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Microtunneling in Glacial Soils- A Historic Look at Risks and Impacts on Contract Price

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ABSTRACT: Some of the most challenging microtunneling in the United States takes place in glacial soils due to the high variability of the material and the risk of encountering cobbles and boulders. Washington State has a long history of microtunneling in these challenging conditions. The first microtunnel in Washington State was designed in 1993 and constructed in 1994 and since then over 40 microtunneling projects have been constructed. Although all of these projects have been completed, many of them have had significant technical and contractual difficulties.

This paper is a historical study of microtunneling in Washington State that examines how the industry has evolved due to challenges associated with microtunneling in glacial soils. It presents an overview of projects that have been completed in Washington and the geotechnical conditions that have been encountered. It presents projects that have faced significant challenges during construction and highlights projects where microtunneling machines have been unable to progress due to geotechnical conditions. On those projects, the construction remedy will be discussed and the contract documents will be evaluated to determine measures that were available to handle contractor claims for extra compensation. The paper will report any contractor claims of a differing site condition.

The paper also evaluates how contract documents have evolved to incorporate risk sharing measures as the industry and Owners have learned lessons. It presents how specifications have changed and how machine designs have been modified to handle the glacial soils.

1. INTRODUCTION

Microtunneling projects have been specified and constructed in Washington State for the last 20 years. The soil conditions in Washington have proven to be challenging due to their glacial (and sometimes alluvial) origin. Many of the projects have been constructed in soils with a significant amount of gravel, cobbles, and boulders of granitic or basaltic origin. Although it is possible to successfully microtunnel through most of these materials with the correct MTBM equipment and qualified operators, it can be far more challenging than microtunneling in soils where gravel, cobbles, and boulders do not exist. As a result, there have been a large number of projects where the microtunneling machines have become stuck or required removal for repair, resulting in large construction claims.

2. EARLY CONTRACTING PRACTICES

When microtunneling projects were first specified in Washington, it was fairly common for project owners and the consultants to use a traditional approach to bidding construction projects. Many of the projects had performance specifications, based on the traditional approach wherein the contractor bears responsibility for its means and methods and thus is expected to select the MTBM that it believes is best suited to the ground conditions indicated in the Contract. In addition, subsurface conditions were indicated mainly by boring logs only. If some form of geotechnical report was used at all, it was not a baseline report but rather a data report that summarized the boring logs.

This traditional approach to bidding microtunneling began to show its weaknesses early in the history of Washington microtunneling projects. This was due in part to the fact that MTBM equipment has inherent limitations. While it can operate successfully in many soils under high groundwater head, it is also constrained by the fact that: 1) The power of the MTBM is limited by its smaller size, limiting the size of motor that can be housed within the machine; 2) The face of the MTBM typically can't be accessed to change or repair cutterheads or remove obstructions, especially under high groundwater head; 3) contractors tend to use MTBM heads and machines that are the most economical to obtain, rather than to design or procure a machine to suit a particular job, especially in a low-bid atmosphere; 4) Soft ground cutterheads on MTBMs tend to get "gravel bound" in soils containing cobbles and gravel; and 5) Abrasive soils tend to cause extreme wear on the face and slurry equipment and to reduce overcut.

Due to these challenges, it became apparent that relying on the traditional approach to bidding microtunneling jobs needed to be re-examined. With increasing frequency, jobs failed due to alleged Differing Site Conditions (DSCs). In claims and litigation, owners began to pay settlements because of alleged ambiguities and inconsistencies in their Contract Documents. For example, a specification based on the traditional "let the Contractor pick its means and methods" school of thought would be paired in the Contract Documents with an array of geotechnical borings that did not fully represent the site geotechnical conditions. The Contractor would argue that the borings failed to warn of the existence of cobbles or boulders because none were encountered in the drilling. On the other hand, the Owner would argue that "everyone knows" cobbles and other obstructions are present in glacial soils and that the Contractor was required to select an MTBM suited to those conditions. This traditional approach led to costly disputes and failed jobs.

3. PROJECTS IN WASHINGTON

Table 1 lists over 40 microtunneling projects that have been constructed within Washington State as of the time that this paper was written. Although the list is meant to be exhaustive, it is possible that other microtunneling projects have taken place in Washington State over the last 20 years, of which the authors are not aware. The vast majority of the project information was collected from the author's files; however, some of the information was collected from the internet, previously published papers, various resumes, and contractor qualification information in the public domain. The authors invite readers to point out any omissions or discrepancies within the table.

