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EVALUATION OF HORIZONTAL DIRECTIONAL DRILLING (HDD)

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A report of the findings of
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Evaluation of Horizontal Directional Drilling

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16. Abstract

Horizontal Directional Drilling (HDD) is defined as “A steerable system for the installation of pipes, conduits, and cables in a shallow arc using a surfaced launched drilling rig. Traditionally HDD is applied to large scale crossings such as rivers in which a fluid filled pilot hole is drilled without rotating the drill string, and this is then enlarged by a wash over pipe and back reamer to the size required by the product.” (Trenchless Data Service 2000). This technology has been in existence since the 1970’s. It is currently an efficient, safe, cost effective method for highway bores and is the current industry standard for trenchless technology for bores between 2 and 48-inch diameters and 600 ft to 1800 ft in length. However, according to the manual for *Accommodation of Utilities on Right-of-way of the Illinois State Highway System - 1992*, it is currently prohibited under state highways for bores over 6 inces. Bores of greater size must be done by the jack and bore method. The manual is being re-written and will include a provision for an HDD option, but it will not define the parameters under which approval can be granted.

The objective is to study the effects of horizontal directional drilling (HDD) for utilities under pavement and within the right of way of the State of Illinois in order to aide in the writing of the policy and procedures for administering permit requests for HDD. This report covers Phase I of the work described under the scope of work section.

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EXECUTIVE SUMMARY

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ACKNOWLEDGEMENT AND DISCLAIMER

This publication is based on the results of ICT-R27-SP16, **Evaluation of Horizontal Directional Drilling.** ICT-R27-SP16 was conducted in cooperation with the Illinois Center for Transportation; the Illinois Department of Transportation; and the U.S. Department of Transportation, Federal Highway Administration.

The Technical Review Panel Chairperson was Terri Peterson.

The contents of this report reflect the view of the authors, who are responsible for the facts and the accuracy of the data presented herein. The contents do not necessarily reflect the official views or policies of the Illinois Center for Transportation, the Illinois Department of Transportation, or the Federal Highway Administration. This report does not constitute a standard, specification, or regulation.

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SCOPE OF WORK

Horizontal Directional Drilling (HDD) is defined as “A steerable system for the installation of pipes, conduits, and cables in a shallow arc using a surfaced launched drilling rig. Traditionally HDD is applied to large scale crossings such as rivers in which a fluid filled pilot hole is drilled without rotating the drill string, and this is then enlarged by a wash over pipe and back reamer to the size required by the product.” (Trenchless Data Service 2000) This technology has been in existence since the 1970’s. It is currently an efficient, safe, cost effective method for highway bores and is the current industry standard for trenchless technology for bores between 2 and 48-inch diameters and 600 ft to 1800 ft in length. However, according to the manual for *Accommodation of Utilities on Right-of-way of the Illinois State Highway System - 1992*, it is currently prohibited under state highways for bores over 6 inches. Bores of greater size must be done by the jack and bore method. The manual is being re-written and will include a provision for an HDD option, but it will not define the parameters under which approval can be granted.

The objective is to study the effects of horizontal directional drilling (HDD) for utilities under pavement and within the right of way of the State of Illinois in order aide in the writing of the policy and procedures for administering permit requests for HDD.

Consideration should be given to the overall safety, aesthetic quality, costs and difficulty of construction and maintenance of both the utility facility and the highway.

The economic savings is primarily for the utility. The Federal Highway Administration (FHWA) generally encourages the Illinois Department of Transportation (IDOT or Department) to consider cost savings for the utility as a cost savings for the taxpayer. In some instances, if the purpose of the bore is for a reimbursable relocation, the department has a direct savings as well.

HDD should provide less damage to the right of way, since it requires smaller bore pits or open trenches. It would allow the utility to be placed under trees, rivers, concrete drives, sidewalks, pavements and buildings as well as roadways.

It should provide for improved safety of the traveling public as most of the work can be done off right of way, more quickly and with less manpower and equipment.

It should improve maintenance since the HDD installed facilities are generally deeper, thus reducing the chances the lines will be hit by IDOT’s maintenance crews. Additionally, it should reduce the number of relocations for future roadway expansion, and should provide some additional protection from rupture. However, that is not always necessarily the case as many of the applicants want to go the minimum required depth required.

SUPPORTING RESEARCH

There are numerous technical documents on the procedure of directional drilling. One of the most comprehensive is the study by Purdue University for the Civil Engineering Joint Transportation Research Program in 2002, “Development of a Decision Support System for Selection of Trenchless Technologies to Minimize Impact of Utility Construction on Roadways”. The main limitation of this study, however, is that it provides a general overview for the decision-making among types of trenchless technology based on size and length of pipe. It does not specifically address any procedural parameters or potential dangers to roadways.

Plan of Study:

Phase I:

1. Paper research to develop general information, comparison study to Jack and Bore method and recommendations on the following:
   a. Cost comparison of directional drilling compared to Jack and Bore.
   b. Horizontal and vertical location requirements and clearances.
   c. Industry codes and other government regulations or provisions.
   d. Preservation and restoration of highway facilities, appurtenances, natural features, vegetation and limitation on the utilities activities in right of way.
   e. Protection of traffic during and after installation including traffic control, access control, open pits, material storage and vehicle parking, timing of projects, length of time to construct.
   f. Direct and indirect environmental and economic effects including loss or impairment of productive agricultural and liabilities associated with future relocations.
2. View a directional drill for a larger size pipe to get a feel for the process and evaluate for possible conflict of interest.
3. Establish preparatory information to continue in Phase II:
   a. Recommendations on what should be studied.
   b. A listing of possible damage to roadway.
   c. A preliminary decision and the viability of the method and its possible restrictions.
   d. Procedures for the directional bore method to reduce damage to sidewalks and driving pavement.

Phase II:

HDD is done routinely on Illinois right of way for pipes and casings under 6 inches. There are many places where IDOT has experimented with larger pipes and IDOT staff have observed many larger installations under rivers and non-state roadways.

Mathematical, theoretical or actual physical testing of to resolve the following:

- How much bigger the borehole should be than the pipe. Some industry papers recommend 1.5x the pipe diameter. There is a chart in another document that strays from this. For jack and bore, the borehole diameter can only be 1 inch larger than that of the pipe being installed. This can become problematic for very large bores and for bores over very large distances. The results of too small a hole include hydraulic build up and the "locking" of the pipe, Bentonite being pushed through the pavement and pavement buckling.

- The angle of curvature allowed for various pipes or a mathematical ways of determining that. The "long sweeping arc" can be the deciding factor in the pressures exerted on the pavement and on the long-term viability of the pipe, yet there is very little advice as to how to properly evaluate the risks based on the arc.
- Type of casing – steel welded, HDPE, PVC chemically welded**,** and Certa-Lok Yelomine. IDOT specifications say only that it must be continuous pipe, which is too vague. Is welded pipe continuous? Is chemically welded continuous?
- Type of pipe – a list of approved pipes for casings and for carrier pipe would be helpful.
- Wall thickness requirements of casing and of carrier pipe .
- Size of pipes to be encased: Currently our spec reads any bore over 6 inches must be encased. There is a discrepancy between districts if 6 inches refers to a hole diameter or a pipe diameter greater than 6 inches. A restriction to a 6-inch hole would mean only 4-inch and smaller pipe would be allowed.
- Location and soil conditions: In one instance where the staff viewed a large HDD, the soil conditions were problematic because of sand lenses causing back reamer "drop". The driller compensated for that by keeping pressure on the reamer from both directions.
- Procedure: some procedural thing might affect the road. Contractors drill through, attach the casing to the reamer head and pull back the casing or they pull back a reamer, and then pull a casing. In between, there is a period of time that leaves a void under the pavement. They are not allowed to leave the void for longer the 24 hours but this length of time is a concern. In cases where large pipes are used, the contractor may use multiple back reams to reach the correct diameter rather than a single, full-size ream. How much should each ream be allowed to increase the diameter of the hole?
- Speed: The speed of the drilling is very important. While IDOT will not govern how fast to go, it should be noted that if the Bentonite waste is getting higher and pushing through the surface, the problem might be speed. Slowing down might remedy the situation and that would be good to know.
- Use of Bentonite: How much? How fast? What issues arise with spilled waste? Should we always require a Benonite?
- If it is necessary to pull back to avoid utilities what should be done about the pull back void?
- Should a survey be conducted in the area before and after all bores? The day of the bore? The day following? If there is a difference then should another survey be done on the location one week later?
- Qualifications of the contractor

CHAPTER 1 INTRODUCTION TO HDD

Horizontal directional drilling (HDD) is a common practice for installing utilities and pipelines under roads or railroad tracks. It is an ideal technology because it does not require large excavation pits nor does it greatly interfere with traffic. When drilling the initial borehole, the drill can be easily tracked and its path altered unlike other trenchless technologies such as jack and bore. HDD is also versatile as it can be used for large diameter pipelines and pipelines spanning a large distance.

1.1 THE HISTORY OF HDD

Martin Cherrington first conceived horizontal directional drilling in the 1960's. He first realized the value of underground drilling when he and another contractor were given the same job: lay down telephone lines in Los Angeles. The only difference was that Cherrington was using an open trench method while the other contractor was using drilling to lay down cables. That contractor arrived two weeks after Cherrington yet managed to finish two weeks before him. This led Cherrington to believe there was merit in looking at underground drilling methods.

In 1964 Cherrington founded Titan Contractors, which specialized in utility road boring. It was an opportune time for the company's formation because of a building boom in Sacramento and a recent "beautification" decree from the First Lady, Lady Bird Johnson. The decree was instated to clean up America by getting rid of utility lines which were an eyesore and hazardous during seismic and extreme weather events. As a solution, Sacramento proposed placing all utilities underground. Despite a favorable environment and HDD's merits, however, other, more familiar, tunneling technologies like jack and bore and auger boring were usually preferred.

One of the main problems was the lack of control when drilling. It was often very difficult to make a straight bore, and the drill bit would resurface in unexpected places (like the middle of the road). Cherrington realized a solution when an engineer from P G& E invited him to consider a project for placing a gas line underneath the Pajaro River. The project would require drilling underneath the river, and the variability of the drill bit's direction would make it challenging. To find a solution, Cherrington experimented with angled bores on a similar river, trying several different angles. He observed that the steeper the angle of the bore, the greater the achieved distance. This relationship between angle and distance helped prove that with "optimum entry angle, proper drilling techniques and the right downhole tool assembly" (Cherrington) HDD could be used to cross a river. Since then, familiarity with HDD has increased, and it has become a much more routine method for projects requiring a non-evasive boring solution.

