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GRADE CONTROL FOR MICROTUNNELS IN VERY LOOSE AND VERY SOFT SOILS

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ABSTRACT: Microtunneling has made many advances over the years and is now used in a variety of difficult ground conditions. One of these is low (zero) blow count soils. These very loose (non-cohesive) and very soft (cohesive) soils are prone to increased settlement, overexcavation, and diving of the microtunneling machine with loss of grade control. The first reaction of most owners and engineers is “let’s do ground improvement,” with jet grouting often being their solution. The result is a substantial increase in construction costs. The introduction of grout also changes the chemistry of the ground and can “kill” the slurry used by the machine in no time. There are many other solutions with far less cost impact. These methods include the use of:

- Pilot tube guide rails
- Pilot tubes to guide the microtunneling boring machine (MTBM)
- External or internal pull rods to improve grade control
- Pipe buoyancy compensation
- Lighter-weight machines
- Controlled excavation rates
- Lightweight and cone-shaped cutter wheels
- Articulated machines
- Extendable overcutters
- Well thought out designs

This paper discusses the various methods and evaluates their effectiveness in controlling grade in very loose to loose and very soft to soft soils.

1. INTRODUCTION

Microtunneling has made many advances over the years and is now used in a variety of difficult ground conditions. One of these ground conditions is low (zero) blow count soils. These very loose (non-cohesive) or very soft (cohesive) soils are prone to increased settlement, overexcavation, diving of the MTBM with loss of grade control, and difficulty in regaining grade because of insufficient steering reaction.

The greatest risk for the machine to dive in low blow count soils occurs when it is launched from a shaft. Ground disturbance and slow mining progress just outside a shaft often create conditions that will not adequately support the machine or will lead to over excavation. Therefore, ground improvement around shafts is often warranted as part of launch preparation.

If these soils are encountered elsewhere in a drive, the first reaction of most owners and engineers is “let’s do ground improvement,” with jet grouting often being their solution. The result is a substantial increase in construction costs. There are number of ways to deal with very soft soil that do not require ground improvement. This paper looks at various methods to help maintain grade control in soft ground conditions.

2. DEFINING VERY SOFT SOILS

Difficult ground conditions in microtunneling are generally viewed to be problematic soils that could lead to settlement of the MTBM or provide no passive resistance to affect steering corrections for line and grade. The Standard Penetration Test (SPT) is perhaps the most common field test performed during site investigations. The SPT is a numerical resistance value that includes the dynamic end resistance and the frictional side resistance (Lutenegger, 2008). SPT N-values are used to establish correlations with a variety of engineering properties of soils. Most of the correlation data have been made using N60 values (60% efficiency).

SPT-N values are obtained with an automatic hammer or a cat-head and hammer system. If low blow count materials are anticipated, SPT sampling should be performed in strict accordance with ASTM D 1586 (cat head and hammer and “A” rod at 3 lb/ft [4.5 kg/m]). The automatic hammer typically is coupled with heavier “NWJ” rods (11 lb/ft [16.4 kg/m]) and a hammer that weighs around 350 lb (159 kg) as compared to the 140 lb (64 kg) hammer in the SPT test. Using the heavier rods and a heavy hammer could lead to N-values being artificially low and low blow count material being characterized too conservatively, as very loose to loose or very soft to soft. However, in some geographic areas, drillers primarily use automatic hammers. If an automatic hammer is used, the energy delivered should be measured so an accurate correction factor can be determined to correct N80 values to N60 values. Also, borehole vane shear tests should be considered in very soft clay and silt to provide a measure of shear strength and machine-bearing capacity independent of the SPT N-value.

Even though there is a standardized procedure for performing the test (ASTM D1586), anyone who has worked the back end of a drill rig recording blow counts can probably attest to the variability of mechanical, environmental, and human factors under which SPT N-values are obtained. One unique SPT N-value that raises concern is the N=0 value. The implication here is that the soil does not offer enough frictional or end resistance under the weight of a 140 lb (64 kg) hammer and accompanying rods. These are sometimes called “weight-of-hammer” soils. By virtue of confinement and overburden pressure, soil mechanics theory would support the notion that the soil should attain some strength because of overburden weight and consolidation settlement. Strength can be assessed by performing vane shear tests as suggested above. Regardless of whether the N-value is 0 or a value slightly higher than 0, the soils are prone to settlement or are too weak to provide sufficient passive resistance to affect steering corrections. Kwong (2009) offers an SPT N-value of 4 as a rule of thumb to demarcate the point where soft (cohesive) or loose (non-cohesive) soils would be prone to settlement or not provide sufficient resistance to affect steering corrections. For purposes of this paper, soils with an N-value of 4 or less are referred to as low blow count soil.

3. GROUND IMPROVEMENT

When low blow count soils are encountered on a project, a designer’s first thoughts are typically to incorporate some form of ground improvement. The problem with this approach is that it can generate a whole new set of problems, which could be more difficult to address during construction.

