DESIGN AND CONSTRUCTION OF A DEEP WATER MARINE OUTFALL

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Abstract
King County Wastewater Treatment Division (WTD) is building a new wastewater treatment plant to serve the northeast portion of its service territory in the metropolitan area of Seattle, Washington, USA. The project includes an associated 13 mile long conveyance system (four tunnel segments) that will discharge effluent to Puget Sound, a marine estuary in western Washington. This presentation will cover the design considerations and construction of the outfall which consisted of 417 feet of 84-inch diameter polyurethane lined and coated steel pipe and twin parallel 63-inch diameter mostly bottom laid HDPE (5,018 feet & 4,768 feet). Each of these outfall pipes includes 250-foot long diffuser sections which are staggered to provide a 500 foot mixing zone. The flanged steel pipe was constructed using cut and cover from the shoreline to an existing grade depth of -4 feet MLLW. This section was shored with sheet pile to limit the trench width in a sensitive eelgrass bed. The first 494 feet of the HDPE pipes were also installed using cut and cover with 237 feet shored and 257 feet side sloped. Shoring, excavation and pipe installation was done from a crane on a temporary platform as well as from a barge. The remaining HDPE was bottom laid with concrete or coated ductile iron collars to provide differing degrees of ballast depending on the slope conditions. The HDPE pipe was fabricated remotely in two strings at a site 17 miles away and towed to the outfall site separately to be installed using controlled submergence. The presentation will review the two pipe materials and construction methods used for the project and the benefits of each in this application. Material selection by the design-builder was done to assure a performance specification of a 75 year design life. The HDPE fabrication and anchor attachment process will be shown. Pipe backfill and shoring removal was the reverse of the installation process and when completed the site was ready for eelgrass restoration. Eelgrass had been harvested from the pipeline alignment and propagated at a remote site. The project was a huge success for the WTD and design-build team. It was finished 22 months ahead of the required date for 8 million dollars (20%) less than engineer's estimate. The project won 10 regional, national and international peer awards including ENR's Best of the Best Projects for 2009 in the Civil/Public Works category.

Background

King County Wastewater Treatment Division (WTD) is the regional utility that conveys and treats wastewater more for than 1.5 million residents in the Seattle Metropolitan area (King, and portions of Snohomish and Pierce counties). Formerly called Metro, the regional clean-water agency now operated by King County has been preventing water pollution for nearly 50 years to protect public health and water quality. The WTD serves 17 cities and 17 local sewer districts.

A regional wastewater planning effort in the late-1990's determined the need for a new wastewater treatment plant to provide additional capacity within the WTD service area. The Brightwater Project is a 36 MGD membrane bioreactor wastewater treatment plant, with peaking capacity of 130 MGD provided through chemically enhanced primary sedimentation and blending effluents. The plant is located in the northeast portion of the service area and 13 miles of tunnel convey effluent to a deepwater marine outfall in Puget Sound. Ultimate capacity for the plant will be 54 MGD average dry weather and 170 MGD peak.

WTD prepared a RFQ/RFP for a design-build contract for the deep water marine outfall segment of the project. Triton Marine Construction Inc. of Bremerton Washington led the selected design-build team. Major construction subcontractors included American Construction and Mark Duffy Commercial Diving.

WTD provided project management, engineering and accounting staff. Vanir Construction Management served as WTD's construction management consultant and inspection staff. Vanir also provided additional engineering expertise in marine outfalls for design review. CDM and Landau Associates were retained as WTD's geotechnical consultant.

Design and Outfall Description

The Triton Marine design team included Dayton & Knight, Ltd. Consulting Engineers (now Opus-DaytonKnight) as the lead designer supported by HWA Geosciences, Zentech Belgium, Anchor Environmental (now Anchor QEA, LLC), Art Anderson Associates, Cooper Zietz Engineers and Northwest Corrosion Engineering. The design team hit the ground running as soon as a notice of selection was announced in late August 2007. Triton had proposed an aggressive schedule with construction in the summer of 2008. Drawings and specifications, including reviews at 60%, 90% and 100%, were completed by May 2008 as the construction crews began to mobilize.

