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Successful Risk Management Through Specialized Construction Inspection for Pipe Jacking

Joel Staheli, Staheli Trenchless Consultants, Lynnwood, WA
Kimberlie Staheli, P.E., Staheli Trenchless Consultants, Lynnwood, WA
Mark Hutchinson, P.E., Staheli Trenchless Consultants, Lynnwood, WA

1. ABSTRACT

Often trenchless designs include significant effort focused on managing risk. Designers attempt to evaluate and mitigate risks during design. Owners and Engineers develop contract documents attempting to implement risk sharing between the Owner and the Contractor to control the risk cost included in the bid. One contract document intended to manage risk is the Geotechnical Baseline Report (GBR). GBRs have had mixed results in fulfilling their purpose in the trenchless industry. Of significance is the minimal guidance on implementing GBRs during construction. Often a construction management team will be tasked with implementing a GBR without any prior knowledge of the baseline development or the Engineer's intention on execution. This has resulted in disputes on GBR definitions, delineations, and the inability to distinguish a differing site condition.

This paper presents case histories where pipe jacking was specified in highly variable soils. To manage geotechnical risks GBRs were developed to define the geotechnical conditions that would be considered Differing Site Conditions (DSC), allowing the Contractors additional compensation should certain conditions be encountered that negatively impact construction progress. Through clear transfer of information and active construction management procedures, including collaboration between the Contractor and the CM team, the GBRs were successfully implemented and the DSC were easily distinguished. This paper will present the details of the projects where obstructions were encountered and will focus on the implementation of the GBR by the CM team, specifically the specialized construction inspector and how the baselines were effectively used to avoid any construction claims on projects where multiple obstructions were encountered.

2. INTRODUCTION

Several projects have been completed in the greater Seattle area using pipe jacking methods in dense to very dense soils containing cobbles and boulders. The Owners and Designers often identified cobbles and boulders or other challenging soils as a significant risk and expend a tremendous amount of effort to develop contract documents that allow risk sharing mechanisms to avoid disproportionate up-front costs and/or large cost over-runs due to claims. Through the evolution of trenchless pipe jacking construction, Owners have expended tremendous efforts to reduce the number of DSC claims by performing significant geotechnical investigations and developing geotechnical baseline reports (GBRs). However, there has been a wide variation in the implementation of GBRs, depending on the interpretation of the construction management team and the Contractor and circumstances have occurred where the GBR did not achieve the intent of the Designer or the Owner. This paper details how CM teams, Design teams, and a specialized construction inspector effectively managed two projects and avoided costly DSC claims by working together to plan and understand how the GBR would be implemented and tracked.

3. 60-INCH PIPE JACKING PROJECT #1 – DESIGN AND CONTRACTING

A number of projects have been constructed in the Pacific Northwest with the objective of reducing the number of combined sewage overflows (CSOs) into the area waters. One such project included a 30-inch diversion sewer and a 12-inch discharge force main. A detailed geotechnical investigation of the project area, including several soil borings indicated subsurface conditions along the alignment were glacial in nature, primarily consisting of ice-contact deposits underlain by glacial till. Approximately 1,000 feet of the new conveyance pipeline was designed as pipe jacking in three drives of approximately 250, 370, and 375 feet to reduce impacts to the traveling public along a busy arterial street, maintain access to homes and businesses, and to avoid an intersection congested with existing utilities.

Drive 1 was primarily within the ice-contact deposits, consisting of dense/hard silty sand and silty clay with trace gravel. Drives 2 and 3 were primarily within glacial till, consisting of very dense/hard silty sand and sandy silt with gravel. Both units had standard blow count N-values ranging from 14 to 50/3”, with an average N value of 36 blows per foot for the ice-contact deposits and 52 blows per foot for the glacial till.