Ground improvement methods typically considered include jet grouting, compensation grouting, soil-cement mixing, and dynamic compaction. These improvement methods are designed to improve soil strength by increasing the density of the soils or modifying the in situ composition of the soil. The problem is the density or in situ composition may not be uniformly improved. There may still be low blow count soil or soft zones where MTBM settlement and pipe flotation could still occur. The introduction of cement and grouts into the formation will also

change the soils' strength characteristics. When we attempt to change the strength, soft and hard zones can be created, which behave like mixed-face conditions. It is well documented that soft/hard zone interfaces can lead to overexcavation of the soft zones and formation of voids and sink holes exposed at the surface. Non-uniform soft to hard interfaces can also cause steering difficulties if the MTBM deflects off the improved material. The configuration of the improved ground is a consideration for assessing uniformity of the improved ground. For example, the physical process of jet grouting or compensation grouting can preferentially erode weaker materials and result in bulges of harder material in the improved zone. In comparison, the soil mixing process is more capable of uniform improvement zones because it does not utilize high pressure to erode or displace the ground. The other consideration is set times. Grouts will get stronger with time, so how quickly after grouting should the microtunneling be done? What happens if the project is delayed: Will the improved ground be harder than originally anticipated?

On many projects, the new installation is sharing space with other utilities. If ground improvement methods are used, these other utilities will be exposed to the effects of the new work. These utilities could settle, heave, and become compromised. Grout under pressure is looking for voids to fill, whether in the ground or in existing piping. A crack in an existing pipeline could lead to a major third-party impact.

Even if ground improvement methods are to be used, should the ground be improved as a series of columns or within a horizon? How wide and deep should the ground improvement work extend? These are important questions because the machine "views" the soft ground surrounding the improved zone as a preferential medium. Some examples showing ground improved zones using jet-grouted columns are included in Figure 1. Flat-faced panels are also possible using the cutter soil mixing (CSM) method. This method is currently being used for microtunneling machine support in soft soils on the Balch Consolidation Conduit in Portland, Oregon. Regardless of the method, if a well-defined corridor along the pipe alignment is improved, the cost could be very high.

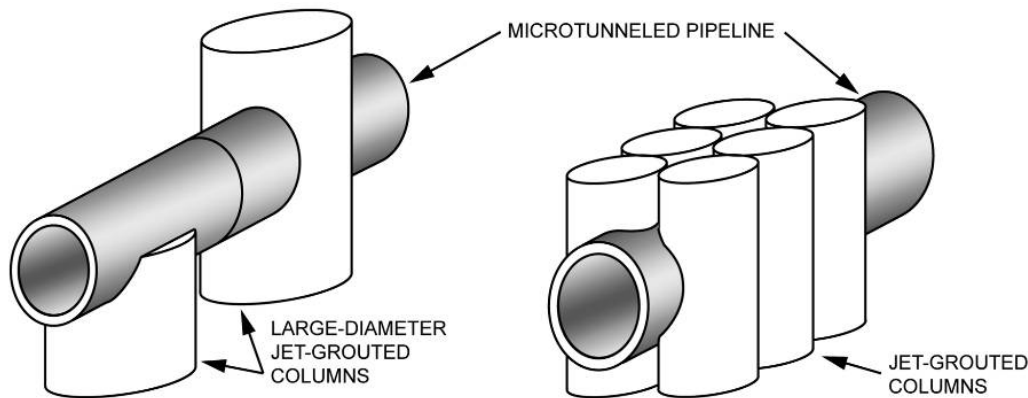


Figure 1. Examples of ground improvement approaches used to maintain grade control during microtunneling.

Besides the potential for mixed face conditions, the introduction of cements and grouts into the ground will change the chemistry. Microtunneling supports the tunnel face with bentonite slurry. Adding cement to the soils will neutralize the positive ions in the slurry, causing the slurry to lose its ability to support and transport the excavated ground. The addition of cement into the ground will result in an increased need to change and replace the slurry used on the job. This will result in higher costs for materials and disposal.

4. VARIOUS MEANS TO HELP CONTROL GRADE

With low blow count soils, the ground is in a loose state, and when the microtunnel pipeline is being installed the ground is being disturbed. The disturbance will either densify, loosen, or maintain the in situ state of the ground. The weight of the machine wants to compact the ground underneath it, whereas the pipe is prone to float, which is likely to result in machine settlement, pipe flotation, and possibly sagging of the pipeline. The goal of the microtunneling installation in low blow count soil conditions is to compact and densify the soil beneath and around pipeline, preferably during the jacking process. If we can densify the ground, we are more likely to maintain the design grade.

Steps should be taken by the engineer during design and by the contractor during construction to ensure the ground is being compacted by the microtunneling operation. The first step in the design process is to ask if microtunneling is the right construction method. In low blow count soils, it might be better to use the pilot tube method or pipe ramming. Both methods eliminate the need for a heavy machine at the front end. Both methods incorporate compaction and ground displacement at the front end of the pipeline. These concepts allow the ground to be densified during the pipeline installation process. This type of approach needs to be incorporated into the microtunneling process.

