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DESIGN & CONSTRUCTION OF THE WEST DON LANDS STORM WATER CONVEYANCE SYSTEM

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ABSTRACT: Waterfront Toronto is undertaking a large scale, urban renewal project of the West Don Lands in Toronto, Ontario. As a part of this development, a large flood protection landform was constructed to protect the site from flooding by the Don River, requiring storm water on the site to be redirected to the west. A new storm water outfall was needed to convey this redirected flow out to Lake Ontario. To meet the City of Toronto's 2006 Wet Weather Flow Management Guidelines, storm water needs to be treated before it can be discharged into the environment. The Storm Water Conveyance System (SWCS) project is the first phase of the overall storm water management for the West Don Lands and includes the entire underground infrastructure to manage storm water flow and to allow for a storm water treatment facility that will be built in the second phase of the project. The major components of the SWCS project are two large-scale underground oil grit separators, a vortex drop shaft, deep rock tunnels, an overland flow inlet, a large diameter storage shaft, an overflow structure, and an outfall connection to Lake Ontario. One of the more unique components of the SWCS project was the overflow structure, a large tower in the center of the main shaft that always contains water at lake level and allows storm water to overflow the storage system in large storms and bypass treatment. This structure was built using pre-cast concrete components that were post-tensioned to secure all the segments together. This approach required significant planning and design to ensure that the pre-cast segments were watertight upon completion. This paper discusses the design and construction of the hydraulic structures and components that make up the entire Storm Water Conveyance System for the West Don Lands redevelopment.

Keywords: structures; storm water; tunnels; pre-cast; post-tensioned; construction

1. PROJECT OVERVIEW

1.1. Background

Waterfront Toronto is undergoing a large scale, urban renewal project of the West Don Lands in Toronto, Ontario. As a part of this development, a large flood protection landform is required to protect the site from flooding by the Don River and storm water on the site needed to be redirected to the west. A new storm water outfall was required to convey this flow to Lake Ontario.

To meet the City of Toronto's 2006 Wet Weather Flow Management Guidelines, storm water needs to be treated before it can be sent out into the lake. The Storm Water Conveyance System (SWCS) project is the first phase of the overall project and includes the entire underground infrastructure to manage storm water flow from the West Don Lands and to support the future storm water treatment facility.

1.2. System Operation

The storm water management system consists of two pathways for flow to enter the system; a minor system and a major system. Figure 1 illustrates the components of the entire SWCS.

