

# Bertha Rescue Shaft – SR99 Tunnel



Seattle Tunnel Partners (STP) started mining on Seattle's SR99 tunnel on July 30, 2013, working slowly through a 15 ft (4.6 m) thick fiber-reinforced concrete headwall. Once through the headwall, the machine would move through roughly 400 lineal ft (122 m) of jet grout-improved soil at a rate slightly over 6 ft (1.8 m) per day. It was anticipated that once through the improved area, Bertha—the world's largest tunnel boring machine—would move at a rate of 35 ft (10.7 m) per day. By the end of October 2013, Bertha had mined roughly 430 ft (131 m), averaging 4.73 ft (1.4 m) per day, and had begun mining within native soils. By the start of December 2013, tunneling reached the 800 ft (244 m) mark and Bertha averaged 12 ft (3.7 m) per day, achieving as much as 42 ft (12.8 m) of progress on some days. However, on December 6, 2013, Bertha began to stumble and all progress quickly came to a halt.

## Preliminary Investigation

Initial reports stated that an obstruction had stopped the machine in its tracks. Malcolm Drilling received an early morning call on Sunday, December 8, 2013, from STP to rapidly mobilize a Bauer BG-50 drill rig with crews to investigate what was hindering Bertha's progress. Malcolm's equipment and crews flew into action and were completely mobilized and operational by mid-week. The preliminary investigation involved installation of 10 deep



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dewatering wells to reduce the hydrostatic head within the ground around the machine and allow STP personnel to inspect the cutter head from within the shaft for presence of obstructions. By the close of December 2013, the wells were installed and the dewatering system was fully commissioned. STP crews were then able to inspect the cutter head and found small fragments of a steel pipe wrapped around the outside of the shield. The steel was apparently from an abandoned 10 in (0.25 m) diameter monitoring well casing previously installed by WSDOT (Washington State Department of Transportation) to monitor groundwater conditions for the design and planning of this very project. After the steel was cut out of the head and cleared from Bertha's path, she attempted to move forward but was only able to manage a slow crawl.

## Further Exploration

Following the preliminary investigation, the project team decided to install a series of 3.3 ft (1 m) diameter holes in front of the tunnel boring machine (TBM) cutter in an attempt to encounter, identify and remove the obstructions from the tunnel alignment. Remnants of a steel well casing were encountered, but no other indications of buried obstructions were identified.

A determination was made by STP to further investigate the material present at the front of the machine. A Davey Drill 725 duplex rotary drill was brought in to install eighteen 6 in (0.15 m) diameter probe holes 5 ft (1.5 m) on center across the face of the cutter head. In the 18 drilled holes, six obstructions were found between 55 ft to 78 ft (16.8 to 23.8 m) in depth. Small fragments of steel were found, and the drill casing could not advance any further. In an attempt to remove these obstructions, Malcolm was directed

to drill four shafts 5 ft (1.5 m) in diameter at these specific locations. The exploratory work was completed by the end of February 2014, yielding a clear path for the mining to continue northward. However, once Bertha was cleared to go, the immediate lack of progress pointed towards a larger issue. The machine's internal main bearing had been damaged during the initial drive. Removal and repair of the main bearing and seals would require a significant effort to create an access shaft large enough to take apart the entire cutter head assembly and gain access to Bertha's inner workings.

## Design of the Access Shaft

Malcolm was brought in as a constructability consultant to assist with designing and building a vertical access shaft. Many obstacles were overcome in designing an access shaft that would work with the primary project constraints: space and access. First, with the Puget Sound directly to the west and the aging twin-decked Highway 99 viaduct in use to the east, the jobsite had well-defined physical boundaries. Second, 5 ft (1.5 m) diameter tangent piles spaced on 6.5 ft (2 m) centers ran along both the east and west sides of the tunnel corridor. These piles were installed for settlement mitigation during tunneling and protection of the existing viaduct and seawall. Third, a very high water table, only 8 ft (2.4 m) below grade, needed to be cut off. Finally, schedule implications had to be considered when selecting the best path forward to get this very high-profile project back on track.

