Municipal Advisory Board

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MAB Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of HDPE (PE4710) Pipe in Municipal Applications

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FOREWORD

This guide was developed by the Municipal Advisory Board (MAB) and published with the help of the members of the Plastics Pipe Institute, Inc. (PPI).

This publication is intended as a guide for engineers, users, contractors, code officials, and other interested parties for use in the design, construction and installation of high-density polyethylene (HDPE) pressure water piping systems. The local utility or engineer may need to modify this guide to adapt the document to local conditions, operations, and practices.

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The MAB serves as an independent, non-commercial adviser to the Municipal & Industrial (M & I) Division of the PPI. Once adopted, MAB will consider revising this guide from time to time, in response to comments and suggestions from the users. Please send suggestions of improvements to Camille George Rubeiz, PE, F. ASCE, at crubeiz@plasticpipe.org.

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MAB Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of HDPE (PE4710) Pipe for Municipal Applications

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1. Scope

1.1 These guidelines describe the design, selection considerations, and installation procedures for the placement of polyethylene (PE) pipe belowground using mini-horizontal directional drilling (mini-HDD) equipment. The primary focus of this document is on pipe constructed of **high density polyethylene (HDPE) with a material designation code of PE4710, for municipal applications, including potable water and sewers**. For convenience, the term “HDPE” is used as a generic term to refer to the PE4710 material. Related properties for this material are provided in the “Plastics Pipe Institute Handbook of Polyethylene Pipe”.(**1**)[1] The pipe may be supplied in continuous lengths on a reel or discrete segments assembled together, typically by fusion, in the required length.

1.2 Horizontal directional drilling (HDD) represents a form of trenchless technology. The equipment and procedures are intended to minimize above and below ground surface damage, restoration requirements, and disruption to traffic, with little or no interruption of existing services. *Mini*-horizontal directional drilling (mini-HDD), also know as “guided boring”, is typically used for the relatively shorter distances, shallower depths, and smaller diameter pipes associated with local distribution lines, in comparison to *maxi*-horizontal directional drilling (maxi-HDD), typically used for longer distances, greater depths, and larger diameter pipes, such as major river crossings. ASTM F1962 provides detailed information and guidelines for the placement of polyethylene pipe using maxi-HDD technology.

1.3 *In contrast to ASTM F1962, from which the present guidelines are partially derived (see Section 7 and Appendices B and C), the present document is intended to provide useful information for the less sophisticated, and less well-controlled, mini-HDD technologies and installations, as reflected in the planning and design practices. Thus, mini-HDD warrants more simplified analysis, and correspondingly more conservative assumptions, than used in ASTM F1962. The objective is to provide an outline and brief description of proper procedures to be followed for mini-HDD operations, with reference to existing industry standards and guides that provide greater detail, as appropriate. However, it is also the intention of this document to provide useful details for specific aspects that may not be conveniently available in other sources. Examples of the latter include drill rig setup information, such as setback distances, as a function of drill rod characteristics and rig setup parameters, as well as a simple methodology for selecting the strength (wall thickness) of HDPE pipe as a function of route geometry.*

1.4 For convenience, the dimensions and other quantities are provided in the customary inch-foot-pound units.

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[1] The boldface numbers in parentheses refer to the list of references at the end of this document.

2. Referenced Standards and Specifications

ASCE 108, *ASCE Manuals and Reports on Engineering Practice No. 108, Pipeline Design for Installation by Horizontal Directional Drilling*

ASTM F714, *Specification for Polyethylene (PE) Plastic Pipe (SDR-PR) Based on Outside Diameter*

ASTM F1055, *Standard Specification for Electrofusion Type Polyethylene Fittings for Outside Diameter Controlled Polyethylene and Crosslinked Polyethylene (PEX) Pipe and Tubing*

ASTM F1962, *Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings*

ASTM F2620, *Standard Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings*

ASTM F3190, *Standard Practice for Heat Fusion Equipment (HFE) Operator Qualification on Polyethylene (PE) and Polyamide (PA) Pipe and Fittings*

AWWA C901, *Polyethylene (PE) Pressure Pipe and Tubing, 3/4 in. (19 mm) through 3 in. (76 mm), for Water Service*

AWWA C906, *Polyethylene (PE) Pressure Pipe And Fittings, 4 in. through 65 in. (100 mm through 1,650 mm), for Waterworks*

CI/ASCE 38, *Standard Guidelines for the Collection and Depiction of Existing Subsurface Utility Data*, American Society of Civil Engineers

MAB-01, *Generic Electrofusion Procedure for Field Joining of 12 Inch and Smaller Polyethylene (PE) Pipe*

MAB-02, *Generic Electrofusion Procedure for Field Joining of 14 Inch to 30 Inch Polyethylene (PE) Pipe*

OPSS 450, Ontario Provincial Standard Specification *Construction Specification for Pipeline and Utility Installation in Soil by Horizontal Directional Drilling*

OSHA 3075, *Controlling Electrical Hazards*

TIA/EIA-590A, *Standard for Physical Location and Protection of BelowGround Fiber Optic Cable Plant*

3. Terminology

3.1 "Horizontal Directional Drilling" (HDD) is a technique for installing product pipes, including utility lines, below ground using a surface-mounted drill rig that launches and places a drill string at a shallow angle to the surface and has tracking and steering capabilities.

3.1.1. The drill string creates an initial (pilot) bore hole, of several inches diameter, in an essentially horizontal path or shallow arc which may be enlarged during a secondary operation, or sequence of such operations, through use of a reamer. The product pipe or utility line is typically installed during the final reaming operation, or, if necessary, as a separate, last step in the process. The predetermined path of the bore is maintained by tracking the path of the pilot bore using a manually operated overhead receiver or a remote (wireline or wireless) tracking system, and performing steering and path corrections by controlling the orientation of the drill head. The drill head has a directional bias, such as a slanted face or mud motor on a slightly bent portion ("bent sub") at the leading drill rod. Turns and corrections are accomplished by pushing the drill string forward with the drill head oriented in the direction desired. Continuous rotation of the drill string allows the drill head to bore a straight path. Soil penetration is accomplished using high pressure, low volume fluid jets and/or mechanical cutting. The drilling fluid volume is controlled to avoid or minimize the creation of voids during the initial boring and back-reaming operations. The drilling fluid serves several purposes, including stabilization of the bore hole, removal of cuttings, lubrication for the drill string and product pipe, and cooling the drill head and transmitter electronics. Typically, the resultant slurry created by the combination of the drilling fluid and soil cuttings gradually solidifies into a solid mass encapsulating the product pipe.