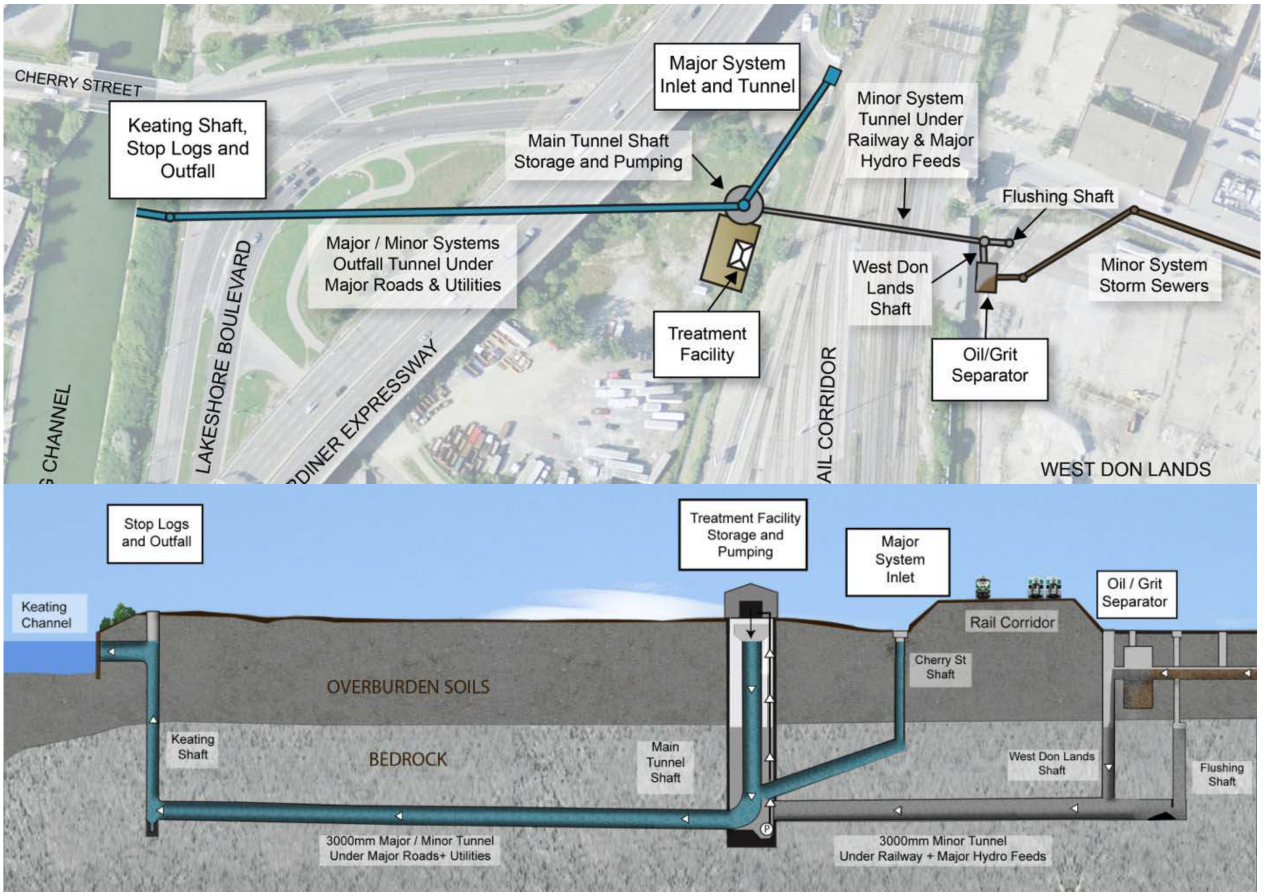

Figure 1. Storm Water Conveyance System.

1.2.1 Minor System

The minor system consists of the storm flows that are conveyed by the storm sewer network around this site. The minor system flows enters the SWCS via two large scale oil-grit separators (OGS) contained within a large underground concrete structure. The OGS removes the majority of the suspended solids in the storm water and is the first stage in the treatment process. The flow exits the oil-grit separator and drops down a shaft to a deep rock tunnel via a vortex inlet.

The deep rock tunnel conveys the flow to a large storage shaft where the water is stored. The water is pumped out of the shaft by two submersible pumps to a treatment facility that removes the remaining sediment from the water and provides seasonal UV disinfection. In most storm events, the treatment rate cannot keep up with the inflow of water. The large diameter and depth of the main storage shaft provides a large volume to store the water, allowing the treatment process to operate at an economical flow rate. Should the storm event exceed the capacity of the storage shaft, it is designed to overflow into an overflow structure located in the center of the main shaft and allow the water to bypass treatment and flow by gravity to the lake.

Storm water that is treated at the treatment plant flows by gravity back to the overflow structure in the middle of the main shaft where it flows through in inverted siphon and outfalls into the Keating Channel.

1.2.2 Major System

The major system consists of the storm flows that exceed the capacity of the storm sewer network. These large flows utilize the full cross section of the roadways around the site as open channels and flow down the roads.

Due to the site topography surrounding the SWCS, this overland flow cannot flow directly to the lake by gravity, as there is a low point in the system that would cause major flooding if this large flow is not captured.

To capture this flow, a large overland flow inlet was installed at the low point in the system. Flow that enters the overland flow inlet flows by gravity to the lake by an inverted siphon, and shares the same outfall tunnel that the minor system uses.

2. MAJOR COMPONENTS

2.1. Oil Grit Separator

The oil grit separator (OGS) serves as the main barrier to debris entering the storm water quality facility, and is the first level of treatment of the storm water. Flow enters the large buried structure through a municipal concrete storm sewer. The incoming flow is split into two vortex separating chambers which use a spiralling column of water to allow the sediment to drop out of suspension and sink to a debris pit at the bottom of each chamber. The water exits the vortex separating chambers through a fine screen opening and passes through an oil baffle before it exits the chamber.

