UBC Emergency Water Supply System - Team 12

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EXECUTIVE SUMMARY

Aquastor Inc. has been selected to design an emergency water supply system for the University of British Columbia's Vancouver Campus. There is currently no water supply on campus and failure of existing supply lines from Metro Vancouver would result in no water supply in the area. Aquastor has designed a resilient system to provide the campus with water during emergency situations. Based on current and future use, and applications of World Health Organization and AWWA Guidelines, a capacity of 10 million litres has been selected.

Aquastor's design consists of two five million litre reinforced concrete tanks, constructed underneath UBC's Ken Woods Field. A secant pile wall system will resist lateral loading, while a friction pile foundation system will increase earthquake resistance and bearing capacity.

Construction will take approximately six months, with estimated completion in October 2018. The overall cost of the project is $12.8 million. The completed project will provide emergency water supplies to the Vancouver campus, while minimally impacting the environment and surrounding areas. The design is extremely resilient and has a high factor of safety, and is the best option for this design.

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

1.0 INTRODUCTION

1.1 BACKGROUND

The Vancouver Campus of the University of British Columbia (UBC) does not have any water storage facilities. Water is currently supplied from Metro Vancouver's Sasamat reservoir and carried to the campus via two water mains, each several kilometers long. In the event of an emergency and subsequent failure of the existing water supply the campus and its users would be left without water. Aquastor is pleased to present the following design for a new emergency water storage system for the UBC's Vancouver campus.

The design has been created with the following objectives in mind:

- To supply enough water during an emergency to allow relatively normal operation to continue;
- The storage system will withstand potential earthquakes, as it is located in an area highly susceptible to earthquakes;
- During construction, minimal disruption to the university will occur;
- Impact to the environment will be minimized during construction and operation of the system.

1.2 SITE OVERVIEW

The chosen location for this project is Ken Woods Field, in the southern half of the UBC campus, which can be seen in **Figure 1** below.

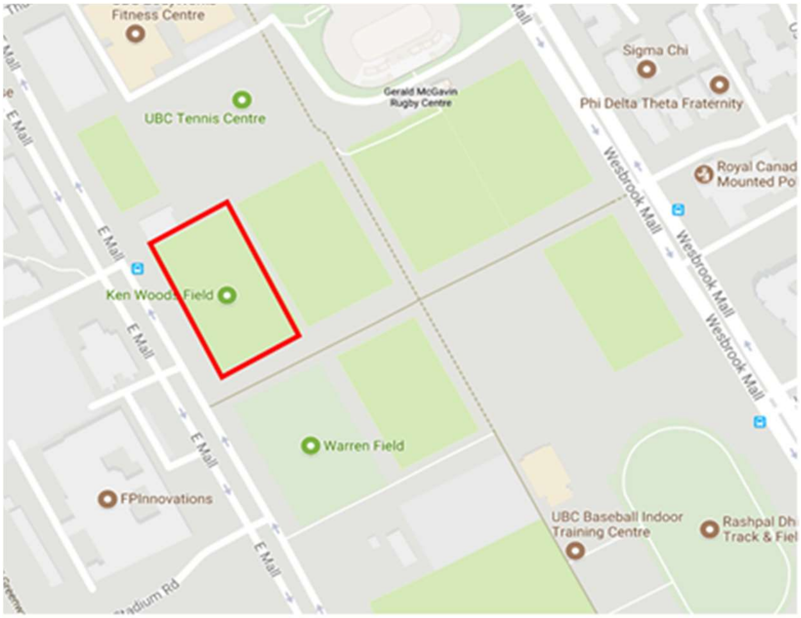


FIGURE 1: TANK LOCATION ON KEN WOODS FIELD

This location is close to the center of the existing water distribution system, is located in the high pressure zone of campus and is close to the main campus. The water storage system is to be placed underground, to ensure no impact to UBC's aesthetic after completion. Ken Woods Field is a turf field, which will allow it to be easily rolled up and stored during construction and then reinstalled afterwards.

As Ken Woods Field is used for many events, Aquastor has designated an area south of the field to serve as a temporary replacement for the duration of construction, to minimize impacts on the surrounding community.

1.3 PROJECT OBJECTIVE AND SCOPE OF WORK

The design presented here has been developed to provide water storage on the campus, which will continue to function in the event of an emergency. The overall scope of work includes the water storage tanks and all structural, geotechnical and hydrotechnical components they are comprised of and all piping and utilities infrastructure required for the tanks to connect to UBCs existing water distribution system. A complete review of UBCs current water distribution network was not completed and it is recommended that this occurs in a future project.

1.4 DESIGN CRITERIA

The main design problem is to provide sufficient water supply to the UBC campus and meet demands, both current and future, in the event of a failure of the current system. Since Vancouver is in a high earthquake risk zone, the scope of the design problem includes providing a resilient emergency water supply system while minimizing catastrophic and environmental impacts to the UBC campus. The provided final detailed design satisfies the criteria outlined below and is governed by the design loadings as follows.

Design Loadings

- Structural Gravity Demands:
    - Dead Load of 16 kPa (1 m soil cover);
    - Dead Load of 23 kPa (Distributed self-weight of concrete tank over circular area);
    - Dead Load of 69 kPa (Distributed weight of water over circular area);
    - Live Load of 4.8 kPa (Athletic field users);
- Structural Lateral Demands:
    - Interior tank water pressure of 4.9 kPa;
    - Seismic base demands from 0.381g peak ground acceleration, per NBCC;
    - Lateral Earth Pressure of 16 kPa;
- Hydraulic Demand Flow:
    - 40 L/s through distribution pipes.

Design Criteria

1. Design Life: The two concrete reinforced tanks are designed for 35 years with regular maintenance and waterproof membrane provided. An excess of 100 years is expected as the design life of the ductile iron distribution pipeline.
2. Capacity: A detailed analysis of the various water demands, including population, the UBC Hospital, academic labs and fire flow was undertaken to determine an appropriate capacity. For five days of emergency water supply, a 10,000,000 L capacity is adopted.
3. Water Quality: Aquastor conformed to standards (AWWA, UBC Technical Guidelines) during preliminary design and water quality will be managed with consideration of water turnover and recirculation within the tanks.
4. Resiliency: One emergency that could occur is an earthquake so the water storage must be seismically resistant. Seismic considerations have played heavily into design of the system to ensure maximum resiliency during the design earthquake with return period of 2475 years.
5. Safety: Risk analysis of stability and safety of the structure in populated areas is undertaken in the preliminary design phase, in order to minimize impacts to the neighborhood in event of a failure.
6. Codes and standards: The detailed designs adhere to the following required codes and standards: American Water Works Association (AWWA), UBC Technical Guidelines, Canadian Standards Association (CSA), Canadian Foundation Engineering Manual, and 2015 National Building Code of Canada (NBCC).

1.5 DESIGN ISSUES

During detailed design, effort was made to address issues such as reducing environmental and community impact of the project, as well as efficiently using the space on campus for the storage system. The provided final detailed design addresses the issues outlined below.

1. Public/Stakeholders: An effective First Nation Engagement Plan must be prepared and disruption to everyday operation and recreation of UBC should be minimized.
2. Environmental: Impacts on the environment of UBC will be kept to a minimum and drainage, soil erosion and any other adverse environmental impacts have been considered in the design.
3. Cost: The design is optimized with efficient cost trade-off while minimizing expenses for operation and maintenance.
4. Location: Limited space is available on UBC campus that will not lead to neighbourhood disruption. Location needed to meet requirements for the size of the tanks and related systems while minimizing disruption and was selected to fulfill these needs.
5. Construction Schedule: Care must be taken to ensure that disruption to campus life from construction is minimized.

1.6 DESIGN OVERVIEW

1.6.1 TANK OVERVIEW

The design consists of two 7000 m^3 concrete tanks to allow for redundancy in case of a failure. Concrete was chosen as the building material because of its durability, constructability, and low cost. The tanks will be placed under Ken Woods Field in the high pressure zone of UBC. The tanks are 36 m in diameter and 7.7 m deep. Each tank is designed to hold 5000 m^3 of water, with 1.8 m of freeboard. There will be columns placed throughout the tanks to accommodate roof, soil, and above ground loads, and baffle walls throughout the tanks to reduce the dynamic force of the water in the event of an earthquake. Secant piles surround the tank and are connected to the roof slab to resist lateral earthquake loads. Friction piles will be arranged in a circular pattern underneath the tank to help support the weight in low bearing capacity soil. Tank access will be through a ventilated hatch and ladder that connects to the edge of Ken Woods Field.

1.6.2 PIPE SYSTEM OVERVIEW

The tanks are connected to the distribution system through a 200 mm inflow pipe and a 450 mm outflow pipe. The outflow pipe is approximately 1 km long and connects to the existing 600 mm UBC main. The tanks are connected by a 450 mm pipe and bypass system that will allow either tank to remain operational if the other fails during an emergency. The tank system will be equipped with one submersible pump for water distribution and one recirculation pump to promote water turnover within the tanks. Chlorine will be injected as required to ensure water quality remains acceptable.

2.0 DESIGN TOOLS AND GUIDELINES

2.1 TECHNICAL CONSIDERATIONS

There are a number of technical considerations for this project. These include earthquake risks, water quality, structural reinforcement and pressure zones.

Earthquake Risks

The UBC campus is located in an area of high earthquake risk and therefore earthquake risks must be accounted for. The National Building Code of Canada (NBCC) requires structures to be designed for 2%/50 years risk or the 1 in 2475 year earthquake. Using the 2015 NBCC the seismic hazard for 2%/50 years for this location (latitude: 49.258179, longitude: -123.243375), is a peak ground acceleration (PGA) of 0.381g where g = 9.81 m/s^2, gravitational acceleration. The soil at this site is predicted to have a high chance of liquefaction. Both the PGA and the high liquefaction potential were considered during design, resulting in a robust and resilient design.

Water Quality

It is important for water quality in both the storage tanks and distribution system to be maintained. It is recommended that water turnover is approximately 1/3 per day with complete turnover every 3 to 5 days to avoid old water, which can result in microbial activity as the chlorine residual drops. The American Water Work Association (AWWA) recommends a maximum of 5 days between complete turnovers to avoid excessive water age. During regular operation of the system water will be cycled through the system and distribution system as it is used and complete turnover will occur every three days. Mixing is also required in storage systems as it mitigates any stagnant water or short-circuiting of water. Velocity differences during filling and emptying in normal operation, combined with baffle walls, will allow for appropriate mixing.

In the emergency situation, the worst case scenario has been assumed for water quality: that complete failure of Metro Vancouver's system occurs and the storage tanks are the only source of water on campus, with no ability to be additionally filled. In this case, Aquastor has design for a five day storage capacity to align with AWWA requirements for water age. Chlorine residual will be constantly monitored throughout the five days and booster disinfection will be added by hand if quality drops below acceptable levels. A recirculation pump will be installed in the tanks to avoid stagnant water and facilitate mixing.

Structural Reinforcement

Load demands on the tank's structural components are high. Furthermore, the concrete slab elements experience high bending moments due to two-way loading and moderate spans of 5 m between column supports. To increase the capacity and ductility of the concrete, steel reinforcement was used in the design of all tank elements. In addition to higher bending capacity and axial force capacity, the reinforced concrete tank elements experience ductile failure modes governed by the steel reinforcement, which conforms to CSA standards.

Pressure Zones

The UBC campus is segregated into two pressure zones: high and low. The high pressure zone is serviced from a pump house that distributes water at 100 psi. The low pressure zone is gravity fed at Metro Vancouver's operating pressure, approximately 60 psi. The two pressure zones are separated and distinguished by a series of pressure reducing valves. To ensure an inflow rate to the system of 40 L/s, the tanks were placed in the high pressure zone.

2.2 SPECIFICATIONS

A list of required technical specifications can be found in **Appendix B** and are incorporated into the Issue for Construction (IFC) drawings found in **Appendix A**.

The specifications cover technical requirements related to the construction work and installation, site preparation and quality of workmanship for all structural, geotechnical and hydrotechnical components of the design. In all cases, work should be carried out exactly as described in the Technical Specifications and IFC Drawings and to the satisfaction of the Owner. In cases of discrepancy, work should be carried out in accordance with the Technical Specifications, which take precedence in all cases.

2.3 SOFTWARE

2.3.1 SAP

To confirm the structural design hand calculations were accurate, SAP2000 was used to model the structural capacity of tank, including the floor slabs, the perimeter walls, and the roof slabs. The dimension of the components, material properties, loads, and load combinations were modelled according to the results from hand calculation.

The dynamic load from the water, the lateral load from the soil, and the uplift from the soil are not considered in this analysis. The friction piles are modeled as spring supports at the bottom of the tank. The secant piles are not modeled and there is no lateral load from the soil assigned to the perimeter walls.

After running the simulation, the deflection and the bending moment of all members are checked to make sure the concrete would not fail. The picture below shows the analysis of the floor slab of the tank as an example. The maximum bending moment (among all three directions) throughout the floor slab is color coded and the largest bending moment read from **Figure 2** (orange in this case, which corresponds to 1700 kNm to 3400 kNm) is compared to the capacity of the structure.

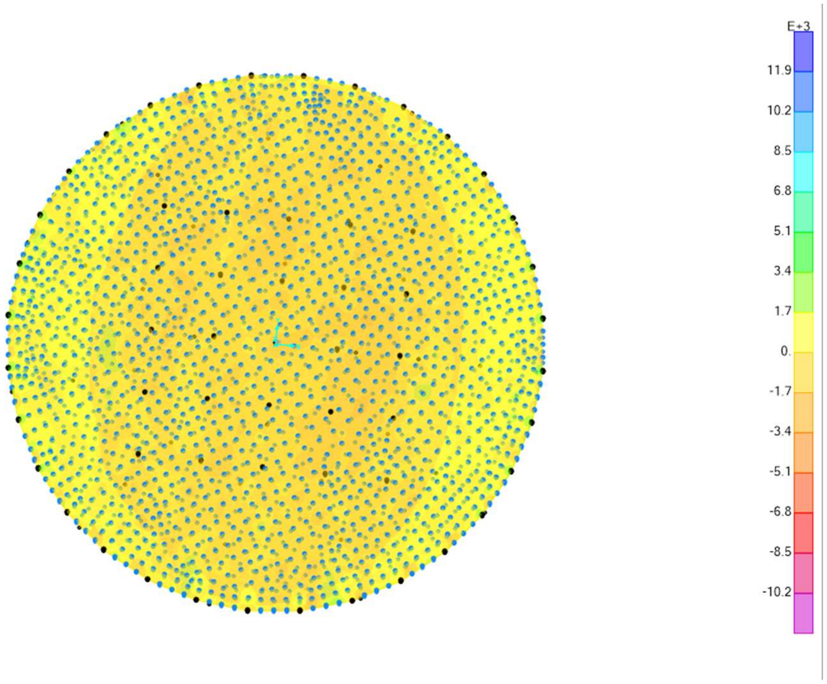


FIGURE 2: SAP MODEL

2.3.2 AUTOCAD

The drafting and drawing software, AutoCAD, is used to create all the detailed issued for construction drawings enclosed with this report. The drawings are drawn to scale with appropriate dimensions and drawings notes, annotated in AutoCAD. Aquastor is confident in the delivered drawings and its accuracy to standard construction practices.

2.3.3 EPANET

To analyze the existing distribution system on UBC the program EPANET was used. A file was provided by the client with the entire system prebuilt to scale. EPANET allowed Aquastor to clearly view the high and low-pressure zones distinguished by the pressure reducing valves. This was vital in determining the final location for the water storage tanks. The program also provided the specific diameters of every water line on campus, showing the existing 600mm water main from Sasamat reservoir that the constructed water tanks will connect to. An EPANET simulation also allowed Aquastor to see the effect the water tanks would have on the pressures of the existing distribution system.

Using this existing system, an additional node, representing the water tanks, was placed on the EPANET model. Placed in the location of the Ken Woods field, the node was assigned a demand of 39 L/s, the inflow rate that the water tanks will require to achieve a water turnover rate of 3 days. After implementing this change and analyzing the model it was found that all pressures and velocities remained within acceptable values. The outflow pipe connecting to the pipe that connects Sasamat Reservoir to the UBC Pump house connects before the UBC Pump house and is outside of UBC's pressure zones. Thus, this connection was not modelled on EPANET as it would not affect pressures or velocities in the distribution system.

However, the existing EPANET model provided initially did not work when run. For a successful run, several pipe diameters had to be changed on the model and were given estimated diameters based on other values in the system.

Junction 1

Property	Value
*Elevation	94
Base Demand	39
Demand Pattern	
Demand Categories	1
Emitter Coeff.	
Initial Quality	
Source Quality	
Actual Demand	39.00
Total Head	181.52
Pressure	87.35

FIGURE 3: EPANET MODEL

2.3.4 SKECTHUP

SketchUp was used during the preliminary design phase of this project. A model of the preliminary design was made to help conceptualize the tank and pipe network for the preliminary presentation. Once the design moved into the detailed design phase, other programs such as SAP, AutoCAD and EPANET were used to make detailed drawings and analyze the system.

2.4 STANDARDS

2.4.1 AMERICAN WATER WORKS ASSOCIATION

American Water Works Association (AWWA) standards for equipment and material used in treatment and distribution of drinking water.

2.4.2 NATIONAL BUILDING CODE OF CANADA

The 2015 Nation Building Code of Canada (NBCC) was followed for all structural components and foundations. The entire system complies with the seismic design hazards and requirements found in the NBCC.

2.4.3 CANADIAN FOUNDATION ENGINEERING MANUAL

The Canadian Foundation Engineering Manual was used as a guideline in the design of the secant pile walls and friction piles. All geotechnical work was compared to this, to ensure it was completed to an acceptable standard.

2.4.4 CANADIAN STANDARDS ASSOCIATION

The Canadian Standards Association (CSA) was followed for structural and reinforced concrete components.

2.4.5 UBC TECHNICAL GUIDELINES

UBC Technical Guidelines were followed for all distribution piping and accessories, to ensure the design complies with requirements specific to the UBC Vancouver campus.

3.0 DESIGN OUTPUTS

3.1 GEOTECHNICAL AND FOUNDATION COMPONENTS

Ken Woods Field is located at the south end of the UBC campus. Soil information for design was based on *Hydrogeological and Geotechnical Assessment of Northwest Area UBC Campus, Vancouver* from Piteau Associates (2003), which focused on soil conditions at the north end of campus. Lacking other sources of information, this data was assumed to be applicable for the south end of campus as well. Two boreholes, one located near the existing powerhouse and one near Acadia Drive, were the closest to the site and information from those boreholes was used in design. Soil at the site was determined to be mostly a sand and silt mixture, with silt layers. Most of the UBC campus is within the Quadra 1 sand unit, which is a well-sorted and medium grained sand. A high water table, approximately 1 m below surface, was assumed. Due to lack of site information, more conservative site conditions were assumed, which includes a high water table. A high chance of liquefaction was assumed, based on the soil conditions, high water table and the chance of leakage from one of the tanks.

3.1.1 SECANT PILE WALLS

The assumed soil conditions would create difficulties excavating down to the required 8 m, resulting a large excavation with huge side slopes. The lateral loads from earthquakes are large and would require excessive reinforcement in the tank walls. As a solution to both these issues, a secant pile wall was designed.

The secant pile wall consists of a single row of interlocking piles, which will circle around the outside of each tank. Secant pile walls consist of a series of soft piles, followed by the installation of reinforced piles in between. The resulting wall has been designed to resist all lateral loading, from both soil and seismic loads. The secant pile walls will be installed first, and excavation will occur after. The walls will provide enough resistance that a much smaller area will need to be excavated and large side slopes will not be required.

The soft piles are unreinforced concrete piles, with a diameter of 0.9 m. The reinforced piles that will be installed second also have a diameter of 0.9 m and will overlap 0.15 m on either side of the soft piles, as can be seen in **Figure 4** below. This will result in an effective diameter of 0.6 m for all secant piles. Each tank will be encircled by 205 piles, for a grand total of 410 secant piles, each extending 30 m deep.

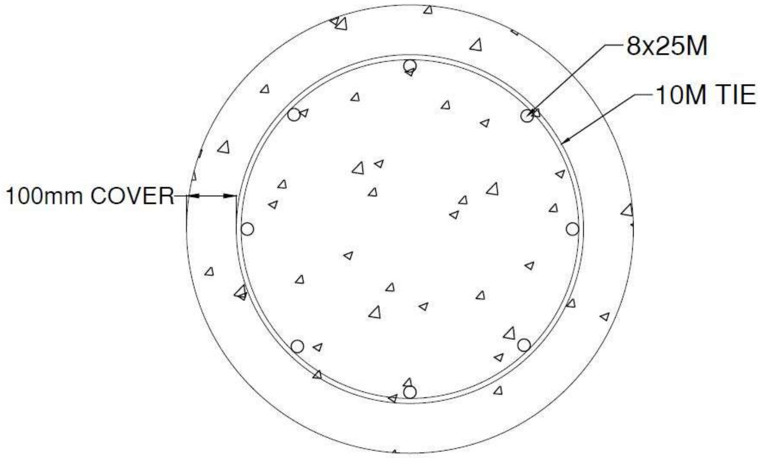


FIGURE 4: SECANT PILE DETAILS

Calculations related to secant piles can be found in **Appendix E** drawings can be found in **Appendix A** and specifications can be found in **Appendix B.** The construction plan, including secant pile installation can be found in **Section 4.0**.

3.1.2 FRICTION PILES

Friction piles were selected to help support the weight of the concrete tank on low bearing capacity soil and to mitigate possible liquefaction conditions. The piles were designed using the Canadian Foundation Engineering Manual assuming the following parameters:

- $\gamma_{soil} = 16\ KN/m^3$
- $\gamma_{concrete} = 24\ KN/m^3$
- Weight Tank & Water= 86052 KN
- $\phi = 27º$
- Nq = 18

Note that the bearing capacity factor Nq was obtained by using a bearing capacity factor vs Friction angle graph. After analyzing multiple pile diameters and depths, 600 mm diameter piles hammered to a depth of 20m were chosen. Each pile has a bearing capacity of 1935 KN, therefore 45 piles are needed to support the weight of a full tank. The design uses 49 friction piles for contingency. The minimum spacing between piles was calculated to be 2.5 m, however the spacing between piles varies from 3 m to 7.7m. To evenly distribute the resistance of the piles on the tank, they were placed in circular layers underneath the tank. To ensure that the load could be treated as a distributed load along the bottom of the floor slab, concrete cones were attached to the top of each pile as shown in **Figure 5.**

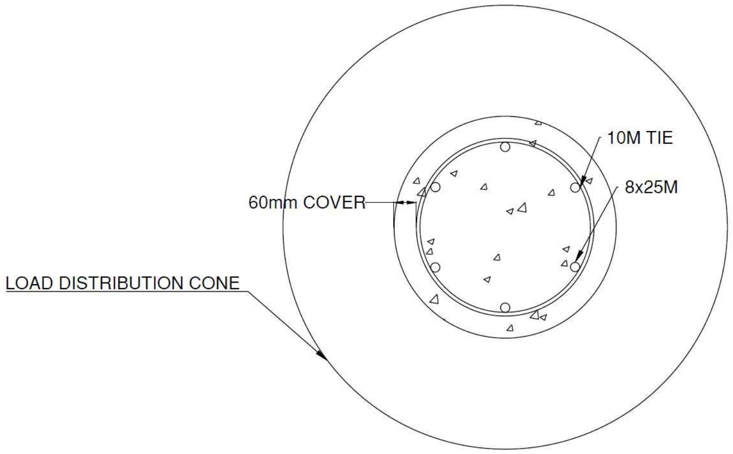


FIGURE 5: FRICTION PILES DETAILS

Detailed Calculations for the friction piles are found in **Appendix E** and the drawings are found in **Appendix A.** Refer to **Section 4.0** for the friction pile construction plan and sequence.

3.2 STRUCTURAL COMPONENTS

The structural components of the tank are made entirely of steel reinforced concrete. The components were designed in accordance with CSA guidelines. Sample calculations can be found in **Appendix E**, and full detail drawings can be found in **Appendix A.**

3.2.1 ROOF SLAB

The gravity loads mentioned in **Section 1.4** are evenly distributed on the roof slab. The slab is 300 mm thick, 39 m in diameter and has reinforcement in both directions. Dimensions meet deflection control requirements, per CSA A23.3, and the selected thickness is suitable. The slab was designed as many smaller two way slabs, supported on all four corners by columns. The worst case flexural failure condition was established, and all reinforcement was designed to resist this moment. The constant reinforcement spacing provides a conservative design that is easy to construct. Minimum temperature reinforcement is provided and CSA standards are met. The roof slab detail is shown in **Figure 6**. The roof slab extends beyond the tank walls and rest on the secant piles with a 500 mm thick gap between the walls and piles. This is to ensure the tank structure and secant piles will have the same lateral displacement during an earthquake and reduce seismic damages.

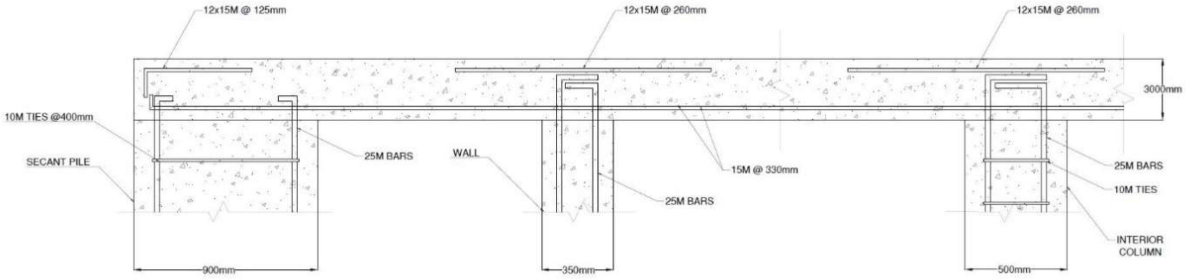


FIGURE 6: RC ROOF SLAB DETAILS

3.2.2 COLUMNS

Following the load path, gravity load from the roof slab is evenly distributed to the 25 evenly spaced columns throughout the tank, and the tank wall. Columns reduce the span length of the roof slap and distribute the bending moment demands. The cylindrical column was designed by estimating the shape as a smaller square. The columns were designed to resist buckling. The columns are concentrically loaded, so the minimum eccentricity was calculated to determine the bending moment in the columns. Conservative assumptions were made and a high factor of safety was chosen to account for the dynamic load of the water in the event of an earthquake.

The diameter of the cylindrical columns is 500 mm, and they are 6.8 m tall, and the column detail can be found in **Figure 7**.

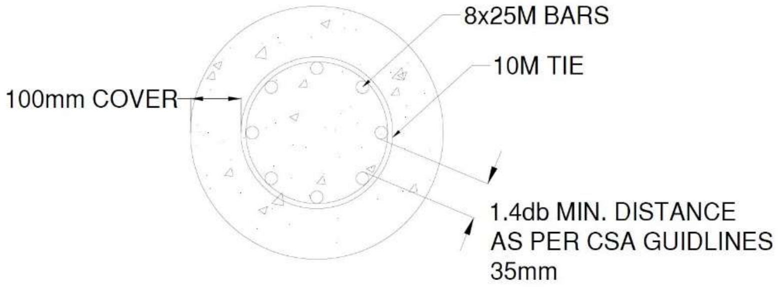
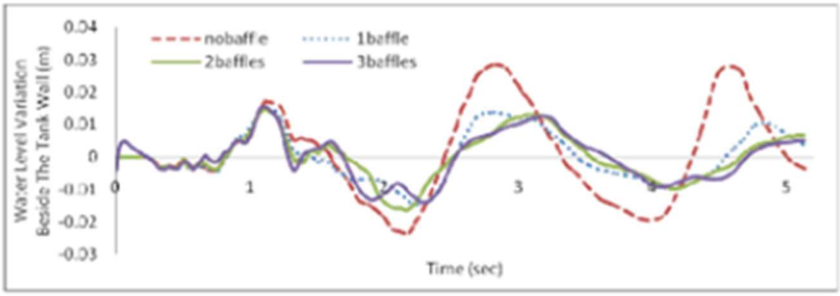


FIGURE 7: RC COLUMN DETAIL

3.2.3 BAFFLE WALLS

In the event of an earthquake the external excitation of the surrounding ground will result in extreme sloshing of the water inside the tank. To prevent excessive damage from this hydrodynamic load, baffle walls will be installed inside of the tank to minimize and suppress the effects of sloshing.

As found in “Earthquake Resistant Engineering Structures VIII” the direct effects of baffle walls on the water level variations during an earthquake are shown below. The scaled down model of a 10,000 m^3 tank is directly comparable in size to Aquastor’s design. When baffles are placed perpendicular to a flow they change the direction of the flow and suppress the magnitude of fluid slosh. Additionally, the baffles will be perforated to break up the main water jet into a more uniform current over a larger area.



The water level variations beside the wall of 1/36 scaled-down 10000 m^3 tank with no, 1, 2, and 3 baffle(s) subjected to the scaled record of Kocaeli earthquake (Sakarya record).

FIGURE 8: EFFECTS OF BAFFLE WALLS ON WATER LEVEL VARIATIONS

Additionally, the baffle walls will provide a means to direct the flow of water inside the tank during normal operation. This increases the chlorine contact time and results in a more even chlorine distribution providing a more effective disinfection process. Water will flow in a serpentine path from one end of the tank to the other as shown below.

Five large baffle walls will be installed inside of each water tank to effectively separate the tank into smaller sections. Each baffle wall will be attached and mounted to the columns inside of the tank and will be constructed out of concrete.

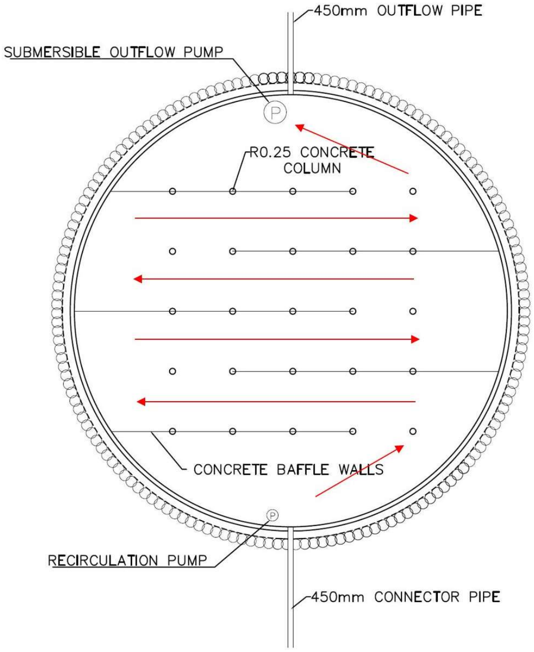


FIGURE 9: BAFFLE WALL CONFIGURATION

3.2.4 WALL

The wall of the tank was designed as a basement wall. The design consists of two curtains of rebar, in both the vertical and horizontal directions. Two curtains of rebar are required since the wall thickness is greater than 250 mm. The wall is 350 mm thick and 6.8 m tall. Because the secant piles help resist the lateral load of the soil, it was assumed that the greatest load on the walls would be from the water when the tank was full. The walls are designed for the worst case scenario, further adding to the safety of the design. Axial load from the roof slab is not assumed in the analysis, as this is a more conservative assumption. A detail of the wall is shown in **Figure 10.**

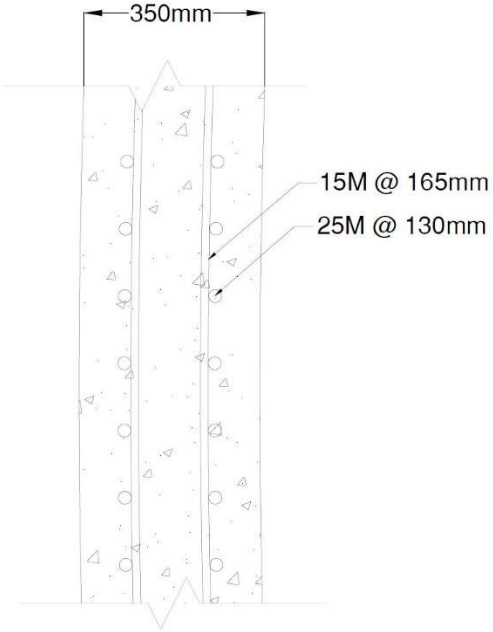


FIGURE 10: RC WALL DETAIL

3.2.5 FLOOR SLAB

The design gravity loads are transferred to the floor slab, along with the weight of the water and the upward force from the soil. It was determined that the punching shear failure mode of the floor slab would be a moment at the base of a column. This moment is created by the force from the soil underneath the tank. The worst case design scenario occurs when the tank is empty. To resist this moment, the thickness of the concrete slab was increased to 750 mm, as well as the amount of reinforcement. The alternative method is to design the floor slab according to foundation design; however, the chosen method of analysis is intended to be conservative to account for underestimation of loads. As a result, the floor slab is thicker than the standard slabs. Again, the entire slab was designed to resist this worst case scenario. This makes the design more conservative, more likely to resist an earthquake, and easier to construct. A detail of the floor slab is shown in **Figure 11**. The load path is completed through the transfer of loads from the floor slab to the foundation piles.