3.1.2 "Mini-Horizontal Directional Drilling" (mini-HDD) is a class of HDD typically employed for boring segments less than 600 feet in length, at depths up to 15 feet, and placing pipes up to 12 inches diameter. The equipment is characterized by a thrust or pullback capability of up to 20,000 lbs, with a torque less than 950 ft-lbs. Mini-HDD machines weigh less than 9 tons.(**2**)

3.1.2.1 Mini-HDD equipment is typically used for installing pipes for water, sewer and gas lines, as well as for ducts and conduits for local distribution utility cables (electric power, communications), beneath local streets, private property, and along right-of-ways. Smaller mini-HDD machines, sometimes referred to as "micro-HDD" equipment, or possibly even pit launched, are appropriate for installing pipes for service lines or laterals to homes or businesses. Improved technology and greater experience gained by contractors (excavators) have also allowed mini-HDD equipment to place lines on an accurate grade, including gravity sewer lines**(3),** possibly combined with the use of a "pilot tube"**(2).** The creation of the pilot bore hole and the reaming operations are generally accomplished by fluid jet cutting and/or the cutting torque provided by rotating the drill string. The locating and tracking systems may utilize a manually operated overhead (walkover) receiver to follow the progress of the initial pilot bore, or possibly a remote tracking/steering system. Figures 1 and 2 illustrate typical mini-HDD equipment and pilot boring and back-reaming operations, including product pipe or utility line placement.

3.1.3 "Maxi-Horizontal Directional Drilling" (maxi-HDD) is required for installations far beyond the capability of mini-HDD technology. Maxi-HDD is capable of accurately boring holes on the order of a mile in length, and placing pipes of up to 48 inches diameter or greater, at depths up to 200 ft. Thrust/pullback and torque capability can be as much as 100,000 lbs and 80,000 ft-lbs, respectively, and the machines may weigh as much as 30 tons.(**2**), or greater. Maxi-HDD is therefore appropriate for placing pipes under large rivers or other major obstacles. The corresponding equipment and technology are very sophisticated relative to that of mini-HDD, including wireline or wireless tracking systems, and the applications tend to be individual, relatively complicated major installations, requiring the services of experienced engineers throughout the process, including during the planning, design and installation phases. Maxi-HDD machines typically utilize mud motors on a bent-sub for cutting in soil or rock formations. ASTM F1962 provides detailed information and appropriate practices for maxi-HDD operations.

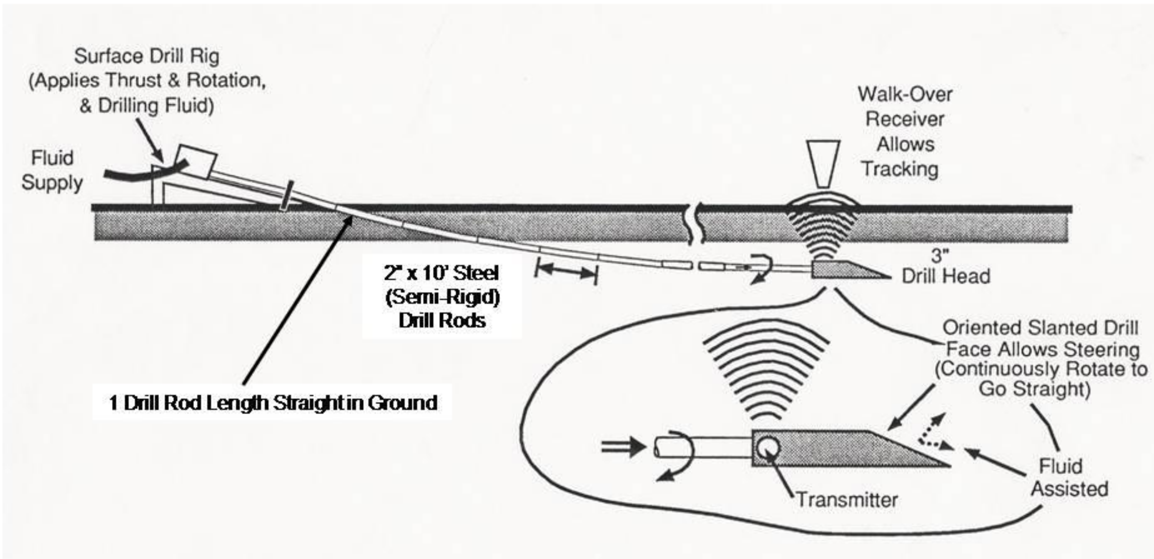

Figure 1 Typical Mini-HDD Equipment and Pilot Boring Process
(Source: Outside Plant Consulting Services, Inc.)

3.1.4 "Midi-Horizontal Directional Drilling" (midi-HDD) is a category that is intermediate to mini-HDD and maxi-HDD, with regard to equipment capabilities and planning and engineering effort. Midi-HDD may be employed for boring paths up to 1,000 feet in length, at depths as much as 75 feet, and placing pipes up to 24 inches diameter. Midi-HDD equipment may be used for crossing beneath rivers and roadways. It is noted that the distinctions between mini-HDD, midi-HDD and maxi-HDD vary, depending upon the reference, and is not always entirely consistent with that indicated in Section 3.1.2.(**3**) *Guidelines for the use of midi-HDD machines and practices may be obtained from the present guidelines, as suggested herein, and/or ASTM F1962, depending upon the particular application and the judgment of the contractor or engineer*.

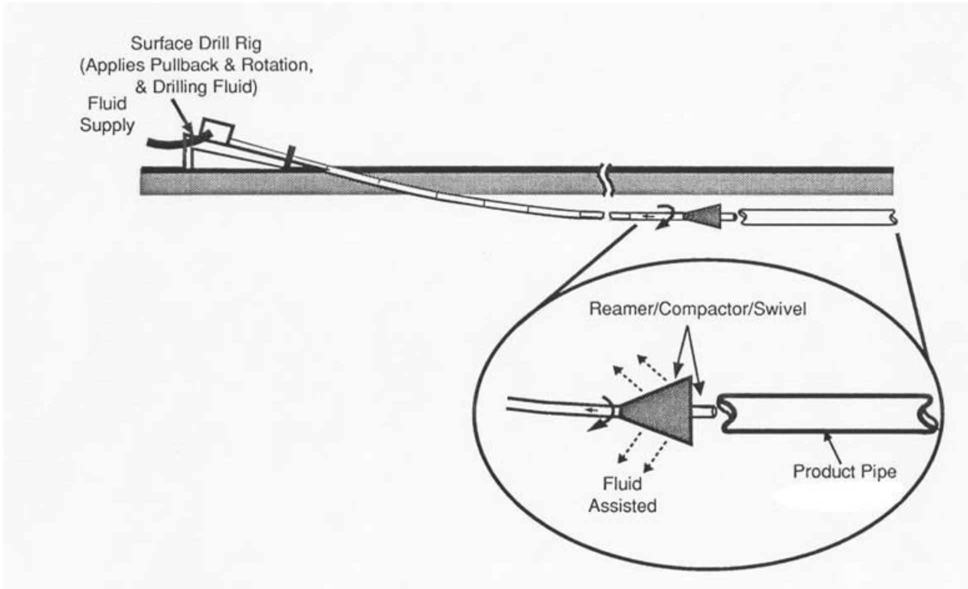

Figure 2 Typical Mini-HDD Back-Reaming and Pipe Pullback Process
(Source: Outside Plant Consulting Services, Inc.)

3.2 "Dimension Ratio" (DR) is the ratio of pipe outer diameter to minimum wall thickness. Higher DR values therefore correspond to thinner, weaker pipes and lower values to thicker, stronger structures.