Malcolm had extensive experience with secant pile compression rings and suggested building a circular access shaft of overlapping secant piles that would allow excavation support and water cutoff without requiring anchoring of the walls in an area without space or easement for tiebacks. The initial design included 7 ft (2.1 m) diameter secant piles in a circular ring with jet grouting in between the existing tangent piles and behind the machine to provide water cutoff for internal maintenance of the machine, as well as controlling water where the machine entered the access shaft.

Designed by Brierley & Associates, this shoring option was put out to bid to select drilling contractors. Upon initial review of the design, Malcolm proposed an alternative option to install 3 m (9.8 ft) diameter drilled secant piles that required fewer shafts and reduced schedule. Once awarded the project, Malcolm worked closely with Brierley & Associates to finalize the design; considering equipment capabilities that could be utilized on the project.

## Jet Grouting and Small Diameter Shaft Installation

Construction started in May 2014 with the jet grouting work scope. Jet grouting between the existing tangent piles would have been difficult because of the large amount of concrete over-break due to the poor soil conditions; this was remedied with a Davey 725 drill that predrilled each hole with 6 in (0.15 m) tooling, clearing a space for the jet grout monitor and casing to reach the design depth. Upon completion of jet grouting along the tangent pile lines, efforts continued with construction of a transverse grout curtain, or cutoff wall, behind the TBM tail shield. The purpose of the cutoff wall was to encapsulate the TBM shield to manage groundwater during the critical phase of shaft breaking. Once jet grouting was complete, the drilled shaft crews mobilized to begin the next phase of work.



Aerial view of project site



To incorporate the existing tangent piles, small diameter (1 m or 3.28 ft) drilled shafts had to tie the tangent piles together to create a continuous outer wall and provide bearing for the cap beam to be placed on the east and west walls. The cap beams would later be used to carry the gantry crane to disassemble and repair Bertha. Work was completed with a Bauer BG-50 installing piles up to 130 ft (40 m) in depth. There was difficulty maintaining verticality, which was specified to be within 6 in over 130 ft (.15 m over 40 ft) as checked with a SoniCaliper. This was a result of the excess concrete over-break of the existing tangent piles, and field adjustments were made to accommodate these issues. The contractor had the ability to work with the designer's field representative onsite daily, which kept the project moving forward through the complex and schedule-critical work.

continuous wall to accept the various loading conditions present throughout the stages of work. However, continued dewatering, pressurizing of the TBM heading and work within the tunnel horizon caused soil loss over time. This was first apparent when a 550 cu yd (420.5 cu m) sinkhole appeared in front of Bertha shortly after she first halted. It was further evidenced by drilled shaft excavation removal of large quantities of TBM soil conditioner at horizontal distances greater than 80 ft (24.4 m) to the northeast of the TBM cutter face. A dynamic environment materially different than the rest of the project site had been created over time. Consequently, during drilled shaft construction, sinkholes manifested to existing grade, requiring evacuation of all heavy drilling equipment while the safety and stability of the working platform was assessed. After mass excavation and earthwork, a

large volume of quarry spalls was imported to the site to create a stable working platform, or mattress, to stage the drilling equipment. Subsequently, quarry spalls were carried deeper into the soil profile with each tooling penetration. As a result, the combined presence of a quarry spall mattress at grade along with quarry spalls throughout the vertical soil profile created an environment that was not conducive to jet grouting methods. As an alternative to jet grouting methods, Malcolm mobilized two Foremost DR-24 vertical drill rigs to drill and flush these confined spaces with high strength cement grout in order to treat the areas needed for the shoring design.



