North American Society for Trenchless Technology (NASTT)
No-Dig Show 2011

Washington, D.C.
March 27-31, 2011

Paper E-2-02

CONSTRUCTION OF THE BALCH CONSOLIDATION CONDUIT— SUCCESSFUL MICROTUNNELING IN VERY CHALLENGING SOIL CONDITIONS

Kimberlie Staheli, Ph.D., P.E.[1], Scott Clement, P.E.[2], Mark Hutchinson, P.E.[2], John Fowler[3]

[1] Staheli Trenchless Consultants, Seattle, WA
[2] City of Portland, Bureau of Environmental Services, Portland, OR
[3] J.W. Fowler, Inc., Dallas, OR

ABSTRACT: This paper presents the many challenges and lessons learned during construction of the Balch Consolidation Conduit Project in the City of Portland. The project includes microtunneling 6,800 feet (2,073 m) of 84-inch (2,134-mm) concrete pipe in five drives and 1,200 (366 m) feet of 54-inch (1,372-mm) concrete pipe in two drives. The project was completed with an alternative contract delivery method in which the Owner, Designer, and Contractor collaborated from the 60% design level forward to successfully complete the project.

The soils on the project were very challenging. Very soft soils would not support the weight of the machine, and ground modification was required along select portions of the alignment. This was accomplished by installing cutter soil mixing (CSM) panels on precisely designed intervals to support the machine. This is the first time CSM panels have been used for ground modification for microtunneling applications. Details of the machine's interaction with the CSM panels and the challenges associated with designing panel locations are presented.

The project included a 1,690-foot (515-m) drive through aggressive gravels that had proven to be very difficult to microtunnel on previous projects in the Portland area. During that drive, the machine hit a large object, presumed to be a boulder or rock shelf that caused the machine to deviate significantly from line and grade. Instead of digging a rescue shaft to retrieve the machine, the project team worked together to continue tunneling. This paper describes the machine reaction during the interaction with the large object and the necessary remedial measures that were put in place to allow microtunneling to continue.

1. INTRODUCTION

The Bureau of Environmental Services (BES) in Portland, Oregon, provides sewer and storm water collection services for the City of Portland and surrounding areas. The Balch Consolidation Conduit Project was the final piece in a massive combined sewer overflow (CSO) program. A detailed description of the project background can be found in Cozzi et al. (2011). During the design of the project, it became clear that microtunneling would be the preferred installation technique for the 84-inch pipeline because of the significant depths of installation, surficial landfills, and concerns about public disruption due to open cut. As subsurface conditions in the Portland area are known to have extensive amounts of fill that can contain a number of things not conducive to microtunneling, BES decided to use an alternative form of contracting. The contract for the Contractor consisted of two contracts. The first allowed the Contractor to participate in advancing the design from 60% construction documents to 100% construction documents. This allowed the contractor to work with the design team of Kennedy Jenks, Jossis

Consulting, Staheli Trenchless Consultants, and BES. This arrangement allowed the Design Team to incorporate its ideas and design around the Contractor's experience and talents. The second contract for construction was a fixed fee plus reimbursable cost contract. This contractual relationship allowed all parties to work collaboratively on all issues that arose during construction.

At the 60% design level, BES issued a Request for Qualifications, to which a number of contractors responded. After evaluation of the qualifications, three contractors were asked to prepare a proposal through a Request for Proposal (RFP). In the RFP the contractors were asked to evaluate the project and develop specific solutions to some of the challenges on the project, which included very soft soils and very aggressive open-graded gravels. An intense evaluation was conducted with BES and the Design Team, and the selection panel chose J.W. Fowler to construct the Balch Consolidation Conduit.

2. SCOPE OF PROJECT

The Balch Consolidation Conduit Project included 6,800 feet (2,073 m) of 84-inch (2,134-mm) microtunneling that was installed in five drives. It also contained a single drive of 54-inch (1,372 mm) microtunneling that was completed as a single drive. All pipe installed by microtunneling was reinforced concrete jacking pipe. Figure 1 shows a plan view of the project site indicating the microtunneling drives on the project. The 84-inch microtunnels are shown in blue and the 54-inch microtunnel is shown in red.