It is widely recognized throughout the Pacific Northwest that glacial outwash and glacial till may contain cobbles (rock particles between 3 and 12-inches) and boulders (rock particles larger than 12-inches) due to the unsorted nature of the sediments as they are deposited directly by glaciers. Ice-contact deposits consist of a mixture of till and recessional outwash, and so may also contain intermittent cobbles and boulders (Troost & Booth, 2008). However, with standard soil investigation drilling equipment using a hollow stem auger, cobbles and boulders are not directly observed during the geotechnical investigation and must be inferred by the high blow counts and local experience within the soil conditions.

The project Owner was interested in sharing the risk of encountering obstructions along the design alignment. They elected to use a Geotechnical Baseline within the pipe jacking specification in conjunction with a Geotechnical Data Report to inform the Contractor how obstructions would be paid within the contract documents. Baseline language was inserted into the pipe jacking specification to provide both a basis for bidding and for evaluating and resolving DSC claims. The specification included the following language to address under what circumstances potential obstructions would be considered for extra payment:

> *Up to six obstructions will be encountered along the casing alignment. Potential obstructions encountered along the alignment that are ingested by the excavation equipment due to their size, location, and orientation shall not be considered one of the six obstructions. Obstructions in excess of the six included in the bid price shall be considered for [extra] payment… (HDR, Inc., 2012)*

4. 60-INCH PIPE JACKING PROJECT #1 – CONSTRUCTION

The Contractor elected to use a 60-inch outside diameter (OD) Akkerman 480B tunnel boring machine (TBM) for the three drives. The cutterhead is accessible from the front of the TBM to easily remove obstructions; however, removal of the conveyor is typically required to access the face of the excavation with hand tools including rock drills, rock splitters, and roto-hammers. Figure 1 shows the TBM in the jacking shaft prior to launch.

Before construction started the CM team, Design team, and specialized construction inspector worked together to ensure an effective plan was in place to monitor and track any obstructions during the three drives. The inspector’s plan was to do a time and motion study where he would track all the Contractor’s activities on site, by the minute, in his field book. Included in his field notes would be a detailed record of the progress of the pipe jacking operations, the Contractor’s personnel and equipment on site, delays, materials encountered, as well as detailed information on any obstructions encountered, including type and size of the obstruction, and amount of time it took the Contractor to remove each one. The inspector’s plan also included taking detailed photos of every obstruction with a tape measure for scale, as well as photos of all other important pipe jacking activities on site.

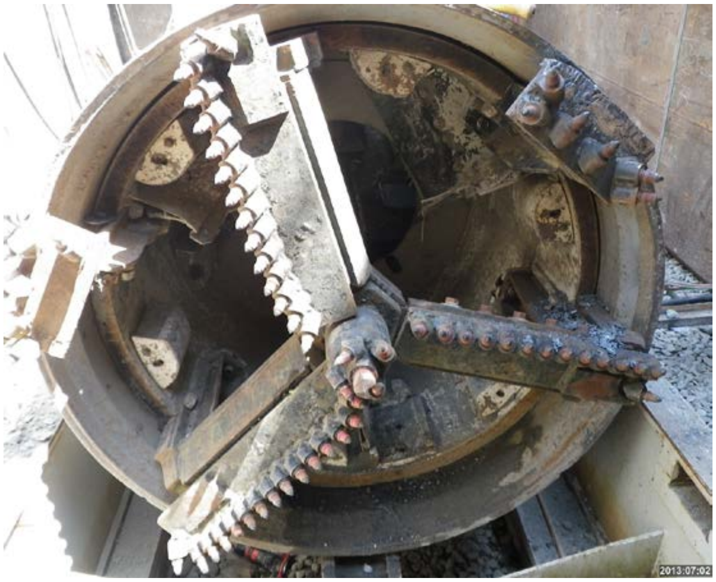


Figure 1. TBM in the jacking shaft.

Before construction was underway, the specialized construction inspector and Contractor met to discuss the GBR to ensure both parties were under the same understanding of the definitions of obstruction. The two parties also came to a unified understanding of when the Contractor would start to claim time and materials if an obstruction was encountered. The understanding they agreed upon was that if an obstruction was hit that stopped the forward progress of the TBM, and if the Contractor made sufficient attempts to remove or engulf the obstruction with the cutterhead, then the Contractor would remove the conveyer belt and begin removing the obstruction by hand. They decided that the time to start tracking time and materials was when the Contractor started to remove the conveyor belt from the TBM to gain access to the face. This preliminary discussion and understanding of the GBR between the Contractor and the specialized construction inspector ended up being critical, as many obstructions were encountered during the three drives.

