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Woods Trunk Sewer Replacement Project – A Challenging Trenchless Technology Case Study

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ABSTRACT: The Bureau of Environmental Services (BES) owns and operates the wastewater collection and treatment system that services over 550,000 citizens in the City of Portland, Oregon. BES is focused on improvement of the wastewater and storm water systems that protect the precious natural river resources that gave birth to the City and provides the economic and recreational vitality that will dictate the quality of life in the 21st century and beyond. BES continues to evolve its management and operations in its third century of stewardship as a leader in the application of trenchless technologies for wastewater collection system infrastructure projects.

Recently, a project to replace nearly one-half mile of 30-inch and 24-inch diameter combination trunk sewer in the Woods basin of southwest Portland was identified as an emergency project requiring immediate repair. The 1880's era brick and stone sewer is buried fifty feet beneath existing freeways and four important arterial streets. The sewer completely failed at one location leading to a sinkhole, and exhibited significant signs of distress in other locations over 2,500 linear feet. An emergency repair and diversion scheme was completed, and a complete design effort was started immediately thereafter. BES engineers, with the assistance of stakeholders and consultants, completed a design that resulted in the use of five separate trenchless segments to augment the traditional open trench construction method. The emergency construction work started in the summer of 2005, and continued into 2006 to include 817 feet of microtunneling, and 469 feet of cured-in-place pipe (CIPP) in two sizes. It also included two auger bores, one of 140 feet and a second more challenging auger bore 365 feet in length, and 163 feet of pipe bursting a side sewer.

1. INTRODUCTION

In late July of 2005, BES received a phone call from the Oregon Department of Transportation (ODOT) regarding observed settlement of a freeway on-ramp to Interstate 5 in southwest Portland. Aware that an old brick sewer runs beneath the area, BES investigated the 50 foot deep sewer to determine if the line was functioning properly. This inspection was completed using closed circuit television (CCTV) equipment by the Bureau of Maintenance (BOM). A significant sewer defect was found 75 feet upstream of the manhole adjacent to the on-ramp. The brick sewer, originally 30 inches in diameter, had partially collapsed to a severe ovality, such that only nine inches of height remained open. With the winter fast approaching BES notified City Council that an emergency existed that would threaten property as well as health and safety of the public.

An emergency response to the failing sewer was developed. This was followed by a final design that included many trenchless aspects. The trenchless components of the sewer reconstruction will be described by recounting design and construction details and presenting lessons learned during design and construction. The paper will close with a look at a 'triple bottom line' of economic, social and environmental measurements.

2. EMERGENCY PROJECT

Prior to the ODOT contact in 2005, BES Maintenance Engineering had identified a number of deficiencies with the combined sewer but had difficulty completing a structural assessment because of obstructions or access restrictions. Bricks were found in downstream manholes and the sewer conveyed flow with an unusually high soil load. Two soil borings were drilled near suspected problem areas in the summer of 2003 to better define the scope of the project. One borings was drilled in silty debris fill in a grass cloverleaf at the northwest corner of the Ross Island Bridge, an important and heavily traveled connection to downtown. The second was completed about 350 feet west of the first in the grass island between SW Water and SW Corbett Avenues. Piezometers were installed in both borings to monitor changes in ground water levels.

Design: City Council approved an Emergency Ordinance to address the collapsed sewer adjacent to Interstate 5. Design focused on compiling a basic construction plan that called for bidders to propose an excavation and shoring method to reach the 50 foot deep sewer, and to temporarily reconnect the sewer so that it could function during the upcoming winter season. This approach allowed for a relatively quick completion of bid documents with some basic project background information. BES requested an immediate response for means and methods to meet the very tight time frame.

Two heavy sewer construction firms responded with proposals for the work. One approach was to drill and drive steel H-Piles in a rectangular arrangement, and place wood lagging with whalers and tie-backs at intervals to the bottom of the excavation. This would provide access to the break and additional length of sewer to complete a reconstruction. The second contractor, J.W. Fowler, and proposed the use of 'z' shaped sheet piles in a cell measuring 20-ft. by 40-ft. with the long dimension parallel to the existing sewer, with several sets of steel H-beam whalers. This would allow enough room for placement of a pipe jacking set up to place a steel casing outside the existing failing brick sewer, which would then be bored out and new concrete pipe would be placed for temporary flow through the winter. BES chose this latter alternative.