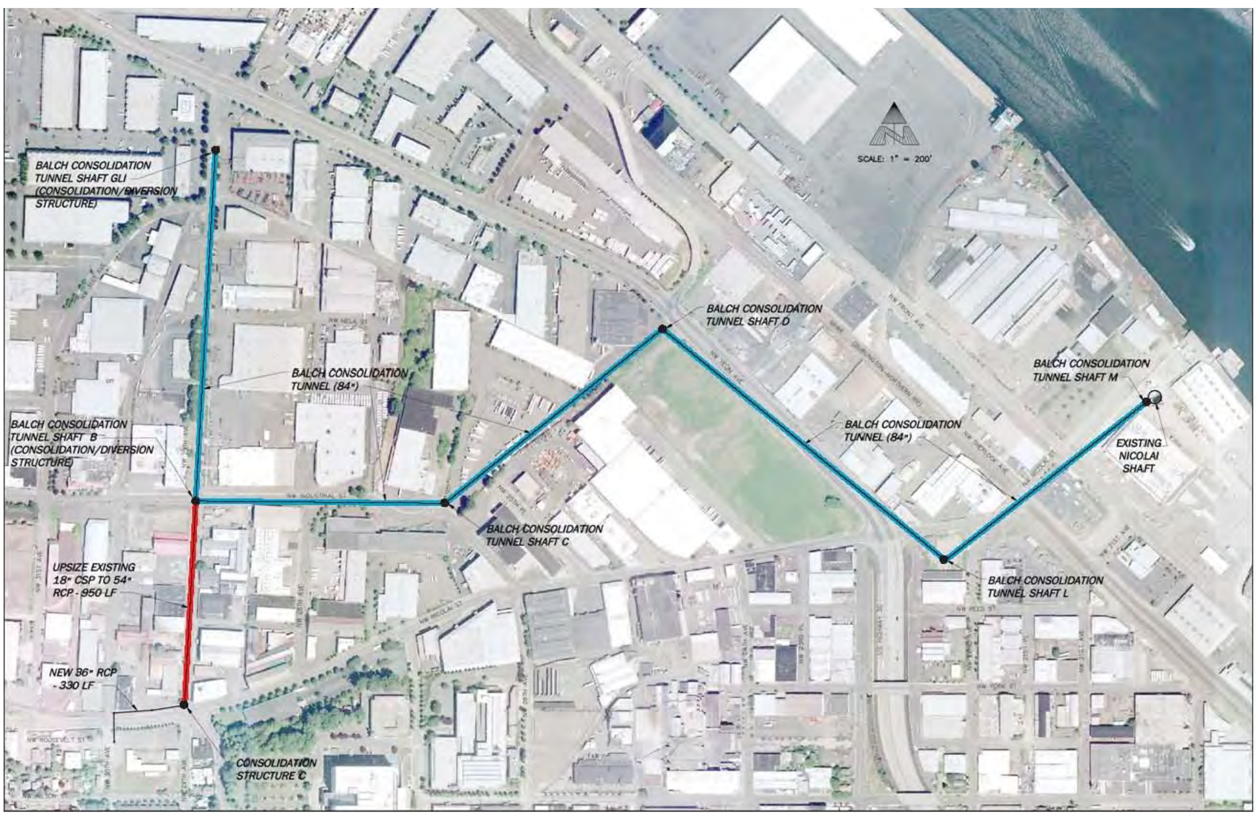

Figure 1. Balch Consolidation Conduit—alignment plan view.

After the 60% design was completed and the Contractor had joined the Design Team, it was decided that a new machine would be procured for the construction of the 84-inch microtunnels. The Contractor and the Design Team performed research and reached out to a number of manufacturers to determine the capabilities of the different machines and their ability to handle the wide range of soil conditions that were anticipated on the project. After a tremendous amount of negotiation, the team elected to purchase a Herrenknecht AVND 2000 machine. In addition to the base machine, additional features were added such as access to the face from within the machine, an air lock unit to allow access to the face under pressurized air, a telescopic jacking system that would be integrated into the head (basically an intermediate jacking station located in the section behind the machine), an additional steering joint to allow augmented steering in very soft soil conditions, and D-Mode, which enabled face stabilizing in sensitive or open-graded gravelly grounds.

Two of the microtunneling drives have been constructed without any significant issues. As such, details of these drives would not make a very interesting paper. Therefore, the authors have chosen to focus on two drives that presented serious challenges: one in design and the other in construction.

3. DESIGN CHALLENGES

The central focus of any microtunnel design is the geotechnical conditions. On the Balch project, the Design Team was presented with a wide array of soils ranging from very soft clays and silts to very dense open-graded gravels and a possible interface with the Troutdale Formation, known to have cemented layers containing cobbles or boulders. Because of the wide range of ground conditions, it was critical to either have a microtunneling machine that was capable of excavating through this wide range of materials or to use more than one machine.

Perhaps the most challenging drive on the project was from Shaft B to Shaft GLI. This drive was 1,640 feet (500 m) in length and ranged from 24 to 42 feet (7.3 to 12.8 m) in depth. Figure 2 shows a profile of the B to GLI drive.

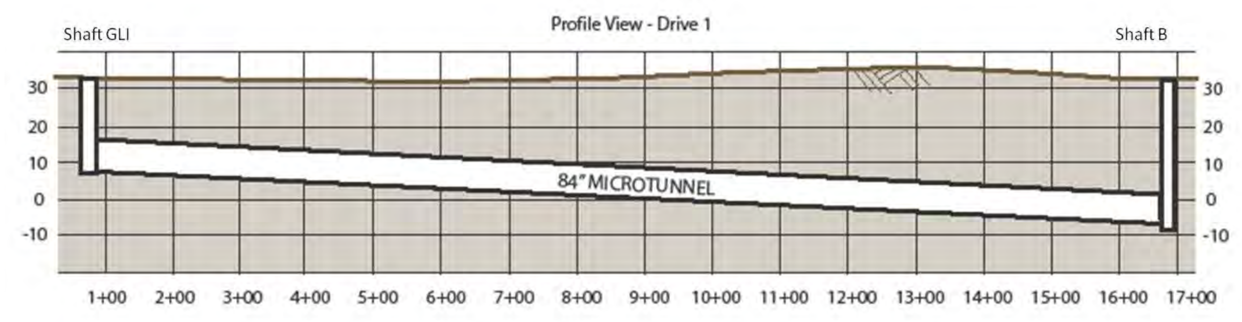

Figure 1. Profile of the B to GLI alignment.