Drive 1 was approximately 250 feet in length and was anticipated to be primarily through ice-contact deposits. Construction progressed smoothly for the first two 20-foot casing sections, through hard/dense silty clay and silty sand as anticipated. However, around the 40-foot mark the Contractor encountered a rock of about one-foot in the longest dimension, which required them to remove the conveyor belt to access the face to remove. It took just over an hour for them to remove the rock from the excavation face. Approximately 20 feet later, the Contractor encountered a second rock, this one about 9-inches in the longest dimension. The second rock took around 20 minutes to remove from the face. The remainder of the 250-foot drive was completed without incident. The drive took 8 days in total, resulting in an average production of 31.5 feet per day.

Drives 2 and 3 were both approximately 370 feet in length and were both anticipated to be primarily within very dense/hard glacial till. During Drive 2, the Contractor encountered five rocks that required a stop in excavation progress to remove. The smallest was approximately 8-inches in the longest dimension, requiring less than 30 minutes to remove, and the largest was approximately 36-inches in the longest dimension, requiring 16 hours to remove. During Drive 3, the Contractor encountered 15 rocks, the smallest approximately 8-inches in the longest dimension and the largest approximately 24-inches in the longest dimension, taking less than 30 minutes and 8 hours to remove, respectively. The inspector verified and recorded the size and time it took the Contractor to remove every obstruction encountered during the three drives. Table 1 shows a list of all the rocks encountered that involved a stop in forward progress and required the Contractor to remove from the excavation face, along with the associated removal duration. As per the contractual baselines in the specification, all rocks encountered past the initial six were considered eligible for extra payment.

Table 1. List of Rocks Encountered During all Three Drives.

Drive Number	Approximate Length (in the longest dimension)	Approximate Time to Remove
1	12 inches	1-1.5 hours
1	< 12 inches	≤ 0.5 hours
2	< 12 inches	≤ 0.5 hours
2	12 to 24 inches	2-3 hours
2	12 to 24 inches	1.5 hours
2	36 inches	16 hours
2	12 inches	≤ 0.5 hours
3	12 inches	≤ 0.5 hours
3	12 to 24 inches	1 hour
3	< 12 inches	≤ 0.5 hours
3	12 to 24 inches	5 hours
3	12 to 24 inches	10 hours
3	12 inches	≤ 0.5 hours
3	12 inches	1-1.5 hours
3	< 12 inches	1 hour
3	< 12 inches	2 hours
3	< 12 inches	1 hour
3	< 12 inches	1.5 hours
3	< 12 inches	2 hours
3	24 inches	5 hours
3	< 12 inches	≤ 0.5 hours
3	24 inches	8 hours

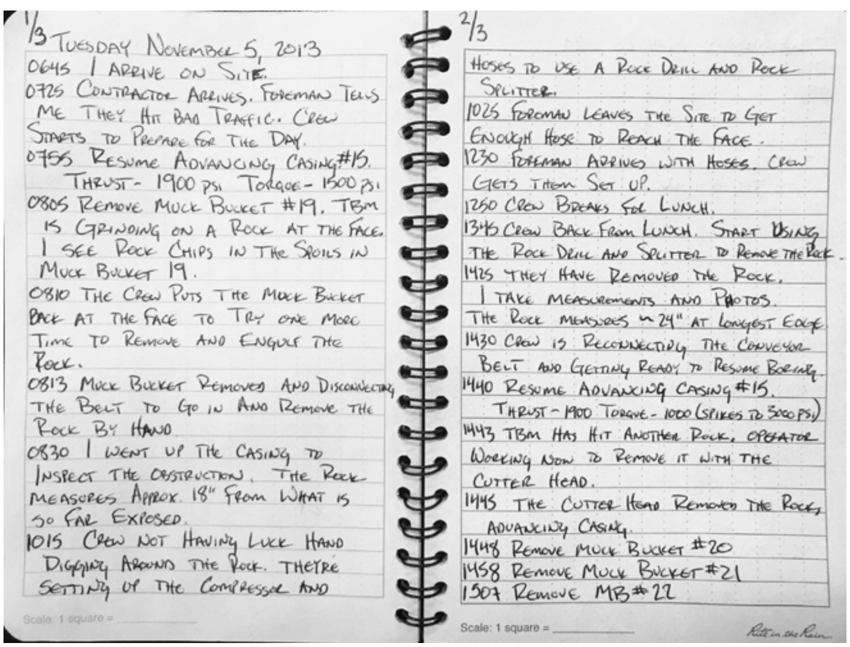
Note:
1) Size and removal times are approximate.
2) Rocks that required more than two hours to remove are shaded.
3) Rocks below the horizontal line were considered a valid DSC.

