the report was that under submerged pipe outlet conditions, the spiral drainage motion entrains and concentrates air into the centre of the pipe, making it very difficult for the air to escape. This creates instabilities in the flow regime, resulting in occasional air pressure surging, which reduces the overall efficiencies in the pipe. ONE7 Consulting considers these findings to be reasonable, and reiterates the recommendation to incorporate an orifice of minimum diameter 200mm to allow for air venting. It is anticipated that this will result in increased flow rates through the spiral drain (up to 4.19 m^3/s peak flow), which will increase the overall drainage capacity of the system.

3.4.2 Confined Space Entry

Each tank will have two access points. One will be located above the flow trough, allowing maintenance of the trough and sluice gate. A second access point will reside directly above the middle of the tank. This allows easy access for HVAC removal of accumulated solids in the depression of the tank floors.

During periodic maintenance activities, workers may be required to enter one of the tanks. While all reasonable efforts have been made to minimize potential worker hazards in the design of the detention tanks, such activities would nonetheless be deemed 'confined space entry' by WorkSafeBC. It is therefore imperative that all workers entering the tank be properly qualified and trained for confined space entry.

3.4.3 Water Quality Improvements & Environmental Considerations

The design of the underground detention tanks provides specific environmental benefits as it offers the opportunity to improve the water quality of flow exiting the system. Using the sluice gate incorporated into the weir design, stormwater can be directed into the detention tanks even at flow rates lower than the design overflow. This would allow total suspended solids (TSS) in the stormwater runoff to settle on the tank floor, thereby improving the quality of the water being pumped out. The removal of the sediment accumulated on the floor of the detention tanks could be scheduled at quarterly intervals (to be confirmed by further analysis following construction), and could be carried out by a hydro excavation (hydrovac) contractor.

The Sustainable Sites Initiative (SITES) evaluates progressive industry practices for landscape design that encompass the entire project life cycle from the planning stages to demolition. Reducing water demand, filtering and reducing stormwater runoff, providing wildlife habitat, reducing energy consumption, improving air quality, providing improvements to human health, and increasing outdoor recreation opportunities are all examples of landscape design functions that may be qualify a project for certification under the SITES program. ONE7 Consulting considers there to be additional merit to getting this project SITES certified, and while UBC has yet to successfully certify a project under this initiative, the auxiliary benefits provided by the underground detention tanks (i.e. sustainable stormwater re-use and improvement in stormwater runoff quality) are considerable enough to warrant application for certification.

3.5 Permitting

The underground tanks have been designed under the guidance of the following Provincial and Federal building codes:

- BC Building Code (2012)

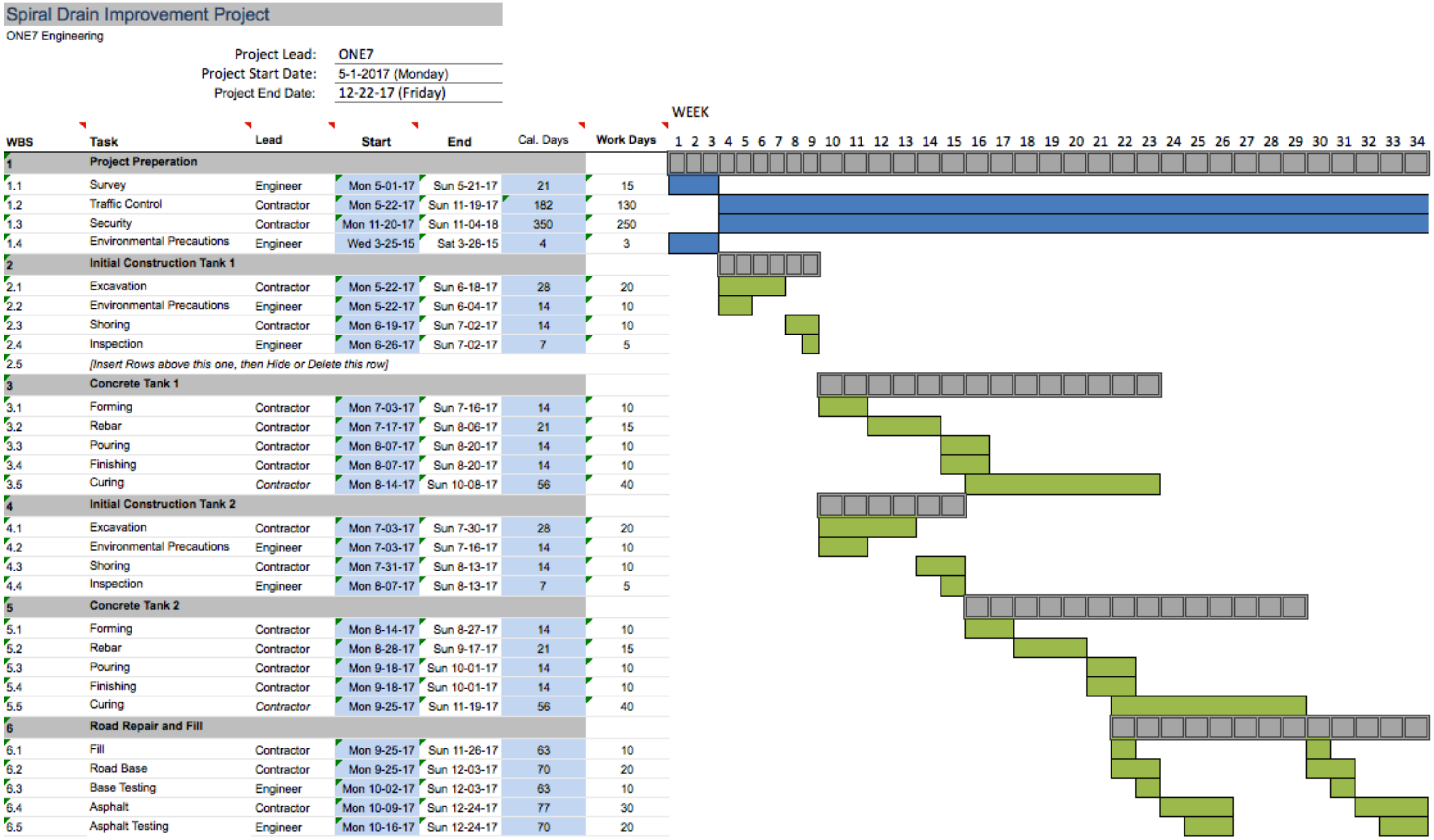
Permits that must be obtained prior to construction begin include, but are not limited to:

- UBC Building Permit (as the project has a total value greater than $2.5 million)
- UBC Excavation and Backfill Permit
- UBC Service Connection Permit for connection to the existing storm sewer system

Additionally, during construction it is imperative that the contractor be held accountable to comply with

- The Federal *Fisheries Act*
- The Federal *Species At Risk Act (SARA)*
- The Federal *Migratory Birds Convention Act (MBCA)*
- The British Columbia *Water Sustainability Act*

4.0 Schedule



Spiral Drain Improvement Project

ONE7 Engineering

Project Lead: ONE7
Project Start Date: 5-1-2017 (Monday)
Project End Date: 12-22-17 (Friday)

WBS	Task	Lead	Start	End	Cal. Days	Work Days
1	**Project Preperation**					
1.1	Survey	Engineer	Mon 5-01-17	Sun 5-21-17	21	15
1.2	Traffic Control	Contractor	Mon 5-22-17	Sun 11-19-17	182	130
1.3	Security	Contractor	Mon 11-20-17	Sun 11-04-18	350	250
1.4	Environmental Precautions	Engineer	Wed 3-25-15	Sat 3-28-15	4	3
2	**Initial Construction Tank 1**					
2.1	Excavation	Contractor	Mon 5-22-17	Sun 6-18-17	28	20
2.2	Environmental Precautions	Engineer	Mon 5-22-17	Sun 6-04-17	14	10
2.3	Shoring	Contractor	Mon 6-19-17	Sun 7-02-17	14	10
2.4	Inspection	Engineer	Mon 6-26-17	Sun 7-02-17	7	5
2.5	*[Insert Rows above this one, then Hide or Delete this row]*					
3	**Concrete Tank 1**					
3.1	Forming	Contractor	Mon 7-03-17	Sun 7-16-17	14	10
3.2	Rebar	Contractor	Mon 7-17-17	Sun 8-06-17	21	15
3.3	Pouring	Contractor	Mon 8-07-17	Sun 8-20-17	14	10
3.4	Finishing	Contractor	Mon 8-07-17	Sun 8-20-17	14	10
3.5	Curing	Contractor	Mon 8-14-17	Sun 10-08-17	56	40
4	**Initial Construction Tank 2**					
4.1	Excavation	Contractor	Mon 7-03-17	Sun 7-30-17	28	20
4.2	Environmental Precautions	Engineer	Mon 7-03-17	Sun 7-16-17	14	10
4.3	Shoring	Contractor	Mon 7-31-17	Sun 8-13-17	14	10
4.4	Inspection	Engineer	Mon 8-07-17	Sun 8-13-17	7	5
5	**Concrete Tank 2**					
5.1	Forming	Contractor	Mon 8-14-17	Sun 8-27-17	14	10
5.2	Rebar	Contractor	Mon 8-28-17	Sun 9-17-17	21	15
5.3	Pouring	Contractor	Mon 9-18-17	Sun 10-01-17	14	10
5.4	Finishing	Contractor	Mon 9-18-17	Sun 10-01-17	14	10
5.5	Curing	Contractor	Mon 9-25-17	Sun 11-19-17	56	40
6	**Road Repair and Fill**					
6.1	Fill	Contractor	Mon 9-25-17	Sun 11-26-17	63	10
6.2	Road Base	Contractor	Mon 9-25-17	Sun 12-03-17	70	20
6.3	Base Testing	Engineer	Mon 10-02-17	Sun 12-03-17	63	10
6.4	Asphalt	Contractor	Mon 10-09-17	Sun 12-24-17	77	30
6.5	Asphalt Testing	Engineer	Mon 10-16-17	Sun 12-24-17	70	20

Figure 6: Construction schedule.

Construction will commence May 1st, 2017, with the concrete forming occurring in the summer months. This mitigates traffic congestion around two major parkades: the Rose Parkade and the North Parkade. Two separate work crews are recommended; one will be able to commence the earthworks of the second tank while the concrete crew builds concrete forms and pours the structure into place. This overlap would enable efficient use of work crews, efficient use of equipment, and minimize the mobilization for the two sites. The anticipated date of substantial completion is December 22nd, 2017.

With the unique shape of the concrete forms – and the size of design – it is recommended to use an experienced contractor with thorough knowledge of concrete forming and support. Proper shoring and design of sufficient concrete forms are to be prioritized in a project of this size.