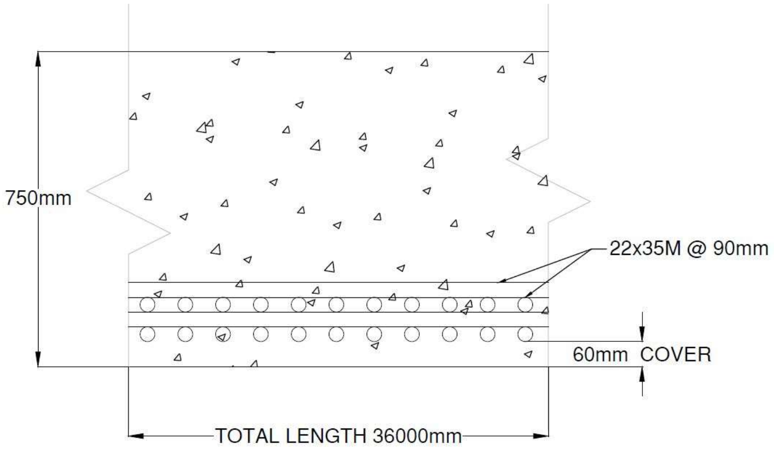


FIGURE 11: RC FLOOR SLAB DETAIL

3.3 PIPE NETWORK

The pipe network is designed to operate in parallel with the existing system to ensure minimal disruption to the existing network and to reduce any additional operating procedures and expenses. As described earlier, the pipe network design comprises of four main components:

1. Inflow Connection;
2. Outflow Connection;
3. Tank-Tank Connection;
4. Emergency Bypass.

The new system complies with AWWA, NSF 61, and UBC Technical Guidelines. All new pipes are specified Class 50 ductile iron and includes the necessary valves to allow for isolation during maintenance and repairs. Flexible couplings will be included in the designed pipe lengths to ensure two points of flexibility to accommodate for differential settlement between the existing pipes and the new tanks. All connections to active UBC water mains will be done through “wet taps” which allows connections to be made with gate valves so that the existing distribution system will experience no interruptions.

3.3.1 INFLOW CONNECTION

The new 200 mm inflow connection will connect UBC's existing 250 mm distribution line to the western face of the southern tank. The connection will be made perpendicular to the existing distribution line using a wet tap which means a 200 mm gate valve will be needed at this location. This gate valve, along with the gate valve just before the connection to the southern tank, will ensure proper isolation during maintenance and repairs. A check valve is also included in the design to ensure the correct direction of water flow. Flexible couplings are included in the designed pipe lengths to ensure two points of flexibility to accommodate for differential settlement between the existing pipes and the new tanks, as seen in **Figure 12** below. Further details on the connection and appurtenances including the flexible couplings and valves can be found in the detailed design drawings in **Appendix A**.

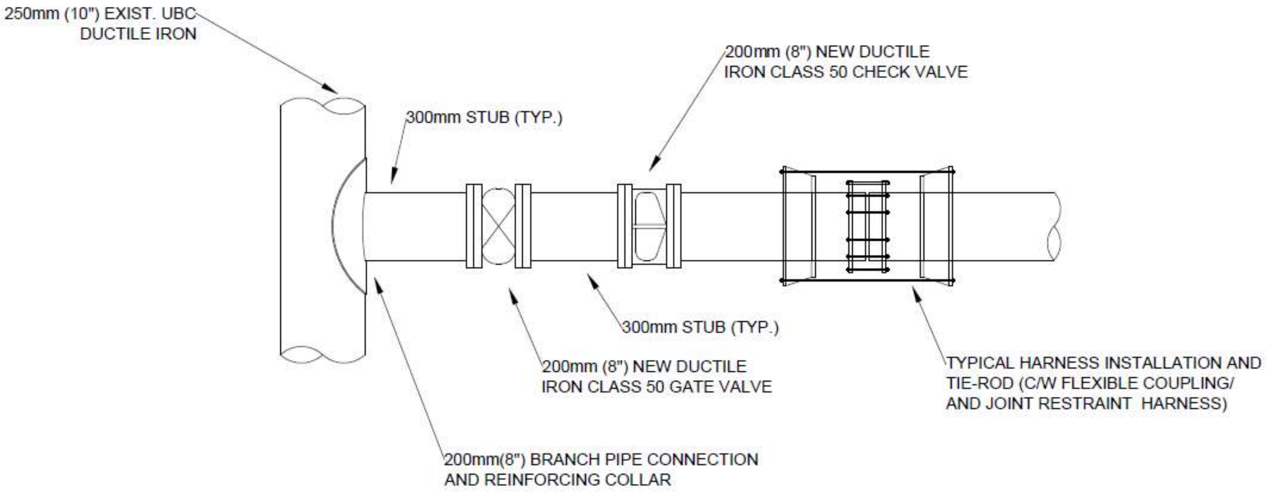


FIGURE 12: EXCERPT OF DETAILED INFLOW CONNECTION DESIGN

3.3.2 OUTFLOW CONNECTION

The new 450 mm inflow connection will connect the tanks to UBC's existing 600 mm main distribution line. The existing distribution line is one of two water mains which feeds water from Metro Vancouver to UBC's pump house. The tanks are connected to UBC's existing system in this way to utilize the current pumping system that UBC has in place to reduce the amount of new infrastructure introduced in this capital project.

The connection to UBC's existing 600 mm main will be completed using a wet tap which means a 450 mm gate valve will be needed at this location. The connection will be made perpendicular to the existing distribution main. This gate valve, along with the gate valve just before the connection to the northern face of the northern tank, will ensure proper isolation during maintenance and repairs. Additionally, to avoid back flow into the tank and to ensure water flows in the correct direction when supplying UBC during regular operation and emergency situations, a 450 mm check valve is also included at this location. Flexible couplings are included in the designed pipe lengths to ensure two points of flexibility to accommodate for differential settlement between the existing pipes and the new tanks. Further details on the connection and appurtenances including the flexible couplings and valves can be found in the detailed design drawings in **Appendix A.**

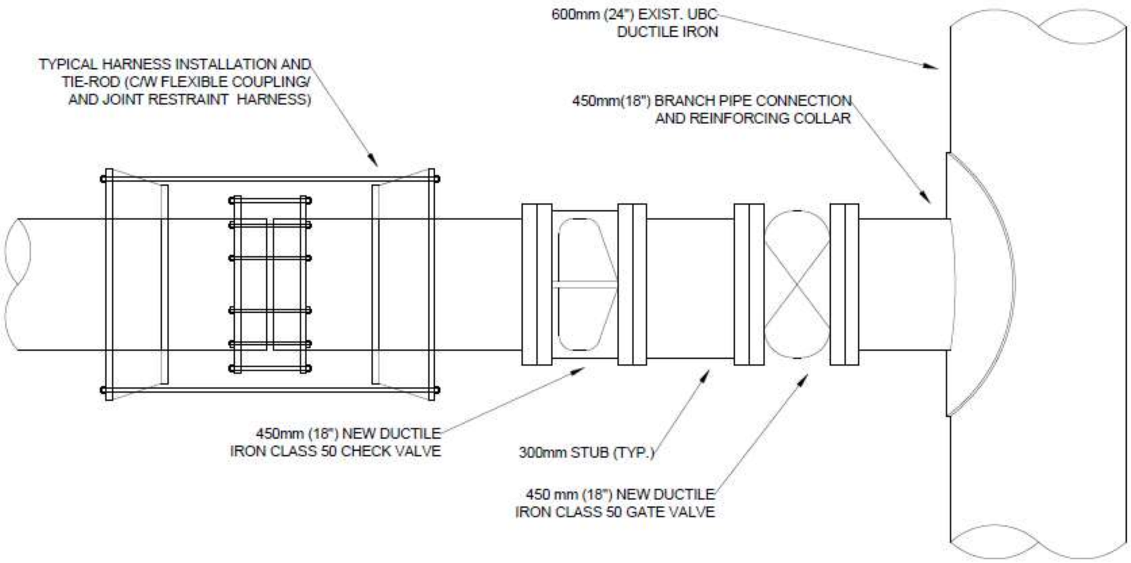


FIGURE 13: EXCERPT OF DETAILED OUTFLOW CONNECTION DESIGN

3.3.3 TANK TO TANK CONNECTION

A new 450 mm connection was designed to allow flow between the two emergency reservoirs during regular and emergency operating scenarios. The connection is a straight length of pipe which includes gate valves at both ends to ensure proper isolation during maintenance and repairs. Flexible couplings are included in the designed pipe lengths to ensure two points of flexibility to accommodate for differential settlement between the new tanks. Further details on the connection and appurtenances including the flexible couplings and valves can be found in the detailed design drawings in **Appendix A.**

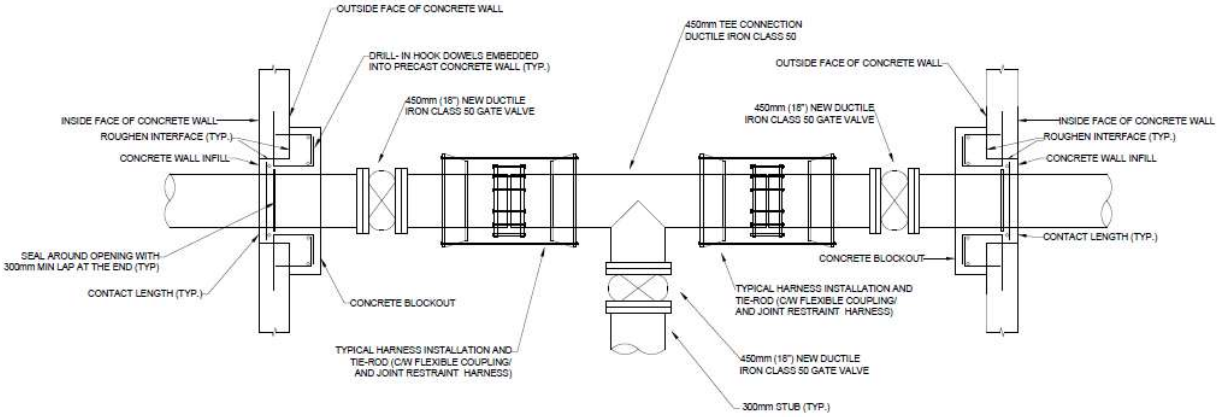


FIGURE 14: EXCERPT OF DETAILED TANK-TANK CONNECTION DESIGN

3.3.4 EMERGENCY BYPASS

To improve the resiliency of the design and to provide contingency in the case of failure in the tanks or connections to between the tanks, an emergency bypass was included in the network design. The bypass was designed to ensure operation of the new network would continue in the case of failure in either one of the tanks. This is also important to the maintenance of the tanks, as the water level can be drawn down in one of the tanks while the second tank is able to continue operating. This is described further in **Section 5.0**.

The emergency bypass network includes two components – the bypass of the southern tank and the bypass of the northern tank. For the bypass of the southern tank there is a direct connection to the new inflow connection and the northern tank, completely isolating the southern tank from the system. This allows maintenance and repairs to be made without taking the network offline. This network includes two 200 mm gate valves and a 200 mm short radius 90 degree elbow. The gate valves ensure isolation of this bypass line so it is not used during regular operation.

For the bypass of the northern tank, there is a direct connection from the southern tank to the 450 mm outflow line. Through the use of this connection, water can flow from the southern tank directly to the distribution line, completely isolating the northern tank from the system. This allows maintenance and repairs to be made without taking the network offline. This network includes two 450 mm gate valves and two 450 mm short radius 90 degree elbows. The gate valves ensure isolation of this bypass line so it is not used during regular operation.

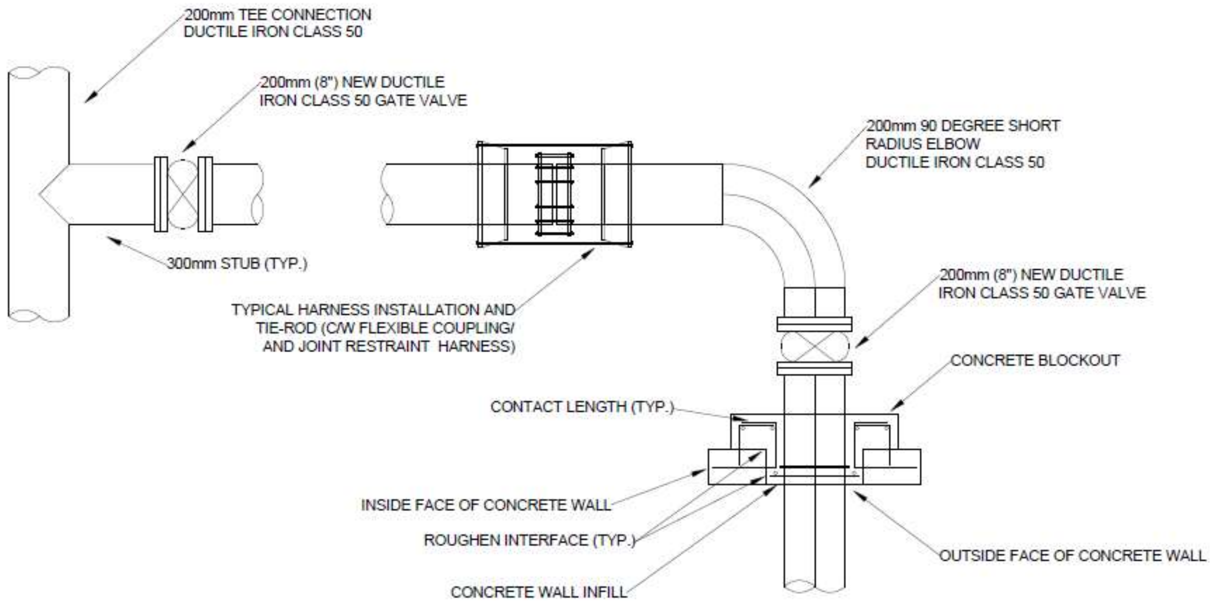


FIGURE 15: EXCERPT OF BYPASS DETAILED DESIGN

3.3.5 PUMPS

3.3.5.1 INLINE PUMPS

To promote a water turnover rate of 3 days, it was determined that the outflow pumps would be run 24/7 achieving a flow rate of 40 L/s. With this design, both tanks will experience complete water turnover approximately every 3 days and is the least expensive option compared to running the pump at a higher horsepower for a faster water turnover rate.

The outflow line connects directly to the pipe that connects Sasamat Reservoir to the UBC Pump house. As this connection is before the UBC Pump house, it is outside of the UBC pressure zones, however based on the EPANET model it operates at pressures around 60 psi. Taking into account the elevation difference between the tank locations and the pump house, and the friction loss along the 950 meters of pipe, it was determined that a pump head of 40 meters was required to meet the pressures of the intersecting pipe.

To meet these specifications two 625S300-2-AA Grundfos submersible pumps were selected to provide a constant outflow of 40L/s at 40 meters of head. The corresponding pump curve is shown below and an efficiency of 71.3% will be achieved. A variable frequency drive will be attached to each pump and the flow rate will be slowed to 23 L/s in the event of an emergency to ensure water supply for a period of 5 days.

The existing pressure inside of the UBC distribution system is sufficient to provide the 40 L/s of inflow required to replenish the water that is leaving the tank at the same rate.

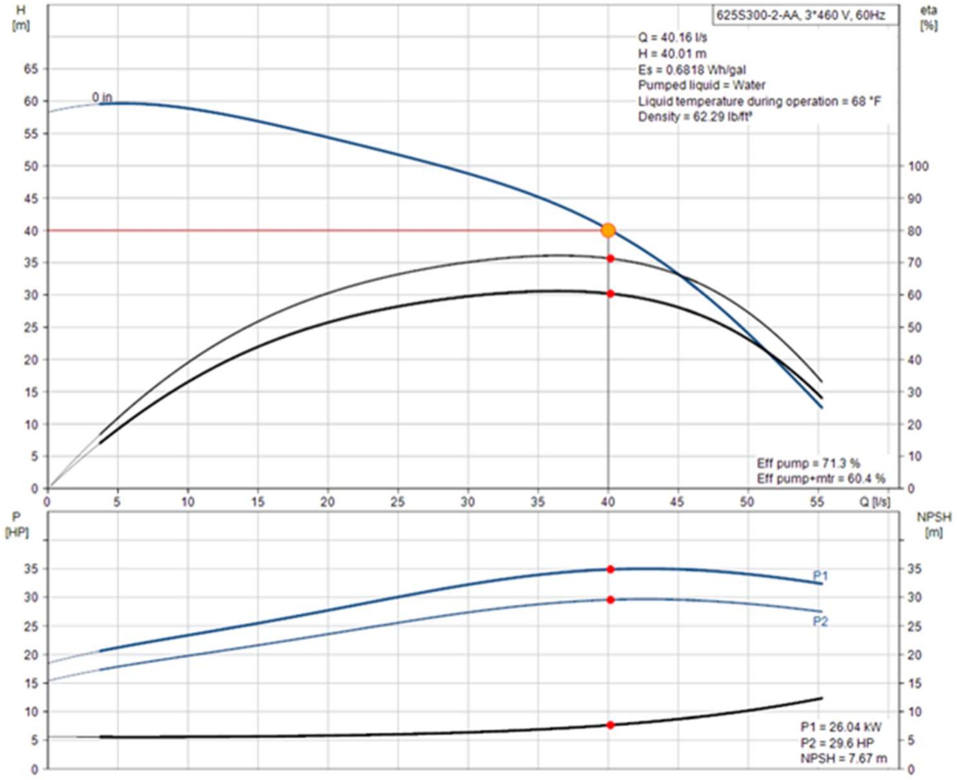


FIGURE 16: INLINE PUMP CURVES

3.3.5.2 CIRCULATION PUMPS

To facilitate flow between the two tanks, circulation pumps will be added to the entrance of each tank. As flow enters the first tank at 40L/s, the circulation pumps ensure flow travels to the second tank in sequence at the same flow rate. This prevents the upstream tank from filling faster than the downstream tank. And ensures consistent flow of 40L/s throughout the system. These pumps will be submersible 625S150-1-A pumps as provided by Grundfos.

3.4 ADDITONAL COMPONENTS

3.4.1 EMERGENCY HOSE SYSTEM

In the scenario that the pumping station at the UBC powerhouse, or the constructed water main to the powerhouse is compromised in the event of an earthquake, a hose system will be provided to allow the water tanks to be accessed as a 'point of use' system. A 30 m long and 125mm diameter supply hose, comparable to the hoses used in firefighting scenarios, will be provided for each water tank. The supply hoses are designed to operate at pressures of up to 200 psi which is comparable to the pressure provided by the pump at the water tanks. During normal operation the hoses will be stored in the basement of the UBC Baseball Indoor Training Centre.

3.4.2 BACK-UP GENERATOR

If power is lost for an outstanding period of time, and emergency backup generator is provided to supply the required 25 kW to operate all pumps in the system. It is recommended that the Generac Protector, Automatic Standby Generator (120/240V Single-Phase) be used, however other comparable models are also acceptable. If required, trained personnel will disconnect the electrical connection between the pumps and the UBC electrical grid and reroute the wiring to the generator. When not in use, the backup generator will be stored with the hoses in the basement of the UBC Baseball Indoor Training Centre.

4.0 CONSTRUCTION PLAN AND SEQUENCING

The overall construction is scheduled in four phases: site preparation, mainline construction, testing & service tie-in, and backfill & site restoration. The general construction logistics are to complete construction connecting the pipe to the pump house at the same time as the tank construction. Both tanks will be constructed at the same time to maximize efficiency. Testing will be carried out when the pipes and the tanks are ready. The main site will not be backfilled until the tanks have passed the test to minimize the amount of rework for repair. Following is a detailed description of the construction sequence.

4.1 SITE PREPARATION

4.1.1 PRE-CONSTRUCTION INVESTIGATION

Before construction starts, the engineers in charge will walk through the site with the owner's representatives and the construction manager. Investigations will be carried out as a final confirmation of the site condition. This will not only make sure the site condition has not changed since the start of the design phase, but also bring all parties together to witness and reach an agreement on the site condition.

4.1.2 SITE ORGANIZATION

The project will start with setting up the fences, site trailers, and construction signs. The site layout is arranged to optimize the travel distances of various construction activities while avoiding all safety hazards. The current high-level site layout ensures adequate access to laydown and storage areas. The laydown area should have adequate space to store additional excavated material and can be extended if necessary. Site trailers would also be located near the laydown area; most likely in the southern portion near the vehicle access point. Additionally, there will be adequate room for excavators, dump trucks and other necessary heavy construction vehicles around the tank construction area. A high-level version of the site layout can be seen in the **Figure 17** below. Further information on heavy vehicle access is covered in **Section 4.1.3.**

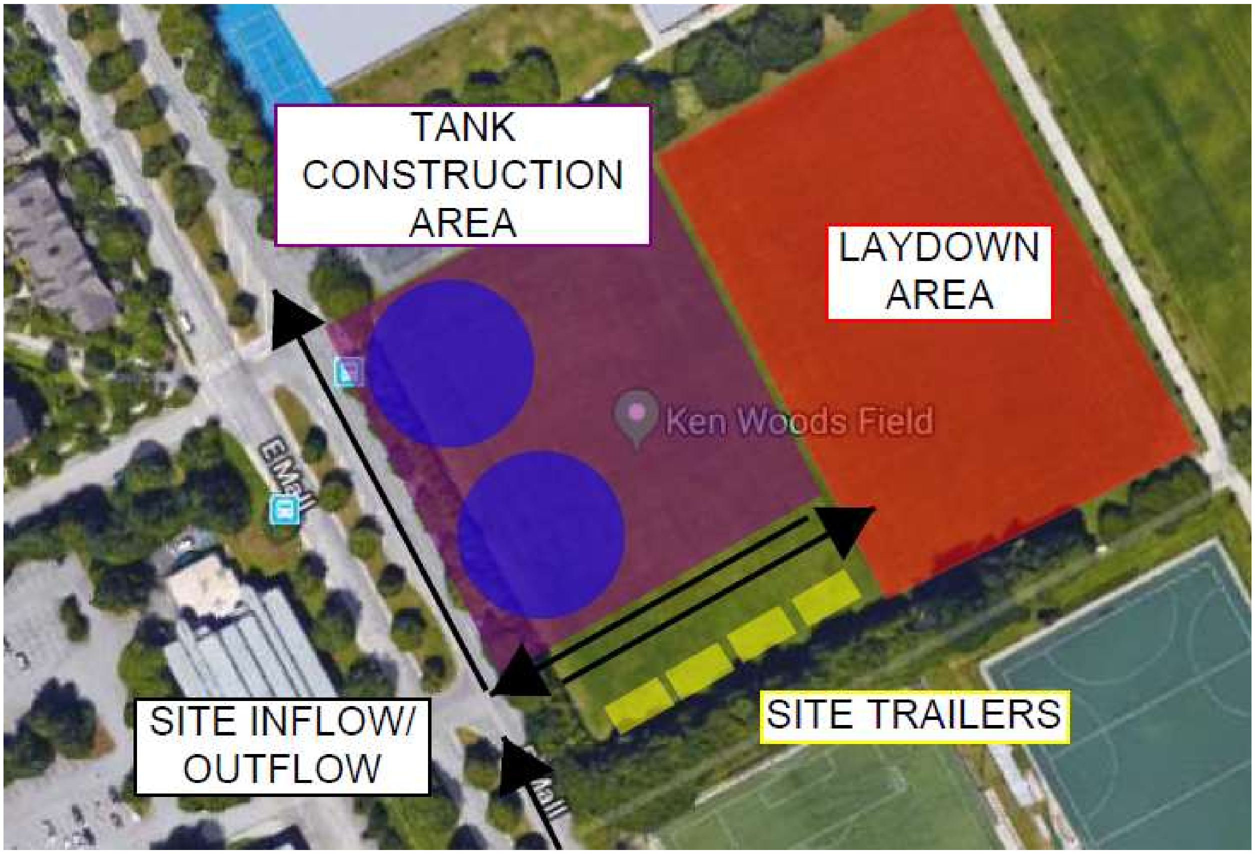


FIGURE 17: HIGH LEVEL SITE FLOW AND ORGANIZATION

4.1.3 VEHICLE ACCESS AND HAULING ROUTES

To control traffic flow of heavy construction vehicles through the work site, one directional flow has been selected to be the ideal solution. As described in **Figure 18** below, the blue lines indicate construction vehicle flow into the construction laydown area and the red lines indicate construction vehicle outflow. This will help increase consistency in truck routing to avoid the number of roads and pedestrians impacted by construction vehicles in regard to noise, dust, and safety. Additionally, it will prevent heavy vehicles from turning left into the laydown area which will reduce congestion and obstruction to commuters on the UBC campus.

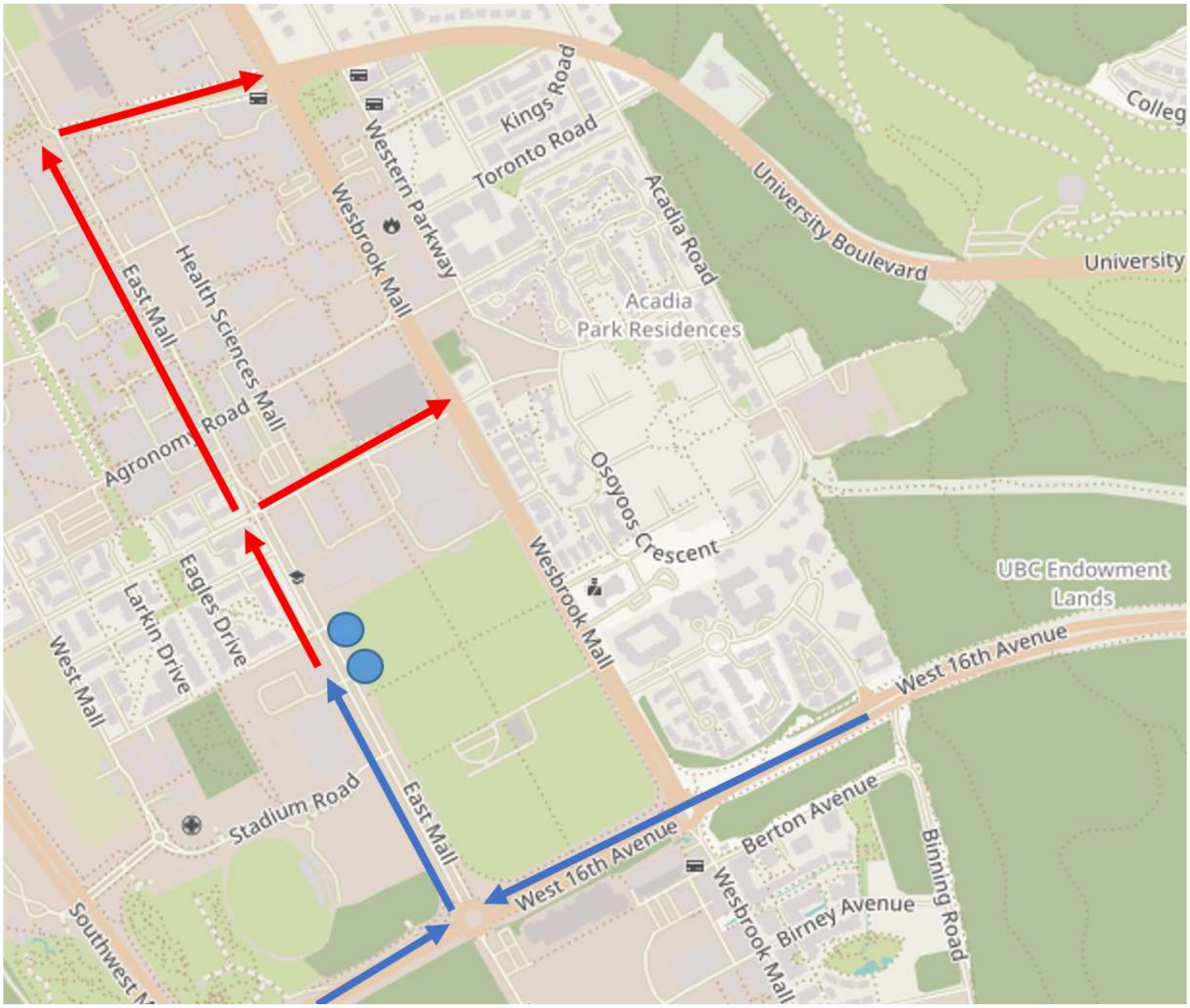


FIGURE 18: HEAVY CONSTRUCTION VEHICLE INFLOW (BLUE) AND OUTFLOW (RED)

The selected hauling site, for the large amount of soils that will need to be disposed of, is the Vancouver Landfill. The proposed site is approximately 30 km from the construction site at UBC. The contractor must submit soil samples for every load to ensure they comply with the strict guidelines set by Vancouver Landfill to ensure soils can be disposed of at this location. In the case of contaminated soils, alternative dump sites need to be considered and approved before the start of excavation.

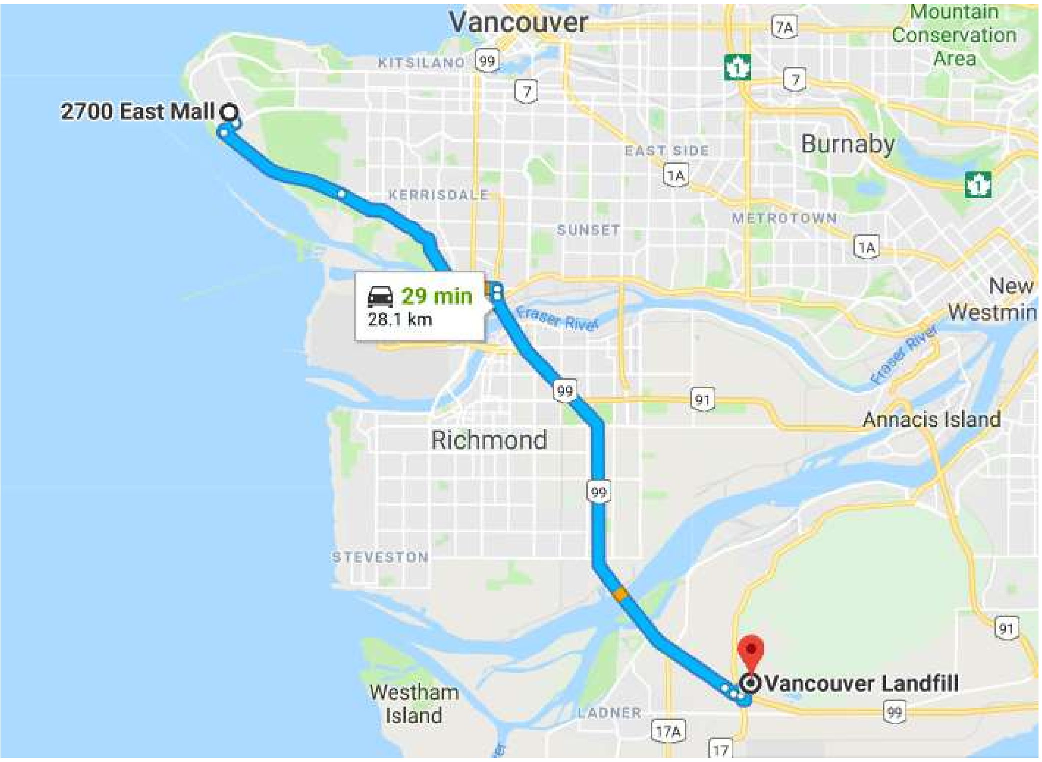


FIGURE 19: PROPOSED SOIL DISPOSAL SOIL AND ROUTE

4.2 MAINLINE CONSTRUCTION

4.2.1 TANK CONSTRUCTION

The tank construction will start after the site has been set up. It includes the construction of the foundation system, the tanks, tank interior, and the roof slab.

4.2.1.1 THE FOUNDATION SYSTEM

The turf field on site will first be stripped away to make room for construction. The secant piles will be built before the excavation. This is because the secant piles are designed to resist the lateral loads from the soil and no shoring or over-excavation is required during excavation.

For the construction of secant piles, first, holes will be drilled for every other secant piles according to the designed layout. Pre-assembled concrete forms and rebar cages will then be sent down before the concrete is poured. Then the rest the piles will be poured with the same method. The secant piles for the two tanks will be constructed simultaneously. Once the secant piles are complete, excavation begins.

When the site has been excavated to the designed depth, the friction piles will be driven into the soil. The soil will be graded and prepared for tank construction.

4.2.1.2 TANKS

The floor slab will be poured continuously for each tank to avoid construction joints, which may cause potential leakage. Temporary walkways will be established before, during, and shortly after the placement of the floor slab.