Of interest is that of the 22 rocks encountered, only six resulted in a delay time greater than two hours. Of the remaining 16 rocks, only two were larger than 12-inches in the longest dimension and thus considered boulders (the remaining 14 rocks were determined to be cobbles). However, as the baselines did not stipulate a size requirement, all of the rocks encountered past the initial six were eligible for extra payment. The detailed information on each obstruction was documented by the inspector in his field notes and with photos and was shared in near real time with the Owner, and Design and CM teams.

Figure 2 shows one of the larger boulders that was encountered during Drive 3, taking approximately 10 hours to remove using a hand-operated rock drill and rock splitter. The picture is taken from inside the shield, by the inspector, looking out at the excavation face. The curved lines on the face of the rock are thin grooves created by the cutting teeth during the revolution of the cutterhead. Due to the density of the soil holding the boulder in place, it was able to remain suspended even after removal of the supporting soil beneath it. The operator and inspector were alerted to the presence of this and other rocks by both surges in the torque pressure on the cutter head and the sound of the scraping of the cutting teeth against the rock as the cutting arm would pass over it.

Figure 2. Boulder embedded in the excavation face. Picture is taken from inside the shield by specialized inspector.

In total, Drive 2 took 15 days to complete and Drive 3 took 24 days, resulting in an average production rate of 25 and 15 feet a day, respectively. Once the pipe jacking was successfully completed the Contractor and inspector reviewed their own field notes and daily reports and independently calculated the amount of time it took to remove all obstructions by hand. Because there was a mutual understanding from the beginning of what constituted an obstruction and how the Contractor's down time would be tracked, the difference between the Contractor's and inspector's calculated time for removing the obstructions was within 15 minutes of each other. The inspector quickly submitted his findings in a report and spreadsheet similar to Table 1 to the Owner. The Owner was then able to use the report to easily determine what the Contractor was owed, according to the Contract Documents. Figure 3 is an excerpt from the inspector's field notes, provided as an example of the documentation and record keeping that allowed for this successful outcome.



1/3 TUESDAY NOVEMBER 5, 2013
0645 I ARRIVE ON SITE.
0725 CONTRACTOR ARRIVES. FOREMAN TELLS ME THEY HIT BAD TRAFFIC. CREW STARTS TO PREPARE FOR THE DAY.
0755 RESUME ADVANCING CASING #15.
THRUST - 1900 psi TORQUE - 1500 psi
0805 REMOVE MUCK BUCKET #19. TBM IS GRINDING ON A ROCK AT THE FACE. I SEE ROCK CHIPS IN THE SPOILS IN MUCK BUCKET 19.
0810 THE CREW PUTS THE MUCK BUCKET BACK AT THE FACE TO TRY ONE MORE TIME TO REMOVE AND ENGULF THE ROCK.
0813 MUCK BUCKET REMOVED AND DISCONNECTING THE BELT TO GO IN AND REMOVE THE ROCK BY HAND.
0830 I WENT UP THE CASING TO INSPECT THE OBSTRUCTION. THE ROCK MEASURES APPROX. 18" FROM WHAT IS SO FAR EXPOSED.
1015 CREW NOT HAVING LUCK HAND DIGGING AROUND THE ROCK. THEYRE SETTING UP THE COMPRESSOR AND