The size of equipment and machinery must also be considered while examining the construction schedule for this project, noting that UBC is a high traffic site with narrow access roads. Both tank sites provide limited space for the storage of large machinery and site trailers. As such, a preliminary planning session is suggested in order to properly allocate space on site to meet the contractor's eventual needs.

To minimize costs, the staging of each leg of the schedule is very important. Equipment costs can be minimized by ensuring that the transition of site excavations is not delayed. If the foundation work and the excavation is not completed by the time the concrete crews have completed their work on the first site, the crews will either have to demobilize from site or wait for the end of the excavation, shoring and foundation works. This is the critical path for the project and active communication between the two crews should be maintained daily, especially nearing the end of their anticipated completion of each portion of the construction. It is recommended that weekly construction meetings are held with the contractor and subcontractors on site to ensure the smooth progression of the project and to clearly identify any issues as they occur.

In Section 8.0, alternative land uses above each retention tank are considered. This has the potential to impact the end date of the project if alternative land uses were preferred over the installation of asphalt parking lots.

5.0 Costs

A Class B cost estimate was employed based on the up-to-date drawings and specifications. The purpose of this estimate is to give an indication of the feasibility of this project and its involved construction processes. It can also act as a reliable source for actual quantity takeoff and can be referenced as part of the bidding process. Therefore, this estimate acts as the current and final Engineer's Estimate for construction and bidding. A thorough breakdown of the cost estimates can be found in Appendix D.

5.1 Estimation Scope

As part of the Class B cost estimate the construction expenses, operations costs, permit expenditures, and a contingency were all considered. Therefore, the cost projections involved are: materials, workforce, equipment, transportation, and maintenance. Management and engineering contributions were also included as part of the expenses. Additionally, contingency and risk were also accounted for as eventualities or unforeseen possibilities that may happen during the project lifetime. Contingency was evaluated at 10% based on previous experience.

All of the cost estimates are calculated or converted in actual Canadian dollars. British Columbia Provincial Sales Tax (P.S.T) is also charged on the purchased/rented materials and equipment in this cost estimate. Inflation is not included as part of this engineer's estimation scope.

5.2 Estimating Methodology

A combination approach of both the actual cost and historic data approach was used as the estimating method. This took into consideration the actual performance of the work, and compared historic data related to this project that are similar in magnitude and scope.

Material and equipment costs were based on actual market prices and the required quantity was calculated according to drawing specifications. Subsequent labor and equipment estimates were divided into crews using an actual work performance basis, while costs associated with construction methods were correlated to historic data. The work rates of each specific employee with their respective equipment were then based on the average salary rates in BC for their respective position.

5.3 Estimate Accuracy

This Class B cost estimated carries a corresponding assessment accuracy of ± 25%. It is important to note that the contingency accounts for eventual planning omissions, variations in prices and design scope changes. Accuracy on the other hand is a testament for liability, and describes how error-free one's estimate is.

To improve the accuracy of the estimate, it is advised to hire an economist to study the effects of inflation and escalation in the grand scale of this project. Furthermore, as the project progresses and milestones are reached, better estimates will be evaluated.

5.4 Cost Summary

The final class B total cost estimate for the project is $5,500,000 ± 25%. A simplified project cost breakdown is provided in Table 10 below. A complete breakdown of the cost estimates can be found in Appendix D.

Table 10: Simplified project cost breakdown.

Cost Description	Cost (CAD $)
Materials	$2,500,000.00
Permits	$100,000.00
Labour	$1,300,000.00
Equipment	$1,100,000.00
Contingency	$500,000.00
Total	$5,500,000.00

A contingency of $500,000, corresponding to 10% of the total project cost, has been included in the cost estimate as per standard industry practice. These funds will remain unused unless needed to compensate for unforeseen circumstances. This may include increases in labour or material costs, as well as design changes and additional engineering required during the construction phase.

6.0 Triple Bottom Line

Aside from pure economic analysis, it is important to consider the project benefits in terms of the Triple Bottom Line.

6.1 Social Benefits

UBC strives to bring community integration and safety to its campus and its surrounding neighbours. The underground detention tanks aid this goal in a number of ways. First, flooding of the UBC campus and its neighbourhoods has been an issue during heavy rain storms; the tanks mitigate this and show UBC's proactivity in defending against climate change. Next, the tanks, being installed underground, are non-intrusive, and the land on top can be used for facilities that are both aesthetically pleasing and help bring learning and integration to the surrounding community. Finally, the tanks provide a means of containing a 1/100-year storm without the molestation of the spiral drain – a part of UBC's engineering heritage.

6.2 Economic Benefits

The underground detention tanks, though costly to install, also bring an economic benefit to UBC. By developing the capacity to retain a 1/100-year rain event, UBC protects its property from flooding and water damage. The neighbouring residents will also see the benefits of flooding protection, and this may prevent a potential lawsuit in the future. Additionally, by storing water on campus, UBC has avoided the need to install new, expensive stormwater discharge infrastructure. Finally, a large amount of water will now be stored on campus; should suitable water re-use activities come about, there may be monetary savings through reducing the amount of water bought from Metro Vancouver.

6.3 Environmental Benefits

UBC has long been a proponent of environmental stewardship. As such, the underground detention tanks will continue in that theme. The cliffs surrounding UBC – and the residences constructed near them – are sensitive to erosion. Containing the 1/100-year storm greatly reduces the effects of stormwater on the cliffs. Moreover, the tanks can essentially act as settling chambers. This results in a reduce concentration of total suspended solids (TSS) in the stormwater being discharged to the ocean through the spiral drain infrastructure. Finally, by encouraging the re-use of detained stormwater, pressure can be reduced on Metro Vancouver's drinking water reservoirs in times of drought.

7.0 Project Risks and Stakeholders

7.1 Stakeholder Analysis

The key stakeholders of this project were identified in a previous ONE7 Engineering report. The following parties are considered to be integral contributors to or beneficiaries of a successful completion of the detention tank project:

UBC ONE7 Engineering group: Project planning and design team responsible for providing feasible design options to increase the capacity of the north drainage catchment of the UBC campus, and a corresponding work plan consisting of cost estimates, project schedules, and recommendations on operation and maintenance.

UBC Students and Faculty: The main beneficiaries of this project. The infrastructure designed by ONE7 Engineering will protect the students, faculty, and campus infrastructure from future flooding and/or other water related disasters.

Neighbourhood: People living in the surrounding area will benefit from this project as the adjacent neighbourhoods will be protected from excessive flooding. In addition, the project will improve the local environmental values and minimize the impact of campus discharge on neighbouring watercourses.

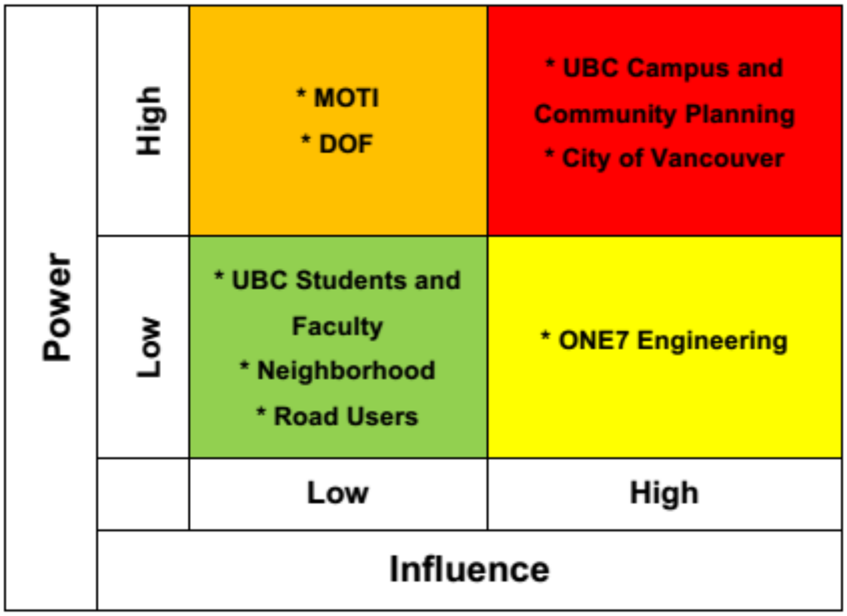
Road Users: An increase in the capacity of the north drainage catchment of the UBC campus the will significantly reduce the potential risk of flooding on the road. This will impact vehicles, bicycles and pedestrians on the road.

Ministry of Transportation and Infrastructure (MOTI): The roads surrounding UBC's north catchment are owned by MOTI; any construction on or adjacent to these roads should meet the criteria set forth by MOTI. Moreover, any anticipated traffic issues or delays resulting from the construction receive MOTI consultation.

Federal Department of Fisheries and Oceans (DFO): The Federal Department of Fisheries and Oceans maintains goals for retaining runoff volume, maintaining and improving quality of runoff discharge to streams, as well as reducing the peak runoff flow rates prior to discharge into receiving waters. These three goals will be achieved by the design produced by the ONE7 engineering group.

City of Vancouver: An increase in the capacity of the north drainage catchment of the UBC campus will decrease the risk of destructive flooding, thus reducing the risk of property loss due to flooding.

Figure 7 displays the project stakeholders in a power-influence chart to categorize them for the benefit of the project proponent.



Power		Influence: Low	Influence: High
Power	High	* MOTI * DOF	* UBC Campus and Community Planning * City of Vancouver
Power	Low	* UBC Students and Faculty * Neighborhood * Road Users	* ONE7 Engineering
		Low	High
		Influence	

Figure 7: Influence vs Power chart.

7.2 Risk Identification and Management

The following risks to this project have been identified, and appropriate response actions have been suggested:

Table 11: Risk identification and management.

Risk #	Description	Response
1	Structural failure causes collapse or leaking of detention tank	Avoid by ensuring that design work is completed to a high standard and monitoring contractor for quality assurance & quality control
2	Detention tank fails to function as intended during storm event	Avoid by ensuring that design work is completed to a high standard as well as having back-up pump and power supply on hand at site
3	Schedule delays in construction period cause inconvenience to local residents and angers stakeholders	Mitigate by keeping local residents informed of schedule changes as early as possible
4	Cost overrun	Mitigate through thorough budget management and professional project management practices
5	Local residents complain due to construction noise (?)	Accept risk
6	Eutrophication of stormwater retained in tank	Minimize by ensuring periodic flushing of tanks via sluice gate
7	Solids settled in tank cannot be properly removed	Transfer risk by hiring hydrovac contractor
8	Injury, Fatality or Worker's Compensation claim occurs related to tank maintenance	Transfer risk to owner by specifying that all workers entering the tank must be properly qualified and trained for confined space entry by WorkSafe BC
9	Injury or Fatality occurs during construction phase	Avoid risk by ensuring that construction contractor is reputable, and follows site specific safety plan
10	Applicable permits not issued in time for construction begin	Minimize by identifying and applying for all relevant permits as early as possible

The risks above were evaluated in a risk matrix as shown below, incorporating the appropriate mitigation strategies. As shown by the risk matrix, none of the identified risks to this project pose a threat significant enough to halt the project.

