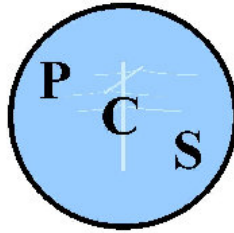




Outside Plant Consulting Services, Inc.



Buried Duct Network (BDN) Field Trials at The University of Texas at Arlington

Final Report

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EXECUTIVE SUMMARY

Underground space use has historical roots; its use has evolved up to the point where it is useful for transportation of goods and public services. Underground space use using common utility ducts has become more common in the last decades due to a wide array of advantages, including the reduction maintenance potholes and less excavation and repair of roads and right-of-ways. This report investigates the feasibility of using small diameter (mini) horizontal directional drilling (a trenchless technology method) for installation of a common utility duct approach called Buried Duct Network (BDN). The BDN approach is described as a hybrid system that combines the low-cost features of direct-buried construction with the upgrade capabilities of underground conduit systems. Buried Duct Network (BDN) is an integrated system that facilitates maintenance and future upgrades of buried communications and power lines to provide improved and cost-effective hardware and practices, compared to conventional buried construction procedures. The BDN system is easier to understand if is thought as a shared trench and facility between among different utility companies. The implementation of this network may reduce the risk of conventional direct-buried construction methods which can lead to damaged roads, gas lines or other facilities. However, the foremost function of the BDN system is to provide a degree of upgrade capability for direct buried utility cables.

In this research, a set of two full-scale field trials were planned and executed along two local roads in Arlington, Texas and inside the property of The University of Texas at Arlington. The overall conception of the BDN system is composed of two phases; Phase One, which covered the feasibility studies, and an outdoor demonstration; Phase Two, which consisted different field trials to verify hardware designs and to identify the best construction practices.

Before these field trials began, a through planning of the work was performed. This process included selections of a contractor and pipe supplier, and decision on the alignments and profile of the field trials. The planning phase also included soil investigations and a topographic survey of the site. As part of this project, the investigators examined the process needed to install the BDN system using mini-HDD method.

The full scale trials at UT Arlington served as a test to identify better construction practices for BDN, especially when using trenchless technology. Most of the construction issues encountered during these trials are inherent to trenchless construction nature; for instance, the drilling speed for Mitchell Street trial was higher than the installation speed of South Davis Drive trial due in part to hard layers of soil encountered. Unexpected hard layers of soil are not uncommon in any mini-HDD project and may delay the installation of conduits. Also the clogging of the reamer openings for the drilling fluids is identified as a construction issue and a risk in any BDN project using mini-HDD, because it in part, it led to the rupture of a water pressure lateral at South Davis Drive.

Due to the good acceptance of the BDN system among utilities and to the successfulness of the BDN trials at UT Arlington, an ASCE manual of practice is being prepared under the title: “Below ground Pipeline Networks for Utility Cables” - *ASCE Manuals and Reports on Engineering Practice No. 118*. Research papers, journal articles and presentations are also in the agenda to explain and expand the knowledge in this area among the academy and the industry.

When using trenchless technology for installing the BDN system, a careful investigation of the soil conditions or a time allowance must be encouraged in order to reliably forecast the total duration of the project. The use of a pullback and pressure monitoring system in the pullback operations is also recommended, because it gives the engineer or contractor on site a tool to verify the pullback force and prevent any issues that may arise.

Because BDN is intended to be used by contractors all over the U.S. and in different site conditions, it is recommended for other similar research projects, an investigation on the suitability of HDPE or other conduit materials in the BDN concept as well as longer installation runs. This analysis will provide to the contractors a set of conduit materials suitable for the BDN system, reducing the bias towards fused PVC pipes. A comparison of life cycle cost which includes social, operation and maintenance costs between the BDN system and the conventional buried cables would further demonstrate benefits of the BDN system. It is also important to conduct a market analysis of BDN for different types of utility systems. A research study to compare the feasibility, cost, and duration between open-cut and trenchless methods for the BDN system is particularly recommended. This proposed research study may include a construction productivity comparison, a total cost of the project comparison with a special attention to traffic disturbance and social costs.

CHAPTER 1

INTRODUCTION, BACKGROUND AND OBJECTIVES

1.1. Introduction and Background

Buried Duct Network (BDN) is an integrated system that facilitates maintenance and future upgrades of buried communications and power lines to provide improved and cost-effective hardware and practices, compared to conventional buried construction procedures. The BDN system is easier to understand if is thought as a shared trench and facility between among different utility companies. The implementation of this network may reduce the risk of conventional direct-buried construction methods which can lead to damaged roads, gas lines or other facilities. However, the foremost function of the BDN system is to provide a degree of upgrade capability for direct buried utility cables.

The buried duct network can further be described as a hybrid system that combines the low-cost features of direct-buried construction with the upgrade capabilities of underground conduit system. The most cost-effective and efficient configuration includes construction of a joint-trench, occupied by several cooperating utilities or users. Figure 1-1 illustrates the generic BDN concept, which includes an integrated system of conduits and handholes.

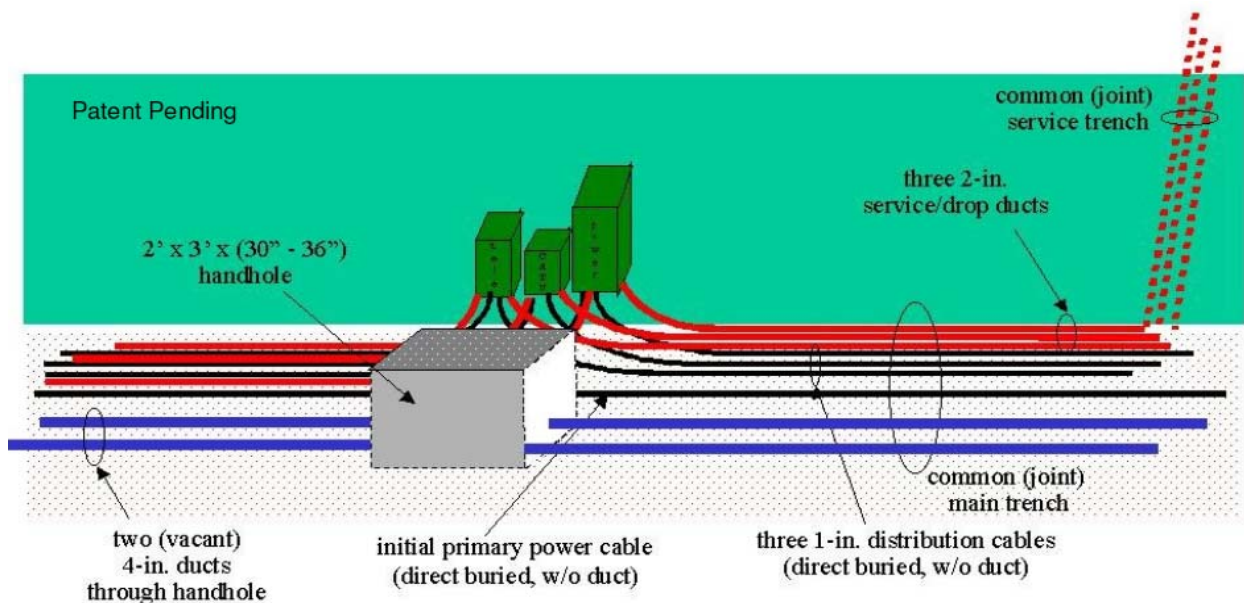


Figure 1-1 Generic BDN Concept

The development of the BDN system as an alternate tool against common direct buried construction procedures consists of two phases:

- Phase I – feasibility study, and
- Phase II – field trials.

Phase I was developed and evaluated during the period between November 12, 2004, and June 10, 2005, and included:

- Studies to develop the most optimum BDN architecture
- Reviews of the belowground and overhead construction trends for utility installation
- Reviews of the relevant National Electrical Safety Code (NESC) rules
- A development of a life-cycle cost approach
- A construction and assembly of a laboratory scale model
- Performance of an outdoor field experiment

The Phase I outdoor field experiment verified the feasibility of the BDN system and was conducted on May 3, 2008, at a Michigan State University's off-campus facility. For this experiment, a specially modified Pencell Handhole was buried with one 4-in. (102-mm) Smooth-Cor duct and one 4-in. (102-mm) (Polyvinyl Chloride) PVC rigid duct for the main upgrade paths. A 2-in. (51-mm) PVC duct was used for service connections. Figure 1-2 shows the final configuration of the handhole and conduits for this field experiment just before being backfilled.

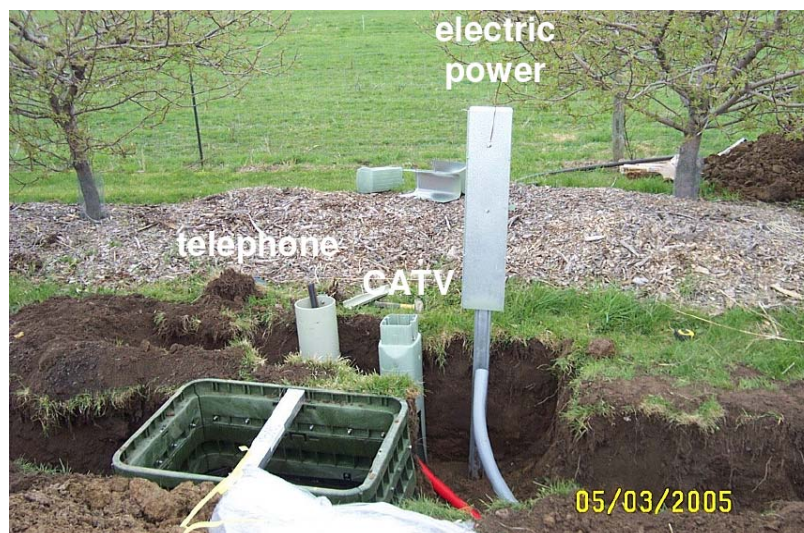


Figure 1-2 Final Configuration for Phase I Field Experiment

As a result of Phase I efforts, the advantages of the BDN system were identified. The advantages of the system are many, such as:

- Applies to new residential developments with open-cut trenching or when reconstruction activities occur
- Provides a convenient and safe upgrade capability for direct-buried utility lines without additional digging or drilling
- Encourages cooperation and cost-effective, joint construction practices by utilities
- Provides convenient installation of handholes considering their bottomless design and mouseholes access points
- Use of continuous flexible HDPE (High Density Polyethylene) and/or more rigid PVC duct for main distribution paths or service ducts as desired

As mentioned earlier, the development of the BDN system included two phases. This report presents details of the Phase II trial at The University of Texas at Arlington. Phase II requires the development of more accurate prototypes, detailed installation procedures and a full-scale trial to verify the hardware design and construction practices. The effort to continue with Phase II comes from the strong interests in the BDN system among utilities, suppliers' high motivation, and the very successful Phase I's outdoor experiment.

1.2. Objectives and Scope

This report will verify the hardware designs and practices using two full-scale trials within the property controlled by The University of Texas at Arlington (UT Arlington) using trenchless technology. These full-scale field trials were conducted over Mitchell Street, and Davis Drive – on the UT Arlington campus. To conduct these field trials, first a list of objectives was identified as:

- Provide a degree of upgrade capability not considered in traditional low-cost “direct-buried” construction
- Perform a full-scale field trial to investigate BDN's implementation issues and/or better construction practices
- Install via trench or trenchless all the necessary components of BDN system, such as: handholes or ducts
- Monitor progress and forecast the duration of similar future projects using the full-scale trials at UT Arlington
- Provide UT Arlington a convenient network for future installation of communications cables to serve local university facilities

1.3. Summary

Buried Duct Network is a hybrid system that combines direct-buried features with upgrade capabilities, and serves as a shared trench between different utilities. It is composed of an

integrated system of conduits and handholes, which if implemented, will reduce multiple utility trench construction. The development of the BDN system consisted of two phases; phase I, feasibility study, and phase II, field trials. The latter phase is the subject of this report and consists of two full-scale trials within property controlled by UT Arlington to verify hardware designs and identify the best construction practices.

CHAPTER 2

LITERATURE REVIEW

2.1. Underground Space Use by Utilities

As discussed by A. Erdem, 2008; underground space use has historical roots in many cultures and usually the reason for this is more than one: to conserve energy, to overcome tight zoning regulations, to minimize the impact on historic buildings or to expand open space capacity. Today underground space use is an integral component of the total transportation network, which compromises highways, railways, waterways, pipelines, wires, and ducts that transport people, goods and public services (Canto-Perello, et al., 2009).

One of the ways that the human kind has taken advantage of the underground space use is by building common utility ducts or common utility conduits. This is the frequent name used for belowground structures that carry more than one utility line; they are also called utility tunnels (see Figure 2-1). Utility tunnels promote joint use of underground right-of-ways and they date back to the nineteenth century. One of the very best examples to date is the sewer network of Paris and London, where water pipes and electric cables were added to the existing sewer line. “Nowadays, utility tunnel construction projects have increased at cities where Olympic Games or any other mega event have been celebrated during the last decades” (Canto-Perello, et al., 2009). Although a change in methods of traditional burial for utilities never comes easily, the advantages of utility tunnels indubitably out-weigh the disadvantages in many situations.

Essentially two groups of underground utility construction exist, one is an array of conduits often called common utility ducts and another one is called direct burial. Both have been commonly used and proven in the industry. Advantages of such methods are wide, such as the reduction of manhole maintenance, one-time relocation and less excavation and repair in roads and right-of-ways (EDPO-Taiwan, 2005).



Figure 2-1 Utility Tunnel (Canto-Perello, et al., 2009)

It is undeniable that urban utility tunneling has become an attractive choice in creating underground spaces for utility networks; however, there are other varieties such as the BDN system installed with small diameter (mini) horizontal directional drilling (HDD)¹ explained in this report. The installation of the BDN ducts via trenchless is an important topic to investigate. As Barras and Mayo 1995, describe, “utility companies around the country may investigate the feasibility of mini-(horizontal) directional drilling to replace open trenching, especially in congested areas where the maintenance of good public relations is important.” The main component of their study is a comparison of the installation costs via conventional open trenching and mini directional drilling. Their research proved mini-HDD to be an economically competitive tool in urban environment when replacing three 3-in. (76 mm) diameter conduits. The authors also found that in rural areas open trenching is less expensive and encouraged, and that generally costs more to mobilize a mini-directional drilling crew than a conventional trenching crew.

2.2. Summary

Since historical times, underground space has been used for sheltering and transporting of goods. Utilities as part of the total transportation network have recognized the advantages of installing their lines underground, using systems such as the utility tunnels. These common utility ducts carry more than one utility line, promoting the joint use of right-of-ways. The BDN system explained in this report is a new system that provides another cost-effective method for underground space for utilities. BDN, in combination with mini-HDD, may reduce the impact of utilities in high congested areas as presented in this report.

¹ For more information on trenchless technology methods and horizontal directional drilling, refer to Najafi (2005).

CHAPTER 3

PLANNING – SITE EVALUATIONS

3.1. General Description of the Work

As part of Phase II for BDN development, a set of two BDN system field trials were performed at UT Arlington campus between October 23, 2008, and November 18, 2008. The trials comprehended the installation of two 4-in. (102-mm) conduits as well as necessary handholes along West Mitchell Street and South Davis Drive, two local roads in Arlington, Texas. The two trials had a total length of 2,200-ft (671-m) with the first trial 600-ft (182-m) in Mitchell Street and the second trial 1,600-ft (488-m) in South Davis Drive. The depth of installed handholes from ground surface varied between 36-in. (914-mm) to 42-in. (1,067-mm) depending on the type of handhole used (see section 3.6.2 Handholes). Due to the necessity to safely surpass various types of obstacles such as driveways, trees, underground utilities and culverts, mini-horizontal directional drilling (mini-HDD) was the construction method of choice to install the conduits. A collateral benefit of using mini-HDD in UT Arlington trials was to prove the feasibility of installation of BDN system in established areas for which open-cut construction would not be desirable or possible. Figure 3-1 shows a general layout of the construction site.



Figure 3-1 General Layout of BDN Pilot Study (Source: Google Maps)

3.2. Work Plan/Schedule

Preconstruction activities began in spring of 2008, with coordination with UT Arlington's department of telecommunication services. Due to convenient weather, the work was scheduled to begin in late October or early November of 2008. After a review process of the design, a

kickoff meeting was held on October 22, 2008, at UT Arlington Center for Underground Infrastructure Research and Education (CUIRE) main facilities to explain the final construction drawings and address inquiries from the participating parties.

At this meeting, the contractor (SPARUS Corporation of Dallas, Texas) and the pipe supplier (CANTEX, Inc. of Mineral Wells, Texas) scheduled their activities for pipe delivery and joint fusion. The meeting participants addressed the logistics for the two trials as well as the location of the fused pipes along the construction site. Due to limited budget and contractor's equipment availability, a 3-step operation to install the conduits was proposed by the contractor as shown in Figure 3-2. The first step included construction of a pilot bore; the second step included reaming and pushing forward the mud trapped inside the borehole; finally in the third step, the conduits were installed. Following this procedure, a clean and smooth borehole was produced and the two conduits were pulled with less pulling loads within the limits of the available mini-HDD equipment (20,000 lb or 89 kN pullback).