3.2.1 "Standard Dimension Ratio" (SDR) refers to specific values of dimension ratio.

3.2.2 The Iron Pipe Size (IPS) system is based on specified outer diameters and SDR values, such as provided in ASTM F714, AWWA C901, or AWWA C906.

3.2.3 The Ductile Iron Pipe Size (DIPS) system is based on specified outer diameters and SDR values, such as provided in ASTM F714 or AWWA C906.

3.3 The degree of bending to which a drill rod, or product pipe, may be subject, without damage or degradation, is a function of the size and material of the item. There are several alternative measures of the degree of allowable curvature as presently used in the industry; see Figure 3.

3.3.1 "Radius of Curvature", or "Bend Radius", is the distance from the center of the circular path or configuration, in a plane, to the perimeter.

3.3.2 "90° Bend Radius is the distance along a 90° portion (quadrant) of the perimeter of the circular path.

3.3.3 "Degrees per Rod" is the angular change along a single rod length.

3.3.4 The various measures for quantifying the allowable curvature are related by the following formulae:

$$\text{90° Bend Radius (ft)} = 90 \times \text{Rod Length (ft)} / \text{Angular Change (deg/rod)} \quad (1a)$$

$$\text{Radius of Curvature (ft)} = \text{90° Bend Radius (ft)} / 1.57 \quad (1b)$$

Radius of Curvature (ft) =57.3 x Rod Length (ft) / Angular Change (deg/rod) (1c)

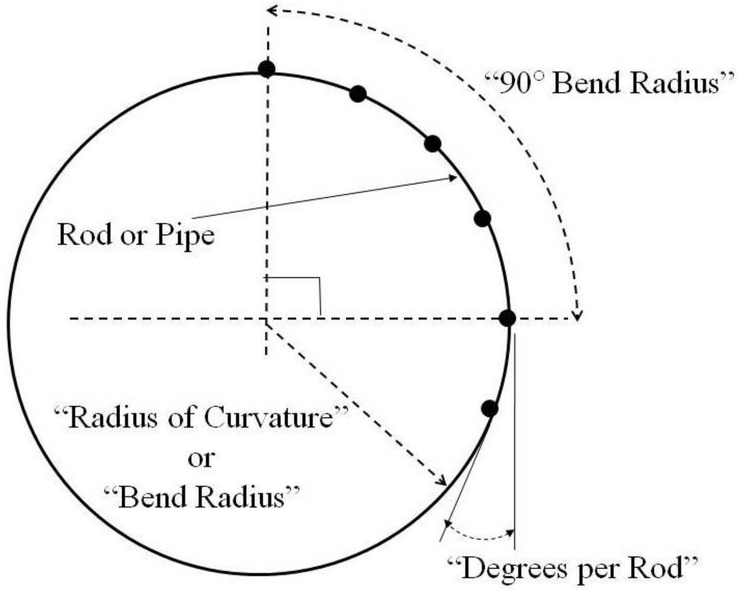

Figure 3 Rod or Pipe Curvature Terminology
(Source: Outside Plant Consulting Services, Inc.)

Figure 4 illustrates the above relationships. See Appendix A for examples quantifying the bending capability of typical drilling rods, using the various terms. There is significant quantitative difference between the 90° Bend Radius and Radius of Curvature. The latter (Radius of Curvature) is approximately $^{2}/_{3}$ of the 90° Bend Radius. For convenience, except where otherwise indicated, the Radius of Curvature (Bend Radius) measure will be used in the present document.

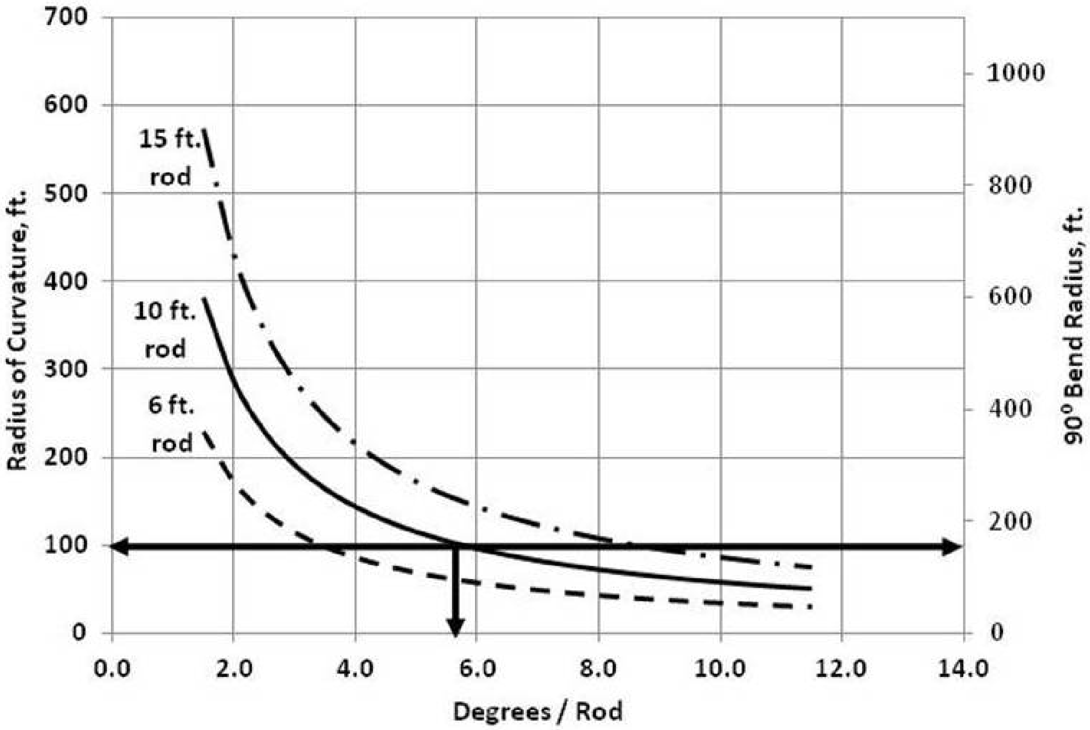

Figure 4 Allowable Curvature Relationships
(Source: Outside Plant Consulting Services, Inc.)

4. Preliminary Site Investigation

Section 4 describes the background information that would assist the contractor or engineer in planning the project, in order to help ensure an efficient, successful installation during the later construction phase. This investigation includes an evaluation of surface and subsurface conditions to determine the compatibility of the site with the proposed directional drilling operation. Of particular importance is the need to understand the presence and nature of **existing belowground utilities**, as discussed in Section 4.2 in order to avoid damage to such lines.

4.1 *General Considerations*

4.1.1 Unlike maxi-HDD installations, typical mini-HDD projects may be brief undertakings, requiring as little as a single day, such as for a road crossing, or less for a service line, to extended periods of many months or more for a large scale upgrade of degraded utility distribution lines serving an entire community. The feasibility and desirability of using mini-HDD for a particular project, as opposed to a larger machine (e.g., midi-HDD), or open-cut trenching, depends upon many factors, including soil conditions, location of other utilities, environmental aspects, and particular features and characteristics of the existing area. The size and anticipated duration of the project is an important consideration with respect to the amount of preliminary planning and investigations that may be practical.

