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AD-A284 680



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**TRENCHLESS EXCAVATION
CONSTRUCTION
IN FEDERAL
CONTRACTING**

BY



SCOTT K. HIGGINS

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TRENCHLESS EXCAVATION CONSTRUCTION IN FEDERAL CONTRACTING

AN INDEPENDENT RESEARCH STUDY
SUBMITTED TO THE FACULTY OF THE

SCHOOL OF CIVIL ENGINEERING
PURDUE UNIVERSITY

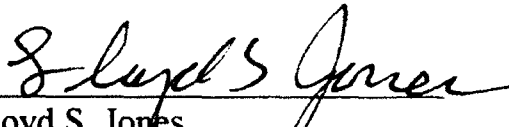
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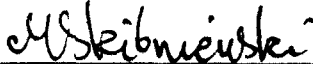
JULY 6, 1994

In Partial Fulfillment of the Requirements
for the Degree of
MASTER OF SCIENCE IN CIVIL ENGINEERING

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ABSTRACT

The industry related to Trenchless Excavation Construction (TEC) is seeing wide spread expansion. Technological developments in the last twenty years have been applied to TEC and now allow the installation of underground utility lines under previously developed properties and in difficult soil conditions. Large municipalities and industrial owners have greatly benefited from projects constructed using TEC.

The Naval Facilities Engineering Command (NAVFAC) is the construction and maintenance arm of the Navy and manages projects world wide. It is governed in its contracting by the Federal Acquisition Regulations (FAR) which among many things attempts to encourage fair and equitable administration of contracts. The FAR does this by restricting proprietary language and actions in government contracts and also by focusing contracts on final products versus construction methodology.

Since TEC is new, unfamiliar, and is often viewed to be a methodology and not a final product, NAVFAC's specification writers have been concerned about addressing TEC in their contracts. The purpose of this research project is to give NAVFAC designers and specification writers a Guide Specification that allows for TEC, provides them a comparison project that shows how TEC may be utilized, and also to make them aware of the basic concepts of TEC via a NAVFAC magazine article.

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CHAPTER 1

PROJECT DESCRIPTION

1.1 STATEMENT OF THE PROBLEM

From the beginning of time, objects have been buried by digging a hole, placing the objects in the hole, and then filling in the hole. This simple process has been the traditional means of constructing underground utility lines and designers have specified this in their construction projects.

Trenchless Excavation Construction (TEC) describes the methodologies and equipment utilized to install underground utility lines without using exclusively traditional cut and cover trenching. TEC in its most basic form, describes the process where pits are excavated using traditional digging equipment and then connected by digging a small bore hole between the holes. TEC encompasses many different methods that include small versions of tunneling equipment to adapted well drilling technologies. It has greatly benefited from recent developments in materials, optics, computer control systems, hydraulics, and soil mechanics (Iseley, (1988)).

The multitude of new technologies and methods has made it difficult for specifiers to modify guide specifications and design manuals. Contractors and vendors have been well educated in the capabilities of the TEC technologies, however, designers are lagging behind them (Koswatz (1992)). Specifiers have been suspicious of vendor and contractor claims and the result is that it is only recently that the owners have been specifying TEC in their contracts (Iseley (1993)).

TEC has been demonstrated to be extremely successful in placing utility lines in previously developed properties, in varied soil conditions, under busy roads, in ground

with a high water table, or in contaminated soil (Stein, Mollers, Bielecki, (1989)) These conditions are frequently found on Navy facilities. As of 1993, over 250,000 feet of utility lines have been installed in the United States using trenchless technologies (Norris, Bennett, and Iseley (1993)). However, as of 1994, less than 10,000 feet of those lines were installed on NAVFAC maintained facilities (Schwartz, (1994), Holcomb, (1993) and Torielli (1994)).

In terms of microtunneling, Iseki equipment has installed over 130,000 feet of pipe in the United States as of 1994 (Iseki, Inc., (1994) and Norris, Bennett, Iseley (1993)). Equipment manufactured by Iseki Inc. is the most widely used in this country. Only 2500 feet of microtunneled pipe has been installed on Navy bases (Schwartz (1994)). This is despite the fact that most naval facilities contain heavy industrial operations and many of them are on the National Priority List of Superfund cleanup sites.

The Naval Facilities Engineering Command (NAVFAC) has contracted for TEC sparingly up till now. When used, it has been incorporated primarily as a modification to an open-cut contract or as a substitute method employed by a subcontractor. NAVFAC's guide specifications do not address TEC except for references to utilizing horizontal boring in passing under rail road tracks (Marquez (1993)).

1.2 INTENT AND OBJECTIVE

The intent of this project is to provide NAVFAC with a guide specification that addresses TEC and to provide NAVFAC's designers with enough background information about TEC that they can confidently specify it without fear of dispute and with assurance that the references are current and accurate.

1.3 METHODOLOGY AND SCOPE

This study was performed as three distinct projects. First, a comparison was made of three possible methods of installing a sewerline. The purpose of the comparison was to generate cost and scheduling information that designers can use to get a feel for the differences between traditional cut and cover trenching and two common TEC methods

The second project was the creation of a draft guide specification for TEC. The guide specification was written in conformance with NAVFAC's format. It incorporates parts of several specifications that have already been used successfully by municipalities and suggested specifications from trade associations. The source specifications were modified to fit the NAVFAC format and the special requirements of the Federal Acquisition Regulations.

The final project is an article written for the Navy Civil Engineering Magazine. The purpose of the article is to provide navy engineers a basic introduction to TEC and to discuss a project where it was successfully employed.

Information for this research study was collected from many sources. A great resource was the Trenchless Technology Center at Louisiana Tech University. NAVFAC's guide specification office provided format information and encouragement (Marquez (1994)). Several vendors and manufacturers provided invaluable technical information and utility contractors provided insight into methodology.

1.4 FEDERAL ACQUISITION REGULATIONS

The FAR, part 9.505-2(a)(1) states in part:

"If a contractor prepares and furnishes complete specifications covering nondevelopmental items, to be used in a competitive acquisition, that

contractor shall not be allowed to furnish these items, either as a prime contractor or as a subcontractor, for a reasonable period of time, during the duration of the initial production contract." (Mouritsen (1993))

This restriction has discouraged contractors from submitting specifications directly to NAVFAC. They also fight the additional problem of trying to navigate the non-proprietary restrictions of the FAR (Torielli, (1994)) (this is clearly shown by Appendix E). While trade associations need not worry about this provision because they do not directly contract with NAVFAC, NAVFAC is a relatively small governmental agency and hasn't received much attention from organizations such as the National Utility Contractor's Association. Despite NAVFAC's recent efforts in the area of Design/Build contracting, most utility projects are relatively small compared to most of the Congressionally sponsored Military Construction projects.

1.5 DEFINITIONS

Trenchless Excavation Construction technologies encompass much more than the familiar horizontal boring or pipe grouting previously used on Naval facilities. In addition, they include: microtunneling, directional boring, pipe bursting, and pipe jacking ("Trenchless Excavation Construction Methods: Classification and Evaluation" (1991)).

Definitions (according to the article "Trenchless Excavation Construction Methods: Classification and Evaluation" (1991)):

"Microtunneling: Microtunneling Horizontal Earth Boring -- a process characterized as highly sophisticated, laser guided, remote controlled system providing the capability of continuous accurate monitoring and control of the alignment and grade.

Directional Drilling: A process that utilizes a specially built drill rig that thrusts the drill stem through the ground while bentonite drill mud operates a down hole motor, functions as a coolant, and facilitates spoil removal by washing the cuttings to the surface to settle out in a retention pit. The path of the borehole is monitored by a down hole survey system that provides data on inclination, orientation, and azimuth of the leading end. Direction is controlled by a bent housing used to create a steering bias.

Pipe jacking: Differentiated from Microtunneling Horizontal Earth Boring by requiring the necessity of workers being inside the pipe during the excavation and/or spoils removal process. Prefabricated concrete, steel, or fiberglass pipe may be utilized as the jacking pipe. The excavation process varies from manual to highly sophisticated tunneling boring machines.

Utility Tunneling: Utility Tunneling is differentiated from the major tunneling industry by virtue of their size and use (i.e., conduits for utilities rather than as passageways for pedestrian and/or vehicular traffic. Further, while the excavation methods for Utility Tunneling and Pipe Jacking may be identical, the differentiation is in the lining systems with the most popular being steel tunnel liner plates, steel ribs with wood lagging, and wood box tunneling."

CHAPTER 2

COMPARISON PROJECT

2.1 INTENT AND OBJECTIVE

Appendix A is an analysis of a hypothetical sewerline project that can be constructed using several methods. This case study compares project schedules, incremental costs, quality of final product, and individual characteristics of the different methods. The purpose of the paper is to give engineers a better understanding of the capabilities of each of the methods.

2.2 PROJECT DESCRIPTION

The three construction methods compared are: open-cut trenching, pneumatic pipe ramming and microtunneling. The case study construction project is based on the installation of a 20 foot deep sewerline project that is over 1000 feet in length and will be placed in sandy-clay. This hypothetical situation provides a great means of comparing the performance of the methods.

2.3 COMPARISON SUMMARY

The cost comparison was not based on total estimated project cost. Incremental mark-ups related to overhead and profits are not included. Common work activities shared by the three methods were also not included. Several of these common work activities include:

- Mobilization/demobilization
- Surveying costs
- Trenching from terminal manholes to existing manholes and performing the tie-ins.
- Pot-holing the location of important cross-buried utilities.

- Establishment and maintenance of traffic controls.
- Using an excavator to lower pipes into position.

Excavator costs were calculated using a R. S. Means' estimating software program and are based on an excavator similar to a Caterpillar 235C (*Caterpillar Performance Handbook*, (1990)). Construction durations were calculated using the same quantities used to estimate cost.

The estimated cost to pipe ram is significantly higher than the other two methods. The higher prices are primarily a result of greater sheetpile quantities and because the pipe casing had to be oversized. Sheetpiling costs are significantly higher for pipe ramming because an additional pit may be needed. Pipe ramming can only be accomplished in comparatively short distances and this means an additional pit would be required.

The ramming method requires a larger casing size. The pipe ramming cutting head isn't guided and thus the casing must be large enough to allow for grade fluctuations (TT Technologies, Inc., (1993)). This resulted in higher casing material and grouting costs. The costs related to handling larger soil volumes also added to the difference between pipe ramming costs and the costs of microtunneling.

The equipment costs for microtunneling are significantly higher than for the other two methods. The cutting head must be thoroughly rebuilt after each major project. The cost of the support equipment is also very high. The computerized control system, slurry handling system, and jacking platform are included in the estimates of monthly ownership and operating costs.

Costs resulting from handling soil and backfill are significantly lower for both of the trenchless technologies. If soil contamination was a problem, these lower soil handling

cost would result in even greater savings. This also holds true for dewatering. The pumped quantities are often significantly more for open-cut trenching. Disposal, treatment, or handling of this water could be a very expensive problem if the water is contaminated or discharge is regulated.

Open excavations can be deemed a "confined space" for occupational health reasons. If the surrounding soil is contaminated, the safety precautions mandated for working in confined spaces may make a trenchless technology the only practical means of installing a utility line through the area.

All three methods can handle varying soil conditions. Pipe ramming is the most limited in terms of its ability to cut through large deposits of rock or hard objects. Open-cut trenching allows you to examine difficult conditions or unknown buried objects. Microtunneling can drill through most rock and man-made structures. Unless tunneling progress is noticeably slowed, only an examination of cuttings will show what is being excavated. This means that microtunneling should only be done well beneath known structures. A comparison of the typical site layouts shows that both of the trenchless technologies require less space and are less disruptive to traffic and facility operations.

2.4 PROJECT CONCLUSIONS

The constructions of deep utility lines can be technically challenging and are particularly difficult when installed in previously developed areas. Open-cut trenching is the traditional means of performing this type of work. It allows for good grade control, can be used in varying soil conditions, and is well understood.

Recent innovations have resulted in optional methods that need to be considered when designing these utility projects. Soil contamination, dewatering, and disruption will be less

if a trenchless technology is used. One optional method, pipe ramming, is inaccurate and noisy, but fast. It results in significantly less disruption to traffic and less excess soil. Another method, microtunneling, is highly accurate, versatile, and fast (Iseki Inc., Sales Brochure (1993)). It is technically challenging and requires large capitalization in equipment. Its speed and side benefits may result in lower costs if difficult conditions are encountered.

A specific equipment recommendation for this test project would depend on site and contractor specific information that is beyond the scope of the paper. It is apparent that trenchless technologies can be a viable alternative to traditional open-cut excavating.

CHAPTER 3

NAVFAC GUIDE SPECIFICATION

3.1 FORMAT

NAVFAC has a large selection of guide specifications that are distributed to the major engineering field divisions. The specifications are divided into standard CSI format sections. The sections can be combined or used separately to form contracts. On a quarterly basis, the specifications are distributed on Compact Disk as a part of the Construction Criteria Base (CCB) system.

The information on the CD-ROM disks is easily manipulated and CCB program allows designers to quickly cut and paste specification sections and to reference applicable standards. Appendix B was written with formatting marks that are required by the CCB program.

NAVFAC guide specifications are written in a way that they may be used as a basis of the contract or incorporated into a larger contract document. They must be written in a fashion that allows the designer maximum flexibility in terms of materials, sizes, quantities, and execution.

At the end of the specification section there are several notes to the designer. These are reminders and explanations about items in the section. There are references to these notes located through out the section. The notes to the designer are not included in the contract document after the specification has been drafted.

3.2 REVIEW OF EXISTING SPECIFICATIONS

With the assistance of Mr. Walt Schwartz, Nova Group Inc., and Dr. Iseley, Trenchless Technology Center, I collected specifications from several projects (City of Houston, Texas, City of Ventura, California, and City of Tacoma, Washington) and a draft specification submitted to the Indiana Department of Transportation (INDOT) (Hancher, White, and Iseley, (1989)). None of these specifications were written in a format that is compatible with the FAR and with exception of the draft INDOT specification, all are written in a manner that specifies particular methods.

As stated previously, a NAVFAC guide specification needs to be non-proprietary and allow the designer maximum flexibility in selecting materials and methods. The Trenchless Technology ("Draft Guideline Specification for Microtunneling", (1994)) published a guide specification that allows for the use of many different types of carrier and casing pipe. It also listed many standards and references. These were incorporated into Appendix B.

The cities of Houston, Texas, and Tacoma, Washington, recently utilized specifications for microtunneling that contain excellent provisions. They contain provisions that govern excavation construction, alignment and settlement control, and traffic interference. These discussions were incorporated into Appendix B. According to Norris, Bennett, and Iseley (1993), forty percent of all microtunneling projects have been installed for the City of Houston.

3.3 SPECIFICATION REFERENCES

The first major section of the specification includes lists of references cited in the document. These references include standards, design manuals, and safety regulations.

The documents are included because they may be incorporated into the contract by reference. Several of the standards further reference other standards and they are in turn incorporated into the contract.

The CCB computer program is written in a way that automatically references appropriate standards as the designer selects desired materials and methods of execution in the text of the section. My goal in the preparation of this section was to list as many relevant references and standards as possible. The designer should have access to all of these documents and it is their responsibility to double check for applicability.

3.4 RELATED SPECIFICATION SECTIONS

Two other specification sections are listed and referenced in the TEC specification. The Mechanical General Requirements section discusses broad issues relating to utility work and will usually be needed. The other section that is referenced is the Environmental Protection section (01560).

This section is important because among other things, it is where the designer tells the contractor where to store and dispose of spoils and discharges. It also is where the testing of potentially contaminated materials is discussed. Since soil contamination on naval facilities is often a problem, this section is very important to the contract.

3.5 SUBMITTALS

NAVFAC contracts typically require extensive submittal review. The CCB system is designed to automatically generate a submittal requirements registry as the designer selects materials and methods. Appendix B contains several suggested submittals that should be developed by the contractor. The designer should review all technical

submittals. The contracting official should review all environmental, safety, and traffic plans.

TEC is very complicated and requires extensive review by the designer. With numerous combinations of equipment, materials and methods possible, it is imperative that the designer has an opportunity to review shop drawings, equipment characteristics, and also safety plans.

3.6 PROJECT DESIGN

The designer must consider many different external loads imposed on the manholes, casings and supporting structures incorporated in a TEC project. These loads can include earth pressures, truck loads, seismic loads, sheetpile insertion/extraction construction loads, hydrostatic and buoyancy forces. Internal loads such as water hammer, vibration, and mixed phase (gulping) forces must be considered. Their impact of these loads are dependent on the substance carried in the utility pipe.

Casing pipe diameters are determined by considering several factors. The casing pipe must match closely with the diameter of the cutting head. Over-cutting can cause serious problems (Bennett, Iseley, Najafi, and Khanfar (1993)). If the casing pipe will contain carrier pipes, the diameter of the casing must allow for sufficient room to insert and support the carrier pipes. The remaining void is typically filled with a light weight cementous grout. The design requirements of carrier pipes will dictate their diameters and configuration. Several carrier pipes may be placed inside a single casing depending on the nature of the utility line. The casing must be sized accordingly.

The designer must decide the depth of the boring. The design requirements of the utility lines will be the major factor in selecting the depth. The article by Bennett, Iseley,

Nafaji, and Khanfar (1993) states that microtunneling bore holes should be covered by at least six feet of soil or 1.5 times the diameter of the casing. Gravity sewerlines have very limited possible grade profiles while electrical ductbanks can be constructed in various configurations and depths. The designer must consider ground heave, hydrostatic pressures, cross-buried utilities, connections, and economics when considering the depth of the bore holes. Iseki, Inc., (1993) claims that their tunneling machines can operate to depths of approximately 100 feet below grade. This gives the designer great flexibility to go under rivers, roads, obstructions, and cross-buried utilities.

The thickness of the casing pipe is determined by considering applied jacking forces, soil pressures, and other external loads. Under certain conditions the designer may want to consider using a cathodic protection system. This may be required if the casing pipe will also act as the carrier pipe of petroleum products and is made of or contains ferrous materials.

TEC gives the designer great flexibility in selecting an alignment for the utility line. If a sufficient depth is chosen, the line can easily pass under roads, structures, or even rivers. This can also reduce the number of manholes required. Other utility lines that need to be placed along the same alignment can be buried directly over the TEC installed line.

The distance between manholes or access pits is usually a function of the type of utility line installed. Electrical duct lengths are restricted by the cable pulling capacity of the installer, sewerline section lengths are limited by cleaning equipment and grade, and other fluid handling lines by the location of connections to other pipes. In most cases the length of the individual sections is far less than the jacking capacity of a microtunneling machine (Post (1993)).

Under certain conditions it may be possible for microtunneling machines to bore through intermediate manholes. The mole can continue on to a more distant manhole that serves as a receiving pit (Post (1993) and Schwartz (1994)). Receiving pits must be large enough to remove the cutting head and since they may need to be larger than a standard manhole, this could save excavation effort.

This technique may also reduce the number of jacking/launching pits. It should also be stated that each jacking pit may be used to launch several bore holes. This may require the construction of several thrust blocks, but it is very practical to use the same pit to launch a machine in opposite directions. After one drive is completed, the jacking frame is turned around and repositioned inside the pit. The support equipment doesn't need to be moved and this can dramatically reduce set-up time.

3.7 MATERIALS

Appendix B allows the designer to pick several different types of carrier pipes and casing materials. Current production methods will allow the contractor to place a separate carrier pipe inside the jacked casing pipe or if soil conditions allow, the casing can also serve as the carrier pipe.

The designer must select the carrier pipe to match project requirements and the casing is selected based on several factors. Carrier pipes must suit the material that is going to pass through them and/or cables that will be pulled into them.