Large storms will overflow the flow splitting weir wall and bypass the grit vortex separators. For this type of event, a large bar screen is located on top of this weir wall to prevent major debris from entering the system that could damage the pumps. Figure 2 illustrates the components of the oil grit separator.

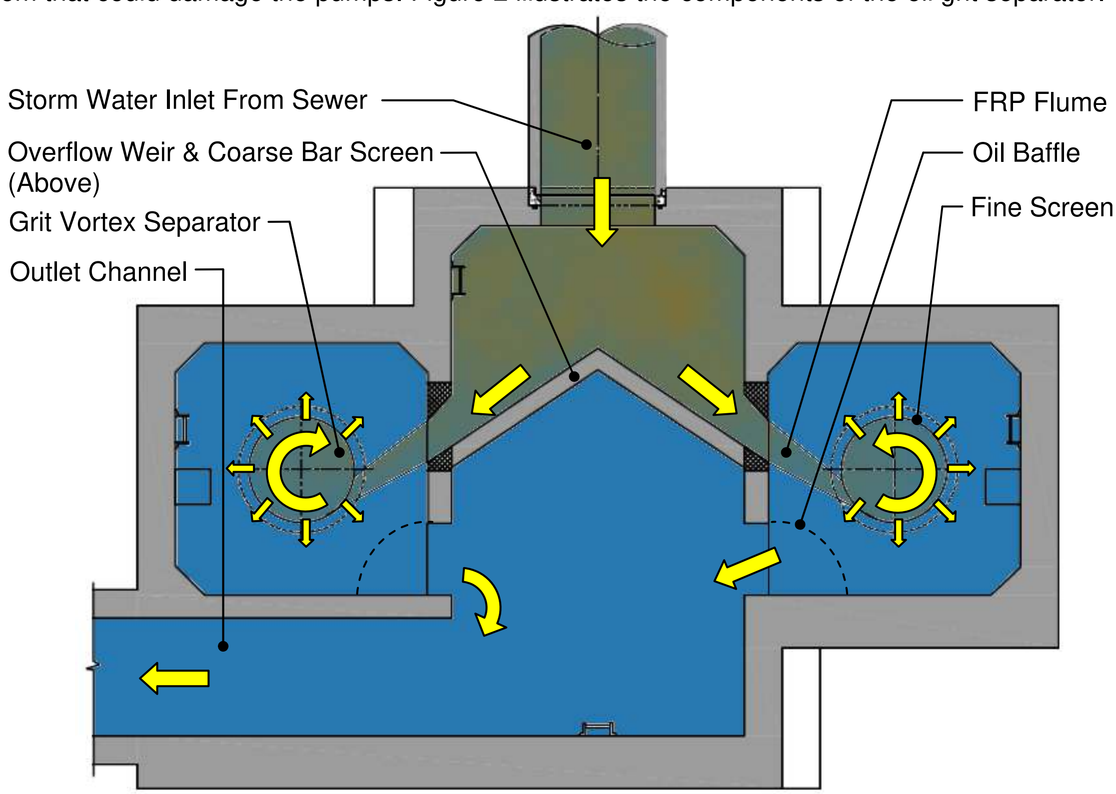

Figure 2. Oil Grit Separator.

The OGS structure is a large scale buried concrete structure, measuring 16 m x 10 m x 13 m deep, that houses two fibre reinforced polymer (FRP) vortex separators. A secant pile wall was used to shore the excavation and to provide a watertight barrier to the high ground water located on site. Tiebacks were used to further control the excavation, including some that extended below an adjacent railway line, which needed to be de-stressed after the construction of the structure was complete. The excavation extended in to the underlying shale bedrock, which was excavated without the use of shoring.

2.2. Vortex Drop Shaft

Water exiting the OGS needs to drop 15 meters in elevation to the invert of the rock tunnels that convey the flow to the storage shaft. To minimize the turbulence and erosion that would occur at the bottom of the drop, a vortex drop shaft was used.

The storm water entering the vortex drop structure is accelerated by increasing the steepness of the channel before the drop. As the channel drops it narrows to help direct the water to meet the tangent of the circular drop shaft. This accelerated and narrowed flow helps the water to adhere to the wall of the drop shaft. Figure 3 illustrates how the vortex inlet drop functions.