4.1.2 For relatively extensive projects, such as for upgrading utility lines across a community, the owner of the facility to be placed or his representative (e.g., a geotechnical engineer), or the (potential) contractor, should perform a preliminary site investigation well in advance of the construction. Ideally, the owner would conduct as much of the preliminary investigation as possible to allow a meaningful and equitable bidding process. The contractors would conduct additional investigations to assist them in the bidding process, as well as to provide guidance for the actual construction, following awarding of contracts. For projects of very limited duration, the contractor may perform only a brief study, to verify the general feasibility and determine the equipment and resources required to successfully complete the task.

4.1.3 The presence of special obstacles or situations must be considered. For example, the presence of pollutants or contaminants in the construction area must be identified, including corresponding arrangements for spoil disposal.

4.2 *Existing Belowground Utilities*

4.2.1 Mini-HDD technology was primarily developed as means of installing new utility lines in developed areas, including residential applications, and at various crossings of limited extent, with minimal surface damage. However, in order to avoid damage to belowground facilities, public or private, as well as to judge the magnitude of the effort, it is essential to understand the nature of such lines and structures, including types and likely locations and depths. Information obtained at the preliminary stage will help guide the subsequent more detailed inspections and locations required immediately prior to, and during, the actual construction stage.

4.2.2 The new distribution lines will generally be placed along the main right-of-way (ROW), and associated service lines will typically be installed laterally beneath the individual properties. Since minimum specified clearances must be maintained from existing lines in the ROW, the available remaining space within the ROW should be verified, as a measure of the potential difficulty of the installation. New distribution cables will routinely be crossing existing service lines for individual buildings, residences or structures, which will be exposed during the construction stage (Section 6.2.3). In addition to the utility service lines, the presence and frequency of privately installed electric or lawn sprinkler lines within the community should be considered.

4.2.3 **Important regulations and damage prevention procedures are discussed in Section 6.**

4.3 *Surface Investigation*

4.3.1 The surface area of immediate interest corresponds to that specified or desired by the owner of the new facility, consistent with the utility network architecture, including the number and size of pipes required, and their termination points.

4.3.2 The contractor should review the construction site to verify there is sufficient room for the drill rig and auxiliary equipment, vehicles, trailers, ... at both ends of the bore. The drill rig working areas should be reasonably firm, level, and suitable for the movement of rubber tires or treads. For PE pipe of relatively large diameter, not provided on a reel, for which pipe prefabrication is necessary, appropriate space must be provided for the fusion equipment, as well as an area for temporarily placing the assembled pipe. The presence of possible interfering aboveground structures or overhead power or telephone lines should be considered with regard to equipment movement.

4.3.3 The ability for the tracking and monitoring system to function properly may be hampered by the local conditions, along the path to be bored. Conventional walkover receivers require direct overhead access, while more sophistical systems may allow remote tracking. Potential sources of interference to the electronic locators of mini-HDD tracking systems include overhead structures or wire lines, as well as steel-reinforced concrete sidewalks, driveways, and roads.

4.3.3 The use of drilling fluids requires that a source of water, preferably potable, be available for mixing. Although drilling fluids are not considered hazardous materials, excess fluid and associated spoils must be disposed of properly. The location of an appropriate disposal area, consistent with local regulations, should be identified in advance of the construction, as part of the preliminary or planning phase.

4.3.4 Although noise levels associated with mini-HDD equipment are generally not excessive, there may be restrictions on work hours in areas near residential buildings, hospitals, or other institutions.

4.4 *Subsurface Investigation*

4.4.1 The effectiveness and efficiency of most belowground construction operation is dependent upon the soil conditions, and is especially relevant for HDD technology. Directional drilling installations must simultaneously penetrate and maneuver through the soil, using less aggressive techniques than conventional open-cut trenching. Problematic soil conditions can slow progress and/or lead to damage to public and private property and safety hazards. It is therefore important to perform an investigation of the local soil characteristics and ground conditions, including potential obstacles, to verify the feasibility of employing mini-HDD for the proposed project, as well as to result in more realistic cost estimates and avoid inequities to the owner or contractor. In order to be cost-effective, however, the extent of the subsurface investigation, should be compatible with the magnitude of the overall project.

4.4.2 The soil investigation should attempt to evaluate conditions at the nominal placement depth of the product pipe. Mini-HDD technology is capable of placing utility lines or pipes as deep as 15 ft. In many cases, however, the desired or required depth for utility distribution lines will be relatively shallow -- possibly within five or six feet of the surface. (Greater depths may complicate subsequent repair and maintenance procedures.) Such mini-HDD installations will also likely be in established areas, including residential communities. Thus, the relevant belowground conditions are not necessarily that of virgin soil at greater depths, but that of disturbed or filled areas, possibly including various debris or obstacles resulting from prior construction activities.

4.4.3 For relatively large scale projects, the investigation may include a review of published reports from various government agencies (e.g., state or county soil conservation service reports, U. S. Geographic Survey, U. S. Army Corps of Engineers reports). However, in recognition of the possible lack of correlation of such virgin soil studies relative to the possibly disturbed conditions, at shallow depths, as described above, records from previous local construction projects, of large or small extent, would be of particular value, if available from other utilities or owners. The latter information may also reveal the presence of belowground structures, including those that may have been abandoned. Construction information and experiences from previous local projects involving trenchless methods, requiring boring of any type, would be most relevant.

4.4.4 *Soil Investigation Tests* – If warranted by the scope of the project, existing subsurface information may be supplemented by local soil tests, at strategic locations and relevant depths, to verify the conditions. Possible characteristics to be evaluated include standard classification of soils, standard penetration test values, rock type and strength and (Mohs) hardness.(ASCE 108) ASTM F1962 provides reference ASTM test methods for soil evaluation studies, as appropriate. Additional information is available elsewhere.(**4**)

4.4.5 For some mini-HDD applications, such as large scale upgrades of distribution facilities in established areas, random blockages due to man-made debris would not be evident based upon soil testing at a limited number of locations. Depending upon the depths of interest, object dimensions, and soil conditions, existing technology (e.g., ground penetrating radar) may be capable of electronically scanning the subsurface to detect obstacles of various sizes. Such technologies are continuing to evolve and their practicality, including economic feasibility, will depend upon the local conditions and concerns.(CI/ASCE 38)

4.4.6 *Suitability of Soil Conditions* -- Table 1 indicates the suitability of horizontal directional drilling as a function of the general characteristics of the soil conditions in the area and depths of interest.