Scale: 1 square = ________

2/3
HOSES TO USE A ROCK DRILL AND ROCK SPLITTER.
1025 FOREMAN LEAVES THE SITE TO GET ENOUGH HOSE TO REACH THE FACE.
1230 FOREMAN ARRIVES WITH HOSES. CREW GETS THEM SET UP.
1250 CREW BREAKS FOR LUNCH.
1345 CREW BACK FROM LUNCH. START USING THE ROCK DRILL AND SPLITTER TO REMOVE THE ROCK.
1425 THEY HAVE REMOVED THE ROCK.
I TAKE MEASUREMENTS AND PHOTOS.
THE ROCK MEASURES ~24" AT LONGEST EDGE
1430 CREW IS RECONNECTING THE CONVEYOR BELT AND GETTING READY TO RESUME BORING.
1440 RESUME ADVANCING CASING #15.
THRUST - 1900 TORQUE - 1000 (SPIKES TO 3000 PSI)
1443 TBM HAS HIT ANOTHER ROCK, OPERATOR WORKING NOW TO REMOVE IT WITH THE CUTTER HEAD.
1445 THE CUTTER HEAD REMOVED THE ROCK, ADVANCING CASING.
1448 REMOVE MUCK BUCKET #20
1458 REMOVE MUCK BUCKET #21
1507 REMOVE MB #22

Scale: 1 square = ________ Rite in the Rain

Figure 3. Excerpt from the inspector's field notes.

5. 66-INCH PIPE JACKING PROJECT #2 – DESIGN AND CONTRACTING

As in the first case study, this project was constructed in the Pacific Northwest. The purpose of this project was to connect new users to the Owner's system, connect existing users to gravity lines without using pumps, and install a key new water main under an Interstate. The 530-foot crossing of the Interstate was designed and specified as an open shield pipe jack at a 64 to 72-inch diameter to convey a 12-inch HDPE sewer main and a 30-inch restrained joint ductile iron water main.

A detailed geotechnical investigation of the project area, including several soil borings indicated the subsurface conditions along the alignment were glacial in nature. The glacial till consisted of very dense/hard sand and silt with gravel, with blow counts in the 50/6" to 50/3" range. As per the Geotechnical Data Report (GDR), the unit was assumed to contain cobbles and boulders.

In addition to the GDR, a GBR was prepared for the trenchless crossing. Among the many goals of the GBR was to assist in administering the DSC clauses contained in the contract documents. As part of this effort, the GBR established three classification groups for boulders to establish what may or may not be considered a DSC, and thus eligible for extra payment. The three classification groups established for boulders were as follows:

Classification #1: This group included all boulders less than 14-inches in diameter in the longest dimension, which were not eligible for extra payment. The GBR states:

> *All costs of any kind incurred in connection with ingesting and excavating boulders that measure up to 14 inches shall be included in the base bid and are not compensable under the Differing Site Conditions Clause or otherwise. The District is not providing specific quantities or specific strengths of boulders that measure up to 14 inches because such boulders are too frequent in number to measure, from a quantitative standpoint, with any certainty* (Shannon & Wilson, Inc., 2013).

Classification #2: This group included all boulders between 14 and 25-inches in the longest dimension, of which the Contractor was instructed to plan on encountering five. The GBR states:

> *For baseline purposes, the Contractor is instructed that it is responsible for all costs associated with excavating and removing five boulders measuring from larger than 14 to 25-inches, whether such excavation and removal is accomplished with the trenchless equipment or requires additional intervention for removal* (Shannon & Wilson, Inc., 2013).