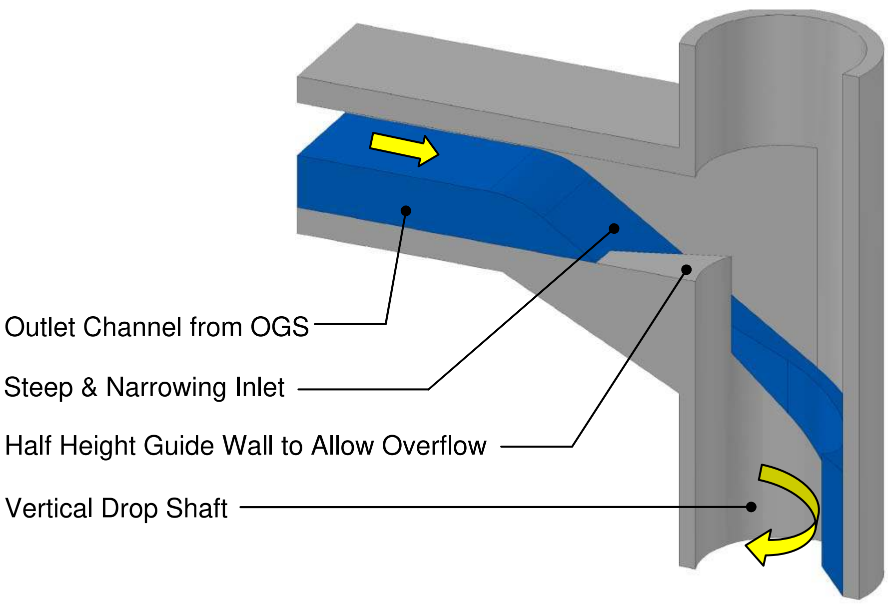

Figure 3. Vortex Drop Shaft.

The shaft was constructed using a secant pile wall shoring system in the overburden soils and was excavated by a large diameter auger, which augured both the overburden and the shale bedrock. The shaft was lined using cast-in-place concrete.

The design of any kind of drop structure requires careful though and planning on how to deal with erosion of the structure due to the turbulent nature of the hydraulics involved. Although a vortex drop was used to help mitigate these issues, its effectiveness varies with the changes in flow. Because of the variable nature of storm water flow, it is expected that erosion will still occur at the base of this drop.

To account for the erosion of the structure, the base of the shaft was constructed with a concrete slab that is designed to allow for over half of its thickness to be eroded away without losing its structural capacity. No rebar was placed in this upper portion of the slab to ensure that corrosion would not be an issue as the slab surface wears away.

2.3. Rock Tunnels

Rock tunnels serve to convey the storm water within the system. They pass the flow from the OGS to the main storage shaft and from the overland flow inlet and overflow structure out to the outfall at the Keating Channel.

Tunnels were chosen to avoid disturbance to major highways, roads, railway lines and utilities that surrounded and crossed the project.

The rock tunnels were constructed in the Georgian Bay Formation, a shale bedrock that is common across a large part of southern Ontario. All three tunnel headings were bored from the main shaft, using a main beam tunnel boring machine (TBM). The use of a main beam type TBM allowed all the tunnel headings to be constructed as blind headings, where the TBM was pulled back to the main shaft for removal upon completion.

The tunnels were lined with an unreinforced cast-in-place concrete liner. The tunnel lining operation occurred daily, where approximately 30 m would be poured each day. This short duration between concrete pours coupled with the lack of rebar in the concrete lead to lots of shrinkage cracks, which was expected during the design. To minimize infiltration into the tunnels, all actively leaking cracks in the tunnel liner were sealed with polyurethane injections.

The original design for the connections between the tunnels and shafts utilized smooth radius elbows to minimize the hydraulic losses at these joints. However, due to equipment problems, the contractor elected to use a large sized TBM. This increased tunnel diameter provided sufficient hydraulic benefit to eliminate the smooth radius elbows and switch to a simpler junction at all the shaft-tunnel connection locations.

2.4. Overland Flow Inlet

The major system in storm water management consists of the overland flow that exceeds the capacity of the minor storm sewer system. Due to the topography in the area, the overland flow could not flow directly out to the lake.