Other concepts to consider include:

- Developing a support system
- Developing a rigid pipeline
- Controlling advance and excavation rates
- Operating the machine continuously
- Using lightweight machine and pipe
- Using lightweight cutter wheel
- Providing pipe buoyancy assistance
- Using an active steering joint
- Using an extendable copy cutter
- Selecting the appropriate design grade
- Using a two-pass system

4.1 Developing a Support System

The pilot tube method involves installing a pilot tube into the ground. The 6-in. (150-mm) diameter pilot tube has an angle point that displaces and compacts the soil in place. The compaction effect of the pilot tube should increase the density of the soil around the tube. The pilot tube is lightweight, and the accuracy and positioning of the tube are known for the entire length of installation. Pilot tubes could be installed in the invert to serve as guide rails and as a support system for the microtunneling. This concept is shown in Figure 2.

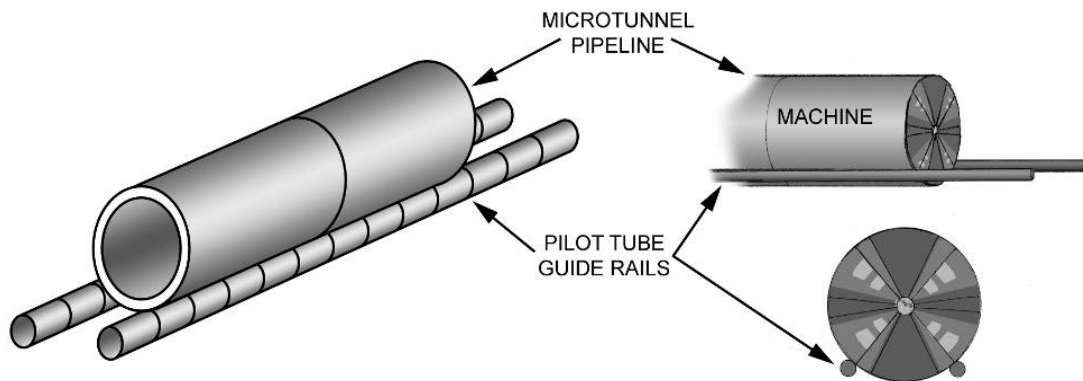


Figure 2. Using pilot tubes as guide rails for the microtunnel.

The merit of this concept for support is that the grade of the microtunneling can be continuously monitored by the theodolites and light sources in the pilot tubes. If deflections are noted by the machine operator, i.e., losing sight of the pilot tube light ring, the excavation process of the MTBM can be stopped and the MTBM pushed forward to compact the soil in front of the machine. The drawbacks to this concept are that pilot tube drive lengths are limited to about 500 ft (152 m).

In tunneling, pipes are installed in the tunnel crown to form a pipe canopy. The use of pilot tubes in the invert is like creating a pipe cradle. While Figure 2 shows the use of two pipes for a cradle, it could be made of three, four, or five

pipes. These pipes could also be interlocked to improve the stability of the cradle. The pilot tubes would also be a perfect system to add cables or rods to pre/post-tension to make the support system stiffer.

A variation of the pipe cradle is to directly replace the 6-in. (150-mm) diameter pilot tube with a plastic grout sleeve before microtunneling. Using a packer system, compensation grouting can be installed along the grout sleeves. Figure 3 shows this concept. Compensation grouting should be completed before the pipeline is installed because the grout could seize the pipe and prevent completion if done during tunneling, or worse, plug the machine chamber.

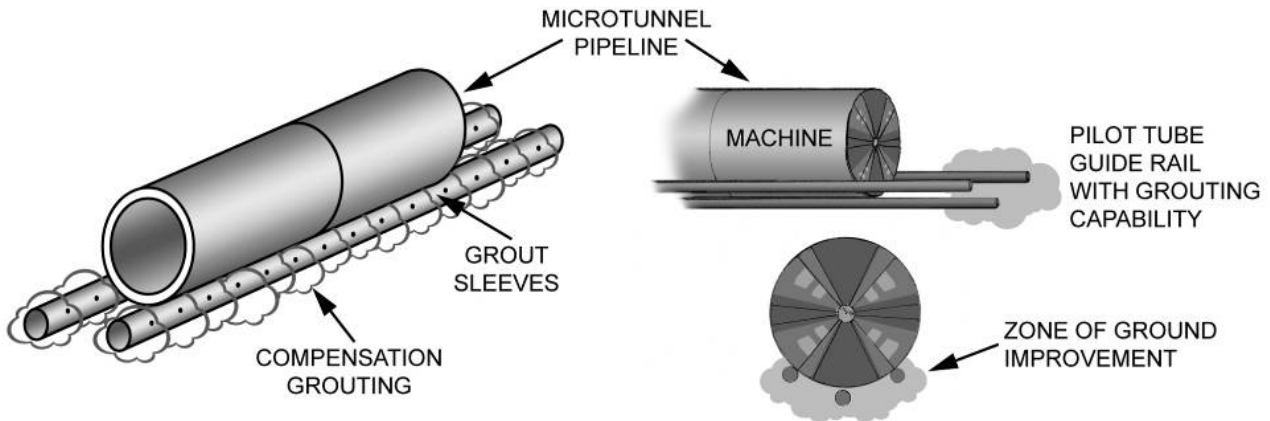


Figure 3. Using pilot tubes in the invert to install grout sleeves and grout for grade control.