Once the concrete floor slab has gained adequate strength, the construction of walls and columns will start simultaneously. As water stops will be used at the base of the perimeter walls, special attention is needed to ensure their positive positioning. The procedures specified in the code will be strictly followed to ensure the water tightness of the tanks.

Each wall or column will be poured in a continuous operation without horizontal joints. An enriched fine-aggregate mix shall be used at the base of the walls and columns to improve embedment of the horizontal base water stop and the reinforcement. The perimeter wall of each tank will also be poured in a continuous operation to avoid vertical joints.

4.2.1.3 TANK INTERIOR

The tank interior construction will happen before the roof slab is poured for the ease of construction. The membraned will be applied to the walls, slabs and the columns at the same time as long as the site is not overcrowded. The membranes over the construction joints at the base of the walls and columns will be lapped with extra care.

The submersible pump, ladders will be installed prior to the application of the membrane in the adjacent area to avoid undesired penetration. The submersible pumps will be sufficiently braced according the instruction given by the manufacturer. Rough cleaning of the tank interior will be done before the roof slab is constructed as it is still accessible from the top.

4.2.1.4 ROOF SLAB

The construction of the roof slab will proceed after the tank interior in two stages. Stage one will be the majority of the slab area leaving a smaller area for removing the scaffolding and formworks for stage one. Extra precaution should be taken when setting up the scaffolding to make sure the waterproof layer is not damaged. All equipment and temporary installations will be removed from the tank before the construction of stage two roof slab. The scaffolding and the formwork will be removed from the roof hatch of the tank once the concrete has gained sufficient strength. The connection between the two pours will be arranged in accordance with the structural load path and special attention is needed to ensure structural integrity.

4.2.2 PIPELINE CONSTRUCTION

The piping system is not in the critical path of this project. Trench excavation can start at the beginning of the project followed by soil improvement if needed, pipe installation, and backfill. The detailed schedule will be coordinated with UBC traffic planning to minimize disruption. The pipe connecting the two tanks will be constructed after the bulk excavation is complete. Two holes will be drilled through the interlocked secant piles at the connection.

4.2.2.1 EXCAVATION

Pipe laying supervisor should plan the excavation work, equipment and manpower to fit the plans provided as well as carefully investigate the construction site before moving equipment on site. The trench must be wide enough to permit proper installation of the pipe and to allow room to assemble joints and tamp backfill around the pipe. Size of pipe, type of soil, and type of excavating equipment govern the width. Pavement should be broken in straight lines using appropriate tools and methods.

It is required that pipe be installed with a minimum earth cover as specified by UBC Technical Guidelines. Trench depth and type of soil encountered are vitally important because they govern the need for shoring the trench during water main installation. Further boreholes and soil testing will need to be completed before the type of shoring procedure is determined; however, from current data available sheet piling and temporary shoring will be needed in most areas. Pavement removal is also part of trench excavation and should be completed using straight line cuts outside of the wheel path.

Rock must be excavated so that it will not be closer than 6-inches to the bottom and sides of the pipe for diameters up to 24-inches and no closer than 9-inches for diameters 30-inches or larger. When excavation is complete, a bed of sand, crushed stone, or earth free from stones or large clods should be placed on the bottom of the trench and leveled and tamped to the abovementioned depths. A straightedge can be used to check the bottom of the trench to detect high points of rock that may protrude through the cushion. (DIPRA, 2016).

4.2.2.2 COMPACTION

The trench bottom should be even to give the barrel of the pipe soil support for its full length. Soft subgrade may prove a problem in swampy areas or in loose sand. The trench bottom can be improved by adding crushed stone up to 2-inches in diameter. The stones should be compacted and, if necessary, additional stone added to bring the trench bottom up to proper grade line. Bumping the pipe with the backhoe bucket in order to obtain grade is discouraged due to the possibility of such practice causing damage to the pipe and/or lining. In extreme cases, it may be necessary to drive piling and use cross bracing or clamp the pipe to pile caps to maintain line and grade. Appropriate thickness design procedures for pipe on supports should be used in this instance (DIPRA, 2016).

4.2.2.3 PIPE LAYING

The material specified by UBC technical guidelines for all new water mains is ductile iron. Upon receiving the material, it should be carefully inspected for damage that may have occurred in transit. Material found to be defective due to manufacture or damaged during shipment should be recorded in the delivery receipt or similar document by the carrier's agent.

The polyethylene tube should completely cover the pipe before it is lowered into the trench. A shallow bell hole in the trench bottom should be made to be able to lower the pipe and make up the joint. Ensure the polyethylene wrap is overlapped at the ends of the pipe where it should be secured with circumferential tape.

FIGURE 20: POLYETHYLENE WRAPPING AROUND DUCTILE IRON PIPE (DIPRA, 2016)

Restrained mechanical joints will be used to secure the pipe lengths together and resist thrusting forces as an alternative to thrust blocks where space is limited or soil behind the thrust block may be disturbed; otherwise regular mechanical joints will be used. The mechanical joint has four parts: a flange cast with the bell; a rubber gasket that fits in the bell recess; a gland, or follower ring, to compress the gasket; and tee head bolts and nuts for tightening the joint. Joint assembly is very simple and requires only one tool — an ordinary ratchet wrench. (DIPRA, 2016).

4.2.2.4 BACKFILL

Carefully backfill the trench according to the procedures in AWWA C600 Standard and UBC Technical Guidelines. To prevent damage during backfilling, allow adequate slack in the tube at the joint. Backfill should be free of cinders, rocks, boulders, nails, sticks, or other materials that might damage the polyethylene. Avoid damaging the polyethylene when using tamping devices.

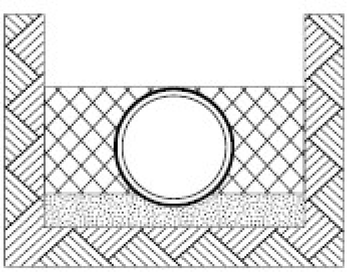


FIGURE 21: TYPICAL BACKFILL WITH BEDDING AND COMPACTED FILL MATERIAL

4.2.2.5 BLOW OFFS AND VENTS

The discharge for blowoffs and drains should be installed so that there is no possibility of sewage or other contamination entering the water main. The blowoffs and drains should discharge above ground and have an air gap of at least two pipe diameters at the sewer or receiving stream. Air release and vacuum vents should be provided at high points in the line as well as in areas of negative pressure. All dead ends on new mains should be closed with plugs or caps that are suitably restrained to prevent blowing off under pressure. All dead ends should be equipped with suitable blowoff or venting devices (DIPRA, 2016).

4.3 TESTING & SERVICE TIE-IN

The pipes will be filled from a local hydrant, followed by tests and inspections by the engineers, owner's representatives, and relevant authorities. Newly installed pipelines are normally pressure tested to confirm proper installation of joints and fittings. When the new pipeline is initially filled, a calculation of a volume of make-up water is determined according to the size and length of the pipeline being tested. The make-up water allowance accounts for the absorption of water by the lining and the extension (lengthening) of pipe joints due to the thrust forces that occur when the pipeline is first pressurized. The allowance is not a measure of leakage through improperly installed joints (DIPRA, 2016).

Then the tank will be disinfected to meet the standard for receiving drinking water. All new water systems or extensions to existing systems should be disinfected in accordance with ANSI and AWWA before being placed in service. Disinfection of mains will be accomplished with chlorine or other disinfecting agents through the continuous feed, slug, or tablet method. Following chlorination, the main should be flushed as soon as possible (within 24 hours) since prolonged exposure to high concentrations of chlorine can damage the seal and coat of system components. After the final flushing, bacteriological tests should be performed in accordance with state and local regulations to ensure that there are no coliform organisms.

The tanks will be filled to its maximum water level for 24 hours. During the next 72 hours, the drop of water level will be measured to compare against calculated water loss due to the evaporation. If the water loss is within an acceptable range, the project will proceed to the next step. Otherwise the testing will be extended to 5 days, by the end of which the average water loss will be used to compare to the standard.

4.4 BACKFILL AND SITE RESTORATION

Once the tanks have passed the water tightness test and necessary repair has been undertaken, the site will be backfilled and graded. The turf field will be laid as original and the surrounding landscape will be restored at the same time.

4.5 ANTICIPATED ISSUES

1. Removal of scaffoldings and formworks

The removal of the scaffoldings and formworks of the roof slab will be challenging as the tank is an enclosed space with a small roof hatch opening. The issue will be addressed by pouring the concrete in two stages. The first stage will be the majority of the area with the scaffoldings and concrete forms being transported through the smaller area left behind. Then the scaffolding and formworks for stage two pour will be transported through the roof hatch.

2. Narrow space between secant piles and tank walls

Narrow spaces between the secant piles and the tank walls is also a challenge while constructing the formwork of the roof slab between the wall and the secant piles. Extra safety precaution will be taken to avoid hazard of confined space.

3. Integrity of interior waterproof layer

The waterproof layer at the interior of the tank can be damaged while the roof slab is being constructed. The ends of the scaffoldings should be wrapped to avoid scratching or penetration of the membrane.

4. Pipe connection through secant piles

Holes will have to be drilled through the interlocked secant piles for the pipes. Special attention is needed to make sure the structural integrity is not compromised.

5. Continuous pour of tank walls

To avoid construction joints that may lead to water leakage, the 7m tank walls will be poured in one continuous operation. The mixing of aggregates and cement required extra attention to ensure adequate bonding.

5.0 MAINTENANCE PLAN

5.1 OBSERVATIONS REQUIRED AFTER CONSTRUCTION

Once construction is complete a series of tests are required to ensure the system is operating as intended, as detailed in **Section 4.3**. “To verify the source of water from a suspected leak, it may be helpful to check for chlorine or use a non-toxic dye inside the tank” (AWWA). The most effective way to locate leaks is to use a trained diver to place a water-proofing membrane or a sterile cotton ball over a suspicious crack or rock pocket. The diver should have an underwater camera, as well as underwater note-writing material.

5.2 TANK MAINTENANCE

All maintenance procedures are according to AWWA standards.

5.2.1 RATIONALE FOR MAINTENANCE

Preventive maintenance will always be less expensive than crisis maintenance. Without regular maintenance possible faults caused from the construction process or even over time, may go without notice. If not repaired, these can result in costly fixes, or in extreme cases, compromise the tank system.

It should be noted that having an underground tank means that the water is kept much cooler. This combined with the lack of light, means that algae growth is eliminated. This elongates the lifespan of equipment such as pumps and valves and ensures that the water quality remains high and suitable for use. Concrete also keeps water much cooler than any other material so there is a far less likelihood of algae or other growth (Versatile Tanks, 2017).

5.2.2 MAINTENANCE PROCEDURE

Tanks should be examined after one year of service or during any time there is a suspected problem.

1. Constantly monitor tank water pressure and water levels.

If water levels vary outside of normal levels, the tank will be valved off and the water level will be checked. Suitable water tightness is achieved if the tank does not lose more than 0.05% of its full-tank volume in a 24-hour period

2. Monthly visual inspections

Assess the condition of the surrounding field and analyze the pressure and flow data from the tank.

A qualified plumber should also carry out a routine check on back flow prevention valves inside the tank once every 12 months.

3. Conduct a comprehensive investigation every 5 years

American Water Works Association (AWWA) states that, "Tanks should be washed out and inspected at least once every five years." (AWWA M42-88).

A trained diver is employed to inspect the tank. All valves and pumps will be closed and turned off prior to inspection. Divers will locate any possible defects or cracks along the interior of the wall, roof, and floor surface by locating silt buildup or releasing an indicator such as a USEPA/NSF approved dye or a sterile cotton ball.

Leaks can also be found in the tank, when the tank is drained and observed from the inside. The tank must first be washed out and drained before inspection begins. The key duties are as follows.

Check Sanitary Conditions: roof openings, access hatches, low spots, vents, overflows.

Check Structural Conditions: foundations, ladders, walls, baffle walls, cracks, and erosion.

Check Coating Conditions: type of current coating, thickness of coating, adhesion/cohesion, and typical life of an interior coating is 12-15 years.

Check Safety Conditions: OSHA standards, ladders, fall prevention, access hatches, and handrails.

After inspection is complete and after leaving the tank, check that all access hatches are locked.

With the redundancy of having two water storage tanks, when performing a full maintenance check on one of the tanks, the other tank can remain in operation due to the constructed bypass system in the pipes. This prevents the entire system from being compromised in the rare event that an earthquake occurs during a dry inspection of one of the tanks.

"Underground water tank inspections can also be performed with a robot, which eliminates the need to drain the tank and does not require lock out/tag out procedures or confined space permits, because no one enters the tank. However, to perform a robotic inspection the underground tank must be equipped with a manway at least 24 inches wide." (Henderson, 2017)

5.2.3 REPAIRS

If the tank fails the water tightness test or has any other defects found through the inspection process, the tank shall be repaired after permission from UBC.

Rock pockets and other defective concrete can be repaired using Epoxy Injection Grouting. The defective concrete is removed and replaced with non-shrink aggregate grout and bonded to the concrete using an epoxy agent. When epoxy grouting is needed, a low-viscosity, two-component, water-insensitive, nontoxic epoxy-resin system with an inline metering and mixing system will be used and procedure will follow procedures provided by AWWA D115-95.

5.2.4 SAFETY CONSIDERATIONS

Safety conditions of fixed ladders are as per 29 CFR 1910.27:

- Minimum design load of 200 lbs;

- 12 in. rung distance;
- 16 in. minimum side rail distance;
- 7 in. toe clearance;
- 15 in. clearance from centerline;
- 30 in. headroom.

The water tank is a confined space and the washout inspection team must have a minimum of a 3-person crew and follow the permit required confined space rules. This includes having at minimum an Attendant, Entrant, and Supervisor.

Under water observations undertaken by a diver should never occur without carefully observing safety procedures. All valves at outlets should be guarded or closed, and suitable lighting should be provided.

5.3 PIPE MAINTENANCE

The pipe network will undergo regular maintenance to guarantee the water quality and pressure being delivered to UBC. The following sections outline the tests, procedures and standards we will follow though the lifetime of the pipe network.

5.3.1 FLUSHING

Flushing of the system will be mandatory after the initial installation of the pipe network, and after any maintenance efforts. Flushing will help evacuate foreign material within the system which can cause leakage at the valves. By opening and closing valves multiple times during the expected line pressure and flow will push foreign material out of the system. Table 9 of the Ductile Iron Pipe Installation Guide outlines the required flow rates needed to flush out pipes of different diameters. To ensure the safety of the campus, service will be temporarily disrupted until the pipe system is properly flushed and disinfected.

5.3.2 PHYSICAL REPAIRS

Throughout the lifetime of the pipe network, it will be exposed to various risks for damage including corrosion, ingrown roots and freezing. To avoid extended service disruption, regular maintenance is going to be conducted throughout the network. To help facilitate maintenance, we will have an inventory of repair material onsite including but not limited to joint split sleeves, interior joint seal devices and bell clamps. Physical maintenance of pipes will also follow the sanitary and disinfecting procedures outlined in AWWA C651 to ensure the integrity of system. To ensure the safety of the workers and the public during repairs, AWWA standard safety procedures will be followed. To further guarantee safety, only experienced crews will be contracted for repairs, and all repairs will be followed by hydrostatic pressure tests and a thorough flushing of the system.

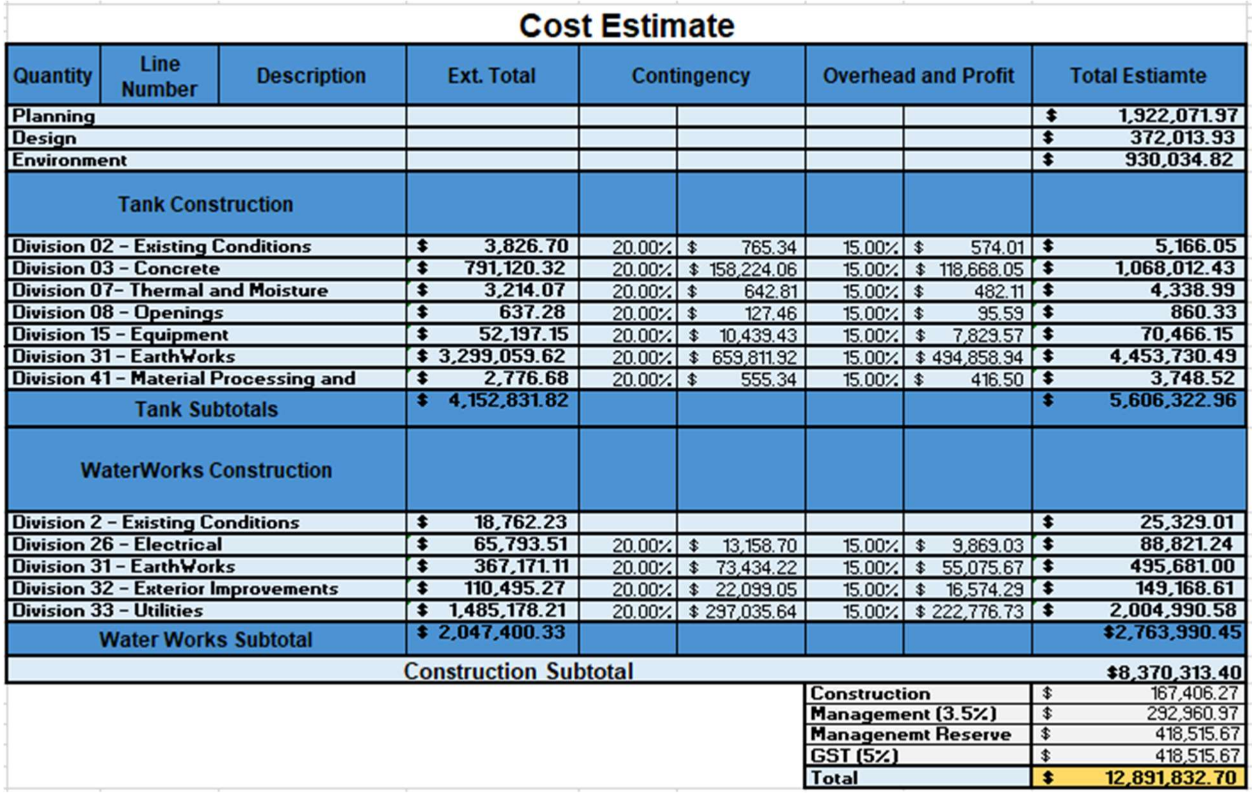
5.4 COST

Maintenance costs covering the lifetime of the system are estimated to be 30% of the total cost of the project.

6.0 COST ESTIMATE

The detailed cost estimate was completed through the use of RS Means which has an accurate and extensive database for labour, material, and equipment rates. The estimate was split into 2 parts, one focused on the tank and one focused on the pipe network. The 2016 Standard Format was used to organize line items which is also consistent with RS Means. To ensure no construction costs were missed, the construction plan to account for all the labour, material and equipment costs for each component of both the tank and the pipe network was used. Once all the unit rates were filled in quantities calculated during the design phase were used to obtain a base cost for the project. Each item was marked up 20% for contingency and an additional 15% for overhead and profit to give a price of $5,606,322.96 for the tank and $2,763,990.45 for the pipe network. To obtain the cost of the whole project, administration, management, planning, design and other critical items were added to the construction costs to give a grand total of $12,891,832.70. A Breakdown of the estimate is featured below, however the detailed estimate can be found in **Appendix C.**

Table 1: Cost Estimate Overview



Cost Estimate

Quantity	Line Number	Description	Ext. Total	Contingency		Overhead and Profit		Total Estiamte
Planning								$ 1,922,071.97
Design								$ 372,013.93
Environment								$ 930,034.82
Tank Construction								
Division 02 – Existing Conditions			$ 3,826.70	20.00%	$ 765.34	15.00%	$ 574.01	$ 5,166.05
Division 03 – Concrete			$ 791,120.32	20.00%	$ 158,224.06	15.00%	$ 118,668.05	$ 1,068,012.43
Division 07– Thermal and Moisture			$ 3,214.07	20.00%	$ 642.81	15.00%	$ 482.11	$ 4,338.99
Division 08 – Openings			$ 637.28	20.00%	$ 127.46	15.00%	$ 95.59	$ 860.33
Division 15 – Equipment			$ 52,197.15	20.00%	$ 10,439.43	15.00%	$ 7,829.57	$ 70,466.15
Division 31 – EarthWorks			$ 3,299,059.62	20.00%	$ 659,811.92	15.00%	$ 494,858.94	$ 4,453,730.49
Division 41 – Material Processing and			$ 2,776.68	20.00%	$ 555.34	15.00%	$ 416.50	$ 3,748.52
Tank Subtotals			$ 4,152,831.82					$ 5,606,322.96
WaterWorks Construction								
Division 2 – Existing Conditions			$ 18,762.23					$ 25,329.01
Division 26 – Electrical			$ 65,793.51	20.00%	$ 13,158.70	15.00%	$ 9,869.03	$ 88,821.24
Division 31 – EarthWorks			$ 367,171.11	20.00%	$ 73,434.22	15.00%	$ 55,075.67	$ 495,681.00
Division 32 – Exterior Improvements			$ 110,495.27	20.00%	$ 22,099.05	15.00%	$ 16,574.29	$ 149,168.61
Division 33 – Utilities			$ 1,485,178.21	20.00%	$ 297,035.64	15.00%	$ 222,776.73	$ 2,004,990.58
Water Works Subtotal			$ 2,047,400.33					$2,763,990.45
			Construction Subtotal					$8,370,313.40
						Construction		$ 167,406.27
						Management (3.5%)		$ 292,960.97
						Managenemt Reserve		$ 418,515.67
						GST (5%)		$ 418,515.67
						Total		$ 12,891,832.70

7.0 SCHEDULE

The construction of the tanks will take 25 weeks from May 1st, 2018 to October, 22th, 2018. Following is a table summarizing the milestones for all stages. A Gantt chart of the construction schedule with detailed activities can be found in **Appendix D.**

TABLE 2: SCHEDULE OVERVIEW

Construction Stages	Dates
Foundation system	May 8th, 2018 - July 13th 2018
Storage system	July 17th, 2018 - September 12th, 2018
Pipe construction	May 4th, 2018 - June 20th, 2018
Service tie-in and testing	September 13th, 2018 - September 25th, 2018
Backfill and site restoration	September 25th, 2018 - October 22th, 2018

8.0 RECCOMENDATIONS FOR DESIGN IMPROVEMENT

To analyze and provide a solution to the design problem, a number of reasonable design assumptions were made. If more site data and accurate water model are provided, the proposed water supply and distribution design can be significantly improved in terms of structural performance, cost and construction impacts. The following is list of recommendations for design improvement.

- EPANET Model: An accurate EPANET water model would be helpful to determine if the implementation of the design would work within the existing system. For a successful run, several pipe diameters had to be changed on the model based on estimated values;
- Below Grade Behavior during Earthquake: More information and expertise on the behavior of below grade concrete during an earthquake is required to better design the structural components of the tank. Currently, the tank is designed for earthquake risks by assuming larger load factors;
- Dynamic Analysis: Access to finite element analysis software will be helpful to allow us to model our design more accurately and reduce the number of assumptions made, and potentially a program that could model dynamic loads such as an earthquake;
- Additional Site Condition Data: CPT testing and additional borehole samples for the soil in the area so there is a better idea of the soil quality and the improvements that would have to be made to reduce liquefaction risks;
- Additional Utilities Data: Survey data of below ground utilities to detect any potential clashes of existing and proposed utilities.

9.0 REFERENCES

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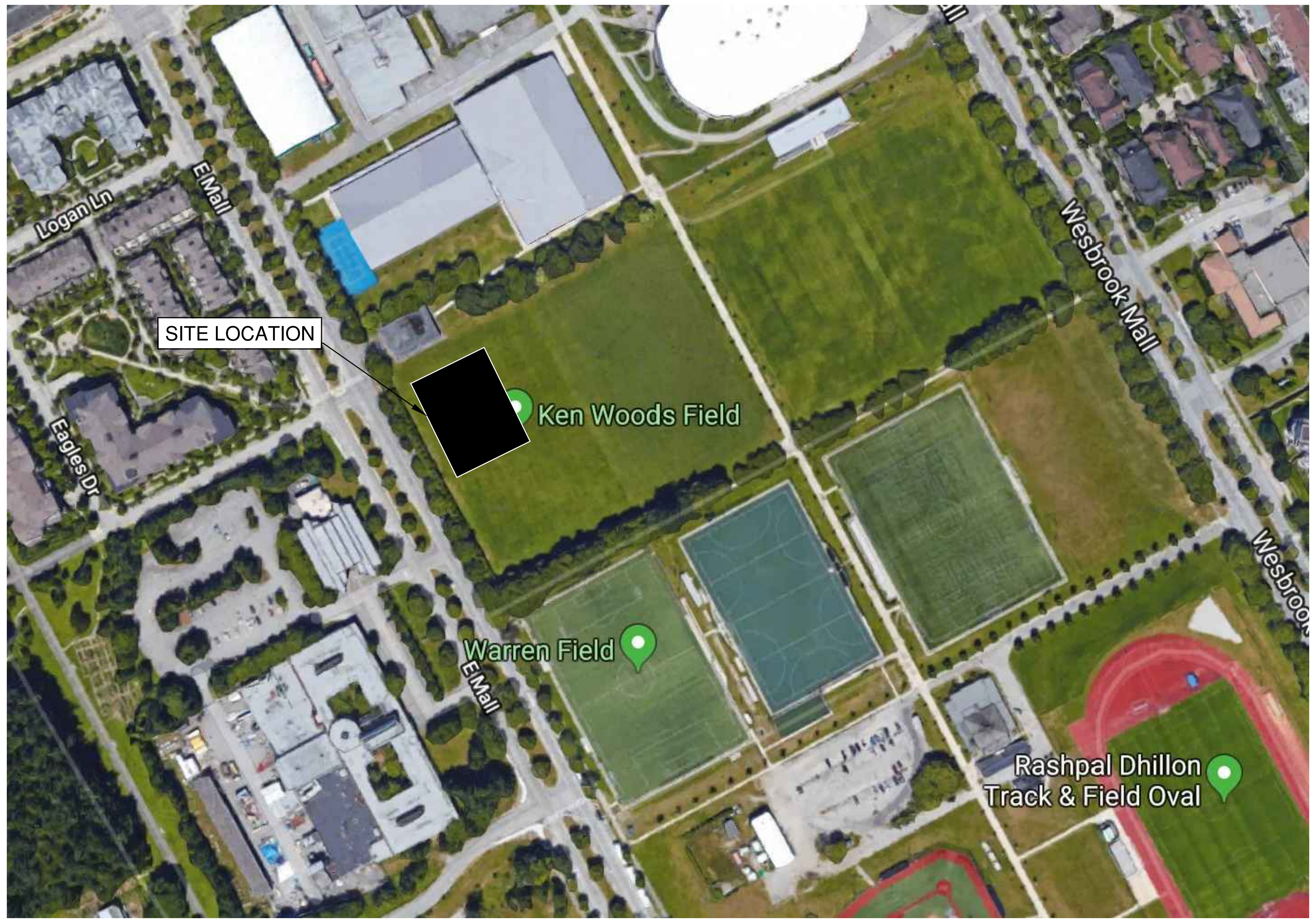
APPENDIX A: DETAILED DESIGN DRAWINGS

AQUASTOR

UBC WATER STORAGE SUPPLY SYSTEM
ISSUED FOR CONSTRUCTION
APRIL 2018



DRAWING INDEX

TECHNICAL SPECIFICATIONS
CONSIDERED IN DESIGN

ACI	**CONCRETE**
	301-16 Specifications for Structural Concrete
	302.1R-15 Guide to Concrete Floor and Slab Construction
	347R-14 Guide to Formwork for Concrete
	360R-10 Guide to Design of Slabs-on-Ground
	364.11T-15 Managing Alkali-Aggregate Reaction Expansion in Mass Concrete
	421.3R-15 Guide to Design of Reinforced Two-Way Slab Systems
	311.4R-05: Guide for Concrete Inspection
	350.3-06 Seismic Design of Liquid-Containing Concrete Structures and Commentary
	439.4R-09 Report on Steel Reinforcement - Material Properties and U.S. Availability (Reapproved 2017)
	ITG-4.2R-06 Materials and Quality Considerations for High-Strength Concrete in Moderate to High Seismic Applications
	SP-127: Earthquake-Resistant Concrete Structures--Inelastic Response and Design
	304: Measuring, Mixing, Transporting, and Placing Concrete
	305: Hot Weather Concreting
	306: Cold Weather Concreting
	308: Curing Concrete
CSA	**CONCRETE**
	A23.1-14/A23.2-14 - Concrete materials and methods of concrete construction / Test methods and standard practices for concrete
	S269.3-M92(R2013) - Concrete Formwork
	A3000-13: Cementitious Materials Compendium
	A23.1 - Concrete Materials and Methods of Concrete Construction
	A23.2 - Test Methods and Standard Practices for Concrete
	A23.3 - Design of Concrete Structures
	A23.4 Precast Concrete - Materials and Construction
	G30.18 - Carbon Steel Bars for Concrete Reinforcement
	W186 - Welding of Reinforcing Bars in Reinforced Concrete Construction
	G164 - Hot Dip Galvanizing of Irregularly Shaped Articles
	O86 - Engineering Design in Wood (Limit States Design)
	S269.1 - Falsework for Construction Purposes
	S269.3 - Concrete Formwork
	A3000 - Cementitious Materials Compendium
	A283 Qualification Code for Concrete Testing Laboratories
ASTM	**CONCRETE**
	ASTM C125-18 Standard Terminology Relating to Concrete and Concrete Aggregates
	ASTM C33/C33M-16e1 Standard Specification for Concrete Aggregates
	ASTM D4258-05(2017) Standard Practice for Surface Cleaning Concrete for Coating
	ASTM C150 / C150M - 17 Standard Specification for Portland Cement
	A704 / A704M - 17 Standard Specification for Welded Steel Plain Bar or Rod Mats for Concrete Reinforcement
	D1752 - Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
	F593 - Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction
	C309 - Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
	C260 - Standard Specification for Air Entraining Admixtures for Concrete
	C157 - Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
	C494 - Standard Specifications for Chemical Admixtures for Concrete
	C1433 - Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains and Sewers
	A36 - Standard Specification for Carbon Structural Steel
	PIPE
	A674 – Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids
	A716 - Ductile Iron Culvert Pipe
	A746 - Ductile Iron Gravity Sewer Pipe

MAPEI	**CONCRETE**
	03 01 30 Maintenance of Cast-In-Place Concrete
	03 06 00 Concrete Admixtures
Xypex Chemical Corp	**CONCRETE**
	03 05 00 Integral Waterproofing of Concrete
NMS	**PILES**
	31 08 13 - PILE LOAD TESTING
	31 61 13 - PILE FOUNDATIONS, GENERAL REQUIREMENTS
	31 63 23 - BORED CONCRETE PILES
	31 62 13.19 - PRECAST CONCRETE PILES
	EXCAVATION
	31 22 16.13 - ROADWAY SUBGRADE RESHAPING
	31 23 33.01 EXCAVATING, TRENCHING AND BACKFILLING
	31 23 16.26 ROCK REMOVAL
	PIPES
	33 11 00 - GROUNDWATER SOURCES
	33 14 16 - SITE WATER UTILITY DISTRIBUTION PIPING
	33 14 16.13 - INCOMING SITE WATER UTILITY DISTRIBUTION PIPING
	33 65 16 - DISTRIBUTION PIPING - PVC - FRP
ADSC	**PILES**
	Specifications for the Construction of Secant and Tangent Pile Wall Systems Using Drilled Shafts
ANSI/AWWA	**PIPES**
	C104/A21.4 - Cement-Mortar Lining For Ductile Iron Pipe and Fittings
	C105/A21.5 – Polyethylene Encasement for Ductile Iron Pipe Systems
	C110/A21.10 - Ductile Iron and Gray Iron Fittings
	C111/A21.11 - Rubber-Gasket Joints for Ductile Iron Pressure Pipe and Fittings
	C115/A21.15 – Flanged Ductile Iron Pipe with Ductile Iron or Gray Iron Threaded Flanges
	C116/A21.16 – Protective Fusion-Bonded Coatings for the Interior and Exterior Surfaces of Ductile Iron and Gray-Iron Fittings
	C150/A21.50 – Thickness Design of Ductile Iron Pipe
	C151/A21.51 - Ductile Iron Pipe, Centrifugally Cast
	C153/A21.53 - Ductile Iron Compact Fittings
	C600 - Installation of Ductile Iron Water Mains and Their Appurtenances
	C606 - Grooved and Shouldered Joints
	C651 - Disinfecting Water Mains
	VALVES
	C500 - AWWA Standard for Metal-Seated Gate Valves for Water Supply Service
MSS	**PIPES**
	SP-60 – Connecting Flange Joint between Tapping Sleeves and Tapping Valves
	SP-111 - Gray Iron and Ductile Iron Tapping Sleeves
ASME	**VALVES**
	B16.34 Valves – Flanged, Threaded, and Welding End
	B16.1 Cast Iron Pipe Valves Flanges and Flanged Fittings
	B16.5 Pipe Flanges and Flanged Fittings – NPS ½ Through NPS 24
ANSI/NSF Standard 61	**VALVES/PIPES/OTHER**
	Drinking Water System Components-Health Effects