Classification #3: The boulders in this group were considered a valid DSC and thus eligible for extra payment. This included all boulders greater than 25 inches in the longest dimension and any boulders in the 14 to 25-inch range beyond the initial five. The GBR states:

> *Additional compensation under the Differing Site Condition Clause will be considered when the number of boulders measuring from larger than 14 to 25 inches exceeds five and for boulders measuring over 25 inches. To be considered for additional payment under the Differing Site Condition Clause, such boulder must exceed the quantity or dimension state herein (more than five boulders measuring larger than 14 to 25- inches or boulders greater than 25 inches) and stop forward progress of the open shield pipe jacking machine in spite of diligent efforts by the Contractor to overcome such boulder* (Shannon & Wilson, Inc., 2013).

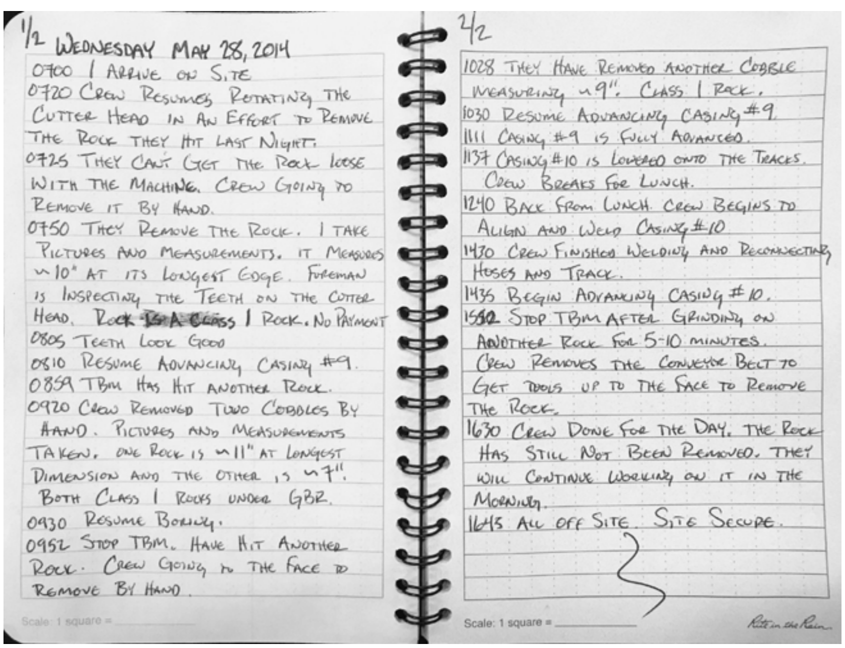
6. 66-INCH PIPE JACKING PROJECT #2 – CONSTRUCTION

Prior to the project bidding, planning for the potential obstructions as shown in the geotechnical documents were discussed with the CM and Design teams and the specialized construction inspector. The inspector planned to use the same record keeping systems he used in Project #1, including a time and motion study recording the progress of the pipe jacking operations, Contractor's personnel and equipment on site, delays, materials encountered, as well as detailed information on any obstruction encountered, including type and size of the obstruction, and amount of time it took the Contractor to remove each one.

Figure 4. Front view of the TBM prior to launch.

When the same boring Contractor that worked on Project #1 was awarded this project it was fairly easy for the inspector and the Contractor to come to a unified understanding of the GBR and how it would be followed and how the recording of time and materials was to be done, in the event obstructions were encountered. The Contractor elected to use a 66-inch OD Akkerman WM66SC TBM. Figure 4 is a picture of the face of the machine, prior to launch, showing the cutterhead.

The Contractor launched the TBM and was able to advance five 20-foot casing sections without encountering any boulders. On the sixth casing section a rock was encountered; however, upon removal it was discovered to be less than 14 inches in the longest dimension and thus in classification group #1 and not eligible for extra payment. Over the next 80 feet of installation, the Contractor encountered eight additional rocks that required stopping the machine for removal. Of the rocks encountered, all were either determined to be cobbles (less than 12 inches) or boulders in the 12 to 14-inch range and thus in classification group #1. The removal of these rocks generally took between 10 minutes and two hours depending on the orientation and placement of the rock with respect to the excavation face.
The inspector verified the sizes of each of these rocks as well as the time it took the Contractor to remove each and recorded it in his field book. Figure 5 is another excerpt from the inspector's field notes depicting the details of the non-pay rocks.