Casing pipes are subjected to large compressive loads during jacking and must also stand up to lateral soil loading. The pipe joints are subjected to extremely large compressive forces and their design is critical. The joints must transfer jacking forces during the installation process and in some cases are of a larger diameter than the rest of

the pipe. This subjects them to additional shear stresses as they are passed through the bore hole.

Appendix B allows the designer and contractor to pick the best combination of carrier/casing pipes from various materials including: ductile-iron, polyvinyl chloride plastic, reinforced concrete, fiber glass, and steel. The designer must consider alignment, connections, wall thicknesses, diameter and deformation when selecting the casing material. The TEC specification section addresses each of these concerns for each of the materials.

3.8 PROJECT EXECUTION

Most TEC methods still require some type of excavation to support boring operations. Typically, jacking and receiving equipment is placed at or below the pipe elevation. The pits constructed for these purposes usually ultimately serve as manhole excavations. If the pit is to be used for jacking pipe or a cutting head, one wall of the pit is reinforced so that it can serve as a thrust block. The design of the backstop is critical since the lateral loads developed during construction may exceed hundreds of tons of pressure.

Infiltration of ground water must be controlled. One benefit of using TEC methods is that drawdown of ground water can be dramatically reduced if the original ground water table is close the surface. This can be very helpful in protecting against the subsidence of surrounding structures and roadways. Infiltration can be reduced by using sheet pile for the pit walls, placing a concrete mud slab on the bottom of the pit, and grouting around perforations in the pit walls (Thomas (1993)).

The jacking and receiving pits are often quite large in comparison with typical manhole excavations. The jacking pit must have sufficient length and breadth to accommodate the thrust block, jacking frame, at least one length of pipe and still provide worker access. The issue of settlement is critical to many large excavations. Extreme care must be exercised to make sure that surrounding structures, utilities, roads, or rail road tracks are not affected. Several side effects of TEC work are:

- Settlement of the soil adjacent to the jacking and receiving pits caused by groundwater drawdown resulting from dewatering.
- Vibrations that can result in soil liquefaction, nuisance noise, or settlement. Vibrations can be caused by driving sheetpiles for the pits, compacting soil during backfill operations, cutting head of microtunneling machines, or percussion energies generated by pneumatic ramming machines.
- Ground heave can occur if there isn't enough cover over the pipe installed by the TEC method (Bennett, Iseley, Najafi, and Khanfar (1993)).

These possible complications must be considered when selecting the appropriate TEC method. An extensive investigation of the adjacent facilities must be conducted and then they must be evaluated in terms of their sensitivity to the possible side effects. Surveys for alignment and elevation need to be conducted prior to starting construction. They will need to be repeated during the course of the project to check for problems relating to the work.

In some cases, sensors and monitors may need to be placed on or near important structures. The sensors may be required to monitor noise, vibration, settlement, or possible dust. The effects will be dependent on project and equipment conditions. Site conditions such as soil, foundations, and other structures also play an important role.

3.9 PREEXISTING SUBSURFACE CONDITIONS AND SPOILS TESTING

Subsurface conditions have an obvious impact on any underground utility line project. For trenchless methods, the designer and contractor need accurate information about:

- Soil mechanics
- Existing utilities
- Groundwater elevation and possible tidal influence
- Contamination

Except at pit locations, the excavations will be limited to the horizontal cutting action of the TEC equipment. This is a blind and remote process that will not show indications of problems until cuttings are removed (with the exception of tunnel shield method). In open-cut trenching, the excavator operator can see what he is digging into and can react quickly to problems.

In TEC projects, if the cutting head runs into a buried structure or existing utility line, it could do substantial damage to both the cutting head and the object. The jacking pressures may not even change enough to alarm the operator. This means that the determination of depth and alignment of the boring is dependent on accurate as-built information.

The type of cutting head and spoil removal system are dependent on soil type. Dense rock can only be penetrated by certain microtunneling cutters whereas softer soils can be excavated using many different types of TEC methods such as pipe ramming, horizontal boring, microtunneling, and shielded tunneling (Reyna, Vanegasa, and Khan (1993)). The determination of soil type is frequently accomplished through vertical borings and split spoon sampling.

The samples are taken during the design stage of the project at intervals of approximately 200 feet (Essex (1993)). The samples are taken along the alignment of the excavation and also at locations offset from the alignment. It is common practice to take at least one sample at each manhole location since these are also the locations used for jacking and receiving pits.

The sample borings will typically be pass well beneath the lowest elevation of the lowest invert or deepest TEC boring. The test borings should be analyzed for soil properties including:

- permeability
- compressive strength
- shear strength
- cohesiveness
- suitability for slurry transport
- interaction with lubricants such as bentonite
- organics
- plasticity

The soils classification and data should be shared with prospective bidders. The soil characteristics will govern the type of cutting head required, jacking forces needed, the type of spoil transportation system, the type of casing lubrication required, and advancement rates. The information will also help access the amount of dewatering required because of permeability and water table elevation. Grouting may also be required to stop infiltration.

Typically, the spoils will have to be disposed of off the construction site. If they are transported to the surface by a slurry system, they will need to be separated from the slurry and allowed to dry out. The process of separating the spoils from the slurry is

usually done using settling basins and weirs. The spoils are removed from the bottom of the basins and allowed to dry out via percolation or evaporation. Large temporary stockpiling areas are usually required in order to maximize the exposed surface area of the spoils.

The spoils are frequently tested for hazardous substances prior to ultimate disposal if there has been an indication of contamination. Municipal landfills commonly demand this be done if there is any possibility that there may be a problem. The quantity and types of testing are very site specific. Local landfill rules and environmental regulations will govern the testing criteria and determination of contamination levels. These tests often cost over \$2500 per sample and take more than two weeks to get the results. The spoils need to remain on site until they are cleared for transportation or else there may be a violation of Department of Transportation regulations.

Most environmental agencies state that sampling of potentially contaminated spoils must be taken at reasonable intervals. As an example, the State of Hawaii and the Navy agreed that the definition of reasonable intervals was four tests per 100 cubic yards of spoils for a large construction project. This translated into \$10,000 of testing for every 100 cubic yards of dirt (Fedrick (1993)).

A 36 inch diameter sewerline project that is 1000 feet long and buried 20 feet deep, may generate over 1000 cubic yards of spoils if it is installed using microtunneling. That translates to \$100,000 worth of testing! But compare this value with approximately 15,000 cubic yards of spoils that would have been generated if the sewerline would have been installed using open-cut trenching with imported backfill. That is why the 01560 specification section, entitled "ENVIRONMENTAL PROTECTION" in NAVFAC TEC contracts must clearly discuss the testing and handling of spoils. These requirements

could quickly result in a contractual dispute if it isn't explained in plain language for bidders.

The stockpile of spoils can often take up large expanses of land adjacent to the project site. The stockpiled spoils must be protected from the environment in case of rain and runoff. The Clean Water Act regulates the types of discharge and runoff that can enter storm drains and streams. The stockpile facilities may be expensive and complicated structures.

Certain types of contamination, such as petroleum products, will tend to remain at the top of the groundwater table. Because of this, TEC methods can go beneath the layer of contamination and virtually negate the entire problem. If the limits of contamination can be clearly identified by sampling and testing, the extreme costs associated with spoils testing may be avoided.

3.10 SAFETY AND OCCUPATIONAL HEALTH

An article by Castorina (1994) states that TEC allows contractors to significantly reduce exposure of workers to trench failure and equipment damage to damaging cross buried utilities. TEC equipment such as microtunneling boring machines can be operated remotely from outside the excavations for significant periods during boring operations.

A side benefit of reinforcing the jacking pit to handle pipe thrusting loads, is that the strength of the shoring also protects workers who must enter the excavation. The strong jacking pit construction should also be designed to reduce groundwater infiltration. This will reduce worker exposure to contaminants in the groundwater, reduce electrical shock hazards, and sump pump size.

The U.S. Army Corps of Engineers' Occupational Safety and Health Manual (EM 385 1-1) states that excavations may be deemed to be confined spaces. The ventilation section of Appendix B lists air testing criteria for confined space entry. These criteria should be modified if unlisted contaminants are detected in boring samples.

Unique hazards for TEC project workers include: welding fumes (if the pipes are connected inside the jacking pit), noise (especially if pneumatic pipe ramming is used), and hydraulic line failure. Many microtunneling machines use laser alignment systems that are recognized to be an eye hazard (Yowler (1993)). Viewing the excavation process is not as important in TEC projects as it is in open-cut trenching, so it is common for operations to continue around the clock. Therefore, lighting is important if personnel are working in or around the excavations after dark.

3.11 FINAL INSPECTIONS AND TESTING

The accuracy of microtunneling can be extremely good. The exterior pipe casings can frequently be installed with tolerances better than 2 inches in 100 feet of tunnel (Iseki (1993)). A carrier pipe placed inside the casing can be aligned to even tighter tolerances. Pipe ramming and horizontal boring methods are unguided and thus will result in very poor alignment tolerances. They should only be used for short borings or for situations that do not require strict alignment control.

Final quality checks performed on TEC projects can include alignment surveys, settlement measurements, pressure and leakage tests on carrier pipes, non-destructive testing of pipes and joints, and visual testing of connections. Possible repairs can run the spectrum from spot fixes to the extreme of having to jack the damaged pipe through the tunnel and replacing it.

Microtunneling machine operators usually maintain a record similar to logs produced by drill rig operators. This log should be submitted to the owner as a production quality record. It can be produced automatically if the machine contains a computer guidance system. It would include time, station, alignment, orientation, and production information. This record can easily be converted into part of the "as-built" drawings.

CHAPTER 4

NAVY CIVIL ENGINEERING MAGAZINE ARTICLE

4.1 PURPOSE

Appendix C was written with the intent to publicize the basic advantages of TEC and the existence of Appendix B. The NAVY CIVIL ENGINEERING magazine is a quarterly publication that is sent to all Navy Civil Engineer Corps Officers and to major facility engineering and design officers. The magazine contains articles that discuss topics that are of importance to its readers. This provides a forum for discussing topics such as TEC.

4.2 SUMMARY

Submissions to the magazine are limited to 1500 words and may contain technical content, but are to be written in plain language (Fedele (1994)). Appendix C is an article that discusses the basic concepts of TEC. It defines common terms, lists TEC's potential benefits, and dismisses several common misconceptions that engineers have about TEC. The article also discusses one of the few projects where microtunneling was used on a naval facility.

CHAPTER 5

EQUIPMENT SELECTION USING AN EXPERT SYSTEM

5.1 PURPOSE

The 1994 Directory of the North American Trenchless Technology Industry contained a table entitled "Pipe Rehab, Defect and Solution Matrix". Appendix D is a computer program based on the matrix using VPExpert™ similar to a program written for Appendix A. The program contained in Appendix A was written based on the analysis of the three methods discussed in the paper, but it doesn't include all possible rehabilitation options.

Appendix D was developed to augment the original program and includes repair methods that are less aggressive than total replacement. Designers can use this program to quickly focus on possible solutions to common problems.

5.2 COMPARISON USING AN EXPERT SYSTEM

Appendix A compared several methods of installing utility lines. Various methods can be used to compare the estimated performance of each of the systems but an interesting way of selecting between the methods is by employing an expert system. Table 6 in Appendix A is a listing of computer code developed to select among the three methods using the VPExpert™ micro-computer package. The user is prompted for background information about the project and then heuristic rules are used to recommend an installation method. Selection criterion is based on:

- Pipe length
- Invert depth
- Soil conditions

- Possible obstructions and soil contamination
- Traffic interference
- Impact of installation vibration

The program is composed of If-Then statements that sort through the background information and then recommends a method along with a confidence factor. The confidence factors are a subjective indication of the strength of the recommendation.

5.3 SUMMARY

Pipe defects fall into six major categories. The categories include: accumulated debris, infiltration, broken pipe, misalignment, corrosion, and collapsed pipe. Recommended solutions are based on pipe diameter and pipe material. The solutions are provided in a nonproprietary manner. The directory in Trenchless Technology lists many contractors and vendors that can provide further information about the recommended rehabilitation method.

CHAPTER 6

CONCLUSION

6.1 SUGGESTIONS FOR FURTHER RESEARCH

Soil contamination is a major problem on naval bases. The true niche TEC technologies may become noted for is their ability to upgrade utility lines on facilities that suffer from soil contamination. TEC can virtually stop the infiltration of contaminated groundwater into storm and sanitary sewers. TEC also significantly reduces spoils and dewatering generated during construction. These benefits to owners are worthy of more in depth study.

The excavation and boring activities used in TEC are repetitive in nature. The application of a simulation analysis similar to the one shown in papers by Hastak and Skibniewski (1993) and Vanegas, Bravo, and Halpin (1993) could be used to optimize the construction process. These existing simulations could easily be adapted to TEC methods. The simulation analysis would greatly benefit contractors, but NAVFAC typically specifies that project schedule submittals be prepared in a format such as bar charts or precedence diagrams (COE ER 1-1-11). An effort similar to this study could be used to educate NAVFAC's engineers about the benefits of simulation analysis so that it can be used to satisfy scheduling submittal requirements.

In Trenchless Technology (Iseley (1993)), Dr. Iseley commented in an editorial that he felt that the industry needs to develop model codes for utility construction. This would be a great area of further research. NAVFAC would probably benefit greatly from playing a role in the development of a code. The code would probably simplify the specification process and allow greater uniformity across political and geographic boundaries. A

comprehensive review of NAVFAC's recent facility maintenance contracts might help this process.

6.2 CONCLUSION

The purpose of this project was to explore trenchless excavation construction from the perspective of NAVFAC engineers and designers. The comparison of three different methods of installing utility lines provides insight into the major issues of traditional and new methods. A draft NAVFAC guide specification was developed to give Navy designers the opportunity to include current TEC methods and technologies into their contracts. A Navy Civil Engineering article was written to familiarize Navy engineers with the basic concepts of TEC.

Trenchless Technology Construction is a rapidly developing industry and provides owners an opportunity to fix and install new pipe lines while significantly reducing the impact of the project. It will take a concerted effort to educate engineers and designers about the advantages of TEC. Hopefully this project will aid that effort.

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APPENDIX A

COMPARISON OF METHODS OF INSTALLING UNDERGROUND UTILITY LINES

By Scott K. Higgins, P.E.¹

ABSTRACT: The rise in the number of urban redevelopment projects and the deterioration of our existing underground utilities has resulted in an increase in the installation of underground utility lines in previously developed areas. These projects present unique challenges to designers and contractors. Designers and facility planners must take into consideration the tremendous disruption large excavations may have on traffic flow or facility operations. Stricter regulation governing the discharge of dewatering effluent and potential contaminated soil has greatly increased the complexity of the actual construction. New technologies are being applied to this type of work that can greatly reduce the disruption of facility operations and yet will provide an excellent finished product. This paper will compare three different methods of installing a new gravity sewer line under these conditions. A sewer line project was selected as the basis of comparison because it will typically require deep excavations, strict control of pipe slope and alignment, and the cost of the pipe material is small in comparison to the cost of the equipment used in the installation. The focus will be on the primary equipment used in each method. The primary types of equipment that will be compared are: a medium size tracked excavator, horizontal pneumatic pipe ram, and a remotely operated micro-tunneling machine.

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INTRODUCTION

This paper will compare three different methods that might be used to install a new sewer line. Underground sewer line construction is a difficult process that is made more difficult when the work is to be done in a developed area (Stein, Mollers, and Bielecki (1989)). This is becoming more commonplace as we are forced to replace original infrastructure or upgrade properties to accommodate new facilities. Possible complications include: regulatory restrictions on dewatering discharge, contaminated soil, cross-bearing utilities, and difficult soil conditions compounded by previous backfilling.

The standard method of cut-fill or open-cut trenching has proven to be economical and efficient. When trenching may disrupt traffic or facility operations must be minimized, or difficult soil conditions are encountered, other methods may be more suitable. Open-cut trenching frequently is hazardous to workers, requires dewatering, can damage existing cross-bearing utilities or roadways, and when deep trenches are required, extend beyond the limits of many common excavators. This paper will compare equipment and major resources required by each method to successfully complete an academic project.

COMPARISON CRITERIA

Cost is a primary factor in the comparison of potential methods and designs. For the sake of this paper I will only quantify the costs related to construction equipment utilized and their production capabilities. I will mention qualitatively comparative benefits or drawbacks the methods have in other regards. Specifically, the comparison will include:

1. Production capabilities.
2. Quality of performance.
3. Special construction activities needed to support the actual sewer line installation.
4. Support equipment, crew size and technical requirements.
5. Maintenance required during the project.
6. Versatility in terms of soil conditions, installation depths and pipe materials.

7. Specific benefits and drawbacks of each individual methods.

A final comparison of the costs, benefits, and drawbacks of the methods can be found at the conclusion of this paper. The basis of the comparison is be founded on information provided by manufacturer representatives, publications, estimating software, and the author's personal experience.

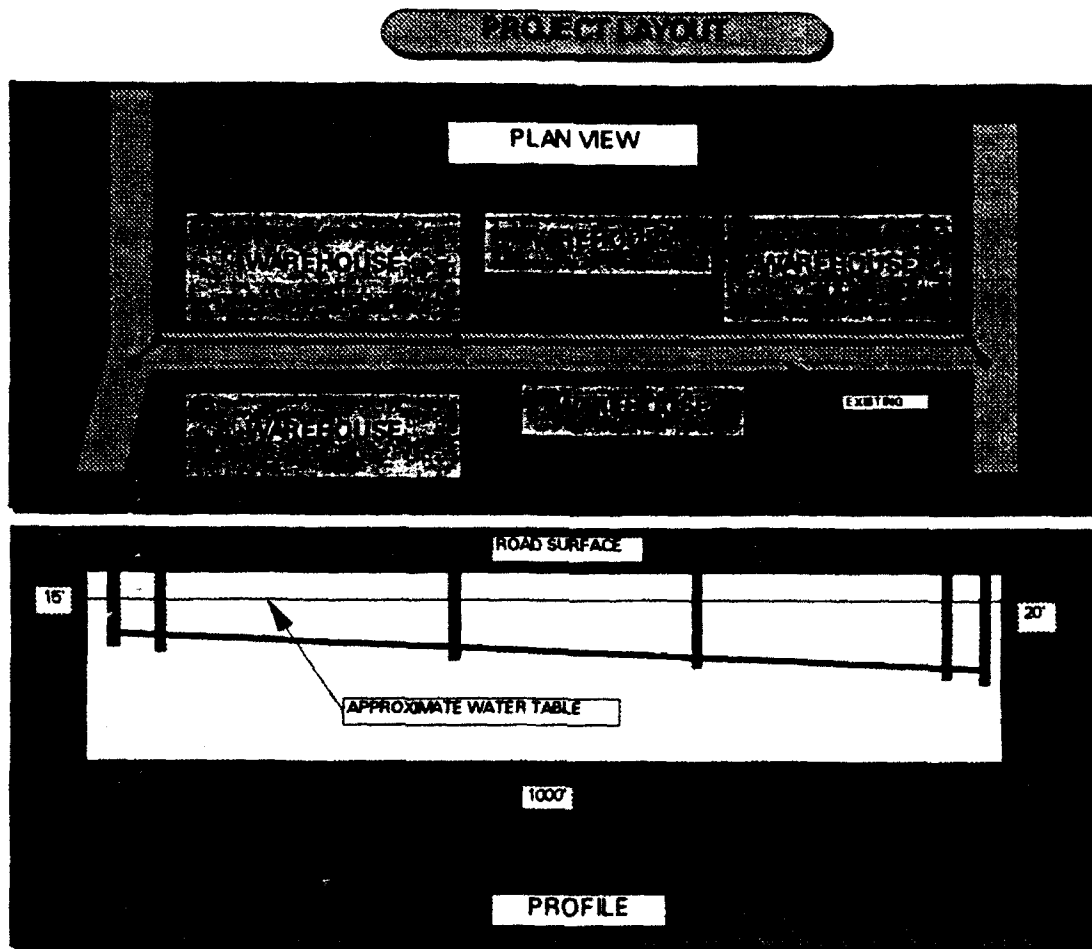


FIGURE 1. Illustration Project Layout (Measurements in feet)

ILLUSTRATION PROJECT

Sewer line projects are very common but also very difficult. For the sake of comparison, I have selected to analyze the capabilities of the three methods in the

execution of an academic illustration project. The illustration project will involve the installation of a 750mm diameter line that is 300m long. The grade of the line is to be 1/2 percent and the alignment will be straight. The lowest invert will be set at 6m below a street that has no grade as shown in Figure 1. Two intermediate manholes are required at a minimum. Cross-bearing utilities will not descend below 3m from the surface and no chimneys or tie-ins are required except at the ends. Carrier pipe material may be either concrete, clay or plastic.