The soil along this drive was characterized by the Geotechnical Engineer as Guilds Lake Alluvium (Shannon and Wilson, 2009) and consisted of very soft to medium stiff silt, clayey silt, and clay with minor constituents of fine grained sand (Staheli Trenchless Consultants et al., 2009). When the initial borings were drilled throughout this section, some of the vertical borings had blow counts that were less than three blows per foot at the planned elevation of the pipeline. The soil was particularly soft in the area around STA 5+00, where many of the borings had blow counts that were zero blows per foot. Because of this information, the Design Team elected to conduct a two-phase geotechnical investigation to further define the characteristics of the soil along the drive. Additional borings, geo-probes, and cone penetrometer tests were conducted to characterize the soils along the drive. In addition, vane shear tests were conducted to determine the in situ strength of the soil. Figure 3 shows the locations of the various tests that were conducted as part of the geotechnical investigation along this portion of the alignment.

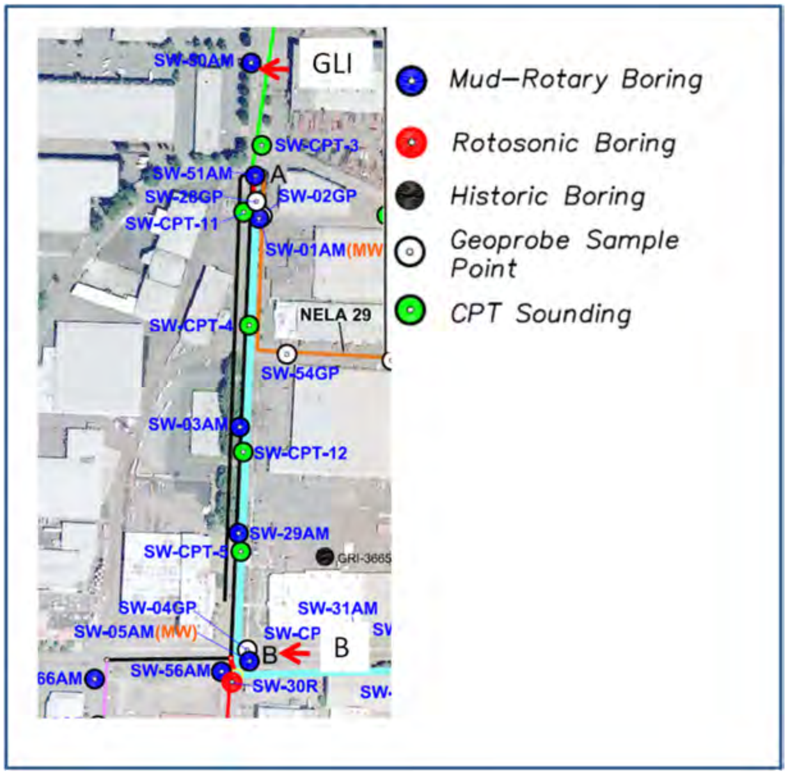

Figure 2. Location of geotechnical testing along the B to GLI alignment.

During the second phase of the geotechnical investigation, vane shear tests were performed in the soft soils and extensive efforts were undertaken by the Geotechnical Engineer, Shannon and Wilson, to correlate the information from the CPT, SPT, and vane shear tests to determine soil strengths. These tests revealed that there were two primary zones along the alignment where the strength of the soil at the elevation of the machine was estimated to be approximately 700 psf (3,418 kg/m^2). After a bearing capacity analysis of the machine was completed and compared to the estimated soil strengths, it was determined that these soils strengths were not sufficient to support the weight of the machine during tunneling. As a result, the Design Team concluded that ground modification was necessary to increase the bearing capacity of the in situ soils.

The original design included jet grouting throughout the entire zone that included the soft soils that would not provide bearing capacity for the machine. However, this was going to be extremely expensive and carried considerable risk because of the high pressures used in jet grouting and the close proximity to existing sewer lines that were known to be fragile. In addition, there were several interfering utilities in the areas where jet grouting was needed that would require relocation. Meetings were held with BES, the Designer, and the Contractor to brainstorm ideas for lowering the cost of the ground modification. During these meetings, the idea of using jet grouting columns was suggested in lieu of grouting the entire area. The weight distribution of the microtunneling machine was analyzed to determine the center of gravity in relation to the length of the machine joints. It was determined that the longest span that could be unsupported was 17 feet (5.2 m). Jet grouting columns were then designed perpendicular to the alignment that were a minimum of 3 feet thick (0.9 m) with a maximum spacing of 15 feet (4.6 m), center to center. The ground modification columns were designed to be minimum to 11 feet (3.4 meters) wide to completely encompass the machine so as not to contribute to deviations in line and grade due to the possibility of the machine excavating partially within a jet grouted column.

In concert with the design of the jet grouted columns, the Contractor had decided to build the microtunneling shafts with a cutter-soil-mixing (CSM) machine. The CSM machine constructs panels that are made of native soil mixed with bentonite and cement. Since the Contractor was going to have a CSM machine on site to construct the shafts, it was decided to use the CSM machine for ground modification, rather than the more common jet grouting technique.