General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project: TECH SPEC
Date: 18.04.2018
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Sheet: 01

1 OVERVIEW PLAN LAYOUT

SCALE: 1:1000

General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address

AQUASTOR

Project Name and Address

WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
CONCRETE TANK

Date
04.08.2018

Scale
AS NOTED

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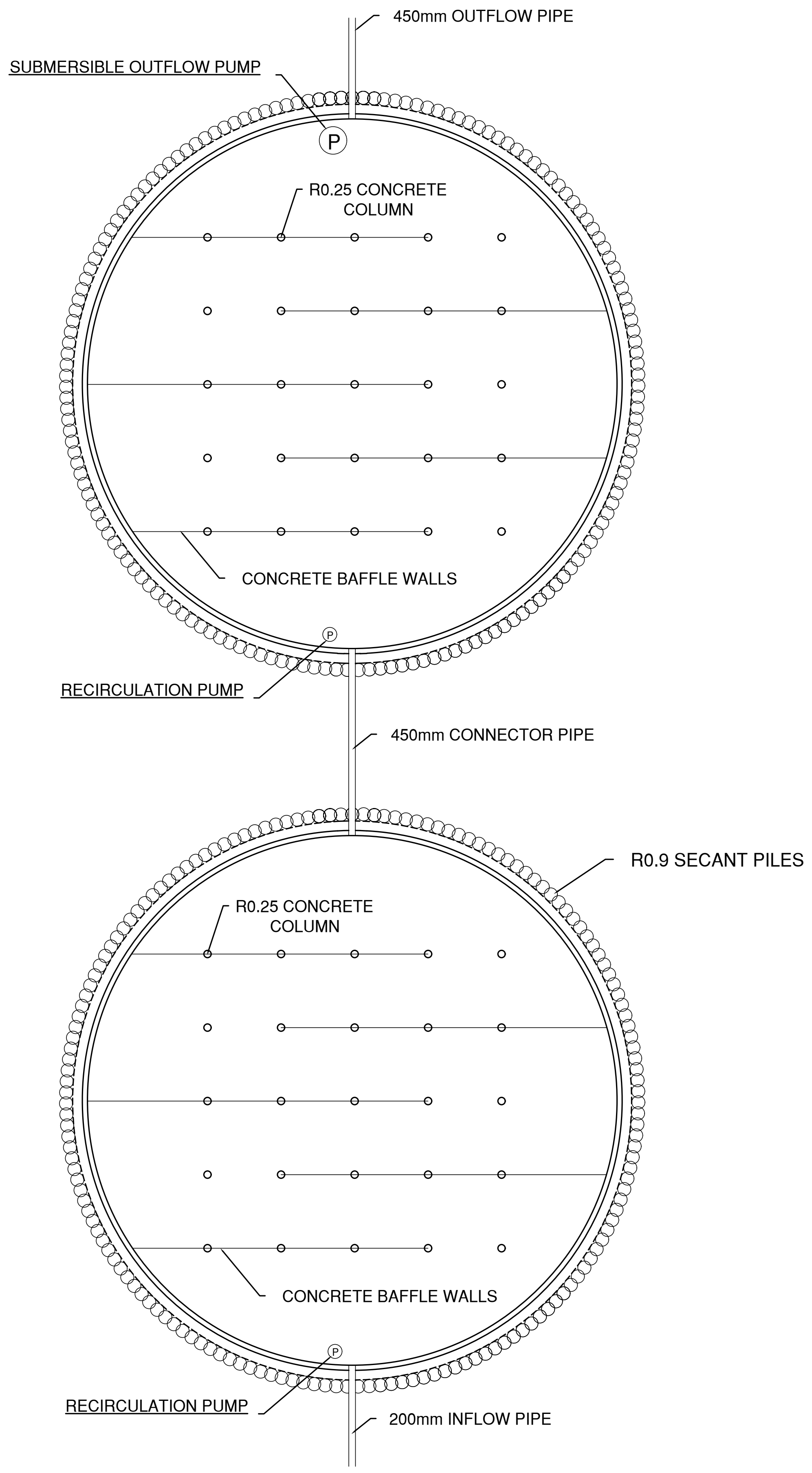

② PLAN VIEW OF TANKS

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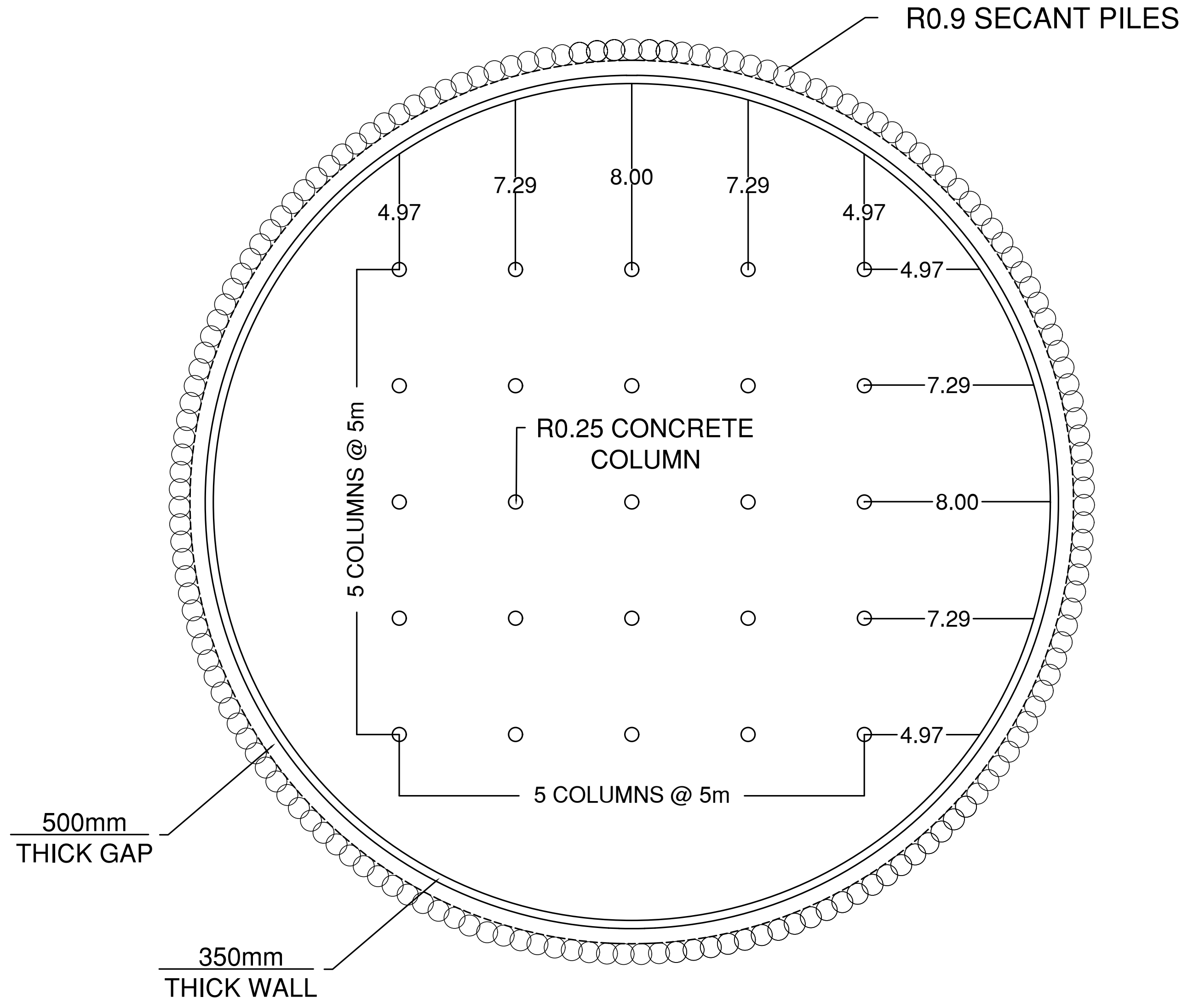

③ PLAN VIEW WITH COLUMNS

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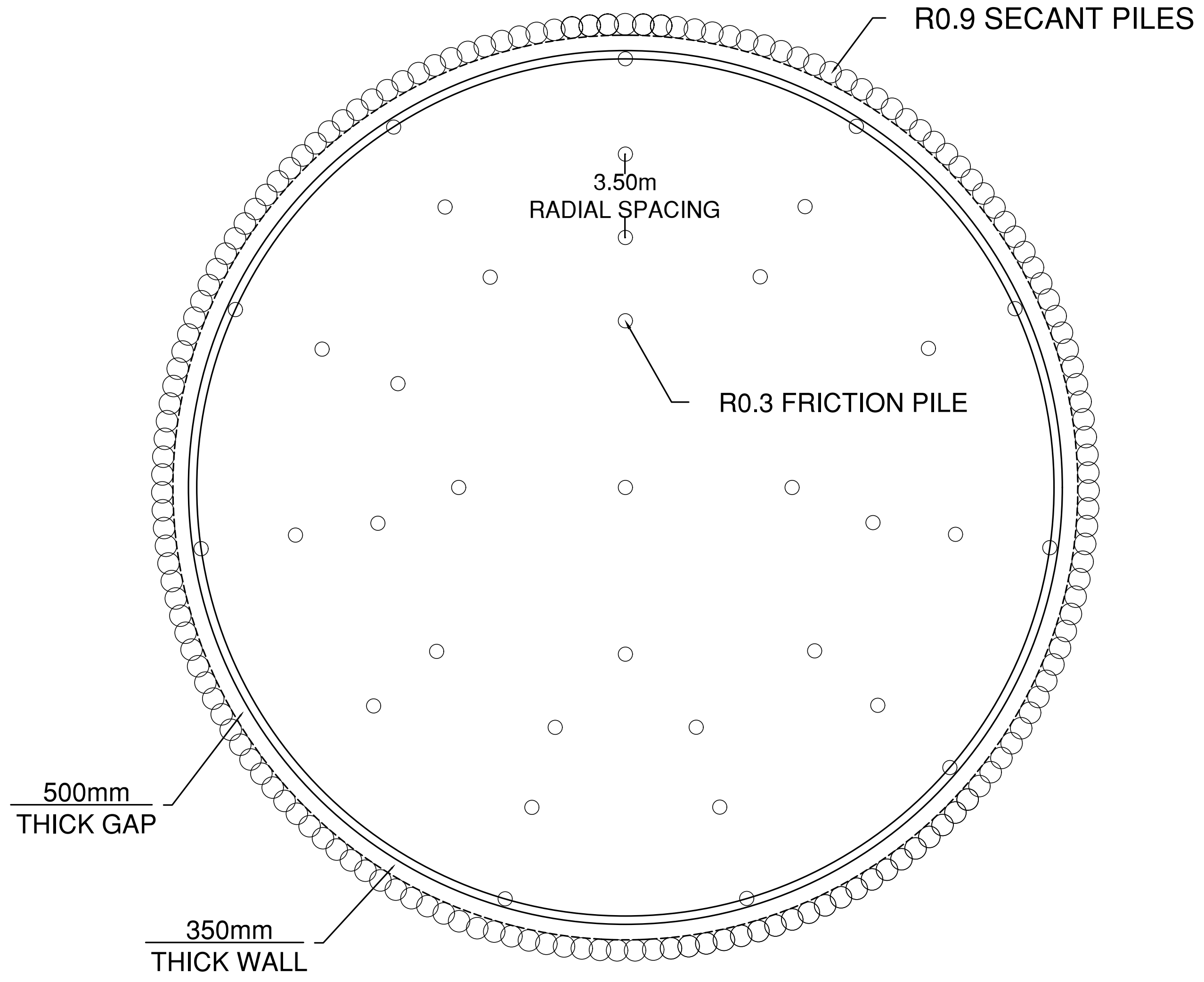

④ PLAN VIEW WITH FRICTION PILES

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General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address

AQUASTOR

Project Name and Address

WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

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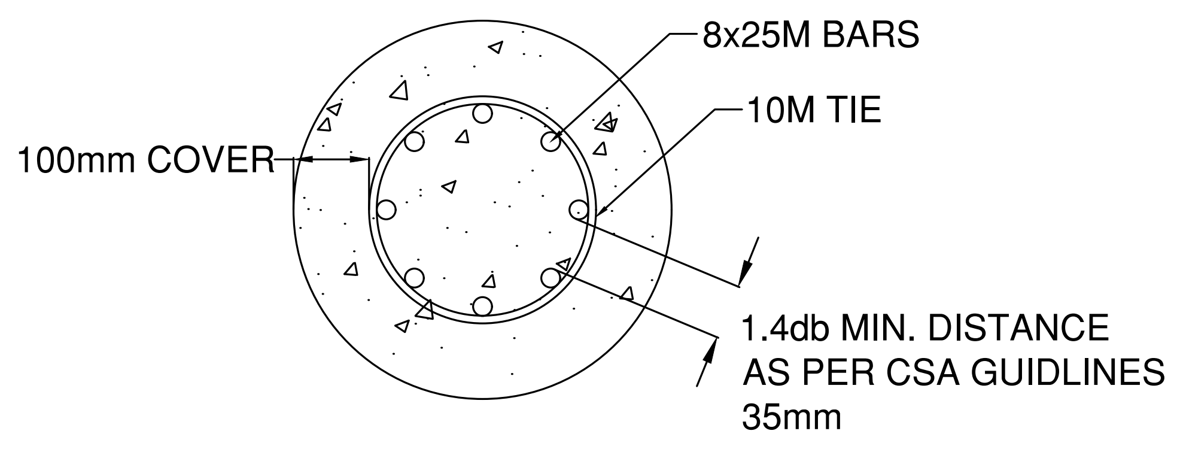

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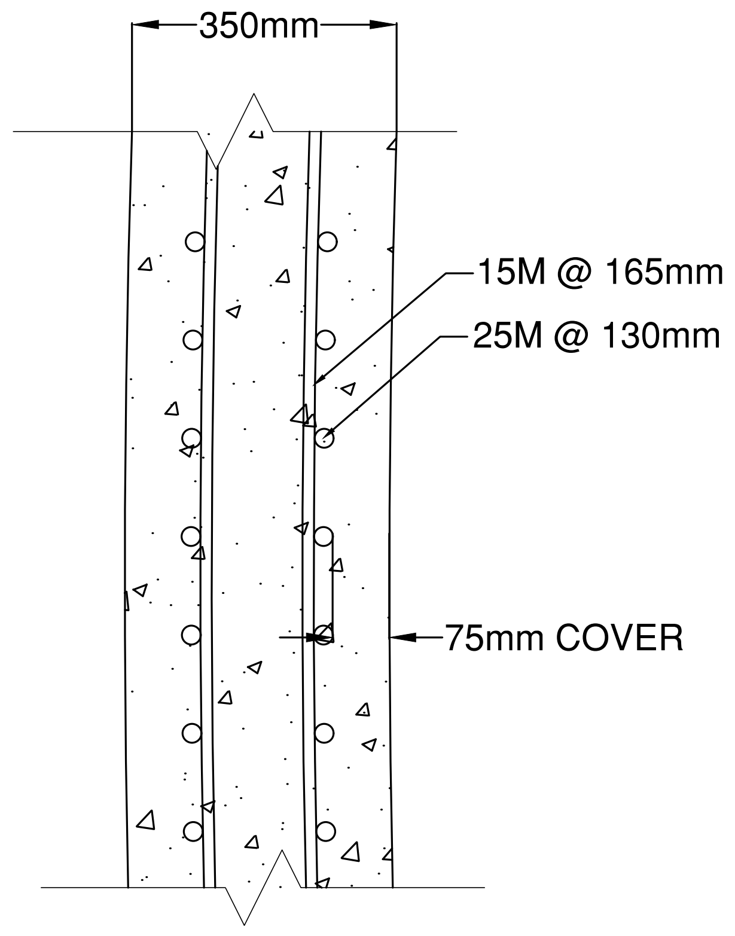

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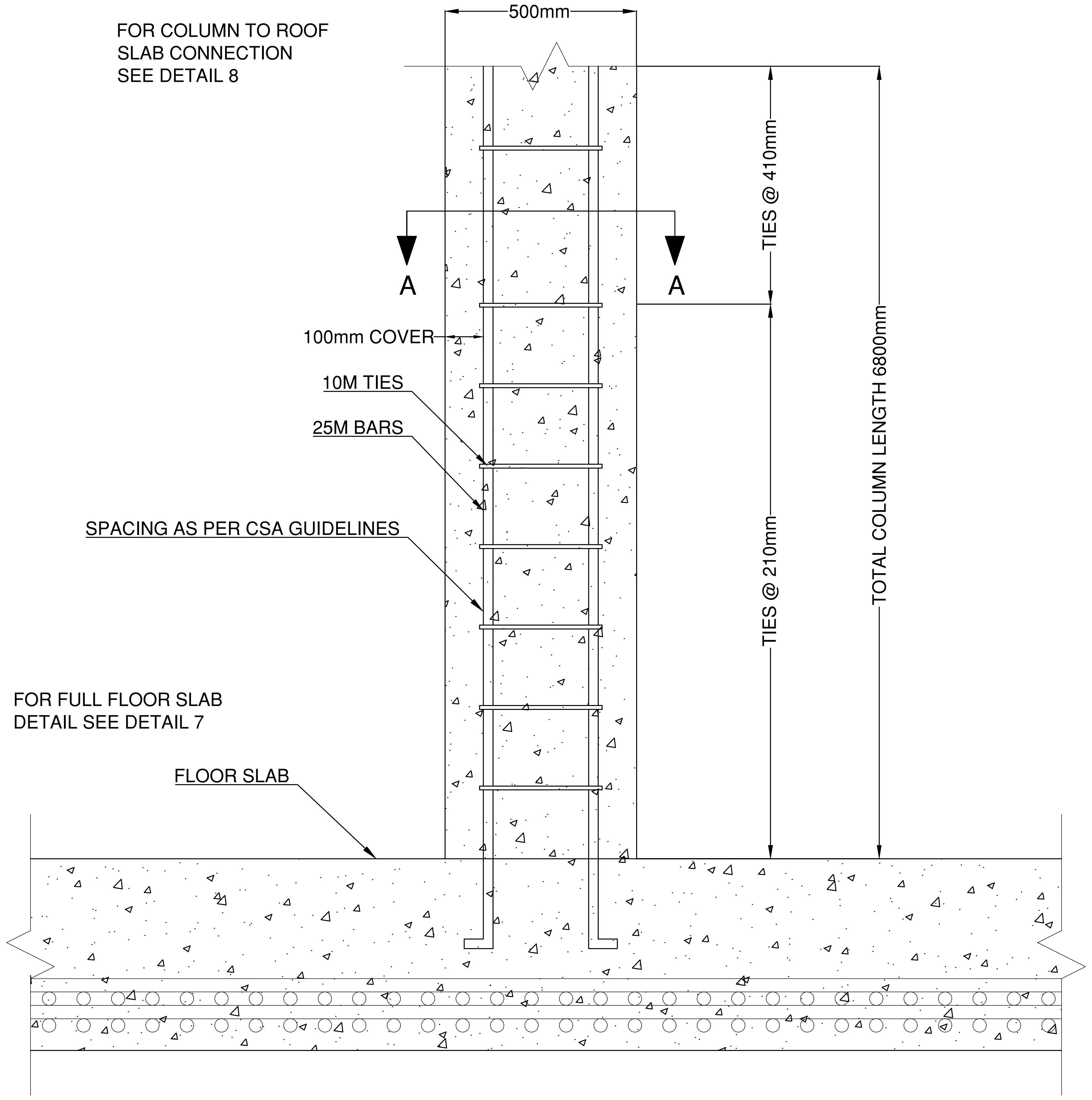

5 TYPICAL INTERIOR TIED COLUMN

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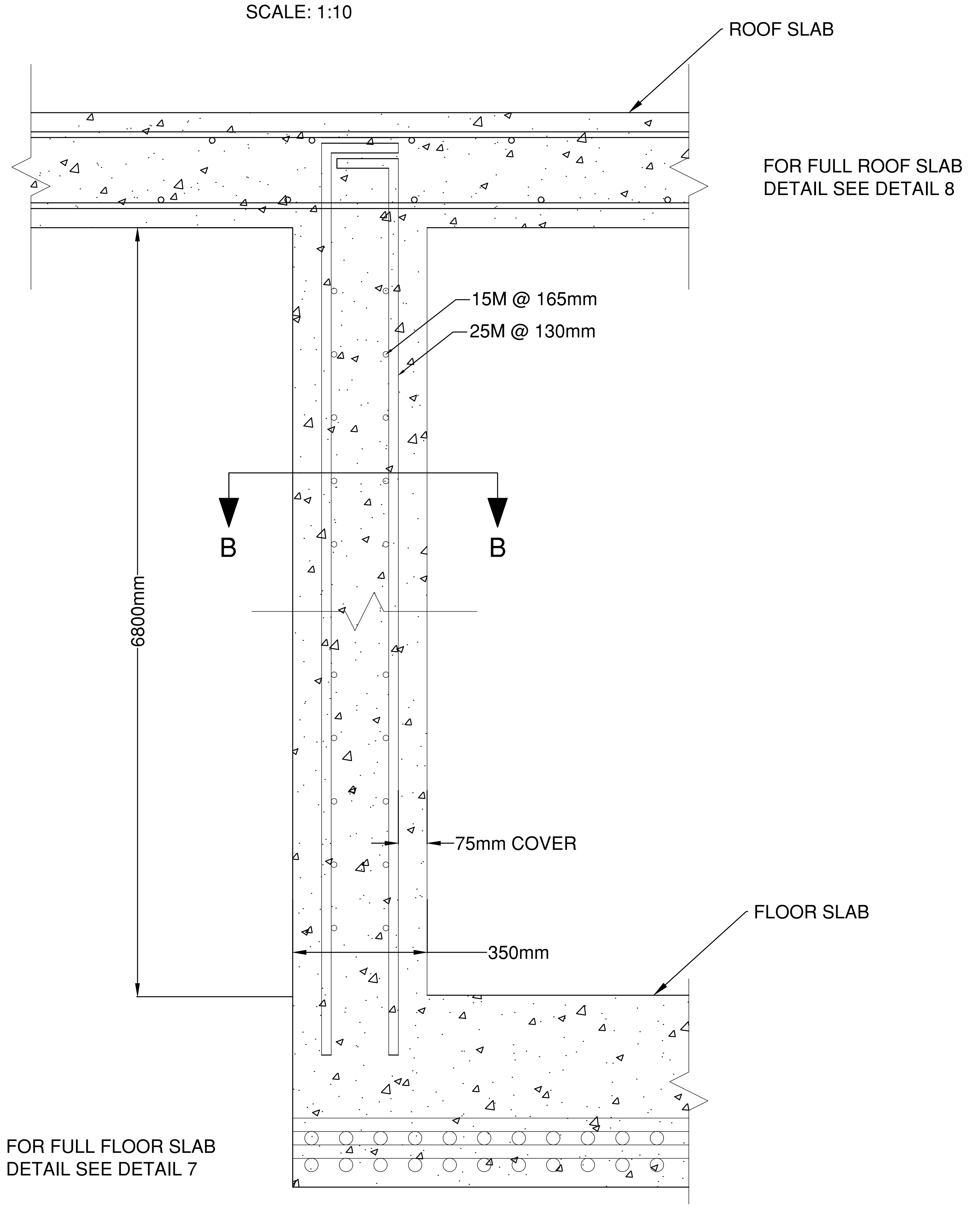

6 EXTERIOR WALL

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General Notes

No.	Revision/Issue	Date
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Firm Name and Address
AQUASTOR

Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
WALL&COLUMN

Date
18.04.2018

Scale
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04

NOTES:
1. BOTH FLOOR AND ROOF SLABS ARE CIRCULAR WITH A DIAMETER OF 36m
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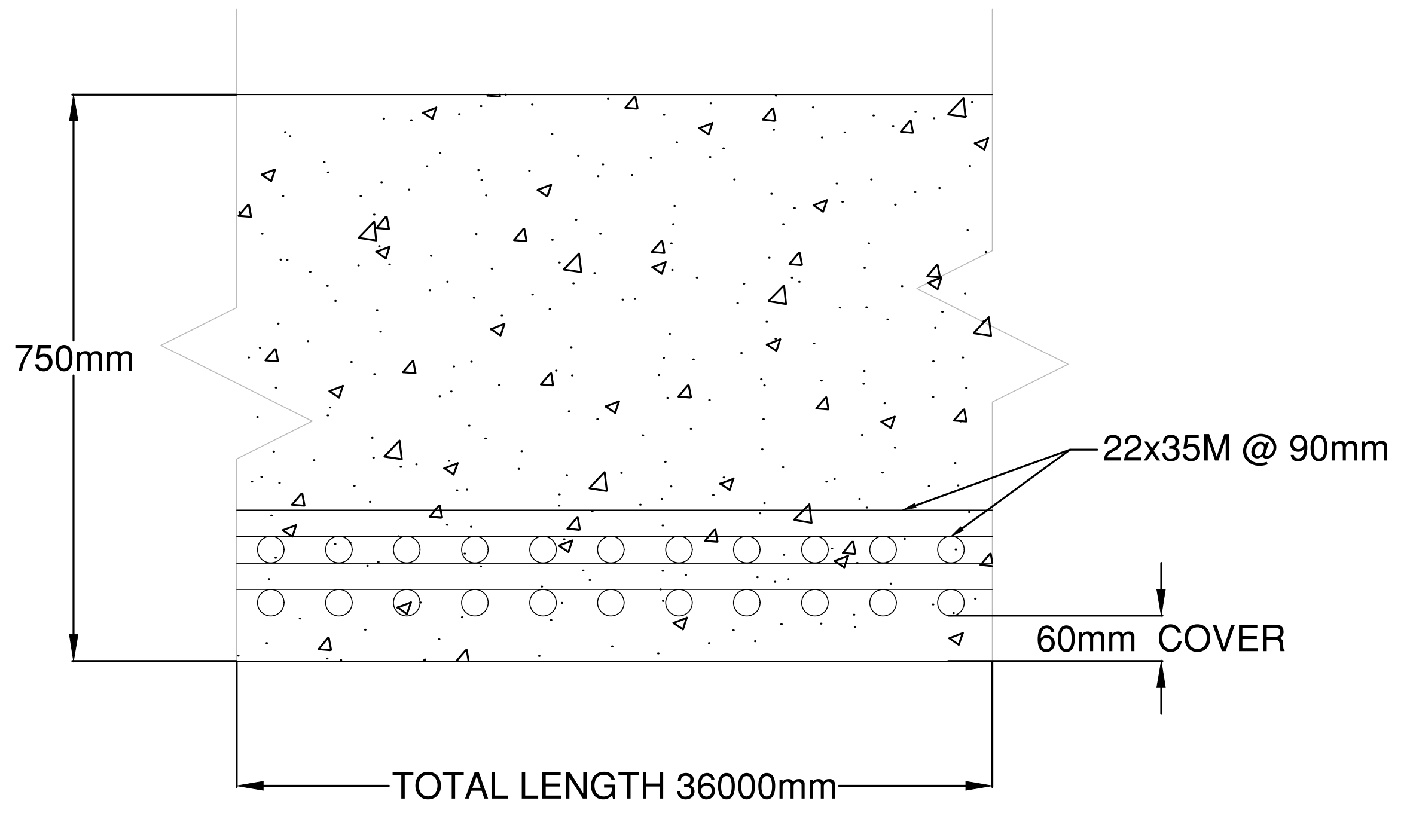

7 FLOOR SLAB
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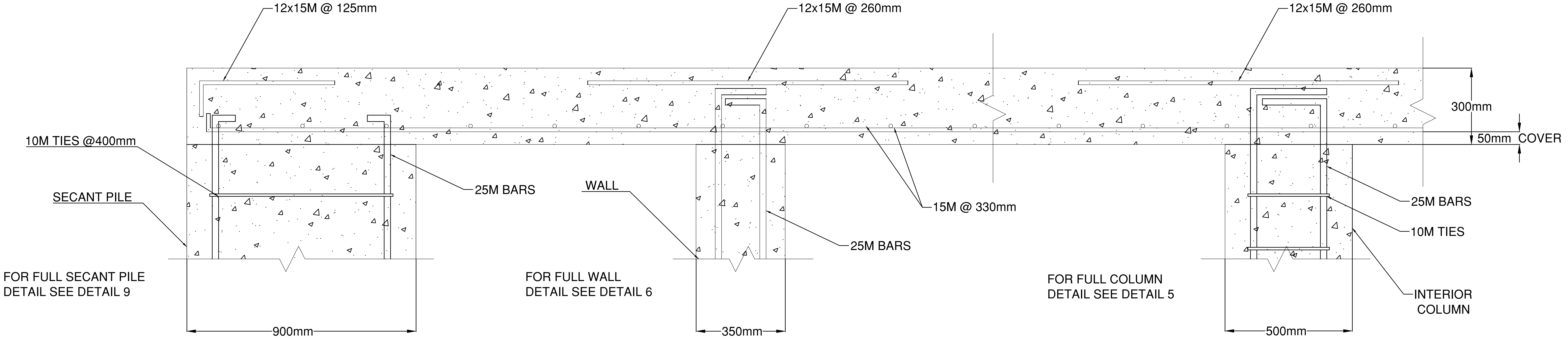

FOR FULL SECANT PILE DETAIL SEE DETAIL 9

FOR FULL WALL DETAIL SEE DETAIL 6

FOR FULL COLUMN DETAIL SEE DETAIL 5

8 ROOF SLAB
SCALE: 1:10

General Notes

No.	Revision/Issue	Date
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Firm Name and Address
AQUASTOR

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WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

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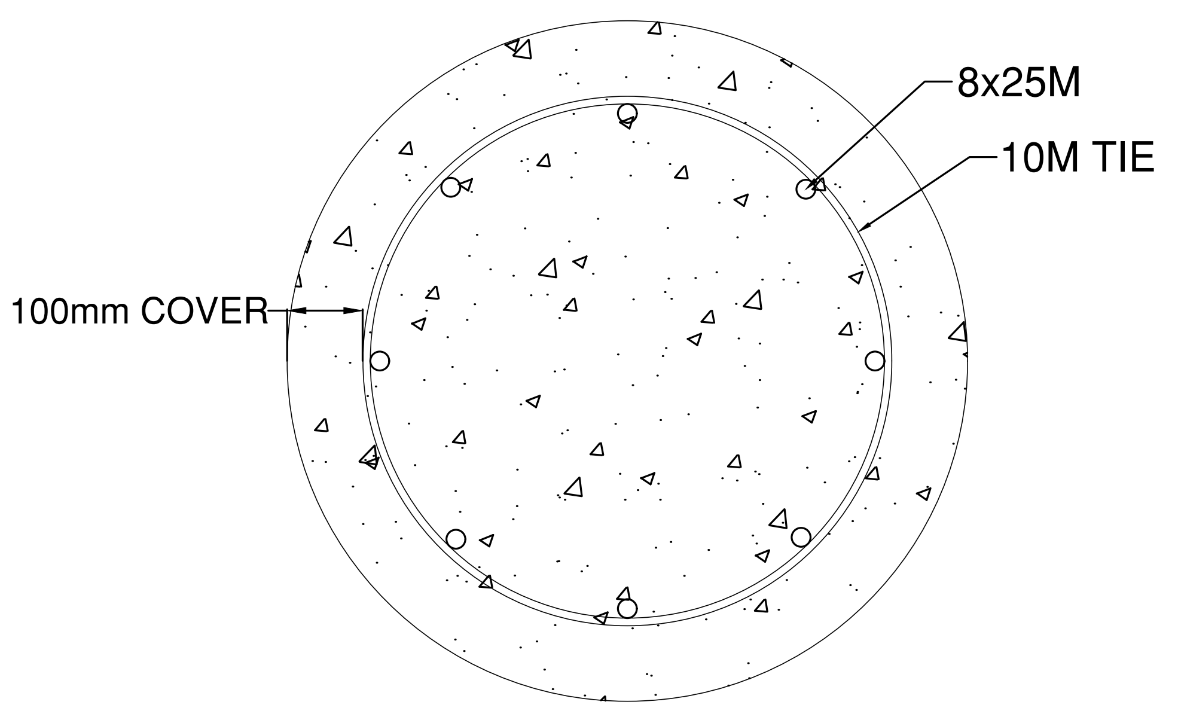