To facilitate the comparison of the three methods, I will compare the performance of each system in uniform soil conditions which consist of sandy-clay. Its insitue density is 1840 kg/BCM and 1600 kg/LCM. The select backfill has a density of 1720 kg/CCM and 1560 kg/LCM. The water Table is nominally 2m below the surface. The ability of systems to perform in other conditions will be discussed. These are fairly common soil conditions and should give a good basis of comparison.

Manhole construction is similar for all the methods. This paper will ignore manhole construction itself, but it will talk about the use of manhole pits for driving and receiving tunneling heads.

OPEN-CUT TRENCHING

PROJECT EXECUTION

Open-cut trenching is the traditional method of installing underground utility lines. Briefly it consists of:

1. Beginning at the downstream end, set the first manhole.
2. Excavate the first trench section. Trench boxes, sheet piling, or shoring will be installed to retain the trench side walls. Support cross-buried utilities.
3. Install the pipe, backfill and compact.
4. Set the next manhole.
5. Continue steps 2 through 4 until the last manhole is set.

6. Connect to existing lines.
7. Repave and stripe.

Traffic control has to be maintained at all times. Trench work is very dangerous so shoring and access will have to be carefully monitored until the trench is backfilled. The trench bottom preparations may include the placement of bedding material, constructing concrete cradles, and/or carefully setting the grade. Figure 2 shows details of the design. Actual preparations depend on soil conditions, design and pipe material.

Compaction of the backfill material is very important. The material must be properly compacted in order to minimize settlement but, over compacting may cause damage to the pipe. Also, the removal of sheet piling must also be closely monitored. Vibratory extraction may further consolidate the backfill and possibly disturb the pipe.

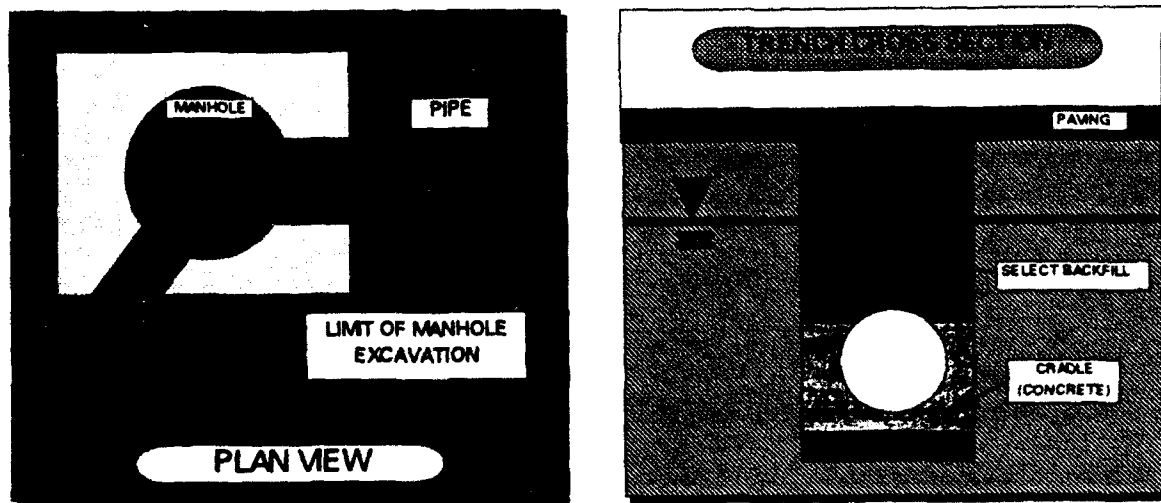


FIGURE 2. OPEN-CUT TRENCHING DESIGN DETAILS

SUPPORT EQUIPMENT

The actual digging of a deep trench will be done by a tracked excavator. In support of the excavator, a front-end-loader or rubber-tired backhoe with a combination bucket will

be needed. The additional piece of equipment would be used to load the excess soil into trucks, move soil piles around, backfill the trench, compact the soil, move shoring materials around the jobsite, and possibly lower pipe into the trench. Figure 3 shows a possible scenario of the site layout where on-site storage space has been minimized.

If sheetpile is used to shore the trench walls, a crane with a vibratory pile head will be required. The crane will be used to insert and extract the sheetpiles. It would also be used to set manholes and lower heavy materials into the excavations. Also, welding and cutting equipment will be required to work on the sheetpiles and templates. Steel working equipment will also be used to install reinforcing steel and set steel shoring and walers.

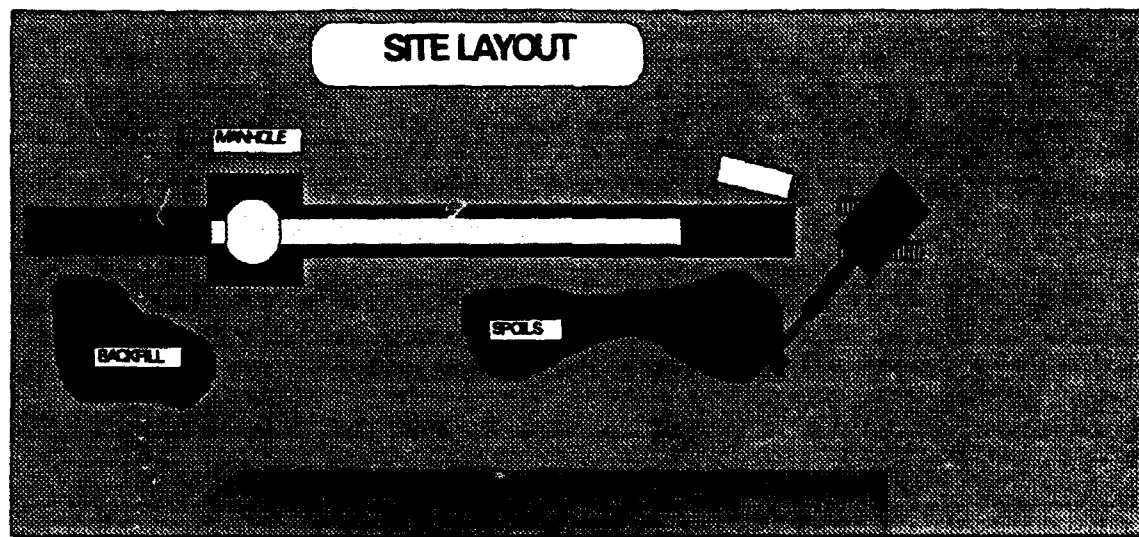


FIGURE 3. Open-cut Trenching Site Layout

Pavement cutting equipment will be required. Backfill compaction can be accomplished by using a vibratory plate attached to the boom of the excavator or the backhoe. A small sled compactor would also be used. At least one dump truck will be required to haul excess soil off the site to bring in backfill. The paving would typically be subcontracted out for this small of a quantity.

SELECTION PROCESS

Many things are factored into the selection process of purchasing any large and expensive piece of equipment. For this paper I restricted my search to excavators manufactured by Caterpillar Inc. They produce a large variety of excavators and also provide a substantial amount of literature about their equipment. The selection criteria will be based solely on the requirements of this project. For this situation, I selected a Caterpillar 235C excavator with a 1077mm wide 1600L trenching bucket.

The first criterion I used to narrow down the field of candidates was the maximum digging depth. The maximum excavation depth shouldn't exceed 8m for this project, so I selected models that had a maximum digging depth of 8m or more. According to the *Caterpillar Performance Handbook*, the 235C excavator equipped with a 3660mm stick has a capability of reaching over 8.12m.

Standard design practice is to set the minimum trench width to approximately 150% of the pipe diameter for deep excavations. This is a soil pressure issue and a practical limitation dictated by ease of installing/extracting shoring and placing the pipe. Therefore, I decided that the trench should be at least 1220mm wide. The bucket would have to be small enough to fit into the trench and also large enough to produce a high level of soil removal. I calculated that the minimum bucket volume needed to be 1200L by using the Caterpillar EMF software and a production rate of 8m of excavation per hour. Table 1 shows that the 235C is capable of performing at this rate.

The 235C is not the smallest excavator that can handle this size bucket and production rate. The 235C can lift up to 14,700kg at a load radius of 3660mm (front). This capacity is helpful when the excavator is used to lower pipe sections into the trench or shift the position of trench boxes.

According to a manufacturer's representative the purchase price of a new 235C excavator is approximately \$230,000.

PRODUCTIVITY CALCULATIONS

An estimate of the soil volumes that would be moved in the course of this project was calculated. These numbers were used to aid the selection process and were the basis of the duration estimates used to compute a possible schedule, Table 2. The schedule was designed with idea that the excavator should be the critical resource. This will give more meaning to comparisons with the other methods' schedules.

CATERPILLAR EMF REPORT

Trenching Model 235C		Estimate Excavator Productivity Ident [TERM PAPER] Hourly O&O [33.00]	
Trench Volume Calculation		Earthmoving Production Estimate	
Trench Volume - cu yd/ft	[1.87]	Cycle Time - min	[0.20]
		Cycles/hr	300.00
Pipe Length - Feet	[8.00]	Bucket Size - Cu Yards	[2.00]
		Bucket Fill Factor %	[100]
Volume - Bank cu yd/Pipe	14.96	Production-Loose cu yd/cycle	2.00
- Loose cu yd/Pipe	17.18	Production-Bank cu yd/hr	522.56
		-Loose cu yd/hr	599.98
Time Per Pipe Estimate		Final Production Estimate	
Volume - Loose cu yd/Pipe	17.18	Minutes Worked per Hour	[50]
Production - Loose cu yd/hr	599.98	Pipes/50 min h	2.30
Time to Dig - min/Pipe	1.72	Production Estimate - ft/h	18.42
Pipe Setting Time - min	[20.00]	Oper. Hrs to Complete Job	54
Total Time - min/Pipe	21.72	Excavating Cost \$ /Foot	1.7917
		Total Cost - \$	1,792

TABLE 1. Caterpillar EMF Productivity Report (Equivalent English Units)

The schedule shows that it might take 8 months to complete the project using a 235C excavator. This estimated schedule is very linear and in reality a similar project would probably take significantly less time to perform. The assumptions used to estimate the schedule were also applied to schedules for the other methods. Therefore, an academic comparison should still be valid. Since many of the activities are repetitive in nature,

simulation analysis similar to the one shown in the paper by Hastak and Skibniewski (1993) could be used to optimize activities and reduce the overall project length.

1	MOVE IN	5d	11/29/93 8:00am	12/3/93 5:00pm	
2	SURVEY ROUTE	1d	12/6/93 8:00am	12/6/93 5:00pm	1
3	POT HOLE	5d	12/7/93 8:00am	12/13/93 5:00pm	2
4	SAWCUT FIRST SECTION	3d	12/7/93 8:00am	12/9/93 5:00pm	2
5	EXCAVATE FIRST MANHOLE	1d	12/14/93 8:00am	12/14/93 5:00pm	4,3
6	SET MANHOLE	4d	12/15/93 8:00am	12/20/93 5:00pm	5
7	TRENCH FIRST SECTION	3d	12/21/93 8:00am	12/23/93 5:00pm	6
8	HAUL OFF EXCESS SOIL	15d	12/23/93 8:00am	1/12/94 5:00pm	6FS -2d
9	SET PIPE AND CRADLE (CURE)	14d	12/22/93 8:00am	1/10/94 5:00pm	6FS -1d
10	BRING IN SELECT FILL	5d	12/28/93 8:00am	1/3/94 5:00pm	7FS -2d
11	PLACE AND COMPACT BACKFILL	14d	1/13/94 8:00am	2/1/94 5:00pm	6FS +7d,8,10
12	EXCAVATE NEXT MANHOLE	1d	2/2/94 8:00am	2/2/94 5:00pm	9,11
13	SET MANHOLE	4d	2/3/94 8:00am	2/6/94 5:00pm	12
14	SAWCUT NEXT SECTION	3d	2/8/94 8:00am	2/11/94 5:00pm	13
15	TRENCH NEXT SECTION	3d	2/14/94 8:00am	2/16/94 5:00pm	14
16	HAUL OFF NEXT SECTION	15d	2/11/94 8:00am	3/3/94 5:00pm	13FS -2d
17	SET PIPE AND CRADLE	14d	2/17/94 8:00am	3/6/94 5:00pm	15
18	BRING IN SELECT FILL	5d	3/4/94 8:00am	3/10/94 5:00pm	15FS -2d,16
19	PLACE AND COMPACT BACKFILL	14d	3/11/94 8:00am	3/30/94 5:00pm	13FS +7d,18
20	EXCAVATE NEXT MANHOLE	1d	3/31/94 8:00am	3/31/94 5:00pm	17,19
21	SET MANHOLE	4d	4/1/94 8:00am	4/6/94 5:00pm	20
22	SAWCUT NEXT SECTION	3d	4/7/94 8:00am	4/11/94 5:00pm	21
23	TRENCH NEXT SECTION	3d	4/12/94 8:00am	4/14/94 5:00pm	22
24	HAUL OFF NEXT SECTION	5d	4/11/94 8:00am	4/15/94 5:00pm	21FS -2d
25	SET PIPE AND CRADLE	14d	4/15/94 8:00am	5/4/94 5:00pm	23
26	BRING IN SELECT FILL	4d	4/19/94 8:00am	4/22/94 5:00pm	23FS -2d,24
27	PLACE AND COMPACT BACKFILL	2d	5/16/94 8:00am	5/17/94 5:00pm	25FS +7d,26
28	EXCAVATE LAST MANHOLE	1d	5/18/94 8:00am	5/18/94 5:00pm	27
29	SET MANHOLE	4d	5/19/94 8:00am	5/24/94 5:00pm	28
30	REROUTE TRAFFIC	1d	5/25/94 8:00am	5/25/94 5:00pm	29
31	SAWCUT FOR DOWNSTREAM CONNECTION	3d	5/26/94 8:00am	5/30/94 5:00pm	30
32	TRENCH DOWNSTREAM CONNECTION	1d	6/1/94 8:00am	6/1/94 5:00pm	31FS -1d
33	HAUL OFF EXCESS SOIL	1d	6/2/94 8:00am	6/2/94 5:00pm	32
34	SET PIPE AND CRADLE	7d	6/2/94 8:00am	6/10/94 5:00pm	32
35	CONNECT, SEAL AND PLUG LINES	2d	6/13/94 8:00am	6/14/94 5:00pm	34
36	BRING IN SELECT FILL	1d	6/3/94 8:00am	6/3/94 5:00pm	32,33
37	PLACE BACKFILL AND PLATE OVER UNTIL CURED	1d	6/6/94 8:00am	6/6/94 5:00pm	36
38	REROUTE TRAFFIC UPSTREAM END	1d	6/7/94 8:00am	6/7/94 5:00pm	37
39	SAWCUT FOR CONNECTION	3d	6/8/94 8:00am	6/10/94 5:00pm	38
40	TRENCH FOR CONNECTION	1d	6/15/94 8:00am	6/15/94 5:00pm	39FS -2d
41	HAUL OFF EXCESS SOIL	1d	6/16/94 8:00am	6/16/94 5:00pm	40
42	SET PIPE AND CRADLE	7d	6/16/94 8:00am	6/24/94 5:00pm	40
43	BRING IN SELECT FILL	1d	6/27/94 8:00am	6/27/94 5:00pm	40,42
44	PLACE AND COMPACT BACKFILL AND PLATE OVER	1d	6/28/94 8:00am	6/28/94 5:00pm	43
45	HOLD FINAL INSPECTION	1d	6/29/94 8:00am	6/29/94 5:00pm	44
46	DIVERT FLOW, CONNECT LINES, AND ABANDON OLD	1d	6/30/94 8:00am	6/30/94 5:00pm	45,36
47	SWEEP, CLEAN, REPAVE AND STRIPE	5d	7/1/94 8:00am	7/7/94 5:00pm	45,46,41
48	DENOBILIZE	3d	7/8/94 8:00am	7/12/94 5:00pm	47

Table 2. Open-cut Trenching Schedule

OPEN-CUT TRENCHING SUMMARY

The use of open cut trenching requires a significantly different design than the other methods. Critical factors in the design include:

- Backfill compaction and soil pressure.
- Pipe material and cradle construction.

Critical concerns are:

- Pavement failure after completion.
- Pipe alignment and joint integrity.
- Effect of extracting shoring or compacting backfill on the new pipe.
- Effect of dewatering on surrounding structures and pavement.
- Traffic disruptions.
- Cross-buried utilities.

Countless projects similar to this one have been successfully completed using open-cut trenching. The level of technical expertise is widely developed and available so the cost of this type of work is well defined and understood. Strict control over operations and quality is very important for trenches this deep, but little training is required beyond that required for normal excavations.

Productivity would be seriously hampered if significant amounts of rock were encountered. An excavator can claw its way through most types of rock but the power requirements needed to displace solid formations of rock at full boom extension are large. Depending on the nature of the rock, an extreme service trenching bucket may be needed as well as a larger excavator with superior power at the required digging depth.

Excavators are very versatile. Buckets can be replaced with impact and compacting attachments. They can remove the soil from the trench, load it into a truck, lower pipe into the hole, and also place and compact the backfill. They require a considerable amount

of room to operate and open-cut trenching disturbs a large area and leaves a scar on the construction site.

Excess soil volumes are very large and the compaction of the backfill material is critical. Dewatering quantities can be very substantial and in the case of this scenario would pose a problem if discharge was regulated.

PIPE RAMMING

PROJECT EXECUTION

An alternative to the open-cut trenching method is installing pipe by pipe ramming. It is a technique where a string of pipe is forced horizontally through the soil using a pneumatic actuator. The lead pipe in the string has a hardened head and various means are used to remove the soil from inside the pipe. The pipe string can be replaced with another carrier pipe or used as an exterior casing for the actual carrier pipe.