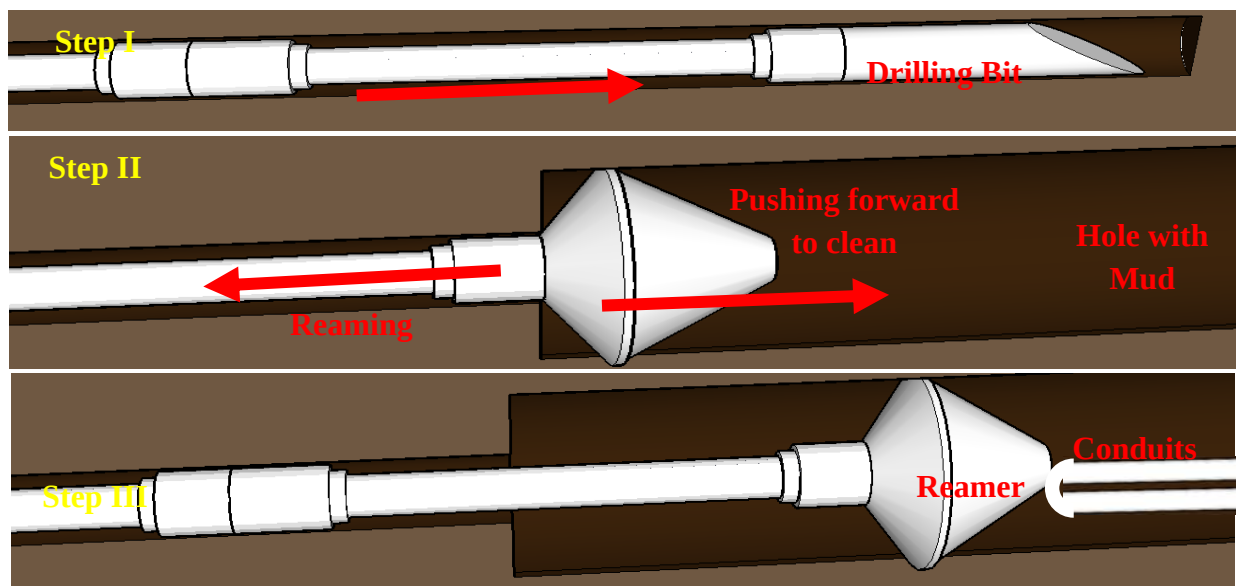


Figure 3-2 Horizontal Drilling Steps to Install the Conduits

In the kickoff meeting, the contractor and pipe supplier agreed on bore plan and the areas where the mini-HDD machine will be positioned. Based on experience, the contractor anticipated a total duration of 10 days for the field trials. Figure 3-3 shows the kickoff meeting attendees.



1. Mr. Jose Ventura, SPARUS, Corp
2. Dr. Mohammad Najafi, UT Arlington Assistant Professor and CUIRE Director
3. Dr. Larry Slavin, OPCS, Inc.
4. Mr. Craig Beal UT Arlington Director of Telecommunication Services
5. Mr. John Morgan, CANTEX, Inc.
6. Mr. Steven Tollefson, CANTEX, Inc.

Figure 3-3 Kick-off Meeting Attendees

It was determined that two field trials will be performed, a first trial along Mitchell Street and the second trial along South Davis Drive. In the preconstruction phase, the contractor visually identified the surface features of underground utilities and submitted a request to DIG-TESS (Texas Excavation Safety System) regarding utility locating along the alignment of the proposed boring operation.

3.3. Project Participants

As shown in Figure 3-4, the phase II trial at UT Arlington included a diversified number of parties: Dr. Larry Slavin (inventor of BDN system and main project manager), Dr. Mohammad Najafi², Mr. Diego Calderon, Mr. Shreepad Maldikar³ and Mr. Cong Zeng⁴, Mr. Wiefu Zhang (the construction management team), Mr. Craig Beal director of the Telecommunication Services Department at UT Arlington (the owner and final user of the BDN system), Mr. Steven Tollefson and Mr. John Morgan from CANTEX, Inc. (pipe supplier and fusion provider of the PVC pipes), Mr. Jose Ventura (SPARUS, Corp, the selected contractor to perform the field trials) and Mr. Joe Dobry from BAROID Industrial Drilling Products - Halliburton (the drilling fluid supplier).

² Assistant Professor at UT Arlington and CUIRE director.

³ Construction engineering & management graduate students at UT Arlington and CUIRE graduate research assistants.

⁴ Exchange visiting student from China University of Geosciences—Wuhan



1. Mr. Shreepad Maldikar, UT Arlington Graduate Student CUIRE Research Assistant
2. Mr. Weifu Zhang, UT Arlington Graduate Student
3. Mr. John Morgan, CANTEX, Inc.
4. Dr. Mohammad Najafi, UT Arlington Assistant Professor and CUIRE Director
5. Mr. Joe Dobry, BAROID Industrial Drilling Products
6. Mr. Jose Ventura, SPARUS, Corp
7. Dr. Larry Slavin, OPCS, Inc.
8. Mr. Diego Calderon, UT Arlington Graduate Student CUIRE Research Assistant
9. Mr. Cong Zeng, China University of Geosciences – Wuhan Exchange Visiting Student

Figure 3-4 Attendees at Field Trial at UT Arlington

3.4. Soil Investigation

As requirements for proper HDD installation, a soil investigation was conducted along the pipe alignment with excavating several potholes. As shown in Figure 3-5, the potholes were located along the field trials path and were at least 15-ft (4.5-m) apart from one another. The soil samples were taken from these potholes at depths of 5-ft (1.5-m); however, soil sample No. 8 was extracted from a depth of 7-ft (2.1-m). No ground water table was encountered during the soil investigation.

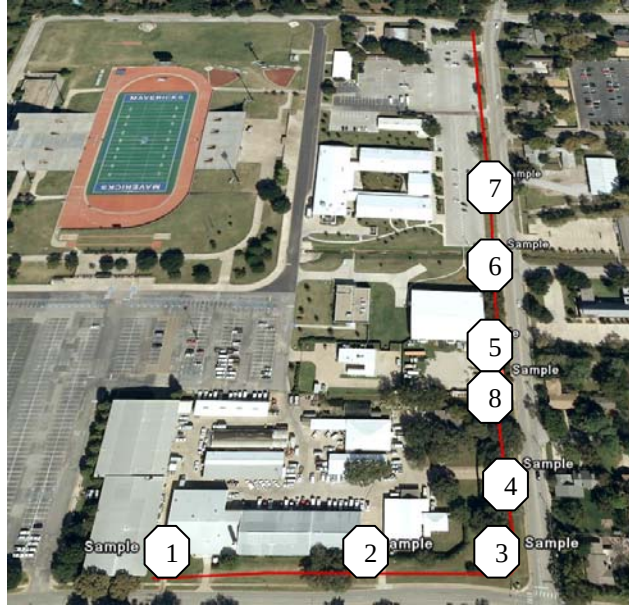


Figure 3-5 Project Soil Sample Locations (1 to 8) (Source: Google Maps)

Adjacent to pothole No. 1, a two story building is located. This pothole was 10 to 20-ft (3 to 6-m) away from the building; so that the impact of the building foundation did not affect the soil sample. A reconnaissance survey was developed for the project site and concluded that the soil on the ground surface was dry clay. The effect of water table on the project site was negligible; it was not encountered at depths higher than 7-ft (2.1-m). Soil tests were taken along the intended installations just before commencing the work; however, some soil samples were taken also as the installation progressed. For instance, a soil sample was taken in pothole No. 8 to investigate why the soil was too hard when pilot boring was in progress. A sample configuration of a pothole is shown in Figure 3-6. The classification, details and properties of the soil samples are presented in Table 3-1.



Figure 3-6 Pit 3 Configuration

Table 3-1 Moisture Content of Soil Samples

Pothole	Depth Sample is Extracted	Moisture Content (%)	Liquid Limit	Plastic Limit	Plasticity Index	Soil Classification
1	5-ft (1.5-m)	12.6	35	20.42	14.58	Sandy Lean Clay
2	5-ft (1.5-m)	9.8	49.2	20.97	28.23	Sandy Lean Clay
3	5-ft (1.5-m)	15	43	21.61	21.39	Sandy Lean Clay
4	5-ft (1.5-m)	11	36.5	14.20	22.30	Sandy Lean Clay
5	5-ft (1.5-m)	31	32	16.34	15.66	Sandy Lean Clay
6	5-ft (1.5-m)	10.6	34.2	15.74	18.46	Sandy Lean Clay
7	5-ft (1.5-m)	9.8	47.6	16.50	31.10	Sandy Lean Clay
8	7-ft (1.5-m)	13.1	-	-	-	Silty Fine Sand

The soil collected from the potholes was classified in accordance with USCS classification system. The liquid limit and plastic limit of the samples were found by following the ASTM D 4318-05 (See Table 3-2). Hydrometer analysis using ASTM D1298-99 (2005) was conducted on all the test specimens as the percentage of silt and clay fraction was very high, and gradation curves were obtained and are illustrated in Appendix B.

Table 3-2 USCS Classification Chart for Soil Samples

Sample	Liquid limit	Plastic limit	Plasticity Index	Soil classification
1	35.00	20.42	14.58	Sandy Lean Clay
2	49.20	20.97	28.23	Sandy Lean Clay
3	43.00	21.61	21.39	Sandy Lean Clay
4	36.50	14.20	22.30	Sandy Lean Clay
5	32.00	16.34	15.66	Sandy Lean Clay
6	34.20	15.74	18.46	Sandy Lean Clay
7	47.60	16.50	31.10	Sandy Lean Clay

After determining the plasticity index and the gradation curves, the soil samples were plotted on a graph, which contains liquid limit and plasticity index (see Figure 3-7). As shown in Table 3-1 most of the soils fell in the region of low plasticity clay having a PI greater 7, and greater than 30 percent passing through No. 200 sieve. Here forth the soil samples from 1 to 7 can be classified as Sandy Lean Clay. Soil sample 8 was silty sand which is classified by wet sieve analysis. At that time it was concluded that below 6-ft (1.8-m), silty sand type of soil could be encountered. Boulders (8-in. (203-mm) and larger in diameter) were not encountered at any pothole.

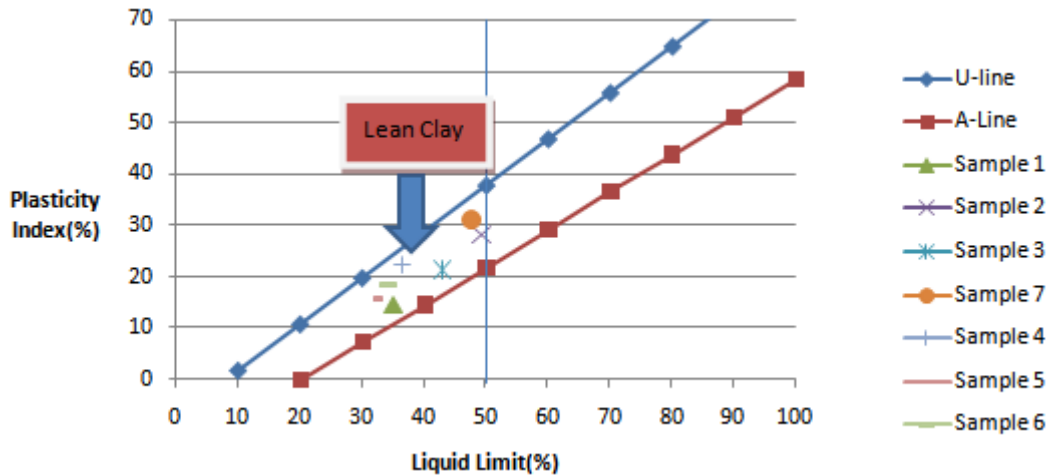


Figure 3-7 USCS Classification Graph for Soil Samples

3.5. Site Surveying

A full topographical survey was conducted for the project site; from the curb to the right-of-way (ROW) for both Mitchell Street and South Davis Drive trials. This stretch of ground included: several driveway openings, trees, sidewalks, parking lots, a drainage creek and many underground utilities that were also located by DIG-TESS. After completion of this survey, the data was imported to AutoCAD Civil 3D 2008. The file then was geographically referenced on grid coordinates, producing an .XML surface with the alignment from the main boring path, and a profile view with elevation call outs every 50-ft (15-m). Figure 3-8, Figure 3-9 and Figure 3-10 show the most probable profile view and the alignment for the boring path determined by the surveying.

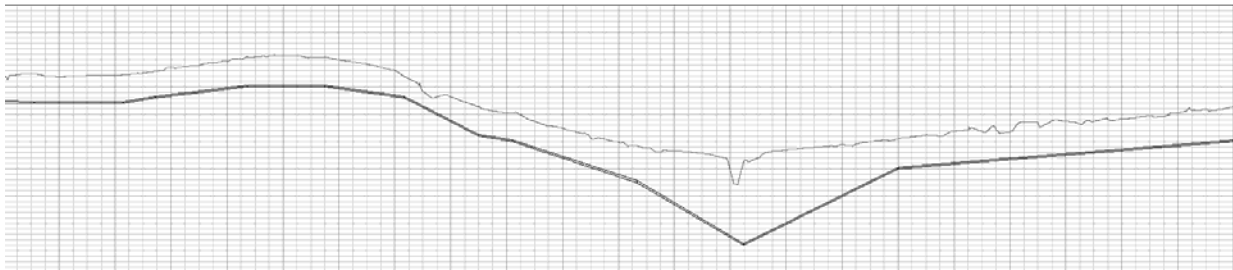


Figure 3-8 Boring Path Profile (Not in scale)



Figure 3-9 Boring Alignment Mitchell Street (Not in scale)

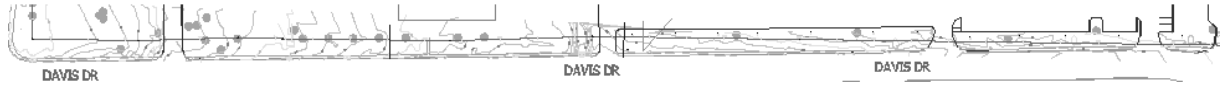


Figure 3-10 Boring Alignment Davis Drive (Not in scale)

The survey aided to illustrate the location of above ground and underground utilities and obstacles with acceptable accuracy for future records; it also helped to illustrate the most probable boring path. This survey was not intended to serve as “as-built” drawings of the construction process, instead, the surveying crew focused mostly on the intended boring alignment and other obstacles mainly. All detail and scale drawings can be found at Appendix A.

3.6. Resources

3.6.1. Conduits

The installation of pipes for the BDN project at UT Arlington was first conceived using conventional trench methods (open-cut). However due to the great number of obstacles crossing the alignment, trenchless alternatives and more precisely mini-HDD was used. This endeavor required specially designed conduits able to bear high tensile forces. For this reason and to test the product, CANTEX Inc. provided PVC conduits for the BDN project at UT Arlington. The conduits are known as CANFUSE and are the result of a co-branded line between CANTEX Inc., and Underground Solutions Inc. These conduits are designed especially for electrical and communications purposes and allow butt fusion, they matched perfect for both Mitchell and South Davis trials.

The conduits were shipped to the site in packages of 40 pipes each one; each conduit in the package had a length of 20-ft (6-m). Each section of pipe had two bell-shape ends as seen in Figure 3-11. Table 3-3 shows the dimensions of one CANFUSE conduit sample used on the site; at the inside of the pipe and at the bell shape.



Figure 3-11 Bell Shape End 4-in. (102-mm) Fusible PVC CANTEX Pipe

Table 3-3 Fusible PVC Sectional Dimensions

Section	Inner Section	Bell-shape Section
<i>Wall Thickness</i>	0.28-in. (7-mm)	0.274-in. (7- mm)
<i>Inside Diameter</i>	3.94-in. (100- mm)	4.34-in. (110- mm)
<i>Outside Diameter</i>	4.49-in. (114- mm)	4.89-in. (124-mm)

As explained by the manufacturer, this schedule 40 PVC pipe is flexible enough for trenchless operations, even being butt-fused. The bell shape allows extra space for communications cables to pass through easier. The average length of the two bell shapes joined was 3.5-in (89-mm). A fused joint sectional view of the conduit is shown in Figure 3-12.



Figure 3-12 Fused PVC Joint

3.6.2. Handholes

Figure 3-13 shows an underground utility box, commonly known as a handhole; which was employed in the BDN system at UT Arlington for joint-usage purposes. It provides accessibility to rout cables to UT Arlington facilities using knockouts located on the sides. To test construction capabilities and reliability of handholes, different brands of them were installed in the field trials. The brands used for these field trials were Pencil 2436-42 and Quazite PG2436.

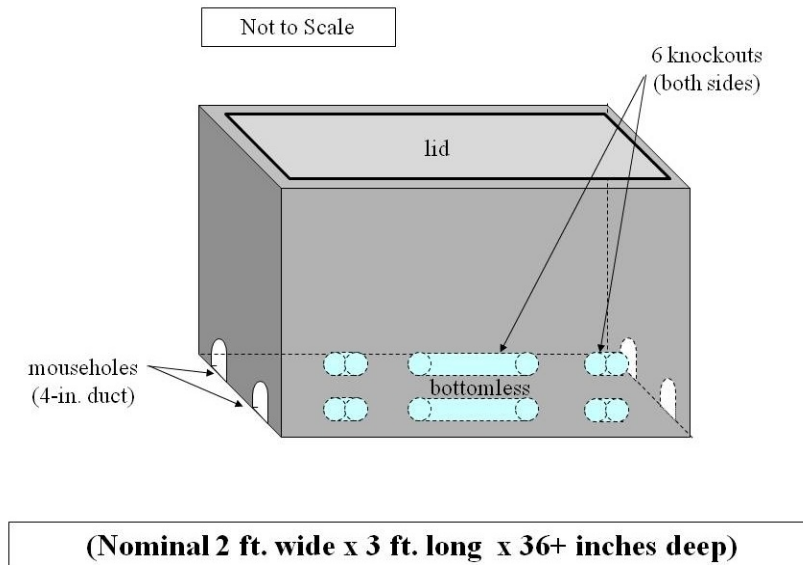


Figure 3-13 Handhole Design

Quazite PG2436 handhole has two major components, a rigid polymer concrete box and two rigid polymer concrete lids. The lids can be attached to the box using two bolts. Due to the stiffness of the polymer concrete box, it does not need internal support for horizontal earth loads. It has two mouse holes of 4.75-in. (121-mm) in diameter, with a separation of 8-in. (203-mm) each one from center to center. Quazite handholes are apparently heavy but in fact are lighter than normal concrete because they are made of polymer concrete (Quazite, 2008). Figure 3-14 shows one of the Quazite PG2436 handholes used in the project; note that for shipping purposes, this handhole has one lid on top of the other one.