The proposed outfall began on shore at the end of a micro-tunnel constructed under another contract which connected to the fourth leg of the conveyance tunnel. The first section of the outfall was 417 feet of 84-inch diameter polyurethane lined and coated steel pipe (see Figure A). This section ran under the beach and tide zone at an angle to the shore then turned and ran mostly perpendicular to the contours. The flanged steel pipe was fabricated and factory coated, and shipped to the site by truck in 40 foot lengths.

Steel was chosen for this section because of the strength and the ability to fabricate a single large diameter pipe which reduced trench width and the associated excavation, bedding and backfill expenses. Steel pipe allowed designers to transmit pipe tensile loads into a concrete and sheet pile seismic anchor system (discussed later).

This portion of the outfall was installed using cut and cover from the shoreline to an existing grade depth of -4 feet MLLW. Sheet pile shoring was used (as dictated by permits) to limit the trench width in the tidal zone and a sensitive eelgrass bed.

Figure A – 84" flanged steel pipe section being installed in the shored trench.

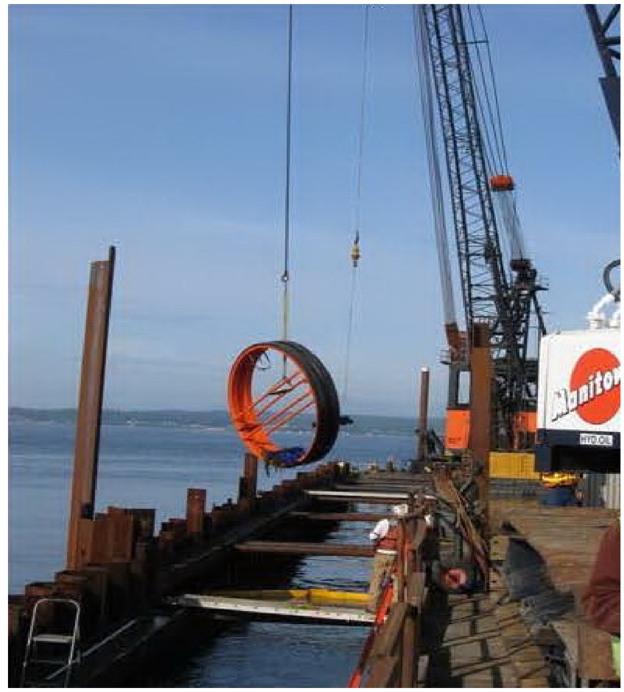

Figure B – Trench shoring and work platform. Joint testing jig is about to go in the water.

In addition to the corrosion protection provided by the pipe coating and lining, the flanged pipe and all the bolts were spot welded to make the entire string electrically continuous. The pipe was connected to an impressed current cathodic protection system located on shore.

Triton elected to construct a temporary work platform along this section of the outfall (see Figure B). The platform had not been included in the permits obtained by WTD. Permit applications and review by a variety of agencies was required prior to the start of construction.

The remainder of the outfall consisted of twin parallel 63-inch diameter, mostly bottom laid, HDPE (5,018 feet & 4,768 feet) placed using controlled submergence which is described later in this paper. HDPE was chosen because of the flexibility and strength of the pipe which would be placed on a slope with the potential for slides during seismic events. The pipe sections are fused together making a continuous pipe. This made it possible to fabricate at a remote location and tow the floating pipe strings to the site. The pipe size used was the largest available in North America for solid wal HDPE.

The first 494 feet of the HDPE pipes were also installed using cut and cover with 237 feet shored and 257 feet side sloped. Shoring, excavation and backfill were done from a crane on a barge. The remaining HDPE was bottom laid with concrete or coated ductile iron collars to provide differing degrees of ballast depending on the slope conditions.