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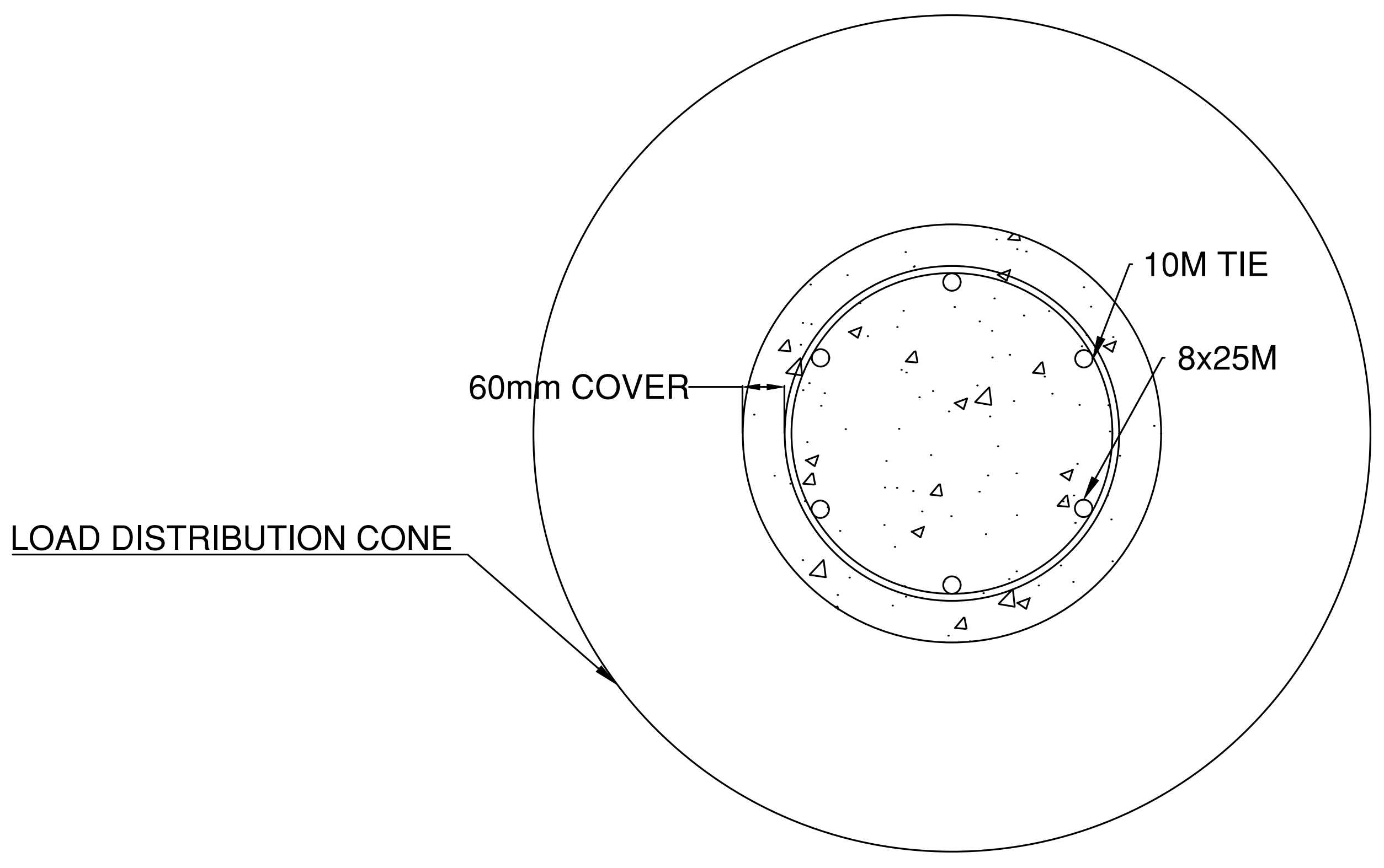

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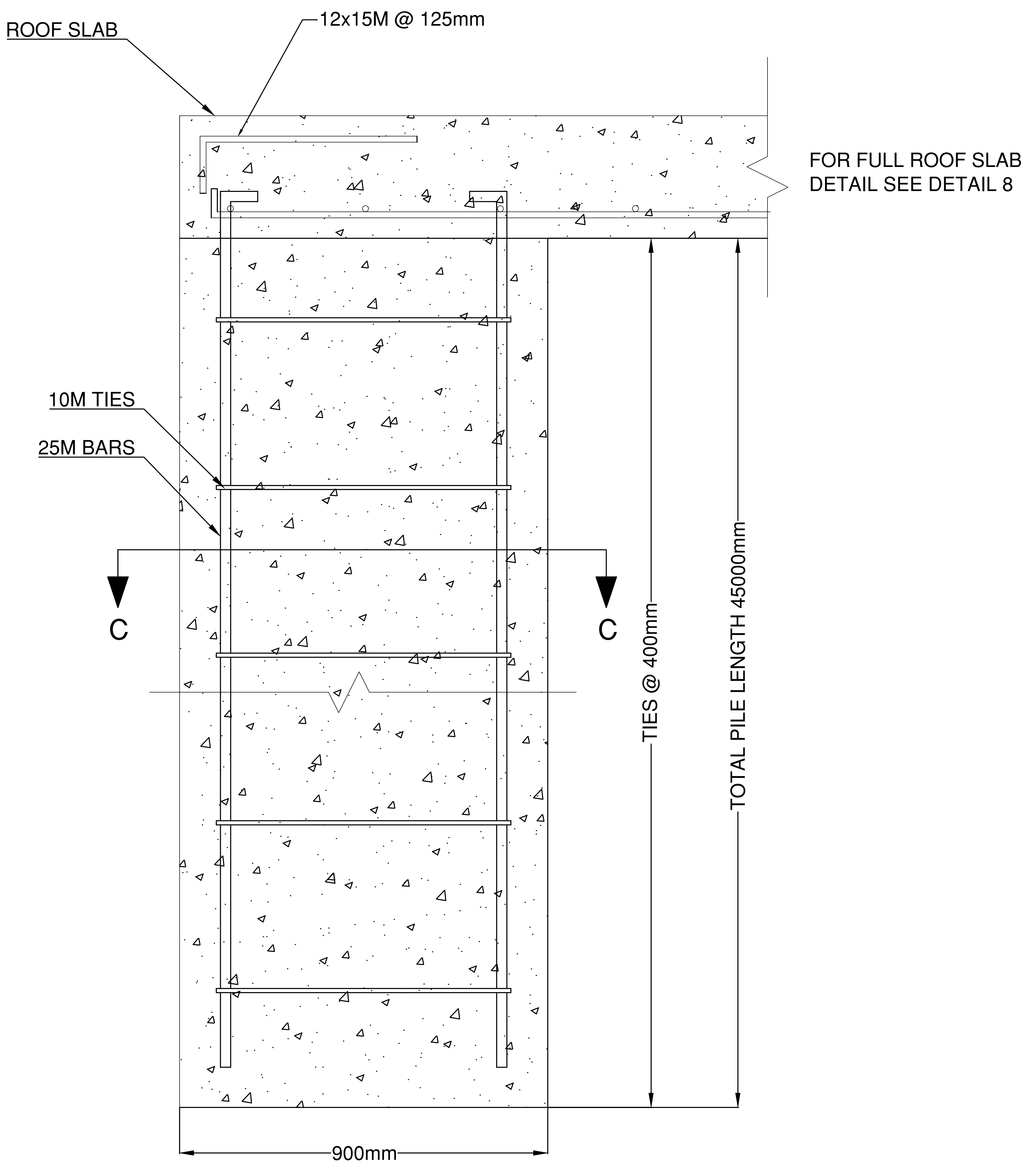

⑨ TYPICAL SECANT PILE
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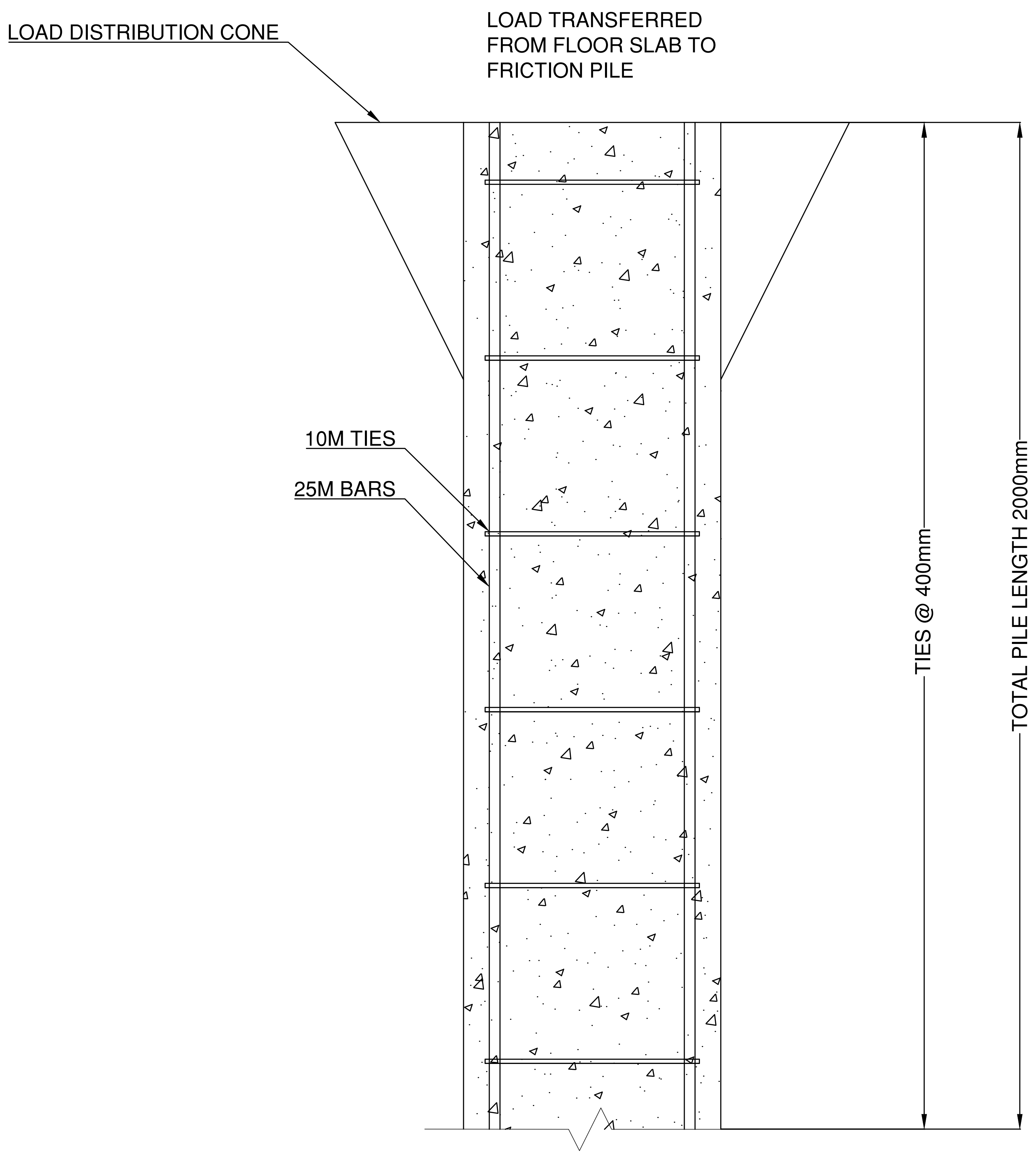

⑩ TYPICAL FRICTION PILE
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General Notes

No.	Revision/Issue	Date
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Firm Name and Address
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Project Name and Address
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UBC
VANCOUVER, BC

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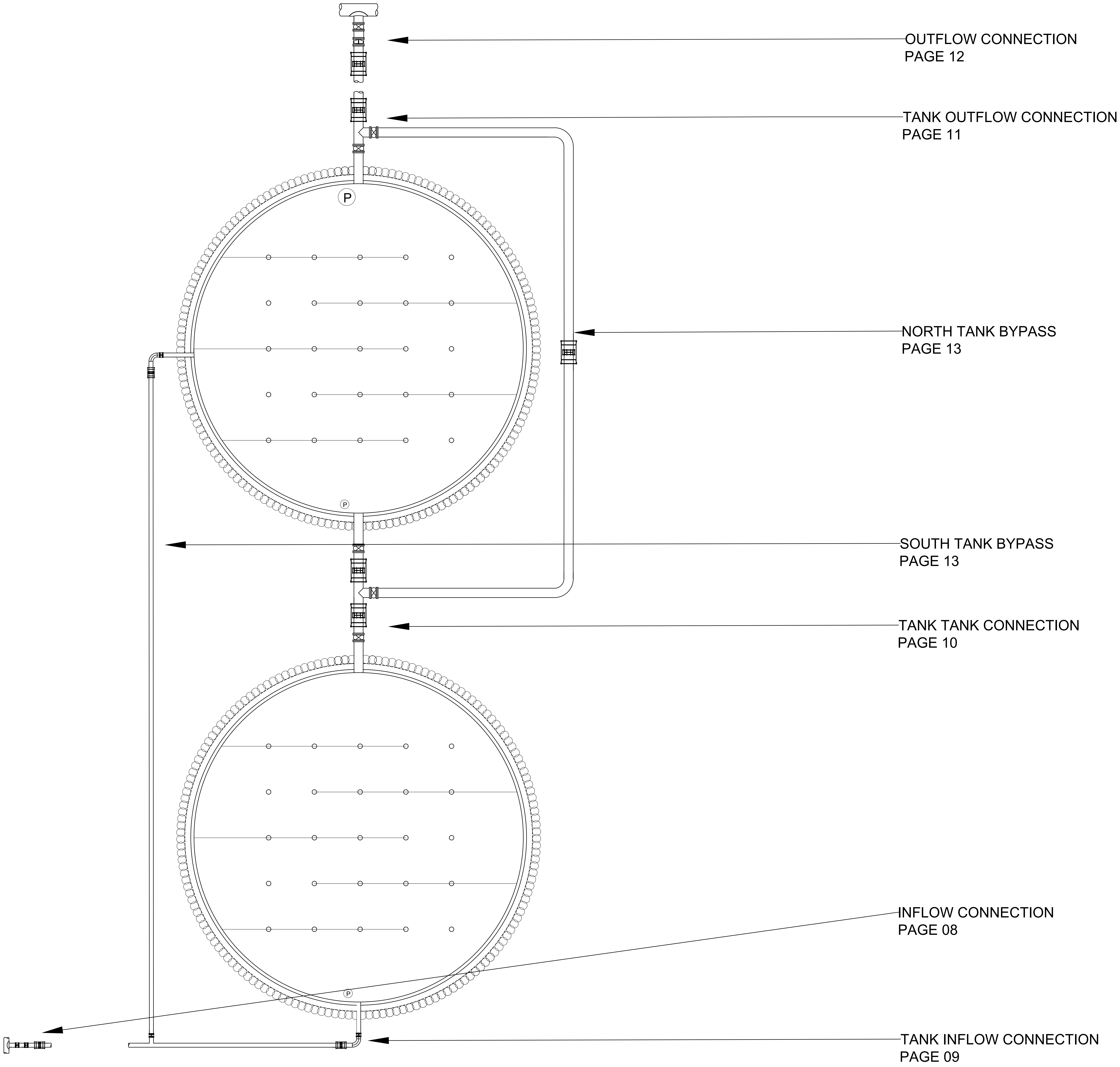

⑪ PLAN SYSTEM OVERVIEW

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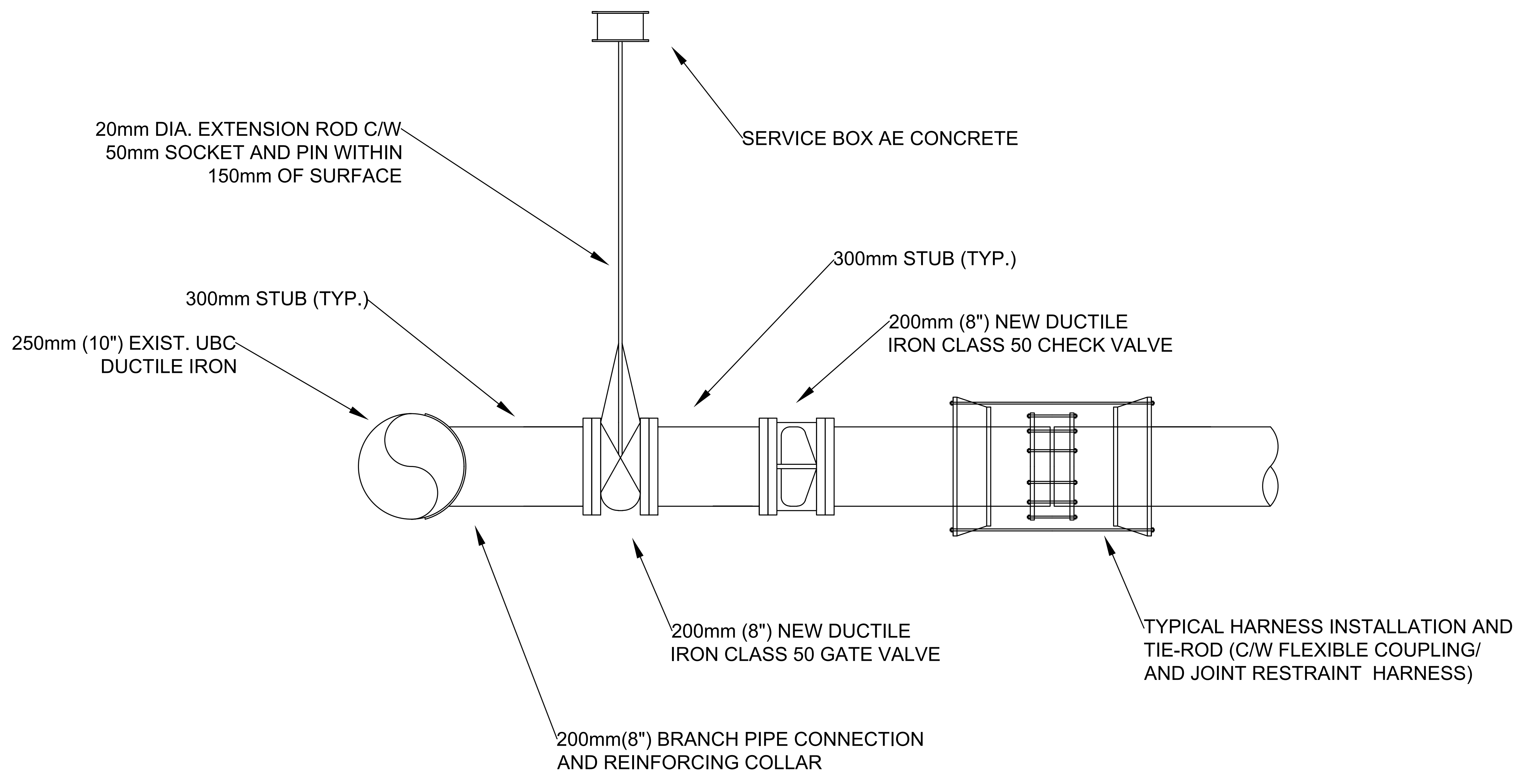
General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

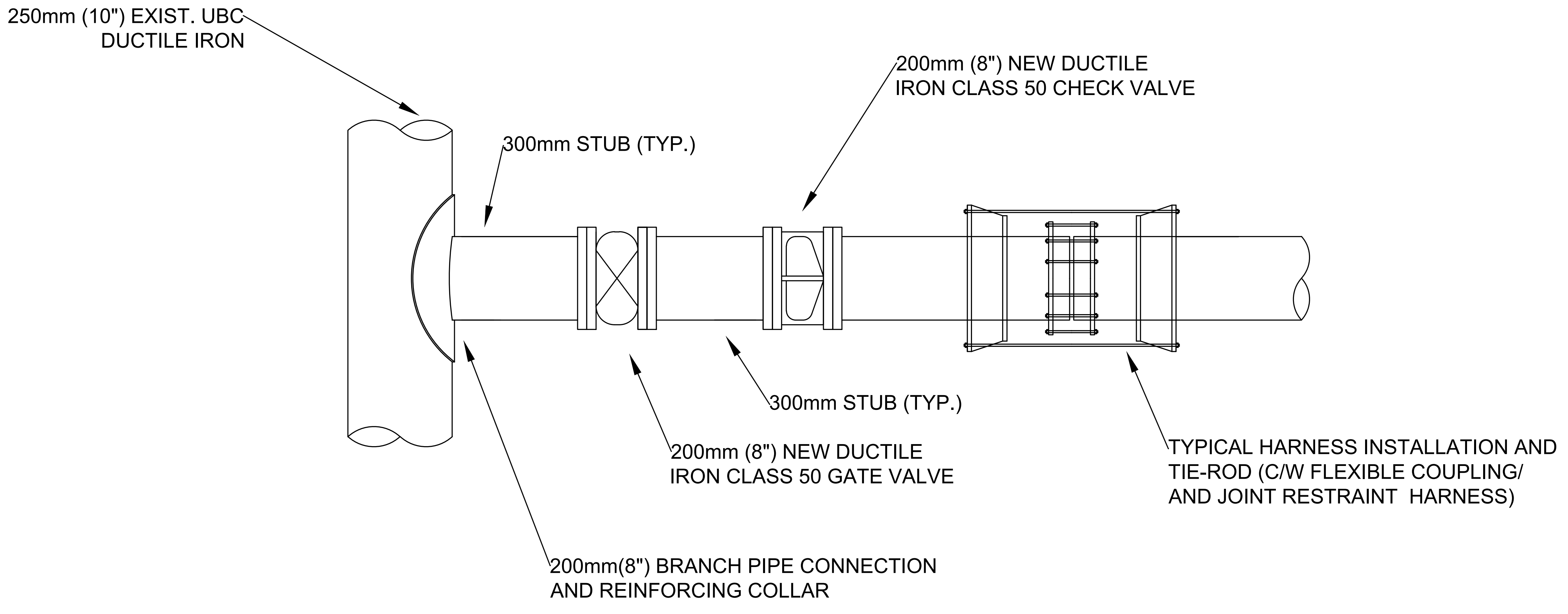
Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project: OVERVIEW
Date: 18.04.2018
Scale: AS NOTED
Sheet: 07



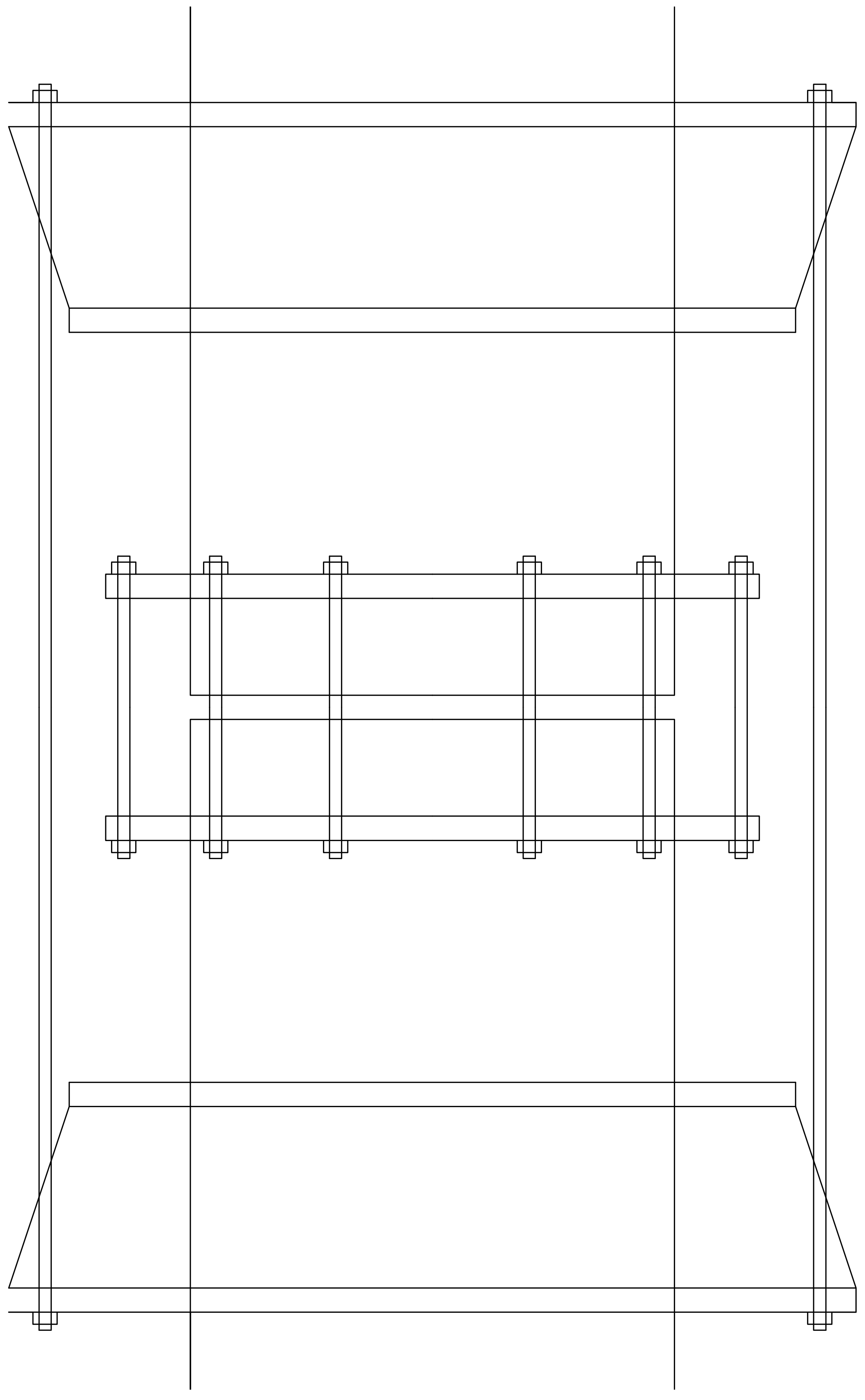
12 PROFILE 200mm INFLOW FROM EXST.

SCALE: 1:10



13 PLAN 200mm INFLOW FROM EXST.

SCALE: 1:10



14 HARNESS ASSEMBLY DETAIL (TYP.)

SCALE: 1:2

NOTES:

1. DETAILS WERE DESIGNED ACCORDING TO SPECIFICATIONS FOUND ON DRAWING 01

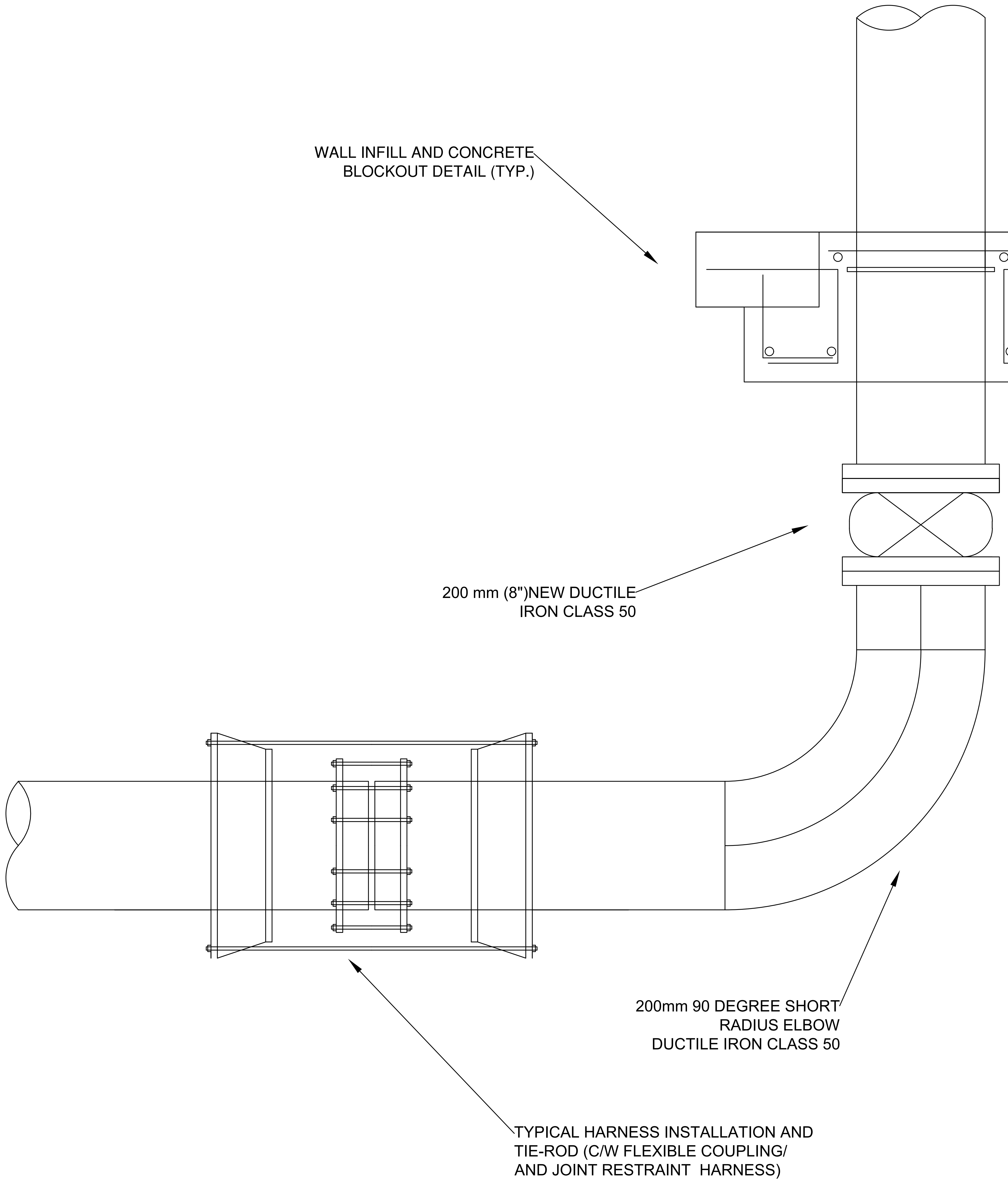
General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

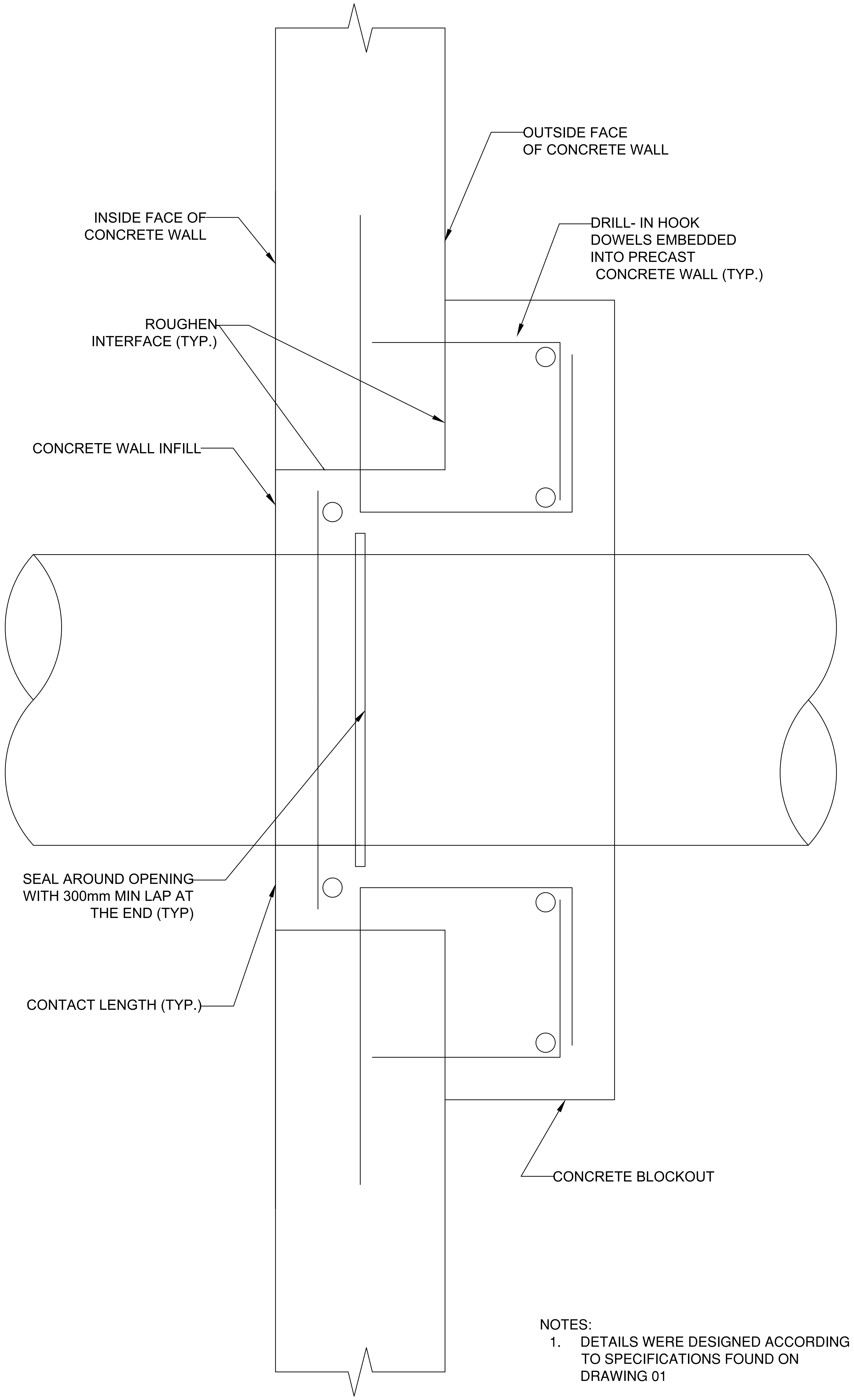
Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
INFLOW CON.
Date
18.04.2018
Scale
AS NOTED
Sheet
08



⑮ 200mm TANK INFLOW CONNECTION

SCALE: 1:5



NOTES:
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⑯ WALL INFILL AND CONCRETE BLOCKOUT DETAIL (TYP.)