Pencell 2436-42 handhole also has two major components, a HDPE box and one rigid polymer concrete lid. The lid can be attached to the box using two bolts; the box comes with internal rigid elements able to support horizontal earth loads. This type of handhole has two mouse holes of 5 3/5-in. (15-mm) in diameter, with a separation of 12-in. (305-mm) from edge to edge. Figure 3-15 shows one of the Pencell 2436-42 handholes used in the project.



Figure 3-14 Quazite PG2436 Handhole



Figure 3-15 Pencil 2436-4

3.6.3. *Mini-HDD*

For both trials a Ditch Witch JT2020 mini-HDD was selected by the contractor to perform the work. The JT2020 is a self-contained horizontal directional drilling unit designed to install buried cable and conduits at distances up to 400-ft (122-m) depending on soil conditions. The unit is designed for operation in temperatures typically experienced in earth moving and construction work environments (Ditch Witch, 2006). Figure 3-16 shows the mini-HDD used to perform the field trials at UT Arlington.



Figure 3-16 Ditch Witch JT2020 Used for Field Trials

3.6.4. Other Resources

Besides the onsite personnel, other types of resources were used and they are listed and illustrated in the table below (See Figure 3-17 and Figure 3-18).

Table 3-4 Equipment Used for UT Arlington Trials

Resource	Description
Fusing Machine	McElroy No. 412: fuse pipe sizes from 4-in-to 12-in (110-mm to 340-mm)
Mini-HDD	Ditch Witch JT2020: 20,000 pounds of pulling power
Backhoes	Mini and medium size backhoes
Vacuum Excavator	Ditch Witch FX 30: 32.8-hp (24.5 kW) Kubota diesel engine
Boring Fluids	BAROID Penetrol® and IDP-433
Handholes	Quazite PG2436 and Pencell 2436-4
Conduits	CANTEX CANFUSE Schedule 40 fusible-PVC
Trucks	Mid-size trucks
Trailers	Mid-size trailers
Gazebos	Small size gazebos for sun protection



Figure 3-17 Other Resources Used by SPARUS, Corp



Figure 3-18 Other Resources used by CANTEX, Inc

3.7. Summary

At the planning stage of the BDN system field evaluations, two field trials were conceived; one along Mitchell Street and another along South Davis Drive. Mini-HDD was selected as the best

construction option due to the majority of obstacles needed to surpass both field trials. After selecting the contractor, the kickoff meeting was held. In this meeting the means and methods to perform the field trials were presented by the contractor, to the owner, the designer and the supplier. Once it was established and after deciding the best alignments for the trials, a complete soil investigation was performed and included soil classifications and gradation curves for eight samples. At the same time the proposed alignment was surveyed and plotted. This chapter finalizes by explaining some of the resources used on site for the field trials.

CHAPTER 4

FIELD EVALUATION INSTALLATION DETAILS

4.1. Process

The field evaluations at UT Arlington began on October 23, 2008, and lasted 19 days (about 4 weeks). In those weeks, more than 20 people became involved; personnel from the construction party, suppliers, management, laboratory and other parties worked with ease and coordination. However, for the physical installation, only a crew of 4 people (for the most part) was needed. The general logical activity sequence of the work is shown in Figure 4-1.

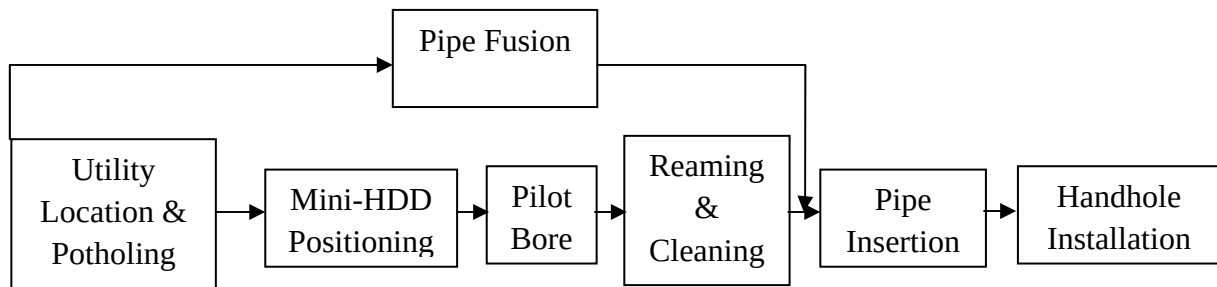


Figure 4-1 General Activity Sequence for BDN Installation

4.2. Mitchell Street Field Evaluation

The Mitchell Street field trial at UT Arlington was planned to have 600-ft (183-m) of installation; however, the total length was 575-ft (175-m) due to modifications on the handholes locations. The sequence of activities needed to perform the field trials at Mitchell Street, will be described in the following sections.

4.2.1. Pipe Fusion

The field trial started on October 24 when the fusible PVC pipes were received and stored. A total of 240 pipes of 20-ft (6-m) long were delivered by SPARUS Corp, to the Civil Engineering Laboratory Building (CELB) in UT Arlington. A delivery of 80 PVC pipe sections was taken directly to Mitchell Street; the remaining pipe sections were stored at the CELB.



Figure 4-2 PVC Pipes Delivered to the CELB

One day was necessary to fuse all the conduits for Mitchell Street trial using a crew of two operators, one truck, one trailer and two fusing machines. Because the need of positioning the fusing machine and the pipes to do the first joint, approximately 35 minutes were taken to perform the first joint; however, once the fusing machine was setup it took approximately 10 to 30 minutes to fuse each one of the following conduits. As told by the CANTEX, Inc. onsite crew members, fusing of PVC pipes is faster at lower temperatures. Figure 4-3 shows two pipes being fused.

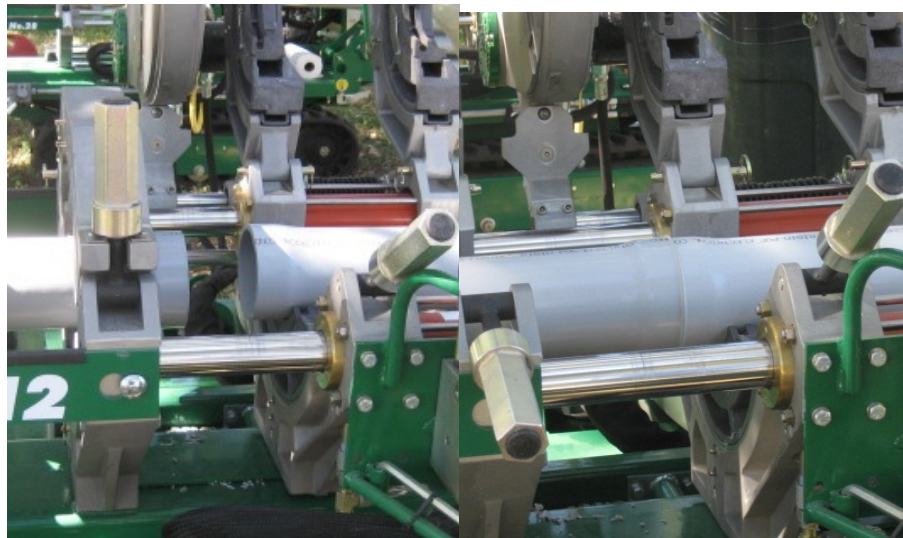


Figure 4-3 Pipes Being Fused in Mitchell Street

4.2.2. Utility Location & Potholing

Standard and logical procedures for identification of underground utilities were performed; such as calling DIG-TESS (“One-Call” agency) or visually identifying valves above ground level. Below is a list of utilities and other obstacles identified for the first field trial.

- A buried diesel tank (see Figure 4-5)
- Sprinkler system
- Telephone net
- High voltage electrical cables
- Traffic lights circuit
- A storm water culvert inlet (see Figure 4-6)
- Big tree roots

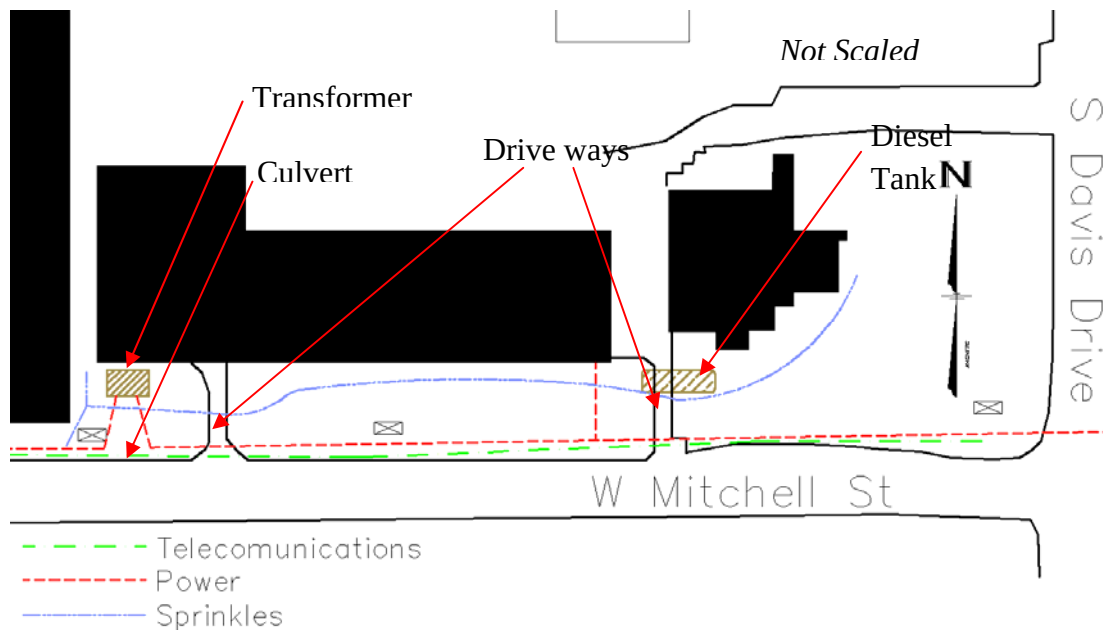


Figure 4-4 Utilities and Obstacles Identified at Mitchell Street Installation

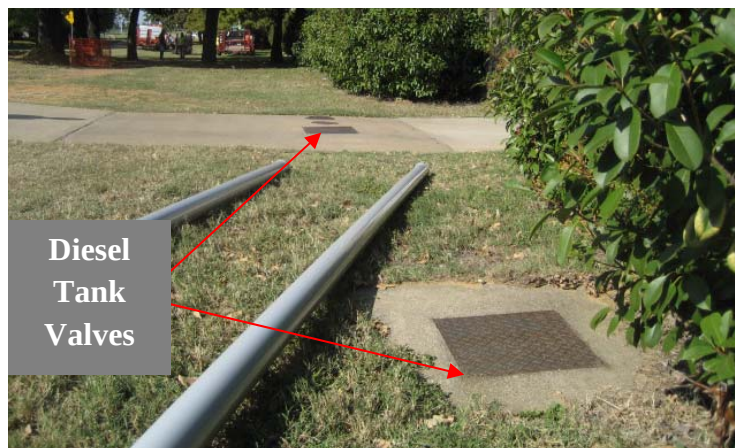


Figure 4-5 Visual Identification of the Diesel Tank Valves



Figure 4-6 Culvert Inlet at Mitchell Street

4.2.3. HDD Positioning

After locating and potholing the underground utilities and following the general planning strategies set at the kickoff meeting, the mini-HDD machine was positioned close to the center of the trial to drill the first borehole (first run) to the east. Dividing the trial into two runs, the first run had a total distance of 390-ft (119-m) and the second run had a total distance of 185-ft (56-m).

On October 28, the mini-HDD machine was setup close to the center of the trial to drill the first borehole (first run) to the east. On October 31, the HDD machine was turned back to drill a second borehole (second run) towards the west. Figure 4-7 shows the position of the HDD machine for the first and second runs, as well as the final positions of the handholes.

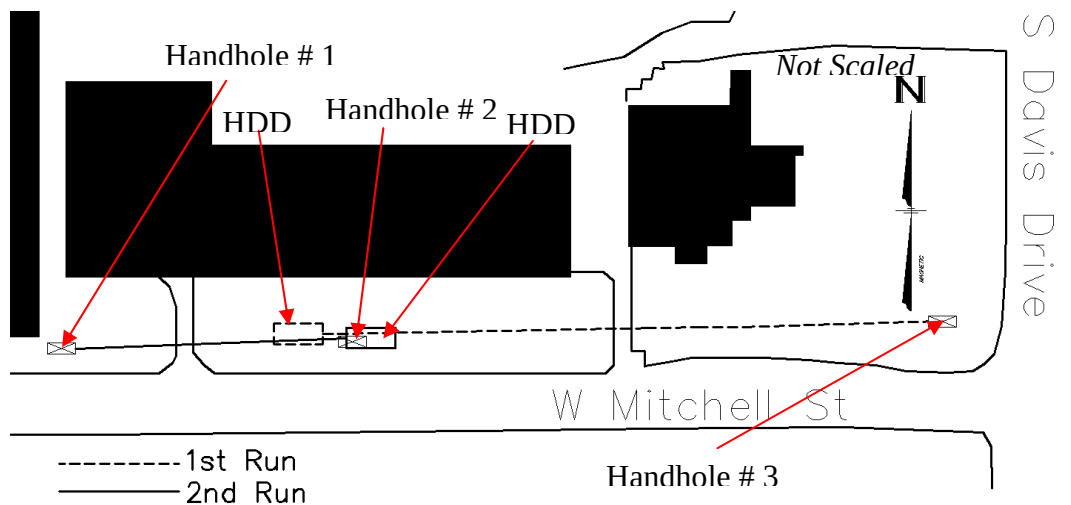


Figure 4-7 HDD Machine Location for Runs 1 & 2

4.2.4. Pilot Bore(s)

The contractor had plan to drill continuously due to poor conditions of the soil; however a delay occurred during the first run because of the necessity of visually identifying the buried diesel tank. But, the combination of the clay content of the soil and a proper mixture of drilling fluids made it easy and fast for the borehole drilling operation.

The drilling fluids used to aid in the drilling operation for the pilot bores were generously provided by BAROID Industrial Drilling Products. The fluids used were Penetrol® and IDP-433 (see Figure 4-8) using the following dosage: for each 500 gallons of water 4 quarters of IDP-433 and two quarters of Penetrol® were combined.

IDP-433 is a liquid polymer used primarily as a viscosifier and borehole stabilizer to prevent reactive shale and clay from swelling and sloughing. It is also useful to provide friction reduction and lubricity in freshwater drilling fluids. As an advantage it also provides compatibility with agents such as BORE-GEL®. Penetrol® is a liquid wetting agent designated to neutralize the sticking tendencies of clay. It reduces surface tension of drilling fluid, which allows faster chip removal, increasing drilling efficiency as well.



Figure 4-8 Drilling Fluids Used

Using above drilling fluids, the mini-HDD machine worked at the following average rates when drilling the first and second pilot bores, Figure 4-9 shows the mini-HDD machine drilling the pilot bore for the second run and Figure 4-10 shows the final depths for the first and second runs:

- RPM: between 2400 – 2650
- Thrust force⁵: < 4000 lbs (17793 N)
- Torque⁶: 600 ft-lb (41 N-m)

⁵ Estimated by the HDD manufacturer using the hydraulic fluid pressure on thrust motor.

⁶ Estimated by the HDD manufacturer using the hydraulic fluid pressure on rotation motor.



Figure 4-9 Drilling Pilot Bore Beneath Driveway (Second Run)

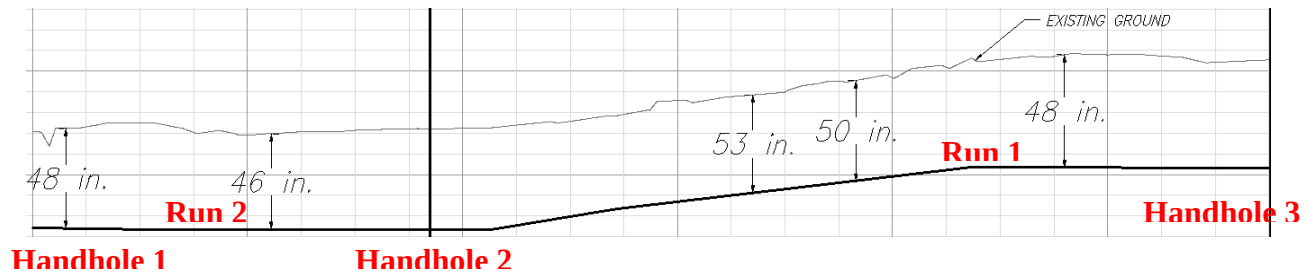


Figure 4-10 Profile View of Pilot Bores (Runs One and Two)

4.2.5. Reaming & Cleaning

After reaching handhole 3 for the first run and handhole 1 for the second run, a 10 1/8-in. (257-mm) solid metal compaction reamer was attached. The vibration of the reamer expanded the borehole up to 12-in. (305-mm) leaving a tight but smooth space for inserting the pipe. To reduce pullback force and allow a successful installation of the two conduits, the borehole was reamed and cleaned at the same time. As explained in Figure 3-2, the mini-HDD operator stopped the reaming approximately each 100-ft (31-m) to push it forward, thus removing/cleaning the reamed soil. Using the same mixing of drilling fluids, the reaming operation took 2.6 hours approximately to complete the first run.



a)

b)

Figure 4-11 a) Reamer Used, b) Cleaned Borehole

The HDD machine worked at the following average rates when reaming the first and second pilot bores:

- RPM: between 2500 – 2700
- Pullback force⁷: < 4000 lbs (17793 N)
- Torque⁸: 1600 ft-lb (109.6 m-N)

4.2.6. *Pipe Insertion*

In any planning operation pipe insertion could be constrained by the availability of fused pipes and the completion of the borehole; however, for this trial the pipe fusing operation was completed a several days ago, leaving the completion of the borehole as the critical activity.