While this approach incorporates grouting, the grout is systematically being placed along the pipeline alignment. The location of the grout is controlled. The ground improvement is within the best horizon and minimizes the potential for full-face or large mixed-face conditions. The additional benefits of this support system are that there are no additional surface work and traffic disruptions. The installation of the grout sleeves and grouting are completed from within the jacking and receiving shafts.

A further variation of this concept for support is a combination of the methods shown in Figures 2 and 3. The pilot tubes are installed as guide rails/support for the microtunnel. The main pipeline is installed using a microtunnel machine and jacked pipe. Sagging and settlement of the pipeline is possible and allowed to occur. After a survey of the pipeline is made, the pilot tube lines are replaced with the plastic grout sleeves. Post grouting is then undertaken to inject compensation grout to lift and reposition the main pipeline at specific locations that are off the design grade. Once the pipeline grade is acceptable, the grout sleeves are backfilled with grout and left in place.

4.2 Developing a Rigid Pipeline

The microtunneling process involves jacking/pushing pipe into the ground behind a machine. The pipe can be of a variety of materials and includes a segment length to allow placement into the jacking shaft. Under normal ground conditions, simply pushing the pipe ends forward keeps the pipe joints engaged. The joints are not fixed, and rotation and deflection of the joints are possible. Maintaining flexible joints allows for the redistribution of jacking forces from one pipe to the next.

However, these degrees of freedom are a disadvantage when the ground conditions consist of low blow count soils. The microtunneling machine settles or dives, and pipe floats during the jacking process. The flexible joints provide no resistance and allow the loss of grade to occur. To counter the joint freedom, we need to stiffen up the joints. One way to accomplish this is to use a steel casing.

Steel casing is either welded or jointed together with Permalok® joints. The joint is rigid. Steering of a steel casing is difficult because the pipeline is so stiff relative to the soil. For low blow count soil conditions, this will be a benefit. The pipeline is acting as a cantilevered beam in the ground. If the microtunnel drive could be launched from

the high side and level, the machine and steel casing could actually be allowed to settle a little to build in the design grade needed for the pipeline.

This concept of a rigid pipeline could be further developed if the designer does not want to use a steel casing. Dywidag bars could be added to the back of the MTBM (Figure 4, Left). The bars would extend inside the pipeline, for example, in the crown, springlines, and invert. Each trailing jacking pipe would include a steel plate to allow the ends of the Dywidag bars to be locked off, placing the pipe string into compression. The pipe joints would be prevented from deflecting. The bars are similar to tie-rods. As each new jacking pipe is added, the bars can be extended and the pipeline recompressed. New tie-rods/bars can also be added. Once the pipeline is installed, the tie-rods can be removed. Installing and adding to the tie-rods/bars inside the pipeline could be difficult and time consuming. Another alternative would be to add pull rods on the outside of the pipeline. This approach is already used by auger boring contractors, as shown in Figure 4 (Right).



Figure 4. Examples of rods used for steering control. Dywidag bars inside the casing to make the casing stiffer (left). Pull rods used for steering control of auger bores (a similar concept can be included with microtunneling) (right).

In the example shown, the pull rods are used to steer the steel casing and auger boring. However, the same concept could be used for the MTBM. The pull rods can maintain a compressive force along the pipeline, keeping the pipe joints fixed during the jacking operation.

Another way to develop a rigid pipeline system is to use the pilot tube method in combination with the MTBM (Figure 5). The lightweight pilot tube is installed at the desired line and grade. The installation of the tube helps compact some of the soil within the microtunneling horizon. Instead of augers being attached to the pilot tube, a microtunneling machine is attached. The machine excavates the soil at a controlled rate based on the advance of the pipe and circulation of the cutting (see Section 4.3). If a rigid pipeline is then attached to the machine, the entire length of pipe from the jacking shaft to the receiving shaft is rigid and should not be prone to diving during excavation, even if the soils are loose. The weak point is the connection between the pilot tube and MTBM, but this connection can be reinforced or an additional step can be added.

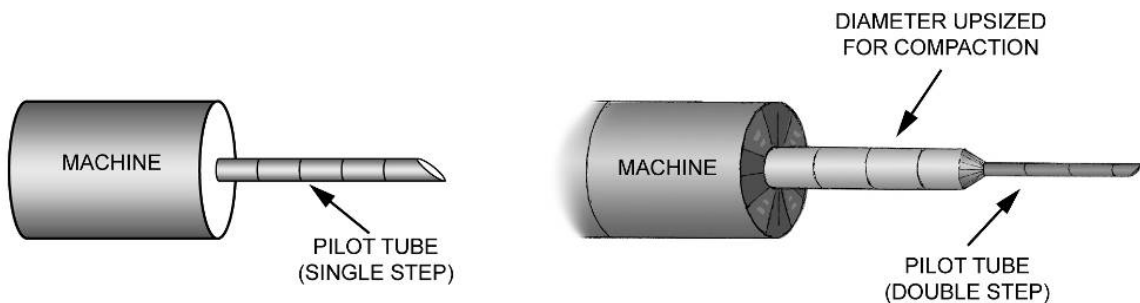


Figure 5. Use of a pilot tube in combination with an MTBM (single step or double step) will create a stiff pipeline system between the jacking and receiving shafts during installation.