This is the first time that CSM panels have been used as ground support for microtunneling through soft soils. CSM panels were placed at the locations shown in Figure 4. Using the CSM panels significantly reduced the risk of damaging the fragile 54-inch sewer that ran parallel to the microtunnel drive because the installation method for the panels did not require the use of high pressure fluid injection.

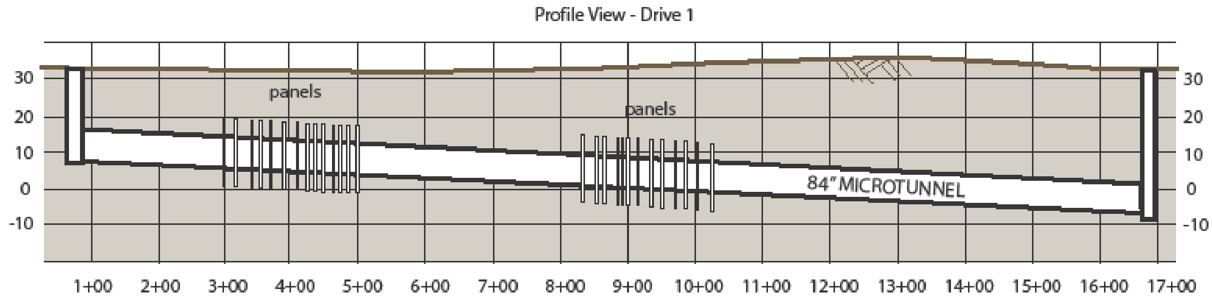

Figure 3: CSM panel locations on the B to GLI alignment.

As the microtunneling machine entered into the very soft soils, the face pressure markedly dropped, which manifested as very low torque readings. However, it was obvious that when the machine progressed through the CSM panels, the torque readings and face pressure would increase. Figure 5 shows the torque readings on the machine as a function of drive length.

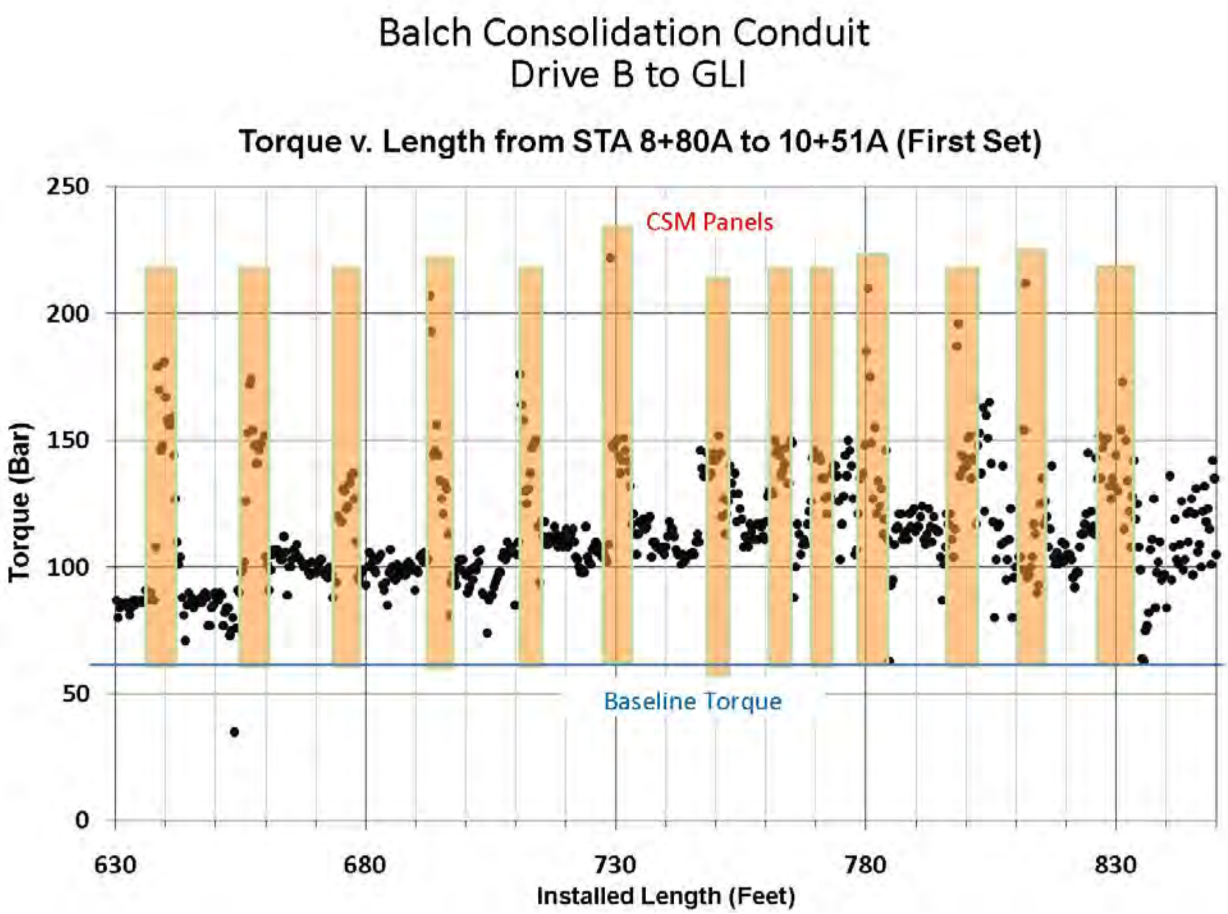

Figure 4. Torque vs. length (the locations of the CSM panels are shown).