Seven subdivisions were identified onsite for the pipe insertion process, they are as follows:

- i. Position the pipe by the entry pit
- ii. Cut the end of the pipe
- iii. Insert and adjusting the pulling eye
- iv. Attach wire ropes between the reamer and the pulling eyes
- v. Pull the pipes through the hole using the HDD machine
- vi. Remove the pulling eyes and the wire ropes
- vii. Uncover the pipes and installing plugs at the exit pit

At Mitchell Street, the location of the pipes before insertion represented a logistical challenge. On one the east end (corner of Mitchell and Davis) the street was very close to the insertion pit, therefore, the only way to insert the two conduits was bending them towards Davis Drive (see

⁷ Estimated by the HDD manufacturer using the hydraulic fluid pressure on thrust motor.

⁸ Estimated by the HDD manufacturer using the hydraulic fluid pressure on rotation motor.

Figure 4-12a). On the west end, a parking lot also constrained the installation; however the driveway was not very close to the insertion pit (see Figure 4-12b).



Figure 4-12 Pipe Location before Pulling a) East End, b) West End

Figure 4-13 shows a special type of pulling devices which were used for both Mitchell Street and Davis Drive trials, this specially designed towing heads seal the inside of the pipe keeping mud and the drilling fluids out of the interior of the pipe. The whole process of pulling the pipe took three hours and four minutes for the first run and around one hour for the second run.



Figure 4-13 Pulling Eyes Used for Mitchell and Davis

Once the pipes were in place, a plug was installed at each end of the two PVC conduits to prevent water flooding inside the conduits. Figure 4-14 shows how the pipes remained after the installation and the extra-space allowed by the borehole. Having the outside diameter of the pipe of 4.5-in. (114-mm) and an extra-space of 2-in. (51-mm) the borehole diameter size was approximately 11-in. (279-mm) (See Figure 4-14).



Figure 4-14 PVC conduits installed

4.2.7. Handhole(s) Installation

The first installed handhole and the most difficult to install, was handhole 1. Due to the proximity of existing underground utilities (especially a high voltage power line), the installation of this handhole took approximately 7 hours. As told by the contractor, the high voltage lines were less than 5-in. (127-mm) apart from the excavation boundaries (see Figure 4-15), leaving almost no-space for the handhole. The contractor enlarged the borehole using shovels, and later cut the mouse holes in the handhole, reducing the spacing between mouseholes to 8-in. (203-mm) approximately. Once all of these were done the modified handhole was lowered down into the pit to install it.

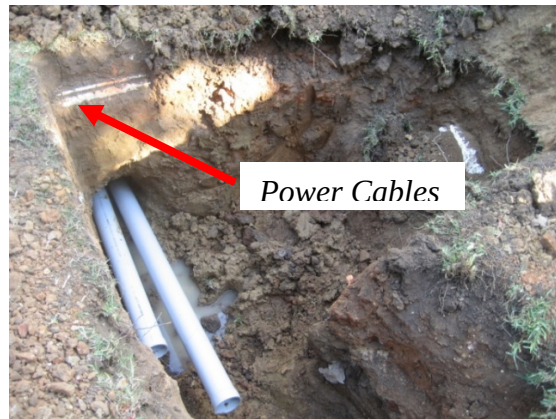


Figure 4-15 Buried High Voltage Power Cables at Handhole 1

4.3. South Davis Street Field Evaluation

The South Davis Drive field trial at UT Arlington was planned to have 1600-ft (488-m) of installation; however, the total length was approximately 1,550-ft (472-m) due to modifications on the handholes locations. The sequence of activities needed to perform the field trials at South Davis Drive, will be described in the following sections.

4.3.1. Pipe Fusion

Immediately after fusing the pipes for Mitchell Street trial, the pipe fusion crew moved their equipment to the South Davis Drive and started joining pipes as per need by the contractor. The crew fused in advance several lines of pipes along South Davis Drive, each one of a minimum length of 300-ft (91-m). Days before the insertion task, extra lengths of pipes were fused up to the required length needed by the contractor depending on the length of the runs. The location and length of the conduits were cross checked between the pipe supplier and the contractor. Also the pipe supplier helped the contractor to move the pipes near the proposed entry pits when needed. Figure 4-16 shows the supplier's crew working on South Davis Drive trial.



Figure 4-16 Pipes Being Added to Fused Line up to Desired Length

4.3.2. Utility Location & Potholing

With a simple walk around the site, days before the commencement of the field trials, it was clearly evident that South Davis Drive trial will have much more existing underground utilities than Mitchell Street. It was possible to determine some obstacles and utilities along the path before calling DIG-TESS, such as:

- Twin box culvert (See Figure 4-17)
- Main gas pipeline
- Main water line running along and across the path
- Sewer main (laterals were expected)
- Big Tree roots



Figure 4-17 Twin Box Culvert at Davis Drive

After calling DIG-TESS and notifying UT Arlington's Department of Telecommunications, some other underground utilities added to the list:

- Sprinkler system
- High voltage buried power cables

Although all the agencies located the utilities and they were potholed, some minor issues appeared due to changes in soil conditions. The first issue happened in the first run of South Davis Drive (see Figure 4-18). At an approximated distance of 360-ft (110-m) from handhole 3, the borehole was expected to run 1-ft (0.31-m) below the water main, however, a hard layer of soil prevented the drilling bit to continue his -6% slope. The mini-HDD operator tried several times to bring the drilling bit back and forth to correct the steering, without any success. After wasting two working hours, the drilling operation was stopped to excavate and rescue the drilling bit. The contractor was also worried about the closeness of the drilling bit to a water main line and the unexpected changes in the soil behavior. After digging the pit to recover the drilling head, it clearly visible that the drilling bit was very close to the water main and that a bed layer of hard and well compacted mixture of sand and iron⁹ was preventing the drilling bit to penetrate downwards (see Figure 4-19). Fortunately, the work was stopped at the right time avoiding a possible catastrophic event. It is import to clarify and consider that a main gas valve was close to the water main line. If the water main line had been broken the blast would affect and broke the gas line as well (see Figure 4-18).

⁹ The mixture of these components was suggested by the contractor; no laboratory evidence of these materials was established.



Figure 4-18 Potholing Water Main Line before Drilling

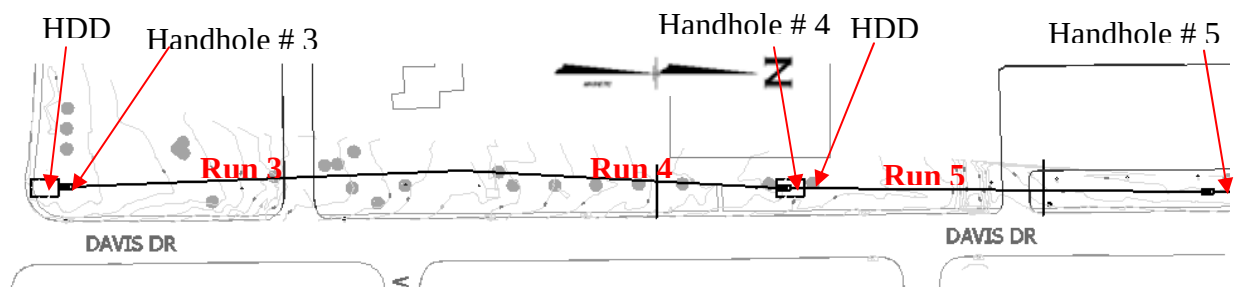


Figure 4-19 Drilling bit Close to Water Main Line

A combination of a clogged reamer and a brittle water pipe was the cause of the second utility issue at South Davis Drive trial. It occurred at about 175-ft (53-m) north of handhole 5; the reamer openings for the drilling fluids got clogged, making it very difficult for the machine to ream back. At that point the reamer has compact the soil and bumping it up the surface. This action broke a small water lateral located just above the borehole. Compared to the first issue, this one had very small risks associated, the valve was closed, the pipe repaired and the reaming continued.

4.3.3. HDD Positioning

As well as the first trial, the positioning operation of the mini-HDD machine became a crucial component in the whole process, because of various reasons, such as: the slope of the terrain, the existing underground utilities and other obstacles. It was also imperative to avoid moving the mini-HDD unit between entrance and exit pits to minimize wasting of time. The different locations for the mini-HDD machine in South Davis Drive trial are illustrated in Figure 4-20. Note that handhole 3 connects South Davis Drive and Mitchell Street trials.



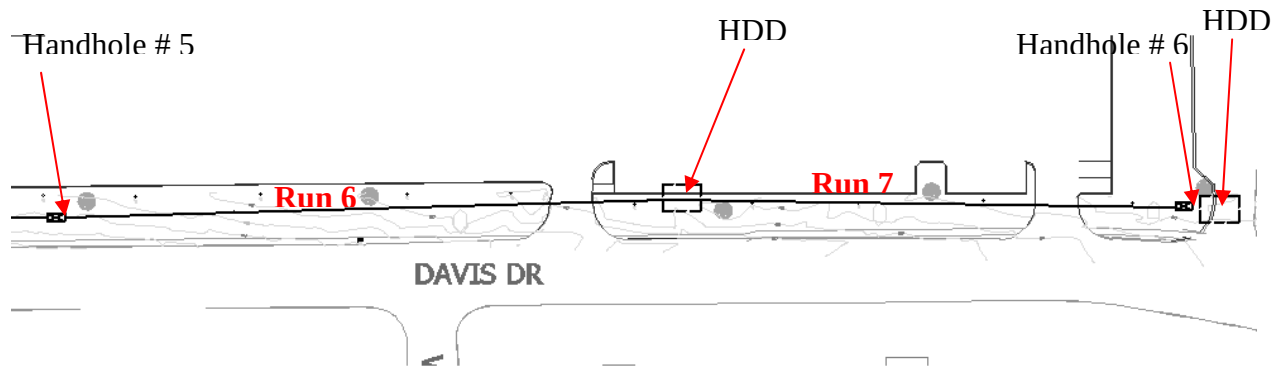


Figure 4-20 HDD Machine Location for Runs 3 to 7

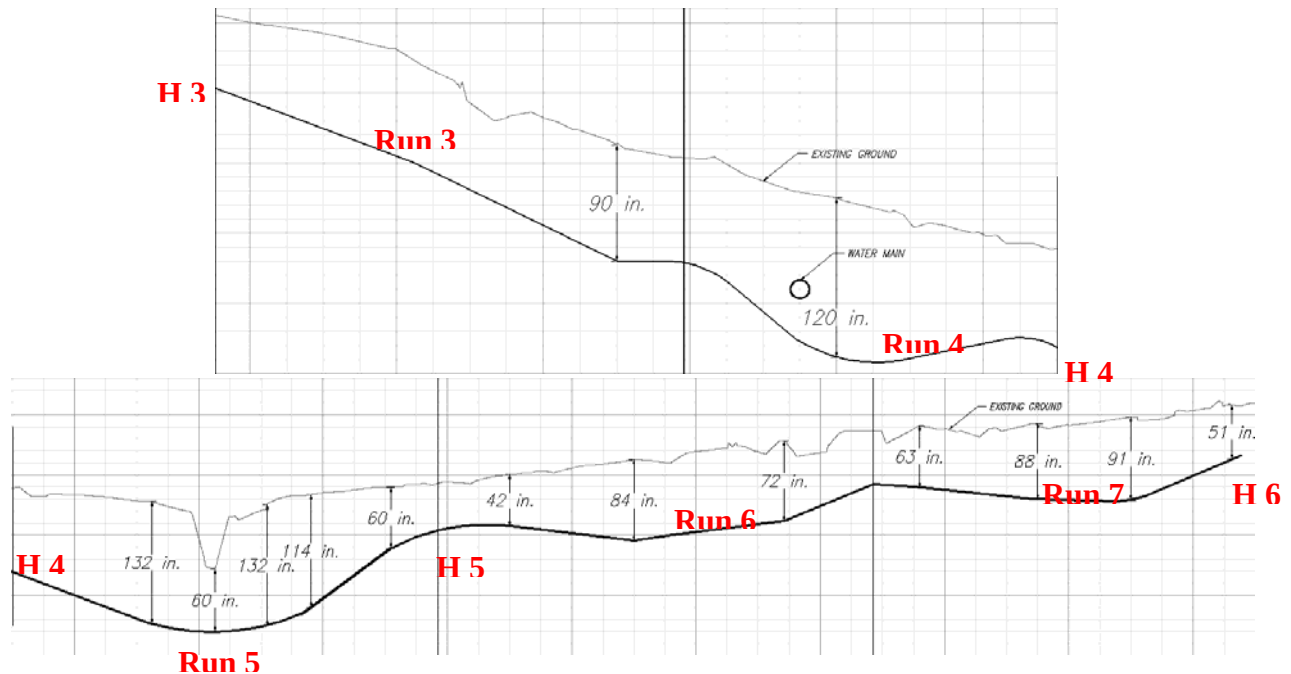
In run 3, the contractor used the slope of the terrain to his advantage, positioning the mini-HDD machine on higher ground and drilling downhill. However, as explained in some sections before, the work had to be stopped at about 360-ft (110-m) from handhole 3 due to a hard layer of soil and the uncertainty of hitting a utility line. Figure 4-21 shows the locating activity while drilling in run 3 at South Davis Drive trial; note the mini-HDD machine on the upper central part of the image.



Figure 4-21 Drilling the First Run of Davis Drive Installation

4.3.4. Pilot Bore

As explained in previous sections, this trial had 5 runs; three of them experienced hard rocky soil (Runs 3, 4 and 5). Because of these soil conditions, some delays occurred at those stages. For this reason IDP-433 and Penetrol® additives were added to the water to lubricate the borehole and stabilize it. Figure 4-22 shows the profiles views of the most probable paths of the pilot bores for runs 3 to 7.



* H: Handhole

Figure 4-22 Profile View of Pilot Bores (Runs 3 to 7)

4.3.5. Reaming & Cleaning

Using the same solid metal compaction reamer used in Mitchell Street trial, the reaming and cleaning operations were performed with none to minor delays. The process went smooth for most of the runs; however, the only run that experienced difficulties was run 3 because of the hard rocky soil encountered. Due to this problem, the process had to be stopped various times. The reaming of run 3 had the least productivity rate among all runs. The reaming operation for the run 5 experience difficulties when the right anchor of the mini-HDD broke into three parts, due to high pullback forces. Run 5 was a challenging run because the need of safely passing a culvert. Figure 4-23 shows the mini-HDD machine performing the reaming of run 5 without the right anchor.



Figure 4-23 Breaking of mini-HDD's Right Anchor at Run 5

4.3.6. Pipe Insertion

As explained before, the pipe fusing operation finished several days before the commencement of the pipe insertion process, which leaved the boring and the reaming activities as critical activities. The seven steps explained in 4.2.6 to install the conduits were also used when installing the pipes at South Davis Drive, they are:

- i. Position the pipe by the entry pit
- ii. Cut the end of the pipe
- iii. Insert and adjusting the pulling eye
- iv. Attach wire ropes between the reamer and the pulling eyes
- v. Pull the pipes through the hole using the mini-HDD machine
- vi. Remove the pulling eyes and the wire ropes
- vii. Uncover the pipes and installing plugs at the exit pit

After finishing the installation of the conduits at run 3, especially bended conduits were installed to connect the two field trials. These especially bended conduits were glued on both ends. Figure 4-24 shows the bends used to join the two main installations.



Figure 4-24 PVC Bended Pipe to Join the Two Main Installations

4.3.7. Handhole(s) Installation

South Davis Drive trial had four handholes, three Quazite PG2436 and one Pencell 2434-42. The actual installation of each of the handholes did not take much time; however, most of the time was consumed dealing with the depth of the pit and moving the surrounding soil around the pits. The average installation time for all these four handholes, was 3 hours and 53 minutes.

4.4. Summary

The BDN construction process using mini-HDD is not very complex, and contains the following activities: pipe fusion, utility location and potholing, mini-HDD positioning, pilot boring, reaming and cleaning, pipe insertion and handhole installation. These activities were analyzed one by one in this chapter for both Mitchell Street trial and South Davis Drive trial with special attention to the investigation of issues and better construction practices.

CHAPTER 5

FIELD TRIALS RESULTS

The field trials held at UT Arlington, were completed in 21 days, including the kickoff meeting through the final day of work and excluding weekends and non-working days. Although the unexpected soil behavior in trenchless operations; the field trials went smoothly and finished as expected. These field trials at UT Arlington demonstrate that the BDN system is feasible in established areas using trenchless technology (mini-HDD). The product suppliers, the contractor and The University of Texas at Arlington, expressed their interest in participating and expanding the BDN system in the campus in the near future.

5.1. Chronological List of Events

Evaluating the notes and video taken on site, it is possible to fill a table describing the major events occurred day by day at the site (see Table 5-1). This table also serves as a summary of the work done for both Mitchell Street and Davis Drive trials at UT Arlington.