Since HDPE has a density slightly less than seawater and when in operation the outfall is filled with less dense fresh water the outfall pipe assembly is naturally buoyant in Puget Sound and it is necessary to ballast the pipe to keep it on the bottom. Concrete collars cast in two halves were installed every 7.5 feet through the buried portion of the pipe and every 15 feet for the remainder. Three types of concrete collars were designed depending on the desired reaction (see Figures C & D).

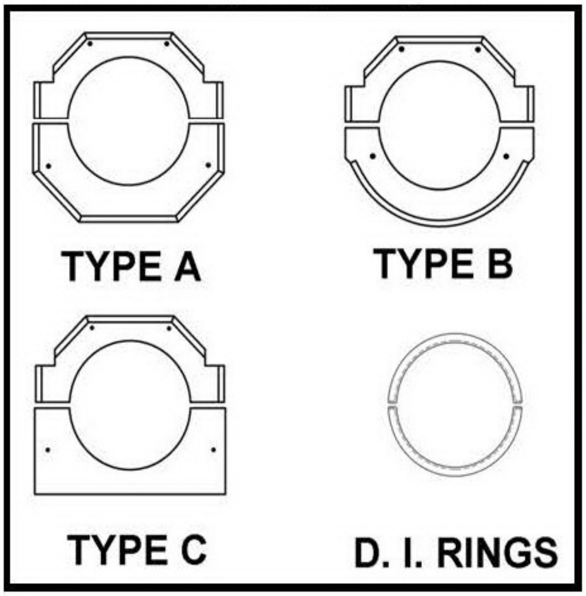

Figure C – Pipeline collar shapes

Figure D – Pipeline collars in storage

In the buried section the collars were designed to mobilize the weight of the adjacent soil as part of the tensile anchorage. With the 7.5 foot spacing, the assembled pipe weighs 30% more than seawater. The next section along the slope was bottom laid and the collars were designed to deflect the weight of soil in the event of a submarine landslide. A 15 foot spacing of the collars in this section gave the pipe a unit weight 15% greater than seawater. The last section of concrete collars was designed to provide a stable base so the diffusers would remain oriented as the modeling had required. Collar spacing here was also 15 feet on center and the resulting outfall pipe was 15% heavier than seawater.

The top of the collars were shaped the same. The bottoms were different and were built according to the location on the alignment and desired effect. They were cast locally with epoxy coated reinforcing to resist corrosion. The two halves were held together around the HDPE pipe using silicon bronze hardware which was selected for long lasting corrosion resistance in saltwater. Each bolt also has anodes for additional corrosion protection. The bolts were tensioned with rubber blocks between the concrete collar and the washer and nut as shown in Figure E. The rubber blocks compensated for thermal expansion and contraction of the HDPE pipe always keeping the anchor bolts in tension and securing the concrete collar to the pipe. Bolt tension was calibrated to ensure that weights would not slip during deployment. Testing the weights resistance to slippage was accomplished using a mockup and stacking weights on top of the attached weight as shown in Figure F.

Figure E – Anchor bolt, rubber compensator block, FRP washer and nut after tensioning.	Figure F – Testing the sliding resistance of a collar. Notice the gap between the two halves of the secured collar.

A profile of the outfall alignment is shown in Figure G. Starting on shore the outfall pipelines are in a trench which day lighted at -80 feet MLLW. From this point out they are laid on the bottom down a fairly steep slope of marine sediment overlying till. The pipelines bottom out at about -660 feet MLLW before rising gently to a flat area at around -600 feet MLLW where the diffusers are located. This site was chosen because of the large area with similar elevation. Minimal elevation difference between the orifices along the diffuser was needed to minimize differential head and flow between the orifices. Washington State Department of Ecology criteria required no more than a 20% difference in flow between the diffusers.