SCALE: 1:2

General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
TANK INFLOW
Date
18.04.2018
Scale
AS NOTED
Sheet
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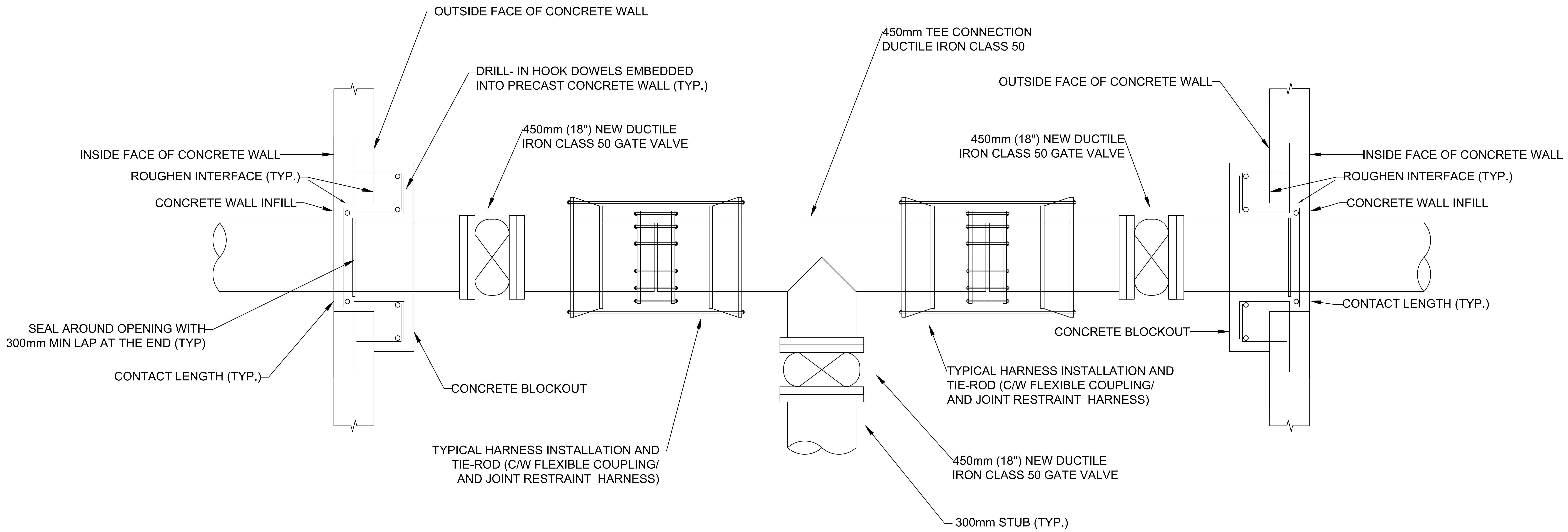

17 PLAN TANK - TANK CONNECTION

SCALE: 1:16

NOTES:

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General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address

AQUASTOR

Project Name and Address

WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
TANK – TANK

Date
18.04.2018

Scale
AS NOTED

Sheet
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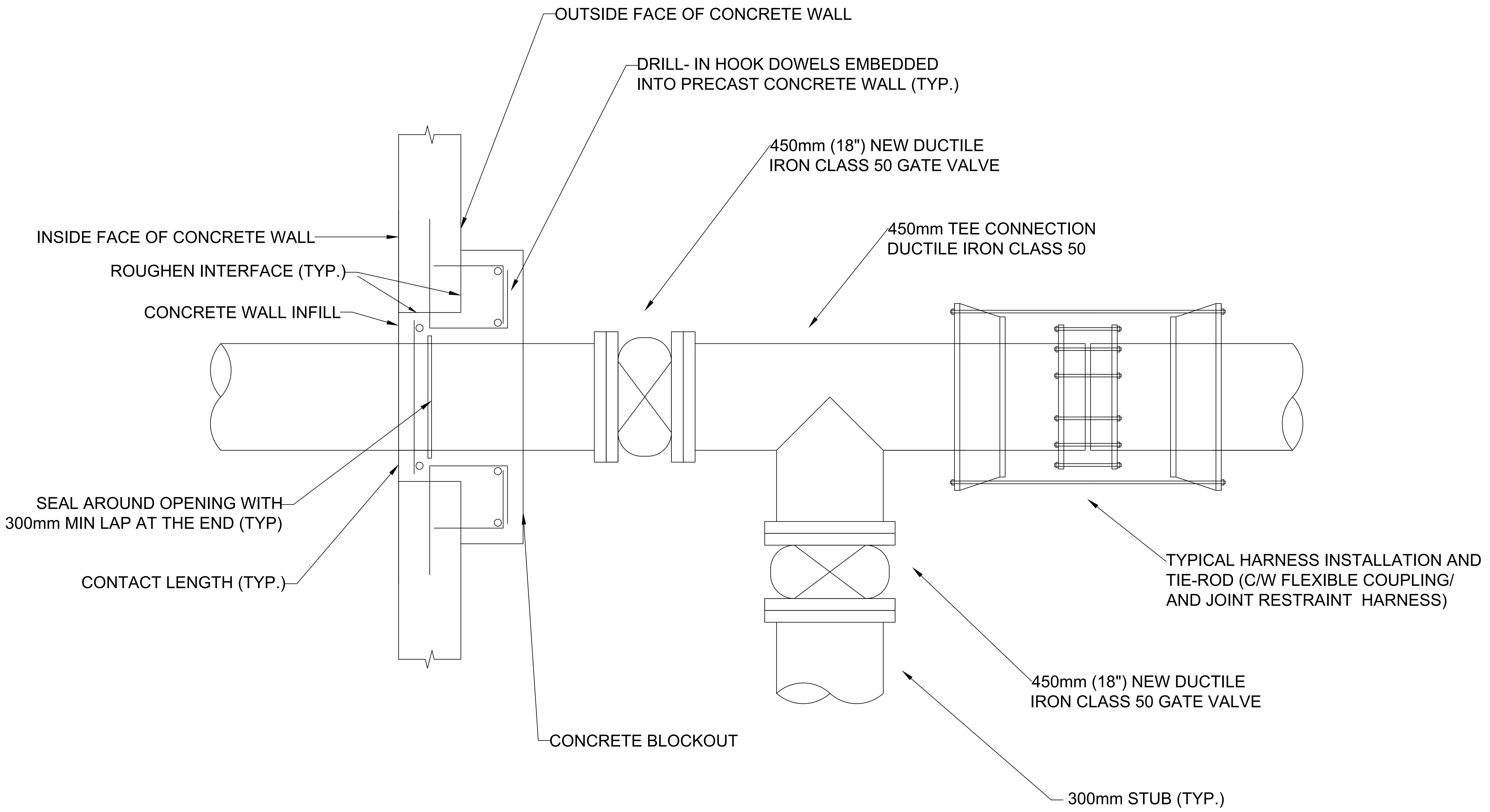

(18) PLAN 450mm TANK OUTFLOW CONNECTION

SCALE: 1:10

NOTES:
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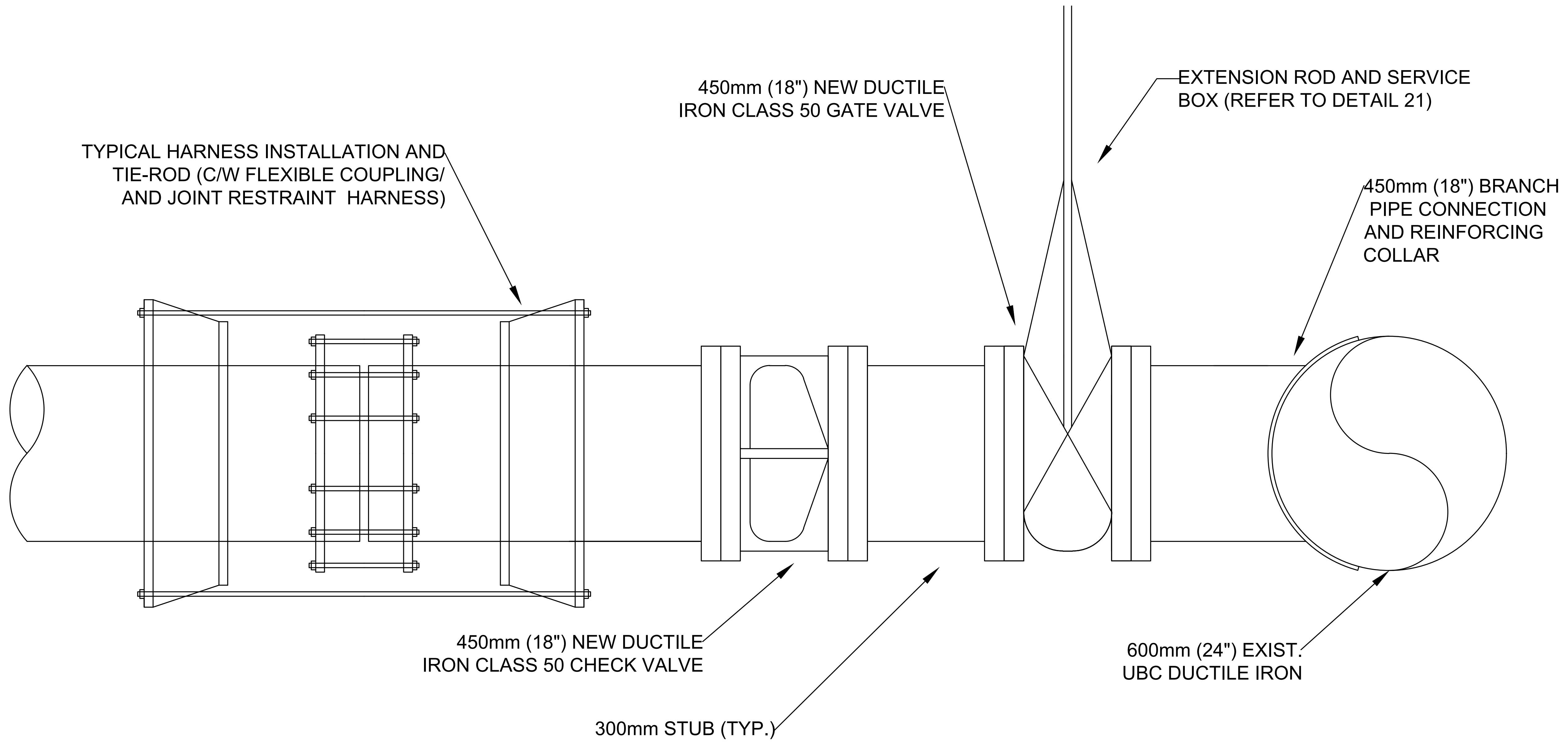
General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

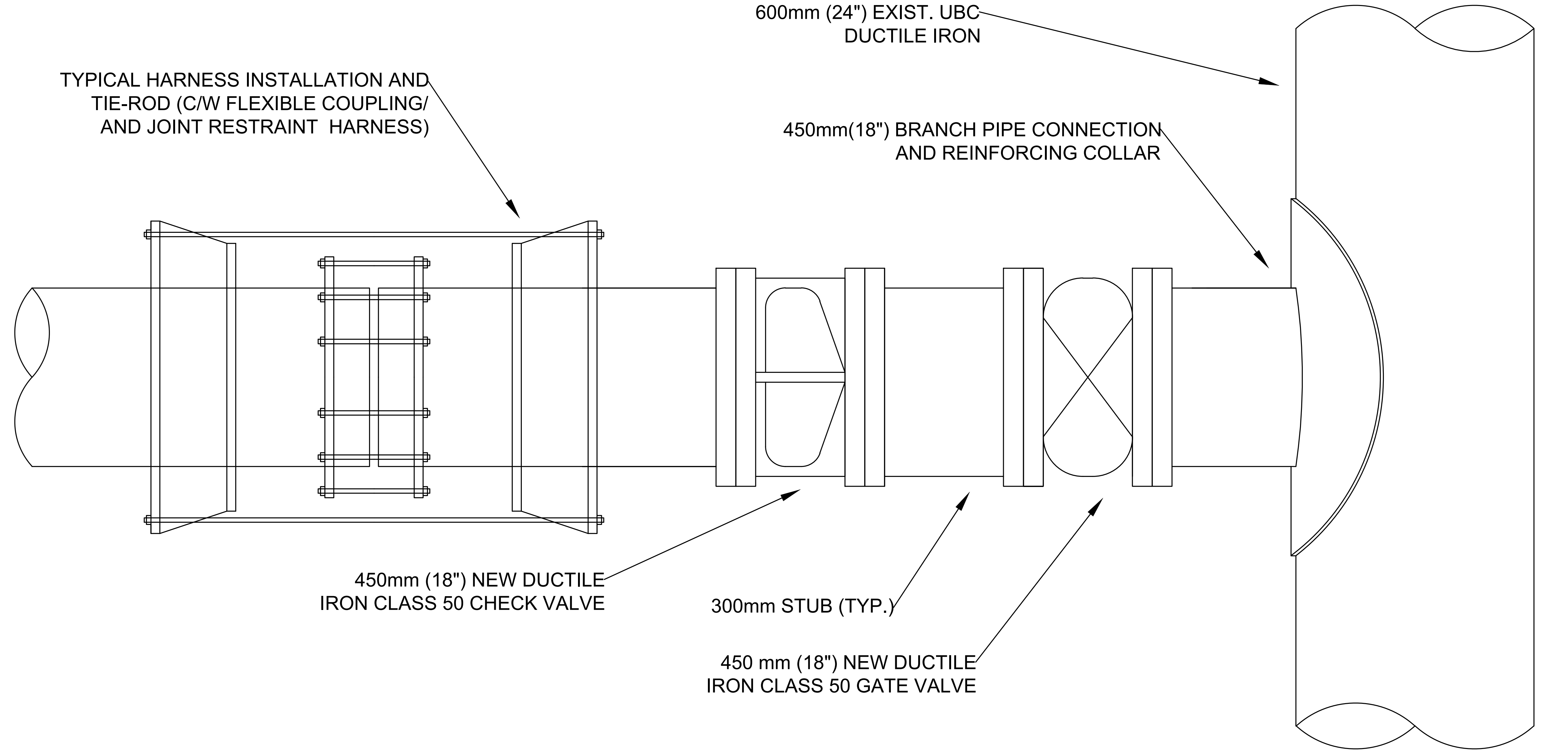
Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
TANK OUTFLOW
Date
18.04.2018
Scale
AS NOTED
Sheet
11



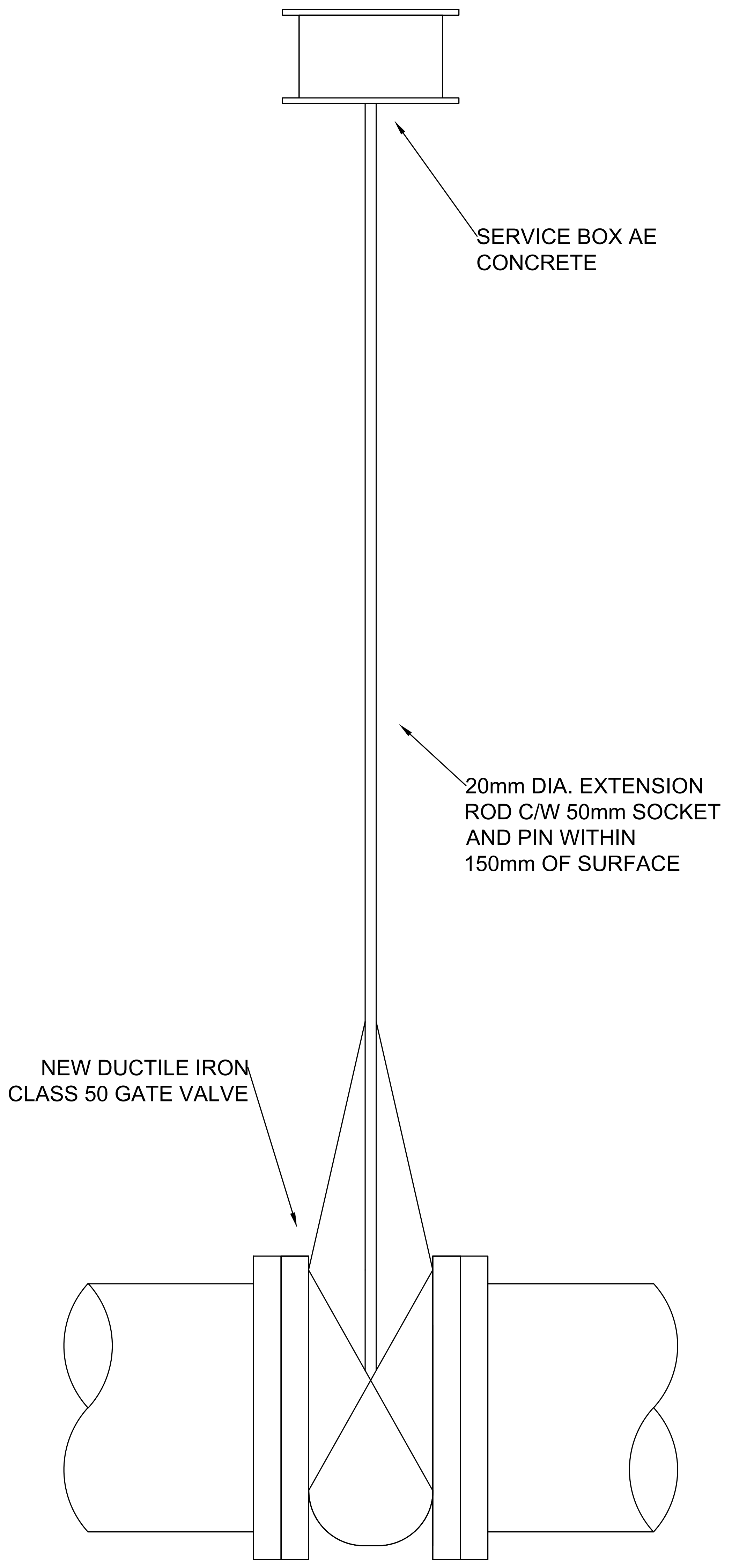
19 PROFILE 450mm OUTFLOW TO EXIST.

SCALE: 1:10



20 PLAN 450mm OUTFLOW TO EXST.

SCALE: 1:10



21 EXTENSION ROD AND SERVICE BOX

SCALE: 1:8

NOTES:
1. DETAILS WERE DESIGNED ACCORDING TO SPECIFICATIONS FOUND ON DRAWING 01

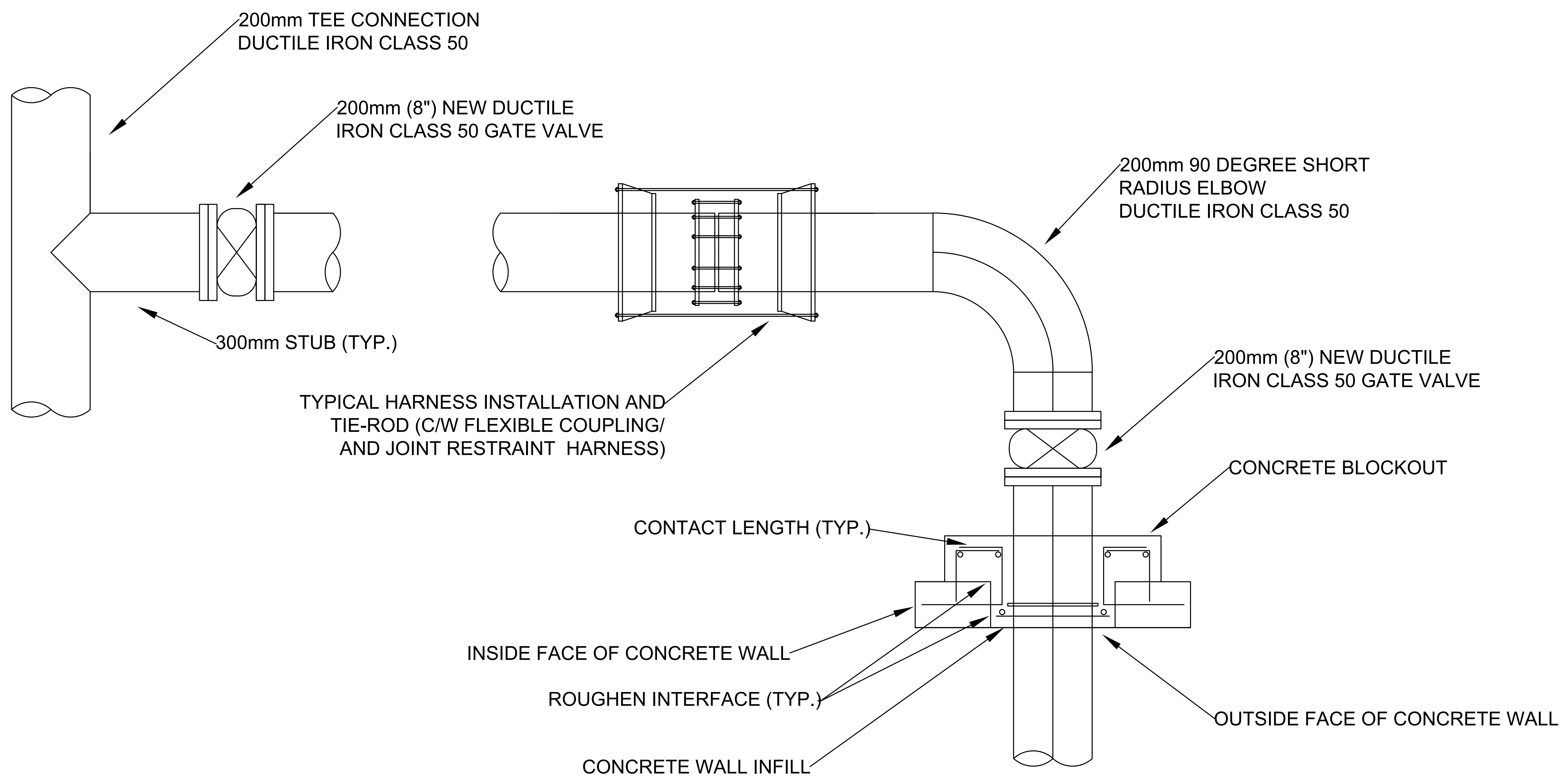
General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

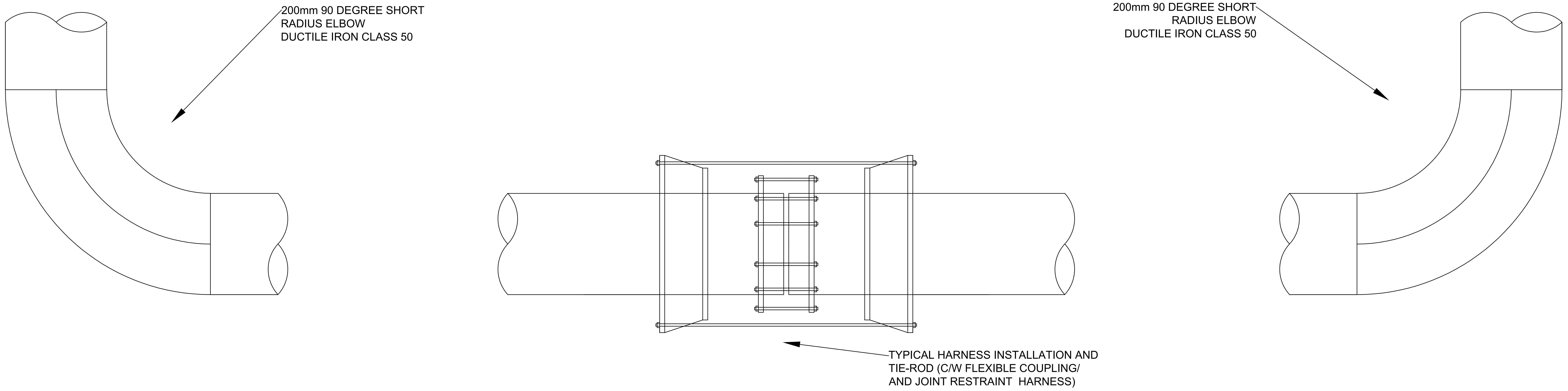
Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project
OUTFLOW CON.
Date
18.04.2018
Scale
AS NOTED
Sheet
12



22 PLAN SOUTH TANK BYPASS

SCALE: 1:10



NOTES:
1. DETAILS WERE DESIGNED ACCORDING TO SPECIFICATIONS FOUND ON DRAWING 01

23 PLAN NORTH TANK BYPASS

SCALE: 1:10

General Notes

No.	Revision/Issue	Date
03	ISSUED FOR CONSTRUCTION	04.18

Firm Name and Address
AQUASTOR

Project Name and Address
WATER STORAGE
CONCRETE TANK
UBC
VANCOUVER, BC

Project BYPASS
Date 18.04.2018
Scale AS NOTED
Sheet 13

APPENDIX B: TECHNICAL SPECIFICATIONS

ACI	**CONCRETE**
	301-16 Specifications for Structural Concrete
	302.1R-15 Guide to Concrete Floor and Slab Construction
	347R-14 Guide to Formwork for Concrete
	360R-10 Guide to Design of Slabs-on-Ground
	364.11T-15 Managing Alkali-Aggregate Reaction Expansion in Mass Concrete
	421.3R-15 Guide to Design of Reinforced Two-Way Slab Systems
	311.4R-05: Guide for Concrete Inspection
	350.3-06 Seismic Design of Liquid-Containing Concrete Structures and Commentary
	439.4R-09 Report on Steel Reinforcement - Material Properties and U.S. Availability (Reapproved 2017)
	ITG-4.2R-06 Materials and Quality Considerations for High-Strength Concrete in Moderate to High Seismic Applications
	SP-127: Earthquake-Resistant Concrete Structures--Inelastic Response and Design
	304: Measuring, Mixing, Transporting, and Placing Concrete
	305: Hot Weather Concreting
	306: Cold Weather Concreting
	308: Curing Concrete
CSA	**CONCRETE**
	A23.1-14/A23.2-14 - Concrete materials and methods of concrete construction / Test methods and standard practices for concrete
	S269.3-M92(R2013) - Concrete Formwork
	A3000-13: Cementitious Materials Compendium
	A23.1 - Concrete Materials and Methods of Concrete Construction
	A23.2 - Test Methods and Standard Practices for Concrete
	A23.3 - Design of Concrete Structures
	A23.4 Precast Concrete - Materials and Construction
	G30.18 - Carbon Steel Bars for Concrete Reinforcement
	W186 - Welding of Reinforcing Bars in Reinforced Concrete Construction
	G164 - Hot Dip Galvanizing of Irregularly Shaped Articles
	O86 - Engineering Design in Wood (Limit States Design)
	S269.1 - Falsework for Construction Purposes
	S269.3 - Concrete Formwork
	A3000 - Cementitious Materials Compendium
	A283 Qualification Code for Concrete Testing Laboratories
ASTM	**CONCRETE**
	ASTM C125-18 Standard Terminology Relating to Concrete and Concrete Aggregates
	ASTM C33/C33M-16e1 Standard Specification for Concrete Aggregates

	ASTM D4258-05(2017) Standard Practice for Surface Cleaning Concrete for Coating
	ASTM C150 / C150M - 17 Standard Specification for Portland Cement
	A704 / A704M - 17 Standard Specification for Welded Steel Plain Bar or Rod Mats for Concrete Reinforcement
	D1752 - Standard Specification for Stainless Steel Bolts, Hex Cap Screws, and Studs
	F593 - Standard Specification for Preformed Sponge Rubber Cork and Recycled PVC Expansion Joint Fillers for Concrete Paving and Structural Construction
	C309 - Standard Specification for Liquid Membrane-Forming Compounds for Curing Concrete
	C260 - Standard Specification for Air Entraining Admixtures for Concrete
	C157 - Standard Test Method for Length Change of Hardened Hydraulic-Cement Mortar and Concrete
	C494 - Standard Specifications for Chemical Admixtures for Concrete
	C1433 - Standard Specification for Precast Reinforced Concrete Monolithic Box Sections for Culverts, Storm Drains and Sewers
	A36 - Standard Specification for Carbon Structural Steel
	PIPE
	A674 – Polyethylene Encasement for Ductile Iron Pipe for Water or Other Liquids
	A716 - Ductile Iron Culvert Pipe
	A746 - Ductile Iron Gravity Sewer Pipe
MAPEI	**CONCRETE**
	03 01 30 Maintenance of Cast-In-Place Concrete
	03 06 00 Concrete Admixtures
Xypex Chemical Corp	**CONCRETE**
	03 05 00 Integral Waterproofing of Concrete
NMS	**PILES**
	31 08 13 - PILE LOAD TESTING
	31 61 13 - PILE FOUNDATIONS, GENERAL REQUIREMENTS
	31 63 23 - BORED CONCRETE PILES
	31 62 13.19 - PRECAST CONCRETE PILES
	EXCAVATION
	31 22 16.13 - ROADWAY SUBGRADE RESHAPING
	31 23 33.01 EXCAVATING, TRENCHING AND BACKFILLING
	31 23 16.26 ROCK REMOVAL
	PIPES
	33 11 00 - GROUNDWATER SOURCES
	33 14 16 - SITE WATER UTILITY DISTRIBUTION PIPING
	33 14 16.13 - INCOMING SITE WATER UTILITY DISTRIBUTION PIPING
	33 65 16 - DISTRIBUTION PIPING - PVC - FRP

ADSC	**PILES**
	Specifications for the Construction of Secant and Tangent Pile Wall Systems Using Drilled Shafts
ANSI/AWWA	**PIPES**
	C104/A21.4 - Cement-Mortar Lining For Ductile Iron Pipe and Fittings
	C105/A21.5 – Polyethylene Encasement for Ductile Iron Pipe Systems
	C110/A21.10 - Ductile Iron and Gray Iron Fittings
	C111/A21.11 - Rubber-Gasket Joints for Ductile Iron Pressure Pipe and Fittings
	C115/A21.15 – Flanged Ductile Iron Pipe with Ductile Iron or Gray Iron Threaded Flanges
	C116/A21.16 – Protective Fusion-Bonded Coatings for the Interior and Exterior Surfaces of Ductile Iron and Gray-Iron Fittings
	C150/A21.50 – Thickness Design of Ductile Iron Pipe
	C151/A21.51 - Ductile Iron Pipe, Centrifugally Cast
	C153/A21.53 - Ductile Iron Compact Fittings
	C600 - Installation of Ductile Iron Water Mains and Their Appurtenances
	C606 - Grooved and Shouldered Joints
	C651 - Disinfecting Water Mains
	VALVES
	C500 - AWWA Standard for Metal-Seated Gate Valves for Water Supply Service
MSS	**PIPES**
	SP-60 – Connecting Flange Joint between Tapping Sleeves and Tapping Valves
	SP-111 - Gray Iron and Ductile Iron Tapping Sleeves
ASME	**VALVES**
	B16.34 Valves – Flanged, Threaded, and Welding End
	B16.1 Cast Iron Pipe Valves Flanges and Flanged Fittings
	B16.5 Pipe Flanges and Flanged Fittings – NPS ½ Through NPS 24
ANSI/NSF Standard 61	**VALVES/PIPES/OTHER**
	Drinking Water System Components-Health Effects