Construction: Prior to construction, BES Maintenance Engineering contracted with a local pumping company to set up a diversion piping system upstream of the collapsed section of pipe. The location was not ideal, since the sewer was fifty feet deep at that location, and the existing manhole was a combined concrete and brick section. Also, the layout was very tight for fitting adequate capacity pumps and plugs for the diversion.

Construction of the emergency shaft in the cloverleaf near the Interstate 5 on-ramp required that a local electric utility, Pacific Power and Light (PP&L), to relocate an anchor supporting a power pole on SW Hood. On September 1, 2005 a utility crew was preparing to do the relocation work when the rear wheel of their truck sank to its axle, exposing a 16-foot diameter sinkhole that extended more than 20 feet deep.

The emergency contractor began constructing a steel sheet pile shaft at the sinkhole location to access and replace the failed sewer. The emergency repair plan anticipated driving the sheet piles through the collapsed sewer and then jacking a 72-inch diameter steel casing around the failed sewer in both directions, removing the bricks until flow could be re-established. Pile driving was completed and excavation of the sheet pile cell had just begun when an unseasonably heavy rainstorm occurred on the morning of Friday, September 30, 2005. During the storm the temporary plug creating the bypass failed. Sewage started seeping from cracks in the ground on the upstream side of the emergency shaft. Within 20 minutes sewage flowed freely overland in excess of 1200 gallons per minute. The contractor constructed earthen berms to divert the flow back into a downstream manhole. In the afternoon a sinkhole developed on the westside of the emergency shaft. The second sinkhole extended at least 15 feet deep and exposed a shelf of buried pavement, believed to be an abandoned bridge ramp, about 10 feet below the ground surface. The edge of the hole advanced uphill to within 25 feet of the westbound Ross Island Bridge ramp before the contractor filled it with approximately 40 cubic yards of 6-inch minus rock.

Construction of the emergency shaft continued in October 2005 after the bypass was partially re-established. Four 10-inch dewatering wells were drilled around the shaft and the contractor proceeded with the top-down installation of the shaft supports and excavation. The bypass functioned properly under low flow conditions but sewage continued to flow into the excavation during storm events. Work was interrupted a few times as storms passed through the area and sewage flooded the shaft. As excavation progressed more than 20 feet below the ground surface, large cracks in the ground developed on the south side of the shaft along with several small sinkholes.

On November 4, 2005 the brick manhole used for the temporary bypass diversion at SW Water Avenue and Woods Street collapsed, sinking 6 feet. A shallower adjacent manhole sank 15 feet. A second diversion at SW First Avenue and Grover Street was already under construction and was put into immediate service. The upstream propagation of failure indicated that the existing brick sewer and manholes did not have the integrity to handle the additional stress induced by bypass pumping. Failure of the bypass system stopped excavation of the emergency shaft and caused reassessment of the project scope. Ultimately, the amount of pipe requiring repair was so large that outright replacement of the trunk system appeared more economical and less risky than repairing or rehabilitating a system that was structurally challenged and impacted other facilities.

The contractor was asked to add a manhole at an intersection upstream of the initial bypass, to allow for significant pump capacity to be used for a prolonged temporary bypass diversion of flow. Eventually, this 25 foot deep manhole was constructed and eight hydraulic pumps were placed in the partially constructed manhole that fed a 12-inch steel and 18-inch HDPE set of discharge lines. This system was in place from December 2005 through May 2006, which corresponded to the first phase of complete replacement of the Woods Trunk Sewer.

Lessons Learned: This project clearly illustrated that flow diversion can control a project of this complexity and it must be given significant attention at the outset. It is important to evaluate whether diversion can be successfully implemented for the required duration of the proposed temporary repair. If successful flow diversion is in question, alternative repair methods should be investigated, and/or another diversion scheme should be implemented. A contingency plan should also be prepared to address any problems that might arise during diversion.

