

Digging in AT DUGWAY

As the TBM was poised to begin its journey along the Dugway Storage Tunnel in Ohio, we caught up with the owner, contractor and designer to find out about progress so far. By Kristina Smith.



FIGURE 1 – Map of the whole system



The Dugway team in front of the Herrenknecht cutterhead

THERE ARE A lot of similarities between Ohio's Euclid Creek Tunnel and the Dugway Storage Tunnel, not least because they feed the same deep pump station. They are the same diameter, constructed through the same geology, with segments from the same supplier and they will even have been bored using the same Herrenknecht TBM and much of the same labor force and subcontractors.

With the Euclid Creek Tunnel successfully completed, it should be smooth sailing then for contractor Impregilo-Salini-Healy JV, which is around 40% through the construction of the Dugway. But of course, where Mother Earth is involved in the proceedings, there is no such thing as smooth sailing. When the TBM begins its (2.8 mile) 4.5km journey at the end of April, it will be leaving 10 months later than initially planned due to difficulties in sinking the starter shaft.

"Most of the challenges and difficulties we were facing we have overcome," says Jim Kabat, project manager for the Salini-Impregilo-Healy JV. "Now we are moving into the final phase which is mining the tunnel. There are some uncertainties related to that, but everything else has been dealt with."

Dugway is the second of eight tunnel

View up Shaft DST8



PROJECT CLEAN LAKE TUNNELS

Tunnel Name	Length (ft)	Width (ft)	Bid Year	Status
Euclid Creek Tunnel	18,000	24	2011	Complete - awaiting flow input
Dugway Storage Tunnel	15,000	24	2015	40% Constructed
Doan Valley Storage Tunnel	10,000	18	2017	Bidding (opened 14 March 2017
	3,000	8.5		
	6,400	8.5		
Westerly Main Storage Tunnel	10,000	25	2018	60% Designed - Bidding in Q4 2017
Shoreline Storage Tunnel	15,600	21	2021	Advanced Planned - Design NTP in 2018
Shoreline Consolidation Sewer	11,700	9.5	2022	Advanced Planned - Design NTP in 2020
Southerly Storage Tunnel	18,350	23	2024	Advanced Planned - Design NTP in 2021
Big Creek Storage Tunnel	22,450	18	2029	Advanced Planned - Design NTP in 2027

Source: NEORSD

projects which make up NEORSD's \$3bn, 25-year Project Clean Lake program which began in 2011. The program will allow the District to meet Clean Water Act regulations by creating a network of storage tunnels to hold the combined flows after rainfall events and deep tunnel dewatering pump stations to convey the flows to the recently upgraded wastewater treatment plant; Euclid Creek and Dugway between them will be capable of storing 117M gallons of wastewater.

Currently when combined sewers fill up following rainfall, they overflow either di-

rectly into Lake Erie or one of the many creeks that terminate in Lake Erie. An estimated 4.5 billion gallons of combined sewer overflow flows into the Great Lake each year, harming the environment and sometimes making the beaches unusable for a while. Once Project Clean Lake is complete, the annual volume will be reduced to less than 500M gallons.

NEORSD awarded the \$153.4M contract for Dugway to the Salini-Impregilo- Healy JV in November 2014. The winning bid was significantly below the Engineer's estimate of \$179M. McNally-Kiewit JV, who con-

structed the Euclid Creek Tunnel put in a bid of \$170M.

The project was procured under a traditional form of contract: "We chose design-bid-build, based on the governing rules of our organization, and the amount of geotechnical, flow monitoring, property acquisition and hydraulic design work required," says Doug Lopata of NEORSD. "The biggest design challenges were meeting our consent decree dates and CSO requirements and avoiding large claims by identifying and investigating all the major risk items."

Lessons learned from the Euclid Creek



Looking down the Starter Shaft

Tunnel project included the “early Identification of utilities to allow for coordination for relocation or avoidance if possible,” says Lopata.