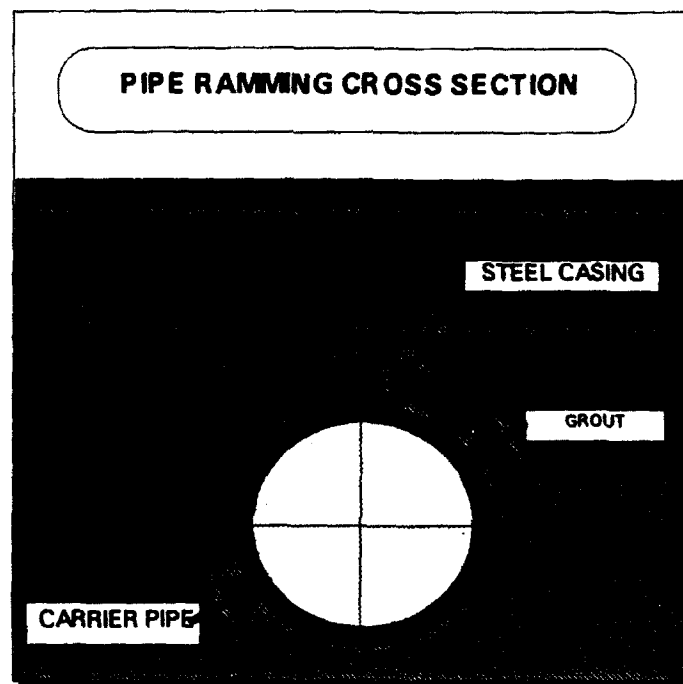


FIGURE 4. Pipe Ramming Design Detail

One of the most popular ramming machines is made by TT Technologies, Inc. Their systems utilize pneumatic pressure to generate a percussion that forces the casing forward through the soil. Extremely high cutting pressures can be developed by their system. According to their sales brochures, this test project would push the limits of their equipment but it provides an interesting comparison.

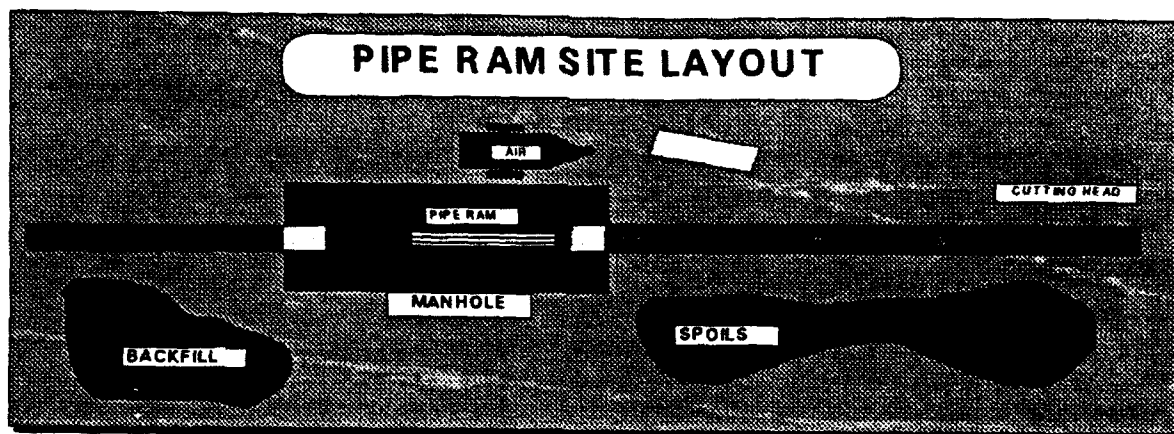


FIGURE 5. Pipe Ramming Site Layout

The cutting head cannot be steered, so it has to either be received at a large pit or pushed to its limits and then excavated. The receiving pit can eventually be used as a manhole. Figure 4 shows a typical cross-section of the excavation and Figure 5 shows the site layout for pipe ramming.

SUPPORT EQUIPMENT

Air pressure for the ramming head is provided by a large air compressor. The size of the compressor is dependent on the size of the ramming equipment and the soil type. The air compressor is also used to eject soil out of the casing after the ramming has been completed. The soil must be disposed of off-site so it must be removed from the ramming pits and loaded into trucks. This can be done by either a large back hoe or excavator.

Excavators tend to have longer stick lengths so for this example an excavator will be used. The excavator can also be used to lower and retrieve pipe sections and ramming equipment from the pits. The excavator will trench between the terminal manholes and existing lines and also dig the pits. To make the comparison between methods more meaningful, a Caterpillar 235C excavator will be used as the basis for scheduling and estimating.

Shoring, sheet piling, and pipe sections will have to be welded so a portable welding machine will be needed. Welding plays a larger part in the production rate of this process than open-cut trenching. The individual pipe sections must be butt welded as they are shoved down the string.

Drilling mud, similar to bentonite, is used to reduce the exterior friction on the pipe casing and also can be used on the inside to aid the removal of the interior cuttings. The bentonite is pumped forward through the casing and ejected along the casing through ports in the pipe.

Because this utility line will serve as a sewer main, strict control of grade is more important than alignment. Since the ramming head is not sterable, the casing can't be directly replaced by a similarly sized carrier pipe. The casing will have to be oversized to allow for variations in grade. A smaller sized carrier pipe will be placed inside the casing and its grade will be adjusted inside the casing. The annulus around the carrier pipe will be filled with a grout. The casing size must be large enough to account for grade variations and still allow the interior pipe to be adjusted to the correct grade.

SELECTION PROCESS

Casing size and soil conditions are the primary factors used to dictate the ramming equipment selection. For this paper, the carrier pipe will be 777mm inside diameter. This means that depending on pipe material, the outside diameter of the bell may be up to 925mm in diameter. To allow for grade variation, the pipe casing needs to allow for at

least 150mm of adjustment per line (80 to 100 meters). Thus the ramming equipment must be large enough to push a 1077mm pipe. The larger the pipe casing, the more expensive the pipe cost and production cost. The next larger size of pipe is 1225mm and this simulation is based on that size. This will require larger amounts of soil, grout, and pipe to be used but the risk is high with a 1077mm pipe.

According to TT Technologies' sales information, a minimum pipe thickness of 18mm inches is required for pipe bores of 10m feet or more. A pipe bore of 90m average will be used for this simulation. A TT Technology's "GOLIATH" ramming system will be required to push a 1227mm pipe (19mm thick and 6.3m long) 90m at a time.

The Goliath is 450mm in diameter, 2845mm, and weighs 2400kgs. TT Technologies' sales information states that it requires 35 m³ per minute of air and operates at 180 strokes per minute. In average soil conditions, such as this case, the rate of propulsion for a Goliath is from 3m to 17 m per hour.

The manufacturer said the purchase price of a fully equipped Goliath ram is \$115,000.

PRODUCTIVITY CALCULATIONS:

An estimate of the soil volumes that will be needed to be removed in the course of using this method was calculated. This method would require an additional manhole due to limits on boring length. Two ramming pits would need to be constructed and could be placed at the manholes adjacent to the center manhole. Each ramming pit could be used to drive in opposite directions. The sections between the terminal manholes and the existing lines would be trenched using traditional means.

The production volumes and times were used to compose a possible schedule, Table 3. Using this method, it could conceivably take 6 months to finish this project using pipe ramming. As with open-cut trenching, this schedule could be optimized by using a simulation analysis such as the one used for tunneling in the article by Vanegas, Bravo,

and Halpin (1993). This simulation could also be used for the final method, micro-tunneling.

1	MOVE IN	5d	11/29/93 8:00am	12/3/93 5:00pm	
2	SURVEY ROUTE	1d	12/6/93 8:00am	12/6/93 5:00pm	1
3	POT HOLE	5d	12/7/93 8:00am	12/13/93 5:00pm	2
4	SAW CUT ALL MANHOLES	3d	12/7/93 8:00am	12/9/93 5:00pm	2
5	EXCAVATE FIRST MANHOLE	10d	12/14/93 8:00am	12/27/93 5:00pm	4,3
6	SET PIPE RAM	2d	12/28/93 8:00am	12/29/93 5:00pm	5
7	PUSH PIPE (FIRST SECTION)	5d	12/30/93 8:00am	1/5/94 5:00pm	6
8	EXCAVATE REMAINING MANHOLES	14d	1/10/94 8:00am	1/27/94 5:00pm	7FS -2d
9	REPOSITION RAM	1d	1/28/94 8:00am	1/28/94 5:00pm	8
10	SET PIPE RAM	2d	1/31/94 8:00am	2/1/94 5:00pm	9
11	PUSH PIPE (SECOND SECTION)	5d	2/2/94 8:00am	2/6/94 5:00pm	10
12	REPOSITION RAM	1d	2/9/94 8:00am	2/9/94 5:00pm	8,11
13	SET FIRST TWO MANHOLES	6d	2/10/94 8:00am	2/17/94 5:00pm	12,9
14	HAUL OFF EXCESS SOIL	15d	12/29/93 8:00am	1/18/94 5:00pm	5FS -1d
15	BRING IN SELECT FILL	8d	2/18/94 8:00am	3/1/94 5:00pm	13
16	PLACE AND COMPACT BACKFILL	3d	2/23/94 8:00am	2/25/94 5:00pm	13FS -3d
17	SET PIPE RAM	2d	2/10/94 8:00am	2/11/94 5:00pm	12
18	PUSH PIPE (THIRD SECTION)	5d	2/14/94 8:00am	2/18/94 5:00pm	17
19	REPOSITION RAM	1d	2/21/94 8:00am	2/21/94 5:00pm	18
20	SET PIPE RAM	2d	2/22/94 8:00am	2/23/94 5:00pm	19
21	PUSH PIPE (LAST SECTION)	5d	2/24/94 8:00am	3/2/94 5:00pm	20
22	REMOVE RAM	1d	3/3/94 8:00am	3/3/94 5:00pm	21
23	SET REMAINING MANHOLES	9d	3/4/94 8:00am	3/16/94 5:00pm	22
24	HAUL OFF EXCESS SOIL	25d	1/31/94 8:00am	3/4/94 5:00pm	8FS -1d
25	BRING IN SELECT FILL	12d	3/17/94 8:00am	4/1/94 5:00pm	23
26	PLACE AND COMPACT BACKFILL	6d	3/22/94 8:00am	3/29/94 5:00pm	23FS -3d
27	REROUTE TRAFFIC	1d	3/30/94 8:00am	3/30/94 5:00pm	26
28	SAW CUT FOR DWNSTREAM CONNECTION	3d	3/31/94 8:00am	4/4/94 5:00pm	27
29	TRENCH DOWSTREAM CONNECTION	1d	4/6/94 8:00am	4/6/94 5:00pm	28FS -1d
30	HAUL OFF EXCESS SOIL	1d	4/7/94 8:00am	4/7/94 5:00pm	29
31	SET PIPE AND CRADLE	7d	4/7/94 8:00am	4/15/94 5:00pm	29
32	CONNECT, SEAL AND PLUG LINES	2d	4/18/94 8:00am	4/19/94 5:00pm	31
33	BRING IN SELECT FILL	1d	4/7/94 8:00am	4/7/94 5:00pm	29
34	PLACE BACKFILL AND PLATE OVER UNTIL CURED	1d	4/20/94 8:00am	4/20/94 5:00pm	33,32
35	REROUTE TRAFFIC UPSTREAM END	1d	4/21/94 8:00am	4/21/94 5:00pm	34
36	SAW CUT FOR CONNECTION	3d	4/22/94 8:00am	4/26/94 5:00pm	35
37	TRENCH FOR CONNECTION	1d	4/29/94 8:00am	4/29/94 5:00pm	36FS -2d
38	HAUL OFF EXCESS SOIL	1d	5/2/94 8:00am	5/2/94 5:00pm	37
39	SET PIPE AND CRADLE	7d	5/2/94 8:00am	5/10/94 5:00pm	37
40	BRING IN SELECT FILL	1d	5/2/94 8:00am	5/2/94 5:00pm	37
41	PLACE AND COMPACT BACKFILL AND PLATE OVER	1d	5/11/94 8:00am	5/11/94 5:00pm	40,39
42	HOLD FINAL INSPECTION	1d	5/12/94 8:00am	5/12/94 5:00pm	41
43	DIVERT FLOW, CONNECT LINES, AND ABANDON OLD	1d	5/13/94 8:00am	5/13/94 5:00pm	42
44	SWEEP, CLEAN AND STRIPE	5d	5/18/94 8:00am	5/20/94 5:00pm	42,30,38,43
45	DEMOBILIZE	3d	5/23/94 8:00am	5/25/94 5:00pm	44

Table 3. Pipe Ramming Schedule

PIPE RAMMING SUMMARY

This is a risky and expensive way of installing a sewer line when grade control is very important. The cost of the steel casing and grouting would quickly rise as the diameter of the hole was increased to compensate for grade. The lack of alignment control would be a

problem unless the owner was willing to allow the manhole layout to wander. It is only conjecture as to whether two strings of pipe could actually come close to meeting at a common manhole as proposed.

This method is not technically challenging but is highly dependent on the welding skills. Soil volumes would be dramatically reduced. This is a low maintenance system but could be very messy. Cutting heads would have to be replaced after each drive. The percussion equipment is rugged and should not have to be overhauled until after the project.

It wouldn't disrupt above ground activities except at the manhole locations and would require less layout area. Even though this method can develop high ramming pressures, it would have difficulty cutting through rock or dealing with obstructions. A major drawback of this method is the vibrations that result from the percussion action of the ram. The noise can be disturbing to adjacent buildings and the vibration can lead to liquefaction of the surrounding soil.

MICRO-TUNNELING

PROJECT EXECUTION

Micro-tunneling is very similar to pipe ramming except that at the head of the pipe string is an articulating cutting head. The pipe is pushed through the ground using hydraulic rams and they in turn push forward the cutting head. The cutting head is a conical crusher that is articulated by internal actuators. The position of the head is monitored by a laser positioning system that can adjust the direction of advancement.

Large scale tunneling of this type is common, but micro-tunneling is used in conditions where the hole is too small for human presence. Thus all the controlling and operations are conducted outside the hole. A control room is usually placed above the excavation and the progress of the machine is monitored remotely via television. A typical site layout is depicted in Figure 6.

The driving pits require a thick mud slab and a thrust block. The thrust block is a large concrete pad that is used by the ram to resist reactionary forces caused by forcing the pipe and cutting head forward. The head is removed at the receiving pit and multiple drives can be made from individual pits.

Alignment and grade control is often superior to open-cut trenching. The pipe can pass beneath roads and structures without a noticeable presence.

SUPPORT EQUIPMENT:

All pits need to be dug by an excavator. The design of the thrust blocks usually requires the construction of a sheetpile wall with reinforced walers. This means that a crane must be used to install and remove the sheets. The steel piles, walers, and pipe will be welded together. Pumping equipment is needed to circulate a slurry used in the cutting process. The slurry lubricates the cutting knives and transports the excavated soil back through the pipe string into settling basins.

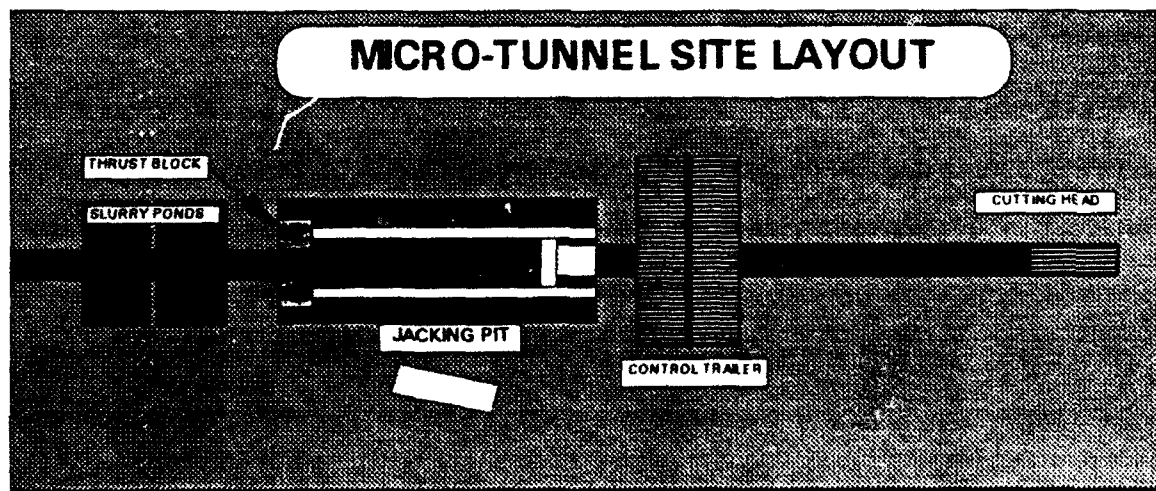


FIGURE 6. Micro-tunneling Site Layout

SELECTION PROCESS:

The selection process for micro-tunneling equipment must consider pipe diameter and soil conditions. Special cutting heads are available for rock, clay, and combinations of soils. A multi-purpose head would be the most versatile and will be the type this paper discusses. The performance of these machines is very accurate. 10mm of variation is considered to be adequate in 100m of boring according to Iseki Inc. sales information and Iseley (1988).

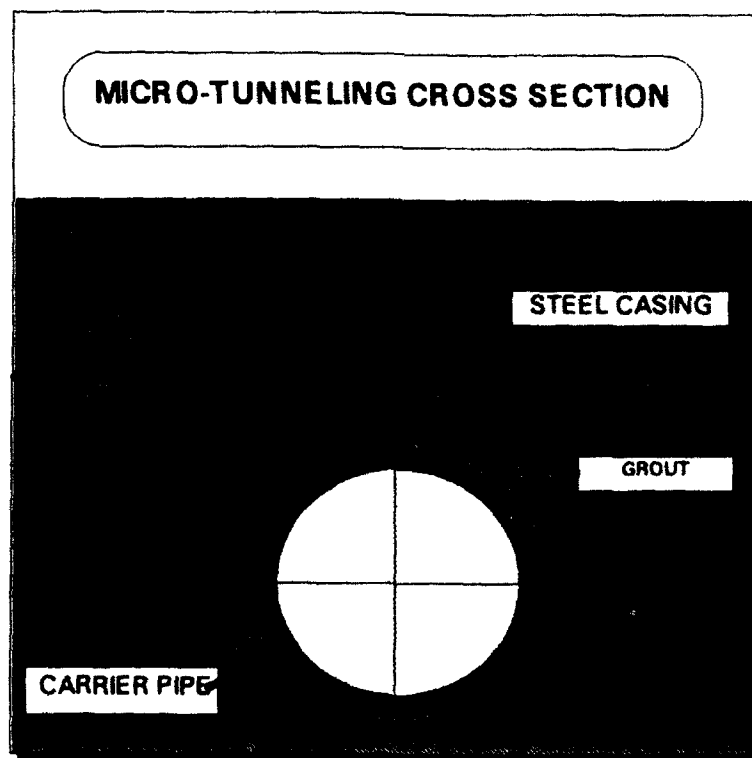


FIGURE 7. Micro-tunneling Design Detail

As with the ramming method, an interior PVC pipe will be placed inside the casing as shown in Figure 7. This means that a pipe of 950mm interior diameter will be needed. An Iseki Uncle Mole will meet these criteria according to their literature. It is a multi-purpose

machine with a driving unit that will produce in excess of 3560kN of cutting force. If bentonite is used as a lubricant, there should be no problem completing a 100m bore without exceeding 445kN of required force.

It has a soil pressure compensation system that allows it to operate to a maximum depth of 35m below grade (and head of water) and it requires a minimum cover of 2m. It can achieve drives of over 400m and can be equipped with computerized alignment controls.

PRODUCTIVITY CALCULATIONS

Drive pit sizes for the two boring machines are equivalent. Actual experience shows that a machine of this size, operating in similar conditions should dig 20m to 35m per day. The constraining activity is the speed at which new pipes are welded together and the equipment is reset for a new push.

Theoretically, this pipe could be installed in one long drive. However the maximum distance between manholes is usually limited by the size of cleaning equipment and tie-ins to other facilities. One drive pit located at the center could bore through the intermediate pits and end at the terminal pit. It could then be turned around and bore in the opposite direction. This was the basis of this paper's estimates (Table 4). It should take this method 4 months to complete this project.

The purchase price of an Iseki Uncle Mole is approximately \$600,000.

MICRO-TUNNELING SUMMARY

Micro-tunneling production rates are similar to those for trenching, but unlike trenching, production rates do not vary with depth. The purchase price of the machine and support equipment is more than three times the cost of most excavators and 6 times the cost of equivalent pipe ramming equipment. Technical expertise required to operate

the machine is very high. It is a hybrid skill, where knowledge of tunneling, vertical drilling, and utility work is required.