On a macro-level Portland recognizes there is an ever present need to focus on pipe condition assessment and pipe criticality, and the importance of a utility's Asset Management and System Plan for rehabilitation and reconstruction of sewer infrastructure. Emergency projects are challenging to a utility due to their unknown scope and dimension, the need for immediate response with imperfect information and the amount of time needed to justify the response to oversight parties.

3. REPLACEMENT PROJECT

Design and Construction Approach: BES management decided that due to the complexity of the project and the time availability of employees with existing project workload, the design would be managed by a consultant with significant experience with large sewer projects. Still a significant level of effort was required from BES design staff, construction management and inspection and geotechnical engineers, among others. To flesh out the necessary details of the microtunnel and auger boring segments of the project, Bennett/Staheli Engineers were contracted for their extensive professional experience as a trenchless technology consultant. The City continued to work with the emergency contractor and several subcontractors to complete the design and construction of the work. The project would be constructed in three phases, based on criticality and the time required to complete the various elements of design work.

Sewer History and Background : The Woods Trunk Sewer was constructed in 1893 next to a seasonal creek in a 30 to 45-foot deep gulch incised in a ¼ mile wide terrace between Portland's West Hills and the Willamette River. Portland has distinctively small, 200 foot square blocks. The gulch occupied a block-wide gap in the grid and roughly paralleled SW Woods Street between SW First Avenue and SW Moody Avenue. Masons built a 24-inch I.D. brick sewer west of SW Corbett Avenue and a 30-inch I.D. brick sewer east of SW Corbett Avenue. The typical section included a base of mortar and brick one foot high, upon which a two layer set of brick was placed with mortar in a circular geometry. An additional layer of mortar was placed outside the pipe. Timbers were placed beneath the sewer to improve bedding and assist in establishing the geometric form of the sewer during construction.

The sewer collected flows from existing residential neighborhoods on the north and south sides of the gulch in addition to the creek near the base of the West Hills. In 1909 the sewer was extended 700 feet west and the creek inlet was moved uphill just to the west of a train trestle The creek inlet was moved approximately 200 feet west again in 1921 when the sewer was extended up the West Hills to the Multnomah County Hospital and a surrounding residential neighborhood. This hospital became the largest teaching/research hospital in the region. Its continued growth over the last 80 years has contributed an increasing load to the combined sewer system. Construction of the Ross Island Bridge (U.S. Highway 26) in the mid 1920's, new Ross Island Bridge and Naito Parkway ramps in the late 1940's, and the I-5 Freeway in the early 1960's obliterated any evidence of the gulch. The grading associated with these projects increased the depth of the sewer 10 to 15 feet and required abandonment of many of the original sewer connections.

Geotechnical Investigation for Design: BES Geotechnical Engineers conducted an exhaustive search for historical records of development in this basin to determine the location and extent of the historic gulch. Sources included City of Portland Bureau of Development Services files, City of Portland public works as-builts (Environmental Services, Transportation Office and Water Bureau), photo archives at the Oregon Historical Society (OHS) and at the Stanley Parr Archive and Records Center (SPARC), Oregon Department of Transportation (ODOT) structural and geotechnical databases, Sanborn Fire Insurance maps and US Army Corp of Engineers aerial photos. Information on historic streetcars and commuter rail lines were found online at PDXHistory.com.

Key historical developments shown on a 1889 Sanborn map reflect wooden trestles/bridges crossing Woods Gulch at five locations. The 1901 Sanborn map showed the same structures and called out post heights ranging from 4 to 47 feet and identified a structure on "20' iron piles" crossing near its confluence with the Willamette River. It carried a 24-inch water line. Historic streetcar lines crossed the gulch at two locations. The 1908 Sanborn map shows embankment fill in place of the "planked streets". In the late 1940's Front Avenue, a major arterial crossing the gulch, was widened. ODOT built a new Ross Island Bridge/ Front Avenue interchange that filled the last remnants of Woods Gulch.