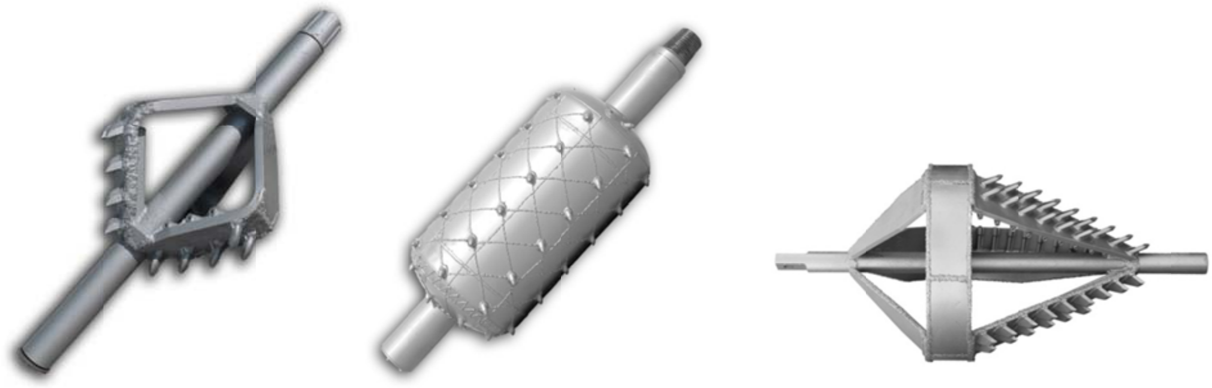
1.2 THE PROCESS

The process of horizontal directional drilling begins with a topographic survey of subsurface conditions. This helps identify the locations of underlying utilities and the soil conditions at the site. The survey also helps determine a drill path and its entry and exit and trajectory.

Once a thorough survey is a complete the HDD site can be set up. A typical HDD site is shown in Figure 2. The site consists of the drill rig, a solids control system and a drilling mud system. The solids control system is responsible for any soil excavated in the drilling process, which can potentially be placed back in the bore once drilling is finished. The drilling mud system is an important aspect of any horizontal drilling project. Drilling mud helps wash away cuttings from the bore and eases the movement of the cutting head through the borehole.

Bentonite is the clay mineral montmorillonite, which increases greatly in surface area when water mixed with water. It is a component of the overall drilling fluid. When drilling a borehole, drilling fluid tends to seep out through the soil walls. Bentonite forms a casing on the borehole walls, which prevents the drilling fluid from seeping out. This wall is commonly called a “filter cake”. The ideal filter cake forms fast, is slick and is tough. Drilling fluid must also have a carrying capacity or “gel strength.” Gel strength is the ability of the fluid to suspend, support and transfer cuttings. The ideal drilling fluid is highly dependent on the geology of the area. This again stresses the importance of a thorough field survey before any work actually begins.

Reamers can vary in size and shape depending on the geology it will be used on. Figure 1 shows three reamers that are commonly used: blade reamers, barrel reamers, and fly cutter reamers.



(a) blade reamer (b) barrel "beaver tail" reamer (c) fly cutter reamer

Figure 1. Reamer configurations used in HDD

A big advantage of HDD is the ability to monitor the movement of the reamer and redirect it throughout the bore. Before any drilling occurs, a foresight bearing is taken to determine the Azimuth bearing to be followed during the crossing. The steering tool is laid at the entrance point and a transit is used to determine the heading. The information is placed in a directional program on a computer to enhance the accuracy of the sensor measurements. (Cherrington et al). This process is illustrated in Figure 3. During the bore, the steering tool is attached to a non-magnetic collar as close to the drill bit as possible, as shown in Figure 4. The steering tool allows for any necessary changes to the bore path.

After the drilling fluid is mixed, the drill bit attached, and the foresight bearing established, the drilling can begin. There are three phases in an HDD bore. The first phase is a pilot hole, which is smaller than the reamer diameter. The pilot hole creates a path from the entry pit to the receiving pit.

The next phase is reaming, which enlarges the hole and prepares it for the pipe or casing installation. More than one reamer size may be used. Multiple passes from entry pit to receiving pit may be made as well. This phase can employ either forward reams or pull reams, as shown in Figure 5. During this process, an Azimuth bearing is used to keep track of the location of the bore, as shown in Figure 6.

The final phase is pipe pullback, where the pipe or pipe casing is attached to the reamer and pulled through the HDD borehole by the drilling machine. Sometimes a backhoe is used to help push the casing and the pipe through the borehole. After the pipe or pipe casing is installed, it is connected to the utility source (water main, electricity etc.) All pits are backfilled and the site is returned to its pre-installation condition.

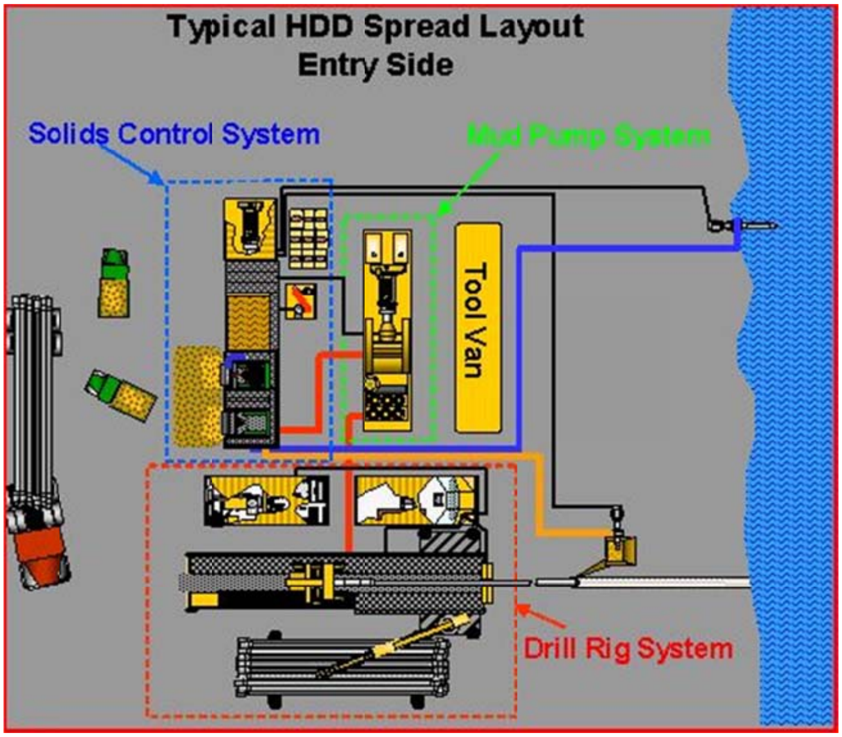


Figure 2. Typical HDD layout, entry side (Cherrington et al).

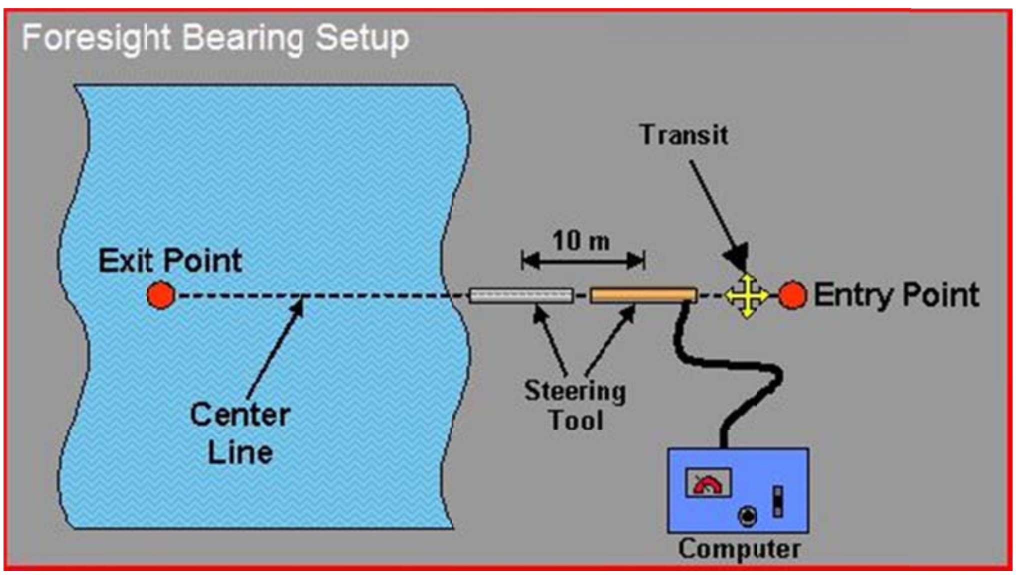


Figure 3. Foresight bearing setup (Cherrington et al).

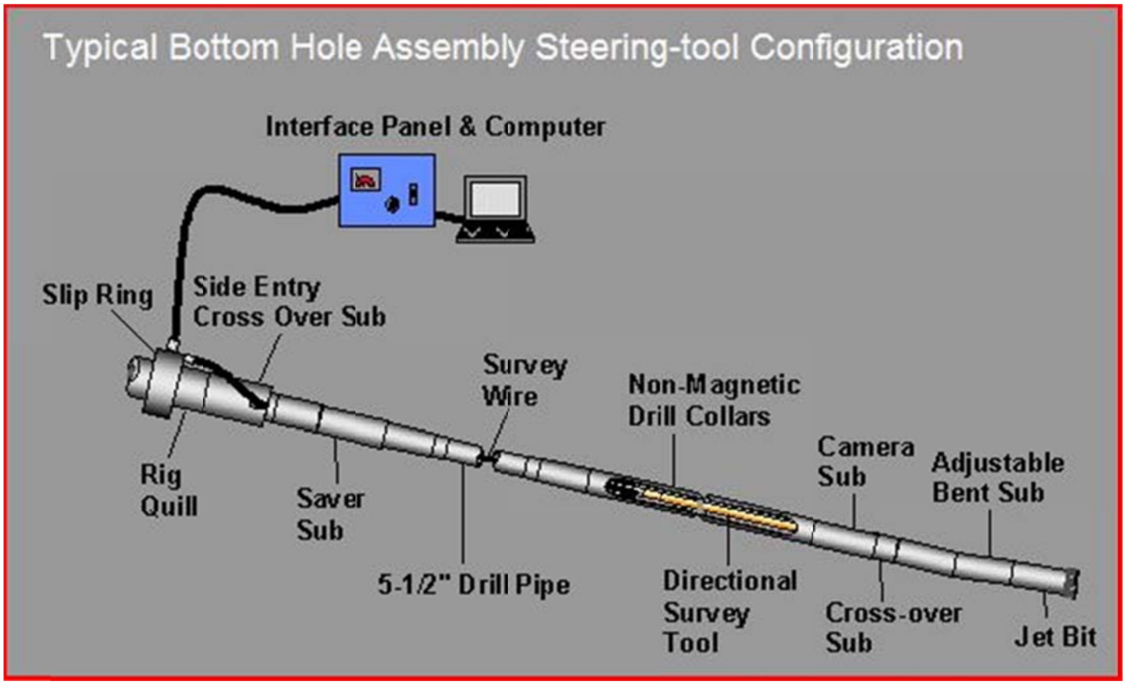


Figure 4. Bottom hole assembly steering tool configuration (Cherrington et al).