Story of the shafts

As well the 24ft (7.3m) ID tunnel itself, Salini-Impregilo-Healy’s package includes the construction of six shafts. At either end of the alignment are two 50ft (15m)-diameter shafts for launching and retrieving the TBM. Between those two points are four further 30ft (9m)-diameter shafts that will convey the flows from existing CSOs into the new tunnel via baffle drop structures; these shafts connect to the main tunnel via adits of varying lengths (see plan).

The three shafts at the Northern end of the alignment are all just over 200ft (60m) deep, whereas those towards the Southern end are deeper, up to 250ft (76m) for the retrieval shaft. However, whereas at the first shaft location (DST-1), there is 95ft (29m) of soft ground above the shale rock, at the most Southerly shaft (DST-8) there is just 15ft (5m).

The soft ground, below a layer of fill material, is made up mostly of clay, silty clay and clayey silt. However, within this are bands of material containing silt, sandy silty, gravelly silt and clayey silt, which behave differently to the main body of material.

Triad Engineering and Contracting constructed three of the four intermediate shafts using steel liner plates and ribs through the soft ground, switching to a vertical boring machine to excavate the rock. The fourth shaft (DST-4) required a deep secant piled wall to provide the temporary support. Nicholson Construction installed

the secant shaft, together with combined continuous flight auger (CFA) piles and cased secant pile walls to form gate structures around 50ft (15m) deep next to shafts DST-4 and DST-5 (see box).

Marra Services constructed shaft DST-8, where there was little soft ground, using excavators equipped with large hydraulic breakers. “It was a slow method, but a proven method and it worked very well,” says Kabat.

By mid-March, two shafts had their final linings in place and final linings for three more were under construction. Triad had excavated all the adits, which range in length from 10ft (3m) to 800ft (243m), using a simple 12ft (3.7m) TBM. All have

finished a short distance from the line of the main tunnel, with the breakthroughs to be made after the main tunnel has been mined.

While construction of most of the shafts went reasonably well, the launch shaft was the one that caused problems. The plan had been to excavate the soil portion using steel ribs and liner plate for support, in conjunction with a vacuum-assisted dewatering system. The dewatering system was targeted to a band of cohesionless silt containing pressurized groundwater.

Salini-Impregilo-Healy attempted several methods of ground water control at the starter shaft, including installing internal vacuum wells and external grouting including jet grouting and permeation grouting. When none of these were successful, the contractor turned to ground freezing.

Geotechnical specialist Moretrench installed a row of refrigeration pipes around the perimeter of the shaft at around 3ft (1m) centres into the bedrock. One concern was that the pressure exerted by the expanded soil due to ground-freezing would cause problems with the steel ribs and liner plates already installed to support the shaft. Calculations revealed that some of the lower ribs would be loaded beyond their design capacity.

“We did some modifications to the ribs in places to strengthen them and we also installed strain gauges on the ribs and load cells behind the liner plates to monitor what was happening during the ground freezing,” says Kabat. “Once we had excavated through the water bearing silt materials, we poured a concrete collar around that area to ensure that everything would remain stable.”

Once through the soil, Salini-Impregilo-



Shotcrete works at DST1

COMBINATION OF PRAD SENSOR AND GOOGLE SKETCHUP ASSURES VERTICALITY OF DEEP PILES



Complex works at Shaft DST-4



Ground conditions at one of the shaft locations, DST-4, called for a different system of temporary support. Rather than the steel lagging and ribs, the designers specified a cased secant piled wall.

With a high water table, and piles that had to extend over 120ft (37m) before they reached the bedrock, achieving the required verticality was important.

"Nearer the bottom of the shaft there was a 10 to 15 foot sand layer and the water table was 12 feet down from the surface, so we had 100 feet of water head in that sand layer," says John Wise, vice president, operations, at piling works contractor Nicholson Construction. "Had we had any deviation between the piles, we would have had big problems with inflow of water."

The required verticality on the cased secant piles was 0.50% which is standard for this type of pile; secant piles were selected because they achieve better verticality than continuous flight auger (CFA) piles. Each of the secondary piles has three inch tubes cast into them so that grout could be injected at the pile/rock interface if there were any leaks observed— though these have not been used.