Table 1 Applicability of Mini-HDD (or Midi-HDD) for Various Soil Conditions (2)

Soil Conditions	Applicability	
	Mini-HDD	Midi-HDD
Soft to very soft clays, silts, and organic deposits	Yes	Yes
Medium to very stiff clays and silts	Yes	Yes
Hard clays and highly weathered shales	Yes	Yes
Very loose to loose sands (above water table)	Yes	Yes
Medium to dense sands (below water table)	Yes	Yes
Medium to dense sands (above water table)	Yes	Yes
Gravels and cobbles less < 2 - 4 in. diameter	Marginal	Marginal
Soils with significant cobbles, boulders, and obstructions > 4 - 6 in. diameter	No	Marginal
Weathered rocks, marls, chalks, and firmly cemented soils	Yes	Yes
Slightly weathered to unweathered rocks	Marginal	Marginal

4.4.6.1 The indications of applicability in Table 1 assume that the contractor and crew is trained and experienced in the use of mini-HDD equipment and technology, employs appropriate equipment for the specific soil condition (drill head, reamers, ...), and has a working knowledge of drilling fluids. The proper use of drilling fluids is a critical aspect of HDD operations, the importance of which is often underestimated. Preferably, contractors have successfully completed industry training courses or seminars specifically addressing mini-HDD methods (see Section 5.9), and have a minimum of one year field experience, and completed 30,000 ft of construction in related projects.

4.4.6.2 "Marginal" conditions will generally result in a lower success rate, but which may be positively impacted by greater contractor experience and training, and the use of consulting services by industry suppliers. Some applications may not be economically feasible for directional drilling using present technology; see Section 4.5.

4.5 *Non-HDD Situations*

4.5.1 Although the present guidelines focus on the use of mini-HDD technology for the installation of polyethylene pipe as the method of choice established areas, it is recognized that in some cases other techniques may be more appropriate. Table 1, for example, provides guidelines for evaluating the feasibility of mini- (or midi-) HDD as a function of soil conditions. Problematic situations may represent isolated portions of a larger overall project, for which individual lines may be installed using alternate methods.

4.5.2 If the conditions, as described above, are not conducive to the use of mini-HDD, it is possible that more conventional methods may be acceptable for isolated situations. Open-cut trenching may be feasible in areas that would not require extensive restoration expenses.

5. Safety and Environmental Considerations

Section 5 discusses potential safety issues and related procedures during buried construction, with special emphasis on means to avoid or minimize risks during mini-HDD operations. Employees must be trained to prevent injuries to themselves during the operation of the equipment and be prepared to mitigate the effects of accidents. Electric power and gas line strikes are specifically addressed. Although not considered to be hazardous materials, the proper handling and disposal of drilling fluid is also discussed.

5.1 *General Considerations*

Safety is a primary concern in any construction activity, including those utilizing HDD. Such issues may be considered to fall into two categories – those directly related to the setup and operation of the equipment itself, and those associated with the proper implementation of utility location, identification and marking procedures intended to avoid contacting and damaging existing utilities. Section 5 addresses the equipment usage issues and Section 6 primarily focuses on procedures to eliminate or reduce hazards associated with damaging existing utilities, including during the initial boring or back-reaming operations.

5.1.2 *Equipment Usage* – It is necessary to ensure that injury does not result to construction personnel or bystanders as a result of the operation of the drill rig and auxiliary equipment. Therefore, it is essential that bystanders, as well as personnel not directly required in the operation, be excluded from the immediate vicinity of the mini-HDD equipment and, to the extent practical, from along the entire bore path. Barriers and warning signs should be visibly placed at the equipment or associated hardware.

5.1.3 *Traffic Control* – Since a primary advantage of HDD, as compared to conventional construction practices, is the minimal disturbance to the landscape and disruption of normal traffic flow, it is important to maintain proper vehicular control. The combination of warning lights, traffic cones and flagmen must be used to ensure a safe working environment for the construction personnel as well as non-construction related passersby.

5.1.4 *Shoring* – Although HDD is a "trenchless" construction method, a limited number of discrete pits are typically required, such as for utility terminations, exposing existing utilities at crossings, to collect excess drilling fluid and spoils, or possibly to clear local blockages. When a worker is required to perform tasks in excavations where a cave-in hazard exists or the excavation is in excess of 5 ft depth, shoring, sloping, or shielding methods must be used to provide employee protection.

5.2 *Safety Training*

Both the contractor and its employees are responsible for ensuring proper safety procedures are followed. The employer must provide access for appropriate training and safety courses, and the employees must be aware of their capabilities and limitations for any assigned work; see Section 5.9. This is particularly the case for operators of mechanized equipment. As a minimum, all drill unit operators and associated personnel, including those in the vicinity of the drill rig or at the opposite (exit) end of the bore, should have received training in first aid and CPR and be familiar with the hazards of working in the vicinity of electrical lines.(OSHA 3075) **The following brief recommendations and guidelines are not intended to replace or diminish the need for proper safety training programs, as provided within the industry or from equipment manufacturers**.

5.3 *Work Clothing*

Proper clothing includes that which should be worn during mini-HDD installations, as well as that which is not appropriate, since it may cause injuries. Protective safety glasses and/or goggles and head gear should be worn at all times, as well as electrical insulating boots and gloves. All protective items should be regularly inspected and maintained to preserve their insulating properties. Potentially **hazardous apparel**, to be avoided, includes **unnecessarily loose clothing or jewelry** since these items may become snagged on moving mechanical parts.

5.4 *Machine Safety*

Due to the potential hazards of operating mechanized equipment of any type, it is important for mini-HDD personnel to exercise special care and comply with accepted industry practices. The drill rig equipment includes chain drives, gear systems, and vises used in combination with heavy drill rods which are inserted, removed, advanced or retracted, representing opportunities for personal injury. Safety shields must not be removed, overridden or compromised in any manner. The mini-HDD equipment, including electrical strike safety features, must be checked at the beginning of each work day to verify proper operation.

5.4.1 *Hydraulic Fluid* – In comparison to the more visible hazards represented by the moving mechanical components, serious injuries may be inflicted by the less apparent hydraulic oil used to power the drill rig. High pressure fluid can penetrate skin or cause blood poisoning. Operating pressures are on the order of several thousand psi, and may lead to leaks at vulnerable connections and damaged hoses. The hoses and connectors must be properly maintained to minimize the risk of leaks and the system pressure should be relieved before disconnecting any hydraulic lines. **Suspected leaks must not be checked using exposed parts of the body**.

5.4.2 *Drilling Fluid* – Similar precautions as above (Section 5.4.1) apply to drilling fluid used to for soil cutting and reaming. The drilling fluid supplements the mechanical cutting provided by the drill head or reamer and, depending upon the equipment design and operation, may also reach several thousand psi within the drill rod assembly, and may lead to leaks at vulnerable connections and damaged hoses. Drilling fluid hoses and connectors must be properly maintained to minimize the risk of leaks and, before inserting or removing individual drill rods from the drill string, the drilling fluid pressure at the rig must be relieved to avoid high velocity fluid squirting from the joint. The reduced drilling fluid pressure level must be verified by the corresponding pressure gauge to verify the pressure has been relieved before disconnecting any rods. As above, **suspected leaks must not be checked using exposed parts of the body**.

5.4.2.1 Due to the possibility of soil clogging the drilling fluid ports of the drill head or reamer, the attempt to relieve pressure at the rig may not result in an immediate loss of pressure within the drill string. In such cases, special care is required when disconnecting the rod. Clogged drill components should be cleared prior to continuing the operation, possibly requiring the drill string to be retracted or exposed.