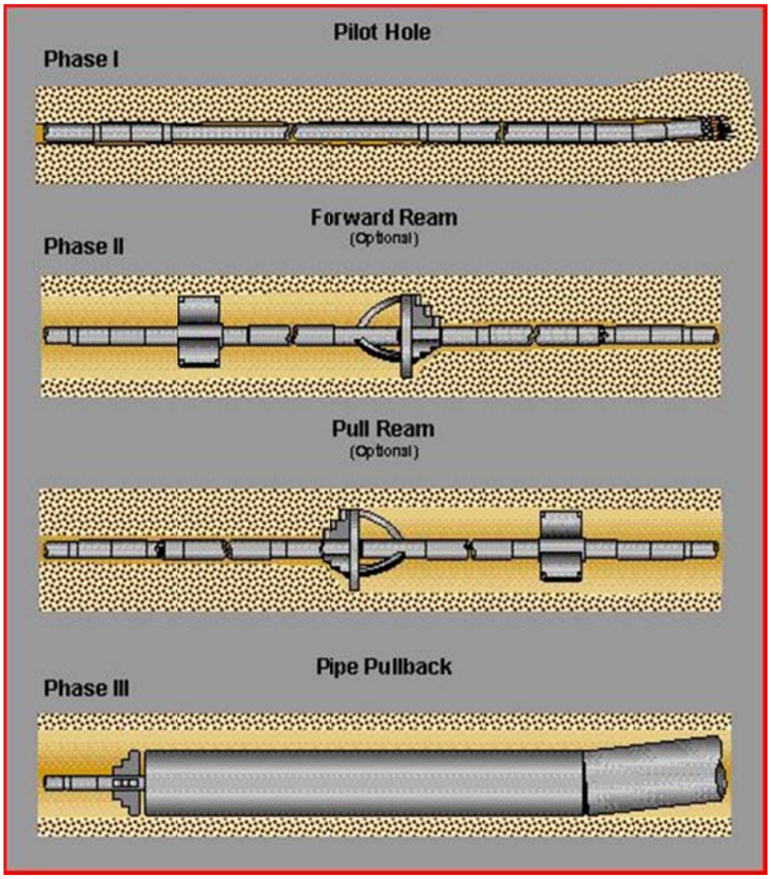


Figure 5. Three phases of HDD drilling. (Cherrington et al)

Figure 6. Tracking device to detect location of reamer within the bore.

1.3 COMPARISON TO OTHER TRENCHLESS TECHNOLOGIES

The other common trenchless technology is a process called “jack and bore” or “pipe ramming”. In jack and bore, a drive pit (Figure 7) and exit pit are excavated and a pneumatic tool and a pipe section are placed in the into the drive pit. The ramming tool is connected to the pneumatic tool and it is used to drive or hammer the pipe section into the soil. After the first pipe section is driven, a second pipe section is welded onto the first and driven into the soil as well. This process continues until the full length of pipe is installed. An auger or vacuum excavator is used to remove the soil inside the pipe.

Jack and bore is used for pipe lengths up to 250 feet (76 m) and is typically used for large diameter pipes. Jack and bores is usually closer to the ground surface than HDD due to the need for large driving and exit pits. Most of the jack and bore process is controlled by its initial setup. The drill path must be carefully planned to avoid critical mistakes. For HDD, the drill path can be adjusted during the drilling process. HDD also does not require the excavation of large drive and exit pits, which makes the process less invasive.

The pros of HDD, when compared to other trenchless technologies, include short setup times due to lack of vertical shafts, long drive installation lengths, possible horizontal and vertical alignment shifts, its ability to move around buried obstacles and its versatility with different topographies or geologic conditions. HDD can be used in underwater environments with saturated soils, soils below permafrost, and even in soils susceptible to landslides and erosion.

The cons of HDD are essentially the same risks posed by any trenchless technology. These risks include the heave or soil collapse and increased cost with difficult geologic conditions. Varying geologic conditions can be a major problem due to the necessary adjustments to the type of bits and reamers being used for installation.

Figure 7. Entrance shaft for a jack and bore operation.

CHAPTER 2 FACTORS CONCERNING HDD

There are several factors to consider when looking at the effects of horizontal directional drilling. A common concern surrounding HDD is settlement or upheaval (Figure 8) at the ground surface due to the boring. In HDD projects, ground movement on the surface is carefully monitored to determine if alterations should be made to the drill path, as it is more economical to prevent problems from arising in the first place.

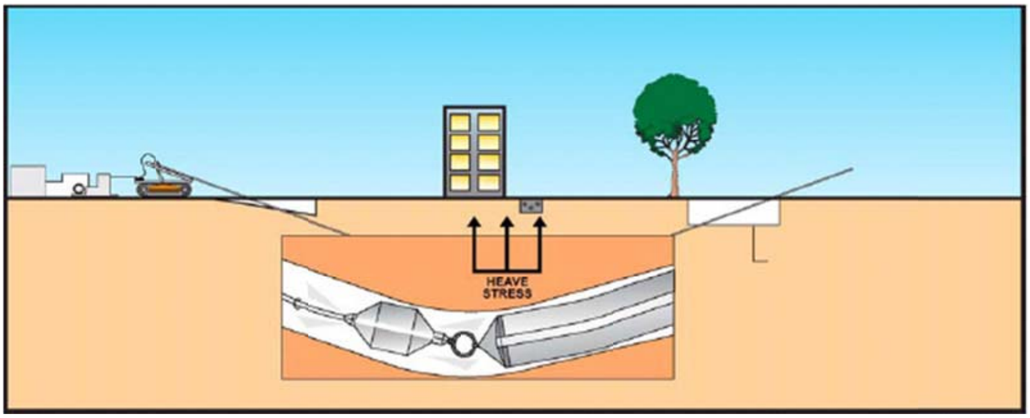


Figure 8. Upheaval from HDD.

For drilling projects, it is mandatory to get a complete geologic survey of the area prior to drilling. Most states require this survey be included in the drill report to note any existing utility lines, the groundwater table, and the soil conditions the drill will likely encounter. Most state policies, however, do not consider soil conditions when making specifications for drilling.

According to *Trenchless Technology,* three factors that affect the volume of soil brought to the surface from the annulus are soil mass loosening, soil strength, and the drilling fluid left in the annulus. Loosened soils have the potential to dilate, increase in volume and become less dense. This will actually help decrease settlement. The loosening of soils could also have a negative effect and collapse, which will increase settlement.

When pulling the conduit through the borehole, it is important that the borehole be slightly oversized to facilitate easy installation. The general rule of thumb is that the back ream should have a diameter that is 1.5 times the diameter of the pipe being installed. This should be increased to 25% if the soil is expected to swell or if boulders or cobbles are expected to be encountered during drilling. Allouche and Ariaratnam give examples of possible back ream diameters versus nominal pipe diameter in Table 1.

Table 1. Allouche and Ariaratnam, 2000

TABLE 1. Recommended Backream Hole Diameter (Popelar et al. 1997)

Nominal pipe diameter (mm) (1)	Backream hole diameter (mm) (2)
50	75–100
75	100–150
100	150–200
150	250–300
200	300–350
250	350–400
≥300	At least 1.5 times product OD

A study was conducted at the University of Alberta on the factors affecting soil settlement in trenchless drilling. One focus was the effects of soil type, more specifically clays and sands. Figure 9 is from the study and illustrates the vertical displacements of clay and sand as functions of lateral distance from the bore path. The graph illustrates that clay experiences more displacement than sand; in fact, almost 3 times more at close range to the bore path. This information is significant when taking into account all geological aspects of the drill site. It can also be noted that the displacement decreases as the distance from the bore path increases, as shown in Figure 10.

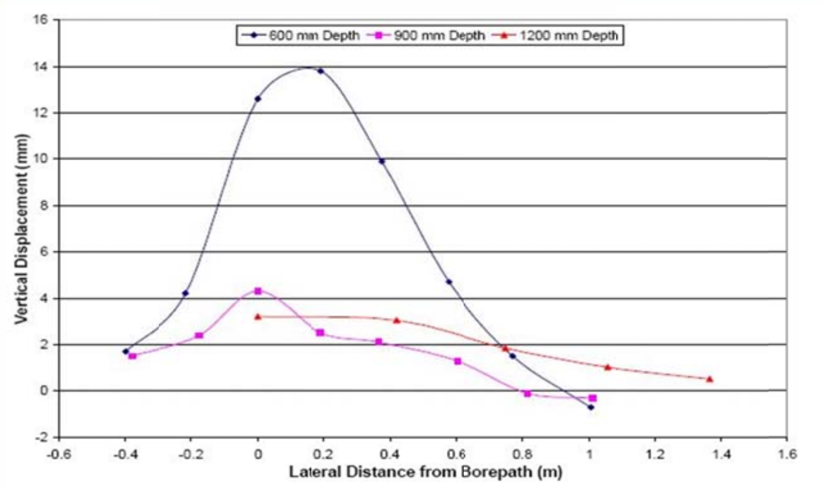


Figure 5: Drilling displacements in clay.