The drive was successfully completed on line and grade because of the support provided by the CSM panels in the soft soils.

5. DRIVE C TO D

The microtunnel drive from C to D was 1,293 feet (394 m) in length and ranged in depth from 53 to 63 feet (16 to 19 m). The geotechnical conditions along the alignment were extremely complex and required numerous borings to characterize the soils at the depth of the alignment. Based on the geotechnical investigation, progressing from Shaft C to D, the microtunneling drive was expected to be within Gravel Alluvium for approximately 350 feet (107 m). The gravel within approximately 100 feet (30 m) of Shaft C was expected to contain significant fines. The drive was then expected to transition to a mixed face of Gravel Alluvium underlain by Sand for approximately 320 feet (98 m). The Sand was expected to be very dense but would exhibit flowing behavior due to the significant groundwater head to which it was exposed. The tunnel was then expected to transition back into full face Gravel Alluvium for approximately 260 (79 m) feet. The tunnel would then enter a zone approximately 80 feet (24 m) in length where the Troutdale Formation would be at the invert location. The tunnel would be in a mixed face of Gravel Alluvium underlain by Troutdale for approximately 120 feet (37 m). The Troutdale Formation in this area is gravel, cobbles, and boulders in a lightly cemented sandy silt formation. The tunnel would then transition into Open Network Gravel with Cobbles for approximately 120 feet. The tunnel would then transition back into Gravel Alluvium for approximately 60 feet (18 m) and terminate in 85 feet (26 m) of Sand. Figure 6 shows a profile of the expected geotechnical conditions.

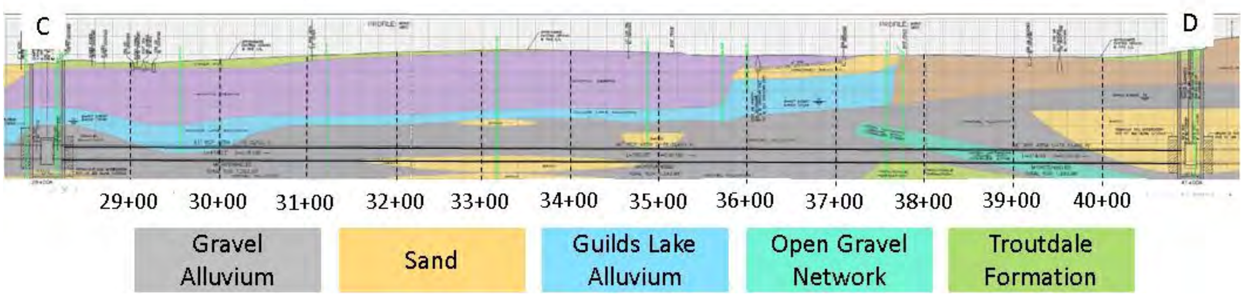

Figure 6. Cross section of Drive C to D showing soil units by color.

The machine was launched into Gravel Alluvium, as expected, and machine parameters, excavation rates, and performance were good. As expected, the material had an increase in sand content at approximately 350 feet (107 m) into the drive, consistent with the geotechnical report. However, unlike the expected conditions, the sandy gravel/gravelly sand was not as dense as expected, as was evidenced by lower torque and face pressure readings than had been seen on the first 350 feet (107 m) of the drive. In fact, the face pressure readings were indicative of medium dense soils, and not the dense soils that had been encountered on other parts of the project.

Then at 459 feet (140 m) into the drive, the machine encountered a very hard object at the bottom of the machine. The object was hard enough to cause the machine to roll 13 degrees. The machine was then shut off as a safety precaution. The cutterhead was rotated in the opposite direction but would stall when it came up on the hard object. With manipulations of the steering cylinders, the telescopic cylinders, and counter-rotation of the head, the machine was able to be freed of the object. However, as the machine passed over the object the machine went into a significant negative pitch and gained grade over a very short distance.

While working to move past the object, the sounds from the machine and the material recovered from the slurry separation plant indicated that the object was geotechnical in nature and likely consisted of a boulder or a “ledge” of the Troutdale Formation that was encountered earlier in the alignment than expected. Either of these things could have caused the machine to behave in the fashion observed.

With the alternative contracting mechanism, the Contractor, Engineer, and Owner were able to meet and discuss the options moving forward. Because of the efforts to get past the object, there was a significant "hump" in the pipe that was less than desirable for the gravity flow sewer. There was the option of digging up the machine because, by luck, the machine was not under a critical structure when the object was encountered. However, digging up the machine would cost over $1 million and would have involved excavation through an abandoned landfill. BES ran hydraulic models and determined that the grade deviations in the system were not large enough to adversely impact the hydraulic conveyance requirements of the tunnel. As a result, it was decided to move forward with the microtunnel and try to drive the machine to a new design grade, as modified by the Engineer.