5.4.2.2 The exit point for the pilot bore represents a potentially hazardous location, from which a safe distance must be maintained by all personnel. The drilling fluid pressure should be relieved as soon as the drill head emerges at the far end, as well as when the reamer emerges from the entry point at the rig end.

5.5 *Electrical Strike*

Although the risk of striking existing belowground utilities or structures is greatly diminished by following proper industry practices, including those described in Section 6, it is difficult to ensure that such an event may not occur. Particular dangers exist with respect to striking electrical or gas lines due to their widespread usage and hazardous nature. **The contractor must follow State or local regulations regarding belowground construction.** Although reluctant to deliberately disrupt service to customers, in some cases the **electric power utility may be requested to shut off service** in the area during the construction activity. These situations may include those where it is difficult to reliably locate or track the progress of the drilling operation due to uncontrollable interference or similar problematic environments. In such cases, as a minimum precaution, the electric power utility should be requested to **disable the automatic reclosure of circuit breakers** (restoration of power), to prevent personnel exposure after the initial open circuit condition (loss of electric power). As a result of these special requests, the utility will be especially aware of the construction activities, leading to more rapid response in the event of an accident.

5.5.1 **An electrical strike safety system must be employed**, and checked at the beginning of each work day to verify proper operation. Such equipment typically includes an electrical strike sensing system, supplemented by grid mats, ground rod, barriers, and proper electric bonding hardware for connecting the components. Workers must wear proper clothing (Section 5.3). All personnel should wear electrical insulating boots and gloves at all times.

5.5.2 A successfully completed pilot bore does not ensure that a utility line may not be damaged during the subsequent reaming or pullback operation, as the bore hole is enlarged. In the event of an electrical strike during the latter operation, exposure to hazardous voltage may exist at both ends of the bore. For example, if several pre-reaming operations are performed, steel (conductive) drill rods are inserted at the bore exit point to maintain the path as the rods are removed at the bore entry. In such cases, grid mats, ground rods, and an electrical bonding system must be used at the bore hole exit, as well as in the vicinity of the drill rig. In comparison to metallic product pipe, the non-conducting nature of plastic pipe essentially eliminates or greatly reduces corresponding risks at the bore exit point (pipe entry) during final pullback of the product pipe.

5.5.3 Specific emergency steps following an electrical strike are provided within industry guidelines, and include precautions regarding equipment and worker movement. The **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**5**)

5.6 *Natural Gas Line Strike*

Since it is difficult to accurately locate existing plastic pipe lines, there is a correspondingly greater risk of striking such facilities. **The contractor must follow State or local regulations regarding such belowground construction.** In some cases, the **gas utility may be requested to shut off service** in the area during the construction activity. Such situations may include those where it is difficult to reliably locate or track the progress of the drilling operation due to uncontrollable interference or similar problematic environments. As a result of these special requests, the utility will be especially aware of the construction activities, leading to more rapid response in the event of an accident.

5.6.1 Specific emergency steps following a gas line strike are provided within industry guidelines, and include shutting and abandoning equipment, and evacuating the area of workers and the public. The **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**5**)

5.7 *Damage to Existing Utilities*

In general, the facility operator and "One-Call Center" or equivalent, (see Section 6.1.1) should be contacted as soon as possible following damage (break, nick, gouge, ...) to other facilities. If there is **danger,** such as due to leakage of gases or liquids, the **facility operator must be contacted immediately** and a call to **911** should be made for emergency response.(**5**)

5.8 *Environmental*

Drilling fluid serves many useful functions, including aiding soil penetration, removal of spoils, bore hole stabilization, lubrication for the drill rods and product pipe, and cooling of the drill head and transmitter electronics. Typical drilling fluid components are not hazardous materials, with the waste material usually considered as excavation spoils, not requiring special disposal procedures. The volume of spoils to be removed from the site may be significantly reduced by means of drilling fluid recirculating systems. The most common additive is bentonite, a naturally occurring type of clay. If clay represents a large component of the native soil in the construction site, a polymer additive may be more appropriate. The bentonite or polymer material used should be National Sanitation Foundation certified. The additive materials should be chemically inert, biodegradable, and non-toxic, and petroleum-based or detergent additives should not be used.(OPSS 450)

5.8.1 *Contaminated Area* – Although the bentonite-water, or commonly used polymer-water, slurry, is not inherently a hazardous material, special disposal may be required when drilling in an area known to be contain toxic pollutants. In such cases, disposal must be in accordance with local laws and regulations, and it may be necessary to de-water the spoils, transport the solids to an appropriate disposal site, and treat the water to meet disposal requirements. It may be also necessary to add grouting to the drilling fluid to ensure proper sealing of the bore hole to eliminate a possible passage for contaminants. Special drilling fluid pumps may then be required.

5.8.2 *Collection Pits* – In order to maintain a neat, orderly work site, occasional small pits must be available for collecting the excess drilling fluid or slurry exiting from the bore hole. A clean work site will help ensure the installation of a clean product pipe, reducing the need to later flush out mud or debris from within the pipe. Excessive drilling fluid and mud in the area may impair the connections and associated grounding characteristics of the equipotential grid mat system. Pits may already be present or required such as for utility access or connections at the ends or along the bore (Section 8.4), thereby serving as convenient receptacles. If not otherwise present, small pits should be provided at the ends, and possible intermediate points to serve this function. The pits should be emptied as necessary.

5.9 *Proficiency*

It is required that employees operating mechanized equipment, including mini-HDD machinery, be qualified for their tasks, and that their employer (contractor) ensure that the operators and other workers in the vicinity have demonstrated proficiency in their duties, particularly safety issues. Primary personnel must have proper training, including classroom and field experience. Industry based HDD training and/or certification courses are available from equipment manufacturers, as well as professional organizations.[2]

5.9.1 *Submissions* – The contractor should submit the following information to the owner or its representative (OPSS 450):

- Work plan outlining the procedure and schedule to be used to execute the work
- List of personnel, including backup personnel, and their qualifications and experience
- Traffic control plan
- Drilling fluid management plan including potential environmental impacts and emergency procedures and associated contingency plans
- Safety plan including the company safety manual and emergency procedures.

[2] HDD training and/or certification courses are available from various sources, including the Center for Underground Infrastructure Research and Education at the University of Texas at Arlington, the Centre for Advancement of Trenchless Technologies at the University of Waterloo, Bowling Green State University, the Trenchless Center at Louisiana Tech University, and the North American Society for Trenchless Technology.

6. Regulations and Damage Prevention

In order to help avoid the potential hazards described above, proper procedures must be adopted to reduce the likelihood of damaging existing utilities. Section 6 discusses such practices, including "call-before-you dig" (811); locating and marking existing utilities, as well as exposing, when appropriate; avoiding mechanized digging within the required tolerance zone; and the use of Subsurface Utility Engineering.