Figure 9. from *Towards the Development of HDD cover guidelines.*

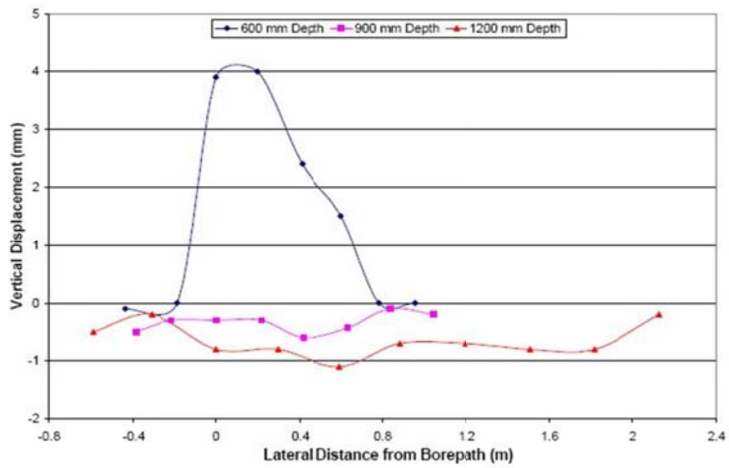


Figure 6: Drilling displacements in sand

Figure 10. from *Towards the Development of HDD cover guidelines.*

The study in Alberta also took into account the importance of the diameters of the pilot hole, ream and pipes. The pilot hole and the reaming process are responsible for upheaval and settlement because of the soil disturbance caused by the drilling process; the greater the ream diameter, the greater the depth of the borehole. Table 2 shows the amount of displacement from different pipe diameters at different locations lateral from the bore path. The table shows the most displacement occurs when using a larger diameter pipe. Also, there is more displacement in clay than in sand.

Table 2. from *Towards the Development of HDD Cover Guidelines* (Leuke 2005).

Pipe Diameters Lateral from Bore Path	Clay (Displacements in mm)			Sand (Displacements in mm)		
	4" Pipe	8" Pipe	12" Pipe	4" Pipe	8" Pipe	12" Pipe
-2	4.1	44.5	n/a	-3.1	0.6	-0.1
-1	8.7	50.3	n/a	-3	1.1	0.4
0	21.8	55.2	102.9	0.9	2	0.1
1	27.2	50.9	100.5	1	2.2	0.9
2	17.5	44.4	44.9	-1.25	1.3	-0.2
3	9.8	33.6	11.9	-2	0.46	-0.1
4	4.1	25.5	6.5	-2.6	0	0.4
5	0.5	19.3	n/a	-3.1	-0.6	0
6	n/a	n/a	n/a	n/a	n/a	-0.1
7	n/a	n/a	n/a	n/a	n/a	0.2

As a recap, when looking at the factors of settlement one must consider: the soil type, the depth of excavation, the pilot, the ream diameter, the pipe diameter and the drilling fluid. Two other integral factors that will be discussed in more detail in the following sections are drilling fluids and different types of reamers.

2.1 DRILLING FLUIDS

Drilling fluids are an important aspect of a drilling operation because they control the stability of the hole during and after drilling. Drilling fluids are typically composed of water, bentonite, soda ash and, in some soils, chemical additives. When specifying the drilling fluid to use, it is important to look at the geological settings and the properties of the water and other fluids being used.

Geological properties determine what is used in the overall drilling fluid. When drilling fluid is used in coarse-grained soils, like sands and gravels, its main purpose is to provide stability to that bore and carry away cuttings. Drilling fluid serves the same purpose in fine-grained soils like clays with one additional task; the drilling fluid must also prevent swelling. At this point, the drilling fluid must not only be composed of bentonite but other chemical additives.

For sandy soils, water is usually mixed with bentonite to create drilling mud. Clayey soils are more of a concern because they react strongly to water, which makes up more than 90% of drilling fluid. The clay problem can be approached in two ways. One can either prevent the clay from interacting with water or alter the properties of clay to lessen the effects of water.

For coarse or sandy soils one needs to control water loss and prevent the sloughing of material at the walls. This can be accomplished by using a water/filtrate control additive like poly-anionic-cellulose (PACs). The PAC binds with the bentonite to seal the wall cake and lessen the loss of water. Completely sealing off any interaction between the water and soil can become expensive, so it is usually a better option to treat the clay. Some common ways to treat the clay are to coat it to prevent it from sticking to steel drill, prevent it from swelling, or flocculate it so that it flows out of the borehole.

In the article *Drilling Through the Clay,* Randy Strickland lists general categories of additives used to treat clay:

1.) Surfactants (drilling detergents)
   -involve coating the surface of clay particles when clay is cut by drill bit.
2.) Polymers
   -partially hydrolyzed poly acrylimite (PHPA).
   -prevent clay from swelling (also known as inhibition).
   -can be used with drilling detergents.
3.) Flocculants
   -bind clay particles together in a flowable liquid slurry.
   -solve problem of removing the clay from the hole without it getting reattached to the sides of the borehole.
4.) Thinners
   -dispersants or de-flocculants.
   -neutralize charges on clay particles and reduce viscosity.

Any of these common additives can be found at many suppliers. Strickland also emphasizes the continued use of bentonite with these additives. Additives do not have “gel strength”, i.e. the ability to keep particles in suspension. This is important when cuttings need to be suspended to allow for washing out the borehole. The amount of bentonite required to allow for suspension is small, 10-15 lbs per 100 gallons of water. In general, for drilling fluid one will need 4 to 5 times the soil volume that is to be cut.

Fluids are necessary for washing out cuttings, lubricating the bore, allowing flow and cooling down the drill. As such, special attention must be given to their selection. Water makes up the biggest percentage of the drilling fluid mixture, so it makes sense that the properties of water will have a big impact on how the drilling fluid behaves. An important property to note is the pH of the water. This can be done easily using ordinary pH strips. The pH of the water controls amount of soda ash (sodium carbonate) necessary to increase the pH to the desired level. The typical goal is a pH between 8.5 and 9.5. Other properties to check include the density of the fluid, which should be less than 9 pounds per gallon. There should be a sand content of less than 1 percent. Filtration of the fluid and the filter cake surrounding the walls of the hole can determine the stability of a bore. Filtrate is the water phase that comes through the filter cake. The allowable amount of filtrate is typically 10-14 cubic centimeters. An acceptable filter cake thickness is about 1/16 of an inch.

Mud viscosity allows for the proper suspension of solids. To measure viscosity one can use a device called the Marsh Funnel (Figure 11) with a graduated container and a stopwatch. The steps for using a Marsh Funnel are:

1.) Hold funnel upright with a finger blocking the smaller outlet.
2.) Pour the drilling fluid through the screen on top of the funnel until the drilling fluid reaches the marked line just beneath the screen.
3.) Remove the finger from the outlet and measure the seconds it takes to fill the graduated container up to the marked 1-quart line.

The viscosity used is dependent on the soil conditions as shown in

Table **3**. After taking a viscosity measurement it can be adjusted accordingly.

Table 3. Viscosity Chart (viscosity in seconds)

Material Being Drilled	Marsh Funnel Viscosity
Water (with no swelling clay)	
Natural Swelling Clays	32 to 37
Normal Conditions (including non-swelling clay and fine sand)	40 to 45
Medium Sand	45 to 55
Coarse Sand	55 to 65
Gravel	65 to 75
Coarse Gravel	75 to 85

Without special attention to fluid properties there might not be enough fluid or the incorrect kind could be used. This could lead to a reduction of discharge, which could lead to a backup and a leak of drilling fluid to the surface. This damage to the surface, known as a “frac-out,” can be seen in the Salem, IL case study.

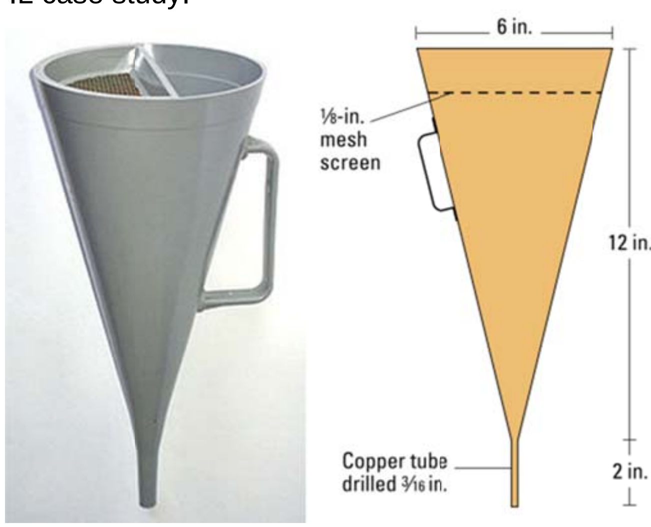


Figure 11. Marsh Funnel

2.2 REAMER TYPES

Reamers are responsible for enlarging the bore after the pilot hole and for installing the new casing or pipe in the hole. Like other aspects of HDD, the type of reamer will depend on the site geology. For reamers, one can place ground conditions into three categories: good, bad, and rock. Good soil consists of consistent sand, packed clays, sandy loam, clay loam or a combination of these. Bad soil consists of loosed, more variable soils, possibly containing cobbles.

2.2.1 Blade Reamer

For good soils one can use a blade reamer, which are ideal for mixing drilling fluid with cuttings from the hole. Blade reamers can have diameters between 4 and 24 inches (102-610 mm). When diameters over 12 to 14 inches are needed, a ring of 2 to 4 inches is placed over the widest part to stabilize the reamer. The delta reamer is a type of blade reamer used for soils that are more compact than what an average blade reamer can handle. These soils include dry, hard soil, some sandstones, and hard clays.

2.2.2 Fly Cutter Reamer

Fly cutter reamers can be used in especially dense soil. This includes sandstone, siltstone and other soft rock formations. The fly cutter reamer looks similar to a wagon wheel and is made like a blade reamer without 80-90% of its front. Fly cutters only use the rear portion, which has a band of 6 to 8 inches over the widest diameter. The spokes of the fly cutter can have nozzles to control the pressure and volume of the fluid as it goes through the hole.

2.2.3 Barrel Reamer

One type of reamer that can be used for varying soil conditions is a barrel reamer. A barrel reamer has a solid, round body and a tapered nose with cutting teeth. The cutting teeth of the barrel reamer make a slightly larger bore than the body of the reamer, which allows fluid to flow through. The pressing of fluid and cuttings against the wall helps keep the borehole walls together and helps develop a wall cake, allowing for easier movement of the reamer.

Fluted reamers are a type of barrel reamer and are shaped so the cutters can cut the same bore as the body. This also works in most ground conditions. A combination of the fly cutter and barrel reamer can be used for mid-sized to large rig operations for large diameter crossings.

The spiral reamer can be used in loose ground conditions, stony ground or places where soil is mixed in with various rock sizes. The reamer looks like a large screw with a bell attached to the back.

2.2.4 Hole-Opener

For rock, most contractors used a rock hole-opener. It is made of several cones and its effectiveness the torque and rotary speed as well as the type of rock. Interestingly enough, hole-openers will not work in clays and sands because it relies on the resistance of the drill head.