Installation of secant shafts

## Secant Shaft Installation and Remaining Jet Grouting

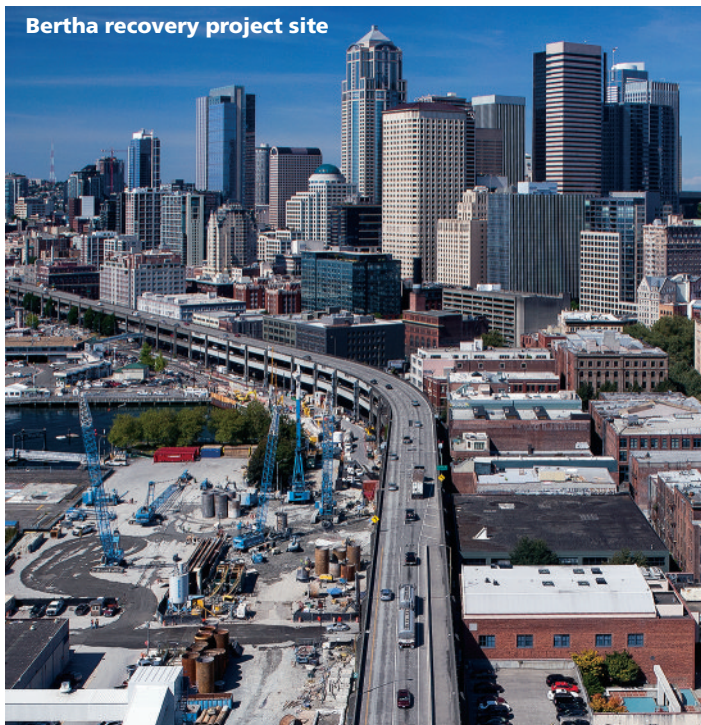
Following completion of the drilled shaft work with the Bauer BG-50, other equipment was mobilized to begin the large diameter shaft installations. Two spreads of equipment and crews began work in mid-June with Liebherr 885 dig cranes, Leffer 3.3 m oscillators and 3 m rotators to start the 8 ft (2.4 m) and 10 ft (3 m) diameter secant pile installations included in the final Brierley & Associates design. The work proved to be very difficult due to primary/secondary installation sequencing and the tight work areas of the job site. The greatest assets to the project were the two Leffer rotators, which installed the piles on location, maintained verticality and had a high rate of advancement compared to conventional casing oscillators. The shaft work was complete by the end of August, leaving the remaining grouting and dewatering work scopes to be constructed prior to shaft excavation.

Following installation of the drilled shafts, the remaining jet grouting scope consisted of treatment of localized soil between the pre-existing tangent piles and the newly installed drilled shafts. Located only on the east and west walls of the access shaft, these soils had to be remediated in order to create a complete and



Liebherr HS 895 crane installing large diameter shafts





Bertha recovery project site



Casing clamshell and oscillators

The work to create this access shaft required a substantial coordination effort and state-of-the-art foundation drilling equipment. There were numerous obstacles to overcome, typical of most emergency jobs, and real-time problem solving was essential to accomplish this monumental task. As of the writing of this article, the contractor, STP, is currently 40 ft (12.2 m) from the bottom of the excavation, which should be complete by the middle of January 2015. Mining the machine into the shaft is scheduled for the first quarter of 2015 to facilitate the final repair. Let's hope this is Bertha's first and only stop prior to finishing her run to the north side of Seattle.