Significant geotechnical investigation and analysis was completed for the project, including more than 20 soil borings. This data was used to develop several alternative alignments for the new sewer. A Geotechnical Interpretive Report (GIR) of the geotechnical information, including laboratory testing of materials, was completed to help Bennett/Staheli design the trenchless portions of the project. BES and Bennett/Staheli jointly prepared a Geotechnical Baseline Report (GBR) for the project. The new design anticipated plans for future redevelopment that will re-privatize some segments of the original alignment and could limit access. BES is committed to building systems it can access and maintain throughout the systems design life.

These investigations revealed that the existing sewer was placed through complexly layered, heterogeneous fill materials of variable origin and quality under 5 significant roadways. Thus, the five trenchless methods are invaluable for the new sewer to prevent disruption of the key transportation units. Each of the five trenchless segments and the construction methods used will now be described in more detail.

4. PIPE BURSTING

<u>Design</u>: This method was used to replace an existing 8-inch CSP side sewer near the upper reaches of the project on SW Barbur Boulevard adjacent to the Ahavath Achim Temple. The main drivers for using the pipe burst method included the ability to minimize surface disruption and the close proximity to adjacent water and power utilities lines and vaults. The horizontal extent of the pipeline segment crossed into two active streets and the Temple parking lot. This method also minimized the amount of excavation and disposal of lead and arsenic contaminated soil identified throughout the area of the project.

A geotechnical report completed for the project summarized investigation at the site. Borings along the alignment were completed using a soil probe method with continuous samples using a Cascade Powerprobe 9600 Pro. The continuous sampling provided soil samples for both geotechnical and geo-environmental studies. The investigation identified contaminants and was used to develop a contaminated media plan. The borings indicated sandy silt fill soil down to the pipe invert and was characterized as soft to medium stiff. No groundwater was encountered, but traces of wood and glass were found.

The new pipeline was a 10-inch O.D ASTM F714, DR 17 HDPE pipe to burst through the existing 8-inch I.D. non-reinforced concrete host pipe. The distance of burst was specified as 163 linear feet, with a range of depths from 9 to 15 feet. The slope through this stretch was approximately 3.5% for 150 feet from the upstream and 15% for the remaining reach of 13 feet, thus a small grade break existed in the line to burst through.

<u>Construction</u>: The contractor completed the pipe burst following the downstream open trench construction that was completed on the rest of the side sewer. The insertion pit was the tail end of the open trench that was shored with active hydraulic cylinders against wooden shield boards. The 4-ft.x 8-ft. bursting pit was excavated just outside the upstream manhole, where the hydraulic jacking system for the static bursting method was installed.

The contractor installed temporary diversion pumps in the upstream manhole, and excavated at the location of the only sewer service in SW Gibbs Street. The HDPE pipe was fused by qualified welders using McElroy fusing equipment. The pipe was then pressure tested to ensure water tightness. The bursting head was attached to the pipe, and the pulling chain was fed down the host pipe from the bursting pit to the insertion pit and attached to the bursting head. The bursting power was provided using Trenchless Technologies Northwest (TTS) 300 system and supplemented by an excavator to relieve the slack on the chain. The bursting time was approximately 20 minutes with no disruptions of progress. Following the successful burst, the line was inspected and found to be in good working condition.

<u>Lessons Learned</u>: Pipe bursting can effectively replace a sewer given the proper conditions related to the surrounding soil and the pipe being replaced. The static method of bursting was ideal since it provided the adequate amount of energy and construction was kept relatively quiet, compared to the pneumatic head method sometimes required for larger bursting energy.

There was significant rainfall in between the time of pipe welding and actual bursting, and after the lateral sewer was exposed and disconnected, so diversion of flows was a tricky matter to maintain for several days prior to completing the work. The pipe effectively articulated through the grade break, which allowed the amount of excavation for the launching pit to be minimized.

5. CURED-IN-PLACE PIPE (CIPP)

The CIPP method was used to rehabilitate two reaches of the existing brick sewer lines. The first line rehabilitated was an existing 24-inch section of the trunk sewer underneath SW Barbur Boulevard. The second CIPP liner was installed in a 48-inch diameter line at the lowest reach of the project near SW Moody Avenue.