MICRO-TUNNELING SCHEDULE				
1	MOVE IN	5d	11/29/93 8:00am	12/3/93 5:00pm
2	SURVEY ROUTE	3d	12/6/93 8:00am	12/8/93 5:00pm
3	POT HOLE	5d	12/9/93 8:00am	12/15/93 5:00pm
4	SAWCUT ALL MANHOLES	2d	12/9/93 8:00am	12/10/93 5:00pm
5	EXCAVATE FIRST MANHOLE	10d	12/16/93 8:00am	12/29/93 5:00pm
6	SET MOLE	3d	12/30/93 8:00am	1/3/94 5:00pm
7	TUNNEL (FIRST SECTION)	10d	1/4/94 8:00am	1/17/94 5:00pm
8	EXCAVATE REMAINING MANHOLES	9d	12/13/93 8:00am	12/23/93 5:00pm
9	REPOSITION MOLE AND JACKS	1d	1/18/94 8:00am	1/18/94 5:00pm
10	SET MOLE	2d	1/19/94 8:00am	1/20/94 5:00pm
11	TUNNEL (SECOND SECTION)	10d	1/21/94 8:00am	2/3/94 5:00pm
12	SET FIRST TWO MANHOLES	6d	12/24/93 8:00am	12/31/93 5:00pm
13	HAUL OFF EXCESS SOIL	5d	12/31/93 8:00am	1/6/94 5:00pm
14	BRING IN SELECT FILL	2d	1/3/94 8:00am	1/4/94 5:00pm
15	PLACE AND COMPACT BACKFILL	1d	1/6/94 8:00am	1/6/94 5:00pm
16	REMOVE MOLE	1d	2/4/94 8:00am	2/4/94 5:00pm
17	SET REMAINING MANHOLES	9d	12/24/93 8:00am	1/5/94 5:00pm
18	HAUL OFF EXCESS SOIL	5d	12/27/93 8:00am	12/31/93 5:00pm
19	BRING IN SELECT FILL	2d	1/6/94 8:00am	1/7/94 5:00pm
20	PLACE AND COMPACT BACKFILL	6d	1/11/94 8:00am	1/18/94 5:00pm
21	REROUTE TRAFFIC	1d	1/19/94 8:00am	1/19/94 5:00pm
22	SAWCUT FOR DOWNSTREAM CONNECTION	3d	1/20/94 8:00am	1/24/94 5:00pm
23	TRENCH DOWNSTREAM CONNECTION	1d	1/28/94 8:00am	1/28/94 5:00pm
24	HAUL OFF EXCESS SOIL	1d	1/27/94 8:00am	1/27/94 5:00pm
25	SET PIPE AND CRADLE	7d	1/27/94 8:00am	2/4/94 5:00pm
26	CONNECT, SEAL AND PLUG LINES	2d	2/7/94 8:00am	2/8/94 5:00pm
27	BRING IN SELECT FILL	1d	1/27/94 8:00am	1/27/94 5:00pm
28	PLACE BACKFILL AND PLATE OVER UNTIL CURED	1d	2/8/94 8:00am	2/9/94 5:00pm
29	REROUTE TRAFFIC UPSTREAM END	1d	2/10/94 8:00am	2/10/94 5:00pm
30	SAWCUT FOR CONNECTION	3d	2/11/94 8:00am	2/15/94 5:00pm
31	TRENCH FOR CONNECTION	1d	2/18/94 8:00am	2/18/94 5:00pm
32	HAUL OFF EXCESS SOIL	1d	2/21/94 8:00am	2/21/94 5:00pm
33	SET PIPE AND CRADLE	7d	2/21/94 8:00am	3/1/94 5:00pm
34	BRING IN SELECT FILL	1d	2/21/94 8:00am	2/21/94 5:00pm
35	PLACE AND COMPACT BACKFILL AND PLATE OVER	1d	3/2/94 8:00am	3/2/94 5:00pm
36	HOLD FINAL INSPECTION	1d	3/3/94 8:00am	3/3/94 5:00pm
37	DIVERT FLOW, CONNECT LINES, AND ABANDON OLD	1d	3/4/94 8:00am	3/4/94 5:00pm
38	SWEEP, CLEAN AND STRIPE	5d	3/7/94 8:00am	3/11/94 5:00pm
39	DEMOBILIZE	3d	3/14/94 8:00am	3/18/94 5:00pm

Table 4. Micro-tunneling Schedule

The quality of the final product is extremely high. Grade and alignment can be controlled to tolerances of a couple of centimeters in runs of more than a hundred meters. The mole can travel under roads, rivers, and structures without noticeable effect. This makes this an extremely attractive method for deep, long utility lines.

As with pipe ramming, excess soil is significantly reduced. Backfill is required only around the manholes. Because the accuracy of this method is so good, the casing size is

limited only by the outside diameter of the carrier pipe. The high degree of accuracy will also allow for the manholes to be set prior to the commencement of boring. The mole can chew right through the manholes as long as it won't encounter large quantities of reinforcing steel.

ESTIMATED QUANTITIES:							
		OPEN CUT TRENCHING		PIPE RAMMING		MICRO- TUNNELING	
ITEM:	UNITS:	QUANTITIES	COST	QUANTITIES	COST	QUANTITIES	COST
SAWCUT ASPHALT	M	700	\$1,065	150	\$220	75	\$127
DEWATERING	DAY	180	\$12,105	180	\$4,035	180	\$4,035
TRENCH EXCAVATION	BCM	4800	\$10,879	2130	\$4,814	858	\$1,334
SHEETPILE SHORING	TON	102	\$56,801	288	\$180,470	120	\$66,589
BACKFILL TRENCH	CCM	4177	\$4,879	2100	\$4,442	900	\$1,903
COMPACT BACKFILL	CCM	4177	\$8,838	2100	\$2,352	900	\$1,008
HAUL EXCESS SOIL OFF	LCM	5538	\$24,299	2915	\$12,795	1284	\$5,548
HAUL IN SELECT BACKFILL	CCM	4177	\$51,750	2100	\$33,095	900	\$12,950
VITRIFIED CLAY PIPE	M	300	\$59,948				
PVC PIPE	M			300	\$5,200	300	\$5,200
STEEL CASING	M			300	\$78,000	300	\$78,000
VERTICAL SHORING	EACH	100	\$8,800				
ASPHALT PAVING	M ²	750	\$4,205	240	\$1,450	100	\$545
STRIPING	M	300	\$882	30	\$100	30	\$100
CONCRETE CRADLE	M ³	400	\$29,799				
CONCRETE MUDSLABS	M ³			43	\$2,287	20	\$1,084
MICRO-TUNNELING	DAY					60	\$72,000
WELD CASING	M			200	\$780	200	\$780
RENT ARC WELDER	DAY			90	\$11,250	60	\$7,500
BENTONITE	BAG			1500	\$3,225	1500	\$3,225
RENT AIR COMPRESSOR	DAY			90	\$6,900		
HORIZONTAL RAMMING	M			300	\$48,000		
PRESSURE GROUTING	M ³			3000	\$45,411	900	\$13,823
TOTALS:			\$271,818		\$424,805		\$276,111

Table 5. Production Cost and Quantity Estimates

COMPARISON

Table 5 is a summary of the production costs and estimated quantities for the three methods. It is not the total estimated project cost. Mark-ups related to overhead and profit are not included. Work activities that are common to the three methods are not included. Several of the common work activities include:

- * Mobilization/demobilization
- * Surveying costs
- * Trenching from terminal manholes to existing manholes and performing the tie-ins.

- * Pot-holing the location of important cross-buried utilities and areas of interest.
- * Establishing traffic controls.
- * Using the excavator to lower pipe into position.

The excavator costs calculated in R. S. Means are based on an excavator similar in size to a Caterpillar 235C. Estimated duration's were calculated using the same quantities used to estimate cost.

The estimated cost to pipe ram is significantly higher than for the other two methods. This directly related to sheetpile costs and costs resulting from oversizing the casing. Sheet piling costs are significantly higher for pipe ramming because an additional pit is needed due to the limits on ramming distance and the large size of the intersecting receiving pit.

The ramming method used a larger casing size to allow for grade fluctuations and this resulted in higher costs for casing material and grouting. The costs related to handling larger soil volumes also added to the difference between *pipe ramming* costs and the costs of micro-tunneling.

The micro-tunneling costs related to equipment are significantly higher than for the other two methods. The cutting head must be thoroughly rebuilt after each major project. The cost of the support equipment is also very high. The computerized control system, slurry handling system, and jacking platform are included in the \$36,000 per month estimates for ownership and operating costs.

Costs related to handling soil and backfill is significantly lower for both of the trenchless technologies. If soil contamination was a problem, this difference could result in tremendous cost savings. This also holds true for dewatering. The pumped quantities are significantly more for open-cut trenching. Disposal, treatment, or handling of this water could be a very expensive problem if the water is contaminated or discharge is regulated. Open excavations can be deemed a "confined space" for occupational health reasons. If the surrounding soil is contaminated, the safety precautions mandated for

working in confined spaces may make a trenchless technology the only practical means of installing a utility line through the area.

All three methods can handle varying soil conditions. Pipe ramming is the most limited in terms of its ability to cut through large deposits of rock or hard objects. Open-cut trenching allows you to examine difficult conditions or unknown buried objects. Micro-tunneling can drill right through most rock and man made structures. Unless tunneling progress is noticeably slowed, only an examination of cuttings will show what is being excavated. This means that micro-tunneling should only be done well beneath known structures. A comparison of the typical site layouts shows that both of the trenchless technologies require less space and are less disruptive to traffic and operations.

COMPARISON USING EXPERT SYSTEMS

Various methods can be used to compare the estimated performance of each of the systems but an interesting way of selecting between the methods is by employing an expert system. Table 6 is a listing of computer code I developed to select between the three methods using the VPExpert™ micro-computer package. The user is prompted for background information about the project and then heuristic rules are used to recommend a installation method. Selection criteria is based on:

- * Pipe length
- * Invert depth
- * Soil conditions
- * Possible obstructions and soil contamination
- * Traffic interference
- * Impact of installation vibration

The program is composed of If-Then statements that sort through the background information and then recommend a method along with a confidence factor. The confidence factors are a subjective indication of the strength of the recommendation.

TRENCHLESS TECHNOLOGY SELECTION	
ENDOFF:	RULE 0
ACTIONS:	IF D > 30 AND
DISPLAY "THIS EXPERT SYSTEM PROGRAM WILL GUIDE YOU"	D < 25 AND
DISPLAY "THROUGH THE EVALUATION PROCESS OF POTENTIAL"	S < CLAY OR
DISPLAY "ALTERNATIVES FOR INSTALLING BURIED UTILITY"	S < SAND AND CLAY OR
DISPLAY "LINES. ENJOY. SCOTT K. HIGGINS"	S < ROCK OR
DISPLAY "*****"	S < MIXED AND
FIND TYPE	W < 4 AND
DISPLAY "THE BEST METHOD FOR INSTALLING YOUR LINE IS:"	W < 200 AND
DISPLAY (TYPE):	L < 50 AND
PLURAL TYPE:	T < YES OR
	T < NO AND
ASK D: "HOW DEEP DOES THE NEW LINE NEED TO GO (DEPTH IN FEET)?"	C < YES OR
ASK B: "SELECT SOIL CONDITIONS:"	C < NO AND
CHOICES B: CLAY, SAND, AND CLAY, ROCK, MIXED:	S < NOT MANY AND
ASK W: "WHAT IS THE PIPE DIAMETER (WIDTH IN INCHES)?"	V < YES OR
ASK L: "HOW LONG IS THE PIPE (LENGTH IN FEET)?"	V < NO AND
ASK T: "WILL THE NEW LINE CROSS A MAJOR ROAD?"	G < VERY IMPORTANT OR
CHOICES T: YES, NO:	G < IMPORTANT OR
ASK C: "DO YOU EXPECT TO ENCOUNTER CONTAMINATED SOIL?"	G < NOT CRITICAL
CHOICES C: YES, NO:	THEN TYPE < MICRO_TUNNELING CNF 100
ASK B: "WILL THE NEW LINE ENCOUNTER CROSS-BURIED UTILITIES AT GRADE?"	BECAUSE THESE SET THE PARAMETERS FOR SELECTING THE APPROPRIATE METHOD:
CHOICES B: YES, LARGE, NUMBERS, YES, LARGE, DIAMETER, NOT MANY:	
ASK V: "WILL VIBRATIONS FROM WORK AFFECT SURROUNDING STRUCTURES?"	RULE 1
CHOICES V: YES, NO:	IF D < 5
ASK G: "HOW IMPORTANT IS GRADE ALIGNMENT CONTROL?"	THEN TYPE < OPEN CUT_TRENCHING CNF 100
CHOICES G: VERY IMPORTANT, IMPORTANT, NOT CRITICAL:	BECAUSE IF DEPTH IS LESS THAN 5 FEET, TRENCHING IS THE ONLY OPTION:

RULE 2	RULE 6
IF D > 45 AND	IF S < NOT MANY AND
L > 200 AND	L < 200 AND
D < 25	D < 50
THEN TYPE < MICRO_TUNNELING:	THEN TYPE < OPEN CUT_TRENCHING:
RULE 3	RULE 7
IF W < 48 AND	IF D < 25
S < ROCK AND	THEN TYPE < THIS WOULD BE CONSIDERED A MINING JOB:
L < 200 AND	
D < 5 AND	RULE 8
S < NOT MANY AND	IF L > 200 AND
D < 25 AND	S < ROCK AND
V < NO AND	D < 30
G < NOT CRITICAL	THEN TYPE < MICRO_TUNNELING:
THEN TYPE < PIPE RAMMING CNF 75	
BECAUSE THIS SETS THE SELECTION CRITERIA:	RULE 9
RULE 4	IF D < 35 AND
IF W < 42 AND	L > 2500
W < 2 AND	THEN TYPE < OPEN CUT_TRENCHING:
L > 200 AND	
D < 45 AND	RULE 10
D < 25	IF W > 200
THEN TYPE < MICRO_TUNNELING:	THEN TYPE < THIS IS A MASS EXCAVATION:
RULE 5	RULE 11
IF L < 35 AND	IF L < 4 AND
D < 35 AND	D < 35
T < NO AND	THEN TYPE < OPEN CUT_TRENCHING:
C < NO	
THEN TYPE < OPEN CUT_TRENCHING:	

Table 6. VPExpert Selection Program

CONCLUSION

The construction of deep utility lines can be technically challenging and are particularly difficult when installed in previously developed areas. Open-cut trenching is the traditional means of performing this type of work. This method provides good grade control, can be used in varying soil conditions, and is well understood.

Recent innovations have resulted in methods that at a minimum need to be considered when considering these types of projects. Soil contamination, dewatering, and disruption can be less if a trenchless technology is used. One method, pipe ramming, is inaccurate but fast and results in significantly less disruption to traffic and less excess soil. Another method, microtunneling, is highly accurate, versatile, and fast. It is technically challenging and requires large capitalization in equipment. Its speed and side benefits may result in lower costs if difficult conditions are encountered.

A specific recommendation about which piece of equipment should be used for this test project would depend on site and contractor specific information that is beyond the scope of this paper. This paper demonstrates that trenchless technologies can be a viable alternative to traditional open-cut excavating.

APPENDIX. REFERENCES

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APPENDIX B

DRAFT

DEPARTMENT OF THE NAVY
NAVAL FACILITIES
ENGINEERING COMMAND
GUIDE SPECIFICATION

NFGS-02311

DATE

SUPERSEDING NFGS-XXXXXXX

SECTION 02311

TRENCHLESS EXCAVATION CONSTRUCTION
USING MICROTUNNELING
XX/94

NOTE: This guide specification covers work related to the installation of utility systems (i.e., electrical power, communications, water, gas, oil, petroleum products, steam, sewage, drainage, irrigation, and similar facilities) utilizing the **microtunneling** trenchless excavation methods. Microtunneling Horizontal Earth Boring is a process characterized as highly sophisticated, laser guided, remote controlled system providing the capability of continuous accurate monitoring and control of the alignment and grade.

1. Microtunneling is ideally suited for placing a 18 inch to 72 inch casing pipe for containing utility lines. Distances between manholes can exceed 1000 linear feet. It is ideally suited for utility lines that must be buried in rock, sand, clay and contaminated soils in depths ranging from 6 feet to 100 feet below grade. Varied soil conditions can be dealt with a single cutting head and dewatering is greatly reduced. There are many manufacturers of equipment that can perform the work described in this specification.
2. Permanent pipe casing can be used as the carrier pipe or a separate pipe may be placed inside the casing. The designer has the option of selecting the casing pipe however it may limit the number of possible bidders.
3. Cathodic protection for steel pipes should be considered where the anticipated degree of corrosion is so great that coating systems, including polyethylene encasement, are not

adequate to protect the piping for the desired life of the system.

NOTE: See Note A located at rear of text.

PART 1 GENERAL

1.1 REFERENCES

The publications listed below form a part of this specification to the extent referenced. The publications are referred to in the text by the basic designation only.

AMERICAN PETROLEUM INSTITUTE (API)

\-API Spec 5L-\ Specification for Steel Line Pipe
\-API Spec 13A-\ Oil-Well Drilling - Fluid Materials

AMERICAN SOCIETY FOR TESTING AND MATERIALS (ASTM)

\-ASTM A 53-\ Pipe, Steel, Black and Hot Dipped Zinc-Coated (Galvanized)
 Welded and Seamless
\-ASTM A 139-\ Electric-Fusion (Arc)-Welded Steel Pipe (NPS 4 and Over)
\-ASTM A 716-\ Ductile Iron Culvert Pipe
\-ASTM A 746-\ Ductile Iron Gravity Sewer Pipe
\-ASTM C 31-\ Making and Curing Concrete Test Specimens in the Field
\-ASTM C 39-\ Compressive Strength of Cylindrical Concrete Specimens
\-ASTM C 76-\ Reinforced Concrete Culvert, Storm Drain, and Sewer Pipe
\-ASTM C 301-\ Vitrified Clay Pipe
\-ASTM C 361-\ Reinforced Concrete Low-Head Pressure Pipe
\-ASTM C 443-\ Joints for Circular Concrete Sewer and Culvert Pipe, Using Rubber
 Gaskets
\-ASTM C 497-\ Concrete Pipe, Manhole Sections, or Tile
\-ASTM C 655-\ Reinforced Concrete D-Load Culvert, Storm Drain, and Sewer
 Pipe
\-ASTM C 822-\ Concrete Pipe and Related Products
\-ASTM C 1208-\ Vitrified Clay Pipe and Joints for Use in Jacking, Sliplining, and
 Tunnels
\-ASTM D 3212-\ Joints for Drain and Sewer Plastic Pipes Using Flexible
 Elastomeric Seals
\-ASTM D 3262-\ "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Sewer
 Pipe
\-ASTM D 4161-\ "Fiberglass" (Glass-Fiber-Reinforced Thermosetting-Resin) Pipe
 Joints Using Flexible Elastomeric Seals
\-ASTM F 477-\ Elastomeric Seals (Gaskets) for Joining Plastic Pipe
\-ASTM F 794-\ PVC Pipe Standards

AMERICAN WELDING SOCIETY (AWS)

\-AWS D1.1-\ Structural Welding Code - Steel
\-AWS D1.5-\ Bridge Welding Code

AMERICAN WATER WORKS ASSOCIATION (AWWA)

\-AWWA C104/A21.4-\ Cement-Mortar Lining for Ductile-Iron Pipe and Fittings
for Water
\-AWWA C111/A21.11-\ Rubber-Gasket Joints for Ductile-Iron and Gray-Iron
Pressure Pipe and Fittings
\-AWWA C150/A21.50-\ Thickness Design of Ductile-Iron Pipe
\-AWWA C151/A21.51-\ Ductile-Iron Pipe, Centrifugally Cast in Metal Molds or
Sand-Lined Molds, for Water or Other Liquids
\-AWWA C200-\ Steel Water Pipe - 6 inch (150 mm) and Larger
\-AWWA C203-\ Coal-Tar Protective Coatings and Linings for Steel Water
Lines - Enamel and Tape - Hot Applied
\-AWWA C205-\ Cement-Mortar Protective Lining and Coating for Steel
Water Pipe - 4 inch and Larger - Shop Applied
\-AWWA C210-\ Liquid-Epoxy Coating Systems for the Interior and Exterior
of Steel Water Pipelines
\-AWWA C213-\ Fusion-Bonded Epoxy Coating for the Interior and Exterior
of Steel Water Pipelines
\-AWWA D1248-\ Polyethylene Plastic Moulding

ARMY CORPS OF ENGINEERS (COE)

\-COE EM-385-1-1-\ Safety and Health Requirements Manual
\-COE ER-1-1-11-\ Network Analysis System

[1.2 RELATED REQUIREMENTS

Section \=01560=\, "Environmental Protection," applies to this section with additions
and modifications specified herein. Section \=15011=\, "Mechanical General
Requirements," applies to this section with additions and modifications specified herein.]