Table 5-1 Chronological List of Events

Date	Event(s)
10/22/2008	Kickoff meeting held
First Day of Work	C*: Potholing utility connections and soil test pits
10/23/2008	S**: No work performed
10/24/2008	C: Potholing
	S: Conduits arrived to site
10/27/2008	C: Potholing
	S: Conduits for Mitchell Street trial fused but not ready
10/28/2008	C: 150-ft (46-m) was drilled for run 1, stopped to locate a buried diesel tank
	S: Conduits for South Davis Drive trial fused but not ready
10/29/2008	C: Drilling and reaming run 1
	S: Segments added to conduits for Mitchell Street trial
10/30/2008	C: Conduits for run 1 pulled
	S: Relocating fused conduits for South Davis Drive trial
10/31/2008	C: Drilling and reaming run 2 completed, conduits pulled for run 2, handhole 1 installed
	S: No work performed
11/3/2008	C: Drilling for run 3 completed
	S: No work performed

Date	Event(s)
11/4/2008	C: Reaming for run 3 completed, conduits for run 3 pulled S: No work performed
11/5/2008	C: Drilling for run 4 completed, run 4 reamed for 262-ft (80-m) S: No work performed
11/6/2008	C: Reaming for run 4 completed, conduits for run 4 pulled. Drilling for run 5 started S: No work performed
11/7/2008	C: Drilling and reaming for run 5 completed, conduits pulled S: Supplier was present at this pulling operation, no fusing
11/10/2008	C: Drilling and reaming completed for run 6 S: Segments added to fused conduits for run 6
11/11/2008	C: Conduits pulled for run 6 (DigiTrak system attached) S: Supplier was present at this pulling operation, no fusing
11/12/2008	C: Drilling and reaming for run 7 completed S: Supplier was present, no fusing
11/13/2008	C: Conduits pulled for run 7 (DigiTrak system attached), sleeve installed joining runs 6 and 7 S: No work performed
11/14/2008	C: Handholes 4,5, and 6 installed S: No work performed
11/17/2008	C: Handhole 3 installed, ground leveled where needed S: No work performed
11/18/2008	C: Handhole 2 installed, mule tape installed in all the conduits. S: No work performed
11/23/2008	C: Resurfacing ground around handholes S: No work performed

*C = Contractor

**S = Supplier

5.2. Personnel and Equipment by Trade

The following section shows a series of information taken on site. This information was tabulated and differentiated from the contractor and the supplier, Tables 5-2 and 5-3 show the amount of resources needed each day by these parties to perform the field trials at UT Arlington. To install the two conduits at both trials, SPARUS Corp used in average, 4 workers, one mini-HDD rig, one backhoe, two trucks, and one vacuum excavator. However, the contractor had 5 workers on site for most of the days. It is expected a similar crew size for a job of a comparable scope. On the other hand CANTEX Inc. used in average 2 operators, 2 fusing machines and 1 truck all the time.

Table 5-2 Personnel and Equipment used by the Contractor

Date	Workers	HDD Rig	Backhoes	Trucks	Vacuum Excavator
10/23/2008	2	-	-	1	-
10/24/2008	2	-	-	1	-
10/27/2008	2	-	-	1	-
10/28/2008	3	1	1	2	-
10/29/2008	3	1	1	3	-
10/30/2008	5	1	1	2	-
10/31/2008	5	1	1	4	-
11/3/2008	4	1	1	3	-
11/4/2008	4	1	1	2	-
11/5/2008	4	1	1	2	-
11/6/2008	5	1	1	2	-
11/7/2008	5	1	1	2	-
11/10/2008	7	1	1	3	-
11/11/2008	5	1	1	3	1
11/12/2008	4	1	1	2	1
11/13/2008	5	1	1	2	1
11/14/2008	6	1	2	3	1
11/17/2008	3	1	2	2	1
11/18/2008	5	1	2	2	1
<i>Average</i>	4	1	1	2	1
<i>Mode</i>	5	1	1	2	1

Date	Operators	Fusing Machines	Pipes	Trucks
10/23/2008	-	-	-	-
10/24/2008	1	-	240	1
10/27/2008	2	2	-	1
10/28/2008	3	3	-	1
10/29/2008	2	2	-	1
10/30/2008	2	2	-	1
10/31/2008	-	-	-	-
11/3/2008	-	-	-	-
11/4/2008	-	-	-	-
11/5/2008	-	-	-	-
11/6/2008	-	-	-	-
11/7/2008	2	1	-	1
11/10/2008	2	1	-	1
11/11/2008	3	1	-	1
11/12/2008	2	-	-	1
11/13/2008	-	-	-	-
11/14/2008	-	-	-	-
11/17/2008	-	-	-	-
11/18/2008	-	-	-	-
<i>Average</i>	2	2		1
<i>Mode</i>	2	2		1

Table 5-3 Personnel and Equipment used by the Supplier

5.3. Pullback Force and Mud Pressure Analysis

A tensile force analysis was conducted for the last two runs of the project and performed using a TensiTrak® unit. The unit is a self-contained wireless tool that measures and transmits data during HDD installations. It also monitors and stores live pullback and mud pressure data assisting engineers/inspectors as well as contractors with real data to prevent inadvertent return of fluids (frac-outs), surface heaves (bumps) and higher pipe installation forces. After the conduits are installed the data is transferred to a computer for analysis, graphing, printing, saving, and e-mailing (Digital Control Inc., 2008).

Using one of these units, the crew members monitored the pullback force and mud pressure in the borehole while installing the conduits for the two last runs (runs 6 and 7) in the South Davis Drive trial. The TensiTrak® unit was installed behind the reamer between the swivel and the product pipes as shown below. Some of the necessary components used in the trial are shown in Figure 5-2 and 5-1.



Figure 5-1 TensiTrak® Downhole Assembly



Figure 5-2 TensiTrak® System Used

For each one of the runs a set of data was obtained and plotted. Figure 5-3 and Figure 5-4 show the pullback force and mud pressure for runs 6 and 7. Note that the peak pullback force for Run 6 was approximately 20,000 lb (88,964 N) which contrasts to the maximum pullback force for Run 7 of 4,000 lb. (17,793 N) This huge difference in values is due in part to the clogging of the reaming tool in run 6, the speed of the conduit pulling operation might also have increased this pullback force. As seen on site, the operator was rushing to demonstrate more productivity, but rather, the operator was reducing the amount of lubrication by speeding the process.

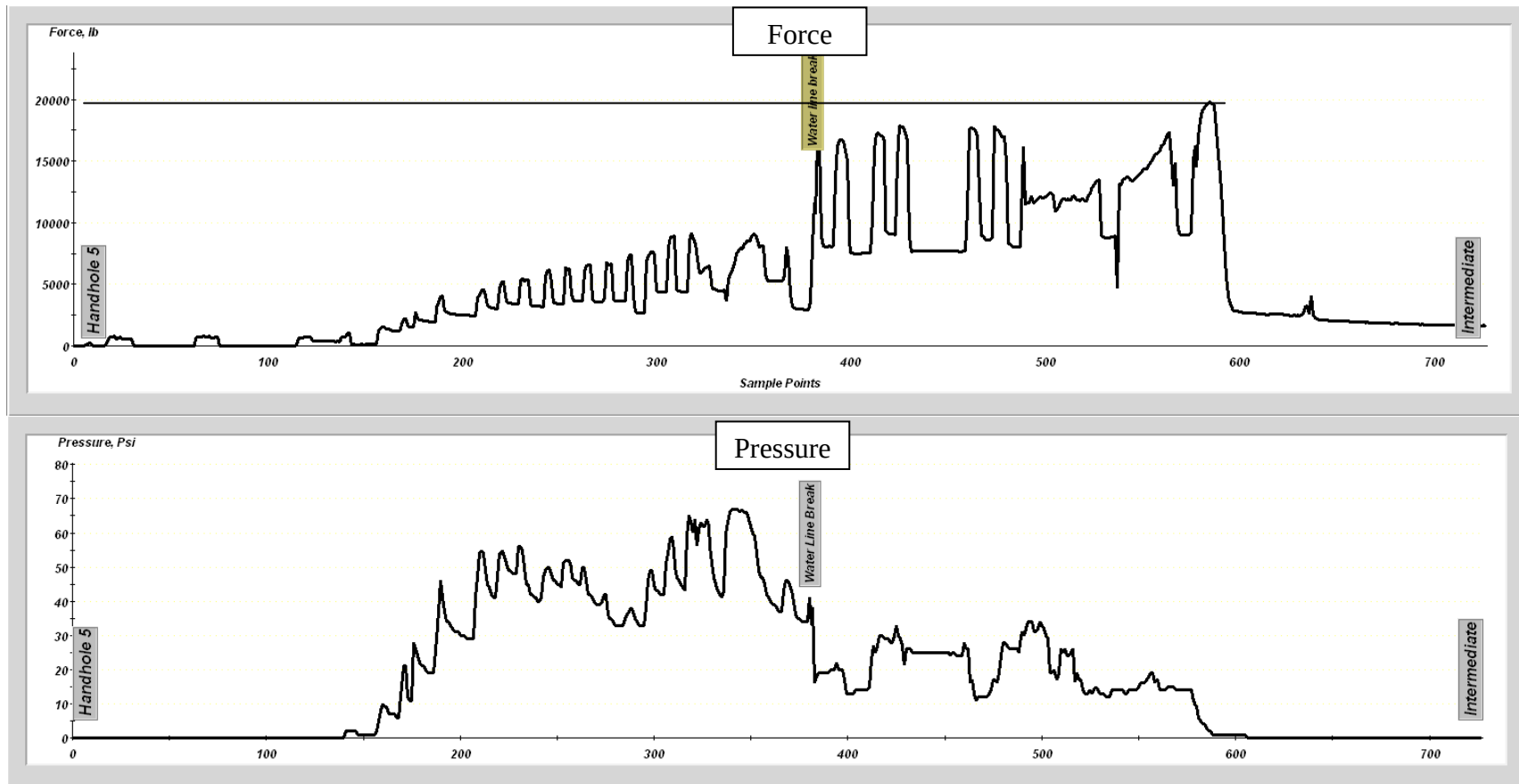


Figure 5-3 Pullback Force and Mud Pressure for Run 6

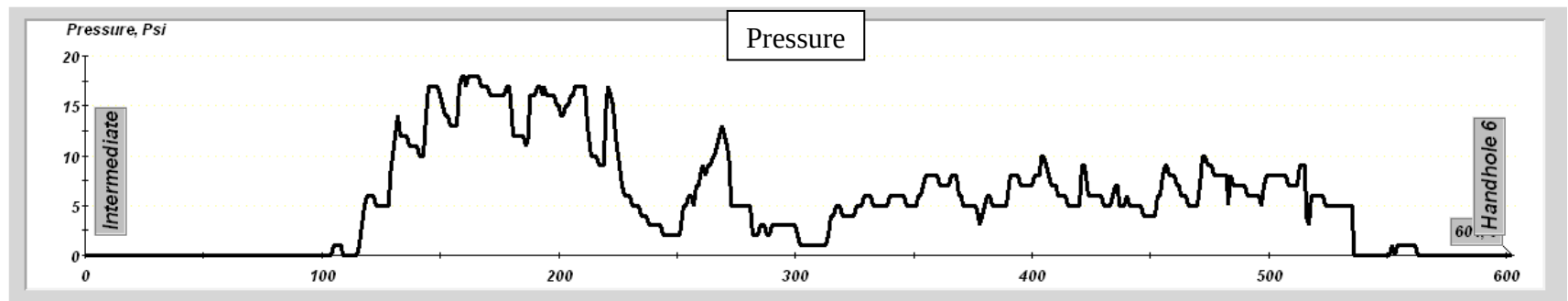
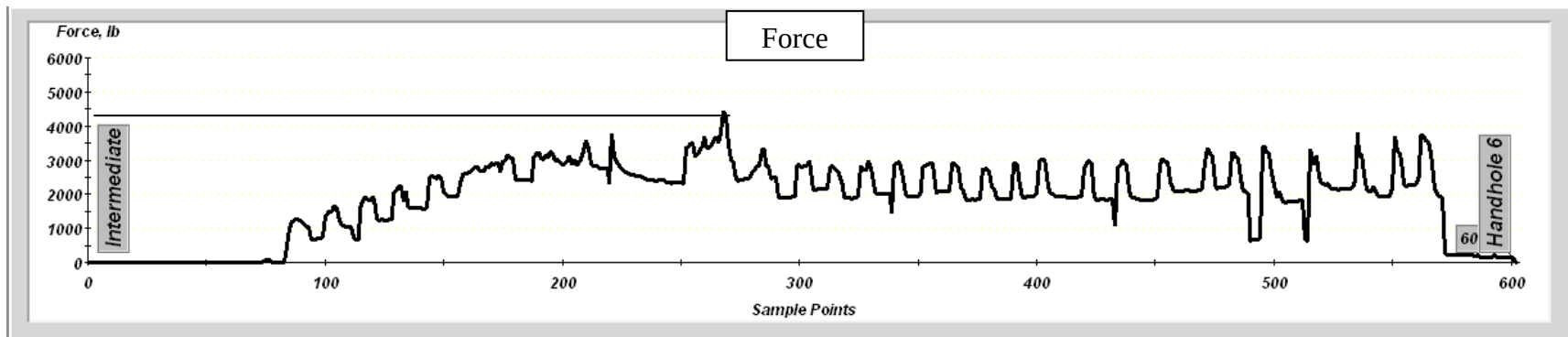


Figure 5-4 Pullback Force and Mud Pressure for Run 7

5.4. Data Analysis

Different types of methodologies were used to analyze the work done, such as: videotaping, still photographs, and note taking (also called as diary), with this data a set of tables were produced and are available in Appendix C. Based on the time and productivity analysis tables on Appendix C, sets of frequency histograms were drawn to illustrate the reader what is the productivity and duration tendency for the most recognized tasks particularly in the field trials at UT Arlington. The following histograms are not intended to establish activity durations for future projects. A summary of the average productivity ratings is shown in Table 5-4.

Table 5-4 Productivity Ratings and Standard Deviations of Activities

Activity	Unit	Average	Standard Deviation
<i>Manual pot holing</i>	cubic ft/worker hr	15	14
<i>Pot holing with backhoe</i>	cubic ft/worker hr	57	36
<i>Boring</i>	ft/worker hr	116	31
<i>Reaming</i>	ft/worker hr	169	94
<i>Cleaning with reamer</i>	ft/worker hr	260	123
<i>Pulling pipe</i>	ft/worker hr	261	82
<i>Handhole installation</i>	handhole/worker hr	1/5	1/8

5.4.1. Duration and Speed Frequency Histograms

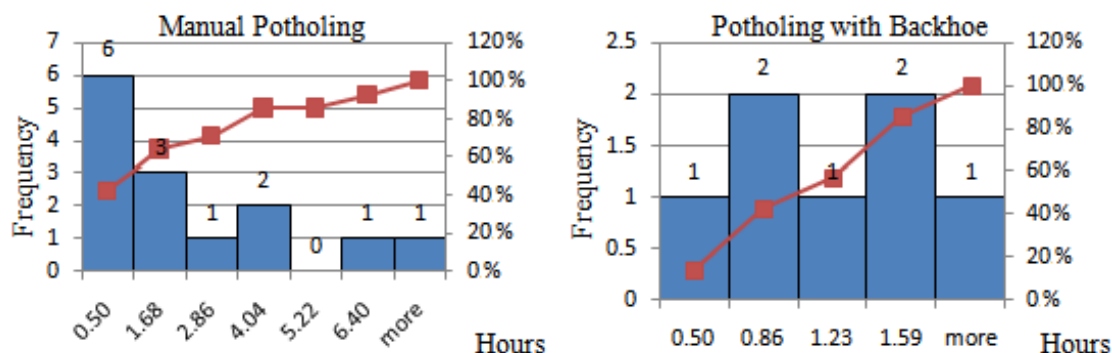


Figure 5-5 Duration of Potholing

The reader must take in account that neither the tendency of manual potholing nor potholing with backhoe discriminates the volume of each pothole or the size of the crew that was working. The histogram shown in Figure 5-6 does not discriminate the brand of the handhole as well.

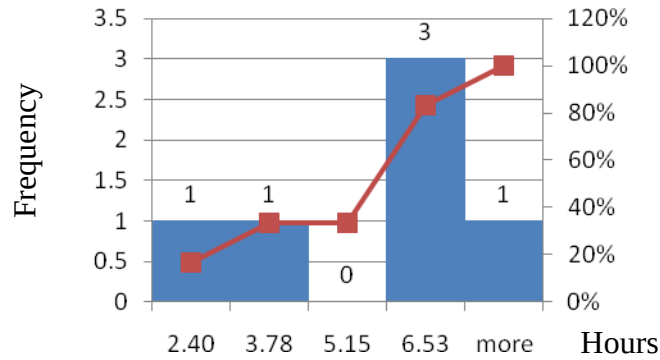


Figure 5-6 Installing Handholes

Duration is affected by the amount of work needed for such activities. As explained before, most of the activities done at Mitchell Street trial and Davis Drive trial did not have the same quantity; therefore, a set of histograms of speed of the process in feet per hour were developed.