Table 12: Risk matrix.

Probability	Almost Certain		🟨	🟥	🟥	🟥
	Likely	5	🟨	🟨	🟥	🟥
	Moderate		3	🟨 4	🟨 10	🟥
	Unlikely		6	7	🟨	🟨 2
	Rare				8, 9	1
		Negligible	Low	Medium	High	Extreme
Impact						

8.0 Alternate Land Uses

With UBC's limited space available for land development, optimization of space is crucial for future developments. Although this report proposes a parking lot on top of the retention tanks, alternative possible uses for this space have also been examined.

Figure 8: Outdoor road hockey box.

The first proposed alternate use would be the installation of an outdoor road hockey box. With UBC campaigning for an increase in the physical activity of its students, providing more sporting options would increase the likelihood of student participation; this has been shown to augment mental wellbeing. The location above the Chancellor Tank would provide easy access to both residents of Walter Gage Student Residence and the nearby residents off campus, as well as to commuter students who arrive by bus or by car. These boxes require minimal construction, comprising of a layer of low grade asphalt, bordered by treated wood or plywood board and chain link cage covering each end of the box. As well, with hockey being one of Canada's official sports, this would offer the opportunity for international students' exposure to Canadian culture, increasing the Canadian identity of the campus, and offering an open space to try a new sport. This may reflect more positively in international students looking for a unique university experience.

Figure 9: Community garden.

The second proposed alternative land use would be the installation of a brick terrace space adjacent to a community garden above the MoA Tank. Adjacent to the Museum of Anthropology, the amount of tourist foot traffic is high, and this space would provide additional incentive to explore the area or to relax. The community garden would represent the urban sustainability movement which is constantly growing in Vancouver. Local residents, students of UBC, and visitors alike could contribute to the garden or simply admire it as a symbol of community and sustainability. The source of irrigation would be the detained water in the underground tanks. A pump would pull stormwater from the sewer into a sand filter encased in an acrylic casing, above ground, and distributed to the plants. This sand filter would be used as an educational tool to demonstrate water treatment processes. As well, this would demonstrate the process of water reuse and the importance of water conservation.

Stormwater reuse is permitted for irrigation purposes in the Vancouver area, and this exhibit would raise awareness for the potential of residential rainwater reuse.

While the design of the retention tanks has been finalized, it should remain open to collaboration on unique solutions for the overlay of the tanks. With the limited space available to UBC, it should be optimized to reflect the needs and values as the campus of a sustainable, forward thinking and health conscious university.

9.0 Implementation of Building information Modelling (BIM)

The use of BIM applications was invaluable during the design phase of the project. Several modelling approaches were conducted using different kinds of software.

At the beginning of the design process, AutoCAD was used to establish the structural model, and to determine the dimensions and rebar installation of the beams, lateral walls, and footings. The architectural model was then built using AutoCAD Revit and SketchUp to get a panoramic 3D view of the tank. For the scheduling and cost estimating, the construction model was built using AutoCAD Navisworks. Finally, AutoCAD Revit helped to determine the precise amount of each material required.

Table 13: Software used in the project design.

Model type	Software	Model Scope
Architectural Model	AutoCAD Revit, SketchUp	3D Architectural design model
Engineering Model	AutoCAD	3D structure model and contract drawings
Construction Model	AutoCAD Navisworks	4D or 5D model with schedule and cost estimate

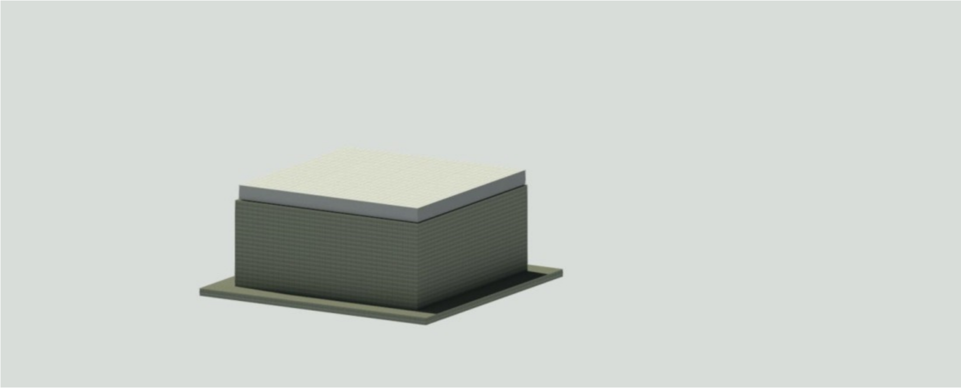


Figure 10: AutoCAD Revit model of a detention tank.

10.0 Conclusion

The main objective of the design presented in this technical report is to improve the capacity of the storm sewer infrastructure draining the north catchment of UBC's campus through the spiral drain. The design was developed in accordance with the provide design criteria, which specified that the system must be able to withstand a 1/100-year storm event. The design of two offline, concrete, underground detention tanks satisfies the capacity requirements.

The total constructions costs are estimated at $5.5 million, and construction itself should take approximately 7 months. The triple bottom line was investigated and, despite the large capital cost, a number of social, economic, and environmental benefits arise from the tanks.

Finally, there is an opportunity to re-design the land directly above the tanks. This report proposes a road hockey box and a community garden, but any positive landscape is welcome.

UBC is an environmental steward and a leading-edge university. The installation of the underground detention tanks will further cement this reputation.

11.0 References

1. Environment Canada. *Historical Climate Data*. 18 11 2015. 15 02 2017.

2. GeoAdvice Engineering Inc. *UBC Stormwater Model System Analysis, Detention Analysis and System Optimization*. Report. Port Moody, 2013.

3. McGraw-Hill. *Clarifier design: WEF manual of practice no. FD-8* (2nd ed.). (2006). doi:10.1036/0071464166

4. National Building Code of Canada. National Research Council Canada. 2015.

5. Northwest Hydraulic Consultants. *U.E.L. Drainage and Shaft Tunnel Hydraulic Model Study*. Report. North Vancouver: Northwest Hydraulic Consultants, 1999.

6. Piteau Associates. *Hydrogeological and Geotechnical Assessment of Northwest Area UBC Campus, Vancouver*. Report. North Vancouver: Piteau Associates, 2002.

7. University of British Columbia. *UBC Integrated Stormwater Management Draft Plan*. Vancouver: University of British Columbia, 2014.

8. WorkSafeBC. *Confined Space Entry Program. A Reference Manual*. WorkSafeBC. 2007. Web. March. 2017.

Appendix A. Sample Calculations

Rational Formula

$$Q = 0.28 \times C \times I \times A = 0.28 \times 0.65 \times 24.6 \times 1.0 = 4.47\frac{m^3}{s}$$

Where:

C = 0.55 (urban, flat) + 0.1 (RI > 25 years)

I = 24.6 mm/hour for a 1/100-year event (Environment Canada)

A = 1.0 km as an approximate measure of UBC's north catchment area (Environment Canada)

Manning's Formula

$$Q = \frac{A}{n} \times Rh^{2/3} \times S^{1/2}$$

Where:

A = cross-sectional area of trough

n = Manning's "n", taken to be 0.013

Rh = Hydraulic Radius

S = Slope

Pump Curve

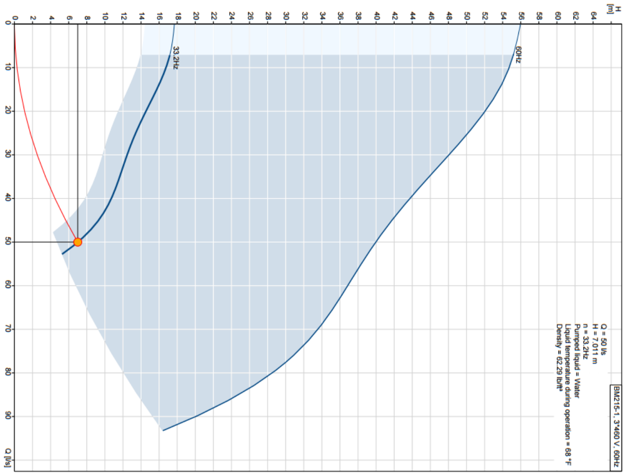


Figure 11: Pump curve.