It should be remembered that anytime the in situ stress condition is changed in low blow count soils, through displacement or adding weight (i.e., grout), the concern over consolidation settlement has to be addressed. The magnitude and timeframe for consolidation settlement are certain to be less because the stress change is localized. Nonetheless, the design must consider the ramifications of changing the in situ stress condition to ensure the long-term performance of the new pipe installation.

4.3 Controlling Advance and Excavation Rates

Microtunneling advance rates tend to be faster in low blow count soils than in soils that are firmer or with higher density. The MTBM needs to be operated in a narrow range for slurry pressure and earth pressure because overexcavation and heave occur much easier in low blow count soils than in dense or firm soils. In saturated low blow count soils, the machine operator may need to operate with special procedures in order to avoid settlement or stay within the line and grade requirements. The machine operator may need to advance without excavation. This means rotating the cutter wheel and advancing the MTBM without allowing the slurry to circulate to the face and mix with the spoils, thereby not excavating. The machine operator circulates the slurry in the event the jacking forces start to increase to where the pipeline may seize or the face pressure increases to the point where heave may occur. Advancing the machine and pipeline without excavation will densify and consolidate low blow count soils.

The selection of the MTBM's cutter wheel revolutions per minute (RPM) will be important. If the RPMs are too high, portions for the soil in front of the machine can liquefy. Slow rotation of the cutter wheel is a required in low blow count soils. Table 1 provides typically range of RPMs for different MTBMs. The use of a bi-directional cutter wheel does not appear to make a difference in low blow count soils to control machine dive.

Table 1. Approximate weights and lengths for various MTBM models and nominal sizes.

Mfg/ Model	Outer Diameter				Capability Description
	31 in. (780 mm)		63 in. (1,600 mm)		
	Weight, lb (kg)	Length, in. (mm)	Weight, lb (kg)	Length, in. (mm)	
Akkerman	9,000/4,900 ⁽¹⁾ (4,100/2,300)	123/121 (3,125/3,075)	44,000/45,000 ⁽²⁾ (20,000/20,400)	154/139 (3,910/3,530)	Mixed ground; Full-face rock ⁽³⁾
Herrenknecht	8,400 ⁽⁴⁾ (3,800)	83/87 (2,100/2,210)	28,660 ⁽⁴⁾ (13,000)	148/126 (3,760/3,200)	Mixed ground; Full-face rock ⁽³⁾
Iseki TCS	8,400 ⁽⁵⁾ (3,300)	118 (3,000)	39,700 ⁽⁵⁾ (18,000)	158 (4,015)	Full-face rock
Iseki TCC	5,900 ⁽⁵⁾ (2,700)	92 (2,335)	36,000 ⁽⁵⁾ (16,300)	135 (3,430)	Mixed ground
Iseki TCM	6,600 ⁽⁵⁾ (3,000)	125 (3,175)	27,800 ⁽⁵⁾ (12,600)	133 (3,380)	Sand, gravel, cobbles
Iseki MEPCB	5,600 ⁽⁵⁾ (2,500)	100 (2,540)	17,700 ⁽⁵⁾ (8,000)	112 (2,845)	Silts and sands

¹ MTBM is mixed-ground capable only

² Component mounted in first pipe

³ Requires different cutter wheel and tooling for different ground conditions

⁴ Individual weights not provided

⁵ No trailing can required

4.4 Operating the Machine Continuously

Continuous operations are another important component for grade control on drives through low blow count soils. An MTBM that sits idle for a period of time may begin to settle under its own weight. Maintaining constant forward motion of the machine may reduce the risk of machine settlement through the duration of the drive. If continuous operation is not feasible, make sure the upward direction steering cylinders are retracted prior to ceasing operation. This will allow for some upward steering upon start-up and reduce some of the bearing pressure at the front of the machine.

4.5 Using Lightweight Machines and Pipe

Microtunneling in low blow count soil requires analyzing which MTBM is best for the particular project and the pipe string that follows. The analysis includes the weight of the MTBM and pipe for buoyancy and the bearing capacity of the soil. The following discussion assumes that the excavation is below the groundwater. If the project will be completed in dry ground, then the owner may want to consider using a different construction method.

The weight of the MTBM as manufactured (Table 1) and pipe are relatively simple to determine. The MTBM can be weighed before being placed into service, and it needs to be weighed in the same condition that it will be in when it goes into the ground. This includes any shims, tooling, and trailing can(s), if used. The trailing cans need to be weighed separately to understand how the weight is distributed. Each MTBM is different, but typically 60 to 70 percent of the weight will be in the front 3 to 4 ft (0.9 to 1.2 m), or cutter wheel end of the MTBM. Most pipe weights can be determined from a pipe manufacturer's specification sheet (Table 2) or fabrication drawing. The pipe must be an acceptable jacking pipe and of an appropriate design for the project.