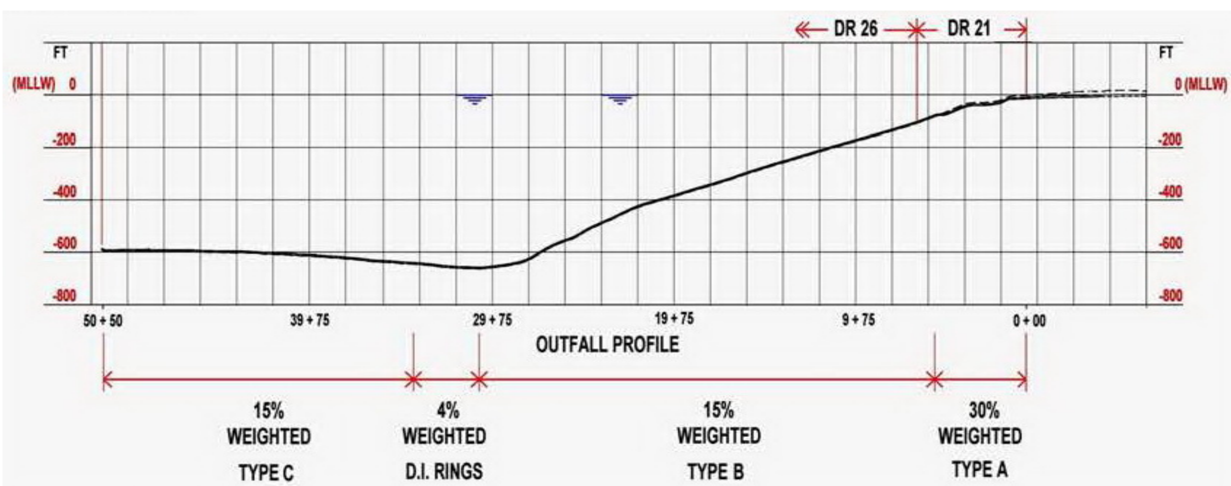

Figure G – Marine Outfall Profile

Several collars through the lower portion of the "U" shaped profile were made from polyurethane coated ductile iron and were designed to provide minimal negative buoyancy to the pipe (4%> than seawater). In a submarine landslide the down slope force on the pipes from sliding soil tensions the pipe and the HDPE pipe will stretch.

The outfall in this section is lighter than the soil/seawater slurry of the landslide and the minimal resistance of the ductile iron collars will allow the pipe to move laterally as the pipe lengthens and then return to the original alignment when the tension forces of the sliding soil subside. Imagine what happens when you push a rope laid that is laid out straight. It curves horizontally if unrestrained and then straightens out when tension is applied.

The anticipated soil force on the HDPE outfall pipes from the design seismic event is in excess of 1,000,000 pounds. The HDPE outfall pipes were laid on the bottom and not anchored to the soil. Therefore the resulting tension force on the pipe needed to be resisted at the top end of the slope. This was done at the end of the steel outfall pipe through a 60 foot long anchor constructed of permanent sheetpile shoring backfilled around the pipe with reinforced tremie placed concrete. The shoring and reinforcing were spot welded and connected to an impressed current corrosion prevention system. The shoring was cut off 4 feet below grade prior to final backfill so the anchor system remains buried.

As previously noted, each outfall pipe includes 250-foot long diffuser sections which are staggered to provide a 500 foot mixing zone. The diffuser orifices are 6” open HPDE pipes fused to the 63” pipe. The orifices are set 30^o off the vertical and alternate sides to aide in mixing. In order to be placed by controlled submergence the outfall pipes need to be under pressure. Gasketed steel plates capped the diffuser orifices. Each plate was held in place with a single bolt that can be removed by a remote operated vehicle (ROV) prior to the start of conveyance system operation (see Figure H).

The end of each diffuser has a coated steel access gate and a dual purpose structure that served as a float during deployment and a stabilizing base when the pipe is on the floor of the Sound. The end gate is shown in Figure I.

Figure H – Diffuser and cap with surrounding HDPE shroud.

Figure I – End gate structure as the pipe is placed into the river.

A key to accomplishing the aggressive schedule was the early focus of the designers on the primary pipe materials and the shoring. Moving those elements along to final design allowed Triton to order these long lead items for spring 2008 delivery.