Appendix B. Design Drawings

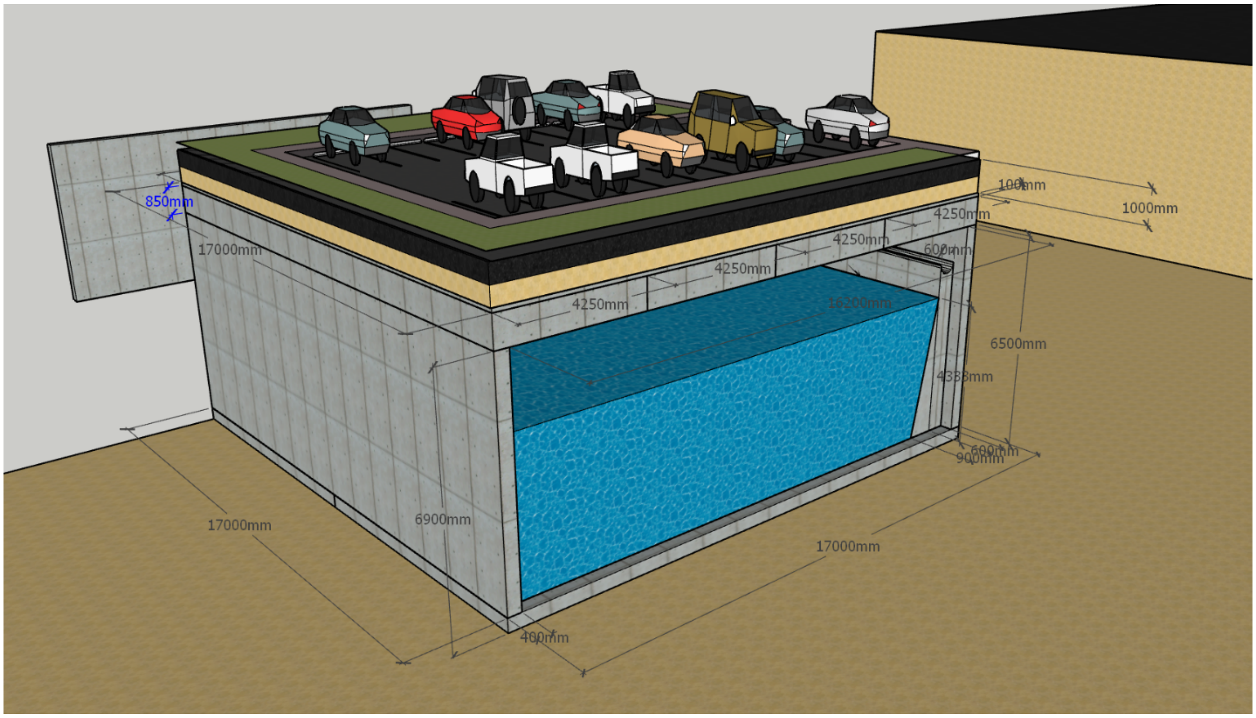
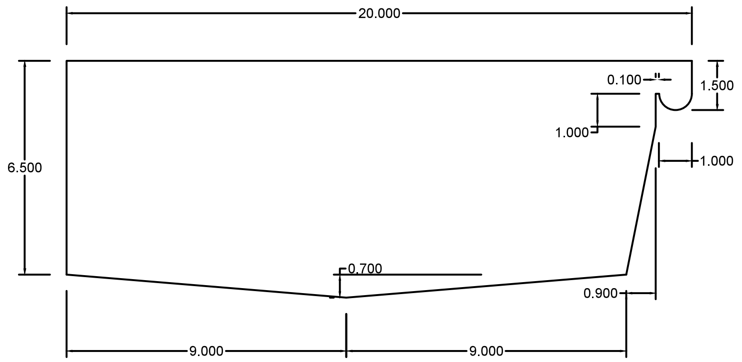
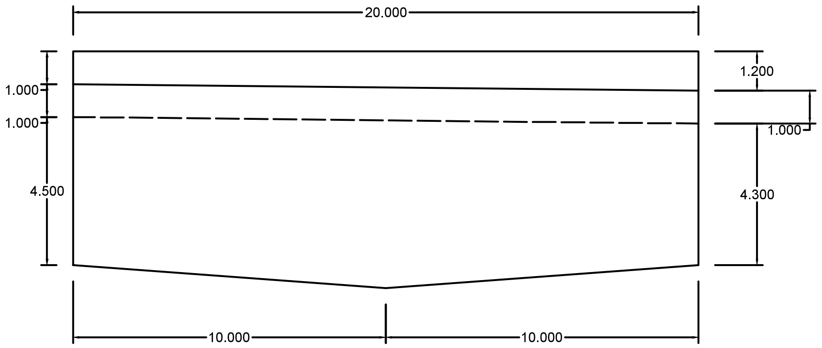


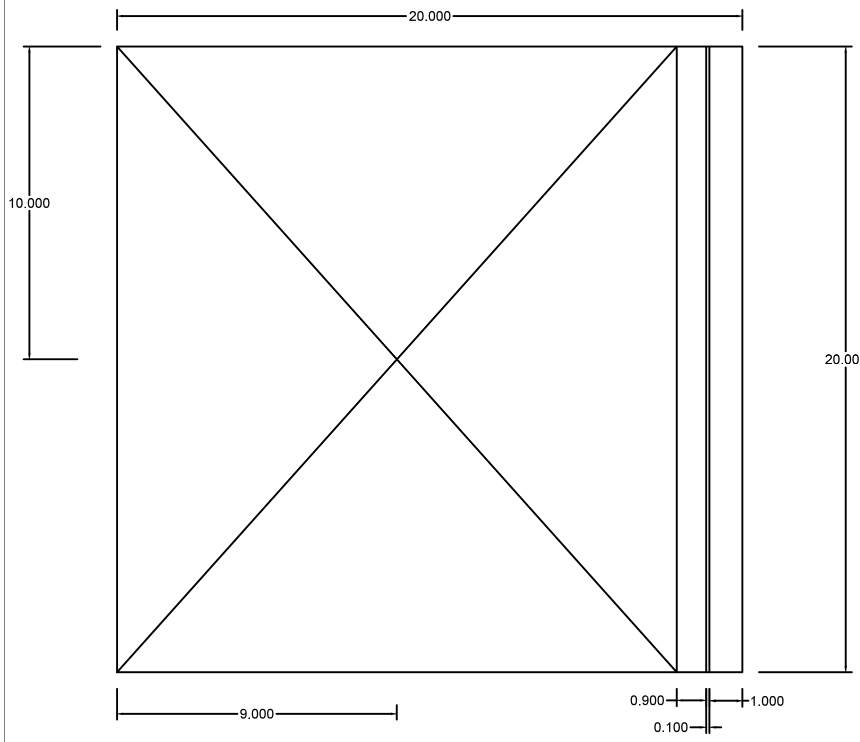
Figure 12: Conceptual model

FRONT VIEW



SIDE VIEW

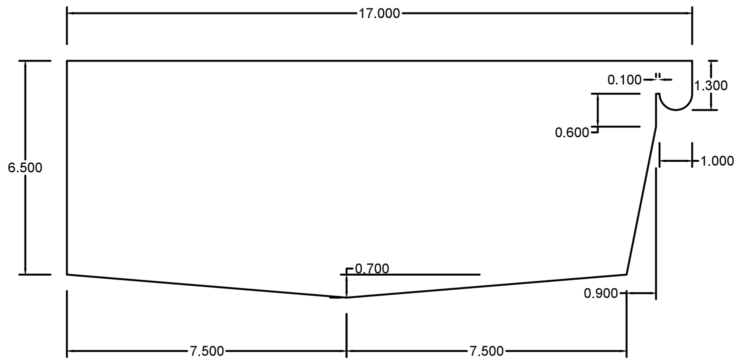




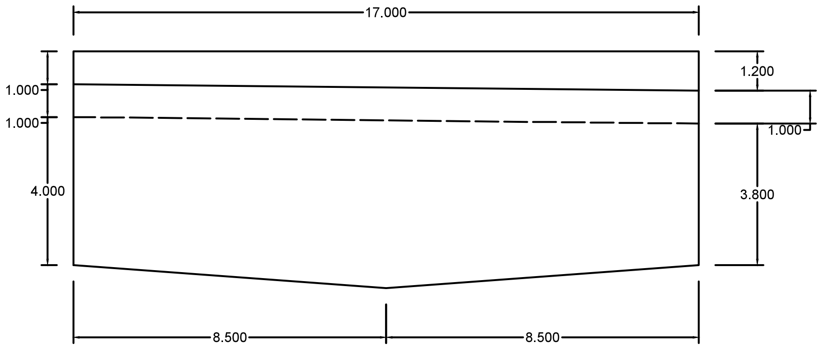
TOP VIEW

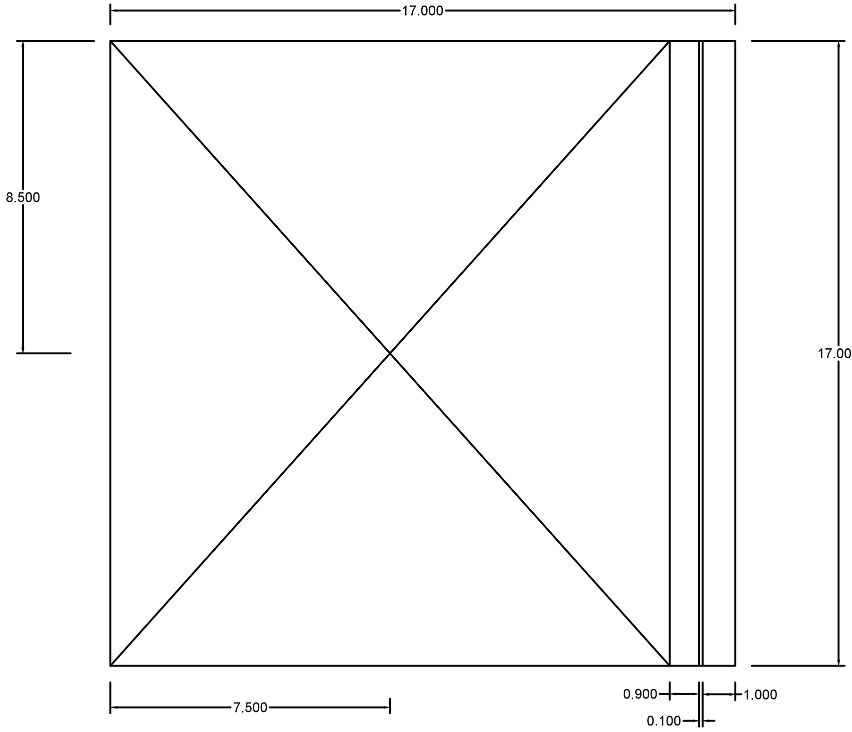
MUSEUM OF ANTHROPOLOGY TANK	
CIVL 446	ONE7 ENGINEERING
KIT CAUFIELD	SCALE 1:200
February 20, 2017	0 1 2