Table 2. Typical weights for nominal 30- and 60-in. outside diameter microtunnel jacking pipe.

Material	Jacking Pipe Outer Diameter			
	30 in. (760 mm)		60 in. (1,525 mm)	
	Wall Thickness, in. (mm)	Weight, lb/ft (kg/m)	Wall Thickness, in. (mm)	Weight, lb/ft (kg/m)
Steel ⁽¹⁾	0.375 (10)	119 (177)	0.75 (19)	475 (707)
CCFMP ⁽²⁾	1.53 (39)	137 (204)	2.13 (54)	380 (565)
Polymer Concrete	2.8 (71)	234 (348)	5.375 ⁽³⁾ (136)	869 ⁽³⁾ (1,293)
Vitrified Clay	3.2 (81)	251 (373)	⁽⁴⁾	⁽⁴⁾
RCP "C" wall	3.75 (95)	365 (543)	5.75 (146)	1,010 (1,503)

¹ Permalok™

² Hobas™

³ 58 in. (1,473 mm) OD

⁴ Pipe size not available

The first set of calculations needs to be completed for a static situation to determine if the MTBM, trailing can(s), and pipe are individually buoyant. If any of these components are buoyant, then the point where positive buoyant forces equalize the negative buoyant forces needs to be determined. The buoyant forces then need to be determined over the remaining portion of the drive and with the MTBM removed at the reception shaft. The second set of calculations must be completed for the bearing capacity of the soil in a static situation. Again, this needs to be completed for each of the components individually. If any of the components exceeds the bearing capacity, the point where buoyant forces equalize the weight needs to be determined. The third set of calculations must determine if any of the component buoyant forces exceeds the confining pressure. If any of the components exceeds the confining pressure, the pipe may float in the ground. The fourth set of calculations must determine what will happen if the soil liquefies and loses its bearing capacity. The confining pressure must equal zero, otherwise liquefaction is not being assumed. These calculations must be completed to determine how far behind the MTBM the buoyant forces are neutral and to determine the buoyant forces for the entire pipe string once the MTBM has been removed at the receiving shaft.

In order to determine the final static condition, these buoyancy calculations need to be completed for the composite tunnel structure in an empty state, normal operating condition, and full capacity. The same buoyancy calculations need to be completed for any residual structures like manholes and access points. These structures need to reflect the actual construction as completed by the contractor to ensure the pipeline does not shear at the structures because of buoyancy of the composite tunnel structure or settlement of the residual structure.

A lightweight MTBM would have a lower total weight. The result of reducing weight is that the MTBM's capability is reduced. Weight is saved by using smaller motors and gear boxes and, in some cases, removing its crusher. Removing or reducing components also allows for reducing structural components, further reducing machine weight. The idea of adding fins to the MTBM has been used, with the fins providing increased bearing surface to help distribute the machine weight. The problem with fins is it adds weight with no pronounced benefit. Table 1

provides the weight of six styles of MTBM in two nominal outer diameters (31 [780 mm] and 63 in. [1,600 mm]). The first and second MTBMs are designed for standard mixed soil, and with the proper cutter wheel and tooling, can be made rock capable as noted; the third is rock capable; the fourth designed for mixed soil; the fifth is granular soils restricted; and the sixth is designed for low blow count soils. This last MTBM does not have a crusher and therefore cannot size material and cannot progress through any material larger than about 2 in. (50 mm).

4.6 Using Lightweight Cutter Wheel

The center of mass (center of gravity, CG) of an MTBM is an important consideration in evaluating the machine weight loading on the soils. Machine manufacturers typically indicate the center of mass for the major machine section components. The center of mass is typically closer to the front of the machine because of the weight of the drive motors, bearing, and cutter wheel. The closer the center of gravity is to the front of the machine, the more prone an MTBM is to diving. An MTBM with a center of gravity located back towards the pipe sections has a reduced tendency to dive. This configuration also takes advantage of buoyancy (particularly buoyancy of the pipe) to reduce the overall machine loads on the soils, which improves steering.

One method for moving the center of mass away from the front of the MTBM is to use a lightweight cutter wheel. Modern machines are typically configured with cutter wheels that are suitable for a wide range of ground conditions so that contractors can bid a wide range of projects with their equipment. In low blow count soils, a cutter wheel specifically designed for soft ground can be up to 50 percent of the weight of a mixed ground cutter wheel. Two types of cutter wheels were utilized on the Overpeck Valley Parallel Sewer Project in New Jersey. The soft ground cutter wheel, used in varved clays, was around 7,000 lb (3,175 kg) lighter than the mixed ground cutter wheel (Cai, 2009).

In soft soils, a lightweight cutter wheel might consist of a spoke type arrangement with large openings (Figure 6, Left). The excavated material can be allowed to pack into the front end of the machine to help densify the tunnel horizon. A caveat is that a lightweight, open-style cutter wheel, if not operated correctly (i.e., the revolutions per minute are too high), could over excavate the low blow count soils. In these soils, the breasting capabilities of a more closed configuration are typically required. A middle ground approach common in the tunneling industry is to remove or swap out various cutters depending on the type of ground. Removing disc cutters and covering the openings with a plate reduce the weight of a cutter wheel in low blow count soils.