Construction

The primary construction site was at Point Wells on Puget Sound (see Figure J). The site was heavily used by the existing petroleum transfer and storage facility, and by the contractor for the fourth tunnel segment. Very little room was available for the Marine Outfall contractor to set up shop and store materials. Work at the site focused on activities that could not be done elsewhere such as shoring, trench excavation and backfill and installation of the steel pipe portion of the outfall and seismic anchor.

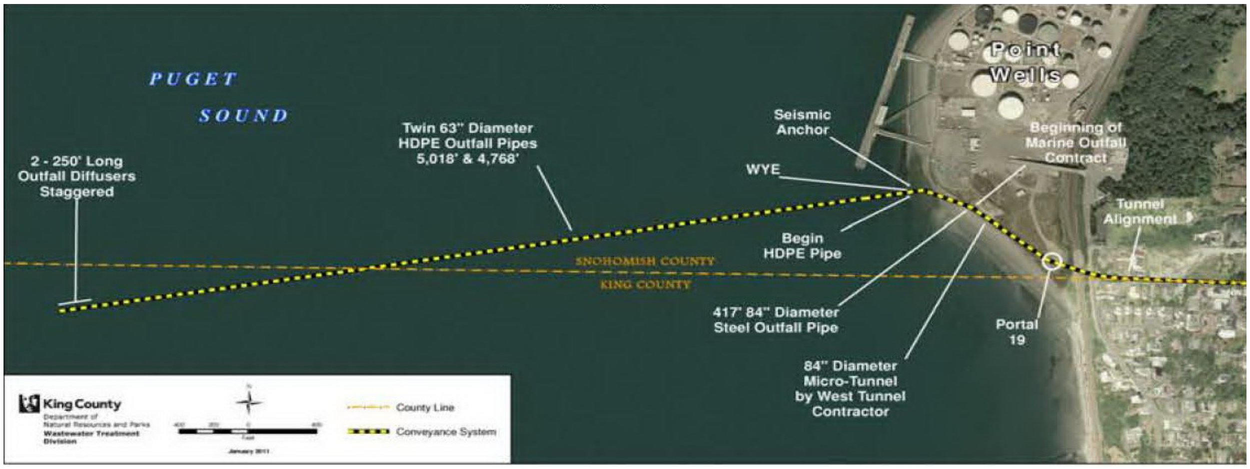

Figure J – Outfall Plan

A separate site along the Snohomish River in Everett Washington, 17 water miles to the north, was used as the location for receiving the HDPE pipe and concrete weights, and assembling the pipe strings. Pipe was supplied by KWH from their factory in Saskatoon Saskatchewan Canada. Shipped by rail and truck in 60 foot lengths the pipe was easily handled by a forklift on site (see Figure K). The pipe sections were fused together and collars attached on land near the river's edge (see Figures L & M). A crane then lifted the newest section of assembled pipe and pushed it into the river where it was moored. See Figure N for the location of the yards and Figure O for a view of HDPE pipe assembly area and river storage of the assembled pipe strings.

Figure K – 63" diameter by 60 foot long HDPE sections being moved around the assembly yard.

Figure L – HDPE fusion machine

Figure M – Attaching concrete collars

Shoring and excavation work at Point Wells began in early June 2008 as allowed by permits. Triton was restricted in how far out the shoring and excavation could proceed according to migration and spawning dates for the various fisheries that inhabited the shoreline. Working with Washington Department of Fish and Wildlife, some restrictions were adjusted to allow limited work to continue in an expedited manor. This resulted from very close monitoring of construction activities, minimizing turbidity and building confidence in the capability to maintain a clean worksite in the tidelands.