CHAPTER 3 RECOMMENDED REGULATIONS BY THE ASCE

The American Society of Civil Engineers' publication *Pipeline Design for Installation by Horizontal Directional Drilling* goes into detail about HDD pipe installation and gives specifications on penetration angles, distance from obstacles, radius of curvature and deviation from drill path:

- Penetration angles should be between 8 and 20 degrees to the ground surface. Twelve degrees is considered optimal. Figure 12 gives a general idea of the appropriate angle of bore.

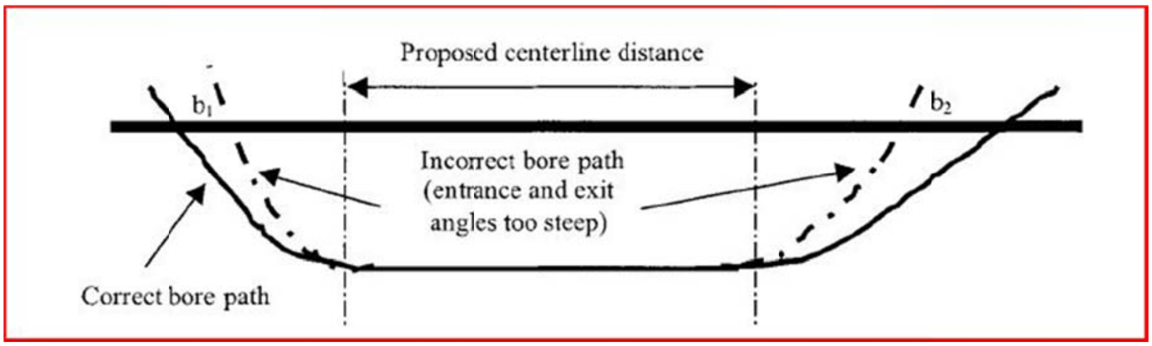


Figure 12. Anderson, Ariaratnam & Leuke, 2004.

- Minimum separation of 15 feet between the drill path and any obstacles.
- Radius of curvature is usually 1,200 times the diameter of the pipe that is being installed.
- Deviation from drill path at the exit pit can be +/- 10 feet in the horizontal direction.

CHAPTER 4 STATE REGULATIONS

State regulations for HDD exist in some states but need further clarification. Most states leave decisions like depth, pipe diameter, pilot-hole diameter or ream diameter to the engineer or contractor. This study gathered information on regulations from the several states; this information is summarized in the sections below.

4.1 ARIZONA

The preferred trenchless technology is jack and bore, but it does provide depth of coverage that can be applied to either HDD or jack and bore. (Policy for Accommodating Utilities on Highway Rights of Way, 2009). The depth is dependent on whether there is a conduit present for the utility cable.

- For direct burial of cable, minimum cover should be 48 inches.
- For cable within a conduit or duct, the minimum cover should be 36 inches.

4.2 ARKANSAS

Arkansas focuses most of its regulation on the depth of cover for different pipelines. There is also an emphasis on the extension of the different pipelines but other important factors like angle of the bore and pipe diameters are left very general and rely more on the opinion of the contractor.

Table 4 from the Utility Accomodation Policy, 2009, shows that the depth of pipeline depends on the type of utility carried in the pipeline. Table 4 also distinguishes between depth from the top of the highway and the depth from the ditch.

Table **5** gives more specific data on the allowed extension past embankments and ditches.

Table 4. Depth of coverage for different pipelines, Arkansas DOT

Type of Pipeline	Depth of Coverage
gas and liquid petroleum (casing)	36" below ditches, 42" below the top of the highway subgrade
gas and liquid petroleum (no casing)	48" below the ditches or below the highway
waterlines (casing)	36" below ditches, 42" below the top of the highway subgrade.
sanitary sewer lines	36" below ditches, 42" below the top of the highway subgrade.
underground electric lines	36" below ditches, 42" below the top of the highway subgrade.
underground communication lines	36" below ditches, 42" below the top of the highway subgrade.

Table 5. Extension for different pipelines, Arkansas DOT

Type of Pipeline	Extension
gas and liquid petroleum (casing)	extends a minimum of 6' beyond the toe of slope of embankment
	sections and a minimum of 6' beyond the bottom of
	existing ditches or back of curb in curbed sections.
gas and liquid petroleum (no casing)	same as with casing
waterlines (casing)	extends a minimum of 6' beyond the toe of slope of embankment
	sections and a minimum of 6' beyond the bottom of
	existing ditches or back of turn in curbed sections.
sanitary sewer lines	extends a minimum of 6' beyond the toe of slope of embankment
	sections and a minimum of 6' beyond the bottom of
	existing ditches or back of turn in curbed sections.
underground electric lines	extends a minimum of 6' beyond the toe of slope of embankment
	sections and a minimum of 6' beyond the bottom of
	existing ditches or back of turn in curbed sections.
underground communication lines	extends a minimum of 6' beyond the toe of slope of embankment
	sections and a minimum of 6' beyond the bottom of
	existing ditches or back of turn in curbed sections.

- Angle of crossing should be as normal to the highway as practical.
- Only dry bores are allowed (wet bores involve the use of jetted water to make bores).
- Cutter head is sized closely to the pipe diameter with an overbore that is less than 5% more than pipe diameter.
- Water pressure should be no more than 10 psi.

4.3 NEW YORK

The New York manual, Requirements for the Design and Construction of Underground Utility Installations Within the State Highway Right-Of-Way, 1997, provides very general information about HDD. Specific regulations include only deviation tolerances of the drill bit and the distance from the surface and are addressed in Table 6. The deviation tolerances are similar to many states, but the distance of the bore from the surface is slightly greater than what is usually allowed (between 2-3 feet).

Table 6. Deviation Tolerances and Distance from Surface, New York DOT

Deviation Tolerances from Original Drill Path	Distance from Surface
"+/- 1%" of the bore length	more than 60" or 5'

4.4 CALIFORNIA

In California's Guidelines and Specifications for Trenchless Technology Projects, 2008, the only specific requirement addressed was a minimum depth of cover depending on the pipe or product diameter as shown in Table 7. It makes sense that as pipe diameter increases, so does the depth of cover, as greater surface disturbance can result from larger bores. Other decisions such as bore radius and drill bit used are left to the judgment of the contractor.

Table 7. Caltrans Encroachment Permits *Guidelines and Specifications for Trenchless Technology Projects*

Pipe or Product Diameter	Minimum Depth of Cover
Under 150 mm	1.2 m
200 to 350 mm	1.8 m
375 - 625 mm	3. 0 m
650 - 1200 mm	**1.6 m**

4.5 IOWA

Iowa’s Requirements for the Design and Construction of Underground Utility Installations Within the State Highwat Right-Of-Way, 1997, provides guideleines for deviation tolerances and depth of cover for utilities. In Table 8, deviation tolerances are different for horizontal and vertical directions. It is more essential to avoid vertical deviation because it could cause problems with settlement or upheaval. The depth of cover for utilities will vary depending on the type of utility being buried (Table 9).

Table 8. Deviation Tolerances, Iowa DOT

Horizontally	Vertically
"+/-1" ft for per 100 ft	"+/- 0.5" up to 100 ft
After 100 ft, you are allowed an extra "+/-.1 ft"	

Table 9. Depth of Cover for Utilities

Type of Utility	Depth of Cover
electric	48"
communications	30"
Other	36"

4.6 KANSAS

Kansas has detailed pipe requirements depending on the kind of product being transported. Table 10 shows that the depth of cover varies for when the pipe is below the crown grade and when it is below the ditch grade. KDOT also has specifications on the hole diameter in relation to the pipe diameter (KDOT Utility Accomodation Policy, 2007).

Table 10. Minimum Depths of Cover

under ditches/ roadways	depth
below crown grade	5'
below ditch grade	3'

Table 11. Diameter of Bore in Relation to Pipe

diameter of pipe	max hole diameter
12" or less	1.5" more than diameter of pipe
greater than 12"	2" more than diameter of pipe

4.7 MARYLAND

Maryland's guidelines come from a source other than its department of transportation. The guidelines come from the Washington Suburban Sanitary Commission (WSSC) which uses HDD in the installation of its water mains. The WSSC has general rules, but pays special attention to the relation between pipe diameter and boring distance, as shown in Table 13. Its chosen deviation tolerances (Table 12) are similar to values chosen by other states.

- The angle of the entry hole should not exceed allowable bending radius of the HDPE pipe.
- Be able to make a turn up to 90 degrees.

Table 12. Deviation Tolerances, Maryland DOT

horizontally	Vertically
"+/- 1" ft	"+/- 0.5 "ft

Table 13. Iron Pipe Sizes to Boring Distance, Maryland DOT

Iron Pipe Size (inches)	Boring Distance (feet)
1.25	400
1.5	400
2	350
2.5	350
3	300
4	250

4.8 FLORIDA

Florida's utility guide, Utility Specification- Quality Control, 2004, specifically prefers HDD for installations. This makes Florida's guide especially useful. The policy points our that displacement can be reduced by adjusting the ratio of the borehole to the pipe diameter.

Table **14** shows suggested borehole diameters relative to the size of the pipe being inserted.

Table 14. Utility Accommodation Policy, 2009

Nominal Inside Pipe Diameter (inches)	Bit Diameter (inches)
2	4
3	6
4	8
6	10
8	12
10	14
12 and greater	Maximum Product OD + 6

Florida's utility guide also gives specifications on the depth of the pipe installation based on what is above the pipe (paved or unpaved ground) and requires a minimum pH for the drilling fluid.

- Below the top of pavement, 36 inches minimum.
- Below existing unpaved ground, 30 inches minimum.
- For installation of the pipe, the drilling fluid advised is bentonite clay or a stabilizing fluid mixed with a potable water of a minimum pH of 6.

Equipment specifications are shown in Figure 15. Pipe size and borehole diameter determine what equipment is used. Unsurprisingly, a larger drill rig, with greater torque, thrust, and pullback force is used for larger pipe installations.

Table 15. Utility Accommodation Policy, 2009

System Description	Pipe Diameter (inches)	Bore Length (feet)	Torque (ft/lbs)	Thrust/ Pullback (lbs)
Maxi- HDD	18 and greater	>1000	>10,000	>70,000
Midi- HDD	Up to 16	up to 1000	1,900 to 9000	20,001 to 69,999
Mini- HDD	Up to 16	Up to 600	Up to 1,899	Up to 20,000

Thrust/pullback requirements are shown in Table 16. Thrust/Pullback Capacity increases with increased pullback distance. These guidelines are used to prevent excess downhole pressure.