6.1 *General Considerations*

Following proper procedures and regulations will help avoid damage to existing belowground facilities, and also reduce safety and environmental hazards for the workers and the public. Government issued permits are required prior to performing any significant construction. The owner of the facility to be installed is responsible for obtaining the permit, possibly with the cooperation and assistance of the contractor. Permits are typically issued by a municipality, county and/or state, depending upon the impacted areas. In some cases, approval may be required from additional agencies (e.g., Environmental Protection Agency). Permits provide approval for crossing beneath roads and railroads, and for installing lines along the right-of-way or within easements. The permits may specify construction requirements to protect existing facilities as well as the public. In some cases, the allowable or required method(s) of construction are specified, including directional drilling and/or open-cut trenching.

6.1.1 *"Call Before You Dig"* – The proliferation of belowground utilities, often mandated by State or local regulations, results in increasing difficulties in avoiding damage to existing facilities when placing new buried lines. Most states have therefore instituted damage prevention laws which address the responsibilities of the facility owners (i.e., owners of existing subsurface utilities) and that of contractors placing the new product pipe. These laws typically require the contractor to follow a "**call-before you dig**" procedure, using a universal **811** number. Each facility owner should belong to a local "**One-Call**" type notification service, or equivalent. The contractor must provide an advance notification of several days to the One-Call center, to allow the various utilities to locate and mark their facilities. Notification is typically required within an interval 48 to 240 hours (2 to 10 days) in advance of actual construction, excluding weekends and holidays.(TIA/EIA-590A) (**5**)

6.1.2 *Other Information Sources* – When a One-Call service, or equivalent, does not exist in a particular area, or where regulations do not require facility owners to belong to such a service, the contractor should check local record centers to identify and contact all possible facility owners, as part of the utility location process, prior to initiation of construction. Sources for obtaining such information include various public records, including those of the local municipal or county public works departments, state public service commission, state corporation commission or attorney general office, or directly from utilities, private companies or institutions known to provide service or have facilities located in the area in question. If a known utility or facility owner does not send a representative or make other arrangements to mark its lines, the contractor should attempt to obtain as much information as possible from the owner, to aid in its location.(TIA/EIA-590A)

A particularly important example of the need for properly identifying all utilities relates to municipal sewer lines, which may not be registered with a One-Call bureau. The consequence of not locating such lines has resulted in the occurrence of "cross-bores", in which the boring operation penetrates a sewer line or lateral and pulls back a gas line, without any immediate obvious indication that this has occurred. At some time in the future, a cleaning operation of the lateral may then result in damage to the gas line, with potential hazardous consequences. **It is critical to avoid or prevent the occurrence of such cross-bore events.**

6.2 *Locating and Marking*

All existing belowground facilities, including lines and structures, must be identified, located, and marked -- including electrical and communications (telephone, CATV, …) cables; natural gas, water and sewer lines; pipes carrying other liquids, chemicals, or gases; and oil tanks or other possible structures. Industry accepted damage prevention procedures such as outlined in CI/ASCE 38, TIA/EIA-590A and other sources(**5**), and briefly summarized herein, should be followed by the contractor to reduce the possibility of damage to existing facilities.

6.2.1 Prior to the arrival of the locators, the mini-HDD contractor should mark the path of the proposed bore route, preferably using a white line or flags, and indicate its name or other means of identification. Although it is the responsibility of each individual facility owner to mark the location of its utility lines, pre-construction meetings with the contractor are useful, and may be particularly important for unusual or difficult projects. Such meetings may be necessary when requesting temporary disruption of electric or gas service, to reduce likelihood of associated safety hazards. In general, belowground facilities within a minimum lateral distance of 10 ft of the proposed bore path should be marked, unless within a greater distance is specified by State or other regulations. Other facilities known to be in the vicinity, but believed to be beyond the 10 ft, or otherwise required minimum distance, should be confirmed by the corresponding owner. The actual paths and depths of identified utility lines are typically not provided during this preliminary process. They may subsequently be determined by the owner of the proposed pipe line or its representative, or the mini-HDD contractor, as described below; see also Section 6.4

6.2.2 *Locating Equipment* –Locating equipment and procedures are generally based upon the transmission of an electrical signal along an available metallic (conducting) element associated with the utility line of interest, typically in combination with an aboveground receiver (Figure 1). The lateral position, and to some extent the depth, are determined by the characteristics of the received signal. For non-metallic (non-conducting) lines or facilities, a metallic tracer wire or discrete electronic markers may have been deliberately placed to facilitate future detection. In other cases, transmitting devices may be able to be placed within plastic or other non-conducting pipe to provide an electronic signal at the surface. Improved methods continue to evolve based upon other technologies, including acoustical techniques and ground penetrating radar.

6.2.3 ***Exposing Existing Facilities*** – When exposing existing utilities to verify depth, non-aggressive "pot-holing" techniques, including manual tools (with electrically-insulated/non-conducting handles) or vacuum type excavators, must be used. It is particularly important to visibly expose and verify the location of lines transporting electricity or gas, oil or petroleum products, or other flammable, toxic or corrosive fluids or gases. In general, **utility lines must be routinely exposed at all anticipated crossings** with the planned bore path, such as where the route along a right-of-way crosses laterals or service lines to residences or other structures (see Section 8.5.4).

6.2.4 *APWA Uniform Color Code* – The paths of existing belowground facilities should be marked, using paint, flags or equivalent, or flags, based upon the Uniform Color Code developed by the Utility Location and Coordination Council (ULCC) of the American Public Works Association (APWA):

White	proposed construction path
Red	electric power
Orange	communications
Yellow	gas, oil, steam, petroleum
Green	sewer, drain
Blue	potable water
Purple	reclaimed water, irrigation, slurry
Fluorescent pink	temporary survey marking