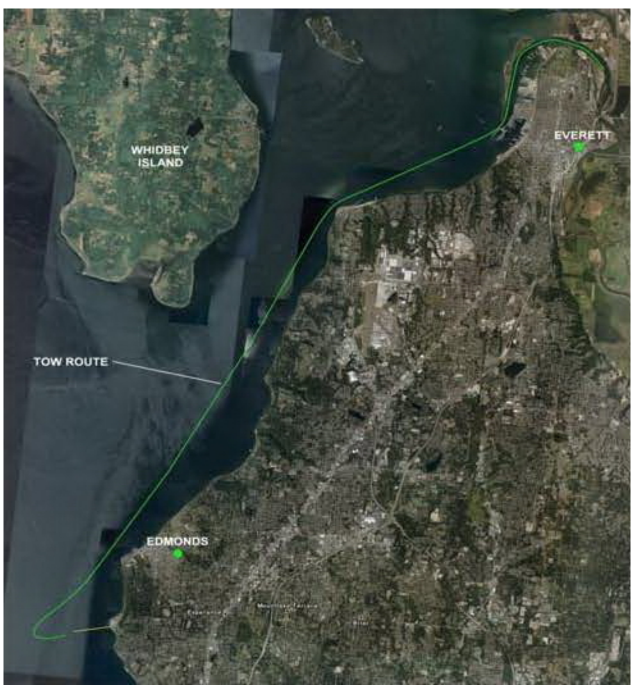

Figure N - Construction work sites

Figure O - Everett yard & river pipe storage

The top two feet of the trench excavation was saved to be place back on top of the trench backfill. Even if none of the biological material in this soil layer was viable when replaced, it was believed that it would provide a better substrate for new growth than deeper soils or clean fill. Excavation from the work platform was segregated and stockpiled on shore while excavation done by the crane on the barge was placed on muck barges and temporarily towed off-site.

The geology of the area indicated that Point Wells was once further above sea level that it is currently. Since the area was a gathering point for native peoples, it was believed that on-shore, tidal and some sub-tidal soil could contain cultural artifacts. Excavation from the work platform down to an elevation of -9 feet MLLW was examined as it was dumped into the soil piles. An archeologist was hired by the County to perform this examination. Nothing was discovered in the excavated soil.

The steel pipe portion of the outfall, including the seismic anchor, was completed in early September of 2008. Deployment of the first of the two HPDE pipe strings (the south outfall) was scheduled for September 8th (a Monday) using controlled submergence. In this process the pipe, sealed, air-filled and pressurized, is floating with water surface at about the spring line. The shore end of the pipe is connected to the steel pipe and the HDPE pipe is gradually flooded, changing it from positive buoyancy to negative and allowing it to sink in place.

The pipe string is kept under tension to control the alignment and the vertical bending radius of the HDPE (see Figure P). Tracking the last pipe collar at the surface and the last one to touch the bottom gives the contractor the geometry of the bend and guides the amount of tension applied to the pipe. A tensiometer on the pulling cable provides direct readout for adjustments of pull by the barge tugs. Pressure in the pipe is maintained by a balance of the pumping water rate at the shore end, and air relief at the end gate structure through hoses to the barge. Survey instruments set up on the work platform allow directions to be given to the pipe tugs to keep the pipe on alignment as it goes went down and adjust for tidal currents and wind.