Table 16. Utility Accommodation Policy, 2009

HDD Bore Equipment Thrust/Pullback Capacity						
Lbs	5,000 to 7,000	7,001 to 12,000	12,001 to 16,000	16,001 to 25,000	25,001 to 40,000	>40,000
Product Size (1) Inches	Maximum Pullback Distance In Feet					
4 or <	400 or <					
6 or <		600 or <				
8 or <			800 or <			
10 or <				1,000 or <		
12 [300] or <					2,000 or <	
> 12 [300]						Engineer's Discretion
(1) for the above, where a single pull of multiple conduits is to be attempted, the applicable product size must be determined by the diameter of a circle that will circumscribe the individual conduits as a group.						

4.9 INDIANA

Indiana focuses on the initial investigation of the geologic properties as opposed to the actual boring process. Indiana most likely relies on the judgement of the contractor after a thorough ground investigation (Jha).

- Depth of boring should be a minimum of 5 feet or twice the size of the pipe diameter of the invert below the invert elevation, depending on which is deeper.
- A minimum of one boring per 150 feet of trenchless pipe shall be obtained.
- If groundwater is present, one should consider an observation well.
- When rock is encountered, a rock core shall be obtained to the required boring depth.

4.10 OREGON

According to Don Turner, a geo-technical designer for the Oregon Department of Transportation, “Trenchless technology is for larger installations of culverts, arches, etc. under road fills and could be several hundred feet long. Current design methods are consulted out and some discussion is included in our Standard Specifications for Construction. However, it is not a complete discussion by any means.” HDD is used for smaller projects like the installation of utilities. Because the projects are small in scale, the contractor makes decisions for individual projects. Like Indiana, the only thing regulated is the initial investigation of the ground conditions (Geotechnical Design Manual, 2009).

- Borings should be 1.5 times the tunnel/pipe diameter. If the final tunnel/pipe alignment is not yet determined, the boring can be 3 times.

CHAPTER 5 CASE STUDIES IN ILLINOIS

5.1 EFFINGHAM, IL

This case study was located in Effingham, IL at the intersection of Willow Street and Grove Avenue. The project studied is the replacement of an 8-inch water main along Willow Street using a directional bore. The pilot hole entered on the southwest corner of Willow St. and Grove Ave. The receiving pit was located on the southeast corner of Willow St. and Grove Ave.

Figure 13. Location of water main replacement

5.1.1 Dimensions

Type of Pipeline: Certa-Lok Yelomine Pipe: ASTM D2241 (Restrained Joint)

1.) Minimum SDR rating 21 (SDR- 21) with minimum pressure rating = 200 psi (1379 kPa) at 23^{o}Celsius.
2.) Gaskets ASTM F477.
3.) Couplings and fitting tested in accordance with NSF 14.
4.) Transition between Restrained Joint and Plane end Pipe with Ductile Iron Solid Sleeve.

Size of Carrier Pipe: 8’ inches

Type of Casing: Centra- Lok Yelomine Pipe: ASTM D2241 (Restrained joint)

1.) Minimum SDR rating 21 (SDR-21) with minimum pressure rating of 200 psi.
2.) Gaskets ASTM F477.
3.) Couplings and fitting tested in accordance with NSF- 14.

Size of Casing: 12 inches

Length of Casing: 74 feet

5.1.2 Process

The site has the usual components of a directional drill project: a solids control system (Figure 14a), a mud pump system (Figure 14b) and a drilling system. A foresight bearing is established so the location of the drill bit can be tracked throughout the boring process (Figure 15).

A pilot hole is drilled after an initial survey of the ground surface. The drill rig is positioned at the entry location at the southwest corner of Willow St. and Grove Ave. An angled bore is begun as shown in Figure 16 **Error! Reference source not found.**to create a pilot hole. After the pilot hole is established, a reamer is used to increase the diameter of the bore. In Figure 17, a reamer with an 8” cutting head is back-reamed from the receiving pit. After reaching the entrance pit, the 8" cutting head is reamed back to the receiving pit. Figures 17a-d show the progression of the reamer. Sometimes multiple reamers are used to gradually increase the size of the bore. In this case, a 16” cutting head follows the 8” cutting head.

When the hole reaches the diameter required for pipe installation, the pipe is back reamed into the bore. In this case, the installation is an 8” water main. The figures below show the 16” reamer moving from the receiving pit back to the entrance pit (

Figure **18**). It also shows the connected 12” casing for the water main ready to be installed by the reamer (Figure 19).

After reaming the hole to the appropriate diameter, phase 3, pipe pullback can begin. The casing is attached to the 16” cutting head (Figure 19). It is then pulled through the bore hole using the drilling machine and with assistance of a backhoe pushing the casing (Figure 20).

After the pipe casing is installed and the 12” water main is placed in the casing, any excess solids and fluids are taken out of the bore. Any open trenches are then backfilled and returned to their former condition.

(a) Water truck for mixing drill fluids (b) A vaccum truck is used to remove spoils

Figure 14. Systems that help retain the shape of the bore hole.

(a) Determining the foresight bearing (b) The Azimuth bearing keeps track of the drill bit

Figure 15. Survey of the before and during drilling.

Figure 16. Angled bore entry.

(a) 8” reamer before boring

(b) 8” reamer first making the bore

(c) 8” reamer before completing bore

(d) 8” reamer after progressing through bore

Figure 17. Different positions of 8” reamer in borehole.

(a) casing to be installed using 16” reamer (b) 16” before placement

(c) 16” after placement (d) reamer before penetration

(e) reamer enlarging the bore

Figure 18. 16" diameter cutting head is back-reamed from the receiving pit. Afterwards, the cutting head is reamed back from the receiving pit.

(a) casing ready for attachment

(b) casing lowered into pit

(c) casing further lowered into pit

(d) casing attached to reamer

Figure 19. The casing for the water main is lowered and connected to the reamer.

(a) casing pulled by reamer

(b) casing moves through the bore

(c) excess drilling fluid and cuttings removed

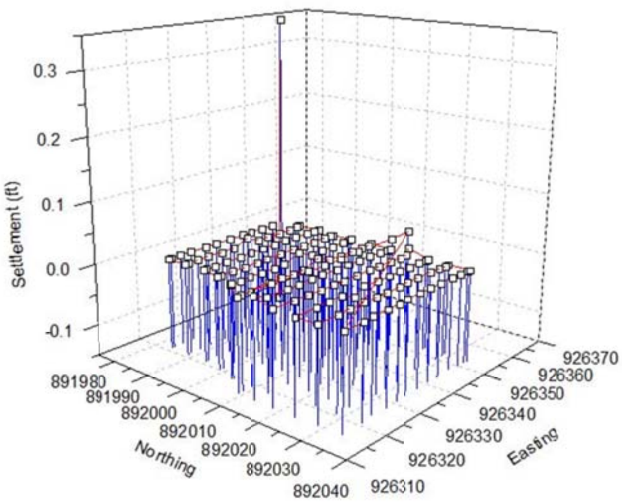
(d) casing reaches the other side of the borehole

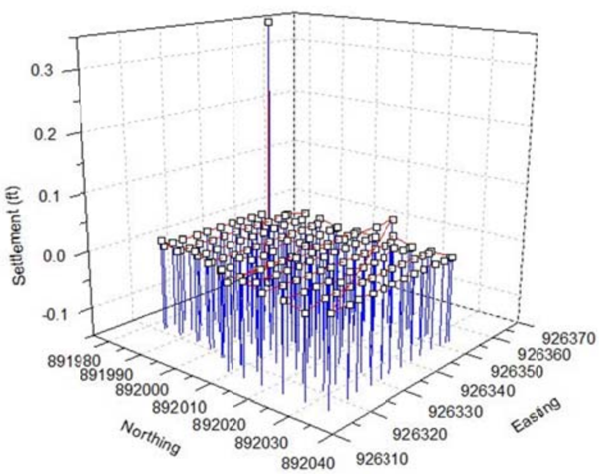
Figure 20. The pipe casing, pulled by the reamer, progresses through the bore.

5.1.3 Settlement/ Upheave of Soil at Different Stages of the Bore

The measurements from Figure 21 are taken after a 2'' pilot hole is drilled from the entrance to the receiving pit. Figure 21 has one spike in settlement but that one point is overridden by the majority of the points showing a relatively flat surface. This indicates that the changes due to this small diameter hole are small if not non-existent which makes sense.

After the pilot hole, two reams of different diameters take place. First, a back ream with an 8'' cutting head is drilled from the receiving pit back to the entrance pit, and then back through again to the receiving pit. Second, a 16'' diameter cutting head is back reamed from the receiving pit to the entrance pit and afterwards is reamed back to the receiving pit. Figure 21 shows a surface almost identical to Figure 21. Despite the two reams of increasing size, the changes in settlement due to the reams are small, if not non-existent.



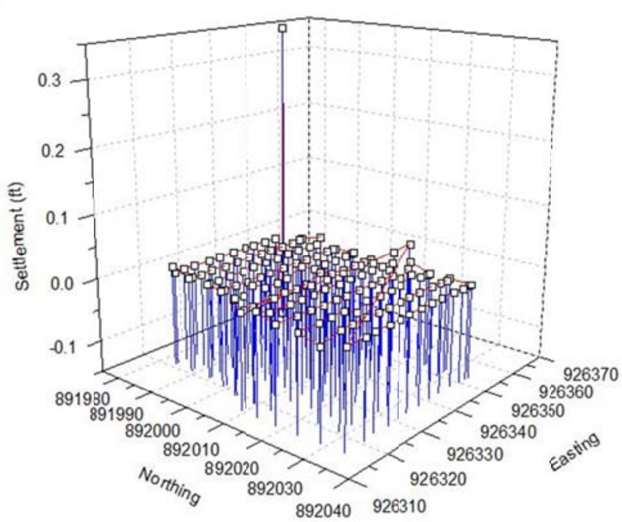


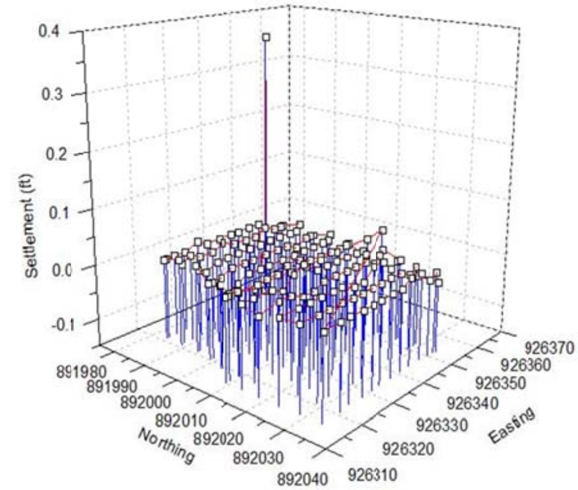
(a) (b)

Figure 21. (a) Settlements after pilot hole, b) Settlements after reaming.