However, this proved to be easier said than done. When tunneling resumed, the entire team assumed that through standard methods of adjusting the steering cylinders and advance rates, the machine would regain pitch, effectively leveling out, and operations would continue as before the object was encountered. This, however, was not the case. When tunneling forward, the machine did not recover pitch and continued to tunnel forward with an extreme negative pitch. At some points, the back of the machine was 14 inches (356 mm) higher than the front of the machine. This induced plowing through the soils, significantly increasing the jacking forces.

In addition, the "hump" that had been put into the pipeline after encountering the object was extremely sharp and stressed the pipe joints beyond a state of equilibrium. As a result, when jacking continued, the axial loads that were put into each joint across the "hump" were distributed through adjacent pipes, making the "hump" higher and wider with each push. Essentially, the pipe was moving both vertically and laterally in the ground to distribute the concentration of jacking forces through the pipe string. Figure 7 shows the as-built survey of the pipeline as it was taken after each 10-foot pipe (3 m) was jacked.

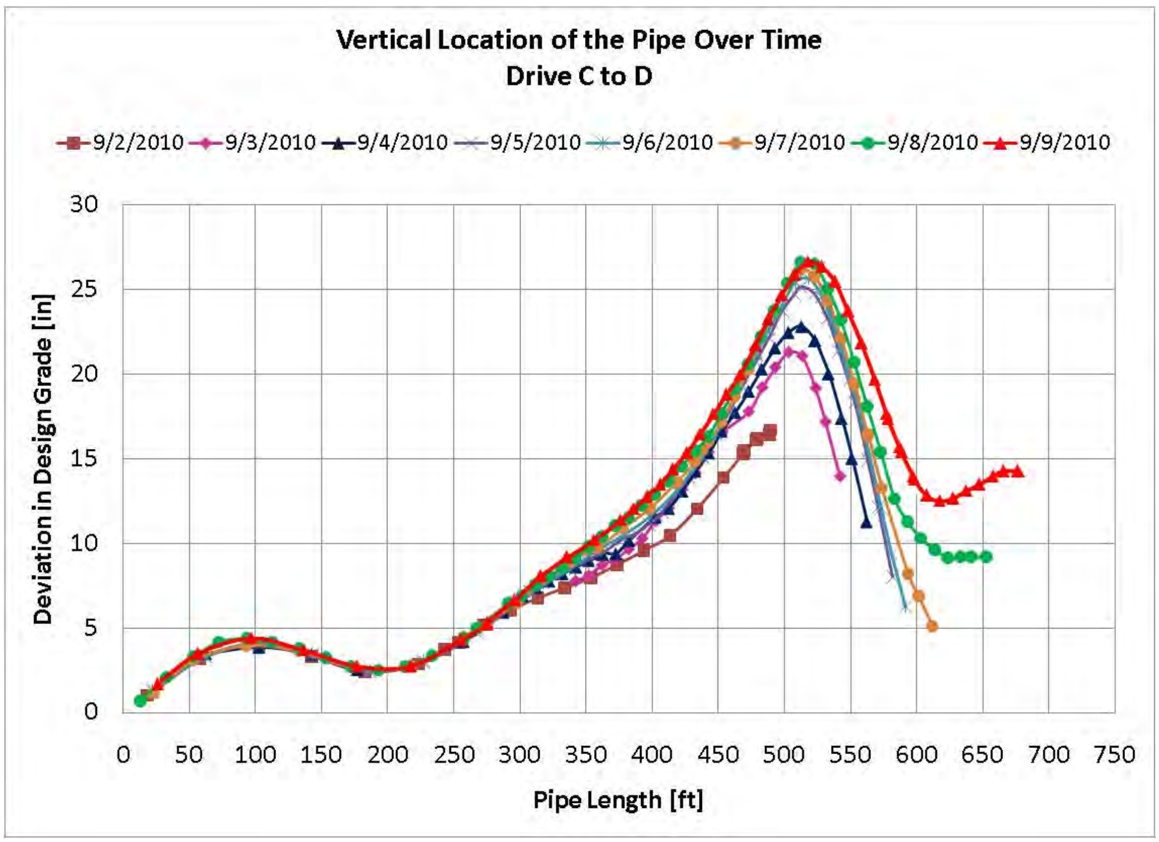

Figure 7. Length vs. deviation from design grade over time (9/2/2010 to 9/9/2010).

When looking at Figure 7, it is interesting to note that the object was encountered at 459 feet (140 m). As a result of encountering the object, the vertical deviation of the pipeline from design grade was approximately 14 inches (356 mm). Moving past the object, the machine "crested," as if moving over a speed bump, resulting in a sharp curve in the pipeline (as can be seen in Figure 7 on 9/3/2010). At that time, the deviation in grade had risen to 21 inches (533 mm). Each day a single 10-foot piece of pipe was jacked and a complete as-built survey of the pipe was conducted to record the location of the pipeline. Although the head of the machine and the first pipe section were trending back toward design line and grade, the reaming pipes continued to move vertically upward and toward the machine. This action distributed the jacking force more evenly throughout the "hump." From September 2 to September 9, the crest of the vertical deviation of the pipe at 459 feet into the drive moved from 14 inches to 27 inches (356 to 686 mm). In addition, the peak of the "hump" in the pipeline shifted from 459 feet (140 m) in the drive to 518 feet (158 m).