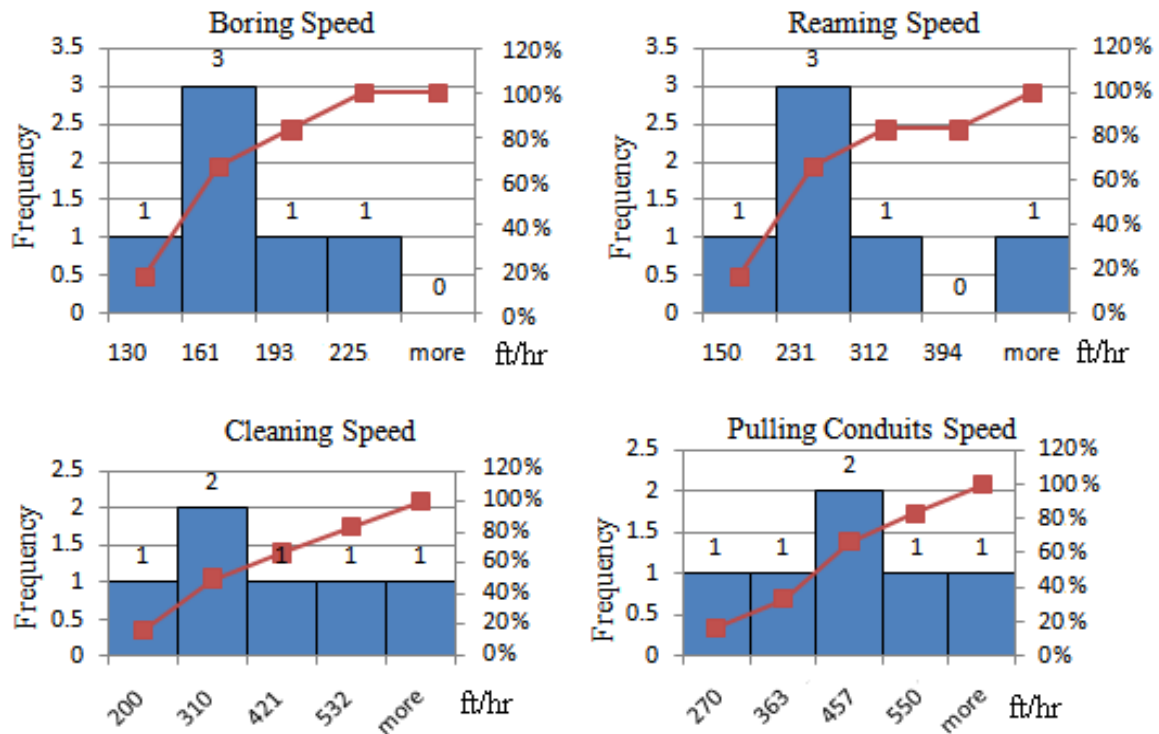


Figure 5-7 Speed Distributions of Major Activities

5.4.2. Productivity Frequency Histograms

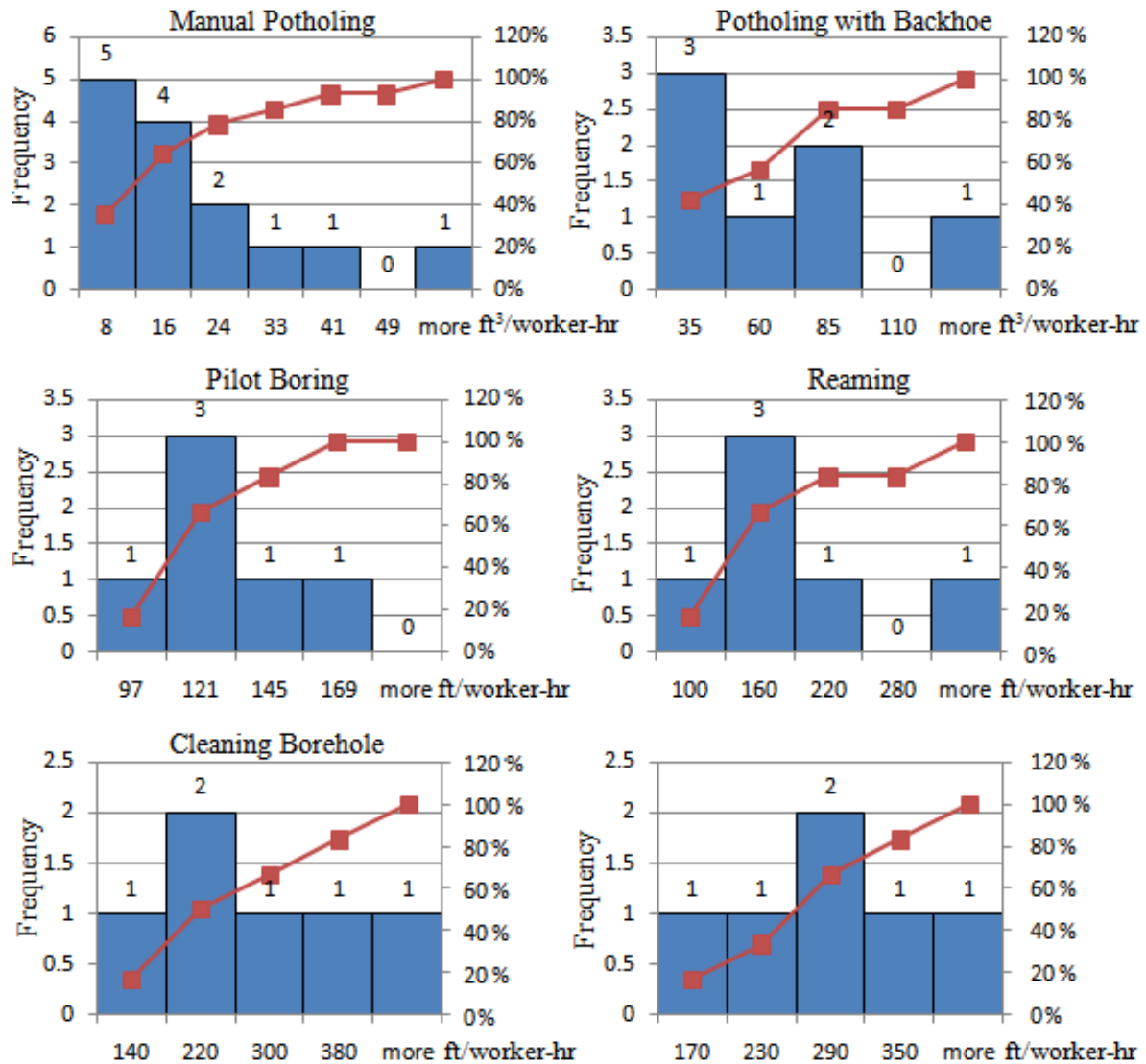


Figure 5-8 Productivity Distributions for Major Activities

5.5. Summary

This chapter stated the results of the field trials and proved the feasibility of the BDN system using mini-HDD. A chronological list of events as well as the list of resources used by either the contractor or the supplier governs the first part of the chapter. The results of the pullback force and mud pressure analysis using a TensiTrak® unit are also explained. The chapter finalizes showing and explaining a set of histograms developed for the most common tasks during the field trials.

CHAPTER 6

CONCLUSIONS AND RECOMMENDATIONS

6.1. Conclusions

The BDN trials at UT Arlington included conceptually design elements; installed using mini-HDD equipment for the conduits and conventional open cut for the handholes. The flawless flow of the construction activities at UT Arlington testifies to a great understanding that the BDN system using trenchless technology is feasible, from both the engineering and constructability perspectives. Moreover, due to the variety of obstacles encountered while installing the conduits at UT Arlington and their similarity to any residential area, it is proper to estimate the viability of the BDN system in any residential or commercial environment, including roads or highways.

The full scale trials at UT Arlington served as a test to identify better construction practices for BDN, especially when using trenchless technology. Most of the construction issues encountered during these trials are inherent to trenchless construction nature; for instance, the drilling speed for Mitchell Street trial was higher than the installation speed of South Davis Drive trial due in part to hard layers of soil encountered. Unexpected hard layers of soil are not uncommon in any mini-HDD project and may delay the installation of conduits. Also the clogging of the reamer openings for the drilling fluids is identified as a construction issue and a risk in any BDN project using mini-HDD, because it in part, it led to the rupture of a water pressure lateral at South Davis Drive.

Due to the good acceptance of the BDN system among utilities and to the successfulness of the BDN trials at UT Arlington, an ASCE manual of practice is being prepared under the title: “Below ground Pipeline Networks for Utility Cables” - *ASCE Manuals and Reports on Engineering Practice No. 118*. Research papers, journal articles and presentations are also in the agenda to explain and expand the knowledge in this area among the academy and the industry.

6.2. Recommendations for Future Study

When using trenchless technology for installing the BDN system, a careful investigation of the soil conditions or a time allowance must be encouraged in order to reliably forecast the total duration of the project. The use of a pullback and pressure monitoring system in the pullback operations is also recommended, because it gives the engineer or contractor on site a tool to verify the pullback force and prevent any issues that may arise.

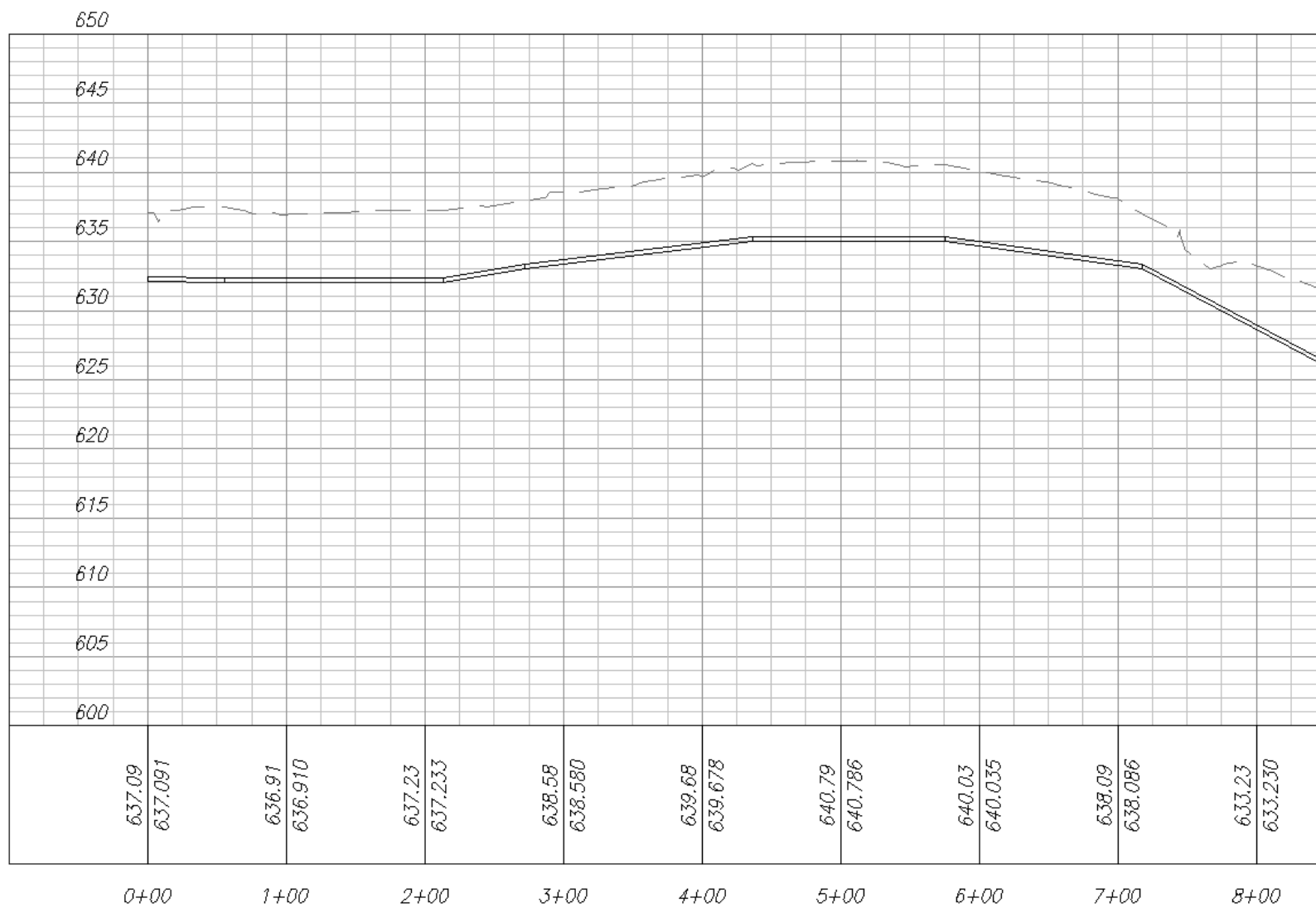
Because BDN is intended to be used by contractors all over the U.S. and in different site conditions, it is recommended for other similar research projects, an investigation on the suitability of HDPE or other conduit materials in the BDN concept as well as longer installation runs. This analysis will provide to the contractors a set of conduit materials suitable for the BDN system, reducing the bias towards fused PVC pipes. A comparison of life cycle cost which includes social, operation and maintenance costs between the BDN system and the conventional buried cables would further demonstrate benefits of the BDN system. It is also important to conduct a market analysis of BDN for different types of utility systems. A research study to compare the feasibility, cost, and duration between open-cut and trenchless methods for the BDN system is particularly recommended. This proposed research study may include a construction productivity comparison, a total cost of the project comparison with a special attention to traffic disturbance and social costs.

CHAPTER 7

REFERENCES

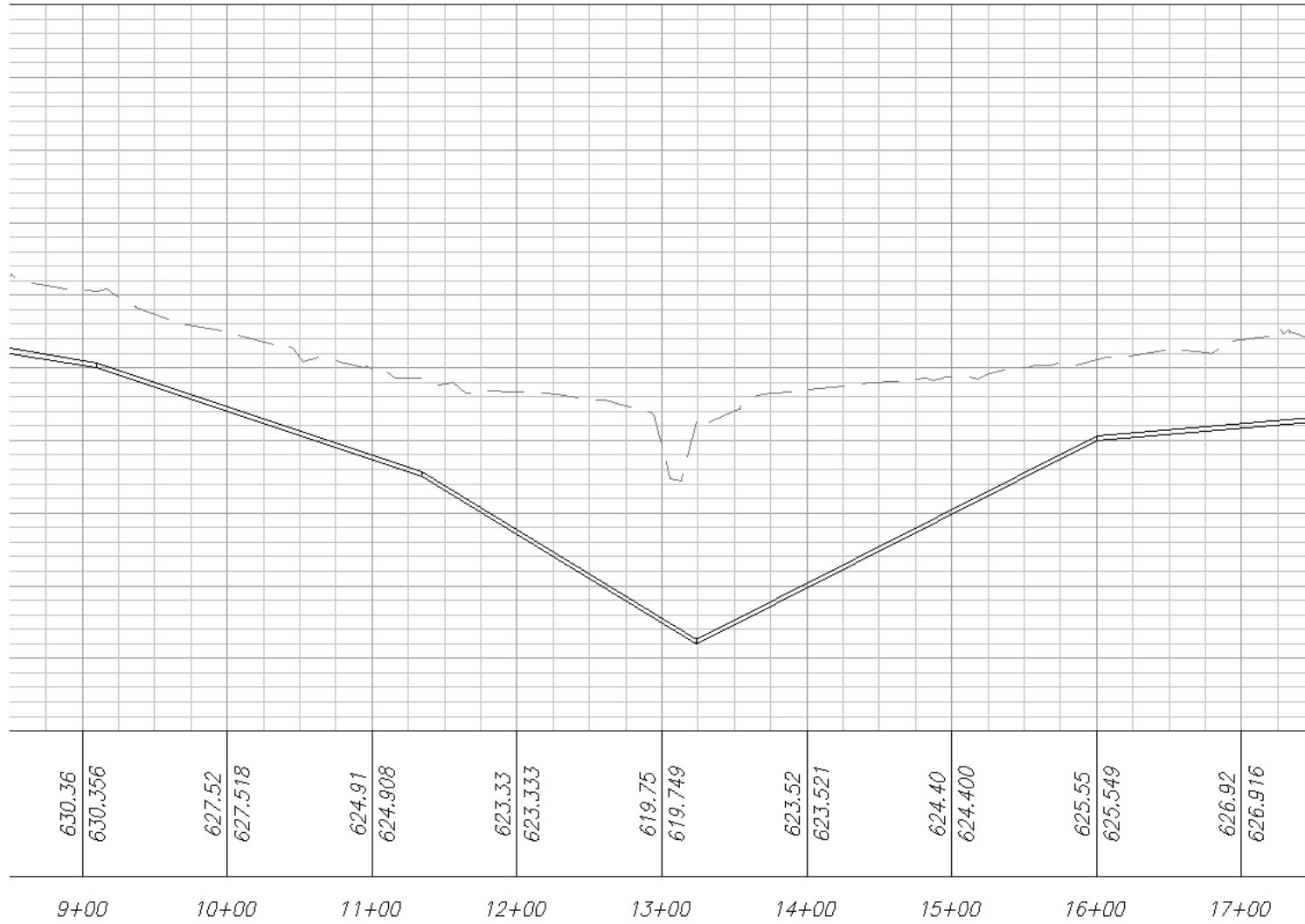
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Appendix A: SURVEYING RESULTS



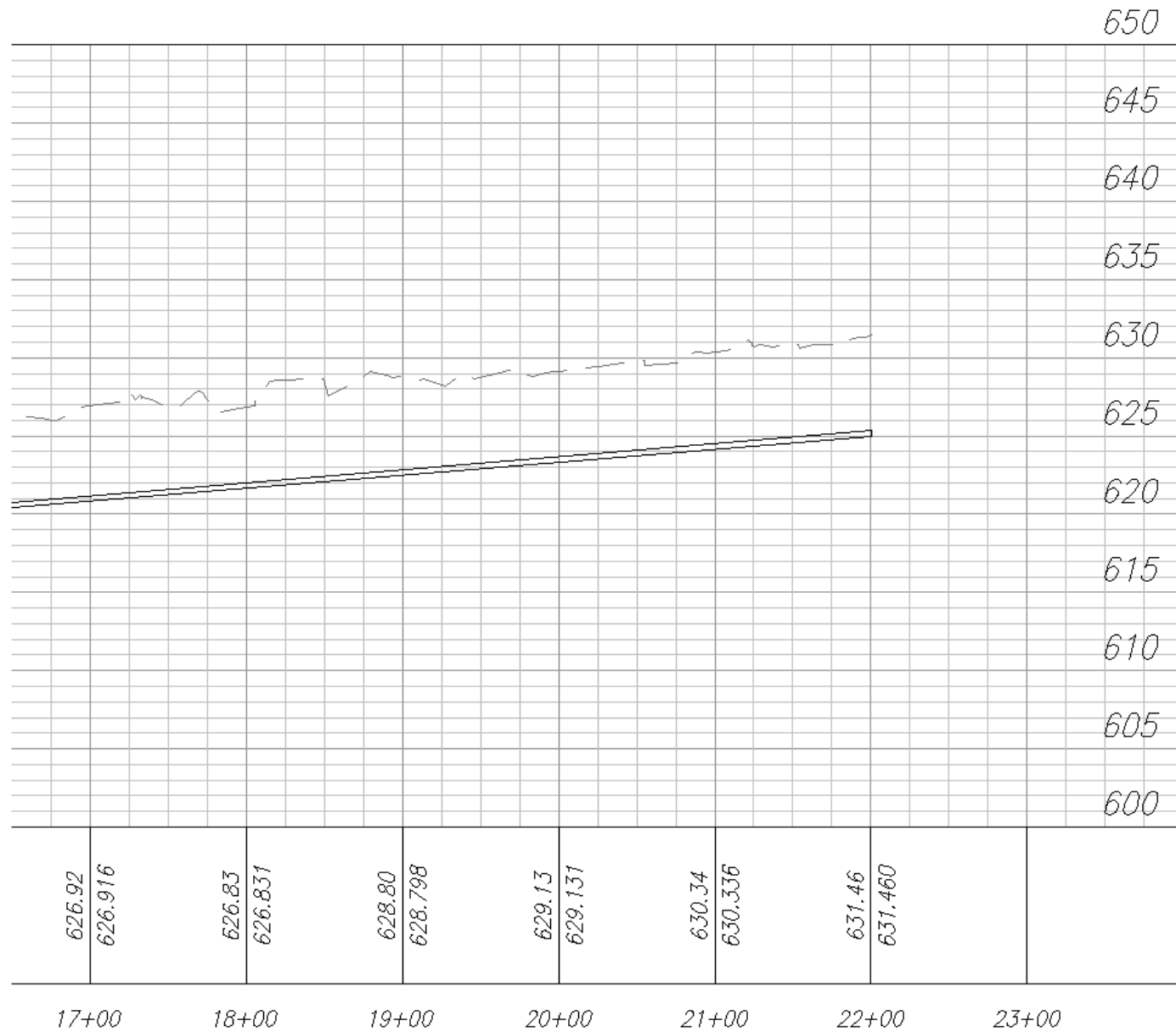
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SEE SHEET 2.2