After the reams, the 12'' diameter casing pipe is pulled into the hole behind the 16'' cutting head. This is done with the help of a backhoe. The 8'' diameter is pulled into the 12'' casing with the drilling machine followed by the backhoe. Then it is reconnected to the water main. Figure 22 has the same flat surface as the previous bores. After the final adjustments there is still no significant settlement in the drilled area.

Figure 22 shows no significant change from the previous graphs. After a week, there is still no settlement apparent.





(a) (b)

Figure 22. (a) Settlement immediately after completion of installation, (b) Settlement 1 week after installation.

Figure 23 shows no significant change from the previous graphs. After a month, there is still no significant upheaval or settlement. The largest settlement that occurred is less than an inch. One can conclude that directional drilling was a success and did not disturb the soil or road above the drilling location.

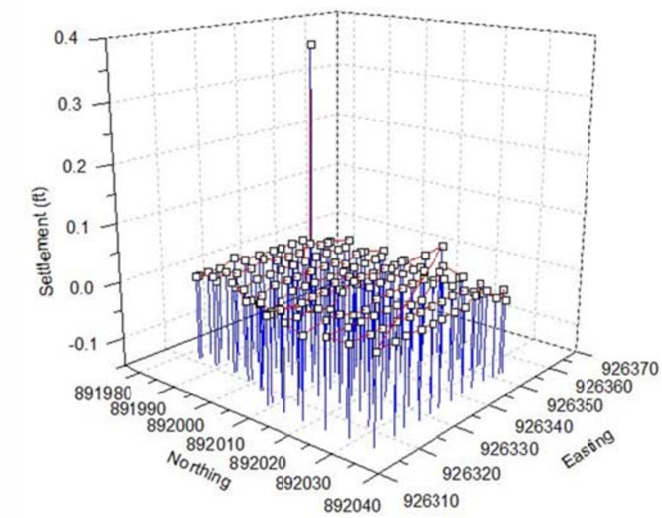


Figure 23. Settlement from Initial to 1 Month After Drilling.

5.2 BEECHER CITY, IL

At Beecher City, a bore was made underneath the railroad tracks located east of the city. These tracks are indicated on the map in Figure 24. Settlement was monitored from both sides (east and west of the tracks), and graphs have been made to document changes.

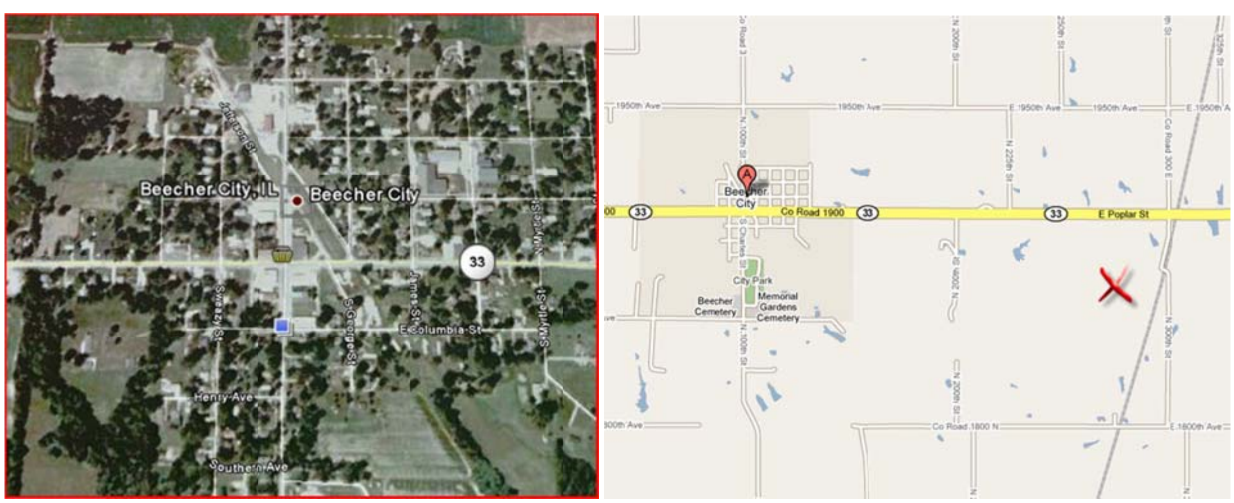


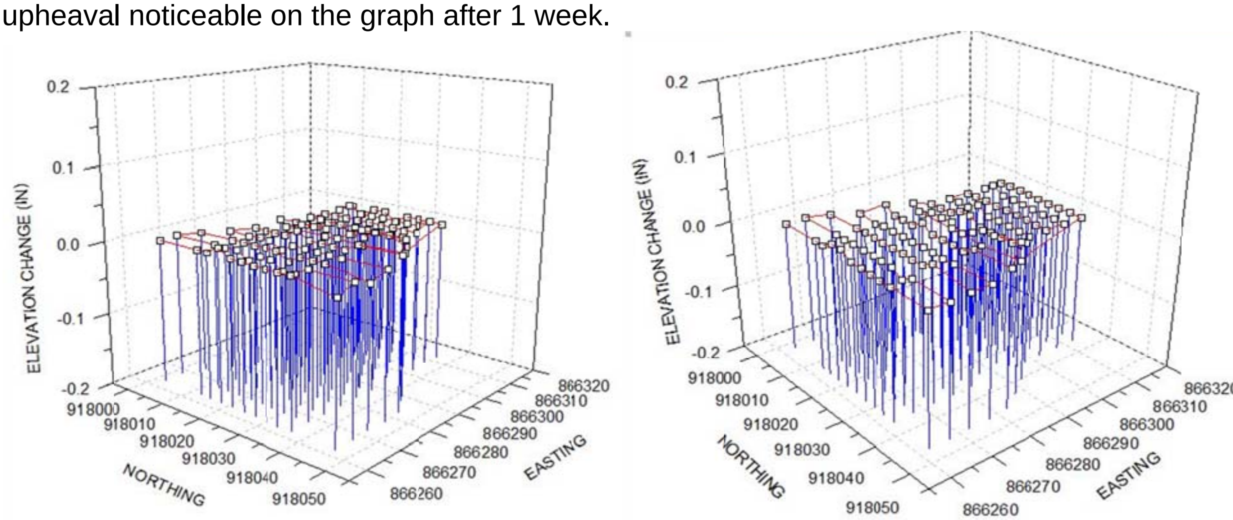
Figure 24. Beecher City map and location of the bore perpendicular to railroad tracks. The site location is marked by an X.

5.2.1 West of Railroad Tracks

This set of graphs represents the measurements taken on the west side of the railroad tracks (Figure 25). Overall, no significant settlement is shown. (A "frac out" occurred at one of these locations "Frac out" is a colloquial term meaning the pavement fractured or the bore had an inadvertent return of drilling fluid)

Figure 25. The west side of the Beecher City borehole.

As seen in figure 26, the surface of the 3D graph is relatively flat indicating that very little settlement occurs from the initial conditions to right after the project is finished.
Figure 26 still presents a flat surface indicating that there is still no dramatic settlement or upheaval noticeable on the graph after 1 week.



(a) (b)

Figure 26. (a) Settlement immediately after completion of installation, (b) Settlement 1 week after installation.

After a month, Figure 27 shows that there is still no dramatic upheaval or settlement. It is safe to conclude it was a successful HDD project.

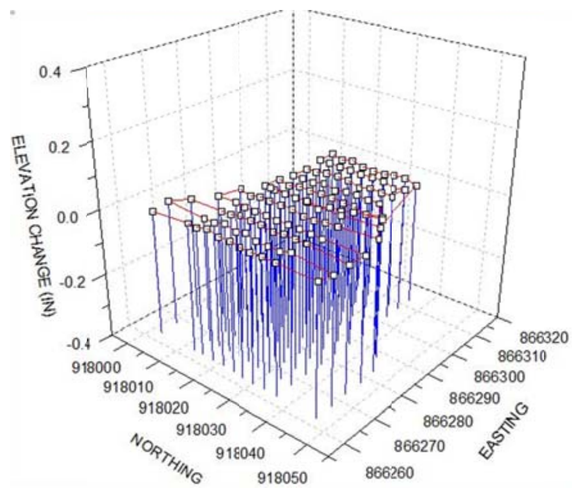
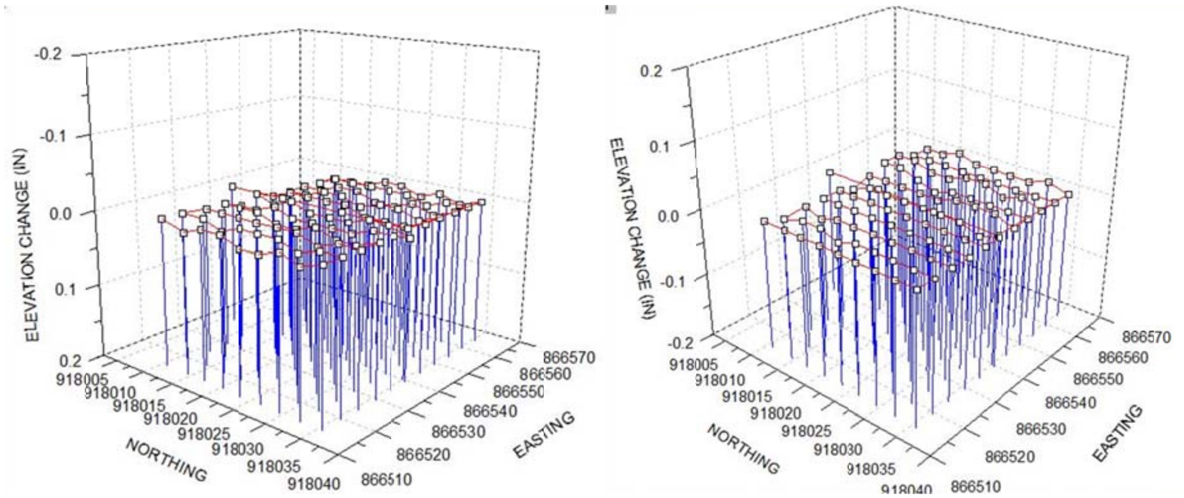


Figure 27. Settlement from initial to after 1 month.

5.2.2 East of Railroad Tracks
This set of graphs represents measurements taken on the east side of the railroad tracks (Figure 28). Like the west side, there is no significant settlement apparent.