FRONT VIEW



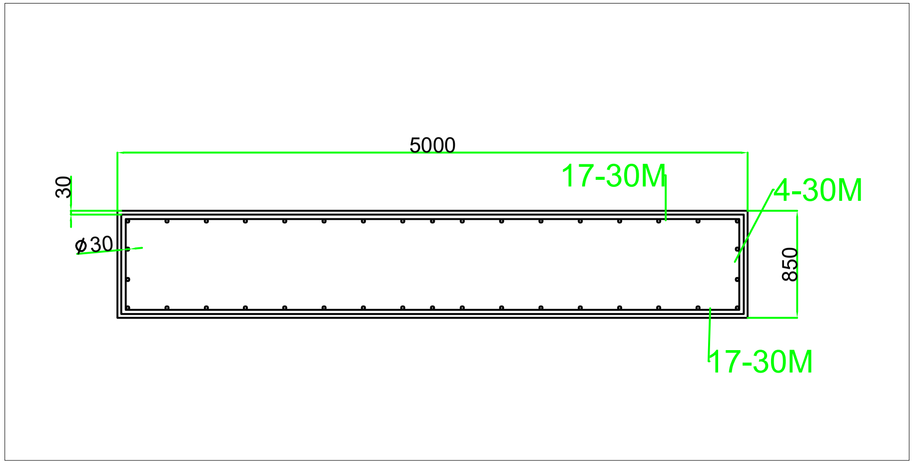
SIDE VIEW



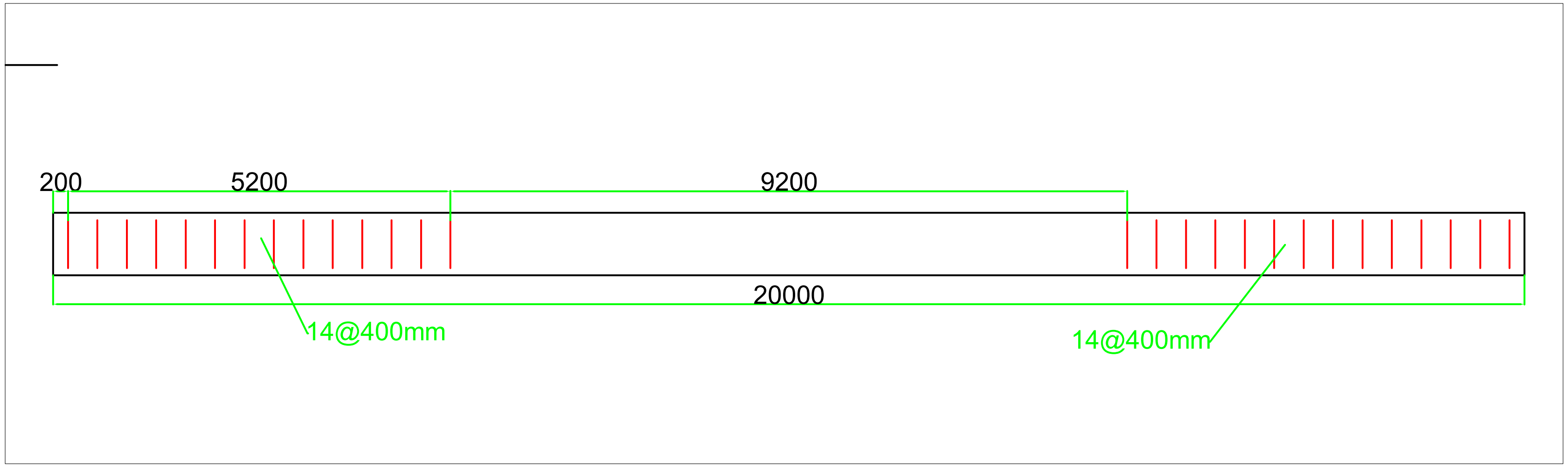


TOP VIEW

CHANCELLOR BLVD TANK	
CIVL 446	ONE7 ENGINEERING
KIT CAUFIELD	SCALE 1:200
February 20, 2017	0 1 2



FRONT VIEW OF A BEAM
1:60



SIDE VIEW: REBAR SPACING
1:100

Issued for	Issue	Date	Issued By
Approval	1	2017.04.02	One7

Relevant Information

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	2017.03.16	QL and SL	SL	SL	

Seal

One7 Engineering Consultants Ltd.

Reinforced Concrete Beam Tank MoA

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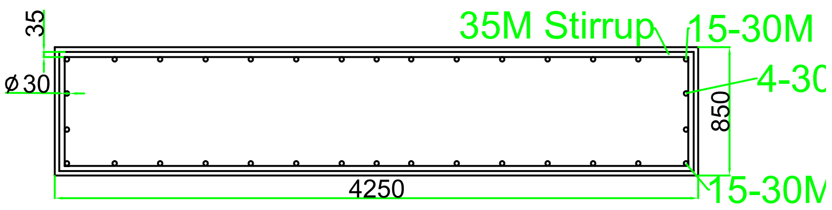
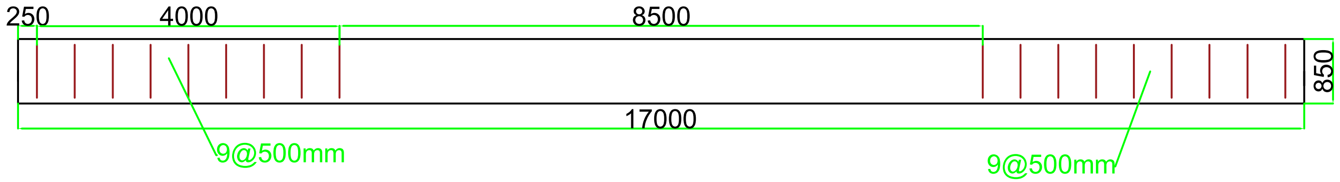
Clients: UBC			**Revision**	0	**Drawing No.**



FRONT VIEW OF A BEAM
1:50



SIDE VIEW: REBAR SPACING
1:100

Issued for	Issue	Date	Issued By
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Relevant Information

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One7 Engineering Consultants Ltd.

Reinforced Concrete Beam Tank Chancellor

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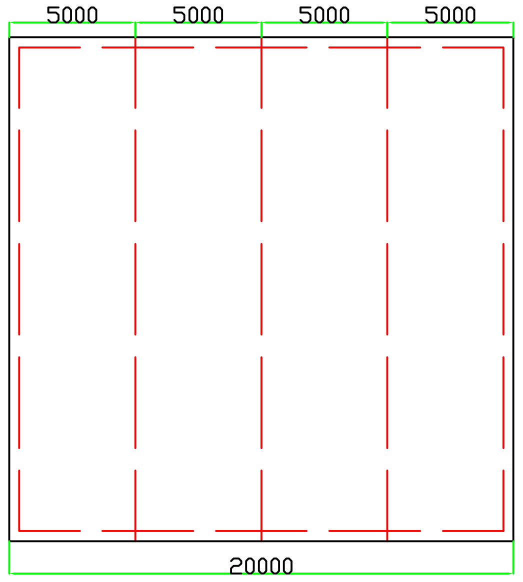

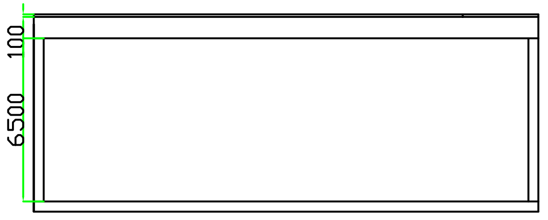

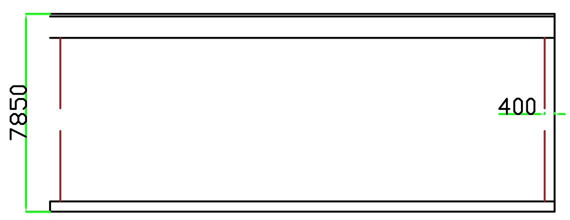

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Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	2017.03.16	QL and SL	SL	SL	

Seal

One7 Engineering Consultants Ltd.

Reinforced Concrete Beam Tank Chancellor

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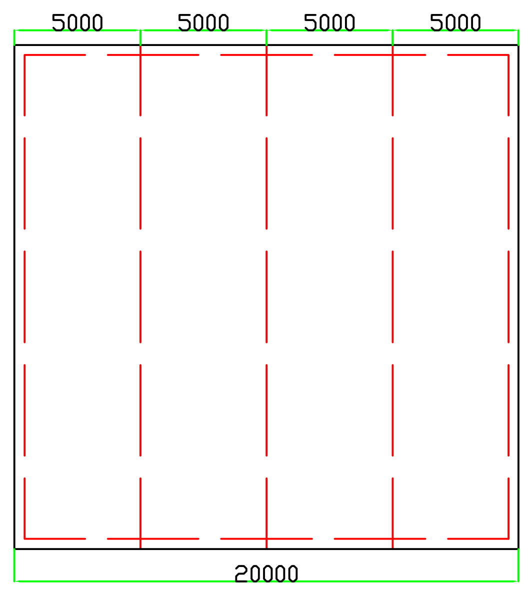

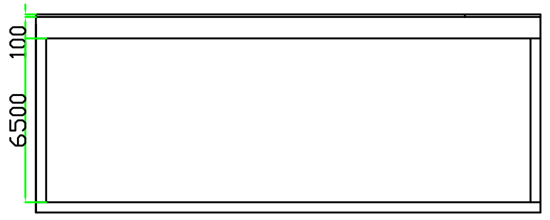

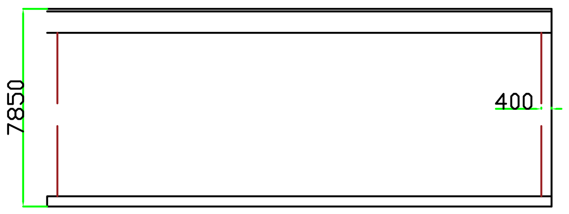

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Approval	1	2017.04.02	One7		0	2017.03.16	QL and SL	SL	SL	

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One7 Engineering Consultants Ltd.

Reinforced Concrete Beam Tank MoA

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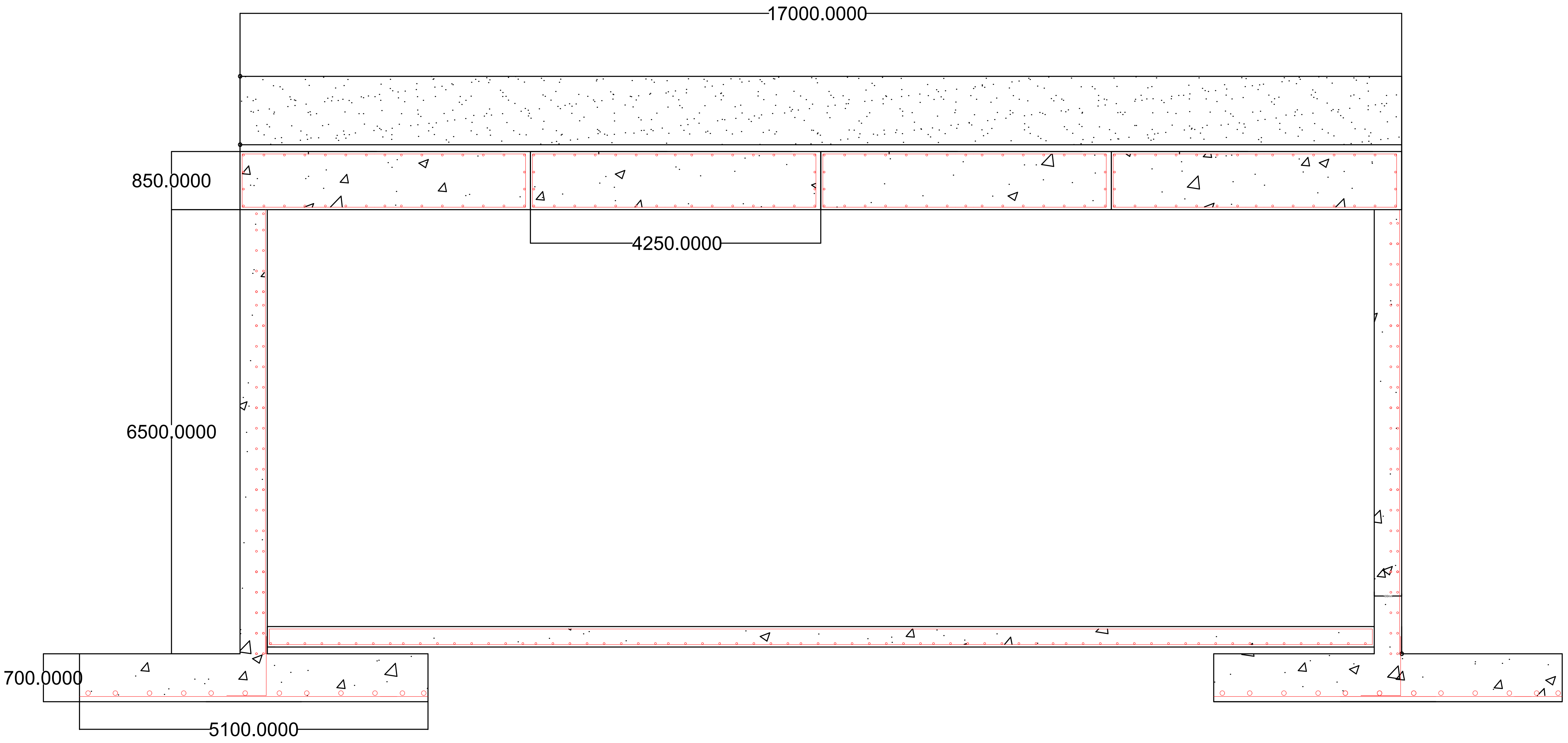

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Issued for	Issue	Date	Issued By
Approval	1	2017.04.02	One7

Relevant Information

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	2017.03.16	QL and SL	QL	QL	

Seal

One7 Engineering Consultants Ltd.