Table 1. Microtunneling Projects in Washington State

#	Project Owner	Project Name	Year	MT Dia.* (inches)	Geotechnical Documents	Total Length (feet)	Number of Drives (lengths)
1	Seattle City Light	Salmon Bay Under Crossing Project	1993	39.3	Geotechnical Report with boring logs	1,594	3 (596, 218, 704)
2	Municipality of Metropolitan Seattle (Metro) - Now King County WTD	Southern Transfer / Interurban Project	1993	54	Geotechnical Report with boring logs	2,714	4
3	Alderwood Water and Wastewater District	Swamp Creek Trunk Extension Sewer Project	1994	48	Geotechnical Report with boring logs	1,037	2

#	Project Owner	Project Name	Year	MT Dia.* (inches)	Geotechnical Documents	Total Length (feet)	Number of Drives (lengths)
4	King County WTD	First Avenue South Bridge - Crossing of the Duwamish River	1995	138	Geotechnical Report with Boring Logs	550	1
5	City of Everett	Effluent Improvements Pipe Replacement I-5 Crossing	1996	230	Geotechnical Summary Report with boring logs	230	1
6	City of Everett	Snohomish River and Ebey Slough Crossing	1997	58	Geotechnical Report with Boring Logs	1570	4 (longest = 450)
7	City of Renton	Sunset Sewer Interceptor	1997	30	Geotechnical Report with boring logs	3,314	9
8	King County WTD	South Lake Union CSO Project	1997	61	Geotechnical Report with boring logs	1,489	3 (longest = 650)
9	City of Seattle	Eastlake Storm Sewer	1997	42	Geotechnical Report with boring logs	3,000	8 (longest = 475)
10	Boeing	Boeing Plant Railroad Crossing	1997	36	Geotechnical Report with boring logs	400	1
11	WSDOT	Highway 202 Crossing	1997	36	Geotechnical Report with boring logs	400	1
12	Municipality of Metropolitan Seattle (Metro) - Now King County WTD	Alki Transfer/CSO Project West - Duwamish River Crossing	1998	88	GDR GBR	540	1
13	Private Housing Developer	Mill Creek Project	1998	24	Geotechnical Report with boring logs	200	1

#	Project Owner	Project Name	Year	MT Dia.* (inches)	Geotechnical Documents	Total Length (feet)	Number of Drives (lengths)
14	Bonneville Power Authority (BPA)	Highway 99 Crossing - Cold Creek Crossing	1998	42	Geotechnical Report with boring logs	1,400	2 (700, 700)
15	Southwest Suburban Sewer District	Sewer Main Replacement Phase II	1999	39.3	Geotechnical Report with boring logs	1,070	2 (640, 430)
16	Pierce County Public Works	Spanaway Loop Bypass Project	1999	75	Geotechnical Report with boring logs	2,500	4 (longest = 675)
17	City of Seattle	Bear Creek Crossing (Tolt 2 Project)	1999	72	GDR GBR	392	1
18	City of Seattle	Snoqualmie River Crossing (Tolt 2 Project)	2000	90	GDR GBR	2,200	2 (1,500, 700)
19	Quadrant Corporation	Novelty Hill Basin Trunk Sewer Phase I	2000	39.3 and 48	Geotechnical Report with boring logs	7,497	19 (longest = 750)
20	King County WTD	Bryn Mawr Sewer Project	2000	36	Geotechnical Report with boring logs	2,400	3 (longest ~ 850)
21	Alderwood Water and Wastewater District	Clearview Water Supply Project	2001	62	GDR GBR	1,335	2 (1,150, 205)
22	City of Kent	South 277th Street Improvement Project	2001	76	Geotechnical Report with boring logs	560	2 (400, 160)
27	King County WTD	South 277th Street Trunk Sewer Project	2002	78	Geotechnical Data Report	477	2 (133, 377)
23	Pacific County	Stormwater Ocean Outfall Project, Joe Johns Road	2002	39	Geotechnical Report with boring logs	490	1