APPENDIX C: COST ESTIMATE

Cost Estimate

Quantity	Line Number	Description	Unit	Material	Labor	Equipment	Total	Ext. Mat.	Ext.Labor	Ext. Equip.	Ext. Total	Contingency		Overhead and Profit		Total Estiamte
Planning																**$ 1,922,071.97**
		Planning 1% of Construction Base Estimate														$ 62,002.32
		Maintenance 30% of Construction Base Estimate														$ 1,860,069.65
Design																**$ 372,013.93**
		Preliminary Design 2% of Construction Base Estimate														$ 124,004.64
		Detailed Design Services 4% of Construction Base Estimate														$ 248,009.29
Environment																**$ 930,034.82**
		Environmental Compensation										20.00%	$ -	15.00%	$ -	$ 930,034.82
Tank Construction																
Division 02 - Existing Conditions											**$ 3,826.70**	20.00%	$ 765.34	15.00%	$ 574.01	**$ 5,166.05**
2	023213100020	Subsurface investigation, boring and exploratory drilling, initial field stake out & determination of elevations, for borings	Day	$ -	$ 734.16	$ 69.19	$ 803.35	$ -	$ 1,468.32	$ 138.38	$ 1,606.70	20.00%	$ 321.34	15.00%	$ 241.01	$ 2,169.05
2	023213100100	Subsurface investigation, boring and exploratory drilling, drawings showing boring details	Total	$ -	$ 335.00	$ -	$ 335.00	$ -	$ 670.00	$ -	$ 670.00	20.00%	$ 134.00	15.00%	$ 100.50	$ 904.50
2	023213100200	Subsurface investigation, boring and exploratory drilling, report and recommendations from P.E.	Total	$ -	$ 775.00	$ -	$ 775.00	$ -	$ 1,550.00	$ -	$ 1,550.00	20.00%	$ 310.00	15.00%	$ 232.50	$ 2,092.50
Division 03 - Concrete											**$ 791,120.32**	20.00%	$ 158,224.06	15.00%	$ 118,668.05	**$ 1,068,012.43**
50	030130620100	Patching concrete, floors, small area, regular grout, 1/4" thick	S.F.	$ 1.83	$ 2.08	$ -	$ 3.91	$ 91.50	$ 104.00	$ -	$ 195.50	20.00%	$ 39.10	15.00%	$ 29.33	$ 263.93
1428.55891	031113050015	C.I.P. concrete forms, aluminum, smooth face, buy, 3' x 8', includes material only	SFCA	$ 15.88	$ -	$ -	$ 15.88	$ 22,685.52	$ -	$ -	$ 22,685.52	20.00%	$ 4,537.10	15.00%	$ 3,402.83	$ 30,625.45
212	031519100030	Anchor bolts, hooked type, single, 1/2" diameter x 8" long, installed in fresh concrete, includes nut and washer, excludes template	Ea.	$ 1.74	$ 2.73	$ -	$ 4.47	$ 368.88	$ 578.76	$ -	$ 947.64	20.00%	$ 189.53	15.00%	$ 142.15	$ 1,279.31
1996.996	033053400500	Structural concrete, in place, chimney foundation (5000 psi), over 5 C.Y., includes forms(4 uses), Grade 60 rebar, concrete (Portland cement Type I), placing and finishing	C.Y.	$ 214.26	$ 156.15	$ 1.10	$ 371.51	$ 427,876.36	$ 311,830.93	$ 2,196.70	$ 741,903.98	20.00%	$ 148,380.80	15.00%	$ 111,285.60	$ 1,001,570.37
16.8971095	033053400700	Structural concrete, in place, column (4000 psi), square, up to 1% reinforcing by area, 12" x 12", includes forms(4 uses), Grade 60 rebar, concrete (Portland cement Type I), placing and finishing	C.Y.	$ 476.14	$ 790.08	$ 104.12	$ 1,370.34	$ 8,045.39	$ 13,350.07	$ 1,759.33	$ 23,154.79	20.00%	$ 4,630.96	15.00%	$ 3,473.22	$ 31,258.97
16.8971095	033113700400	Structural concrete, placing, column, square or round, pumped, 12" thick, includes leveling (strike off) & consolidation, excludes material	C.Y.	$ -	$ 42.54	$ 21.30	$ 63.84	$ -	$ 718.80	$ 359.91	$ 1,078.71	20.00%	$ 215.74	15.00%	$ 161.81	$ 1,456.26
1996.996	033513300150	Concrete finishing, fresh concrete flatwork, floors, basic finishing for unspecified flatwork, bull float, manual float & broom finish, incl edging and joints, excl placing, striking off & consolidating	S.F.	$ -	$ 0.54	$ -	$ 0.54	$ -	$ 1,078.38	$ -	$ 1,078.38	20.00%	$ 215.68	15.00%	$ 161.76	$ 1,455.81
10	038216100300	Concrete impact drilling, for anchors, up to 4" D, 1/2" dia, in concrete or brick walls and floors, includes bit cost, layout and set up time, excl anchor	Ea.	$ 0.07	$ 7.51	$ -	$ 7.58	$ 0.70	$ 75.10	$ -	$ 75.80	20.00%	$ 15.16	15.00%	$ 11.37	$ 102.33
Division 07- Thermal and Moisture Protection											**$ 3,214.07**	20.00%	$ 642.81	15.00%	$ 482.11	**$ 4,338.99**
189.127472	071213200012	Membrane waterproofing, on slabs, felt, 1 ply, mopped	S.F.	$ 0.56	$ 0.66	$ 0.23	$ 1.45	$ 105.91	$ 124.82	$ 43.50	$ 274.23	20.00%	$ 54.85	15.00%	$ 41.13	$ 370.21
161.809059	071213200015	Membrane waterproofing, on walls, felt, 1 ply, mopped	S.F.	$ 0.56	$ 0.66	$ 0.23	$ 1.45	$ 90.61	$ 106.79	$ 37.22	$ 234.62	20.00%	$ 46.92	15.00%	$ 35.19	$ 316.74
226	079216105800	Joint sealants, rigid joint sealants, tapes, sealant, PVC foam adhesive, 1/16" x 1/4"	C.L.F.	$ 11.97	$ -	$ -	$ 11.97	$ 2,705.22	$ -	$ -	$ 2,705.22	20.00%	$ 541.04	15.00%	$ 405.78	$ 3,652.05
Division 08 - Openings											**$ 637.28**	20.00%	$ 127.46	15.00%	$ 95.59	**$ 860.33**
4	081213130025	Frames, steel, knock down, hollow metal, single, 16 ga., up to 5-3/4" deep, 3'-0" x 6'-8"	Ea.	$ 92.69	$ 43.23	$ -	$ 135.92	$ 370.76	$ 172.92	$ -	$ 543.68	20.00%	$ 108.74	15.00%	$ 81.55	$ 733.97

4	089516107000	Louvers, vinyl gable vent, 8" x 8"	Ea.	$ 14.11	$ 9.29	$ -	$ 23.40	$ 56.44	$ 37.16	$ -	$ 93.60	20.00%	$ 18.72	15.00%	$ 14.04	$ 126.36
Division 15 - Equipment											**$ 52,197.15**	20.00%	$ 10,439.43	15.00%	$ 7,829.57	**$ 70,466.15**
3	015433202150	Rent piledriving hammer steam/air 15000 ft lbs @60 bpm, Incl. Hourly Oper. Cost.	Week	$ -	$ -	$ 4,268.90	$ 4,268.90	$ -	$ -	$ 12,806.70	$ 12,806.70	20.00%	$ 2,561.34	15.00%	$ 1,921.01	$ 17,289.05
3	015433202050	Rent piledriving hammer steam/air 4150 ft lbs @225 bpm, Incl. Hourly Oper. Cost.	Week	$ -	$ -	$ 2,968.95	$ 2,968.95	$ -	$ -	$ 8,906.85	$ 8,906.85	20.00%	$ 1,781.37	15.00%	$ 1,336.03	$ 12,024.25
21	015419500200	Crane crew, daily use for small jobs, 25-ton truck-mounted hydraulic crane, portal to portal	Day	$ -	$ 410.40	$ 1,041.20	$ 1,451.60	$ -	$ 8,618.40	$ 21,865.20	$ 30,483.60	20.00%	$ 6,096.72	15.00%	$ 4,572.54	$ 41,152.86
Division 31 - EarthWorks											**$ 3,299,059.62**	20.00%	$ 659,811.92	15.00%	$ 494,858.94	**$ 4,453,730.49**
51833.281	310513100200	Soils for earthwork, common borrow, spread with 200 HP dozer, includes load at pit and haul, 2 miles round trip, excludes compaction	C.Y.	$ 14.62	$ 2.75	$ 5.38	$ 22.75	$ 757,802.57	$ 142,541.52	$ 278,863.05	$ 1,179,207.14	20.00%	$ 235,841.43	15.00%	$ 176,881.07	$ 1,591,929.64
98	310660140500	Piling special costs, cutoffs, concrete piles, plain	Ea.	$ -	$ 92.75	$ -	$ 92.75	$ -	$ 9,089.50	$ -	$ 9,089.50	20.00%	$ 1,817.90	15.00%	$ 1,363.43	$ 12,270.83
7774.99215	311413230200	Topsoil stripping and stockpiling, topsoil, sandy loam, ideal conditions, 300 HP dozer	C.Y.	$ -	$ 0.25	$ 0.84	$ 1.09	$ -	$ 1,943.75	$ 6,530.99	$ 8,474.74	20.00%	$ 1,694.95	15.00%	$ 1,271.21	$ 11,440.90
2591.66405	311413230300	Topsoil stripping and stockpiling, topsoil, sandy loam, adverse conditions, 300 HP dozer	C.Y.	$ -	$ 0.45	$ 1.52	$ 1.97	$ -	$ 1,166.25	$ 3,939.33	$ 5,105.58	20.00%	$ 1,021.12	15.00%	$ 765.84	$ 6,892.53
51833.281	312316462200	Excavating, bulk, dozer, open site, bank measure, sand and gravel, 80 HP dozer, 150' haul	B.C.Y.	$ -	$ 3.19	$ 2.77	$ 5.96	$ -	$ 165,348.17	$ 143,578.19	$ 308,926.35	20.00%	$ 61,785.27	15.00%	$ 46,338.95	$ 417,050.57
51833.281	312319200100	Dewatering, excavate drainage trench, with backhoe, 2' wide x 3' deep	C.Y.	$ -	$ 6.93	$ 3.16	$ 10.09	$ -	$ 359,204.64	$ 163,793.17	$ 522,997.81	20.00%	$ 104,599.56	15.00%	$ 78,449.67	$ 706,047.04
180	312319200600	Dewatering, pumping 8 hours, attended 2 hours per day, 2" diaphragm pump used for 8 hours, includes 20 LF of suction hose and 100 LF of discharge hose	Day	$ -	$ 183.46	$ 26.30	$ 209.76	$ -	$ 33,022.80	$ 4,734.00	$ 37,756.80	20.00%	$ 7,551.36	15.00%	$ 5,663.52	$ 50,971.68
1998.03156	312319300020	Wells, for dewatering, with steel casing, 10' to 20' deep, 2' diameter, minimum	V.L.F.	$ 37.66	$ 7.92	$ 2.59	$ 48.17	$ 75,245.87	$ 15,824.41	$ 5,174.90	$ 96,245.18	20.00%	$ 19,249.04	15.00%	$ 14,436.78	$ 129,930.99
742.108525	312319400200	Wellpoints, single stage system, 2.0 labor hours per LF, installation and removal	LF Hdr	$ -	$ 99.22	$ -	$ 99.22	$ -	$ 73,632.01	$ -	$ 73,632.01	20.00%	$ 14,726.40	15.00%	$ 11,044.80	$ 99,403.21
51833.281	312323130300	Backfill, 6" layers, compaction in layers, hand tamp, add	E.C.Y.	$ -	$ 19.34	$ -	$ 19.34	$ -	$ 1,002,455.65	$ -	$ 1,002,455.65	20.00%	$ 200,491.13	15.00%	$ 150,368.35	$ 1,353,315.13
618	316213232800	Prestressed concrete piles, 20" diameter, 4" wall, priced using 200 piles, 50' long, unless specified otherwise, excludes pile caps or mobilization	V.L.F.	$ 75.48	$ 7.89	$ 5.90	$ 89.27	$ 46,646.64	$ 4,876.02	$ 3,646.20	$ 55,168.86	20.00%	$ 11,033.77	15.00%	$ 8,275.33	$ 74,477.96
Division 41 - Material Processing and Handling Equipment											**$ 2,776.68**	20.00%	$ 555.34	15.00%	$ 416.50	**$ 3,748.52**
1	412213190100	Jib cranes, wall hung, cantilever, 1/2 ton capacity, 8' span	Ea.	$ 1,999.28	$ 777.40	$ -	$ 2,776.68	$ 1,999.28	$ 777.40	$ -	$ 2,776.68	20.00%	$ 555.34	15.00%	$ 416.50	$ 3,748.52
Tank Subtotals											**$ 4,152,831.82**					**$ 5,606,322.96**
WaterWorks Construction																
Division 2 - Existing Conditions											**$ 18,762.23**					**$ 25,329.01**
2	023213100020	Subsurface investigation, boring and exploratory drilling, initial field stake out & determination of elevations, for borings	Day	$ -	$ 558.15	$ 70.40	$ 628.55	$ -	$ 1,116.30	$ 140.80	$ 1,257.10	20.00%	$ 251.42	15.00%	$ 188.57	$ 1,697.09
10	023219100020	Subsurface investigation, test pits, hand digging, light soil	C.Y.	$ -	$ 48.04	$ -	$ 48.04	$ -	$ 480.40	$ -	$ 480.40	20.00%	$ 96.08	15.00%	$ 72.06	$ 648.54
4374.453	024113175010	Demolish, remove pavement & curb, remove bituminous pavement, up to, 3" thick, excludes hauling and disposal fees	S.Y.	$ -	$ 1.42	$ 2.27	$ 3.69	$ -	$ 6,211.72	$ 9,930.01	$ 16,141.73	20.00%	$ 3,228.35	15.00%	$ 2,421.26	$ 21,791.34
100	029110100100	Field testing equipment, sampling & testing soil/sediment, sample collection, field samples, sludge	Ea.	$ -	$ 8.83	$ -	$ 8.83	$ -	$ 883.00	$ -	$ 883.00	20.00%	$ 176.60	15.00%	$ 132.45	$ 1,192.05
Division 26 - Electrical											**$ 65,793.51**	20.00%	$ 13,158.70	15.00%	$ 9,869.03	**$ 88,821.24**
70	260543100200	Trench duct, steel with cover, standard adjustable, straight, single compartment, depths to 4", 12" wide	L.F.	$ 352.44	$ 18.26	$ -	$ 370.70	$ 24,670.80	$ 1,278.20	$ -	$ 25,949.00	20.00%	$ 5,189.80	15.00%	$ 3,892.35	$ 35,031.15

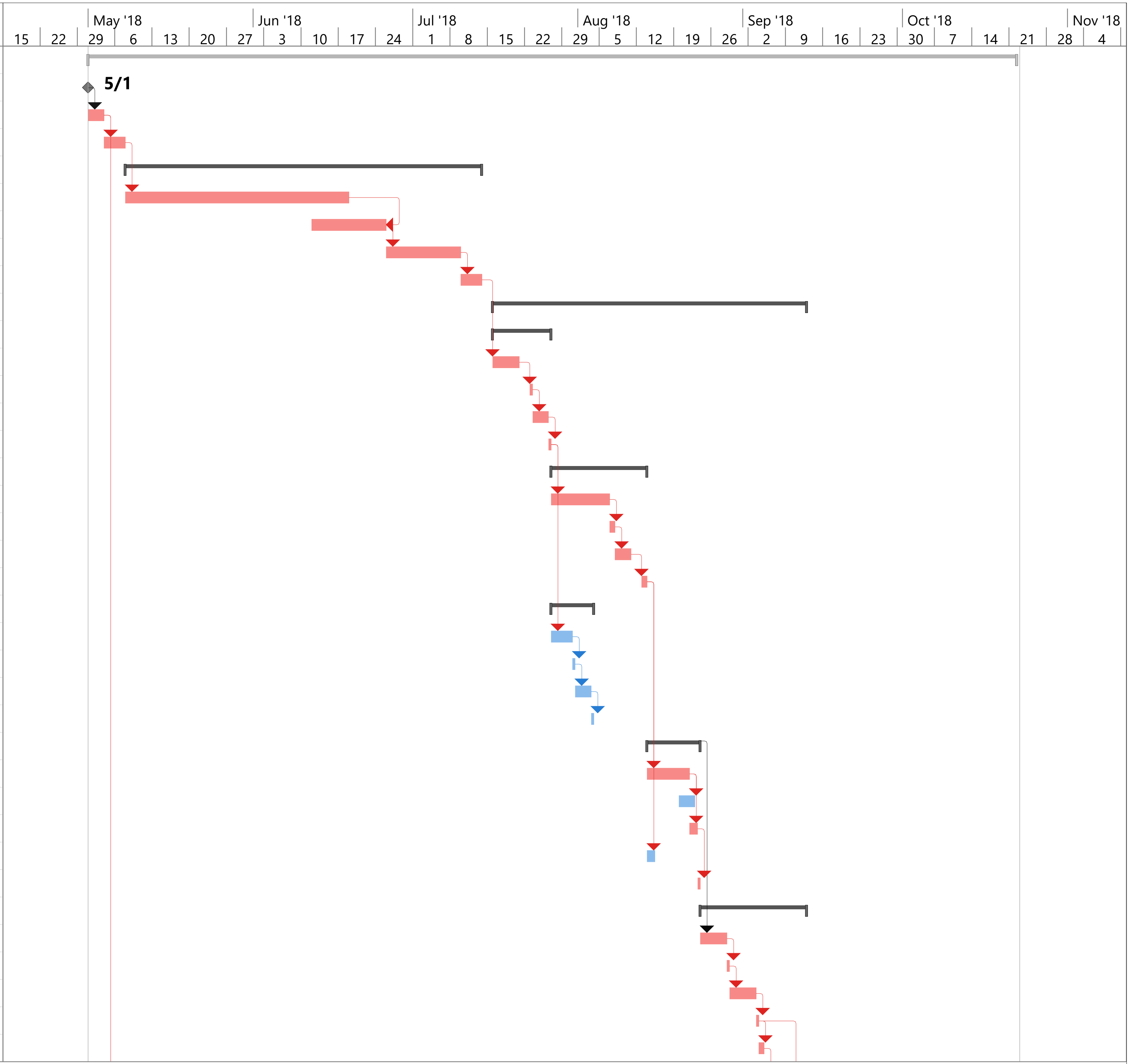
1	262413100300	Switchboards, no main disconnect, 4 wire, 120/208 V, 600 amp, incl CT compartment, excl CT's or PT's	Ea.	$ 4,272.00	$ 585.15	$ -	$ 4,857.15	$ 4,272.00	$ 585.15	$ -	$ 4,857.15	20.00%	$ 971.43	15.00%	$ 728.57	$ 6,557.15
2	262416100200	Load centers, 1 phase, 3 wire, main lugs, indoor, 120/240 V, 100 amp, 8 circuits, incl 20 A 1 pole plug-in breakers	Ea.	$ 91.31	$ 209.99	$ -	$ 301.30	$ 182.62	$ 419.98	$ -	$ 602.60	20.00%	$ 120.52	15.00%	$ 90.39	$ 813.51
1	262419200100	Motor starter, size 1, FVNR, type A, fusible, NEMA 1	Ea.	$ 1,548.60	$ 108.73	$ -	$ 1,657.33	$ 1,548.60	$ 108.73	$ -	$ 1,657.33	20.00%	$ 331.47	15.00%	$ 248.60	$ 2,237.40
1	263213132300	Generator set, diesel, 3 phase 4 wire, 277/480 V, 100 kW, incl battery, charger, muffler, & day tank, excl conduit, wiring, & concrete	Ea.	$ 29,797.20	$ 2,344.75	$ 585.48	$ 32,727.43	$ 29,797.20	$ 2,344.75	$ 585.48	$ 32,727.43	20.00%	$ 6,545.49	15.00%	$ 4,909.11	$ 44,182.03
Division 31 - EarthWorks											**$ 367,171.11**	20.00%	$ 73,434.22	15.00%	$ 55,075.67	**$ 495,681.00**
12033.15	312316462200	Excavating, bulk, dozer, open site, bank measure, sand and gravel, 80 HP dozer, 150' haul	B.C.Y.	$ -	$ 1.74	$ 2.82	$ 4.56	$ -	$ 20,937.68	$ 33,933.48	$ 54,871.16	20.00%	$ 10,974.23	15.00%	$ 8,230.67	$ 74,076.07
120	312319200600	Dewatering, pumping 8 hours, attended 2 hours per day, 2" diaphragm pump used for 8 hours, includes 20 LF of suction hose and 100 LF of discharge hose	Day	$ -	$ 100.49	$ 26.76	$ 127.25	$ -	$ 12,058.80	$ 3,211.20	$ 15,270.00	20.00%	$ 3,054.00	15.00%	$ 2,290.50	$ 20,614.50
3350	312319400110	Wellpoints, single stage system, 0.75 labor hours per LF, installation and removal	LF Hdr	$ -	$ 27.81	$ -	$ 27.81	$ -	$ 93,163.50	$ -	$ 93,163.50	20.00%	$ 18,632.70	15.00%	$ 13,974.53	$ 125,770.73
820.21	312319300020	Wells, for dewatering, with steel casing, 10' to 20' deep, 2' diameter, minimum	V.L.F.	$ 37.35	$ 5.97	$ 2.63	$ 45.95	$ 30,634.84	$ 4,896.65	$ 2,157.15	$ 37,688.65	20.00%	$ 7,537.73	15.00%	$ 5,653.30	$ 50,879.68
12033.15	312323130400	Backfill and compact, by hand, 6" layers, 2 passes 8" lifts, compaction in layers, roller compaction with operator walking, add to above	E.C.Y.	$ -	$ 4.02	$ 2.51	$ 6.53	$ -	$ 48,373.26	$ 30,203.21	$ 78,576.47	20.00%	$ 15,715.29	15.00%	$ 11,786.47	$ 106,078.23
12033.15	312323200022	Cycle hauling(wait, load, travel, unload or dump & return) time per cycle, excavated or borrow, loose cubic yards, 10 min wait/load/unload, 8 C.Y. truck, cycle 6 miles, 15 MPH, excludes loading equipment	L.C.Y.	$ -	$ 3.07	$ 4.21	$ 7.28	$ -	$ 36,941.77	$ 50,659.56	$ 87,601.33	20.00%	$ 17,520.27	15.00%	$ 13,140.20	$ 118,261.80
Division 32 - Exterior Improvements											**$ 110,495.27**	20.00%	$ 22,099.05	15.00%	$ 16,574.29	**$ 149,168.61**
4185	321216130160	Plant-mix asphalt paving, for highways and large paved areas, binder course, 3" thick, no hauling included	S.Y.	$ 14.01	$ 0.80	$ 0.77	$ 15.58	$ 58,631.85	$ 3,348.00	$ 3,222.45	$ 65,202.30	20.00%	$ 13,040.46	15.00%	$ 9,780.35	$ 88,023.11
110	321416100012	Brick paving, without joints, (4.5 brick/SF), 4" x 8" x 1-1/2"	S.F.	$ 3.40	$ 6.62	$ -	$ 10.02	$ 374.00	$ 728.20	$ -	$ 1,102.20	20.00%	$ 220.44	15.00%	$ 165.33	$ 1,487.97
3280.84	321613130404	Cast-in place concrete curbs & gutters, concrete, wood forms, straight, 6" x 18", includes concrete	L.F.	$ 8.33	$ 4.84	$ -	$ 13.17	$ 27,329.40	$ 15,879.27	$ -	$ 43,208.66	20.00%	$ 8,641.73	15.00%	$ 6,481.30	$ 58,331.69
3280.84	321723130020	Painted pavement markings, acrylic waterborne, white or yellow, 4" wide, less than 3,000 LF	L.F.	$ 0.13	$ 0.08	$ 0.04	$ 0.25	$ 426.51	$ 262.47	$ 131.23	$ 820.21	20.00%	$ 164.04	15.00%	$ 123.03	$ 1,107.28
10	329643200100	Tree transplanting, tree removal, shrubs, broadleaf evergreen, 18"-24" high, dig & lace	Ea.	$ -	$ 16.19	$ -	$ 16.19	$ -	$ 161.90	$ -	$ 161.90	20.00%	$ 32.38	15.00%	$ 24.29	$ 218.57
Division 33 - Utilities											**$ 1,485,178.21**	20.00%	$ 297,035.64	15.00%	$ 222,776.73	**$ 2,004,990.58**
3400	330110100060	Corrosion resistance, wrap and coat, add to pipe, 8" diameter	L.F.	$ 5.72	$ -	$ -	$ 5.72	$ 19,448.00	$ -	$ -	$ 19,448.00	20.00%	$ 3,889.60	15.00%	$ 2,917.20	$ 26,254.80
10	330561100020	Storm drainage manholes, frames and covers, frames & covers, including footing, excavation and backfill	Ea.	$ 17,000.00	$ 7,500.00	$ 10,000.00	$ 34,500.00	$ 170,000.00	$ 75,000.00	$ 100,000.00	$ 345,000.00	20.00%	$ 69,000.00	15.00%	$ 51,750.00	$ 465,750.00
170	331413152060	Water supply distribution piping, ductile iron pipe, cement lined, mechanical joint, no fittings, 18' lengths, 8" diameter, class 50, excludes excavation or backfill	L.F.	$ 81.59	$ 9.69	$ 3.81	$ 95.09	$ 13,870.30	$ 1,647.30	$ 647.70	$ 16,165.30	20.00%	$ 3,233.06	15.00%	$ 2,424.80	$ 21,823.16
2	331413900120	Water supply distribution piping, thrust block, 90 elbow, 8 inch diameter, excludes excavation or backfill	Ea.	$ 80.03	$ 14.98	$ 16.03	$ 111.04	$ 160.06	$ 29.96	$ 32.06	$ 222.08	20.00%	$ 44.42	15.00%	$ 33.31	$ 299.81
3280.84	331413152060	Water supply distribution piping, ductile iron pipe, cement lined, mechanical joint, no fittings, 18' lengths, 18" diameter, class 50, excludes excavation or backfill	L.F.	$ 244.77	$ 22.29	$ 8.76	$ 275.82	$ 803,051.21	$ 73,120.08	$ 28,750.00	$ 904,921.29	20.00%	$ 180,984.26	15.00%	$ 135,738.19	$ 1,221,643.74

2	331413900120	Water supply distribution piping, thrust block, 90 elbow, 18 inch diameter, excludes excavation or backfill	Ea.	$ 240.09	$ 34.90	$ 37.35	$ 312.34	$ 480.18	$ 69.81	$ 74.70	$ 624.69	20.00%	$ 124.94	15.00%	$ 93.70	$ 843.33
4	331419100010	Valves, water distribution, 8" Gate Valve		$2,628.00	$ 9.69	$ 3.81	$ 2,641.50	$ 10,512.00	$ 38.76	$ 15.24	$ 10,566.00	20.00%	$ 2,113.20	15.00%	$ 1,584.90	$ 14,264.10
6	331419100010	Valves, water distribution, 18" Gate Valve		$25,744.00	$ 22.29	$ 8.76	$ 25,775.05	$ 154,464.00	$ 133.72	$ 52.58	$ 154,650.30	20.00%	$ 30,930.06	15.00%	$ 23,197.55	$ 208,777.91
1	331419100010	Valves, water distribution, 8" Check Valves		$3,737.00	$ 9.69	$ 3.81	$ 3,750.50	$ 3,737.00	$ 9.69	$ 3.81	$ 3,750.50	20.00%	$ 750.10	15.00%	$ 562.58	$ 5,063.18
1	331419100010	Valves, water distribution, 18" Check Valves		29,799.00	$ 22.29	$ 8.76	$ 29,830.05	$ 29,799.00	$ 22.29	$ 8.76	$ 29,830.05	20.00%	$ 5,966.01	15.00%	$ 4,474.51	$ 40,270.57
Water Works Subtotal											**$ 2,047,400.33**					**$2,763,990.45**
Construction Subtotal																**$8,370,313.40**

Construction Supervision	$ 167,406.27
Management (3.5%)	$ 292,960.97
Managenemt Reserve (5%)	$ 418,515.67
GST (5%)	$ 418,515.67
Total	**$ 12,891,832.70**

APPENDIX D: SCHEDULE

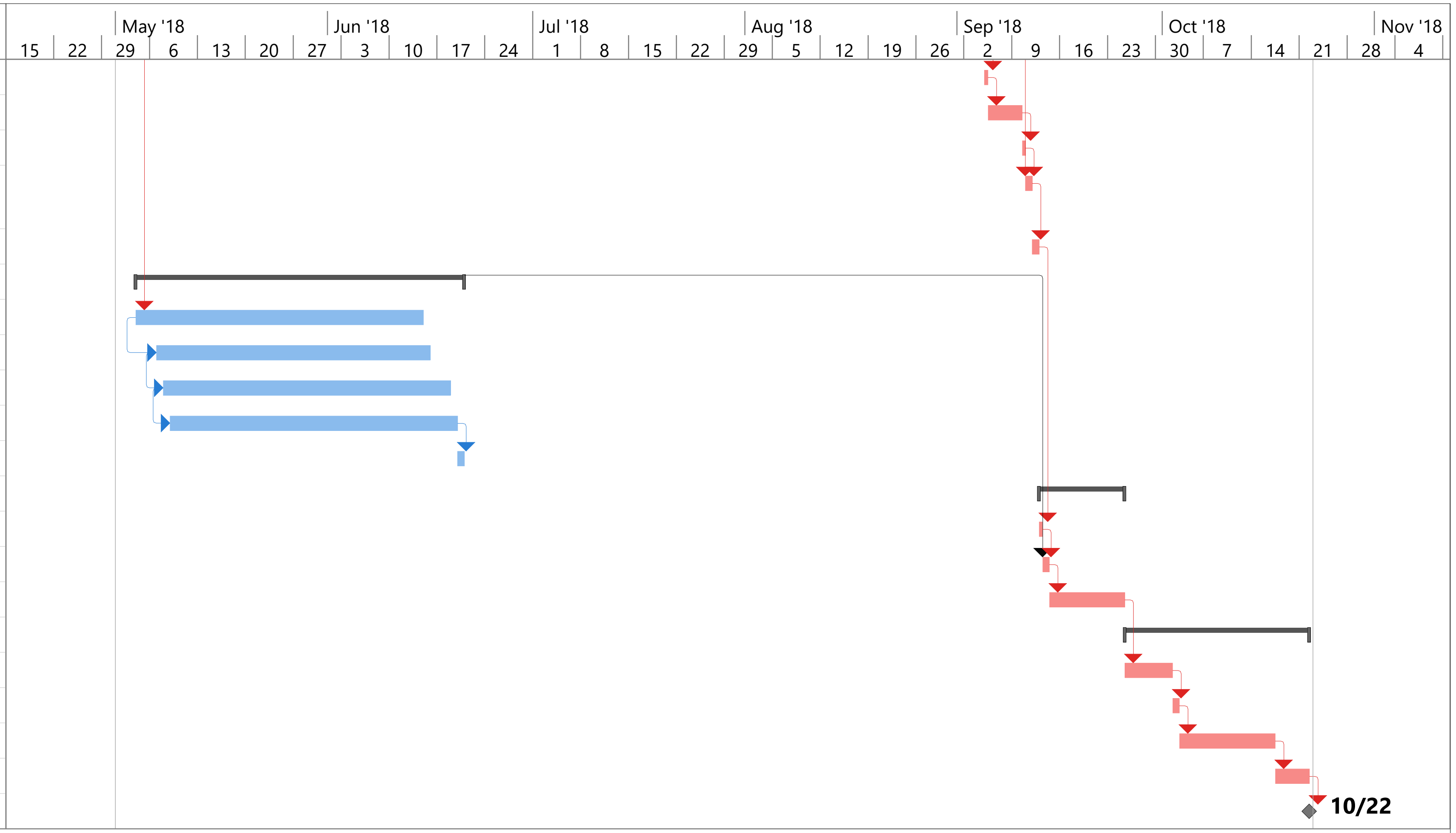
ID	Task Name	Duration	Start	Finish	Predecessors
0	**Underground watertank**	**124.5 days**	**Tue 5/1/18**	**Mon 10/22/18**	
1	Project start	0 days	Tue 5/1/18	Tue 5/1/18	
2	Site set-up	3 days	Tue 5/1/18	Thu 5/3/18	1
3	Stripping the field	2 days	Fri 5/4/18	Mon 5/7/18	2
4	**Foundation system**	**49 days**	**Tue 5/8/18**	**Fri 7/13/18**	
5	Secant piles	30 days	Tue 5/8/18	Mon 6/18/18	3
6	Excavation	10 days	Tue 6/12/18	Mon 6/25/18	5FF+5 days
7	Friction piles	10 days	Tue 6/26/18	Mon 7/9/18	6
8	Grading	4 days	Tue 7/10/18	Fri 7/13/18	7
9	**Storage System**	**43 days**	**Mon 7/16/18**	**Wed 9/12/18**	
10	**Floor slab**	**9 days**	**Mon 7/16/18**	**Thu 7/26/18**	
11	Formwork and rebars	5 days	Mon 7/16/18	Fri 7/20/18	8
12	Concrete pouring	0.5 days	Mon 7/23/18	Mon 7/23/18	11
13	Concrete curing	3 days	Mon 7/23/18	Thu 7/26/18	12
14	Formwork stripping	0.5 days	Thu 7/26/18	Thu 7/26/18	13
15	**Perimeter walls**	**12 days**	**Fri 7/27/18**	**Mon 8/13/18**	
16	Formwork and rebars	7 days	Fri 7/27/18	Mon 8/6/18	14
17	Concrete pouring	1 day	Tue 8/7/18	Tue 8/7/18	16
18	Concrete curing	3 days	Wed 8/8/18	Fri 8/10/18	17
19	Formwork stripping	1 day	Mon 8/13/18	Mon 8/13/18	18
20	**Columns**	**6 days**	**Fri 7/27/18**	**Fri 8/3/18**	
21	Formwork and rebars	2 days	Fri 7/27/18	Mon 7/30/18	14
22	Concrete pouring	0.5 days	Tue 7/31/18	Tue 7/31/18	21
23	Concrete curing	3 days	Tue 7/31/18	Fri 8/3/18	22
24	Formwork stripping	0.5 days	Fri 8/3/18	Fri 8/3/18	23
25	**Tank interior**	**8 days**	**Tue 8/14/18**	**Thu 8/23/18**	
26	Lining	6 days	Tue 8/14/18	Tue 8/21/18	19
27	Baffle walls	3 days	Mon 8/20/18	Wed 8/22/18	26FS-2 days
28	Service connection detailing	1.5 days	Wed 8/22/18	Thu 8/23/18	26
29	Pump Installation	1.5 days	Tue 8/14/18	Wed 8/15/18	19
30	Cleaning of the tank	0.5 days	Thu 8/23/18	Thu 8/23/18	28
31	**Roof slab**	**14 days**	**Fri 8/24/18**	**Wed 9/12/18**	
32	Formwork and rebars - stage 1	3 days	Fri 8/24/18	Tue 8/28/18	25
33	Concrete pouring - stage 1	0.5 days	Wed 8/29/18	Wed 8/29/18	32
34	Concrete curing - stage 1	3 days	Wed 8/29/18	Mon 9/3/18	33
35	Formwork stripping - stage 1	0.5 days	Mon 9/3/18	Mon 9/3/18	34
36	Formwork and rebars - stage 2	1 day	Tue 9/4/18	Tue 9/4/18	35