Nicholson employed a PRAD sensor from specialist supplier Jean Lutz which, attaches to the casing and tracks the average deviation of the piles, communicating via bluetooth technology. These results were confirmed with a traditional Kodex survey. Nicholson project manager Eugene Mirsky

took the output from the PRAD and fed it into Google Sketchup to get a 3D image of exactly where the piles were.

"We started doing the 3D drawings on our last tunnel project in Miami," says Mirsky. "It's a good way of visualizing what is actually out on site, in order to report to the client or to find out if there are any potential issues. If we do all the checking before we excavate, we can remediate in advance." In this case, the 3D sketch told Nicholson that all was well.

The other vital element of deep piles is getting the mix right. "When you are pouring concrete to 122 feet, you really have to pay attention and design your concrete mix so that it does not bleed," says Wise. "A concrete bleeding under its own weight can create all sorts of problems."

As well as a thorough mix-design and testing process before the start on site, Nicholson carried out Bauer Bleed tests and slump tests before any concrete was pumped into the casings. Specialist admixtures helped reduce the bleed of the 4000psi concrete.

Because of the depth of the 4ft (1200mm)-diameter piles, Nicholson employed an oscillator rather than the piling rig to pull out the casings. This worked well, but did add to the congestion of the limited working area.

"The biggest challenges on this project were sequencing and logistics," says Mirsky. "It's in an urban environment, so there wasn't much room for storage, especially

when the casings start to stack up or you've got six concrete trucks on site. It was difficult to maneuver three pieces of equipment – the rig, the crane and the oscillator – on one tight site."

The condition of the working platform also proved difficult, says Wise. The ground was wet and the specification called for the use of slippery drilling polymer in the piles. "We had a lot of rain, we were drilling through clay material and using polymer, so things were messy," says Wise. "We had to spend a lot of time maintaining our working platform to keep it in a safe condition."

As well as the shaft, which will house a baffle drop structure to carry wastewater flows down to the main tunnel, Nicholson also constructed two gate structures at the DST-4 and DST-5 shaft locations that regulate existing flows to the baffle shaft. These are much shallower structures, around 65 to 70 feet (19.8 - 21.3m) deep, constructed with 3.2ft (990mm)-diameter CFA primary piles and 2.9ft (880mm) cased secondary piles.

Nicholson carried out the work in the second half of last year, completing all the piling by the third week in December. Now that the shaft has been fully excavated, and the secondary lining is well underway, it's safe to say that Nicholson's 3D prediction of a leak free shaft was correct.

"They did a good job," confirms Salini-Impregilo-Healy project manager Jim Kabat. "As far as I am concerned, those piles were sealed."

Healy used conventional drill and blast to excavate down to 6 feet (2m) below the springline of the tunnel. The construction of the starter and tail tunnel followed.

"We excavated the top heading for 130 feet in each direction for the starter and tail tunnels and then blasted the bench down to the final invert level of the tunnel," ex-

plains Kabat.

TBM modifications

Having purchased the 27ft (8.2m)-diameter single shield Herrenknecht machine from McNally-Keiwi, Salini-Impregilo-Healy refurbished it on the job site. As well as a general once-over, the contractor made a few

minor modifications which it hopes will aid the smooth-running of the tunneling process.

An extra grease pump was added to supply grease to gaps between the brush seals whose job it is to prevent grout running into the machine. "We want to make sure we can fill the voids with grease," says Kabat.



Above: The TBM in the launch area
Left: The big TBM lift

"We understand there was some grout coming into the machine from the tunnel (on Euclid Creek), so we want to prevent that."

Other changes include new components such as the grout pump. "There are a lot of little things that we hope will increase reliability and make things work better," says Kabat.

A modification aimed to assist with the quality of the ring build is the addition of guide rods to the radial joints. "Some believe that this improves the chances for improved ring build quality," says Mike Vitale, tunnel designer for the MWH/Mott MacDonald JV.