To capture this major system storm flow, a large overland flow inlet was required to drain the low point at the south end of Cherry Street. The overland flow inlet consists of a chamber with open grating. The chamber is located directly on top of a drop shaft that connects to a rock tunnel below. The grating for the inlet required large openings to help prevent debris from getting stuck in the grate. To achieve this high percentage opening, bridge deck grating was used. Even with the large openings, the size of the grating was determined in the hydraulic model assuming that 50% of the area would be blocked in a major storm, as a large amount of debris is commonly found in overland flow.

The shaft for the overland flow inlet was constructed using an auger with a steel casing. There were multiple obstacles found when attempting to augur the hole, including timbers from what appeared to be an old wharf, buried in the lake fill. To penetrate the timbers, a coring bit was used to saw through the wood.

2.5. Flushing System

The rock tunnel that conveys storm water from the OGS to the storage shaft operates like a typical storm sewer, where it will see many cycles of wetting and drying. There was concern that this tunnel may be prone to sediment build up due to this cycling, and due to the stagnation that would occur in the tunnel when the storage shaft fills, and the storm water inflow has stopped.

To prevent any build up of sediment inside the tunnel, a flushing system was developed to clean the system after each storm event that causes the storage shaft to fill beyond a threshold elevation. The flushing system consists of a shaft that fills with water as the storage shaft fills. Once the level reaches a threshold elevation, a vacuum pump over top of the flushing shaft switches on. Once the water has drained out of the main shaft and connecting tunnel, the vacuum pump is switched off and a balloon valve opens to provide a rapid release of air into the shaft allowing the water escape the shaft. This rapid release of water creates a wave that helps flush any sediment remaining in the tunnel. Figure 4 illustrates the operation of the flushing shaft.

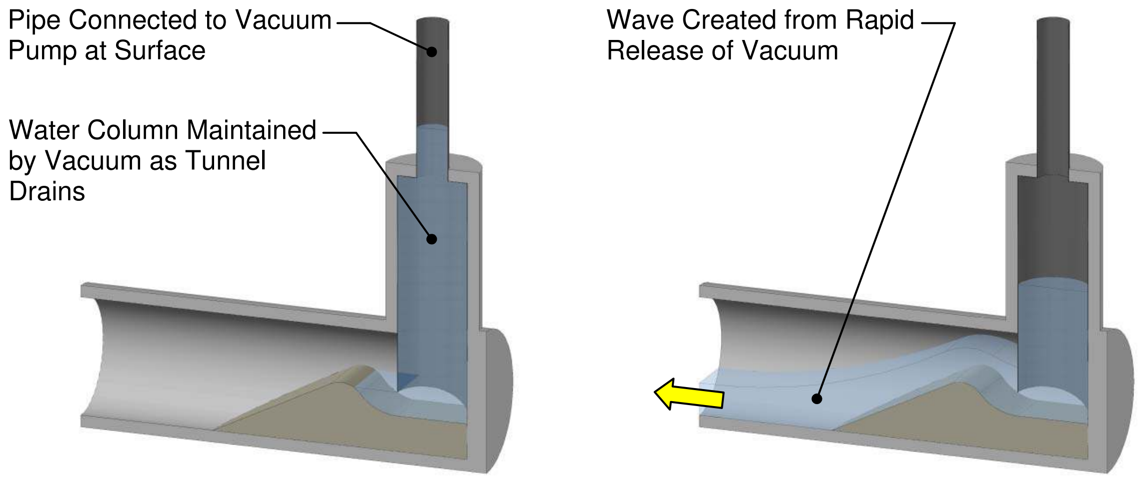

Figure 4. Flushing System.

The flushing shaft was excavating using a cased hole and an auger. The internal lining of the flushing shaft was constructed of stainless steel pipe, continuously welded at the seams to provide an air tight chamber. By creating an air tight chamber for the flushing shaft, the vacuum pump will run more efficiently, as it will not need to overcome leakage. The annulus around the stainless steel pipe was filled with concrete to provide the structure to the shaft.