1.3 DESIGN REQUIREMENTS

1.3.1 Pipe Casing

NOTE: See Note B located at the rear of text.

**NOTE: Provide only those pipe sizes and materials
applicable to the project requirements.**

NOTE: Choose one of the following options.

[Provide pipe casing indicated as []-inch lines of [polyvinyl chloride (PVC) plastic] [clay tile] [concrete] [steel] or [] pipe. Provide utility line accessories, [valves], [connections], and [manholes] as specified and where indicated. Submit *design calculations of pipe casing*\.]

NOTE: Where the casing will not serve as the actual carrier or utility line, specify the appropriate carrier pipe, joints and connections in other specification sections (e.g. Section 02660 or 02720).

1.4 SUBMITTALS

NOTE: Where a "G" in asterisk tokens follows a submittal item, it indicates Government approval for that item. Add "G" in asterisk tokens following any added or existing submittal items deemed sufficiently critical, complex, or aesthetically significant to merit approval by the Government. Submittal items not designated with a "G" will be approved by the Quality Control organization.

Submit the following in accordance with Section \=01300=\, "Submittals."

1.4.1 *SD-02, Manufacturer's Catalog Data*\

NOTE: Use other Specification Sections to require submittals for the actual carrier pipe unless the pipe casing is going to act as the carrier pipe.

- a. *Pipe Casing*\ piping, joints, fittings, valves, and couplings
- b. *Bentonite slurry*\

Submit manufacturer's standard drawings or catalog cuts, except submit both drawings and cuts for push-on [and rubber-gasketed bell-and-spigot] joints. Include information concerning gaskets with submittal for joints and couplings.

1.4.2 *SD-05, Design Data*\

NOTE: See Note C located at the rear of text.

- a. *Design calculations of pipe casing*\
- b. *Design calculations for manhole connections*\

1.4.3 *SD-06, Instructions*\

- a. *Installation*\ procedures for pipe casing

1.4.4 *SD-13, Certificates*\

- a. *Pipe casing*\ piping, fittings, joints, valves, and coupling
- b. Shop-applied *lining [and coating]*\

Certificates shall attest that tests set forth in each applicable referenced publication have been performed, whether specified in that publication to be mandatory or otherwise and that production control tests have been performed at the intervals or frequency specified in the publication. Other tests shall have been performed within 3 years of the date of submittal or certificates on the same type, class, grade, and size of material as is being provided for the project.

1.4.5 *SD-43, Construction Equipment List*\

- a. *Microtunneling Boring Machine*\ equipment to be used

1.5 DELIVERY, STORAGE, AND HANDLING

1.5.1 Delivery and Storage

Inspect materials delivered to site for damage. Unload and store with minimum handling. Store materials on site in enclosures or under protective covering. Store [plastic piping, jointing materials and] rubber gaskets under cover out of direct sunlight. Do not store materials directly on the ground. Keep inside of pipes, fittings, [and] [valves] free of dirt and debris.

1.5.2 Handling

NOTE: Delete coatings not allowed for the project.
AWWA M11 in the chapter on protective coatings
contains information on the relative merits of cement
mortar and coal-tar enamel coatings. See Foreword to
AWWA C210 for information on coal-tar epoxy
coating.

Handle pipe, fittings, valves, hydrants, and other accessories in a manner to ensure delivery to the excavation in sound undamaged condition. Take special care to avoid injury to coatings and linings on pipe and fittings; make satisfactory repairs if coatings or linings are damaged. Carry, do not drag pipe to the excavation. Store [plastic piping, jointing materials and] rubber gaskets that are not to be installed immediately, under cover out of direct sunlight. [Handle steel pipe with [coal-tar enamel] [coal-tar epoxy] coating in accordance with the provisions for handling coal-tar-enamel coated pipe in \-AWWA C203-\.]

PART 2 PRODUCTS

2.1 *PIPE CASING*\ MATERIALS

NOTE: See Note D located at the rear of text.

2.1.1 *Pipe Casing*\

2.1.1.1 Ductile-Iron Piping

NOTE: Insert the necessary Pressure/Thickness Class
to meet project conditions, as determined from
ANSI/AWWA C151/A21.51.

- a. Pipe and Fittings: Pipe, [except flanged pipe,] \-AWWA C151/A21.51-\,
[Pressure Class []][Thickness Class []]. The outside diameter of ductile
iron microtunneling pipe shall be in accordance with \-AWWA C150/A21.51-\.

(1) Deflection: The maximum allowable deflection shall not exceed three percent of the outside diameter of the pipe barrel for pipe manufactured with a rigid lining and/or rigid coating nor five percent for pipe manufactured with a flexible lining and/or flexible coating.

(2) Linings: [Cement mortar shall be in accordance with latest version of \-AWWA C104/A21.4.-\] [Polyethylene lining shall be virgin polyethylene complying with \-AWWA D1248-\ compounded with an inert filler and with sufficient carbon black to resist ultraviolet rays.]

(3) End Squareness: The ends of the pipe shall be perpendicular to the longitudinal axis of the pipe with a maximum deviation of no more than [0.25 inches].

(4) Hydrostatic Test: Each pipe section shall be subject to a hydrostatic test of not less than [500 psi] as per the requirements of \-AWWA C151/A21.51-\. Non-standard joint lengths shall be cut only from full length pipe having satisfactorily passed the required [500 psi] hydrostatic test.

(5) Material Properties: The following are representative minimum values for the physical properties of ductile iron for use as microtunneling pipe for pressure or gravity service.

(a) Tensile strength: Minimum [60,000 psi]

(b) Tensile yield strength: Minimum [42,000 psi]

(c) Compressive strength: The compressive yield strength of ductile iron is [10 to 20 percent] higher than the tensile yield strength. The ultimate strength in compression is not normally determined for ductile metals, though apparent strength in tests may be several times the tensile strength value.

(d) Elongation: Minimum [10 percent]

(e) Modulus of Elasticity: [24,000,000 psi] (tension or compression)

(f) Poisson's ratio: [0.28]

(6) Spigot End Outside Diameter: The Spigot end outside diameter must be within the following ranges: [3 to 12 inches, ± 0.06 inches] [14 to 24 inches, ± 0.05 inches] [30 to 48 inches, ± 0.08 inches] [54 to 64 inches, ± 0.04 inches].

b. Joints and Jointing Material:

NOTE: Do not locate flanged, grooved, or shouldered joints on buried pipelines unless they are in valve pits or chambers.

(1) Joints: Pressure and gravity microtunneling pipe shall have either an integral-bell push-on or rubber gasket coupled joint meeting the following criteria:

(a) Integral-bell push-on joint microtunneling pipe shall consist of a rubber-gasket joint manufactured to conform with \-AWWA C111/A21.11-\ and the dimensions shown in \-AWWA C151/A21.51-\ . The exterior of the pipe shall be coated with a durable cement-mortar or concrete coating applied in such a manner as to provide a uniform outside diameter.

(b) Cement-mortar or concrete strength, reinforcement and method of placement shall be in accordance with manufacturer's recommendations. [Durable Coatings of other types may be substituted provided they maintain a uniform outside diameter and they are approved by the designer.] Rubber gasket coupled microtunneling joint shall be manufactured so as to provide a joint which has the same nominal outside diameter as the pipe barrel.

2.1.1.2 Polyvinyl Chloride Pipe (PVC)

NOTE: See Note E located at the rear of text.

2.1.1.3 Reinforced Concrete Pipe

NOTE: This section covers reinforced concrete pipe intended for use as conveyance systems of sewage and storm water, and for the construction of culverts and industrial casings installed and constructed by jacking methods.

a. Pipe: Pipe, [] inch inside diameter,]class [], wall [], nominal length [] and concrete strength [] psi in accordance with \-ASTM C76-\.

NOTE: See Note F located at the rear of text.

(1) Internal Diameter: The internal diameter of [12 to 24 inch pipe shall not vary by more than $\pm$ [1/4] inch from the design diameter.] [27 inch and larger pipe shall not vary from the design diameter by more than $\pm$ [one] percent or $\pm$ [3/8] inch, which ever is less.]

(2) Wall Thickness: At any location along the length of the pipe, or at any point around its circumference, the wall thickness shall not vary by more than $\pm$ [five] percent.

(3) End Squareness: Each pipe end shall lie within two planes perpendicular to the longitudinal center line of the pipe, spaced at [3/8 inches] apart. The tongue or spigot end shall be square within [3/16 inches] and the groove or bell end of the pipe shall be square within [3/16 inches].

(4) Hydrostatic Test: Each pipe section shall be subject to a hydrostatic test of not less than [10 psi for straight] [13 psi for deflected] alignment as per the requirements of section 10 of \-ASTM C 443-\ and section 8 of \-ASTM C 497-\ . Non-standard joint lengths shall be cut only from full length pipe having satisfactorily passed the required [] psi hydrostatic test.

(5) Roundness: The outside diameter of the pipe shall not vary from a true circle by more than [1.0] percent. The out-of-round dimensions shall be one half the difference between the maximum and minimum outer diameter of the pipe at any one location along the barrel.

(6) Length of Pipe: Finished pipe length shall not deviate from design length by more than $\pm$ [1/8 inch] per foot with a maximum variation of $\pm$ [1/2 inch] in any length of pipe.

(7) Length of two opposite sides: Variations in laying length of two opposite sides of the pipe shall not be more than [[1/4] inch for all sizes through 24 inch internal diameter] [[1/8] inch per foot for all sizes larger than 24 inches in internal diameter], with a maximum of [3/8] inches in any length of pipe.

b. Joints and Jointing Material:

(1) Joints: Joint shall [be formed entirely of concrete and as detailed in the contract drawings, [may] [shall] utilize a rubber gasket or mastic to provide

the seal.] [incorporate an assembly of [steel bands] [or] [steel bell ends and spigot rings and rubber gaskets in accordance with contract drawings.]

2.1.1.4 Steel Pipe

NOTE: This section covers steel pipe used as an encasement for other carrier pipes or it may also serve as the carrier pipe for water, gas, sanitary sewer or other utility products.

NOTE: See Note G located at the rear of text.

a. Pipe: Steel pipe shall be in conformance with [ASTM A 139, Grade B with a minimum yield strength of [35,000] psi] [AWWA C200] [API Spec 5L, Grade B][ASTM A 53][ASTM A 716][ASTM A 746]. Steel pipe shall be welded, seamless, square cut with even lengths[and shall comply of Articles 4.2, 4.3, and 4.4 of the API Spec. 5L].

(1) Roundness: The difference between the major and minor outside diameters shall not exceed [1 percent] of the specified nominal outside diameter or [0.25 inch] whichever is less. [For pipe exceeding 48 inches in diameter, a maximum deviation of [1/2 inch] shall be permitted provided the circumference tolerance is maintained within $\pm$ [1/4 inches].

(2) Circumference: The outside circumference shall be within $\pm$ [1 percent] of the nominal circumference or within $\pm$ [0.50 inches], whichever is less.

(3) Straightness: The maximum allowable straightness deviation in any [10 foot] length shall be [1/8] inch. [For lengths over [10 feet], the maximum deviation of the entire length may be computed by the following formula, but not to exceed [3/8 inch] in any [40 foot] length:

$$(1/8) \times (\text{total length in feet}) / 10 = \text{Maximum Deviation in inches}]$$

(4) Pipe ends: The end of the pipe shall be perpendicular to the longitudinal axis of the pipe and within [1/16 inches] per foot of diameter, with a maximum allowable deviation of [1/4 inch] measured with a square and straightedge across the end of the pipe.

b. Joints: The connection of adjacent pieces of microtunneling steel pipe may be accomplished by [field butt welding,][internal weld sleeves,][integral press fit connectors,]as long as loading and installation design criteria are met.

2.1.1.5 Fiberglass Pipe

NOTE: This section covers centrifugally cast fiberglass pipe for installation by pipe jacking and microtunneling for use in sanitary sewer, storm drain, wastewater collection and industrial effluent applications.

a. Pipe: Fiberglass pipe shall meet the requirements of \-ASTM D 3262-\, Type 1, Liner 2, Grade 3. The method of the manufacture shall be centrifugal casting resulting in a controlled outside diameter. Minimum wall thickness shall be [1.5 inches].

- (1) Roundness: The pipes shall be round within [0.1 percent] of the outside diameter.
- (2) Pipe lengths: Length tolerance shall be $\pm 1/4$ inches per length of pipe.
- (3) End squareness: Pipe ends shall be perpendicular to the pipe axis within a tolerance of $\pm [1/16 \text{ inch}]$.
- (4) Straightness: Pipes shall be straight to within $\pm [1/16 \text{ inch}]$ over 10 feet.
- (5) Jacking strength: The average ultimate axial compressive strength shall be [12,000 psi] minimum. The jacking capacity shall be based on the structural wall (end area) under the gasket groove (reduced cross-section). The allowable jacking capacity shall be determined by applying a 2.5 safety factor.

b. Joints: The pipes shall be connected by gasket-sealed bell-spigot joints. The gasket material shall meet the requirements of \-ASTM F 477-\, The joint shall meet the requirements of \-ASTM D 4161-\ and shall be leak-free under the following conditions:

- (1) External pressures up to [2 bars (29 psi)] from bentonite injection, slurry system operation or groundwater head.
- (2) Internal air testing up to [5 psi].

(3) Gaps between the pipe ends up to [two] percent of the diameter (maximum of [1.00] inches).

[c. The corrosion liner shall consist of a minimum thickness of [0.04 inch] of reinforced polyester resin. The outside pipe coating shall have a minimum thickness of [0.03 inches] and shall consist of thermosetting polyester resin and sand.]

2.1.1.6 Vitriified Clay Pipe

NOTE: This section covers the criteria for the manufacture, quality assurance testing, inspection, installation, and field acceptance testing of vitrified clay pipe to be used in jacking, sliplining, and in tunnels for the conveyance of sewage, industrial wastes, and storm water.

a. Pipe: Vitriified clay pipe shall be manufactured from fire clay, shale, surface clay, or a combination that can meet three edge bearing strength for nominal diameters of: [4 inches 2000][6 inches 2000][8 inches 2200][10 inches 2400][12 inches 2600][15 inches 2900][18 inches 3300][21 inches 3850][24 inches 4400][27 inches 4700][30 inches 5000][36 inches 6000][42 inches 7000] lb/linear foot.

(1) Acid Resistance: The pipe shall be resistant to acid in accordance with test methods specified in \-ASTM C 301-\.

(2) Compressive Strength: Pipe materials shall have a minimum compressive strength of [7,000 psi].

(3) Dimensional tolerances: The outside diameter shall not vary from a true circle by more than [2 percent] of its nominal diameter. The out-of-round dimension is the difference between the maximum and minimum diameters measured at any one location along the barrel and must be limited to less than. Pipe shall not deviate from straight by more than [0.05 inches] per linear foot when maximum offset is measured from the concave side of the pipe.

(4) End squareness: The plane formed by a pipe end shall not deviate by more than [0.005] inches per inch of outside diameter.

b. Joints: Joints shall be capable of supporting a shear load of [50 pounds] per inch of nominal diameter uniformly applied over an arc of not less than [120 degrees] and along a distance of 12 inches adjacent to the joint. Apply an internal [10 foot head (4.3 psi)] of water pressure for a period of one hour. Joints shall fully comply with \-ASTM C 1208-\.

2.2 Concrete

Concrete shall be [3000 psi] and conform with Section 03302 of this specification.

2.3 Bentonite

Bentonite shall conform with \-API Spec 13A-\ and have the capability of mixing with water to form a stable and homogeneous suspension.

2.4 Backfill

Excavated sand may be used for backfill and shall conform with Specification Section 02220 "GENERAL EXCAVATION, FILLING, AND BACKFILL".

PART 3 EXECUTION

3.1 PREPARATION

3.1.1 Access Shafts

a. Construction methods required to provide access shafts for microtunneling shall be subject to approval of the Contracting Officer. Acceptable construction methods may include the use of interlocked steel sheetpiling or precast circular concrete segments lowered in place during excavation.

b. Final dimensions of access shafts selected by the Contractor shall be modified as required following installation of pipe casings to the size and shape of acceptable manhole designs shown on the Contract Drawings[to permit installation of conveyance piping].

c. Shafts shall be of a size commensurate with safe working practices and located as shown on plans. With the approval of the Contracting Officer, the Contractor may relocate shafts to better suit the capabilities of the microtunneling method proposed. Where no locations are given, the Contractor shall determine such locations with the approval of the Contracting Officer.

- d. Shaft locations shall, where possible, be kept clear of road intersections and within a single traffic lane, in order to minimize disruption to the flow of traffic. Support equipment, spoil piles, and materials shall also be located such as to minimize disruption to traffic and are subject to the approval of the Contracting Officer.
- e. The Contractor shall properly support all excavations and prevent movement of the soil, pavement, utilities or structures outside of the excavation. The Contractor shall furnish, place and maintain sheeting, bracing, and lining required to support the sides and floor of all pits and to provide adequate protection of the work, personnel, and the general public. Design loads on the sides of the jacking and receiving pit walls are dependent on the construction method and flexibility of the wall systems.
- f. Construct a starter shaft to accommodate the installation of pipe casings, slurry shield and piping jacking device. Install thrust block as required and consolidate the ground (grout) where the casings exit the shaft.
- g. Construct a receiver shaft to accommodate the installation of pipe casings and the slurry shield. Consolidate the ground (grout) where the casings enter the shaft.
- h. The Contractor shall furnish, install, and maintain equipment to keep the jacking shaft free of excess water. The Contractor shall also provide surface protection during the period of construction to ensure that surface runoff does not enter driving shaft(s). Groundwater dewatering shall comply with the approved dewatering plan and shall not affect surrounding soils or structures beyond the tolerances stated in Specification Section 02311.3.2.2.
- i. Provide security fence around all access shaft areas and provide and shaft cover(s) when the shaft area is not in use.
- j. Design of the jacking and receiving pit supports should also take into account the loading from shield or pipe jacking where appropriate, as well as special provisions and reinforcement around the breakout location. The base of the pits shall be designed to withstand uplift forces from the full design head of water, unless approved dewatering or other ground modification methods are employed.
- k. Where a thrust block is required to transfer jacking loads into the soil, it shall be properly designed and constructed by the Contractor. The backstop shall be normal (square) with the proposed pipe alignment and shall be designed to withstand the maximum jacking pressure to be used with a factor of safety of at least [2.0]. It shall also be designed to minimize excessive deflections in such a manner as to avoid disturbance of adjacent structures or utilities or excessive ground movement. If a concrete thrust block or treated soil zone is utilized to

transfer jacking loads into the soil, the tunnel boring machine is not to be jacked until the concrete or other materials have attained the required strength.