Rebar Insulation for the Detention Located at MOA

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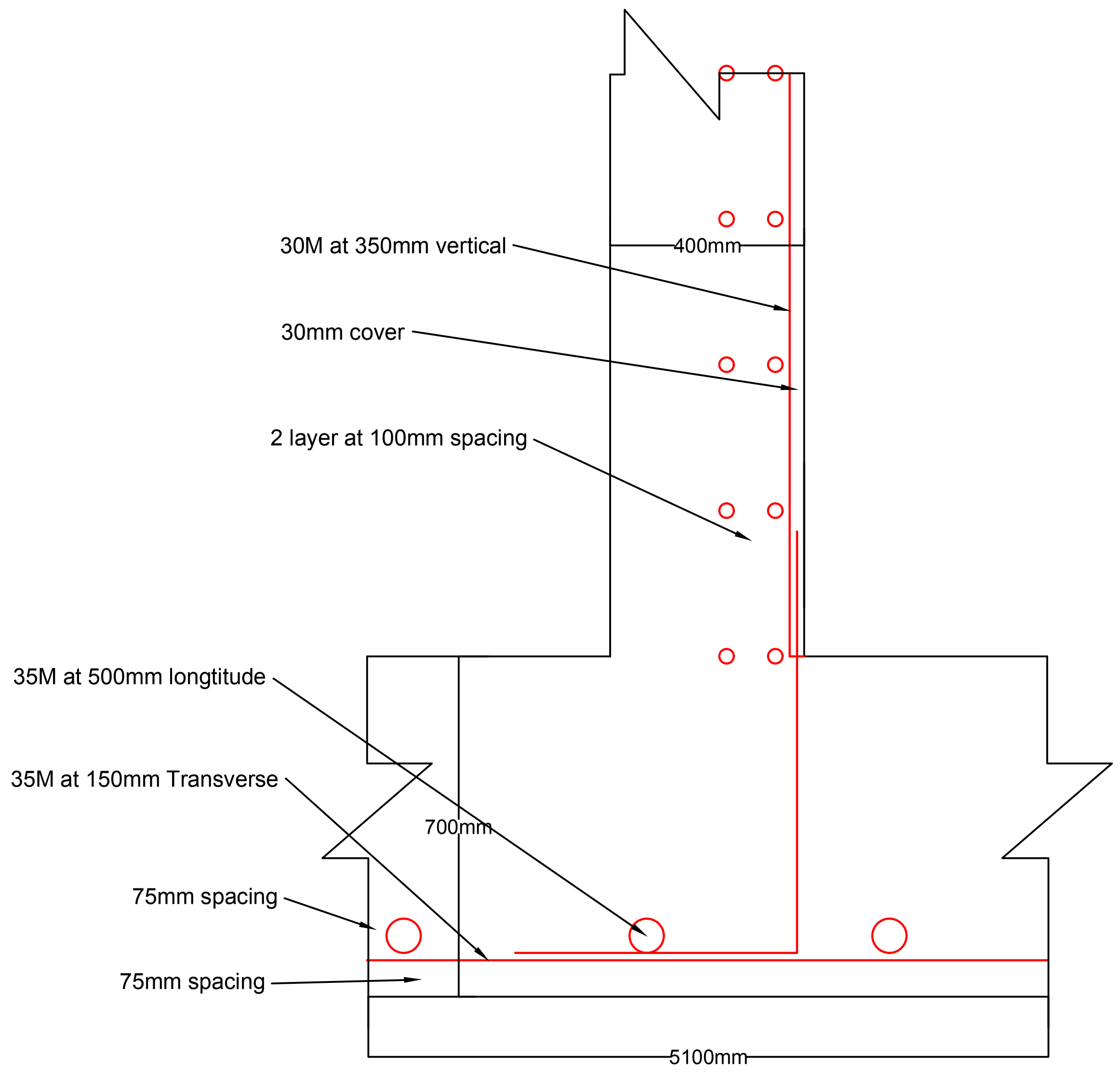
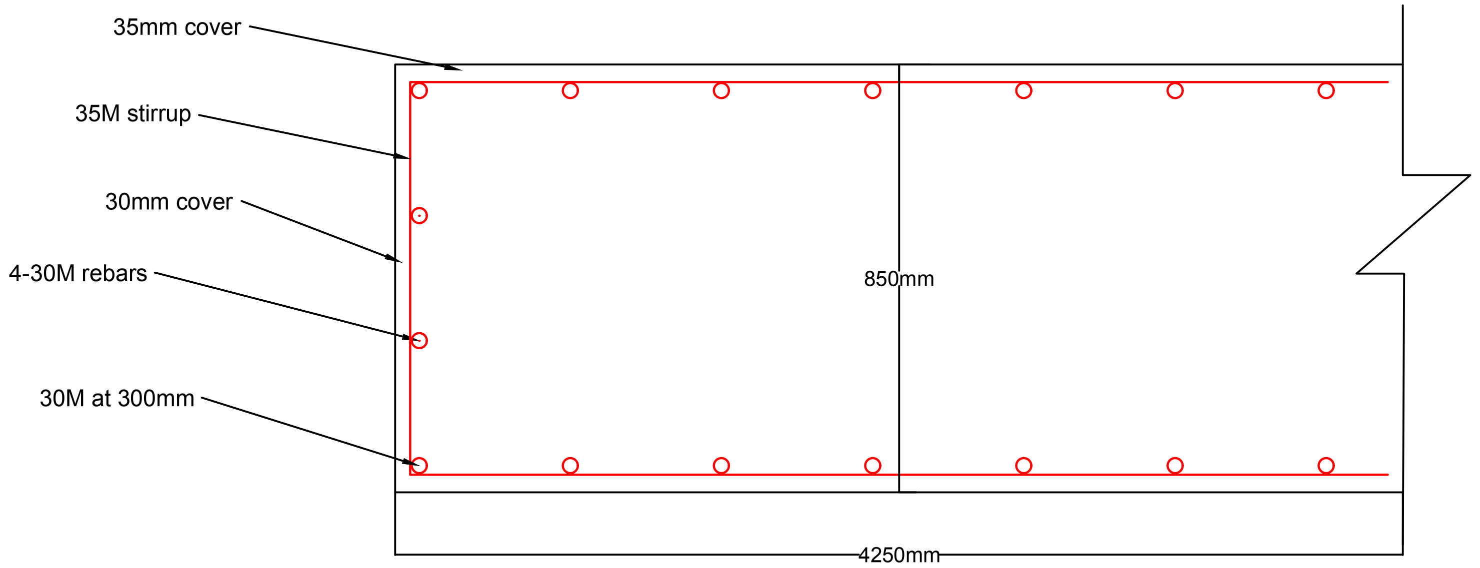
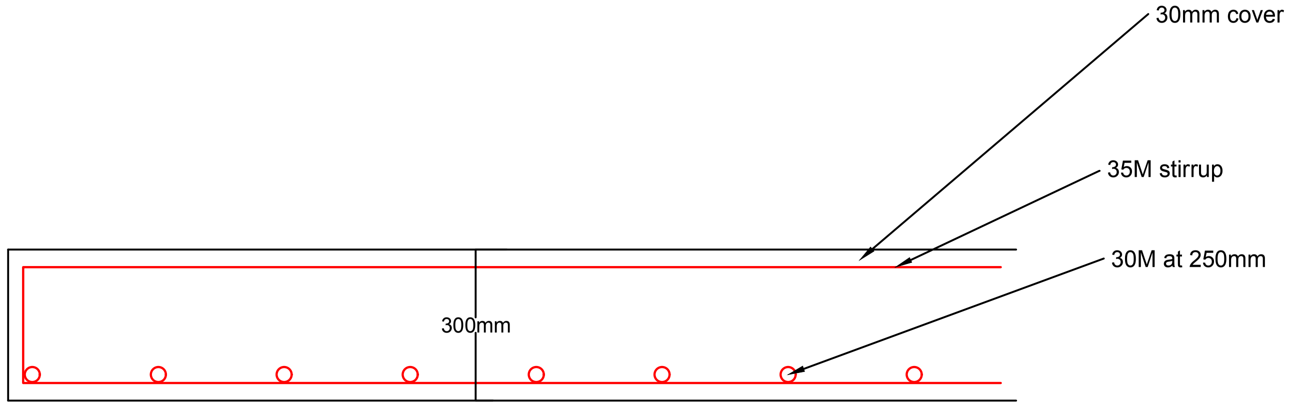


Side Wall and Strip Footing



Top Beam



Bottom Slab

Issued Information

Issued for	Issue	Date	Issued By
Approval	1	2017.04.02	One7

Relevant Information

Rev. No.	Date	Designed	Drawn	Checked	Description of Revision
0	2017.03.16	QL and SL	QL	QL	

Seal

One7 Engineering Consultants Ltd.