Design: The primary factor for using the CIPP method was the sewer locations. The 24-inch sewer runs beneath SW Barbur Boulevard and is 30 feet deep. The 48-inch sewer runs underneath recently installed tracks for the city street car system. For the purposes of design, CCTV inspections were completed on the line segments to verify conditions were appropriate for lining. Both of these segments were found without significant ovality problems (not greater than 2% to 3%) or any lateral sewers requiring reinstatement.

Through hydraulic modeling of the system, it was found that the sewer capacity could accommodate a slight reduction in cross sectional area. The liners were both designed per ASTM F1216-03 (Inversion Method) for a partially deteriorated gravity pipe, with no external groundwater pressure (verified through geotechnical borings). Both designs required a factor of safety of 2 against buckling and a long term deflection of less than 5%. The design calculations resulted in minimum wall thicknesses of the CIPP liner to be 0.66-inch for the 266 feet of 24-inch pipe and 1.08-inch for the 203 feet of 48-inch pipe.

Construction: Insituform Technologies completed both CIPP projects, even though they were completed in two different phases of the project. The liner tube and resin were polyester materials were with Flexural Modulus of Elasticity of 400,000 psi, flexural strength of 4,500 psi and a long term strength reduction of 50% due to long term effects, as measured by ASTM F-126 Section 5.1, Table 1, and ASTM D-790, respectively. Laboratory tests were completed by the City on the flexural strength and thickness of the liner and verified the composition of the liner resin material.

The 24-inch CIPP under SW Barbur Boulevard took place in May 2006, and was integral to establishing a gravity fed diversion system to replace the expensive pumping scenario that resulted from the failure of the existing sewer in the fall of 2005. In order to not damage any additional pipe upstream, it was determined that a new manhole was required to hold diversion pumps. The temporary diversion was put in place prior to mobilizing the liner crew on-site. The liner was launched from an existing concrete monolithic manhole in the Temple parking lot and ended at the new concrete manhole constructed to hold the large flow diversion pumps on SW Second Avenue.

The 48-inch CIPP took place in September 2006, and this required construction of a manhole over the existing brick sewer prior to liner construction. Existing brick manholes over the sewer are only 2 feet in diameter, and did not provide sufficient space to launch a liner. The temporary diversion was again put in place at this location. The liner was launched at the new manhole, and the ended at a manhole located on the new Southwest Parallel Interceptor (SWPI) pipe junction.

Each of the liners was impregnated at the factory and kept refrigerated prior to installation. The installation methods were very similar (i.e. water inversion, boiler heated circulated water curing, and a cool-off period). The 24-inch liner installation required only a series of ropes to pull the liner off the truck to the insertion frame above the manhole, but the 48-inch CIPP was much heavier and required an automated conveyor belt to bring the 48-inch liner to the insertion manhole.

Lessons Learned: CIPP continues to be a cost effective means for rehabilitating sewers with access problems that restrict other rehabilitation or replacement methods. The City provides full time inspection and other quality control and assurance functions to limit the risk of a poor liner “cook” that leads to time intensive re-work by the Contractor. The water inversion and circulated boiled water method of installation continues to be the favored method of producing good quality liners for BES. Also, the need for good access for both inserting and receiving the liner tube can not be overstated. Designers should include new manholes, or modifications to existing structures as needed.

6. AUGER BORING – SHORT SEGMENT

Auger boring was used to construct a short reach of the sewer under and across the west end of the Ross Island Bridge. This short segment permitted the designers to shift the microtunneling alignment operation away from potential buried obstructions in the fill under I-5 to the adjacent native, undisturbed soils.

Design: The primary factor that led to trenchless construction was the need to retain traffic flow at the west end of the bridge throughout construction. Auger boring is a common trenchless technology with a high success rate given favorable geotechnical conditions. The geotechnical baseline report summarized the conditions found through geotechnical investigation which reports medium dense silty sand (alluvium) throughout the boring length, with some potential for 2-foot size boulders and some opportunity for construction fill debris at each end. This report predicted slow to fast raveling material varying through the boring, but no groundwater was encountered at the depth of planned construction. Settlement analysis predicted the potential for 1/4" of settlement during construction at the roadway surface, and called for contact grouting and annular space grouting to address this potential.