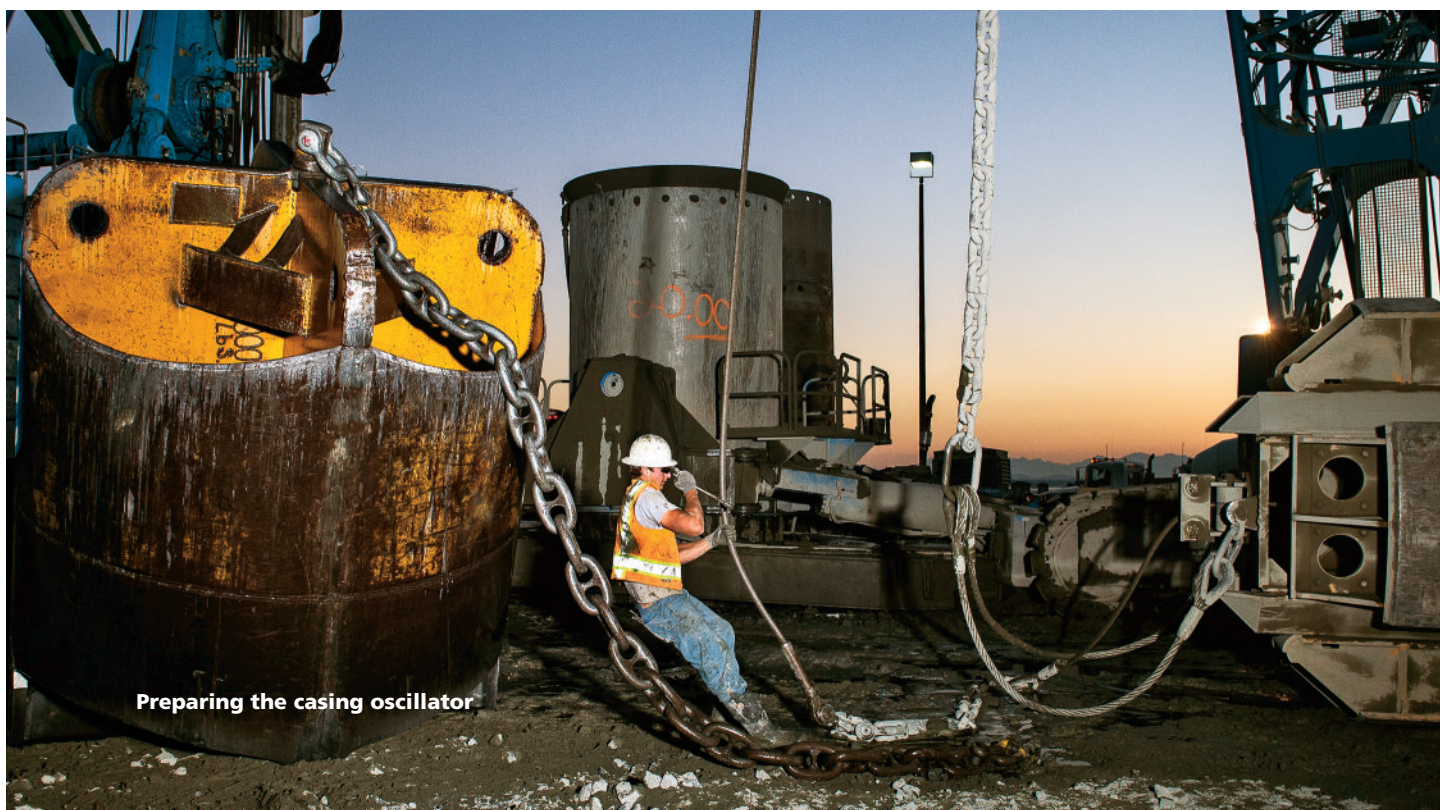
## Finalizing the Access Shaft

Once the grouting work was completed, the installation of the remaining dewatering wells and further geotechnical investigations and instrumentation commenced. The geotechnical investigation showed that the previously assumed silt plug in the bottom of the excavation actually had vertical silty sand seams, thereby raising concern that the shaft bottom had potential to heave. This new obstacle was overcome by enhancing the dewatering design. The original design consisted of eight wells 155 ft (47.2 m) in depth. To eliminate a potential bottom heave condition, eight more wells, four at 155 ft (47.2 m) deep and four more at 205 ft (62.5 m) deep, were added to depressurize the bottom plug for the final state of the excavation.

### Access Shaft Quantities

- 17 - 3.3 ft (1 m) diameter drilled shafts**
- 14 - 4.9 ft (1.5 m) drilled shafts**
- 16 - 8.2 ft (2.5 m) drilled shafts 130 ft (40 m) long**
- 25 - 9.8 ft (3 m) drilled shafts 130 ft (40 m) long**
- 6,400 ft (1951 m) of jet grouting columns**
- 16 - dewatering wells up to 205 ft (62.5 m) long**

*Photos for this article by Constructionimages.com*



Preparing the casing oscillator