Figure 28. The east side of the Beecher City borehole

Like its counterpart across the railroad tracks, Figure 26, the relatively flat surface of Figure 29 indicates that there is no apparent settlement or upheaval after the project has ended. Because this figure looks so much like Figure 29, it is safe to conclude that there is still no dramatic motion of the soil 1 week after drilling.



(a) (b)

Figure 29. (a) Settlement immediately after completion of installation, (b) Settlement 1 week after installation

Figure 30 still looks like the previous figures. Because there are still no changes to the soil profile, you can consider this a successful HDD project as well.

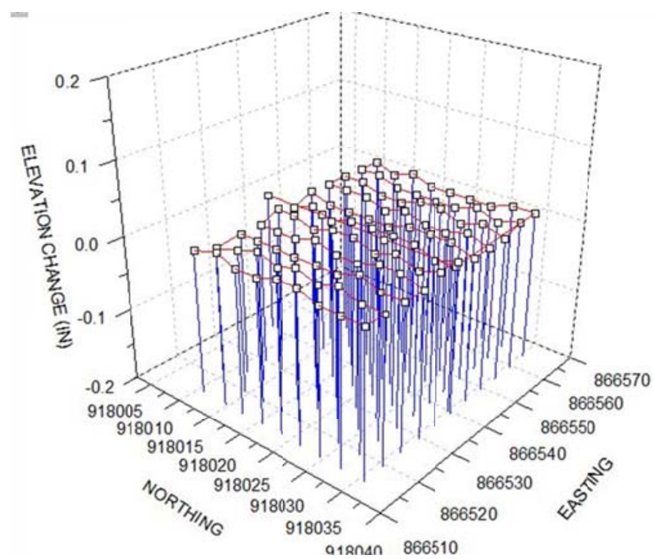


Figure 30. Settlement from initial to 1 month after drilling.

5.3 NEWTON, IL

Sullivan Electric specializes in fiber optics and lays down 3000-5000 feet of line in a week and they were responsible for the project in this case study. Their boring subcontractor was EDT. The project was electric line for the People's State Bank in Newton, IL (Figure 31 and Figure 32). The original plans for the electric line consisted of one 6" pipe and one 4" pipe. The plans changed several times. First, the 4" pipe was dropped. One 6" pipe remained then the plan changed to two 6" pipes (Figure 32). The plan for two 6" pipes was only known a day before actual boring began.

The day before, the city informed the drillers that a water main was located near the ground surface, so the line needed to be at a depth of 10' (below the water main located at 4' and above a sewer line below).

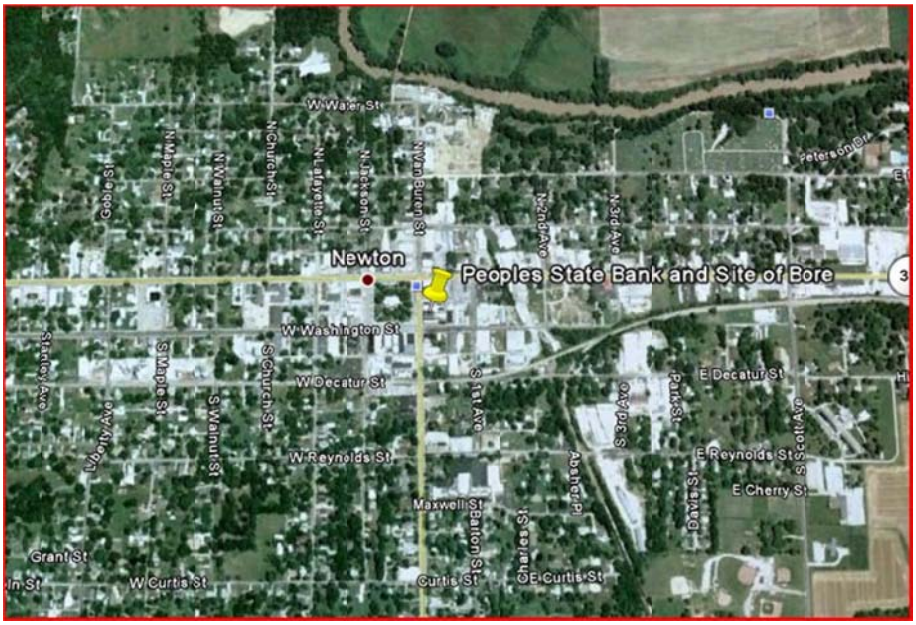


Figure 31. Newton, Il- location of bore

(a) (b)

Figure 32. People's State Bank in Newton, IL (a) site location, and (b) Pipe to be installed by HDD

5.3.1 Sequence of Events

Day 1: On the first day of drilling, the entrance for the bore was cut out from the pavement (Figure 33). Next, the soil was bored with a 5" wide drill to a length of 100 ft. At that point, the drill hit a hard, brittle white rock. The rock could have potentially been shale. At 120 ft. the soil became soft but at 156 ft., hard rock was encountered again. The drill had carbide teeth, which usually have no difficulty going through the rock, but the center was a challenge to bore through.

(a) (b)

Figure 33. Construction activities (a) receiving pit for directional bore, (b) Bentonite and water shown after bore is completed.

Day 2: On the second day, there was still drag on the 8" reamer so drillers changed to a 12" open fly reamer. The 12" reamer became stuck 20' from the boring machine. It spun the 3" drill rod in half. To recover the reamer a 4'X6' hole 10 feet deep was made.

For the road condition, no cracking was seen in the middle of the road, only on the bank side. There was small uplift of the concrete (

Figure **34**).

(a) Small uplift on east side (b) small uplift on edge of pavement

Figure 34. Uplift of concrete.

Day 3: On the third day an 18" reamer was pulled back. This pull-back included the two 6" PVC pipes with outside diameters of 7.5". This was still done in bentonite. The reamer moved slowly.

At this point, the road was raised and moving.

- An issue was the pavement bricks underneath the road. The movement of one will cause the movement of another and cause a “domino effect”.
- An interesting observation was that there was not disturbance of the curb and gutter and at this point.

Because the workers finished in the dark, the full extent of damage was not readily observed. IDOT was later called because the bump on the road was a potential safety hazard, as can be seen in Figure 35. A sign was placed warning of bumpy conditions.

Figure 35. Bumpy conditions created by uplift.

Day 4: On the fourth day, the city observed that soil and water were coming out of the ground (Figure 36). The EDT representative thought it was just excess water from the project, but it could have also potentially been the water main leaking.
Day 6: On the sixth day IDOT was notified, and it was decided that the water was from a hairline fracture in the water main.
Day 7: A meeting took place, and it was decided that the road needed to be excavated and repairs made. The construction can be seen in Figure 37.

Figure 36. Uplift of road from water.

(a) road is opened (b) back filling of the road

Figure 37. Portion of the road is cut to examine damage.

5.3.2 Factors contributing to the failure at Newton

- The main factor is the lack of prior knowledge of ground conditions. Many problems could have been avoided with the proper geotechnical information, including the hard rock in the middle of the bore, the old foundation and the adjustments made to avoid water mains.
- Without the proper geotechnical information, the drillers kept drilling because the push condition were inconsistent and problem spots were followed by sections where the drill would advance with ease.

5.4 SALEM, IL

The case study of Salem, IL is possibly an example of a “frac-out” which is a fracture of the surface with an inadvertent return of drilling fluid. A 4” water main with an 8” steel casing (Figure 38) was to be installed by the Northeast Marion Co Water Company. The borehole was to be located at the corner of Kimundy and Louisville Road. The initial condition in which the bore would take place included dry soil and “lesser pavement” which has oil and chip and a thin surface course.

Figure 38. 4” water main with 8” steel casing.

In Figure 39 possible signs of frac-out are visible. With closer observation one might be able to see the slightly wet edges of the crack indicating leaking bentonite. Other evidence includes the cracks and leaking bentonite on the soil or shoulder at the side of the road in Figure 40. Figure 41 shows another crack from frac-out with more distinctive wetness around the fracture.

(a) close up (b) at a distance

Figure 39. cracks on the side of the road possibly caused by "frac out."

(a) cracks on the side of the road (b) possible leakage of bentonite on side

Figure 40. Cracks from the "frac-out" propagating to the side of the road.

(a) at a distance (b) close up

Figure 41. Another example of cracks from frac out- note the road look slightly wet around the cracks.

The possible causes of this frac-out include the previously described soil conditions, the amount of drilling fluid used during the bore and the amount the hole was filled after the bore.

CHAPTER 6 CONCLUSIONS AND FUTURE RESEARCH

Horizontal Directional Drilling can be a beneficial technology when executed properly. HDD provides a non-invasive method to install pipelines beneath roads and waterways. HDD also allows for alteration of paths mid-bore which is a useful characteristic in situations like the failure at Newton.

To execute HDD properly and prevent damage from occurring one must consider the following factors:

- Pipe diameter
- Ream diameter
- Pull-back force
- Angle of bore
- Depth of cover
- Allowable deviation from drill path
- Drilling fluid
- Type of cutting head

Typical trends for some factors are:

- A ream diameter that is 1.5 to 2 times the diameter of the pipe.
- An allowable deviation of +/- 1% of bore length.
- An angle of bore between 8 and 20 degrees.
- Radius of Curvature 1,200 the diameter of the pipe being installed.
- Standard depth of coverage of 36”-48” for a pipe without casing.
- Standard depth of coverage of 30”-36” for a pipe with casing.
- A distance of 15 ft from any obstacles.

Other recommendations can be taken from specific state regulations:

- Table 11- Nominal Inside Pipe Diameter and Recommended Bit Diameter (Florida DOT)
- Table 12- Allowable Torque and Thrust/Pullback Dependent on System (Florida DOT)

To determine what should be used for any of these variables, the overall controlling factor is the geology in which the driller is boring. Subsurface conditions control the method of drilling, the type of cutting head is used, the drilling fluid needed, the depth of cover and the pullback force. Knowledge of what is underground also pertains to knowledge of existing utilities, which can then be avoided. This paper introduces two successful HDD projects and one failure. The main cause of failure was a lack of knowledge about what was underground. Secondary to geologic conditions, is the size of the conduit being placed underground. Size can affect how much settlement should be expected and controls the size of cutting head and the type of drilling fluid needed. Adjusting drilling methods to the needs of both the geology and the type of conduit will likely lead to a successful horizontal directional drilling project.
The availability of HDD guidlines from other states in addition to the document experience in Illinois can provide sufficient basis for development of HDD guidelines for IDOT. This would be the next step in this endeavor.

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