The design called for a 48-inch diameter (0.625-inch thick wall) steel casing to be jacked into place behind the auger. A 42-inch O.D. ASTM F714 DR 17 HDPE carrier pipe would be installed in the casing and the annular space grouted to prevent long term free settlement. The depth to invert is 16 feet to 22 feet deep, connecting to new concrete manholes at either end.

Construction: The contractor utilized a steel box shielding method for the jacking shaft north of the roadway with a sheet pile front wall, and set the bottom grade to allow for the 4.3% grade on the pipe that was received in the sheet pile (z-shape) downstream shaft. During the upstream shaft excavation, a small amount of concrete debris was encountered. The base was prepared with 6 inches of crushed rock, and 2-inchx12-inch wood planks set the base for the auger machine tracks. A concrete thrust block, with a 4-ft.x8ft. – 1-inch thick steel plate facing was constructed at the back of the pit to accommodate the approximate 70 tons of thrust calculated by the contractor. The flight auger machine was an American Auger 60-1200. The contactor decided to use a 54-inch O.D., 0.75-inch thick walled Permalok steel casing pipe to accommodate the larger capacity Auger they used, which was approved by BES through the submittal process. A steering head kit and water level indicator was added to the auger bore to keep the pipe on line and grade. The casing was jacked such that the cutting head of the leading flights were held back 2 feet from the advancing casing. The drive was checked for line and grade twice during the process, and found to be online. There was no raveling or settlement detected on the surface, aside from one monitoring point next to the jacking shaft. Spoils from the drive were removed by a clam shell and placed in a muck bucket for removal to a disposal facility. Grouting outside the casing followed its placement with a mixture of neat cement and water. The HDPE pipe was then butt fused in the jacking pit and pulled through to the reception shaft. The annular space was filled with blown sand through 4-inch steel pipe inserted through concrete end seals at both ends of the pipe.

Lessons Learned: Steel casings should be designed with a sufficient distance allowed for proper connection fittings to the manhole, and this distance should be considered in the construction process to prevent need for a field cut. The Permalok pipe worked well and its connection type limited the amount of time required since there was no welding required between pipe ends that would have been necessary for raw steel casing.

7. AUGER BORING – LONG SEGMENT

Design: Auger boring was used for constructing a 365-foot reach of the sewer under and across SW Naito Parkway. This crossing segment allowed for the alignment to be placed in the future right of way in the project area that will be developed in the near future. The primary factors that lead to the decision to use auger boring over microtunneling was the concern that old wooden piles from a previously destroyed bridge may be encountered underneath the overpass walls. This scenario would make a rescue shaft very difficult to retrieve a microtunneling machine, but access to the leading face of the casing or removing obstructions would be possible by removing the augers.

The design called for a 48-inch diameter (0.625-inch thick wall) steel casing to be jacked into place behind the auger. A 42-inch O.D. ASTM F714 DR 17, HDPE carrier pipe would be inserted into the casing and the annular space grouted to prevent long term free settlement. The depth to invert is from 18 feet to 28 feet deep, connecting to new concrete manholes at either end. The vertical alignment required clearance below the existing ODOT underpass footings constructed with SW Naito Parkway

This auger boring method was initially considered when the length of boring was only 300 feet. However, it was determined to extend the bore given no significant subsurface conditions prohibited the longer length. The geotechnical baseline report summarized the conditions found through geotechnical investigation and revealed moderately compressible sand-silt alluvium, with some veins of wood and soft silt fill at locations which intersect the gully locations. The receiving shaft at SW 1st Avenue encountered significant groundwater in runny silty sand during the exploration phase; therefore, groundwater control was identified as likely necessary for the Contractor. This report predicted slow to fast raveling material varying through the boring, with groundwater encountered at the invert depth of planned construction. Settlement analysis predicted the potential for ¼-inch of settlement during construction at the roadway surface, and called for contact grouting and annular space grouting to address this potential.