Project: Underground watertan
Date: Sun 4/8/18

Task	▬	Inactive Task	▭	Manual Summary Rollup	▬	External Milestone	◆	Manual Progress	▬
Split	┅	Inactive Milestone	◇	Manual Summary	┏━┓	Deadline	⬇		
Milestone	◆	Inactive Summary	┏━┓	Start-only	[	Critical	▬		
Summary	┏━┓	Manual Task	▬	Finish-only	]	Critical Split	┅		
Project Summary	┏━┓	Duration-only	▬	External Tasks	▬	Progress	▬		

ID	Task Name	Duration	Start	Finish	Predecessors
37	Concrete pouring - stage 2	0.5 days	Wed 9/5/18	Wed 9/5/18	36
38	Concrete curing - stage 2	3 days	Wed 9/5/18	Mon 9/10/18	37
39	Formwork stripping - stage 2	0.5 days	Mon 9/10/18	Mon 9/10/18	38
40	Formwork and scaffolding removal from the tank	1 day	Tue 9/11/18	Tue 9/11/18	35,39
41	Roof hatch installation	1 day	Wed 9/12/18	Wed 9/12/18	40
42	**Piping System**	**34 days**	**Fri 5/4/18**	**Wed 6/20/18**	
43	Trench Excavation	30 days	Fri 5/4/18	Thu 6/14/18	2
44	Soil improvement	30 days	Mon 5/7/18	Fri 6/15/18	43SS+1 day
45	Pipe installation	30 days	Tue 5/8/18	Mon 6/18/18	44SS+1 day
46	Backfill	30 days	Wed 5/9/18	Tue 6/19/18	45SS+1 day
47	Connection to pumps	1 day	Wed 6/20/18	Wed 6/20/18	46
48	**Serivce Tie-in and Testing**	**8.5 days**	**Thu 9/13/18**	**Tue 9/25/18**	
49	Tank interior disinfection	0.5 days	Thu 9/13/18	Thu 9/13/18	41
50	Service tie-in	1 day	Thu 9/13/18	Fri 9/14/18	49,42
51	Testing	7 days	Fri 9/14/18	Tue 9/25/18	50
52	**Backfill and Site Restoration**	**19 days**	**Tue 9/25/18**	**Mon 10/22/18**	
53	Backfill	5 days	Tue 9/25/18	Tue 10/2/18	51
54	Grading	1 day	Tue 10/2/18	Wed 10/3/18	53
55	Landscape	10 days	Wed 10/3/18	Wed 10/17/18	54
56	Site clean-up	3 days	Wed 10/17/18	Mon 10/22/18	55
57	Project completion	0 days	Mon 10/22/18	Mon 10/22/18	56



Project: Underground watertan
Date: Sun 4/8/18

Task	▬	Inactive Task	▭	Manual Summary Rollup	▬	External Milestone	◇	Manual Progress	▬
Split	┅	Inactive Milestone	◇	Manual Summary	┏━┓	Deadline	⇩		
Milestone	◆	Inactive Summary	┏━┓	Start-only	[	Critical	▬		
Summary	┏━┓	Manual Task	▬	Finish-only	]	Critical Split	┅		
Project Summary	┏━┓	Duration-only	▬	External Tasks	▬	Progress	▬		

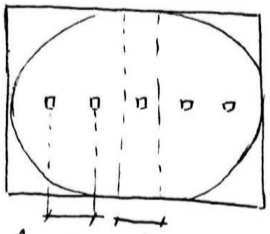
APPENDIX E: SAMPLE CALCUALTIONS

Structural:

Roof Slab

ROOF SLAB

* Figure shows 1 row of columns



$l_2 = 5m$ $\quad \frac{l_2}{2} = 2.5m = l_{2a}$

$W = 36.6 kN/m^2$ [from previous load analysis]

$$M_o = \frac{(w \times l_{2a}) \times l_2^2}{8} = \frac{36.6 kN/m^2 \times 2.5m \times (5m)^2}{8}$$

$\rightarrow$ $M_o = 253 kNm$

Moment Distribution :

Transverse

	outer	midspan
column strip	$-0.65M_o$	$0.23M_o$
moment	$-164.45 kNm$	$58.19 kNm$

Longitudinal

	Outer	midspan
column strip	$-0.65M_o$	$0.35M_o$
moment	$-164.45 kNm$	$88.55 kNm$

Design Moments :

Outer column strip = $-164.45 kNm$

midspan : $88.55 kNm$

Effective depth = $d = h - cover - d_b = 300mm - 50mm - 15mm = 235mm$

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

- calculations in spreadsheet
$f'_c = 30MPa$, b = band width
$d = 235mm$

Required spacing : $s \le A_b \frac{b}{A_s}$ or $s \le 250mm$

Max. reinforcement spacing $s \le 3h$ or $s \le 500mm$

Min. reinforcement : $A_{s\,min} = 0.002 A_s$

Band width:

Exterior: b = column cross-sectional dimension + 3 t

$\Rightarrow b = \underset{mm}{500} + 3 \times \underset{mm}{300} = 1400\,mm$

COLUMN STRIP

	Exterior Column	Midspan	Interior Column
Design Moment (Nmm)	1.64E+08	8.86E+07	8.43E+07
Effective Depth, d (mm)	235	235	235
Column strip width (mm)	2500	2500	2500
Band width, b (mm)	1400	2500	1400
Required Steel Area (mm^2)	2225	1134	1097
Required Spacing (mm)	126	441	255
Max Spacing	250	250	250
Number of bars	11	6	5
Number of bars, actual	12	6	12
Min reinforcement area	840	1500	840

MIDDLE STRIP

	Exterior Column	Midspan	Interior Column
Design Moment (Nmm)	-	8.86E+07	8.01E+07
Strip Width (mm)	-	2500	1100
Required Steel Area (mm^2)	-	1134	1051
Required Spacing (mm)	-	333	209
Number of bars	-	6	5
Number of bars, actual	-	6	6
Min reinforcement area	-	1500	660

Conclusions

Exterior Column	12-15M @ 125mm
Interior Column	12-15M @ 260 mm
Bottom Reinforcement Throughout	15M @ 330mm

Columns

COLUMNS

Load Analysis:

Deadload (DL) = 1m soil cover + concrete self-weight

$\rightarrow DL = [\gamma_{soil} \times depth] + [\gamma_{concrete} \times depth]$

$\rightarrow DL = 16 kN/m^3 \times 1m + 25kN/m^3 \times 0.3m = 23.5 kPa$

Live load (LL) = 4.8kPa (from NBC 2010 - Athletic field)

$$\text{Load combination} = 1.25DL + 1.5LL$$
$$= 1.25(23.5kPa) + 1.5(4.8kPa)$$
$$= 36.56 kPa$$

Tributary area of column = $5m \times 5m = 25m^2$

Axial load on columns $= 36.56kPa \times 25m^2 = 915 kN$

* Estimate circular columns as square columns (smaller area → more conservative)

Diameter = 500mm

Square length = 350mm

Min. eccentricity $= 15 + 0.03h = 15 + 0.03 \times 350mm = 25.5mm$

$M_2 = M_1 = Pe = 915kN \times 10^3 N \times 25.5 mm = 23.3 kNm$

Slenderness Check:

$$\frac{kL}{r} \leq \frac{25 - 10\left(\frac{M_1}{M_2}\right)}{\sqrt{\frac{P_f}{f'_c A_g}}}$$

$r = 0.3h = 0.3 \times 0.35m = 0.105m$

$A_g = 350mm \times 350mm = 122500mm^2$

Assume fixed-fixed support on columns ($k = 0.6$)

$$\Rightarrow \frac{0.6 \times 6.8m}{0.105m} \leq \frac{25 - 10\left(\frac{23.3 kNm}{23.3 kNm}\right)}{\sqrt{\frac{915kN \times 10^3 N}{30MPa \times 122500mm^2}}}$$

$\Rightarrow 38.86 \leq 30.06$ X Slenderness effects considered

$$\delta = \frac{C_m}{1 - \frac{P_f}{\phi_m P_c}}$$

$C_m = 0.6 + 0.4\frac{M_1}{M_2} \geq 0.4 \Rightarrow C_m = 0.6 + 0.4(1) = 1$

$E_c = 4500\sqrt{f'_c} = 4500\sqrt{30MPa} = 24647 MPa$

$$\beta_d = \frac{P_{D,f}}{P_f} = \frac{1.25 \times 23.5kPa \times 25m^2}{915kN} = 0.8$$

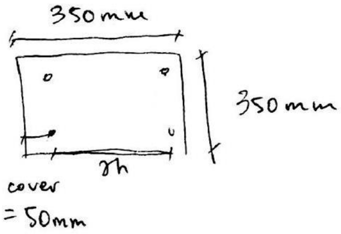
$$I_g = \frac{bh^3}{12} = \frac{350\,mm \times (350\,mm)^3}{12} = 1.25 \times 10^9\,mm^4$$

$$EI = \frac{0.4 E_c I_g}{1+\beta d} = \frac{0.4 \times 24647\,MPa \times 1.25 \times 10^9\,mm^4}{1+0.8} = 6.85 \times 10^{12}\,Nmm^2$$

$$P_c = \frac{\pi^2 EI}{(Klu)^2} = \frac{\pi^2 \times 6.85 \times 10^{12}\,Nmm^2}{(0.6 \times 6800\,mm)^2} = 4061\,kN$$

$$\delta = \frac{1.0}{1 - \frac{915\,kN}{0.75 \times 4061\,kN}} \geq 1.0 \Rightarrow \delta = 1.29$$

$$M_c = \delta M_2 = 1.29 \times 23.3\,kNm = 30\,kNm$$



Design Column $P_f = 915\,kN$, $M_c = 30\,kNm$

Assume $\rho = 0.03$, 25M bars

$$A_s = 0.03 \times (350\,mm)^2 = 3675\,mm^2$$

$$\frac{\gamma h}{h} = \gamma \Rightarrow \gamma = \frac{350\,mm - (2 \times 50\,mm) - 25\,mm - 10\,mm}{350\,mm} = 0.6$$

$$e_x = e_y = \frac{M_f}{P_f} = \frac{30\,kNm}{915\,kN} = 32.8\,mm$$

Min ρ_t:

$$\frac{P_f}{A_g} = \frac{915 \times 10^3\,N}{(350\,mm)^2} = 7.47\,MPa, \quad \frac{M_{fx}}{A_g h} = \frac{30 \times 10^6\,Nmm}{(350\,mm)^2 \times 350\,mm} = 0.47$$

$$\frac{M_{fy}}{A_g h} = \frac{30 \times 10^6\,Nmm}{(350\,mm)^2 \times 350\,mm} = 0.47$$

Using Table 7.4.1 of Concrete Handbook,

(7.47MPa, 0.47MPa) $\Rightarrow \rho_t = 0.01$ $\therefore \rho = 0.03$ is sufficient $> \rho_t = 0.01$

$A_s = 3675mm^2$

$A_b = 500mm^2$, n of bars $= \frac{A_s}{A_b} = \frac{3675mm^2}{500mm^2} = 8$ bars

8-25M

$P_{ro} = \alpha_1 \phi_c f'_c (A_g - A_{st}) + \phi_s f_y A_{st}$, $A_g = (350mm)^2 = 122500mm^2$

$\Rightarrow P_{ro} = 0.8 \times 0.65 \times 30MPa(122500\ mm^2 - 8 \times 500mm^2) + 0.85 \times 400MPa \times 8 \times 500mm^2$

$\Rightarrow P_{ro} = 3208.6\ kN$

$P_{rx} = ?$ $\frac{e_x}{h} = \frac{32.8\ mm}{350mm} = 0.094 \Rightarrow \frac{P_f}{A_g} = 20$, $\frac{M_f}{A_g h} = 1.88$

From Table 7.4.1 $\Rightarrow \frac{P_{rx}}{A_g} = 17.8MPa$

$P_{ry} = ?$ $\frac{e_y}{h} = \frac{32.8\ mm}{350mm} = 0.094$, same as $\frac{P_{rx}}{A_g} \Rightarrow \frac{P_{ry}}{A_g} = 17.8MPa$

Bresler's Equation:

$$\frac{1}{P_r/A_g} = \frac{1}{P_{rx}/A_g} + \frac{1}{P_{ry}/A_g} - \frac{1}{P_{ro}/A_g} \qquad \frac{P_{ro}}{A_g} = \frac{3208.6 \times 10^3 N}{122500mm^2} = 26.2MPa$$

$$\Rightarrow \frac{1}{P_r/A_g} = \frac{1}{17.8\ MPa} + \frac{1}{17.8\ MPa} - \frac{1}{26.2MPa}$$

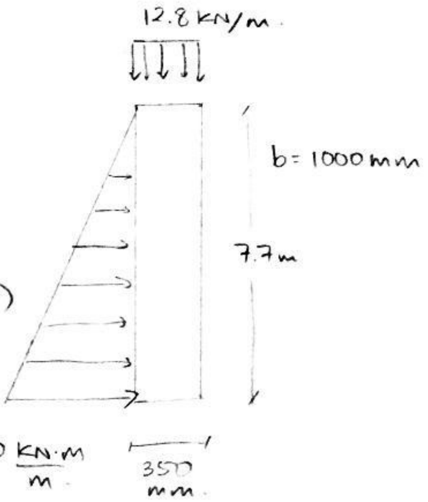
$\Rightarrow P_r = 1651\ kN > P_f = 915kN$ ✓ OK

Walls

Title :
Project No.
Date : m d y
Subject :
Page No.

WALL OF TANK

Full tank scenario
→ force from water in tank
→ no lateral load from soil



approx $w_f = \frac{75.54}{2}$

$= 37.8\ \text{kPa}$

$P = \gamma h$

$(9.81\ \text{kN/m}^3)(7.7\ \text{m})$

$= 75.54\ \text{kPa}$

using Simply supported conditions:

$$M_f = \frac{w_f h_n^2}{8} = \frac{(37.8)(7.7)^2}{8} = 280\ \frac{\text{kN·m}}{\text{m}}$$

$$V_f = \frac{Ph}{3} = \frac{(75.54)(7.7)}{3} = 194\ \text{kN/m}$$

min. wall thickness → $\frac{h}{25} = 308\ \text{mm} \Rightarrow$ use 350mm

→ a more conservative design ignores axial loading.

using 25M → $d = 262.5\ \text{mm}$ $A_b = 500\ \text{mm}$. , $h = 350\ \text{mm}$

$$A_{st} = 0.0015 f_c' b \left(d - \sqrt{d^2 - \frac{3.85 M_r}{f_c' b}}\right) \rightarrow 280\ \text{kN·m}$$

262.5 mm

30 MPa

1000mm

$A_{st} = 3692\ \text{mm}^2$

$$S \leq \frac{A_b 1000}{A_{st}} = \frac{(500)(1000)}{3692} = 135\ \text{mm} \approx 130\ \text{mm}$$

max spacing $= \left.\begin{matrix} 3h \\ 500 \end{matrix}\right\}$ $3(350) = 1050\ \text{mm} > 130\ \text{mm}$ ✓ o.k.

check $\rho < \rho_b = 0.022$ $\rho = \frac{A_s}{bd} = \frac{3692\ \text{mm}^2}{(1000)(260)} = 0.0142$ ✓ ok

$A_{v\,min} = 0.0015 A_g = 0.0015(350\,000\ \text{mm}^2) = 525\ \text{mm}^2$ ✓ o.k.

Title : ______________________________ | Project No.
______________________________ | Date : m d y
Subject : | Page No.

∴ Vertical reinforcement is 25M@130mm.

Horizontal Reinforcement → try 15M bars.

$V_f = 194\ \mathrm{kN/m}$

$$d_v = \begin{Bmatrix} 0.9d \\ 0.72h \end{Bmatrix} \begin{matrix} = 0.9(262.5\mathrm{mm}) = 236\mathrm{mm} \leftarrow ✓ \\ = 0.72(350\mathrm{mm}) = 252\mathrm{mm} \end{matrix}$$

$$\beta = \frac{230}{1000+d_v} = \frac{230}{1236}\ \frac{\mathrm{mm}}{\mathrm{mm}} = 0.19$$

$b_w = 1000\mathrm{mm}$

$$V_c = \underbrace{\phi_c}_{0.65}\underbrace{\lambda}_{1}\beta\sqrt{f'_c}\,b_w d_v = (0.65)(0.19)(\sqrt{30\mathrm{MPa}})(1000\mathrm{mm})(236\mathrm{mm})$$

$$V_c = 159.6\ \mathrm{kN}$$

$$V_r < \text{ or } > 0.125\phi_c f'_c b_w d_v$$
$$= (0.125)(0.65)(30\mathrm{MPa})(1000\mathrm{mm})(236\mathrm{mm})$$
$$= 575\ \mathrm{kN} > 194\ \mathrm{kN}\ ✓$$

$$\therefore\ s \le \begin{Bmatrix} 600 \\ 0.7d_v \end{Bmatrix} = 165.2\mathrm{mm} \leftarrow \text{governs.}$$

$$V_s = V_r - V_c = 194\mathrm{kN} - 159.6\mathrm{kN} = 34.4\mathrm{kN}$$

$A_b = 200\mathrm{mm}^2$ → two curtains ($t > 210\mathrm{mm}$)

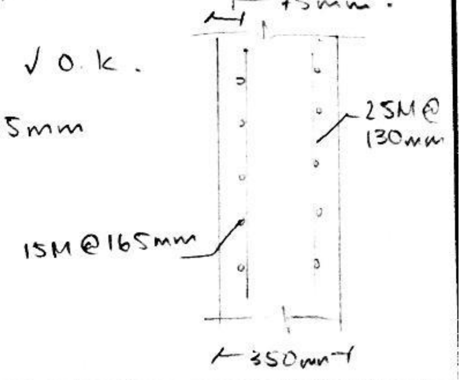
→ use $A_v = 400\mathrm{mm}^2$

$$V_s = \frac{\phi_s A_v f_y d_v \cot\theta}{s} = \frac{(0.85)(400\mathrm{mm}^2)(400\mathrm{MPa})(236\mathrm{mm})(1.43)}{165\mathrm{mm}}$$

$$= 278\mathrm{kN}. \quad 278\mathrm{kN} > 34.4\mathrm{kN}\quad ✓\ \text{o.k.}$$

∴ horizontal reinforcement is 15M@165mm

cover = 75mm (wall exposed to soil)



Floor Slab

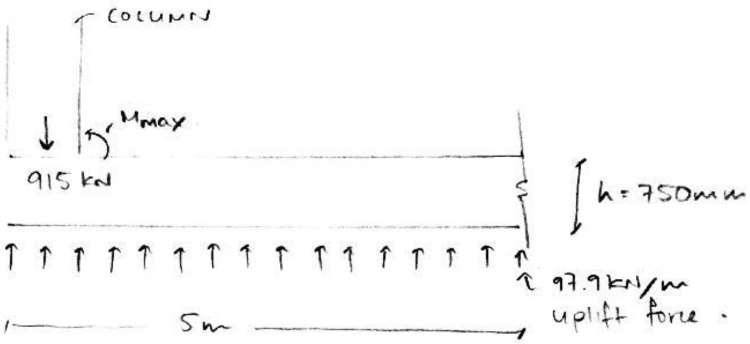
Title :	Project No.
	Date : m d y
Subject :	Page No.

FLOOR SLAB

No water scenario:

using SAP,

$M_{max} = 3132.8 kN{\cdot}m$



using h=750mm, & 35M bars:

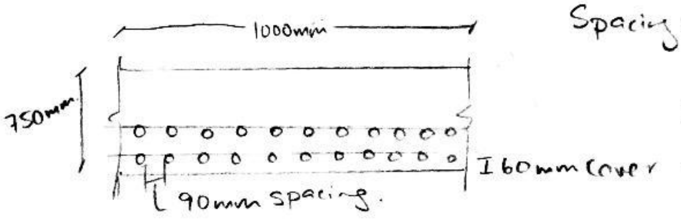
$d_e = 750 - 60 - 35/2 = 672.5mm$

Direct Method: $A_{st} = 0.0015 f_c' b \left(\underbrace{d}_{} - \sqrt{\underbrace{d^2}_{672.5\,mm} - \frac{3.85 \overbrace{M_r}^{3132.8\,kN\,m}}{\underbrace{f_c'}_{30MPa}\ \underbrace{b}_{1000mm}}}\right)$

$A_{st} = 20582 mm^2$

A_b of 35M = 1000 mm ⇒ $\frac{20582}{1000} \approx 22$ bars.

∴ need 2 rows of 11 bars.



Spacing: $\frac{\overset{1000mm^2}{A_b} \times 1000}{\underset{\frac{22000mm^2}{2}}{A_{st}}} = 90.91mm \approx 90 mm$

min spacing: $\begin{cases} 1.4d_b = 49mm \leftarrow \\ 1.4 MSA = 28mm \\ 30mm \end{cases}$ 90.9mm > 49 mm ✓ o.k.

symmetrical two way slab → ∴ same rebar configuration in both directions.

→ 35M @ 90mm.

Load Determination

Title :	Project No.
	Date : m d y
Subject :	Page No.

DETERMINING LOAD:

Weight of tank = $\overset{\text{Roof Slab.}}{\overset{\downarrow}{[1000\,m^2 \times 0.3\,m \times 25\,kN/m]}} + \overset{\text{walls}}{\overset{\downarrow}{[0.3\,m \times 7\,m \times \pi \times 36\,m \times 25\,kN/m]}} + \underset{\text{floor slab}}{\underset{\uparrow}{[1000\,m^2 \times 0.6\,m \times 25\,kN/m]}} = 22665\,KN$

weight of water = $(9.81)\left(\frac{36^2\pi}{4}\right)(6.35) = 63407\,kN$

total weight = 86052 KN

From SAP, soil uplift = 97.9 kN/m.

load from column = 915 kN.

WALL .

Distributed load on wall:

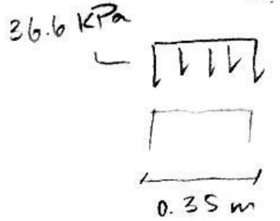
lateral from water ⇒ $P = \gamma h$

$P = (9.81\,kN/m^3)(7.7\,m)$

$= 75.54\,kPa$ at base of wall.

axial load from floor slab ⇒ 36.6 kN/m ← load on roof slab.

$\frac{36.6\,KPa}{0.35\,m} = 12.8\,kN/m$ axial load.



Pump Design

For 3 day water turnover, 72 hours (t) = 259200 seconds

Pipe Diameter = 0.45m

Pipe Length = 950m

Pipe Roughness (e) = 0.12mm (Ductile Iron)

Kinematic viscosity (v) = 10^{-6} m^2/s

Pipe Pressure = 65psi = 448,000 Pa

Pressure head = $\frac{P}{\gamma_w}$ = $\frac{448{,}000Pa}{9810\frac{N}{m^3}}$ = 45.67m

Powerhouse elevation = 88m

Field Elevation = 94m

Water tank has an elevation (z) 6m higher than that of the power station

$$Q = \frac{V}{t} = \frac{10{,}000m^3}{259200s} = \mathbf{0.0386\frac{m^3}{s}} = 38.6\frac{L}{s}$$

$$Reynolds\ Number\ (Re) = \frac{4Q}{v\pi \mathrm{D}} = \frac{4*0.0386\frac{m^3}{s}}{10^{-6}\frac{m^2}{s}*\pi*0.45m} = \mathbf{10.9*10^4}$$

$$Friction\ Factor\ (f) = \left(-1.8*\log_{10}(\left(\frac{\frac{e}{D}}{3.7}\right)^{1.11} + \frac{6.9}{Re})\right)^{-2}$$

$$= \left(-1.8*\log_{10}(\left(\frac{\frac{0.12mm}{450mm}}{3.7}\right)^{1.11} + \frac{6.9}{10.9*10^4})\right)^{-2} = \mathbf{0.0188}$$

$$Pump\ Head\ (h_p) = \frac{P}{\gamma_w} - z + \frac{8fL}{\pi^2 gD^5}Q^2 = 45.67m - 6m + \frac{8*0.0188*950m}{\pi^2*9.81\frac{m^2}{s}*(0.45m)^5}\left(0.0386\frac{m^3}{s}\right)^2$$

$$= \mathbf{36.32m}$$

$$Power\ (\omega_P) = \gamma_w Q h_p = 9810\frac{m^3}{s}*0.0386\frac{m^3}{s}*36.32m = \mathbf{13746\ W} = 13.75kW$$

$$Horsepower\ (HP) = \frac{W}{745.7\frac{W}{HP}} = \frac{13746\ W}{745.7\frac{W}{HP}} = \mathbf{18.4\ HP}$$

BC Hydro rate = \$0.0829/kW*h

$$Power\ Cost\ (\$) = rate*t*\omega_P = \frac{\$0.0829}{kW*h}*72h*13.75kW = \$\mathbf{82.05\ every\ 3\ days}$$

Secant Piles

Soil Properties

Beta	0.3		**Excavation**		
Unit weight	18	kN	Height	7.7	m
Friction angle	27		B, diameter	36	m
Nq	18		alpha	1	
Surcharge	16		**Piles**		
Concrete			Diameter	0.6	
Unit Weight	24	kN	Area of base	0.282743339	
Phi concrete	0.9		Area of Pile Shaft	56.54866776	

Ultimate End Bearing:	22508.292	kN
Ultimate Shaft Friction:	3676.82	kN
Qult	**26185.108**	**kN**
FOS	3.1533203	

Circumfrence of secant pile wall:
122.52211 m

Number of Piles:
204.20352

Total Piles **205**

Depth	Vert Stress kPa	Pore Water kPa	Vert Effective Stress, kPa	Unit Tip Resistance, kPa	Unit Side Friction, kPa
1	18	9.81	8.19	147.42	2.457
2	36	19.62	16.38	294.84	4.914
3	54	29.43	24.57	442.26	7.371
4	72	39.24	32.76	589.68	9.828
5	90	49.05	40.95	737.1	12.285
6	108	58.86	49.14	884.52	14.742
7	126	68.67	57.33	1031.94	17.199
8	144	78.48	65.52	1179.36	19.656
9	162	88.29	73.71	1326.78	22.113
10	180	98.1	81.9	1474.2	24.57
11	198	107.91	90.09	1621.62	27.027
12	216	117.72	98.28	1769.04	29.484
13	234	127.53	106.47	1916.46	31.941
14	252	137.34	114.66	2063.88	34.398
15	270	147.15	122.85	2211.3	36.855
16	288	156.96	131.04	2358.72	39.312
17	306	166.77	139.23	2506.14	41.769
18	324	176.58	147.42	2653.56	44.226
19	342	186.39	155.61	2800.98	46.683
20	360	196.2	163.8	2948.4	49.14
21	378	206.01	171.99	3095.82	51.597
22	396	215.82	180.18	3243.24	54.054
23	414	225.63	188.37	3390.66	56.511
24	432	235.44	196.56	3538.08	58.968
25	450	245.25	204.75	3685.5	61.425
26	468	255.06	212.94	3832.92	63.882
27	486	264.87	221.13	3980.34	66.339
28	504	274.68	229.32	4127.76	68.796
29	522	284.49	237.51	4275.18	71.253
30	540	294.3	245.7	4422.6	73.71

Equations

Vert Effective Stress, σv	(z*γ)-(z*γw)
Unit Tip Resistance	Nq*σv
Unit Side Friction	β*σv
Ultimate End Bearing	Nq*Ab*Unit Tip Resistance
Ultimate Shaft Friction	0.7*Ap*Unit Side Friction*Tan(ϕc)

Soil Properties	
Unit weight	16
friction angle	27
Nq	18

Pile Properties	
Diameter (m)	0.6
Ab (m)	0.282743339

Tank Properties	
Unit weight concrete	24
Weight of Full Tank (Kn)	86052.6693

600 mm Pile Capacity Calculation

	Psu					Pbu				W		Design		
Z (m)	**As**	**Average Sigma v**	**tan(friction angle)**	**Fs**	**Psu (Kn)**	**Sigma v**	**Fb**	**Po**	**Pbu (Kn)**	**Volume**	**W (Kn)**	**Pu (Kn)**	**Number of piles needed**	**Minimum Spacing (m)**
5	3	40	0.509525578	7.337168322	22.01150497	80	1440	80	429.769875	1.413716694	33.92920066	417.8521793	206	2.2
10	6	80	0.509525578	14.67433664	88.04601987	160	2880	160	859.53975	2.827433388	67.85840132	879.7273686	98	2.3
15	9	120	0.509525578	22.01150497	198.1035447	240	4320	240	1289.309625	4.241150082	101.787602	1385.625568	63	2.4
20	12	160	0.509525578	29.34867329	352.1840795	320	5760	320	1719.0795	5.654866776	135.7168026	**1935.546777**	**45**	2.5
25	15	200	0.509525578	36.68584161	550.2876242	400	7200	400	2148.849375	7.068583471	169.6460033	2529.490996	35	2.6
30	18	240	0.509525578	44.02300993	792.4141788	480	8640	480	2578.61925	8.482300165	203.575204	3167.458225	28	2.7
35	21	280	0.509525578	51.36017826	1078.563743	560	10080	560	3008.389125	9.896016859	237.5044046	3849.448464	23	2.8
40	24	320	0.509525578	58.69734658	1408.736318	640	11520	640	3438.159	11.30973355	271.4336053	4575.461713	19	2.9
45	27	360	0.509525578	66.0345149	1782.931902	720	12960	720	3867.928875	12.72345025	305.3628059	5345.497971	17	3
50	30	400	0.509525578	73.37168322	2201.150497	800	14400	800	4297.69875	14.13716694	339.2920066	6159.55724	14	3.1
55	33	440	0.509525578	80.70885154	2663.392101	880	15840	880	4727.468625	15.55088364	373.2212072	7017.639519	13	3.2
60	36	480	0.509525578	88.04601987	3169.656715	960	17280	960	5157.2385	16.96460033	407.1504079	7919.744807	11	3.3
65	39	520	0.509525578	95.38318819	3719.944339	1040	18720	1040	5587.008375	18.37831702	441.0796086	8865.873106	10	3.4
70	42	560	0.509525578	102.7203565	4314.254973	1120	20160	1120	6016.77825	19.79203372	475.0088092	9856.024414	9	3.5
75	45	600	0.509525578	110.0575248	4952.588617	1200	21600	1200	6446.548125	21.20575041	508.9380099	10890.19873	8	3.6

Legend

Psu = Ultimate side shear resistance on the pile shaft
Pbu = Ultimate resistance at the base
W=Self Weight of the Pile
Pu = Ultimate Load Capacity of the Pile
Ab = Area of Base of Pile
Fb = net ultimate resistance per unit area of base
Po = Overburden pressure at level of the base
Nq = Bearing Capacity Factor
As = Surface Area of pile shaft in contact with the soil
FS = Average Ultimate Side resistance per unit area
Z = Depth
Φ = Friction Angle

Equations

$$Pu = Psu + Pbu - W$$

$$Pbu = Ab(Fb + Po) \qquad Psu = As * FS$$

$$Fb = Nq * \sigma v \qquad FS = \frac{Nq}{50} * \sigma v * \tan\Phi$$

$$\sigma v = \text{unit weight} * Z \qquad As = 2\pi * \text{radius} * z$$

$$Po = \sigma v$$