Rebar Insulation of Side Wall, Strip Footing, Bottom Slab and Top Beam for the Detention Located at MOA

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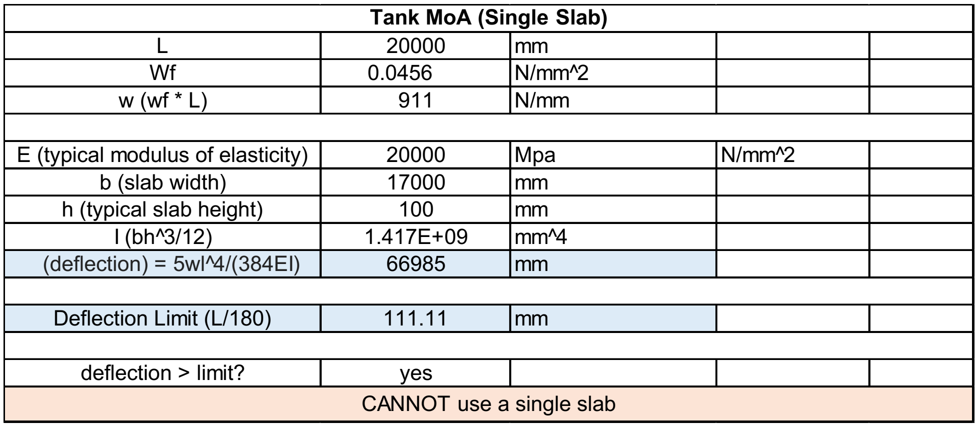
Sheet	1	of	1	**Paper**	A3
Clients: UBC				**Revision**	0

S1

Drawing No.

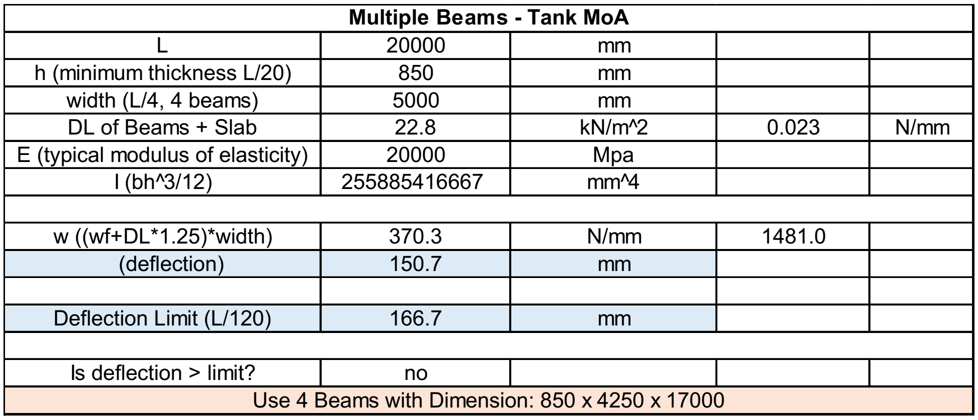
Appendix C. Concrete Design Calculations

Table 14: MoA Tank single-slab deflection failure.



Tank MoA (Single Slab)				
L	20000	mm		
Wf	0.0456	N/mm^2		
w (wf * L)	911	N/mm		
E (typical modulus of elasticity)	20000	Mpa	N/mm^2	
b (slab width)	17000	mm		
h (typical slab height)	100	mm		
I (bh^3/12)	1.417E+09	mm^4		
(deflection) = 5wl^4/(384EI)	66985	mm		
Deflection Limit (L/180)	111.11	mm		
deflection > limit?	yes			
CANNOT use a single slab				

Table 15: MoA tank multiple-beam deflection calculations.

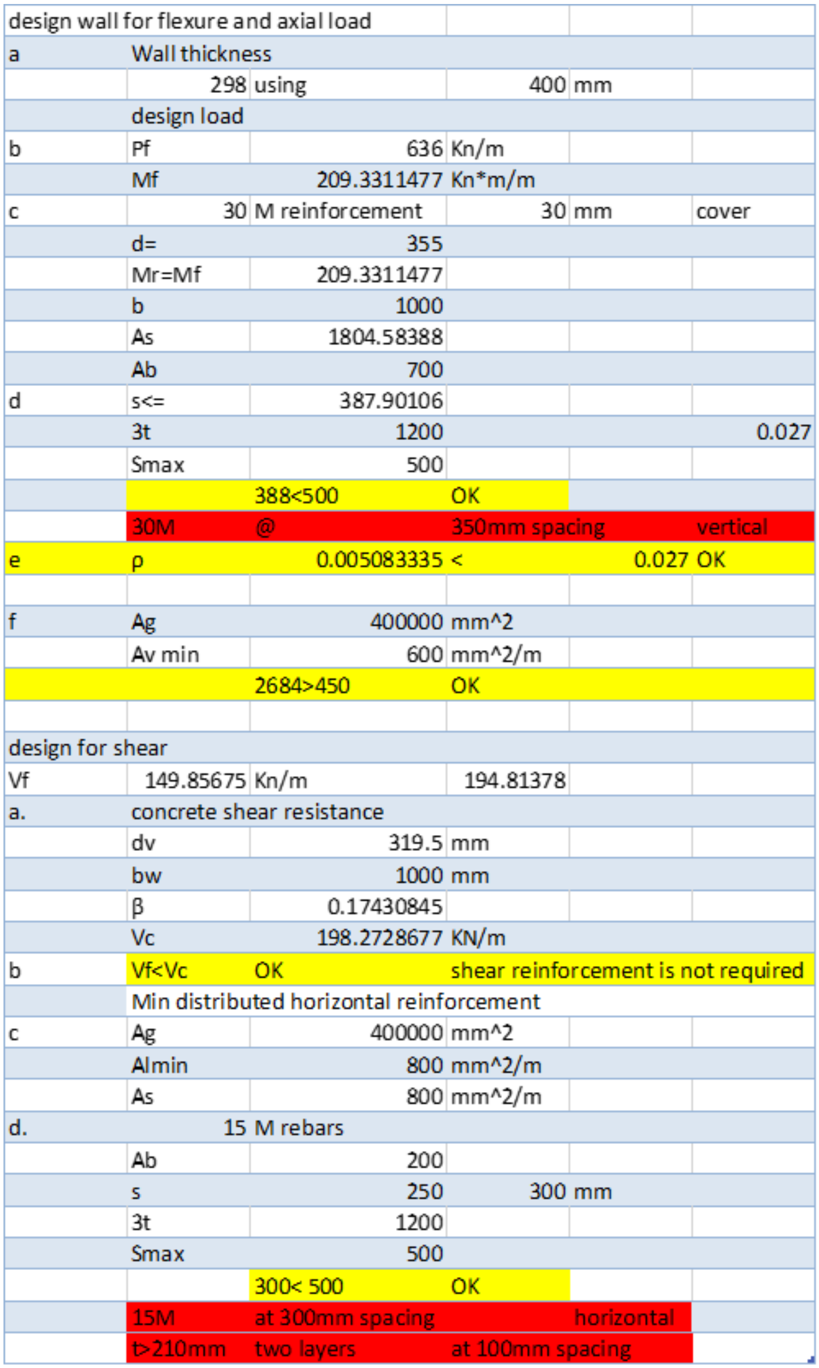


Multiple Beams - Tank MoA				
L	20000	mm		
h (minimum thickness L/20)	850	mm		
width (L/4, 4 beams)	5000	mm		
DL of Beams + Slab	22.8	kN/m^2	0.023	N/mm
E (typical modulus of elasticity)	20000	Mpa		
I (bh^3/12)	255885416667	mm^4		
w ((wf+DL*1.25)*width)	370.3	N/mm	1481.0	
(deflection)	150.7	mm		
Deflection Limit (L/120)	166.7	mm		
Is deflection > limit?	no			
Use 4 Beams with Dimension: 850 x 4250 x 17000				

Table 16: Chancellor Tank shear reinforcement.

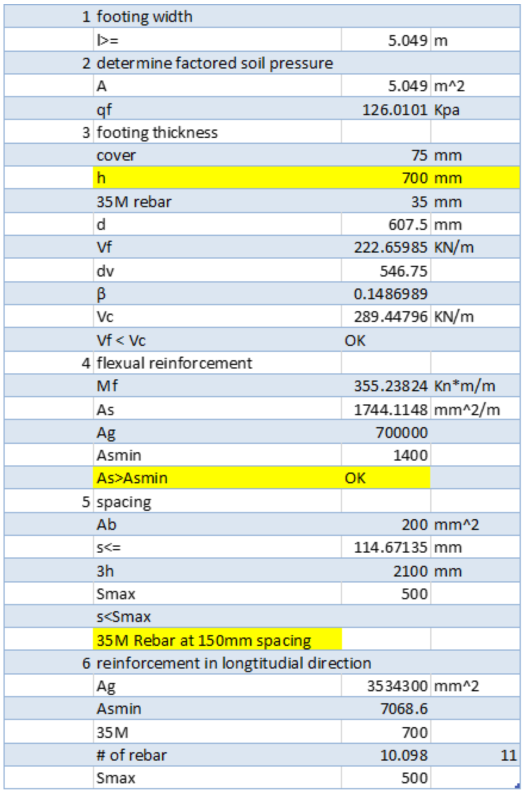
Shear Reinforcement - Tank Chancellor				
L	17000	mm		
bw	4250	mm		
h	850	mm		
ds (35M)	35	mm		
db (30M)	30	mm		
cover	30	mm		
d = h - cover - ds- db/2	770	mm		
dv=max(0.9d, 0.72h)	693	mm		
β = 230/(1000+dv)	0.136			
$V_c = \phi_c \lambda \beta \sqrt{f_c'} b_w d_v$				
Vc	1424515	N	1425	kN
Vf on each ends (w*L/2)	2675056	N	2675	kN
Vf @ dv	2456960	N	2457	kN
Vf @ dv > Vc ?	yes	Shear Reinforcement required		
Vs >= Vf-Vc	1032445	N	1032	kN
$V_s = \frac{\phi_s A_v f_y d_v \cot\theta}{s}$				
Av (35M, 1000*2)	2000	mm^2		
cot(theta)	1.43			
s (spacing)	653			
Smax = min(0.7dv, 600, s above)	485	use 400mm		
Check Minimum Stirrup Requirements (A23.3 Cl.11.2.8.2)				
$A_{v\min} = 0.06\sqrt{f_c'}\left(\frac{b_w s}{f_y}\right)$ (A23.3 Eq.11.1)				
Avmin	1693.838856			
Av > Avmin?	yes	check ok		
check max Vr				
$\max V_r = 0.25\phi_c f_c' b_w d_v$				
max Vr	14358094	N	14358	kN
Actual Vs with new S	1389143	N	1389	kN
Actual Vr with new Vs = Vc+Vs	2813658	N	2814	kN
check maxVr > Vr	yes	check ok		
Rebar sizing				
db min. =s/16	30	use db=30M		
Minimum distance between horizontal rebards = 300mm, so need 2 horizontal rebars				
Minimum distance between rebar on the bottom and top			300	mm
Region where shear reinforcement is not required				
$V_{fx} = V_{f\text{midspan}} + \left(\frac{\frac{l_n}{2}-x}{\frac{l_n}{2}}\right)(V_f - V_{f\text{midspan}})$				
Vfx=Vc	1424515	N	1424.515	kN
Vf	2675056			
Vfmidspan	0			
L/2	8500			
x	3974	mm	from midspan	

Table 17: MoA Tank lateral wall loads.