Construction: The contractor used a steel shield box for the jacking shaft with steel sheets closing the front wall, and excavated the bottom grade at a 5% grade to maintain the desired pipe grade. The base of the jacking shaft was prepared with 6 inches of crushed rock, and 4-inchx12-inch, 20 foot long wood planks set the base for the auger machine tracks. A concrete thrust block, with a 6-ft.x8-ft., 1-1/2-inch thick steel plate facing was constructed at the back of the jacking pit to accommodate the approximate 70 tons of thrust calculated by the contractor. The flight auger machine was an American Auger 60-1200. The contactor decided to use a 54-inch O.D., 0.625-inch thick walled steel casing pipe to accommodate the larger capacity Auger they used, which was approved by BES through the submittal process. Full penetration welds around the entire circumference of the casing were completed between the 20 foot lengths of steel pipe per AWSI-D1.1. During the receiving shaft excavation groundwater was encountered as predicted and pumps were implemented to prevent running soil.

The auger boring was completed successfully. Of significance, the boring did encounter an old wooden pile beneath the overpass. The augers were removed and personnel entry was required into the casing to remove the obstruction. It required roughly 5 days to remove the obstruction and resume auguring.

The HDPE pipe specified in the design was then butt fused in the jacking pit and pulled through to the reception shaft on pressure treated lumber skids that were steel banded to the pipe. The annular space was filled with blown sand through 4" steel pipe inserted through concrete end seals at both ends of the pipe.

Lessons Learned: A longer auger bore can be completed successfully if the subsurface conditions allow, and the equipment is appropriately selected for the conditions. The decision to stretch the limits and use the auger boring instead of the more expensive microtunneling proved to be sound. This reinforces the value of researching the history of the subsurface along the alignment and proper risk analysis and management techniques on the project.

8. MICROTUNNEL

Design: Microtunneling was used for constructing a long reach of the sewer under and across Interstate-5. This segment was constructed outside the gulch and in native soil in the right of way that will be maintained in the future. The primary factors that favored microtunneling versus other trenchless methods (i.e. open-face tunneling, directional drilling, etc.) was to match the appropriate equipment to the subsurface conditions for the proposed alignment. These factors included length, diameter, groundwater conditions, and geotechnical conditions. It was important to select a method with a high chance of success due to the very difficult circumstances that would result from the construction of a rescue shaft on the I-5 freeway, and the requirements to have no settlement at the highway surface.

The design called for a 52-inch O.D./36-inch I.D. (8-inch thick wall) reinforced concrete jacking pipe to be jacked into place behind the microtunnel machine. The depth to invert was designed for 18 to 24 feet deep, connecting to new concrete manholes at either end. The distance of the microtunnel was 817 feet. ODOT required a minimum clearance of 15 feet below the freeway surface.

The geotechnical baseline report identified two distinct types of materials for the alignment (mixed face condition). At the beginning of the drive very dense poorly graded gravel in a silty sand matrix with boulders up to 24-inch was expected to be encountered. This soil was classified as a firm to slow raveling formation by our tunneling consultant. After the first 190 feet of the drive the GBR indicated that the face would transition to loose to medium dense silty sand and medium sandy silt (alluvium). This soil was characterized as slow to fast raveling. Mixed face conditions were anticipated at the transition. No groundwater was encountered at the depth of planned construction. Settlement analysis predicted the potential for 1/4" of settlement during construction, although ODOT required no settlement.

Construction: The contractor used driven steel sheet piles (z-shaped) for both the downstream jacking pit and receiving pit. The bottom of the launching pit was graded at the 8.7% to match the sewer design grade. A concrete slab was poured to provide a base for anchoring equipment, and a reinforced concrete thrust block was poured against the back wall to handle 700 tons of jacking pressure. Controlled density fill was placed outside both pit walls to prevent raveling at the tunnel breakouts.

To control the mined face and prevent surface settlements, the microtunnel machine used was a Soltau RVS600, which is a slurry pressure balance machine (closed face). The jacking frame was provided by Wirth, with two 330 ton cylinders at a 4,250 psi working pressure. As specified in the design, the pipeline included one intermediate jacking station (IJS) within the front string of pipes. A second IJS was to be used if required but was not added as the jacking forces remained well below maximum anticipated. The slurry of water and bentonite suspended the cuttings at the face, and permitted their transmission through a 5-inch diameter discharge line. A laser guidance system was used to track of the actual alignment and assist in steering.