2.6. Large Diameter Storage Shaft

The large diameter storage shaft is used to provide 3,000 m^3 of storm water storage. This large amount of storage allows the treatment process to be optimized and operate at a slower rate. Storms that exceed the capacity of the treatment process will start to fill the storage shaft, and as the storm subsides the water in the shaft will slowly be pumped down by the continuing treatment process.

The storage shaft was also used as the launch shaft for the TBM. The shaft was constructed by installing a secant pile wall shoring system, providing a watertight shoring system.

The finished lining for the shaft was constructed from cast in place concrete. Careful consideration was taken in the design of the main shaft to resist the high groundwater table at the site. The concrete lining was designed as a compression ring to minimize the required wall thickness. The walls were reinforced in the top portion of the shaft to minimize and control concrete cracking, where the concrete is more susceptible to bending forces. The lower portion of the shaft, located in the bedrock was built without use of reinforcement as the hoop stresses were higher, ensuring that the concrete remains in a constant state of compression.

The base slab of the main shaft is subjected to very large flotation pressures from the high ground water table. To resist these large uplift pressures, the base slab was designed and analyzed as a thin shelled dome.

Excavating the rock and placing concrete to a dome shape would have been very difficult. To simplify the design and allow for easier construction, the theoretical shape of the dome was inscribed inside a thick base slab. This slab was poured with a uniform thickness. The approach of utilizing a dome for analyzing the base slab allowed for a 35% reduction in the thickness of the slab as compared to a classical slab type analysis.

The base slab also served to anchor the post tensioning rods that were to be used for building the pre-cast concrete overflow structure.

2.7. Overflow Structure

The overflow structure is located in the center of the main storage shaft. Its main purpose is to allow large storm events to overflow and bypass treatment once the storage shaft reaches its capacity. The overflow structure also doubles as a support column to the roof of the main storage shaft.

The overflow structure consists of two main parts; the weir structure, and the pre-cast concrete pipe tower.

2.7.1 Weir Structure

The weir structure is a large diameter round weir that sits on top of a tower of pre-cast concrete pipes. The overflow structure is hydraulically connected to Lake Ontario. To determine the elevation of the weir, historical lake levels were analyzed to ensure that the weir would be placed high enough to prevent the lake water inside the overflow structure from backflowing into the storage portion of the shaft. However, placing the weir too high would have caused the upstream storm sewers to surcharge and cause flooding. The difference between these two critical elevations was approximately 300 mm. Stainless steel adjustable weir plates were used to allow for some construction tolerance and to provide the ability to adjust the weir height in the future should conditions change. The size of the weir structure was determined by the required weir length to pass the design storm for the system. The required weir length of 22.5 meters necessitated a 7.2 meter diameter weir. The large diameter required for the weir was too large to construct the entire tower at the same diameter, as it would have reduced too much storage volume from the main shaft. To overcome this limitation, the weir structure was designed as a bowl shape that would sit on top of a smaller diameter pipe tower.

The weir structure was pre-cast on site beside the main shaft. A short pipe segment was cast into the bottom of the structure to allow for easy placement on top of the pipe tower during installation. Three large steel lifting plates were cast into the concrete to facilitate lifting the 80 ton structure into its final location. The lifting plates were cut off and covered by a concrete topping after installation.

2.7.2 Pre-Cast Concrete Pipe Tower

The pipe tower served as both a support column for the main shaft's roof, as well as an outlet conduit for both water overflowing the weir and for the regular outlet flow from the treatment process. The base of the tower is constructed on top of two intersecting tunnels; one from the overland flow inlet, and one from the outfall tunnel. Both of these tunnels and the overflow structure are hydraulically sealed from the storage side of the shaft.

The pipe tower was constructed using pre-cast concrete pipe segments. A pre-cast concrete pipe manufacture produced these segments using standard pipe forms, however the reinforcement and concrete used were customized to work in this unique application. Reinforcement was designed to resist both the high bursting pressures from the internal water pressure as well as the high stresses that would be applied to the entire tower after the post-tensioning operation. Sixteen plastic ducts were cast into the walls of the concrete pipes to facilitate installation of the post tensioning rods.