As the drive continued, the machine advanced with a negative pitch for approximately 600 feet (183 m). Although maximum steering inputs were applied to the machine in the lower steering cylinders, the machine would not respond, or would only respond very slightly, throughout the zone from 459 to 600 feet. However, at 600 feet the machine began to respond to the steering input. Due to the very aggressive steering input on the bottom steering cylinders, the machine immediately began to rise, resulting in counter steering. The result of this was a second "hump" in the alignment, as seen in Figure 8.

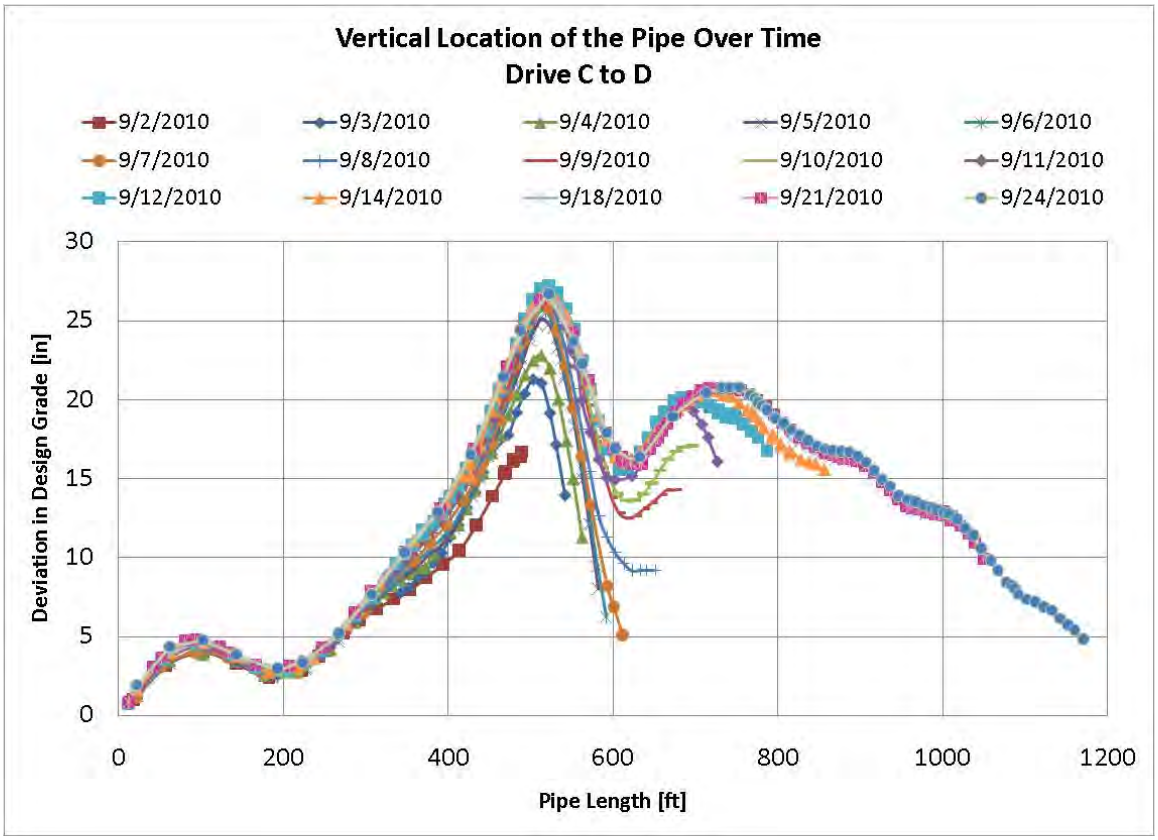

Figure 8. Length vs. deviation from design grade over time (9/2/2010 to 9/24/2010).

Perhaps the most interesting thing about Figure 8 is the documentation of the total amount that the pipe was able to move after installation. For example, at 600 feet (183 m) into the drive on September 7, 2010, the pipeline was only 5 inches (127 mm) out of vertical alignment but ended up being 16 inches (406 mm) out of vertical alignment. This vertical shift underground with approximately 60 feet (18 m) of earth cover on a 101.5-inch (2,578 mm) outer diameter concrete pipe is very rare and only happens in extremely unique circumstances..

One might assume that the soils in this region were very soft to allow the movement of the pipe; however, this was not the case. The pipe was moving under a tremendous amount of jacking force that was acting on an angle due to the misalignment of the pipes due to the vertical deviation. Figure 9 shows the jacking forces throughout the entire drive. It is easy to see that the jacking forces markedly increased when the object was encountered, and continued to rise at an increased rate (as compared to before the object was encountered) until the machine was well beyond the alignment deviations. When examining Figure 9, one should note that the lower jacking forces (between 200 and 300 tons [181 and 282 tonnes]) that can be seen at the bottom of the graph from 500 feet (152 m) to the end of the drive are forces from the telescopic jacking station. This station was located just behind the head. When the object was encountered, the telescopic jacking station was used to push the head forward and to excavate. The main jacks and intermediate jacking stations were then used to propel the pipe forward.