"We are comfortable with guide rods because we've used them on our last two projects, one in DC and one in Portland," says Kabat. "It does require you to be a little bit more careful as you are installing the keystone piece because you have got the guide rod sticking out as you are setting the piece, but it does help hold the shape."

The guide rods are the only change to the segments, which are reinforced with Dramix steel fibers from Bekaert-Maccaferri and supplied by CSI Hanson (now Forterra). Attention to ring-build quality is more important with fiber reinforcement versus traditional rebar, says Vitale:

"Without a rebar cage, the segments are much more susceptible to cracking due to poor ring build. Attention to ring build is critical. If the build starts to suffer, and/or the ring is allowed to 'squat', cracking can occur. If the leading face of the ring goes out of plane, tension cracks become apparent on the stones at all high spots on the leading face of the ring."

"I have seen this in many fiber-reinforced segment tunnels and it is easily explainable, but people tend to deny the cause or blame it on other unrelated factors. When this occurs, careful and gradual packing of the joints can help correct the planarity of the

leading edge of the ring, but ultimately, good ring build and prevention of squatting is the best cure."

The most important factor in preventing ovaling or squatting of the ring is getting the grout right. As this is a rock tunnel, the void outside the segments must be immediately filled with rapid-gel grout, otherwise the springline moves outward and the crown comes down, resulting in the fore-mentioned cracking and 'out of plane' condition. The Euclid Creek Tunnel proved that it was possible to grout a segmental lining through the tail-skin of an open-faced rock TBM, which hadn't been done before.

"Using an open shield in a rock tunnel made the set time and strength of the grout critically important. We knew that going in, but we were able to fine-tune these properties with the contractor by modifying the mix design during construction," says Vitale. "Quality assurance and quality control vigilance was required. Also, McNally-Kiewit found that the mix design itself was not enough: the order the materials were placed in the batch as well as mixing time and mixing equipment all played a role in the success of the grout mix and placement."

BASF, who supplied the grout and specialist input on the Euclid Creek Tunnel, is doing the same on the Dugway. However Salini-Impregilo-Healy has not chosen to copy exactly the mix used on the previous job.

"We went through six months of testing to confirm gel times, set times, flowability characteristics, all of the things you need to get right," says Kabat. "The biggest thing is to ensure we had flowability to fill the void completely as the machine is moving forward, but also to get the initial set."

When asked what the biggest remaining uncertainty is, Kabat pinpoints the grout. "We will need to do some fine tuning to ensure that the operation runs smoothly,"

he says. "The grout is the key component in this whole system. We will have the grouting consultants on site to make any required modifications."

The other potential risk is methane. This ground is classed as potentially gassy. "We have encountered gas in all the shafts; one was shut down for around a month to allow it to vent," says Kabat.

In the tunnel itself, the ventilation system has been designed to deal with any potential gas. "We anticipate that if we do hit any gas, the ventilation system will dispense it so quickly that we may not even be aware of it," says Kabat.

Should the miners encounter a concentration of gas above 20% of the explosion limit, everything but the ventilation system will shut down; there is contingency in the contract for this.

Big lifts

Having refurbished and assembled the TBM on the surface, Salini-Impregilo-Healy decided that it made sense to lower the machine down in as few sections as possible. Ohio firm PSC Crane & Rigging is carrying out the lifting and assembly process using a gantry system with strand jacks.

PSC lifted down the 45-tonne main body in one piece and the entire 170-tonne cutter head. The contractor is using a system of slides to move the main body of the machine backwards and forwards while it installs the tail shield and ring erector.

As NATJ went to press, tunneling was due to start on 24 April. After an initial mining run of around 50 feet (15m) additional backup will be installed; another stop at around 200 feet (60m) in will allow the full backup to be put in place. Muck will be carried along the tunnel and up to the surface by means of continuous horizontal and vertical conveyors, supplied by H+E Logistik.

Hole-through is expected at the end of January 2018. Compared to the Euclid Creek Tunnel which took 14 months to mine 5.5km, nine months for the 4.5km Dugway would be a speedier drive.