#	Project Owner	Project Name	Year	MT Dia.* (inches)	Geotechnical Documents	Total Length (feet)	Number of Drives (lengths)
24	King County WTD	Eastside Interceptor Capacity Restoration Project	2002	90	Geotechnical Report with boring logs	1,900	2 (1,100, 800)
25	King County WTD	Henderson CSO	2002	36 and 72	Geotechnical Report with boring logs	1,000	2 (36" - 260' 72" - 740')
26	King County WTD	Denny Way/Lake Union CSO Project	2003	90	GDR GBR	2,240	3 (970, 760, 710)
28	City of Tacoma - Tacoma Water	Tacoma Second Supply Line - Middle Reach	2004	60	Geotechnical Data Report	702	2 (270, 430)
29	King County WTD	Fairwood Interceptor Project Phase 2B	2005	42	GDR GBR	2,424	7 (174, 180, 297, 299, 315, 405, 754)
30	City of Marysville	I-5 Crossing	2005	36 and 52	GDR GBR	1,700	3
38	King County WTD	Hidden Lake Pump Station	2008	42	GDR GBR	298	1
31	City of Tacoma - Tacoma Water	Tacoma Second Supply Pipeline - I-5 Crossing and Green River Crossing	2006	63	Geotechnical Data Report	1,608	2 (1,100, 508)
32	King County WTD	Juanita Bay Pump Station	2006	90	GDR GBR	140	1
33	Port of Seattle	SE Pond Tunnel	2006	72	Geotech Engineering Report	1,770	2 (680, 1190)

#	Project Owner	Project Name	Year	MT Dia.* (inches)	Geotechnical Documents	Total Length (feet)	Number of Drives (lengths)
34	Alderwood Water and Wastewater District	North Creek Interceptor and Olympus Meadows Trunk Sewer - North Segments	2007-2008	36, 42	GDR GBR	4,065	9 (769, 294, 430, 351, 575, 449, 466, 197, 535)
35	Alderwood Water and Wastewater District	North Creek Interceptor - South Segment	2008	42, 48	GDR GBR	3,412	5 (59, 431, 831, 547, 1,044)
36	City of Mercer Island	Sewer Lake Line and Pump Station No. 4 Replacement Project	2008	60	Geotechnical Report with boring logs	135	1
37	King County WTD	Brightwater East Tunnels - North Creek Connector	2008	72	GDR GBR	2,400	3 (306, 912, 1,178)
39	King County WTD	Brightwater Central Tunnels - Swamp Creek Interceptor	2009	72	GDR GBR	2,300	3 (750, 830, 720)
40	King County WTD	Brightwater West Tunnels - Marine Outfall	2011	84	GDR GBR	540	1
41	Northshore Utility District	LS#10 Replacement Project	2012	60	GDR Baselines in Specification	770	1
42	Soos Creek Water and Sewer District	LS#11 Project	2013	72	GDR Baselines in Specification	435	1

Note: Projects that are shaded had significant change orders or claims.

* Some Project Reference lists MT Machine diameters while others list nominal pipe diameters

GDR = Geotechnical Data Report; GBR = Geotechnical Baseline Report

4. EARLY PROJECTS

When microtunneling projects began to be constructed in Washington in 1993 there was very little microtunneling experience in the United States. At the time there were no U.S. manufacturers of microtunneling equipment: all machines were manufactured in Germany or Japan. As such, there was an extreme lack of experienced operators in the U.S. On some projects, contractors were able to rent/purchase equipment as well as rent operators from the manufacturers in order to learn how to operate the equipment. In those cases, the manufacturer's operators would typically train the contractor's personnel to operate the equipment. This would then result in U.S. operators that were trained on a single project, often in a single soil type. Although this training may have been adequate in some cases, where project soils were similar to those in which the training was obtained, it proved to be problematic on projects with wide ranges of soil conditions or where the operators encountered soils on which they had no training.

In addition to the limited experience by machine operators, the contractors were inexperienced in bidding projects and were not aware of the risks that microtunneling projects carried, especially in soils that were glacially deposited. As such, early projects brought a high number of potential change orders, some of which resulted in large claims paid out.

In the first five years of microtunneling in Washington, between 1993 and 1997, eleven microtunneling projects were constructed with seven of those projects resulting in large change orders or claims, resulting in an overall claim/change order percentage of 64%. Five of the seven change orders were the result of potential/alleged differing site conditions on the microtunneling work; however, two of the seven were change orders related to the construction of the shafts. On these eleven projects, geotechnical reports with some background information and interpretation were provided for the bidders and boring logs were provided; however Geotechnical Baseline Reports were not yet used on microtunneling projects in the Pacific Northwest. Over the next five years, between 1998 and 2002, an additional fifteen projects were constructed - two of which were constructed by private developers from which project information could not be obtained. Of the fifteen projects, eight had significant change orders or claims. One of these projects, the Spanaway Loop By-Pass Sewer project designed by Pierce County Public Works, illustrates the nature of the problem during early microtunneling efforts in the State. This project consisted of microtunneling through glacial outwash soils containing a large number of cobbles. The project was originally bid and awarded to a contractor that was unable to complete the project because the microtunneling machine used could not crush the cobbles. In addition, the specified pipe on the project broke while jacking, well below the allowable jacking force. That contractor was terminated and the project was rebid. A lengthy legal battle between the contractor and the microtunneling machine manufacturer then occurred over the performance of the machine on the project. Pierce County re-bid the project only to have further difficulties. During construction of the re-bid project, the contractor used grout to stabilize the cobbles; however, the specified pipe broke during jacking operations as it had on the original project, resulting in a large claim, mediation, many depositions, and an eventual settlement.