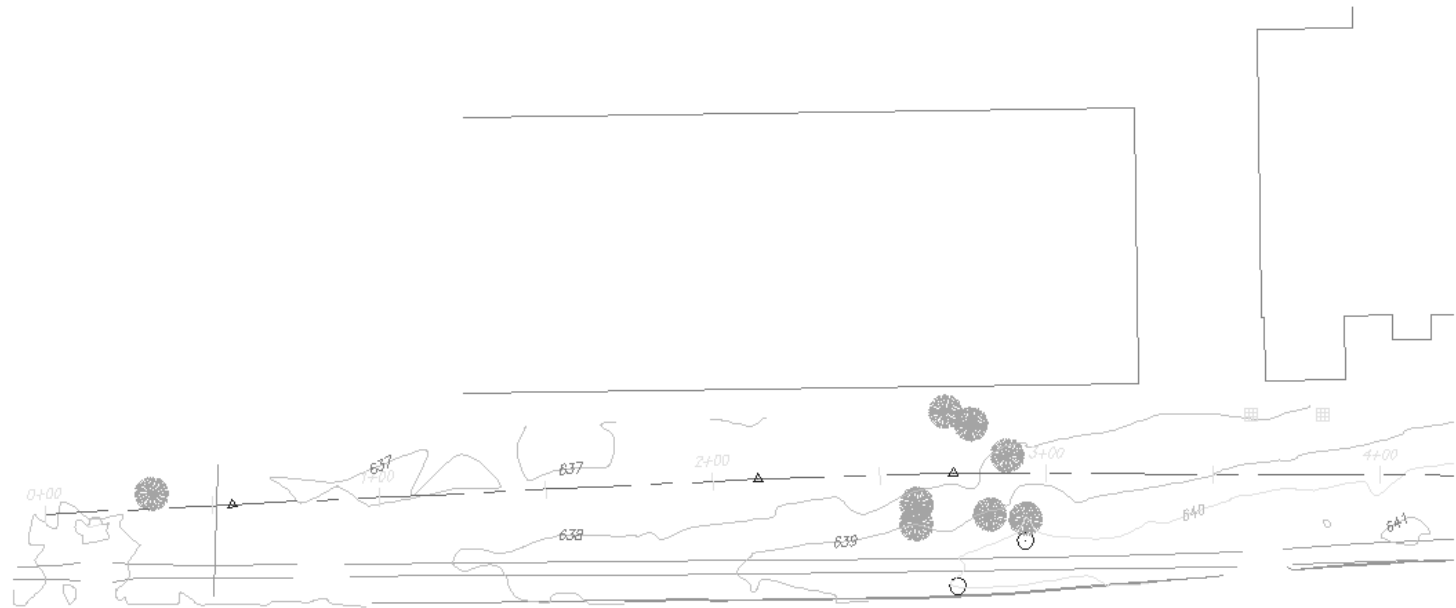
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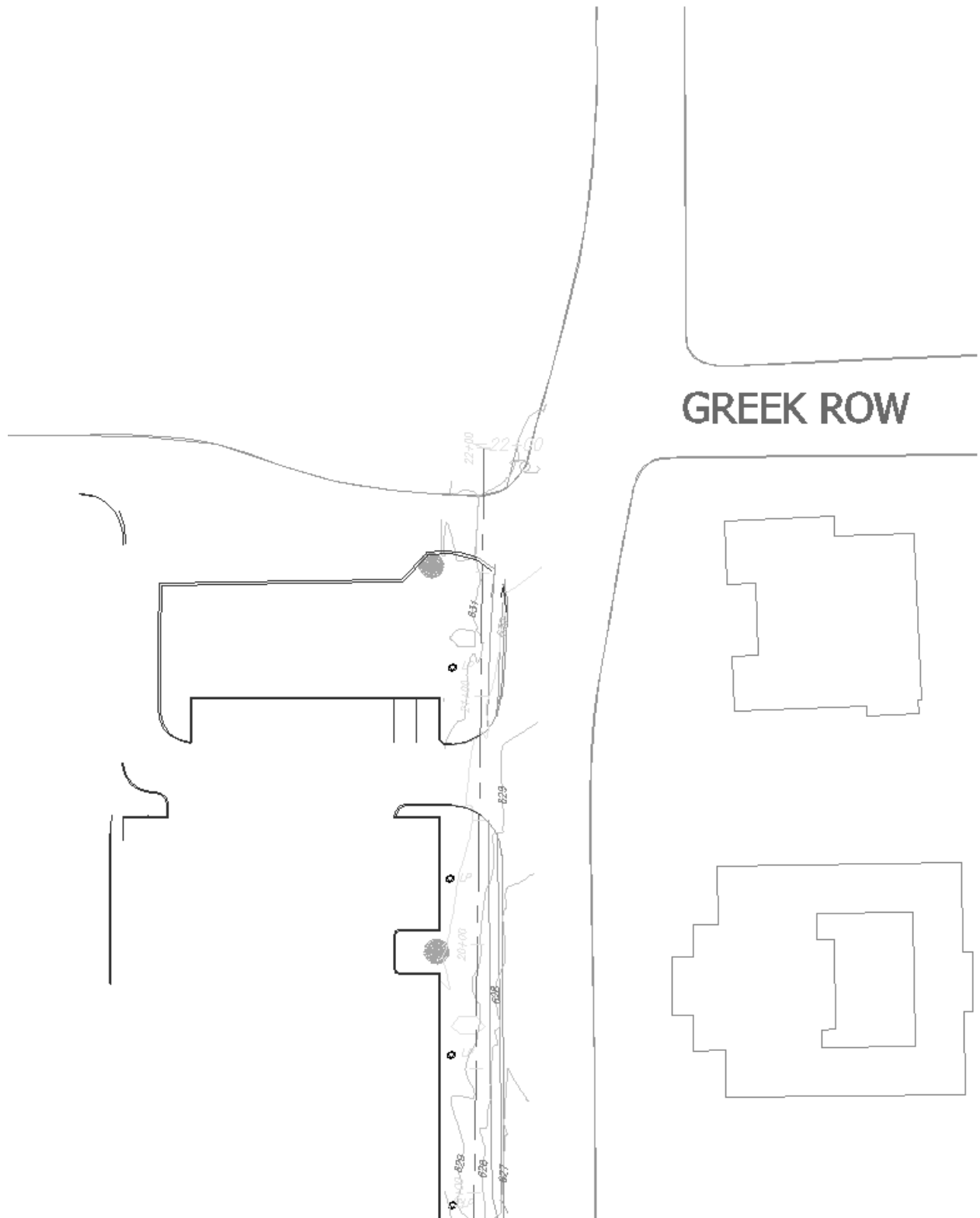
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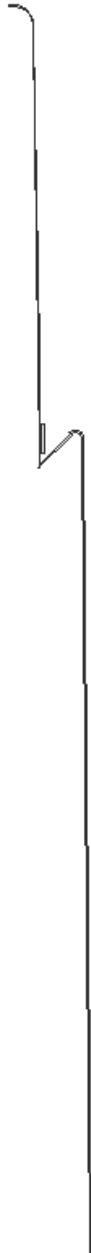
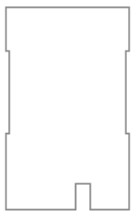
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SEE SHEET 2.2





W MITCHELL

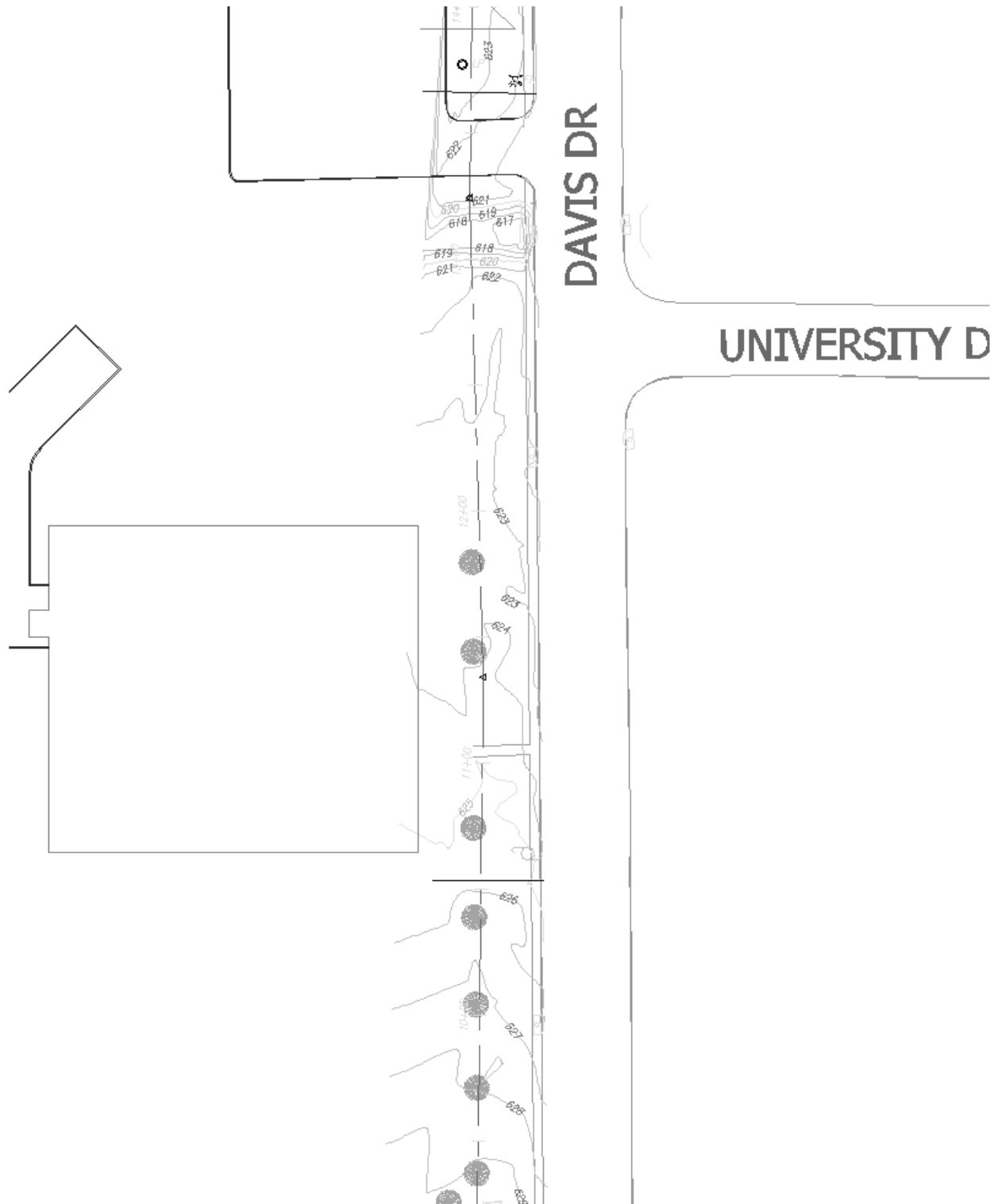


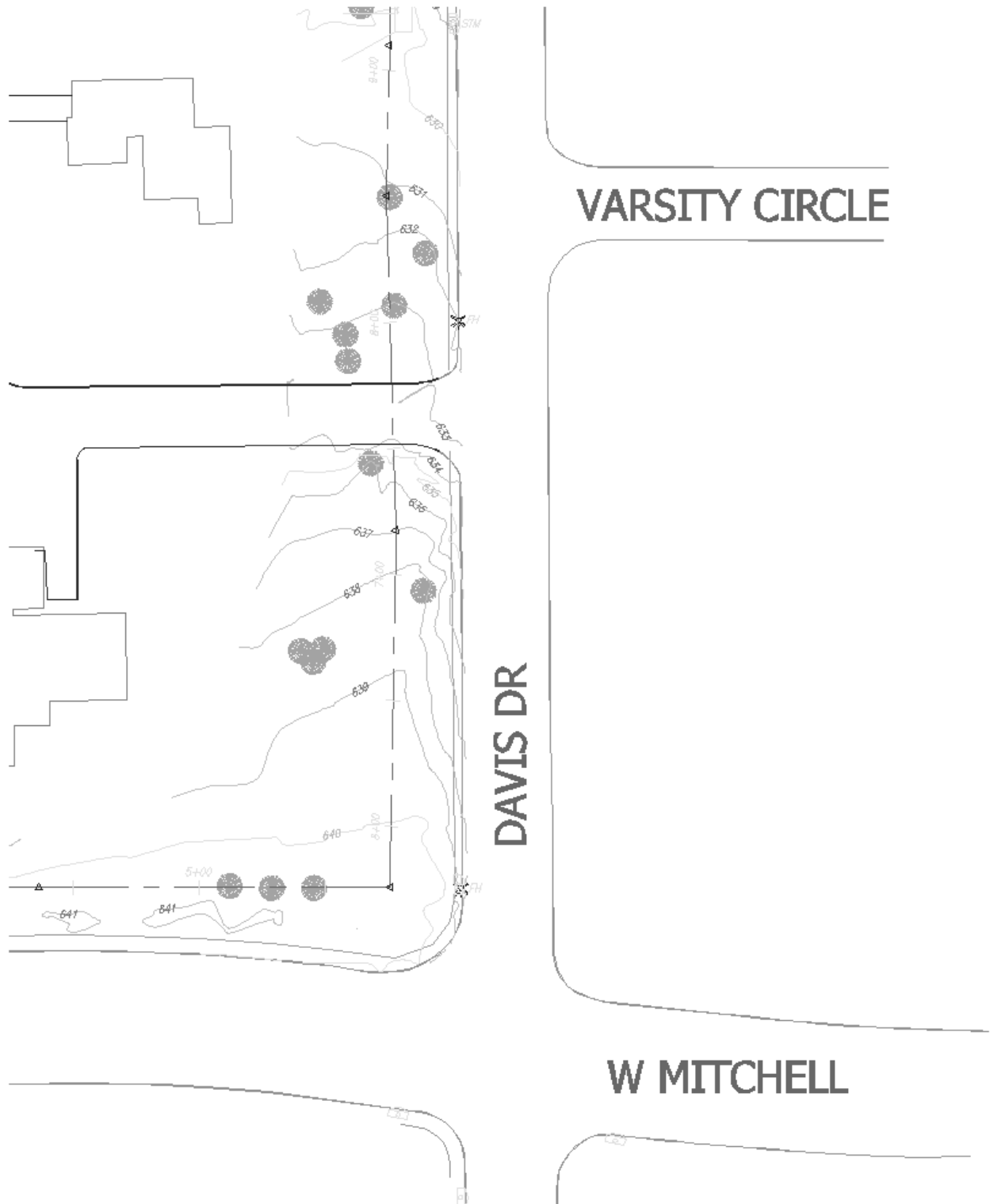


DAVIS DR

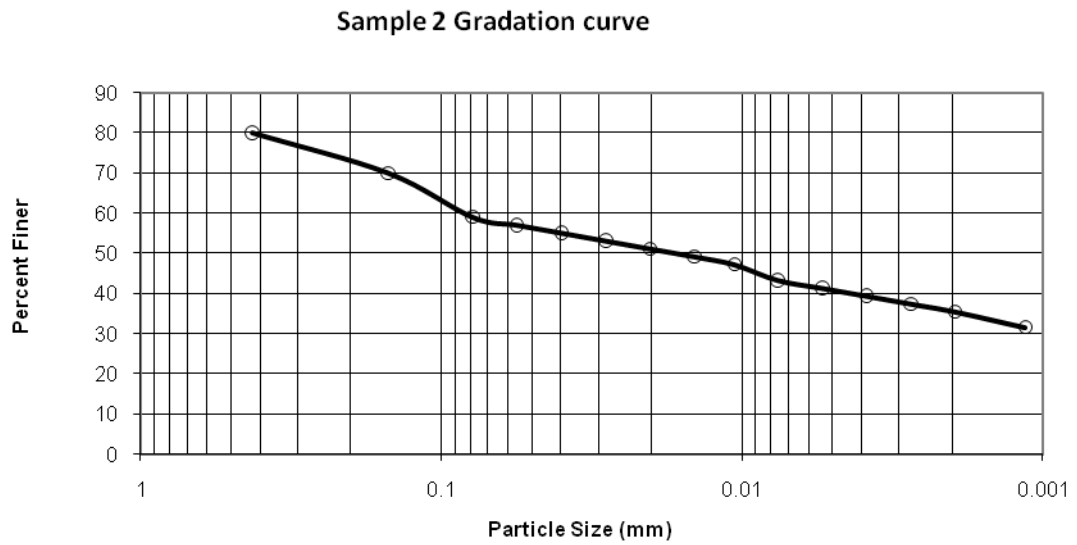
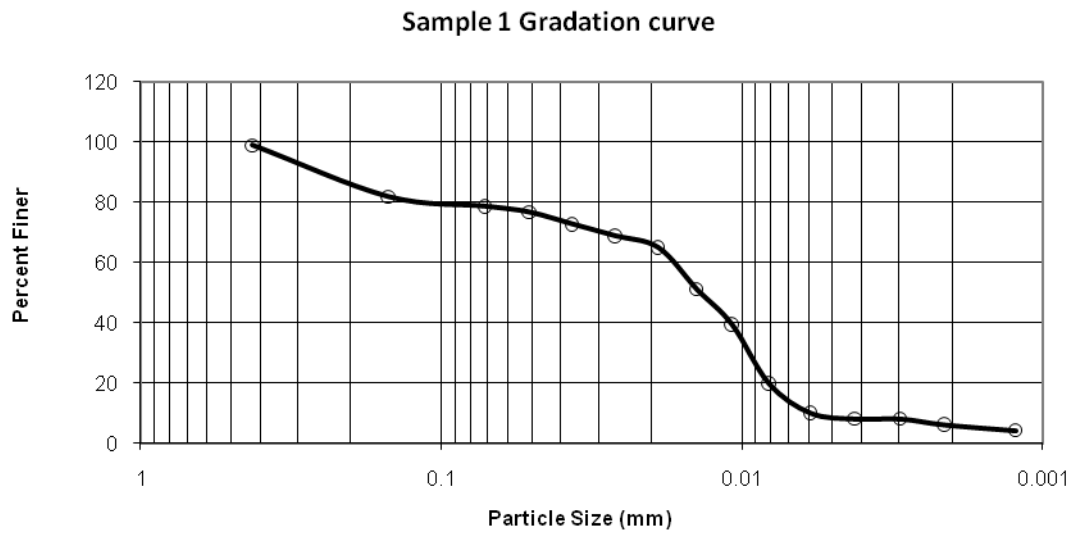
W FOURTH ST