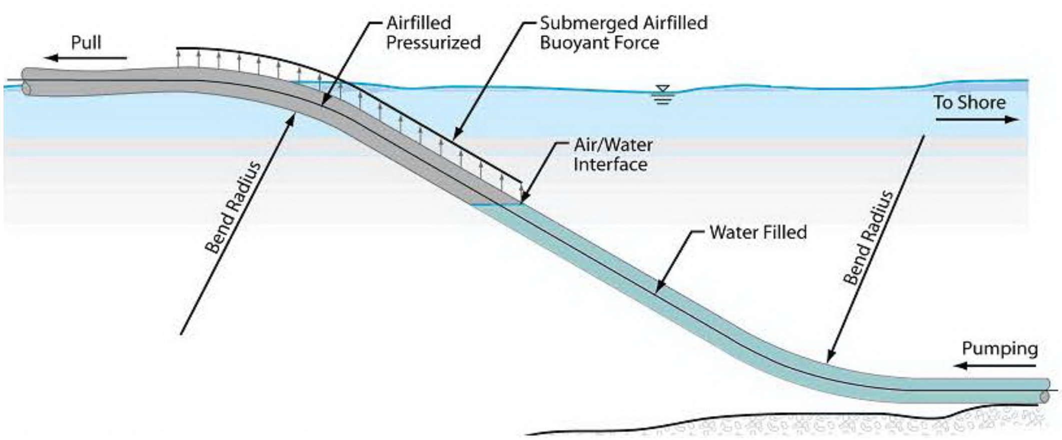

Figure P – Controlled Submergence

The pipe needed to be towed from the assembly and mooring location in the Snohomish River out to Port Gardner and then down the Sound to Point Wells. This journey would take a full day and was planned to start on Sunday early afternoon. Weather forecasts on Sunday, however, indicated a potential for wind conditions on Monday that might exceed the limit for deployment so the Sunday tow was scrubbed. The weather forecasts improved overnight and towing began on Monday as the mooring lines were disconnected and several tugs eased the 5,018 foot long south outfall pipe under bridges, around river bends and out into open water. Towing the pipe string (at a speed of 1 -2 knots) was a long-haul event requiring multiple tugs.

Early on Tuesday morning as the sun rose, the upstream end of the pipe was pulled into place and the pumping spool was connected to the wye at the end of the steel outfall pipe (see Figure Q).

After the outboard end was connected to the winch on the pulling barge, twin tugs began to pull on the barge and apply the needed pipe tension. On the work platform the pumps were turned on and the air filled HDPE portion of the pipe was slowly filled, pulling the pipe below the surface (see Figures R – T).

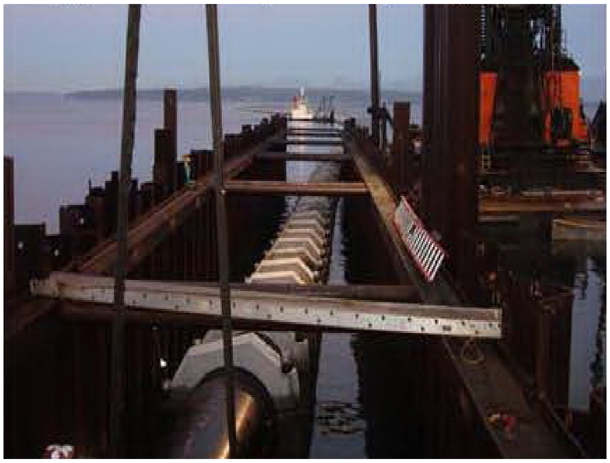

Figure Q – South HDPE outfall pipe as it is pulled into the shoring for attachment to the wye and start of controlled submergence

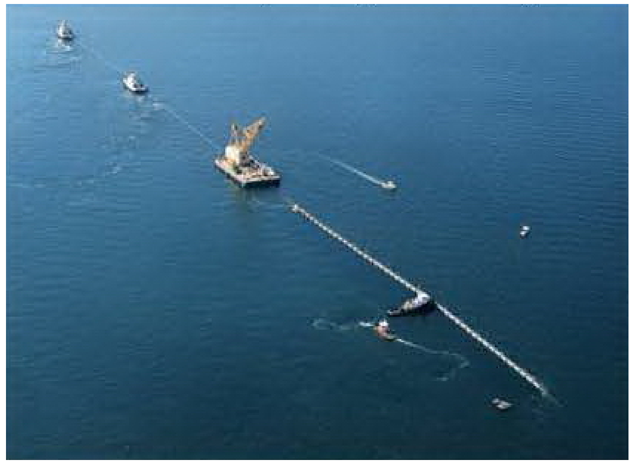

Figure R – Pulling barge in center kept on line and at proper tension by the twin tugs in the upper left. Remaining boats used to keep pipe on alignment.