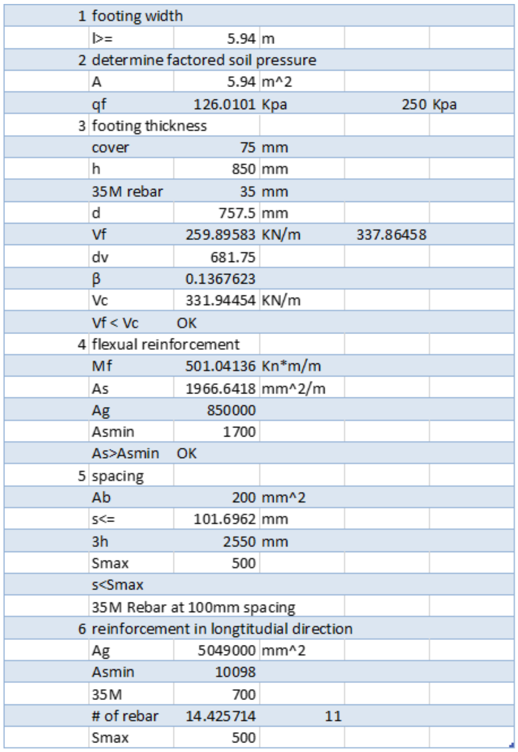
design wall for flexure and axial load					
a	Wall thickness				
	298	using	400	mm	
	design load				
b	Pf	636	Kn/m		
	Mf	209.3311477	Kn*m/m		
c	30	M reinforcement	30	mm	cover
	d=	355			
	Mr=Mf	209.3311477			
	b	1000			
	As	1804.58388			
	Ab	700			
d	s<=	387.90106			
	3t	1200			0.027
	Smax	500			
		388<500	OK		
	30M	@	350mm spacing		vertical
e	ρ	0.005083335	<	0.027	OK
f	Ag	400000	mm^2		
	Av min	600	mm^2/m		
		2684>450	OK		
design for shear					
Vf	149.85675	Kn/m	194.81378		
a.	concrete shear resistance				
	dv	319.5	mm		
	bw	1000	mm		
	β	0.17430845			
	Vc	198.2728677	KN/m		
b	Vf<Vc	OK	shear reinforcement is not required		
	Min distributed horizontal reinforcement				
c	Ag	400000	mm^2		
	Almin	800	mm^2/m		
	As	800	mm^2/m		
d.	15	M rebars			
	Ab	200			
	s	250	300	mm	
	3t	1200			
	Smax	500			
		300< 500	OK		
	15M	at 300mm spacing		horizontal	
	t>210mm	two layers	at 100mm spacing		

Table 18: Chancellor Tank strip footings.



1	footing width		
	b>=	5.049	m
2	determine factored soil pressure		
	A	5.049	m^2
	qf	126.0101	Kpa
3	footing thickness		
	cover	75	mm
	h	700	mm
	35M rebar	35	mm
	d	607.5	mm
	Vf	222.65985	KN/m
	dv	546.75	
	β	0.1486989	
	Vc	289.44796	KN/m
	Vf < Vc	OK	
4	flexual reinforcement		
	Mf	355.23824	Kn*m/m
	As	1744.1148	mm^2/m
	Ag	700000	
	Asmin	1400	
	As>Asmin	OK	
5	spacing		
	Ab	200	mm^2
	s<=	114.67135	mm
	3h	2100	mm
	Smax	500	
	s<Smax		
	35M Rebar at 150mm spacing		
6	reinforcement in longtitudial direction		
	Ag	3534300	mm^2
	Asmin	7068.6	
	35M	700	
	# of rebar	10.098	11
	Smax	500	

Table 19: MoA Tank strip footings.



1	footing width				
	b>=	5.94	m		
2	determine factored soil pressure				
	A	5.94	m^2		
	qf	126.0101	Kpa	250	Kpa
3	footing thickness				
	cover	75	mm		
	h	850	mm		
	35M rebar	35	mm		
	d	757.5	mm		
	Vf	259.89583	KN/m	337.86458	
	dv	681.75			
	β	0.1367623			
	Vc	331.94454	KN/m		
	Vf < Vc	OK			
4	flexual reinforcement				
	Mf	501.04136	Kn*m/m		
	As	1966.6418	mm^2/m		
	Ag	850000			
	Asmin	1700			
	As>Asmin	OK			
5	spacing				
	Ab	200	mm^2		
	s<=	101.6962	mm		
	3h	2550	mm		
	Smax	500			
	s<Smax				
	35M Rebar at 100mm spacing				
6	reinforcement in longtitudial direction				
	Ag	5049000	mm^2		
	Asmin	10098			
	35M	700			
	# of rebar	14.425714	11		
	Smax	500			

Appendix D. Cost Estimate

Underground Water Storage Tanks		QUANTITY TAKEOFF						METHOD				LABOR			MATERIAL		EQUIPMENT		
Item #	**Description**	**No of Pieces**	**Length**	**Width**	**Depth/Height**	**Total Quantity**	**Units**	**Crew Size**	**Worker-Hours**	**Duration (days)**	**Total Worker-**	**Unit Labor Pricing**	**Unit Labor Cost**	**Total Labor Cost**	**Unit Cost**	**Total Cost**	**Unit Cost**	**Cost**	**Total Cost**
1.0	**Setting Out and General Work**																		
1.1	Survey							8	8.00	145	1160.0	$26.00	$208.00	$241,280.00			$50.00	$58,000.00	$299,280.00
1.2	Traffic Control							6	8.00	130	780.0	$31.49	$251.92	$196,497.60			$10.00	$7,800.00	$204,297.60
1.3	Security							4	8.00	130	520.0	$17.00	$136.00	$70,720.00			$10.00	$5,200.00	$75,920.00
1.4	Project Manager							1	8.00	145	145.0	$36.20	$289.60	$41,992.00			$20.00	$2,900.00	$44,892.00
1.5	Project Engineer							1	8.00	145	145.0	$33.14	$265.12	$38,442.40			$15.00	$2,175.00	$40,617.40
1.6	Construction Foreman							6	8.00	145	870.0	$29.00	$232.00	$201,840.00			$10.00	$8,700.00	$210,540.00
1.7	Assistant Project Manager							1	8.00	145	145.0	$27.50	$220.00	$31,900.00			$10.00	$1,450.00	$33,350.00
1.8	Environmental Health and Safety							1	8.00	145	145.0	$40.78	$326.24	$47,304.80			$100.00	$14,500.00	$61,804.80
1.9	Construction Estimator							1	8.00	145	145.0	$28.12	$224.96	$32,619.20			$15.00	$2,175.00	$34,794.20
2.0	**Earth Work**																		
2.1	Excavation (Tank1)		20	20	6.5	2600	m^3	5	8.00	20	100.0	$26.00	$208.00	$20,800.00	$130.00	$338,000.00	$600.00	$12,000.00	$370,800.00
2.2	Excavation (Tank2)		17	17	6.5	1878.5	m^3	5	8.00	20	100.0	$26.00	$208.00	$20,800.00	$130.00	$244,205.00	$600.00	$12,000.00	$277,005.00
2.3	Excavation (Tank1) - manual		20	20	6.5	2600	m^3	5	8.00	20	100.0	$26.00	$208.00	$20,800.00	$130.00	$338,000.00	$10.00	$200.00	$359,000.00
2.4	Excavation (Tank2) - manual		17	17	6.5	1878.5	m^3	5	8.00	20	100.0	$26.00	$208.00	$20,800.00	$130.00	$244,205.00	$10.00	$200.00	$265,205.00
2.5	Fill		20	20	6.5	3382.5	m^3	5	8.00	10	50.0	$26.00	$208.00	$10,400.00	$130.00	$439,725.00	$300.00	$3,000.00	$453,125.00
2.9	Compaction (with compactor)							1	8.00	55	55.0	$26.00	$208.00	$11,440.00			$500.00	$27,500.00	$38,940.00
3.0	**Concrete Work**																		
3.1	Shoring							4	4.00	10	40.0	$19.00	$76.00	$3,040.00			$350.00	$35,000.00	$38,040.00
3.2	Concrete Delivery and Forming					1096	m^3	10	4.00	10	100.0	$24.00	$96.00	$9,600.00	$210.00	$230,160.00	$1,000.00	$100,000.00	$339,760.00
3.3	Concrete pouring					1096	m^3	10	4.00	10	100.0	$24.00	$96.00	$9,600.00	$210.00	$230,160.00	$400.00	$8,000.00	$247,760.00
3.4	Rebar					11000	ft	10	4.00	15	150.0	$23.00	$92.00	$13,800.00	$0.75	$8,250.00	$15.00	$450.00	$22,500.00
3.5	Curing							10	4.00	40	400.0	$25.00	$100.00	$40,000.00			$500.00	$40,000.00	$80,000.00
3.7	**Road Works**																		
3.8	Road Foundation							10	8.00	25	250.0	$36.98	$295.84	$73,960.00					$73,960.00
3.9	Asphalt (with Paver)					2	km	10	8.00	15	150.0	$23.00	$184.00	$27,600.00	$3,500.00	$7,000.00	$380.00	$11,400.00	$46,000.00
4	Paint					10	m^3	5	8.00	10	50.0	$20.00	$160.00	$8,000.00	$50.00	$500.00	$5.00	$100.00	$8,600.00
4.4	**Commissioning and Operation**																		
4.5	Compaction Test							3	2.00	60	180.0	$29.57	$59.14	$10,645.20			$292.00	$175,200.00	$185,845.20
4.6	Concrete Test							3	2.00	70	210.0	$29.57	$59.14	$12,419.40			$500.00	$350,000.00	$362,419.40
4.7	Road Test							3	2.00	10	30.0	$30.00	$60.00	$1,800.00			$65.00	$6,500.00	$8,300.00
4.8	Piping					22	ft	4	2.00	10	40.0	$24.00	$48.00	$1,920.00	$70.00	$1,540.00	$25.00	$2,500.00	$5,960.00
4.9	Pump Station					2	pump	1	2.00	1300	1300.0	$20.00	$40.00	$52,000.00		$300,000.00		$200,000.00	$552,000.00
5.0	**Permits and Fees**																		
5.1	Institutional					7416.334277	ft^2								$5.73	$42,495.60			$42,495.60
5.2	Parking					4305.564167	ft^2								$4.53	$19,504.21			$19,504.21
5.3	Regional Sewerage levy (non- residential)					7416.334277	ft^2								$0.44	$3,285.44			$3,285.44
5.4	Tree Removal					5	Trees								$165.00	$825.00			$825.00
6.0	**Contingency**																		
6.1	Contingency (assumed 10% of total cost)																		480682.58
	Total Cost																		$5,287,508.42