Figure 6. Examples of lightweight cutter wheels. Simple open-style cutter wheel design to allow the machine to be pushed forward and compact the loose soils with minimum rotation (left). Iseki MEPCB with the face completely closed and in a neutral position to provide breasting and compaction (right).

4.7 Providing Pipe Buoyancy Assistance

If the bearing capacity of the soils is insufficient to support the MTBM weight, an alternative to ground improvement could be to use tie-rods to lock the machine to a string of buoyant jacking pipe. The internal tie rods need to be placed so the entire pipe circumference is in compression. The bars can be tightened when the buoyant forces need to be transferred and loosened when steering deflection in the pipe joints is required. The buoyancy forces acting on the rigid pipe string would counteract some of the machine weight and reduce the bearing pressure. Figure 7 illustrates this concept (for clarity, only one tie-rod is shown).

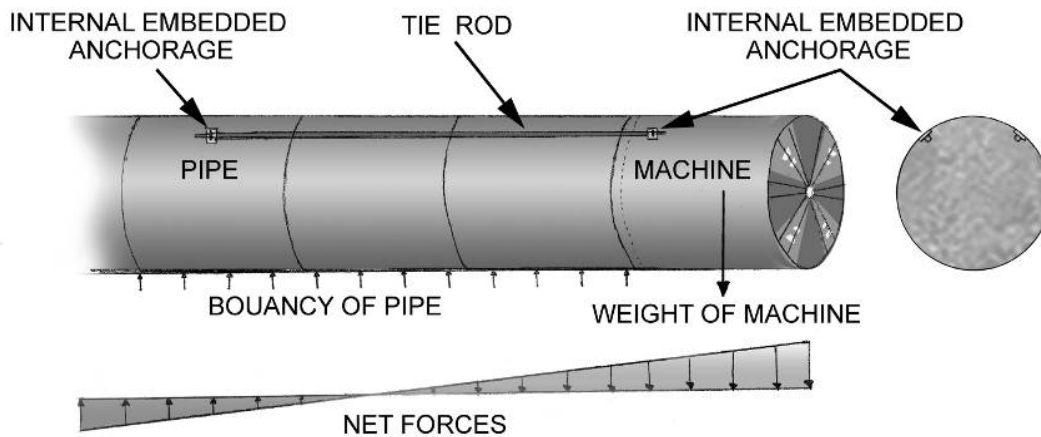


Figure 7. Internal tie-rods engage pipe buoyancy forces to reduce MTBM bearing load.

4.8 Using Active Steering Joint

Another approach to reducing steering difficulties in low blow count materials is the use of an active steering joint. This is a separate steering joint that is placed behind the machine's primary steering joint (Figure 8). The arrangement allows for an extreme upward steering angle to be placed on the machine in the event it shows a constant downward dive under its own weight that cannot be recovered because the normal steering reaction fails due to insufficient soil reaction (bearing capacity). This type of steering is not intended for continuous operation. The technology was first used in the United States on the Hylan Boulevard Oakwood Beach Interceptor Project in Staten Island, New York, in 1989. Seven thousand feet (2,134 m) was completed in eight drives by EE Cruz using an Iseki 1350. Recently, the steering joint was successfully used on a Herrenknecht AVND 1800 MTBM in soft ground on the Overpeck Valley Parallel Sewer Project in New Jersey and is a key feature on a similar 101 in. (2,565 mm) OD machine being used for the Balch Consolidation Conduit Project in Portland, Oregon. A specialty MTBM was developed and used on a project to make 164 ft (50 m) radius curves in soft ground. The MTBM in Figure 9 illustrates the active steering joint principal (Camp, 2000).

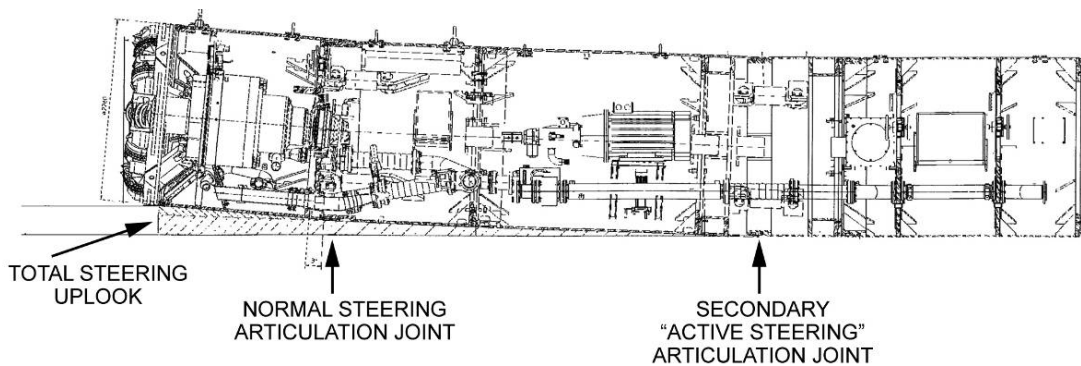


Figure 8. Herrenknecht AVND 1800 MTBM secondary active steering joint, which provides reaction for the initial steering joint.