1. Pit Backfill and Compaction: Upon completion of the pipe drive and approval of the installed pipeline by the Contracting Officer, remove all equipment, debris, and unacceptable materials from the pits and commence backfilling operation. Backfilling, compaction and pavement repairs shall be completed in accordance with Specification Section 02220.

[m. If tremie concrete sealing slabs are placed within the earth support system to prevent groundwater inflow when access shafts are dewatered, the sealing slabs shall be of sufficient thickness to provide a factor of safety equal to 1.2 against hydrostatic uplift in order to prevent bottom blowout when the excavation is completely dewatered.]

3.2 INSTALLATION

3.2.1 Construction scheduling and operational criteria are shown on the Contract Drawings and are specified in Division 01-- "GENERAL REQUIREMENTS" and \-COE ER-1-1-11-\.

3.2.1.1 Installation of Tracer Wire

Install a continuous length of tracer wire for the full length of each run of nonmetallic pipe. Attach wire to top of pipe in such a manner that it will not be displaced during construction operations.

3.2.1.2 Connections to Existing Lines

Make connections to existing lines after approval is obtained and with a minimum interruption of service on the existing line. Make connections to existing lines under pressure [in accordance with the recommended procedures of the manufacturer of the pipe being tapped] [as indicated].

NOTE: See Note H located at the rear of text.

3.2.2 Settlement, Alignment and Tolerances

a. Settlement or heave of ground surface along centerline of microtunneling alignments during and after installation of pipe casings shall not exceed [] inch[es].

b. No more than [] inch lateral and [] inch vertical deviation shall be permitted in the position of the completed jacked pipe casings. [Water shall be free draining between any two points at the pipe invert. No reverse grades will be allowed.]

[c. Overcut shall not exceed [1 inch] on the radius of the pipe being installed. The annular space created by the overcut [may][must] be filled with the lubrication material that is used to reduce soil friction drag on the pipe.]

3.2.3 Microtunneling

NOTE: Select one of the following options. The first option restricts the Contractor to using an unmanned tunneling machine while the second option also permits the Contractor to use tunneling shields.

[a. The tunnel boring machine shall be an unmanned mechanical type earth pressure counter-balanced bentonite slurry shield system. The machine shall be laser guided and monitored continuously, with a closed circuit television system. The machine shall be capable of fully supporting the face both during excavation and during shutdown and shall have the capability, of positively measuring the earth pressure at the face. Excavation face pressure shall be maintained at all times between the measured active earth pressure and 50 percent of the computed passive earth pressure. Fluid pressure applied at the face to stabilize the excavation shall be maintained at level slightly in excess of normal hydrostatic pressure and shall be monitored continuously. the machine shall be operated so as to prevent either surface heave or loss of ground during tunneling and shall be steerable and capable of controlling the advance of the heading to maintain line and grade within the tolerances specified in Section 02311.3.2.2. The machine shall be capable of handling and removing material of high water content from the machine head.

b. Each pipe casing section shall be jacked forward as the excavation progresses in such a way to provide complete and adequate, ground support at all times. A bentonite slurry (driller's mud) shall be applied to the external surface of the pipe to reduce skin friction. A jacking frame shall be provided for developing a uniform distribution of jacking forces around the periphery of the pipe. A plywood spacer shall be placed on the outer shoulder of the pipe casing joint. The thrust reaction backstop shall be properly designed and constructed.

c. The backstop shall be normal (square) with the proposed pipe casing alignment and shall be designed to support the maximum obtainable jacking pressure with a safety factor at least [2.0].

d. The jacking system shall be capable of continuously monitoring the jacking pressure and rate of advancement. Special care shall be taken when setting the pipe guard rails in the starter shaft to ensure correctness of the alignment, grade and stability]

[a. Only tunneling equipment capable of fully supporting the face of the tunnel shall be used for the pipe jacking work described.

b. Tunneling equipment selected for the project shall be compatible with the geotechnical information contained in this contract. The tunneling equipment shall be capable of tunneling through mixed face conditions without exceeding the settlement tolerances specified in Section 02311.3.2.2.

c. Face pressure exerted at the heading by the tunneling machine shall be maintained as required to prevent loss of ground, groundwater inflows, and settlement or heave of the ground surface by balancing soil and groundwater pressures present.

d. Dewatering for groundwater control shall be allowed at the jacking and receiving pits only.]

e. Do not jack pipe casing until the concrete thrust block and tremie seal (if selected), and grouted soil zone in starter and receiving shafts have attained the required strength.

f. The pipe casing shall be jacked in place without damaging the pipe casing joints or completed pipe casing section.

g. After completion of the jacking operation between starter and receiver shafts, the lubricate material shall be displaced from between the pipe casing exterior and the surrounding ground by a cement grout. Pressure and the amount of grout shall be controlled to avoid pipe damage and displacement of the pipe and soil beyond the tolerances specified in Section 02311.3.2.2. Grouting shall be accomplished promptly after pipe installation has been completed to prevent any surface settlement due to movement of soil material into the void space or loosened zone around the pipe casing.

h. Any pipe casing which has been damaged during installation shall be replaced by the Contractor at no additional cost. If a new replacement pipe casing is required extending from the starter to the receiver shaft, it shall be installed in conformance with the Contract drawings and this Specification Section.

[i. Steel pipe casing joints shall be continuously welded with an approved butt joint. The welds shall attain the full strength of the pipe and shall result in a full watertight section. The inner face of internal weld seam shall be flush with the pipe to facilitate the installation of the conveyance pipe in the pipe casing.

j. Perform all welding in accordance with requirements for shielded metal arc welding of \-AWS D1.5 -\ for bridges and \-AWS D1.1-\ for buildings and other structures.]

[i. Fiberglass pipe casing joints shall be fully watertight and shall attain the full strength of the pipe. Casing joints shall be field connected with sleeve couplings or bell and spigot type joints that utilize elastomeric sealing gaskets as the sole means to maintain joint water tightness.

j. The joint shall have the same outside diameter as the pipe so when the pipelines are assembled such that the joints are flush with the pipe inside and outside surface[to facilitate installation of the conveyance pipe in the pipe casing].]

k. All excavated material from tunnel and shaft construction shall be disposed of away from the construction site. On-site storage of material must comply with Specification Section 01560 and must be stored in areas shown on site drawings. Stockpiling shall be permitted on the construction site and material shall be removed at regular intervals not exceeding [] hours.

l. Monitor ground movements associated with the project and make suitable changes in the construction methods that control ground movements and prevent damage or detrimental movement to the work and adjacent structures and pavements. Permissible tolerances with respect to settlement of ground surface and alignment of the pipe casing shall not be exceeded.

m. Install instrumentation, take readings and provide the Contracting Officer with weekly reports containing measurement data with weekly reports to inspector. These actions are meant to supplement the Contractor's monitoring system and do not relieve the Contractor of his responsibility, nor place on the Contracting Officer, responsibility for control of ground movement and protection of the project and adjacent structures. Instrumentation readings shall be continued for a period of [] weeks after pipe casings have been installed to establish that detrimental settlement has not occurred.

n. Unprotected mining of the tunnel bore is not permitted. The tunnel face and bore shall be fully supported at all times.

[o. A topographic survey will be performed by the Contractor before and after Microtunneling and at [] week intervals for a period of [] weeks. Survey

markers will be installed by the Contractor at grid points located at []-foot spacing over an area [] centered on the proposed tunnel alignments. Perform all remedial work including repairing if heave or settlement greater than [] inch[es] is recorded.

p. Approval by the Contracting Officer of the topographic survey and final set of readings provided by the Contractor will constitute [partial] approval of the microtunneling phase of work.]

3.2.4 Ventilation

a. Adequate ventilation shall be provided for all cased tunnels and shafts. The \-COE EM-385-1-1-\ describes the details of the confined space entry procedures and must be abided by. [Local burn permit regulations must be obeyed and complied with.] The design of ventilating system shall include such factors as the volume required to furnish fresh air in the shafts, and the volume to remove dust that may be caused by the cutting of the face and other operations which may impact the laser guidance system. The minimum amount of fresh air to be supplied shall be [] CFM. [Air testing shall be required for the specific conditions to ensure that the following gas concentration requirements are met:

Carbon Monoxide	$\geq 0.005\%$
Methane	$\leq 0.25\%$
Hydrogen Sulfide	$\leq 0.001\%$
Oxygen	$\geq 20.0\%$

3.2.5 Lighting

Adequate lighting shall be provided for the nature of the activity being conducted by workers for the microtunneling. Both power and lighting circuits shall be separated and thoroughly insulated with ground fault interrupters as required. Lights shall comply with requirements stated in the \-COE EM-385-1-1-\ with regards to shatter resistance and illumination requirements.

3.2.6 Spoil Transportation

The soil transportation system shall match the excavation rate with rate of spoil removal. The system must also be capable of balancing groundwater pressures and adjustment to maintain face stability for the particular soil conditions of this project.

3.2.7 Pipe Jacking Equipment

The main jacking equipment installed must have a capacity greater than the anticipated jacking load. Intermediate jacking stations shall be provided by the Contractor when the total anticipated jacking force needed to complete the installation may exceed the capacity

of the main jacks or the designed maximum jacking force for the pipe. The jacking system shall develop a uniform distribution of jacking forces on the end of the pipe by use of thruster rings and cushioning material.

3.2.8 Jacking Pipe

NOTE: Some microtunneling methods utilize a temporary jacking pipe or shield that is replaced by a permanent casing or carrier pipe. This section applies to all jacking pipes, but is intended to ensure that temporary jacking pipes are covered by this specification.

NOTE: See Note I located at the rear of text.

In general, pipe used for jacking shall be smooth, round, have an even outer surface, and joints that allow for easy connections between pipes. Pipe ends shall be square and smooth so that jacking loads are minimized when the pipe is jacking. Pipe used for pipe jacking shall be capable of withstanding the jacking forces that will be imposed by the process or installation, as well as the final in place loading conditions. The driving ends of the pipe and intermediate joints shall be protected from damage.

- a. Any pipe showing signs of failure may be jacked through to the receiving shaft and removed. Other methods of repairing the damaged pipe may be used, as recommended by the manufacturer and subject to approval by the designer.
- b. The pipe manufacturer's design jacking loads shall not be exceeded during the installation process. The pipe shall be designed to take full account of all temporary installation loads.

3.3 FIELD QUALITY CONTROL

3.3.1 Field Tests and Inspections

\+The Contracting Officer will conduct field inspections and witness field tests specified in this section. The Contractor shall perform field tests, and provide labor, equipment, and incidentals required for testing [, except that water and electric power needed for field tests will be furnished as set forth in Section [\=___=\, "___"]].+\ The Contractor will product evidence, when required, that any item of work has been constructed in accordance with drawings and specifications.

3.3.2 Testing Requirements

\+For pressure test, use a hydrostatic pressure [] psi greater than the maximum working pressure of the system. Hold this pressure for not less than [] hours. For leakage test, use a hydrostatic pressure not less than the maximum working pressure of the system. Leakage test may be performed at the same time and at the same test pressure as the pressure test.+\\

-- End of Section --

CRITERIA NOTES

NOTE A: Project Drawings

1. The following information should be shown on the project drawings:
 - a. Plan and location of all new pipelines, including size of pipe casing and carrier pipe.
 - b. Location and profiles of soil sampling and bore holes.
 - c. Location, size, and type of service of existing connecting, intersecting, and adjacent pipelines and other utilities.
 - d. Paved areas and railroads which pass over new pipelines.
 - e. Profile, where necessary to show unusual conditions.
 - f. Manhole and lateral piping bedding conditions.
 - g. Details for the connection of the pipe casing to manholes and infiltration control.
 - h. Location of surrounding structures and sensitivity to settlement, pile foundations, and subsurface structures that could be affected by the project.
 - i. Show traffic plans for work near roadways and possible equipment and spoils storage areas. Spoil storage and removal requires a large area for dewatering and must be strictly controlled in Specification Section 01560. Spoil storage locations and construction need to consider possible runoff into wetlands, streams, or storm drains.
 - j. Maximum working pressure of the system.
 - k. Class or thickness of pipe, including material identification, and limits for same where class or thickness will be different for different sections of pipeline.

NOTE B: Design Requirements:

1. External loads should include earth loads, truck loads, seismic loads, construction loads (i.e., sheetpile insertion/extraction at manholes and pipe ramming/jacking forces) and impact in the design stage of the project; also hydrostatic and buoyancy forces.

2. It is recommended that the following site information should be provided (at a minimum):

- a. Grading analysis of soil particles
- b. Compressive strength of soils
- c. Density
- d. Apparent or unconfined cohesion
- e. Shear strength
- f. Plasticity index
- g. Nature of fill material
- h. Rock type and color
- i. Permeability
- j. Moisture content
- k. Water table depth
- l. Nature of pollutants
- m. Grain size and RQD
- n. Core recovery TCR, SCR
- o. Fracture index
- p. Standard penetration N value
- q. Where possible, soil boring information should be provided at not more than 200 ft. intervals outside the bore of the tunnel and at manhole locations.

3. Use equivalent pipe design for the project conditions (using the applicable criteria for each pipe material) for each different pipe material, although design criteria differ for pipe of different materials.

NOTE C: Suggested Submittals:

1. The following material should be submitted for review by the designer:
 - a. Manufacturer's literature describing in detail the microtunneling system to be used. Detailed descriptions of projects on which this system has been successfully used.
 - b. Method of spoil removal.
 - c. Anticipated jacking loads.
 - d. Method(s) of controlling groundwater at shafts and by the MTBM.
 - e. Shaft dimensions, locations, surface construction, profile, depth, method of excavation, shoring bracing, and thrust block design.
 - f. Verification that the pipe complies with the specification.
2. The following statements may be inserted in other appropriate specification sections:
 - a. Submit qualifications of key personnel proposed to be used in the microtunneling.

b. Submit a detailed description of the microtunneling procedure including construction techniques to provide access shafts required to install pipe casings in conformance with this Specification Section.

c. Where sheet piling of sheeting is required for access shaft excavations or where circular concrete access shafts are being used, submit detailed shop drawings and design calculations to the Engineer in accordance with the requirements of "Shop Drawings, Catalog Cuts, and Samples" of Division 1 - GENERAL PROVISIONS. Submit such drawings and calculations three weeks prior to commencement of excavation. Shop drawings and calculations shall be prepared by a Professional Engineer, licensed in the State in which the work will be performed, who has a minimum of five years experience in the design of soil retaining structures. The shop drawings shall be sealed and signed by the Professional Engineer.

d. Submit a groundwater stabilization plan that covers the excavations for starter and receiver shafts. The Contractor shall verify his method to stabilize anticipated unstable soil conditions. Such verification shall include all calculations and detail drawings for dewatering and grouting systems.

e. Submit a certification by the microtunneling and pipe jacking equipment/machine manufacturer of the energy, condition and operational characteristics of all equipment to be used for installing the specified pipe casings.

f. Submit certified test reports for selected pipe casing material and welding or coupling details for pipe casing joints.

g. Submit a description of the grade and alignment control system. The system shall be equipped with a laser target.

h. Submit details of bentonite injection operation used as lubricant during pipe jacking.

i. Submit details of cement grouting after pipe casing has been installed including injection pressure and method of controlling grout pressures.

j. Submit calculations that clearly state the hydraulic pressure which required to develop the maximum allowable pipe jacking effort and description of controls to ensure that this hydraulic pressure will not be exceeded during pipe jacking operations.

k. Submit calculations demonstrating that the pipe casing selected has been designed to support the maximum anticipated earth loads and superimposed live loads, both static and dynamic, which may be imposed

on the pipe casing. The Contractor shall determine the additional stresses imposed on the pipe during jacking operations and upgrade the quality and strength of the pipe and pipe joints to the extent necessary to withstand the additional stresses imposed by the pipe jacking operation. The details shall be included in the submittal.

l. Submit complete information on Contractor's safety plan for personnel conducting the microtunneling or pipe jacking operations, including provisions for lighting, ventilation and electrical safeguards.

m. The Contractor shall keep and maintain at the construction site a complete set of field drawings for recording as-built conditions. It shall have marked or noted thereon all field information, properly dated, recording as-built conditions. This set of field drawings shall be kept up-to-date. The drawings will include boring logs that show actual horizontal and vertical alignment of the tunnel with respect to the design alignment at station intervals of [].

NOTE D: Allowable Materials:

1. The project specification should allow all carrier piping materials for the utility lines which are suitable for the project, each to be permitted as a Contractor's option. The structural support contribution of the casing pipe and annulus grout may be considered when specifying the thickness of the utility piping. The casing may also greatly reduce infiltration of ground water.

2. Pipe materials which are known to be unsuitable for particular local conditions (i.e., corrosion, deterioration, etc.) should not be permitted for the project for either the casing or the utility piping. However, consider use of more effective protective coatings, etc., where economically feasible. Consider the protective nature of the pipe casing and annulus grout with regards to exterior attack. [Cathodic protection of the casing may also be desirable.]

3. Utility piping material and size should be specified in their own appropriate sections of the specification.

4. Several methods of installing pipe casings are available to the Contractor. Different tunneling machines have different means of installing the casing. Many of the machines allow the pipe casing to be used as the jacking shield and are left in place after the tunneling head has reached the receiving pit. Other machines use a temporary jacking shield that is replaced with a lighter casing. The final casing material doesn't need to be as strong because it doesn't need to jack the cutting head. Fiberglass casing can be an appropriate alternative for these methods. The Contractor should have the option of

selecting an appropriate alternative for the casing based on his tunneling method and the design requirements of the utility lines.

5. The annulus grout (e.g., the grout that fills the void between the casing and the utility line(s)) is traditionally a lightweight grout that is designed to merely stabilize the utility line(s). The utility lines are usually temporarily supported by wooden shims to position them inside the casing prior to grouting.

NOTE E: Polyvinyl chloride Pipe (PVC):

1. PVC pipe may be an ideal conveyance system for sewage and storm water, and for the construction of culverts installed and constructed by microtunneling methods. These pipes require microtunneling systems that generate low compressive loads on the pipe.

Referenced standards for PVC pipe should include:

- a. ASTM F 794 PVC pipe standards
- b. ASTM D 3212 Gasketed joint systems
- c. ASTM F 477 Gasket materials

2. PVC pipe characteristics:

a. Dimensions: Nominal pipe diameters shall be 21, 24, 27, 30, 42 and 48 inches. The outside diameter should have a tolerance of ± 0.100 inches of the average outside diameter. Outside diameter consistence (smoothness) shall be measured by placing a straightedge across the outside wall of the pipe parallel to the flowline. The distance from the straightedge to the outside wall should not exceed 0.075 inches. The variation in the outside diameter from a true circle should not exceed one percent of the nominal outside diameter. This variation represents one half of the difference between the maximum and minimum diameter of the pipe at any one location. Standard pipe length is 8 feet with non-standard lengths varying between 6 feet and 15 feet available. Tolerance on pipe lengths should be $\pm 1/4$ inch. Cut end squareness should be $\pm 1/8$ inch.

b. Axial compressive loads: Since joint and profile configurations vary by pipe manufacturer, the ultimate axial compressive load should be furnished by the pipe manufacturers with a third party certification. Tested samples must include an assembled joint. The allowable compressive load should be obtained by taking the ultimate load and dividing it by a safety factor of at least 2.00.