1/2 WEDNESDAY MAY 28, 2014
0700 I ARRIVE ON SITE
0720 CREW RESUMES ROTATING THE CUTTER HEAD IN AN EFFORT TO REMOVE THE ROCK THEY HIT LAST NIGHT.
0725 THEY CAN'T GET THE ROCK LOOSE WITH THE MACHINE. CREW GOING TO REMOVE IT BY HAND.
0750 THEY REMOVE THE ROCK. I TAKE PICTURES AND MEASUREMENTS. IT MEASURES ~10" AT ITS LONGEST EDGE. FOREMAN IS INSPECTING THE TEETH ON THE CUTTER HEAD. ~~ROCK IS A CLASS~~ I ROCK. NO PAYMENT
0805 TEETH LOOK GOOD
0810 RESUME ADVANCING CASING #9.
0859 TBM HAS HIT ANOTHER ROCK.
0920 CREW REMOVED TWO COBBLES BY HAND. PICTURES AND MEASUREMENTS TAKEN. ONE ROCK IS ~11" AT LONGEST DIMENSION AND THE OTHER IS ~7". BOTH CLASS I ROCKS UNDER GBR.
0930 RESUME BORING.
0952 STOP TBM. HAVE HIT ANOTHER ROCK. CREW GOING TO THE FACE TO REMOVE BY HAND.

2/2
1028 THEY HAVE REMOVED ANOTHER COBBLE MEASURING ~9". CLASS I ROCK.
1030 RESUME ADVANCING CASING #9.
1111 CASING #9 IS FULLY ADVANCED.
1137 CASING #10 IS LOWERED ONTO THE TRACKS. CREW BREAKS FOR LUNCH.
1240 BACK FROM LUNCH. CREW BEGINS TO ALIGN AND WELD CASING #10
1430 CREW FINISHED WELDING AND RECONNECTING HOSES AND TRACK.
1435 BEGIN ADVANCING CASING #10.
1550 STOP TBM AFTER GRINDING ON ANOTHER ROCK FOR 5-10 MINUTES. CREW REMOVES THE CONVEYOR BELT TO GET TOOLS UP TO THE FACE TO REMOVE THE ROCK.
1630 CREW DONE FOR THE DAY. THE ROCK HAS STILL NOT BEEN REMOVED. THEY WILL CONTINUE WORKING ON IT IN THE MORNING.
1645 ALL OFF SITE. SITE SECURE.

Scale: 1 square = ______
Figure 5. Excerpt from the inspector's field notes.

Approximately 200 feet into the drive, the Contractor encountered the first boulder larger than 25-inches. Approximately 25.1-inches in the longest dimension, this boulder took approximately 11 hours to remove from the excavation face. Around 100 feet further, they encountered a second boulder larger than 25 inches, this one being approximately 25.3 inches in the longest dimension. The second boulder took approximately 4 hours to remove. Based on size, these two boulders were both in classification group #3. Figure 6a shows a picture of the excavation face with the first boulder visible at the 9 o'clock position. Figure 6b shows the boulder after removal.

Figure 6. View of the boulder from inside the shield (top) and upon removal (bottom). Pictures taken by inspector, note the tape measure for scale.

Table 2 shows a list of all the rocks encountered that stopped forward progress and required the Contractor to remove the conveyor belt to remove the rock from the excavation face. All details were taken from the inspector's notes. Ultimately, the Contractor ended up encountering 14 rocks less than 14-inches in the longest dimension, many of which were determined to be cobbles. However, as members of classification group #1, these rocks were not eligible for extra payment and the Contractor did not dispute this. Two boulders were encountered in the 14 to 25-inch range, and thus in classification group #2. However, since the Contractor was instructed to include the price of encountering five such boulders in their bid, these boulders were also not eligible for extra payment. Ultimately, the Contractor encountered four boulders above 25 inches in the longest dimension (classification group #3) and each boulder was verified and recorded by the inspector through photos and field notes. As per the GBR, these boulders were each considered a valid DSC and thus eligible for extra payment.