It was during this five year period, from 1998 to 2002 that the use of Geotechnical Data Reports and Geotechnical Baseline Reports began to emerge in microtunnel designs, largely due to the high incident of potential change orders and claims. Of the 15 projects constructed during this time period, four of the projects had contract documents containing GBRs. Of the eight significant change orders or claims, only three of those were on projects containing GBRs.

To summarize, between 1993 and 2002, 15 of 26 microtunneling projects had significant change orders or claims -- approximately 58%.

5. WEAKNESS IN TRADITIONAL APPROACH

The high rate of additional costs on projects illustrated some inherent weaknesses in the traditional approach to contracting used for projects from 1993 to 2002. It was fairly common for owners and their consultants to use a traditional approach to bidding microtunneling jobs. Many of the projects had performance-based specifications where the contractor bears the responsibility for means and methods, and thus is expected to select the MTBM that it believes is best suited to the ground conditions indicated in the Contract. In addition, subsurface conditions were indicated mainly by boring logs only. Owners were just beginning to see that a baseline report might add some value and potentially assist in resolving change orders and claims.

Part of the reason for the high rate of claims noted above (58%) was that microtunneling machines have inherent limitations. While microtunneling machines have operated successfully in many soils under high groundwater head, they are constrained by the fact that:

- The size of the MTBM can limited the power because machines smaller than 48-inches do not have the physical space to house large motors, making it difficult to excavate through large quantities of cobbles or boulders.

- The face of the typical microtunneling machine can't be accessed to change cutters or remove obstructions. Even machines that allow face access only provide limited access and only small changes can be managed from within the machine. Furthermore, the equipment and procedures required are complex, costly, slow, and potentially dangerous.

- Because of the competitive bidding process, contractors tend to use microtunneling machines that are the most economical to obtain, rather than design or procure a machine to suit a particular job. This often leads to less than ideal machine selection.

- Gravel proves very difficult to excavate for "soft ground" cutterheads that cannot develop the necessary torque to rotate when the crushing chamber is filled with gravel. These machines can become "gravel bound" in soils containing large quantities of cobbles and gravel.

- Abrasive soils tend to cause extreme wear on the face, crushing chamber, and slurry equipment that can result in a reduced overcut, problems with the pumps, or the machine becoming stuck.

Due to these challenges, it became apparent that relying on the traditional approach to bidding MTBM jobs needed to be re-examined.

6. CHANGES TO DESIGN DOCUMENTS

As early as 2000, engineers and owners began to change the contract documents, focusing on three primary issues: (1) changing to more prescriptive specifications that included minimum machine requirements and methods, (2) inclusion of pre-qualification or minimum bidder qualification in the specifications, and (3) the use of Geotechnical Baseline Reports (GBR) or geotechnical baseline statements in the specification.

The contract specifications began to include a number of means and methods statements that addressed issues such as (a) the application location and quantities of lubrication; (b) the minimum number and placement of intermediate jacking stations; (c) the coordination between the rate of excavation and the rate of pipe advance; (d) the manufacturing tolerances on the pipe material; (e) minimum safety factors for design of the thrust wall and pipe wall thickness; (f) requirements for setting the laser and recording line and grade; (g) maximum steering deviations over a prescribed distance, etc. The specifications also required the microtunneling contractor to turn in submittal packages that included calculations of estimated jacking forces, face pressure forces, thrust wall design, pipe wall design, and a number of contingency plans should they encounter problems during jacking.

These very specific design elements that included means and methods statements were a way for the Owner to ensure that the contractor was using the best practices for installing the pipelines with microtunneling. Although using best practices is important in all types of soils, it is especially important in glacial soils that are not forgiving due to their very dense nature, their tendency to be very abrasive and their tendency to contain large percentages of gravel, cobbles, and/or boulders.

The contract specifications also began to include pre-qualification, or a minimum bidder qualification, used to guarantee that only contractors with a minimum amount of microtunneling experience were able to bid projects. Early documents set criteria for the contractors that were rather general. For, example, "the contractor shall have completed 'x' number of microtunnel drives at a particular length. As the documents evolved, it was more and more common to see the requirements for the contractor's specific personnel such as the project manager, superintendent, and microtunneling machine operator. These qualification requirements were implemented either by pre-qualification or minimum “bidder responsibility” criteria.