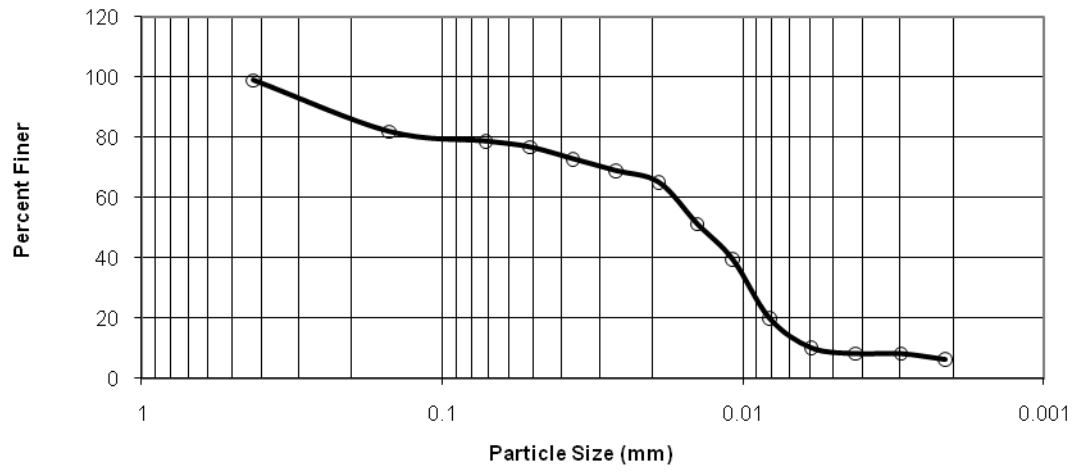




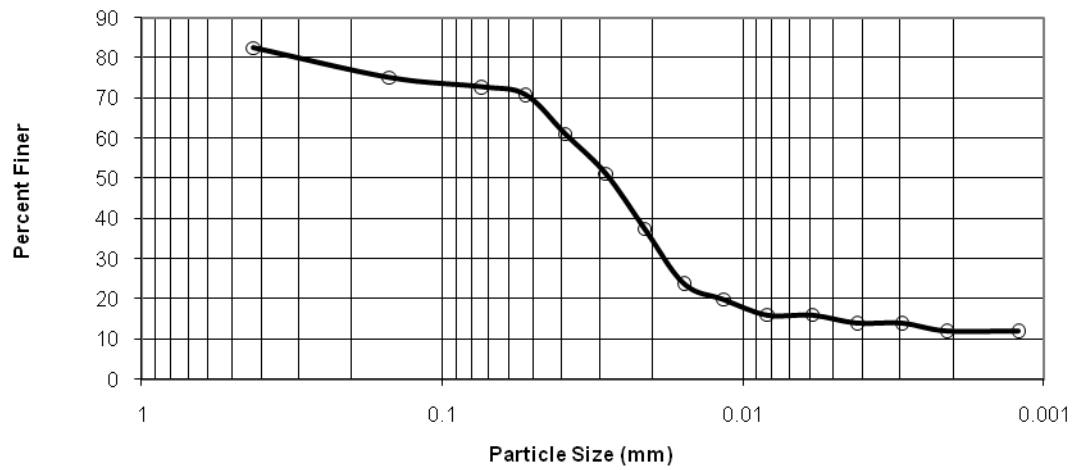
Appendix B: GRADATION CURVES



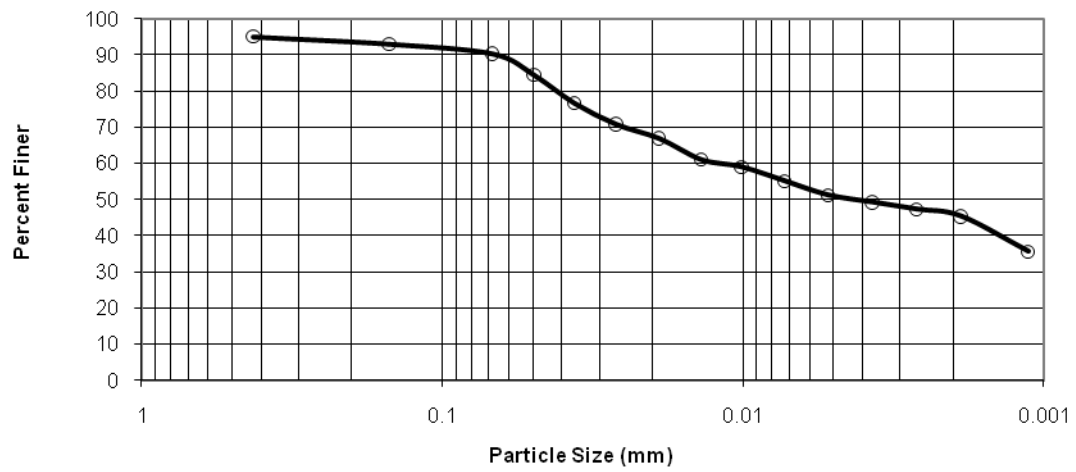
Sample 3 Gradation curve



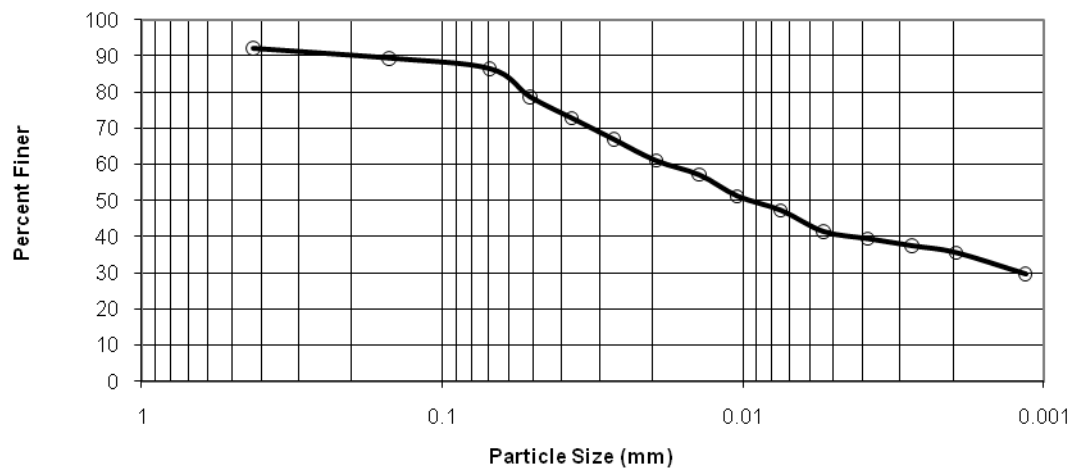
Sample 4 Gradation curve



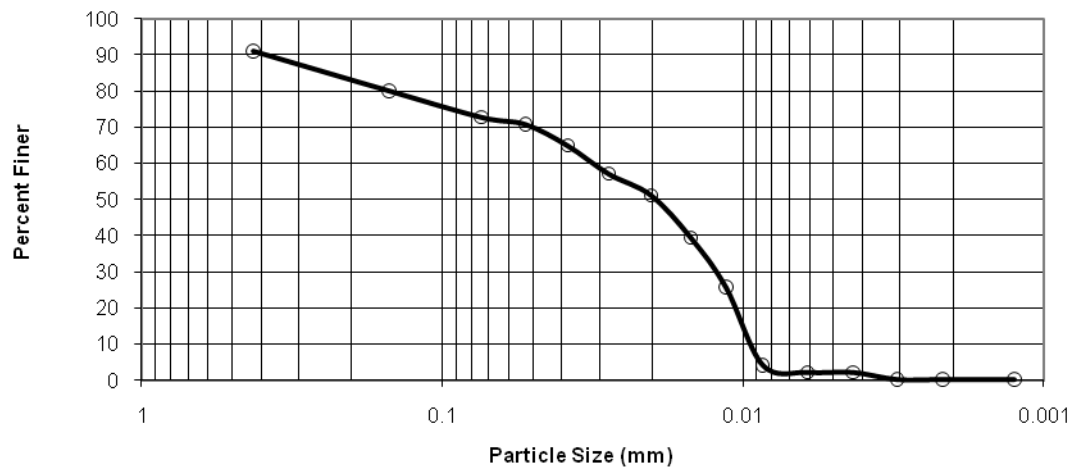
Sample 5 Gradation curve



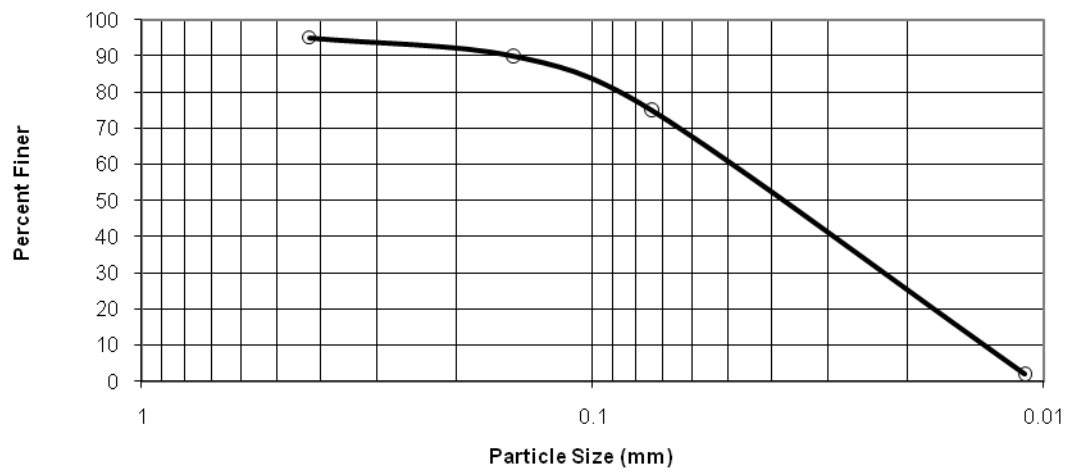
Sample 6 Gradation curve



Sample 7 Gradation curve



Sample 8 Gradation curve



Appendix C: PRODUCTIVITY CALCULATION TABLES

Table C-0-1 Manual Potholing Production

Date	Crew	Time	Total time	Quantity	Productivity
		Crew Hrs	Man Hrs	Cubic FT	Cubic FT/Man Hr
28-Oct	3	0.08	0.25	0.38	2
29-Oct	3	0.22	0.65	0.38	1
29-Oct	3	2.82	8.45	57.04	7
30-Oct	2	7.17	14.33	40.50	3
30-Oct	2	0.17	0.33	10.00	30
31-Oct	3	2.88	8.65	50.00	6
6-Nov	2	0.33	0.67	33.00	50
6-Nov	2	1.17	2.33	51.00	22
7-Nov	2	0.50	1.00	10.80	11
10-Nov	1	5.25	5.25	60.00	11
10-Nov	3	1.00	3.00	50.00	17
11-Nov	3	0.55	1.65	20.00	12
11-Nov	3	3.00	9.00	112.50	13
12-Nov	2	0.22	0.43	15.00	35
Average	2	1.81	4.00	36.47	15.50
Standard Deviation	1	2.17	4.43	30.46	14.09

Table C-0-2 Potholing with Backhoe Production

Date	Crew	Time	Total time	Total	Quantity	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs	Cubic Ft	Cubic Ft/Hr	Cubic Ft/Hr	Cubic Ft/Hr
30-Oct	2	0.47	0.93	0.47	45	48	96	72
31-Oct	3	1.92	5.75	1.92	75	13	39	26
31-Oct	2	1.02	2.03	1.02	168	83	165	124
4-Nov	3	1.40	4.20	1.40	168	40	120	80
10-Nov	2	0.83	1.67	0.83	40	24	48	36
12-Nov	2	0.78	1.57	0.78	30	19	38	29
12-Nov	3	1.33	4.00	1.33	70	18	53	35
Average	2	1.11	2.88	1.11	85.14	34.93	79.94	57.44
Standard Deviation	1	0.48	1.78	0.48	58.81	24.59	48.86	36.34

Table C-0-3 Pilot Bore Drilling Production

Run	Crew	Time	Total time	Total	Quantity	Speed	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs	Ft	ft/hr	Ft/Man - Hr	Ft/Man - Hr	Ft/Man-Hr
Run 1	2	2.68	5.37	2.68	380	141.615	71	142	106
Run 3	2	3.43	6.87	3.43	335	97.573	49	98	73
Run 4	2	1.75	3.50	1.75	250	142.857	71	143	107
Run 5	2	2.02	4.03	2.02	340	168.595	84	169	126
Run 6	2	2.25	4.50	2.25	350	155.556	78	156	117
Run 7	2	1.33	2.67	1.33	300	225.000	113	225	169
Average	2	2.24	4.49	2.24	325.83	155.20	77.60	155.20	116.40
Standard Deviation	0	0.74	1.48	0.74	45.21	41.74	20.87	41.74	31.30

Table C-0-4 Reaming Production

Run	Crew	Time	Total time	Total	Quantity	Speed	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs	Ft	ft/hr	Ft/Man-Hr	Ft/Man-Hr	Ft/Man-Hr
Run 1	2	1.30	2.60	1.30	380	292.308	146	292	219
Run 3	2	2.08	4.17	2.08	335	160.800	80	161	121
Run 4	2	0.55	1.10	0.55	250	454.545	227	455	341
Run 5	2	2.12	4.23	2.12	340	160.630	80	161	120
Run 6	2	2.22	4.43	2.22	350	157.895	79	158	118
Run 7	2	2.33	4.67	2.33	300	128.571	64	129	96
Average	2	1.77	3.53	1.77	325.83	225.79	112.90	225.79	169.34
Standard Deviation	0	0.70	1.40	0.70	45.21	125.92	62.96	125.92	94.44

Table C-0-5 Cleaning with Reamer Production

Run	Crew	Time	Total time	Total	Quantity	Speed	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs	Ft	ft/hr	Ft/Man-Hr	Ft/Man-Hr	Ft/Man-Hr
Run 1	2	0.75	1.50	0.75	380	506.667	253	507	380
Run 3	2	1.33	2.67	1.33	335	251.250	126	251	188
Run 4	2	2.02	4.03	2.02	250	123.967	62	124	93
Run 5	2	0.60	1.20	0.60	340	566.667	283	567	425
Run 6	2	1.00	2.00	1.00	350	350.000	175	350	263
Run 7	2	1.05	2.10	1.05	300	285.714	143	286	214
Average	2	1.13	2.25	1.13	325.83	347.38	173.69	347.38	260.53
Standard Deviation	0	0.51	1.01	0.51	45.21	165.18	82.59	165.18	123.89

Table C-0-6 Pulling 2 PVC Conduits Production

Run	Crew	Time	Total time	Total	Quantity	Speed	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs	Ft	ft/hr	Ft/Man-Hr	Ft/Man-Hr	Ft/Man-Hr
Run 1	4	0.77	3.07	0.77	380	495.652	124	496	310
Run 3	4	0.58	2.33	0.58	335	574.286	144	574	359
Run 4	5	0.72	3.58	0.72	250	348.837	70	349	209
Run 5	4	0.75	3.00	0.75	340	453.333	113	453	283
Run 6	3	0.83	2.50	0.83	350	420.000	140	420	280
Run 7	4	1.50	6.00	1.50	300	200.000	50	200	125
Average	4	0.86	3.41	0.86	325.83	415.35	106.76	415.35	261.06
Standard Deviation	1	0.33	1.34	0.33	45.21	129.59	38.44	129.59	82.46

Table C-0-7 Installing Handholes Production

Handhole #	Crew	Time	Total time	Total	Quantity	Crew Productivity	Machine Productivity	Average Productivity
		Crew Hrs	Man Hrs	Machine hrs		Handholes/Hr	Handholes/Hr	Handholes/Man-H
6	3	1.67	5.00	1.67	1	0.2	0.6	0.4
1	2	7.17	14.33	7.17	1	0.07	0.14	0.105
4	2	2.50	5.00	2.50	1	0.2	0.4	0.3
5	2	5.50	11.00	5.50	1	0.09	0.18	0.135
3	2	5.92	11.83	5.92	1	0.08	0.17	0.125
2	3	6.50	19.50	6.50	1	0.05	0.15	0.1
Average	2.33	4.88	11.11	4.88	1	0.12	0.27	0.19
Standard Deviation	0.52	2.25	5.59	2.25	0	0.07	0.19	0.13