Concrete cover was a primary concern for the pipe tower, as the outside would be subjected to constant wetting and drying cycles as the storage shaft fills and empties. Casting the pipe segments in a pre-cast manufactures facility allowed for this tight control of rebar cover. High density concrete was also used to limit the water penetration into the concrete and help prevent corrosion of the reinforcement.

Joints between pipe segments were the biggest concern with the use of pre-cast concrete, as they would be the most vulnerable spots for leakage. The standard pipe shapes used have bell and spigot joints, with a space for a rubber gasket, which is intended for use in standard concrete sewer pipe installations. The constant high internal water pressures that would be applied to the joints are beyond the normal design conditions for these types of gasket seals. Instead of using the standard seals, the groove around the pipe spigot was grouted solid with cement grout, creating a permanent seal. The joints were prevented from movement by the high post-tensioning pressures that would keep the joints tightly closed.

2.7.3 Installation

Sixteen high strength threaded reinforcing bars were cast into the base slab of the main shaft to serve as an anchor for post-tensioning the overflow structure. The interconnection of the tunnels and the base of the overflow structure was then constructed with reinforced cast-in-place concrete. Once the base for the overflow tower was installed, the sixteen high strength threaded bars were extended to the top of the main shaft and the precast pipe segments were lowered down one at a time. Joints between each pipe segment were glued together with a high strength concrete epoxy adhesive to provide temporary support to the pipe tower and to help provide an initial seal between pipe joints. Once the pipe tower was constructed, a large 500 ton mobile hydraulic crane was used to lift the 80 ton concrete weir structure onto the top of the pipe tower. Figure 5 illustrates the construction sequence, and Figure 6 shows a photo of the assembled overflow structure.

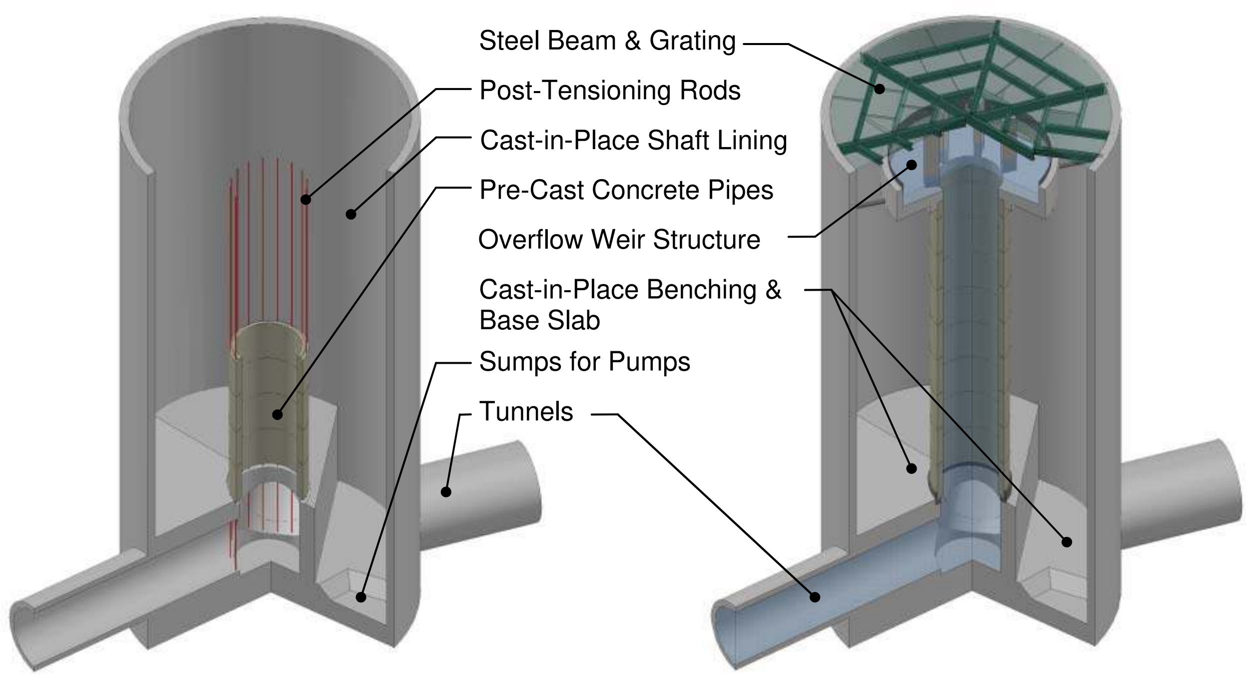

Figure 5. Construction Sequence of the Overflow Structure.