Table 2. List of Rocks Encountered that Required Stopping for Removal.

Casing Number	Approximate Length (in the longest dimension)	Classification Group
CS #6	< 14"	1
CS #8	< 14"	1
CS #8	< 14"	1
CS #9	< 14"	1
CS #9	< 14"	1
CS #9	< 14"	1
CS #9	< 14"	1
CS #9	< 14"	1
CS #10	25.1"	3
CS #13	< 14"	1
CS #15	25.3"	3
CS #16	17"	2 (first)
CS #16	14"	2 (second)
CS #18	< 14"	1
CS #20	26.2"	3
CS #21	< 14"	1
CS #21	< 14"	1
CS #21	< 14"	1
CS #25	34"	3
CS #25	< 14"	1

Note:
1) Sizes are approximate.
2) Boulders in classification group #3 are shaded.

In total, it took 34 days to complete the 530-foot crossing, resulting in an average production rate of 15.5 feet a day. Of those 34 days, approximately 3.5 were spent in removing the fourth boulder in classification group #3, which was encountered less than 20 feet from the reception shaft. The inspector's detailed records showed that this boulder took substantially longer than the others due to both the placement of the boulder on the edge of the machine periphery, and due to mechanical problems with the Contractor's dewatering system (Figures 7a, 7b). The detailed records allowed the CM team and Owner to determine how much time was taken to remove the obstruction and how much time was taken to deal with the mechanical problems, which weren't the Owner's responsibility. Despite these difficulties, the pipe jacking work was successfully completed.

Figure 7. View of boulder from inside the shield (top) and with a tape measure for scale (bottom). Pictures taken by the inspector.

It is interesting to note that of the four documented class 3 boulders, one was within 0.1" and another within 0.3" of the specified 25-inch classification. It was very difficult for the inspector to get an exact measurement of the rocks with just a tape measure and there was some disagreement between the Contractor and the CM team on whether the boulders qualified as a class 3 obstruction. The Contractor hired a company to measure the boulders with large, specialized calipers that would give them a much more exact measurement of the boulders. The measuring of the boulders occurred on site and with the inspector present. The inspector took pictures and detailed notes of the findings so there was no guess work later by the CM team or Contractor. Both boulders did end up measuring greater than 25-inches and therefore were considered class 3 boulders, according to the GBR.

7. CONCLUSION

Ultimately, both projects were successfully completed in challenging ground conditions due to the combined efforts of the Contractor, Owner, and Design and Construction Management teams. As anticipated, numerous cobbles and boulders were encountered within the dense glacial soils. On Project #1, of the rocks considered to be a valid DSC (16 rocks total), the Contractor spent between 40 and 45 hours total on removal over the course of the project. For this extra work they were paid approximately $77,700 via change order. On project #2, of the boulders considered to be a valid DSC (4 boulders total), the Contractor spent approximately 55 hours on removal, with the vast majority of the time attributed to removal of the fourth boulder. For this extra work they were paid approximately $54,000 via change order.

The implementation of the GBR was successful on these two projects because the assumptions and details of the GBR were discussed and adopted by the CM team, Contractor, and specialized construction inspector. The inspector's documentation, including detailed photos with scale, rock size measurements with accurate devices, daily time and motion reports, and constant communication through logs, weekly meetings, and correspondence was critical to the success of these projects. It is therefore recommended that future trenchless projects consider the value of a clearly written baseline, as well as having a full-time specialized construction inspector on site who understands the technology and can record and report all activities as they happen.

8. REFERENCES

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Shannon & Wilson, Inc., 2013. Geotechnical Baseline Report; I-5/164th Martha Lake Gateway Sewer and Water Improvement Project, Snohomish County, Washington.

Troost, K.G., and Booth, D.B., 2008. Geology of Seattle and the Seattle area, Washington, *in* Baum, R.L., Godt, J.W., and Highland, L.M., eds., Landslides and Engineering Geology of the Seattle, Washington, Area: Geological Society of America Reviews in Engineering Geology, v. XX, p. 1-35.