The third trend was the use of GBRs as a geotechnical contract document. The GBR was meant to set a "baseline" of geotechnical risk on which the Contractor's would base their bid price. The baseline conditions are used to establish the existence of a differing site condition and are used in conjunction with the Differing Site Condition Clause in the contract. Any conditions encountered during construction that are more adverse than those set forth in the GBR are subject to potential additional compensation under the DSC clause in the contract. GBR statements were commonly used to approach the risk of encountering boulders. A common GBR example would be to set a baseline for a number of boulders for which the contractor would be responsible. The baseline statement might read, "For baseline purposes, 4 boulders will be encountered along the tunnel alignment."

7. PROJECTS RESULTS WITH INITIAL CHANGES TO THE CONTRACT DOCUMENTS

Between the years of 2003 and 2007, eight microtunneling projects were constructed in the State with only three of those projects having major change orders or claims - a rate of 38%. It should be noted that of the eight projects, 5 of the projects had GBRs and only one of the significant change orders or claims occurred on a project with a GBR.

By the end of 2007, GBRs or baseline indication in specifications began to be used more consistently on microtunneling projects, especially in Western Washington. Between 2008 and present, an additional eight microtunneling projects have been constructed or are in the process of being constructed and a total of five of them used GBRs. Of those, 5 projects have had major change orders or claims - a rate of 63% - reverting back to the high rates seen in the first five years of microtunneling in the state. In addition, all five of the significant change orders or claims are on projects with GBRs.

One cause of this high rate of claims was the way the GBRs were written, sometimes without clearly worded baselines. Many times the Owners intent of the baseline and the way the contractor interpreted the baseline were not in concert. This was especially true when the contract attempted to define an obstruction with particular parameters such as strength and size rather than an object that simply stopped the forward progress of the machine. When this happened, contractors would have dig-ups and argue as to whether they "counted" as obstructions that counted toward the baseline. Additionally, contractors would argue that they had encountered and successfully excavated through boulders that met the definition of "baselined boulders", even though the machine would not get stuck. They would argue that they should receive additional compensation because they excavated through boulders in excess of the number baselines - often arguing that the boulders slowed their progress.

In response to this, contract documents are changing again. First, increased focus on the clarity and precision of the wording of the GBR itself is occurring. Baseline statements are becoming very clear and the impact of exceeding the baseline, and how it will be handled in the contract, is being spelled out. For example, newer baseline statements might read, "For baseline purposes the contractor is responsible for all boulders less than 24 inches in the longest dimension. Any boulders over 24 inches in the longest dimension that stop the forward progress of the microtunnel machine will be eligible for additional compensation under the Differing Site Conditions clause." With this baseline, the contractor would be responsible to include all costs for boulders up to 24 inches in the longest dimension, but would be compensated for any boulder greater than 24 inches that stopped the progress of the machine.

Second, contract documents are beginning to contain both minimum requirements and prohibitions for machine and equipment selection. For example, when the trenchless engineer has determined that certain types of microtunneling machines will be the most successful and certain type of cutterheads and associated equipment are believed to be necessary for success, the specification will establish mandatory minimum requirements for the equipment. This addresses the unique risks associated with microtunneling jobs and is therefore worth considering on any such job.

In addition, when the trenchless engineer establishes that certain cutterheads will likely fail in the anticipated ground conditions, the specification will be written to prohibit the use of specific machines – expressly. The most typical example is to prohibit the use of an underpowered soft-ground head on a microtunneling machine when the trenchless engineer is aware of the presence of gravel, cobbles and boulders in the formation through which the microtunnel will progress. In such cases the specification would include the following: a minimum base diameter such as 48-inches; minimum torque requirements; a particular cutter head design, such as a combination cutterhead with both rock cutters and bits/picks; small face openings limiting the size of particle that can enter the crushing chamber; a reinforced periphery to protect the overcut; and hard facing on the crushing chamber.

8. CONCLUSIONS

The analysis of microtunneling projects in the State of Washington in glacial soils shows that since 1993 at least 42 projects have been constructed or attempted. Of these projects, 23 are known to have had major change orders or claims (note that four of the projects were for private owners for which no information could be obtained). This equates to a rate of 55% of the projects with major change orders or claims. As the industry has advanced, Engineers and Owners have modified contract documents in an attempt to reduce the change order/claims rate. As more projects are specified, we will continue to see changes to contract documents as Engineers and Owners search for the optimum contracting vehicle that can deliver microtunneling projects at bid prices.

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