2.7.4 Post Tensioning & Grouting

Once the pipe tower and weir structure were installed, the entire assembly was post tensioned together using sixteen high strength threaded rods. Each rod was stressed to 839 kN (189,000 lbs.) and locked off with nuts. Once all the rods were stressed, a flowable cement grout was pumped into the post tensioning conduits to lock the rods in place. The post tensioning ducts also served as a pathway to grout the annulus of each pipe joint solid, providing a permanent seal to the joint. A concrete topping was added inside the weir structure to provide a slope towards the outlet, as well as to provide concrete cover over the post-tensioned rods and steel lifting plates.

Figure 6. Photo of the assembled overflow structure.

2.8. Outfall Structure

The outfall structure consists of a vertical shaft connecting the outfall tunnel to a concrete chamber near the surface, and a box culver outfall that extends below the existing dock wall that lines the Keating Channel. The chamber contains a stop log slot and storage for concrete stop logs to allow the tunnel to be isolated and dewatered, allowing for future inspection of the outfall tunnel. Figure 7 illustrates the outfall structure.

The concrete stop logs were site cast and fitted with rubber seals and gaskets to provide a watertight seal. Concrete was chosen to provide long term durability, allowing the logs to be stored partially submerged inside the chamber.

The box culvert outfall was designed with a large cross-sectional area to minimize the velocity of the water discharging into the Keating Channel that would affect boats operating on the navigable waterway.

Steel sheet piles were used to create a cofferdam around the outfall structure to provide a dry work area for construction. A portion of the existing dock wall was removed to allow for the installation of the new outfall box culverts. The wall was cut away using a diamond wire rope saw.

After the box culvert was installed, the dock wall was reconstructed on top of it to restore the continuity of the dock wall. The completed outfall is below the waterline to help prevent any floating debris from migrating back into the storm water outfall when there is no active flow in the storm system.

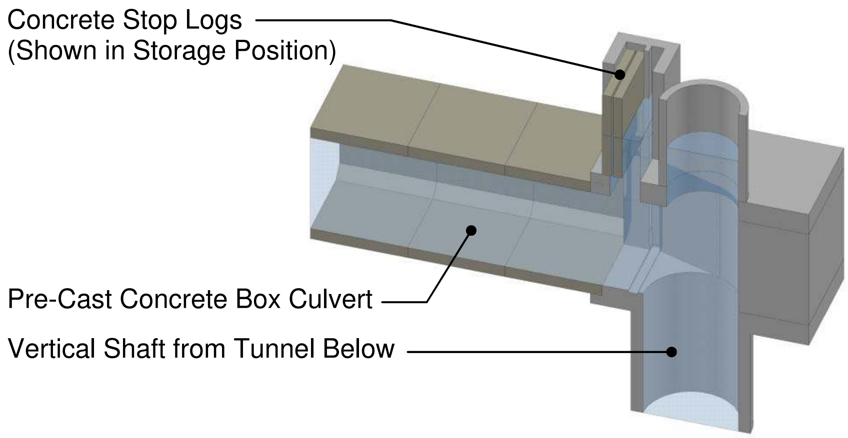

Figure 7. Outfall structure.

3. CONCLUSIONS

The West Don Lands Storm Water Conveyance System utilized many unique hydraulic structures. The design and construction of these structures took careful planning and specific details to ensure long term durability and function.

Water-tightness of the concrete is a major focus in the design and construction of hydraulic structure. The use of waterproof formwork ties, waterstops at all construction joints, rebar detailing to help control and minimize the shrinkage cracking of the concrete and a special concrete mix design to minimize its shrinkage and permeability proved successful for SWCS project.

The use of pre-cast concrete for water containing structures can also be successful, as was demonstrated with the overflow structure. The use of pre-cast helped the project meet a demanding construction schedule. The segmental structure was made watertight by post-tensioning the pre-cast components and grouting all the joints solid with cement grout.

The project was successfully completed in May 2012 after 14 months of construction.