Figure S – On the water view of the outfall pipe, pulling barge and tugs.

Figure T – View from the pulling barge of the end gate and diffuser section.

The process took all day and into the evening before the pipe was full of water and the end gate slipped under the surface. As the winch played out to lower the remaining pipe to the bottom of the Sound it stopped with the end gate at about -90 feet so divers could disconnect the air hoses and undo most of the bolts on the end gate. When this was complete the pipe was lowered the rest of the way to the bottom, the pulling cable disconnected remotely and the outfall was in place.

The second deployment was set for Thursday to give the crew a day's rest. Towing of the north pipe started on Tuesday and it was held in place up the coast until the crews were ready early Thursday morning to repeat the process. At the end of the day Thursday both outfall pipes were in place and the most critical week of the project was complete.

Backfilling the trench for the pipe began as soon it was in place. As the backfilling was completed the shoring and work platform were removed back to the micro-tunnel connection point which was the last section of pipe to be installed. All work below in the tidal zone was complete before the permit deadline of October 15th. The remaining on-shore pipe installation and backfill work continued until mid November when the outfall pipe was hydraulically connected to the micro-tunnel, the trench backfilled and shoring removed. Beach restoration followed.

The final element of the project was installation of the impressed current cathodic protection system for the steel pipe and seismic anchor. Drilling for the anode well started in December and the system went active in late December (see Figure U).

Figure U – Anode well drilling and anode placement.

Figure V – Eelgrass bed after replanting.

The outfall was installed with caps on all the diffusers. These caps are designed to be removed by ROV with the turn of a nut on the caps. The caps kept air in the pipe during deployment and were left in place to prevent sedimentation and marine growth from becoming an issue before the outfall was put in use. Prior to cap removal in 2012 the outfall will be visually inspected by ROV and the diffusers will be surveyed to check for settlement. Given the nearly four years that will transpire after pipe deployment, most of the settlement is expected to have taken place. The designers provided plans for diffuser extensions if any of the ports lie outside of the allowable two foot elevation band required for equal flow from each diffuser. The survey and cap removal work will be done under a separate contract rather than tagging the design builder with the task which has allowed their contract to be closed out.

The outfall alignment went through a band of eelgrass in the subtidal zone. This is good habitat for marine life and WTD committed to harvesting, propagating and replanting the eelgrass after construction. Eelgrass was harvested by Battelle Labs and propagated at their labs in Sequim on the Olympic Peninsula a short distance from the project site. The replanting took place in the spring of 2009 and based on ROV and diver surveys the replanting was very successful (see Figure V).

Change Orders and Construction Costs

Triton Marine's proposed cost for design and construction was $27,599,800. Adding the incentives and materials escalation amount gives a baseline project cost of $29,099,800. The overall project cost was $29,789,272.

Conclusion

The project was a huge success for the WTD and design-build team. It was finished 22 months ahead of the required date for 8 million dollars (20%) less than engineer's estimate. The project won 10 regional, national and international peer awards including Engineering News Record's Best of the Best Projects for 2009 in the Civil/Public Works category.

The success of this project lies in the people involved from all parties and at all levels. Sticking to an aggressive schedule helped keep Triton Marine and their subcontractors within their budgets. WTD proved to be a willing partner in the process and worked to expedite design and submittal reviews, inspections and other processes. All parties to the process approached the inevitable road blocks with open minds and a search for solutions first.

Detailed planning and redundant equipment for critical tasks assured continuous operation with little or no lost time. Separate plans and coordination meetings for each work activity kept all parties in the know and minimized conflict.

About the authors:

Stephen P. Haskell served as Triton Marine's Project Manager for the Brightwater Marine Outfall Design-Build Project. He is co-founder and partner at Triton Marine and has 35 years of industry experience with a specialty in marine, pipeline, and underwater construction. Jon B. Archer, P.E. is Vice President at Triton Marine and served as Project Sponsor. Jeffrey A. Lundt, P.E. served as WTD's Project Manager and Construction Representative.