Note F: Reinforced Concrete Pipe

1. Nominal dimensions: Typical nominal dimensions for reinforced concrete pipe are detailed in ASTM standards [ASTM C 76-][ASTM C 361-][ASTM C 655-][ASTM C 822-]. Pipe meeting these requirements is generally acceptable for jacking.

The permissible variation allowed with respect to these and other dimensions should be in accordance with the variations listed in the section.

2. Pipe lengths: Concrete pipe manufactured for jacking operations should be typically manufactured in lengths of 7.5 to 8 feet. This is primarily a function of the size of the jacking equipment and the excavation. Lengths vary in any given geographical area.

3. Axial compressive strength: Compressive strength test information should be provided from cured test cylinders cast in accordance with \-ASTM C 31-\ and tested in accordance with \-ASTM C 39-\ . Verification tests in the field should be extracted and handled in accordance with \-ASTM C 497-\ . The concrete should have a minimum crushing strength as specified for the appropriate pipe class. Concrete used in jacking pipe should not be less than 5,000 psi.

4. Joints: Historical field data has shown that concrete pipe for jacking applications is commonly of two types, all concrete or concrete and steel. Factors influencing the selection of one of these joint types, or other alternative joints, include:

- a. magnitude of the anticipated jacking forces
- b. joint deflection characteristics
- c. joint shear strength required during the jacking operation
- d. specific site design parameters

5. Joint description: Two primary types of joints are used:

- a. Joint formed entirely of concrete that may utilize a rubber gasket or mastic to provide the seal. Rubber gaskets should be used where water tightness is needed. A compressive bearing strip is required between the faces of the adjoining pipes.
- b. Joint includes an assembly of steel bands or steel bell ends with spigot rings and rubber gaskets. This type of joint also requires a compressive bearing strip.

6. Joint selection: Historical performance has shown that in instances of straight alignment under relatively low jacking forces, both types of joints can be used. Curved alignments and high jacking pressures may require the use of the second type of joint.

7. Axial load capacity: A factor of safety of at least 2.22 should be used for pipes installed by jacking methods. The axial load capacity should be based on the ultimate strength of the concrete and it assumes that the load is uniformly distributed over the bearing surface. Eccentric or concentrated load combinations on the pipe surface should be evaluated for effective surface contact area and reduction in the factor of safety.

Note G: Steel Pipe Casing

1. Coatings: Exterior coatings, if required, should be the type than minimize skin friction between the pipe and the bored hole, such as an epoxy-based polymer concrete, fusion

bond epoxy, liquid epoxy or other product that provides a hard smooth surface. If steel pipe is to be field welded, a procedure for field repairs to the coating should be specified or submitted. The repair should maintain integrity of the coating and minimize repair and curing time, \-AWWA C210-\ and \-AWWA C213-\. The exterior coating of steel pipe used as encasement can often be avoided if the wall thickness is increased by 0.063 inches over the specified thickness.

2. Interior lining: Interior lining of the steel pipe can be shop applied coatings such as liquid epoxy, polyurethane, cement mortar, or appropriate materials depending on service requirements. Refer to \-AWWA C205-\ and \-AWWA C210-\.

Note H: Microtunneling Information

1. The minimum depth of cover over the pipe being installed using the microtunneling process is normally six feet or 1.5 times the outer diameter of the pipe being installed, whichever is the greater. Microtunneling work is executed so as to minimize settlement or heave. The overcut of the tunneling machine or method shall be determined by the need to satisfy settlement or heave tolerances. Overcut should not exceed 1 inch on the radius of the pipe. The annular space created by the overcut usually can be filled with the lubricating material that is used to reduce the friction drag of the soil on the pipe (i.e. bentonite slurry).

Note I: Jacking and Installation Information

1. The length of drive that is possible to achieve with particular equipment is dependent upon the jacking force required to push the pipe, the soil conditions and the depth of the pipe. The jacking force required is a function of many variables including the soil conditions, depth of the pipeline, annular space between the pipe and soil, lubrication of the pipe, material, diameter and strength.

2. When a slurry system is used by the Contractor, the composition of the slurry must be closely monitored for specific gravity and viscosity in certain soil conditions. With an auger soil removal system, the speed of rotation of the auger flight and the addition of water and/or compressed air must be closely monitored.

APPENDIX C

TRENCHLESS EXCAVATION CONSTRUCTION: IS IT TIME TO GET ON BOARD?

By LT Scott K. Higgins, CEC, USN, PE

The trenchless excavation technology is **BOOMING!** Fixing and installing underground utility lines without digging trenches is helping cities and companies avoid mazes of existing utilities and busy roads. The technologies fall into two major categories: repair of existing buried utility pipelines and horizontal earth boring.

Consider the possibilities of what trenchless technologies can do for Navy facility engineers:

- * Instead of enlarging waste water treatment facilities handle ground water infiltration:
 - Reline sewerlines without interrupting service
 - Place new pipes without interrupting traffic
- * Place pipe under layers of contaminated soil and minimize spoils
- * Virtually eliminate groundwater drawdown and dewatering
- * Place pipelines in soil as deep as 100 feet below grade
- * Place pipes below rivers, streets, buildings, or other structures without trenching

These technologies are much more than the familiar horizontal boring or pipe grouting previously used on Naval facilities. In addition, they include: microtunneling, directional boring, pipe bursting, and pipe jacking.

Since trenchless technologies haven't seen wide spread use on Navy bases or in NAVFAC contracting, several misconceptions exist about them.

Misconception Number 1: Trenchless technologies haven't matured enough for government use.

Trenchless technologies have been around for many years. Microtunneling evolved out of the large shielded tunneling technologies and were first developed by Japanese and German manufacturers. Systems using earth pressure balancing cutting faces have been on the market since the 1970's. Since then, thousands of miles of tunnels have been excavated.

Misconception Number 2: Specifying the use of trenchless technologies is proprietary.

Certainly, specifying equipment to perform the work may be proprietary, however, using a specification that allows for the use of trenchless alternatives should pass restrictions in the Federal Acquisition Regulations. There are many manufactures and contractors that can provide services such as microtunneling, pipe jacking, and pipe bursting. Many different methods and materials are available.

Misconception Number 3: Projects that use trenchless technologies will cost considerably more than traditional methods.

Trenching will generally be less expensive for straightforward new pipe installation projects. Trenchless technologies become attractive when complications exist. They become helpful when utility lines need to be placed in:

- * Pipe runs greater than 150 feet at depths greater than 6 feet below grade
- * Groundwater tables near the surface or concerns about subsidence in the adjacent road or buildings
- * Contaminated soil or ground water (spoils are limited to the material displaced by the pipe and around manholes).
- * Pipe sizes larger than 18 inches and smaller than 72 inches
- * Rock or varied soil conditions
- * Areas of high personnel danger (confined spaces, trench wall collapse, or cross buried utilities.)
- * Numerous cross buried utilities (Microtunneling or directional boring can go beneath them).
- * Need for extreme grade control (Microtunneling can be laser guided and can provide alignment control within tolerances of 1 to 2 inches in several hundred feet of boring).
- * Traffic or operations cannot be disrupted by open excavations.

The additional costs related to these complications can quickly make trenchless technologies a competitive option.

Misconception Number 4: Trenchless technology alternatives aren't being used by major customers or owners.

Many large projects have been successfully performed for cities such as Seattle, Washington, Houston, Texas, and Boston, Massachusetts. The Army Corps of Engineers Waterways Experiment Station in Vicksburg, Mississippi is working with the Trenchless Technology Center at Louisiana Tech University to test the capabilities of several different trenchless methods.

RECENT NAVY CONTRACTS

Two deep gravity sewerlines were recently installed at Pearl Harbor, Hawaii, using microtunneling. The first of the projects was a replacement sewerline that originally was designed to be a 24 inch clay tile pipe, over 1000 feet long, and buried at depths of approximately 20 feet below grade. The pipe was to be buried beneath a major road, in soils consisting of clay, coral, and fill. The groundwater table was approximately six feet beneath the road.

The first manhole and fifty feet of pipe were installed and backfilled. Inspection of the work discovered pipe collapsed and joint failure. In the course of excavating the trench, petroleum contaminated groundwater and soil was encountered. Disposal of the contaminated soil, soil testing, and handling was a major concern.

While the parties were considering the possible causes of the pipe failure and methods of dealing with the contaminated soil, the contractor, Nova Group, Inc., proposed several trenchless alternatives. It was finally agreed that microtunneling could be used as an alternative method of installing the new pipe. After the contract was modified, the contractor proceeded to install a 38 inch steel casing with a laser guided earth pressure balanced machine. The machine bored beneath the contaminated zone and significantly reduced the soil and water disposal problem.

The microtunneling machine's cutting head was hydraulically jacked horizontally. A string of steel casing pipe followed the cutting head. Tunnels were bored between manholes and oversized manhole excavations were used as launching pits for the microtunneling machine. Cuttings were pumped in a slurry suspension back through the tunnel to a settling basin.

After the tunnels were finished, a polyvinyl chloride (PVC) carrier pipe was placed inside the 38 inch casing pipe. The annulus between the casing and the carrier pipe was filled with a light weight concrete. The final grade of the pipe was extremely accurate and the new line reportedly reduced groundwater infiltration significantly.

Nova Group, Inc., and the Resident Officer in Charge of Construction Pearl Harbor were recognized by the Hawaii Section of the American Society of Civil Engineers for their efforts on this project. They were presented with a Merit Award for Outstanding Engineering Achievement.

Adjacent to the first contract, a major MILCON project was modified to allow microtunneling. Similar soil, groundwater, traffic, and alignment problems were mitigated by using microtunneling.

Conclusions:

Trenchless excavation construction methods may be added to contracts through modification or specified in the basic contract. A draft microtunneling guide specification

has been submitted for NAVFAC review and possible inclusion into the Construction Criteria Base.

Trenchless excavation methods may be the only alternative for complicated conditions. Don't overlook these possibilities!

Definitions (according to the National Utility Contractors Association's *Trenchless Excavation Construction Equipment and Methods Manual*):

Microtunneling: Microtunneling Horizontal Earth Boring -- a process characterized as highly sophisticated, laser guided, remote controlled system providing the capability of continuous accurate monitoring and control of the alignment and grade.

Directional Drilling -- a process that utilizes a specially built drill rig that thrusts the drill stem through the ground while bentonite drill mud operates a down hole motor, functions as a coolant, and facilitates spoil removal by washing the cuttings to the surface to settle out in a retention pit. The path of the borehole is monitored by a down hole survey system that provides data on inclination, orientation, and azimuth of the leading end. Direction is controlled by a bent housing used to create a steering bias.

Pipe jacking: Differentiated from Microtunneling Horizontal Earth Boring by requiring the necessity of workers being inside the pipe during the excavation and/or spoil removal process. Prefabricated concrete, steel, or fiberglass pipe may be utilized as the jacking pipe. The excavation process varies from manual to highly sophisticated tunneling boring machines.

Utility Tunneling: Utility Tunneling is differentiated from the major tunneling industry by virtue of their size and use (i.e., conduits for utilities rather than as passageways for pedestrian and/or vehicular traffic. Further, while the excavation methods for Utility Tunneling and Pipe Jacking may be identical, the differentiation is in the lining systems with the most popular being steel tunnel liner plates, steel ribs with wood lagging, and wood box tunneling.

Additional Information:

Trenchless Technology Center
Civil Engineering Department
Louisiana Tech University
Ruston, LA 71272-0046

Draft NAVFAC Guide Specification for Microtunneling

APPENDIX D

ENDOFF;
ACTIONS

DISPLAY "THIS PROGRAM IS DESIGNED TO ASSIST YOU"
DISPLAY "IN SELECTING AN APPROPRIATE METHOD OF"
DISPLAY "DEALING WITH YOUR PIPE REHABILITATION"
DISPLAY "NEEDS. IT IS BASED ON A SOLUTION MATRIX PRESENTED"
DISPLAY "IN THE 1994 DIRECTORY OF THE NORTH AMERICAN"
DISPLAY "TRENCHLESS TECHNOLOGY INDUSTRY PUBLISHED BY"
DISPLAY "TRENCHLESS TECHNOLOGY -- LT HIGGINS"

FIND TYPE

DISPLAY "THE RECOMMENDED SOLUTION TO YOUR PROBLEM IS:"
DISPLAY "{TYPE}";
PLURAL: TYPE;

ASK P: "SELECT YOUR PIPE PROBLEM";
CHOICES P:
ROOTS,DEBRIS,INFILTRATION,BROKEN_PIPE,MISALIGNMENT,COLLAPSED_
PIPE;
ASK D: "WHAT IS THE PIPE DIAMETER IN INCHES?";
ASK S: "HOW SEVERE IS THE PROBLEM?";
CHOICES S: SLIGHT,EXTREME;

RULE 0

IF P=ROOTS AND
S=SLIGHT AND
D<15 AND D>5
THEN TYPE=CHEMICAL_TREATMENT_USING_FOAM_FILL CNF 100;

RULE 1

IF P=ROOTS AND
S=SLIGHT AND
D>14
THEN TYPE=CHEMICAL_TREATMENT_USING_FOAM_SPRAY CNF 100;

RULE 2

IF P=ROOTS AND
S=EXTREME AND
D<7 AND D>5
THEN TYPE=CLEANING_USING_A_CABLE_MACHINE CNF 80;

RULE 3

IF P=ROOTS AND

S=EXTREME AND
D>7 AND D<15
THEN TYPE=CLEANING_USING_A_RODDING_MACHINE CNF 80;

RULE 4
IF P=ROOTS AND
S=EXTREME AND
D>15
THEN TYPE=CLEANING_USING_A_BUCKET_MACHINE CNF 80;

RULE 5
IF P=DEBRIS AND
S=SLIGHT AND
D<25 AND D>5
THEN TYPE=CLEANING_USING_A_JET_MACHINE CNF 75;

RULE 6
IF P=DEBRIS AND
S=SLIGHT AND
D>18 AND D<36
THEN TYPE=CLEANING_USING_SPECIAL_JET_NOZZELS CNF 40;

RULE 7
IF P=DEBRIS AND
S=SLIGHT AND
D<37 AND D>17
THEN TYPE=CLEANING_USING_A_CLEANING_BALL CNF 40;

RULE 8
IF P=DEBRIS AND
S=EXTREME AND
D<13 AND D>5
THEN TYPE=CLEANING_USING_A_JET_MACHINE CNF 75;

RULE 9
IF P=DEBRIS AND
S=EXTREME AND
D<17 AND D>7
THEN TYPE=CLEANING_USING_A_RODDING_MACHINE CNF 75;

RULE 10
IF P=DEBRIS AND
S=EXTREME AND
D<37 AND D>15
THEN TYPE=CLEANING_USING_A_BUCKET_MACHINE CNF 75;

RULE 11

IF P=DEBRIS AND

S=EXTREME AND

D<25 AND D>5

THEN TYPE=CLEANING_USING_LIVE_LINE_LIMITED CNF 15;

RULE 12

IF P=INFILTRATION AND

D<37 AND D>5

THEN TYPE=SEALING_PACKER_USING_CHEMICAL_GROUT CNF 75;

RULE 13

IF P=INFILTRATION AND

D>35

THEN TYPE=MAN-ENTRY_SEALING_USING_CHEMICAL_GROUT CNF 45;

RULE 14

IF P=INFILTRATION AND

D<13 AND D>5

THEN TYPE=LINE_SEALING_USING_FLOODING_METHOD CNF 65;

RULE 15

IF P=BROKEN_PIPE AND

S=SLIGHT AND

D<97 AND D>5

THEN TYPE=POINT_REPAIR_USING_OPEN_CUT_EXCAVATION CNF 40;

RULE 16

IF P=BROKEN_PIPE AND

S=SLIGHT AND

D>5 AND

D<25

THEN TYPE=POINT_REPAIR_USING_CURED_IN_PLACE CNF 50;

RULE 17

IF P=BROKEN_PIPE AND

S=SLIGHT AND

D>5 AND

D<31

THEN TYPE=ROBOTIC_REPAIR_USING_EPOXY_INJECTION CNF 50;

RULE 18

IF P=BROKEN_PIPE AND

S=SLIGHT AND

D>5 AND
D<31
THEN TYPE=ROBOTIC_REPAIR_USING_STEEL_SLEEVE CNF 50;

RULE 19
IF P=BROKEN_PIPE AND
S=EXTREME AND
D>5 AND
D<97
THEN TYPE=PIPE_LINING_USING_VARIOUS_METHODS CNF 50;

RULE 20
IF P=BROKEN_PIPE AND
S=EXTREME AND
D>41 AND
D<97
THEN TYPE=PIPE_LINING_USING_MAN-ENTRY CNF 50;

RULE 21
IF P=MISALIGNMENT AND
D>5 AND
D<97
THEN TYPE=PIPE_LINING_USING_VARIOUS_METHODS CNF 50;

RULE 22
IF P=MISALIGNMENT AND
D>41 AND
D<97
THEN TYPE=PIPE_LINING_USING_MAN-ENTRY CNF 50;

RULE 23
IF P=COLLAPSED_PIPE AND
S=SLIGHT AND
D<97 AND D>5
THEN TYPE=POINT_REPAIR_VIA_OPEN-CUT_EXCAVATION CNF 40;

RULE 24
IF P=COLLAPSED_PIPE AND
S=SLIGHT AND
D<19 AND D>5
THEN TYPE=SLIPLINE_USING_PIPE_BURSTING CNF 50;

RULE 25
IF P=COLLAPSED_PIPE AND
S=EXTREME AND

D<97 AND D>5
THEN TYPE=REPLACEMENT_USING_EXCAVATION_OR_TEC CNF 40;

RULE 26

IF D>96

THEN TYPE=TOO_LARGE____THIS_IS_A_TUNNEL;

RULE 27

IF D<5

THEN TYPE=TOO_SMALL____MUST_BE_MORE_THAN_6-IN;

□



DEPARTMENT OF THE NAVY
NAVAL FACILITIES ENGINEERING COMMAND
200 STOVALL STREET
ALEXANDRIA VA 22332 2300

APPENDIX E

IN REPLY REFER TO

11012.18

Ser. DS02B/5292
JAN 22 1992

Mr. Robert J. Torielli
President
PIM Corporation
201 Circle Drive North, Suite 105
Piscataway, NJ 08854

Dear Mr. Torielli:

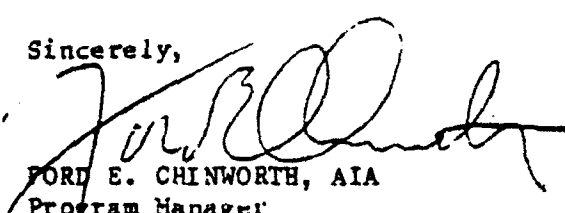
Your letter of 6 January 1992 requested that the Pipeline Insertion Machine be considered for use by the Naval Facilities Engineering Command (NAVFACENGCOM). We greatly appreciate the initiative and effort you have shown in making your process known to us.

Our NAVFAC Guide Specs are under the management of our Headquarters Code DS03, located at Port Hueneme, California. I am forwarding your letter to Mr. Pete Marquez, DS03B who is responsible for NAVFAC Guide Specifications for water supply systems.

I should mention that NAVFAC Guide Specifications are non-proprietary in nature and specify products through the use of either referenced documents (ANSI, ASTM, Federal and Military Specifications) or performance characteristics. We also follow national practice in not dictating methods and means of contractor operations, a principle which will be important as we consider the pipe insertion method.

If we can be of further assistance, you can reach Mr. Marquez at (805) 982-5465.

Sincerely,


FORD E. CHINWORTH, AIA
Program Manager
Specifications and Standards

Copy to:
NAVFACENGCOM (Code DS03B) (w/ref)