The machine was initially built with a set of tools to accommodate the mixed face conditions it would meet, with some cutter tools and some larger openings to address the 18-inch to 24-inch boulders anticipated. Unfortunately, the first launch of the machine stalled and the face had to be exposed within the first 50 feet. The contractor uncovered the head and found no obvious reasons for stalling other than the face was packed with gravel. The machine was reburied and launched again, only to stall a second time. Again, the excavation of the equipment found no obstructions that would have stopped the progress; however, the face of the machine was packed with gravel. The torque required to crush the full head of gravel exceeded the capacity of the equipment. It was decided that a complete re-launch would be completed after the cutting head was modified to close the large openings and the amount of bentonite in the slurry was increased. This proved to solve the problem and the microtunnel was successfully completed.

No settlement was observed in the I-5 freeway, and the work went smoothly once the face configuration was corrected. The concrete pipe was inspected and found to have a significant number of interior defects. The contractor completed preparations on the surfaces at these defects and repaired the areas with synthetic bonding materials and high strength grout to prevent future degradation of the pipe.

Lessons Learned: Mixed face conditions for microtunnels are manageable. The initial design and planned machine configuration may require changes once underway. However, before restarting the machine, the challenges should be well understood and addressed completely.

Reinforced concrete jacking pipe remains a preferred option, but high quality must be maintained throughout the manufacturing and construction process. The concrete pipe received some limited structural damage likely due to stress concentrations and manufacturing issues prior to construction.

9. TRIPLE BOTTOM LINE

BES has decided to visit the economic, environmental and social effects of projects when implementing the strategies for meeting the roles and responsibilities it holds in the City. While this is a project that does not conform to the typical means of sewer infrastructure implementation, several observations for three areas of consideration may be taken from the experience. The use of trenchless technologies certainly played a significant role in having a positive balance in these areas, chiefly by limiting impacts, increasing productivity and providing unique solutions.

Economic Considerations:

- The cost of the project was 10% to 15% higher than normal due to the emergency nature of the work, and the specific portion of work being considered. A measure of the relative cost was taken for the project by having three experts review the contracts for the work prior to starting.
- Higher cost implications of emergency is necessary for a utility required to protect public health and safety.
- No catastrophic impacts to the five vital transportation corridors occurred, which could have had very large economic effects in the area.
- Budgets for rehabilitation and replacement of existing infrastructure should be increased to allow more repairs to be completed prior to emergency conditions emerging.

Environmental Considerations:

- In this case, the chief environmental benefit was to prevent sanitary sewer overflows from the system to the surface from collapsed pipe.
- While there is no possibility of separating the storm and sanitary flows in this basin, an opportunity presented to allow for increased opportunity for stormwater infiltration in a small area of the project, reducing flow to the combined system and providing recharge of the groundwater aquifer.
- As part of the subsurface design process, it was determined that a portion of the project would encounter contaminated soils in areas of excavation. These materials, where encountered, were removed and disposed of at an appropriate facility.
- An environmentally protected zone at the upper end of the project will be enhanced as a result of emergency actions taken to access the sewer for repairs. This will include regrading, and removal of invasive plants species and revegetation of the areas with native vegetation.

Social Considerations:

- The heaviest impacts to citizens came from the large temporary bypass system that was required for 18 months. This included pumps and above ground piping effecting neighborhood walking and driving paths.
- Trenchless technologies did allow for the five large regional transportation roadways to continue operation with little interruption, even during peak commute hours.
- The opportunity was provided to show how important public support is for the important mission of infrastructure management and the cost implications of replacing the aging sewer system.

10. REFERENCES

Duyvestyn,,G., Staheli, K. and Wood, J. (2006), Woods Street Trunk Geotechnical Baseline Report and Investigation Report, *BES Project 8208 Specifications*, Volume 2 of 2.