When the pipe was being pushed over the main grade deviation area, it was necessary to use the intermediate jacking station because the main jack, at 1,200 tons (1,089 tonnes), did not have enough force to propel the entire pipe string. This is because a tremendous amount of the force was being used to move the pipeline vertically and horizontally toward the machine, rather than to propel the pipe along the design alignment. At times when the intermediate jacking station (IJS) was advancing over the first "hump," the maximum extension on the IJS was 1 inch (25 mm) when the hydraulic cylinders were at the maximum pressure. At that point, there was much concern that the pipe was going to get stuck because of the excessive jacking thrust requirement.

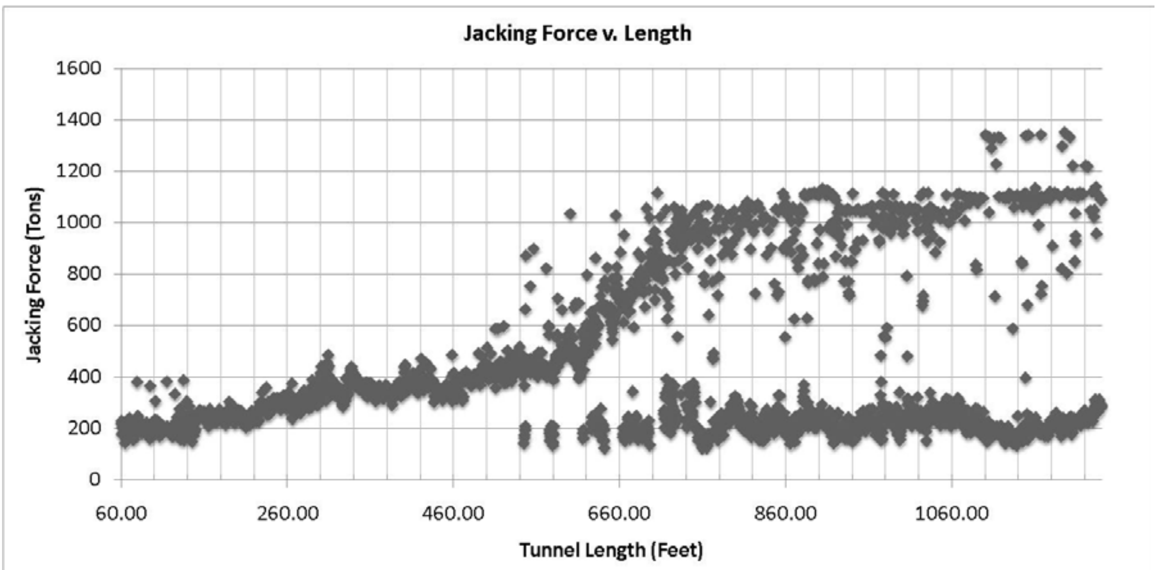

Figure 9. Length vs. jacking forces for Drive C to D.

At the end of the drive, it can be seen that although the face pressure and excavation forces were eliminated from the total jacking force by independently using the telescopic station to excavate, jacking forces were still spiking at the main jacks at 1,380 tons (1,252 tonnes). This was right at the maximum force available from the jacking frame and beyond the design limit of the jacking shaft. However, the drive was completed successfully and close to the original construction budget.

6. CONCLUSION

The Balch Consolidation Conduit Project had many challenges that required a team effort to overcome. By using an alternative contracting mechanism, people from the design team, the contractor, and the owner, could work together to develop a solution that made the most sense for the overall project.

On the drive from B to GLI, the contractor was able to use CSM techniques to build soil modification panels to support the microtunneling machine through the soft soils. This allowed the economy of using a machine that was on the site, the use of contractor's own labor force, and the team to adjust the panel design during the microtunneling construction should other areas of soft soil be discovered. This offered a tremendous cost savings to the Owner over jet grouting, which would have required the mobilization of a specialty subconsultant.

On the drive from C to D, the Owner, Design Team and Contractor working together allowed for a positive outcome to a highly challenging issue. On most design-bid-build projects when obstructions are encountered, shafts fail, settlement occurs, etc, the Contractor quickly moves into the "who pays" mode while the Owner moves into the "who's fault" mode of discussion. The positioning by the Owner and the Contractor often takes precedence over solving the problem. Meanwhile, precious time is expended which typically equates to increased change order or claim costs (due to stand-by or the time to fix the issue) in the long run. Had we been using a design-bid-build contract, when the obstruction was encountered, the Contractor certainly would have filed a potential change order based on a differing site condition. At that point, the Contractor likely would have wanted to dig up the machine to "prove" to the Owner that a large obstruction had been encountered that had forced the machine off of line and grade. By using the alternative contracting mechanism, both teams move very quickly into solving the problem with little discussion about fault or who pays because it is already understood that the Owner will pay. There is always some positioning as the traditional Owners and Contractors fall back into their old habits of blaming first and solving the problems second. However, within short order the team will work together to find the lowest cost solution to the problem that is in the best interest of the project and work together in a collaborative partnership.

7. REFERENCES

Cozzi, R., Moore, B, and Jossis, R. (2011). Another success for the City of Portland using alternative contracting methods to deliver the Balch Consolidation Conduit, ***Proceedings of No-Dig 2011***, Washington, D.C., March 27–31, 2011.

Shannon and Wilson (2009). ***Geotechnical Data Report, Balch Consolidation Conduit***. September, 2009. Portland, OR.

Staheli Trenchless Consultants (2009). ***Trenchless Construction Methods, Balch Consolidation Conduit***. September, 2009. Portland, OR.