Figure 9. Double articulated Iseki TCT 1200 (57.9 in. [1,471 mm] OD)

4.9 Using an Extendable Copy Cutter

A reduction in steering resistance can be achieved by adjusting the overcut. If the overcut is slightly increased in the crown of the tunnel with an extendable copy cutter, the resistance to upward steering is reduced and the soil loading due to steering is also reduced (Figure 10). For an MTBM, the cutter would be engaged in a preset location so that it extends and retracts within a narrow range from approximately 10 o'clock to 2 o'clock, allowing the cutterhead to steer up. Similar to the active steering joint, operation of the cutter would be on an as-needed basis to improve steering through low blow count soils. The design and application of this cutter is important, as it could allow the slurry to flow along the annular space, short-circuiting the closed loop slurry system.

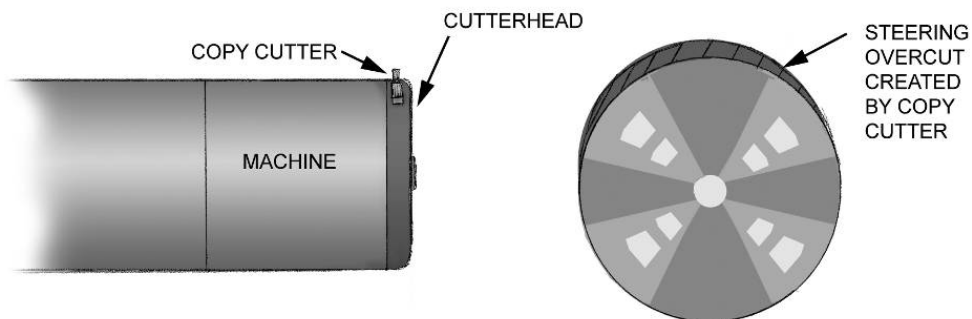


Figure 10. An extendable cutter used to excavate a larger steering overcut.

4.10 Selecting the Appropriate Design Grade

There are simple considerations that should be evaluated when planning a microtunneling project in low blow count soils. Consider flexible design grade for microtunneling drives in low blow count soils. Downgrade drives are generally preferable for projects where jacking and receiving shaft locations are flexible. The downgrade drive could be started relatively flat, allowing settlement to make the design grade. This approach will also reduce efforts required to steer up. Alternatively, if jacking and receiving shaft locations are fixed and an upgrade drive is required in low blow count soils, consider designing drives with a steeper grade than hydraulically necessary such that the design grade can still be obtained if the machine experiences a constant downward dive.

4.11 Using a Two-Pass System

If the risk to grade deviations is unacceptable for a particular installation, consider a two-pass system. This approach utilizes a casing, installed by microtunneling, to contain the initial pipeline. The casing is sized to allow enough

room to adjust the grade of the carrier pipe as it is installed inside the casing. Prior to carrier pipe installation, the finished casing grade must be surveyed. The grade of the carrier pipe is controlled using adjustable casing spacers. The drawback to this approach, besides the additional cost of casing materials, is that a larger machine is required to install the casing. The use of a larger machine increases the risk of grade problems in low blow count soils.

5. CONCLUSIONS

As with any other trenchless method being contemplated, a thorough and complete geotechnical investigation is at the forefront of the design phase. An investigation should include borings in order to describe the soil profile along the alignment, field tests to characterize the consistency, and laboratory tests to describe the strength and physical characteristics of the materials. One of several objectives of the subsurface investigations is to develop strength information on the soils along the alignment. Most often, the first indicator of soil strength is obtained through the Standard Penetration Test that provides standardized N-values that are correlated to soil strength or density. At this time, if N-values are below the demarcation point denoted for increased potential for machine settlement or steering problems, the field investigation can be re-evaluated to ascertain whether there are procedural issues with the drilling and sampling methods that could be yielding low N-values. If not, the field tests could include other tests, such as vane shear tests, to verify that the materials are indeed as soft as the SPT tests indicate.

If the design is presented with low blow count soils, consideration may want to be given to some of the options presented herein other than “let’s do ground improvement.” These options might present the basis of ideas from which to initiate dialogue with local contractors and machine operators to arrive at different and innovative approaches to the installation.

Other ideas to consider when planning and designing a project with low blow count soils are:

- Configuring the installation so that all the low blow count soils are in one or two drives
- Incorporating flexible grade tolerances with downgrade drives that would allow a machine to settle while maintaining hydraulic performance, or alternately at a steeper grade than hydraulically necessary to offset anticipated settlement if an upgrade drive is dictated by project constraints
- Planning for multiple shifts so drives through low blow count soils can be completed with continuous operations
- Selecting a “stiffer” horizon for the microtunnel that might be deeper or along a different alignment.

6. REFERENCES

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