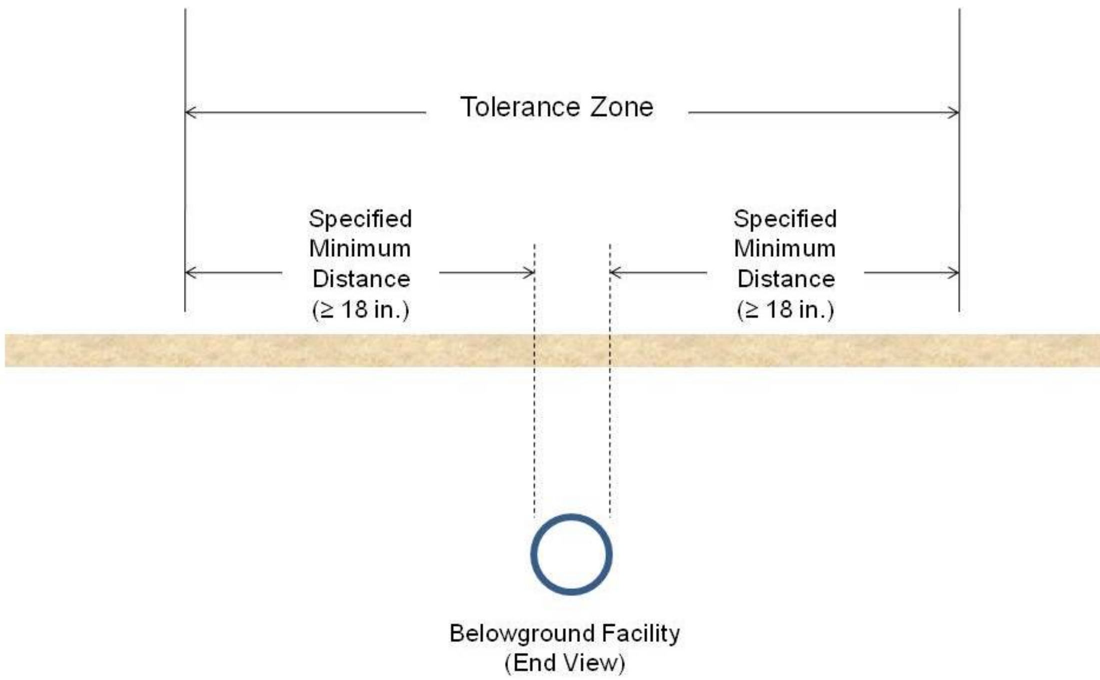

Figure 5 Tolerance Zone

6.3 *Tolerance Zone*

The tolerance zone (Figure 5) defines the region within which the contractor must use non-aggressive methods of digging, such as manual tools or vacuum excavation. **The width of the zone is specified by local regulations and varies among the states.** A minimum of 18 inches from the outer edges of the facility is recommended, unless a greater distance is specified by State or local regulations.(**5**) For relatively close adjacent parallel utility lines (within twice the minimum specified distance laterally from each other), the tolerance zone is determined from the outer edge of the outermost utility line on each side. No portion of the cutting tool for the pilot bore, or the reamer used to expand the hole, is allowed to enter the tolerance zone.

6.4 *Subsurface Utility Engineering*

Subsurface Utility Engineering (SUE) refers to an engineering process for obtaining reliable information regarding belowground utility lines, including types and specific (lateral and depth) locations. The general principles and techniques of SUE are provided in CI/ASCE 38, which defines four general levels of quality based upon the amount and detail of information obtained for characterizing the existing facilities. Quality Level D is the lowest level, corresponding to the least detailed and/or least reliable information, with Quality Level A the highest level, corresponding to the most detailed and/or most reliable information. Although the higher quality levels are more costly to achieve, such information is required for some stages of the mini-HDD construction process.

6.4.1 *Quality Level D* – The minimum level of information is based upon existing utility records. Such information is primarily useful for the purposes of project planning and route selection only.

6.4.2 *Quality Level C* – In addition to the information from Quality Level D, this level includes information obtained from a field visit and a survey of above-ground facilities, such as manholes, valve boxes, posts, etc., and correlation of this information with existing utility records. As a result, the presence of additional belowground utilities, or erroneously recorded location information of utility lines, may be determined. Although such information may be adequate for areas with minimal belowground facilities, or where possible repair is not a major issue, this quality level would typically not be sufficient for proceeding with construction in established areas.

6.4.3 *Quality Level B* – In addition to the information from Quality Level C, the use of surface locators for identifying and marking the existing utility lines, as previously described in Section 6.2, results in more useful, reliable information.

6.4.4 *Quality Level A* – In addition to the information from Quality Level B, the highest quality level includes the use of non-aggressive digging equipment at critical points to expose the utility to determine the precise horizontal and vertical position of underground utilities, as well as the type, size, condition, material, and other characteristics. Mini-HDD operations include such locating procedures at crossings and other critical locations, as described above (Section 6.2.3).

7. Pipe Design and Selection Considerations

Section 7 provides a practical method for selecting the appropriate strength (wall thickness) for the HDPE pipe to be installed using mini-HDD. In particular, the procedure presented herein provides a means of selecting the pipe strength to withstand the required pulling loads during installation, as well as avoid collapse due to hydrostatic pressure at the desired placement depth. This methodology is based upon a simplification of ASTM F1962, sometimes referred to as the "PPI" method(**1**), which was originally developed by extending an existing method applicable to HDPE pipe(**6**) by incorporating several additional physical considerations. The procedure in ASTM F1962 has been widely and successfully used in the industry and has been adopted in several commercially available products for performing initial design calculations for the installation of HDPE pipe.(**7**, **8**) It is recognized that other design tools also exist, but, due to the complexity of the HDD process and the sensitivity of the predictions to the model and assumed parametric values, do not necessarily provide equivalent results.(**9, 10**)

7.1 *Objectives*

The pipe selection process for HDPE pipe is equivalent to determining the minimum wall thickness, or maximum DR value, that is sufficient to withstand the long-term operational loads as well as the stresses due to the installation process. Similar to its decision to select HDPE pipe based upon its various advantageous properties, including its compatibility with HDD and other pulling processes, it may be assumed that the owner of the facility will specify a pipe diameter and minimum wall thickness consistent with the long term operation of the facility, based upon independent technical analysis provided by its own staff and/or with industry support. This includes the ability to satisfy internal fluid flow requirements and withstand internal pressure for pressurized lines in combination with external pressures due to soil and surface loads (e.g., traffic) at various depths and conditions. Such design considerations are addressed in various sources, including "**The Plastics Pipe Institute Handbook of Polyethylene Pipe**".(**1**) These operational design loads may be assumed to be essentially independent of the installation method. In contrast, the HDD process imposes its unique installation loads due to the tensile forces imposed on the pulling end of the pipe, and the temporary hydrostatic pressure associated with the drilling fluid/slurry at the installed depths. (There is an additional limitation that recommends a minimum depth of cover during the mini-HDD installation, based upon avoiding possible negative effects at the ground surface, such as surface heaving or drilling fluid leakage, as described in Section 8.1.3.) **The appropriate pipe minimum wall thickness will be the greater of the values necessary to safely withstand (a) the various long-term operational (including soil and surface) loads and (b) the short-term installation (and pre-operational) loads associated with the mini-HDD operation.** *The present guidelines primarily focus on the latter issues*.

ASTM F1962 provides a methodology for selecting HDPE wall thickness for pipe installed by maxi-HDD, including for river crossings, in order to withstand the installation process. Such operations are typically major events, requiring extensive preliminary investigations and engineering planning, analysis and support, including the use of software tools, as available. For these applications, it is necessary and desirable to perform as accurate engineering analyses as possible, consistent with the present capabilities, in an attempt to reduce the likelihood of significantly over- or under-designing the pipe, either of which may lead to serious economic consequences. Such considerations do not generally arise in mini-HDD applications, which are often part of a large-scale upgrade of facilities in a community or geographic area. Mini-HDD operations typically comprise short, shallow installations and detailed calculations of pipe stresses and loads due to the installation forces are generally not necessary or practical. Thus, the relatively complicated, extensive analyses, such as provided in ASTM F1962, are not appropriate for the present purposes. However, if the pulling distances are relatively long, or the pipe relatively deep, or a thin-walled product is being considered, it is advisable to perform a limited, approximate analysis to provide confidence in a successful installation. *The present pipe selection guidelines, derived from those in ASTM F1962, therefore provide a simplified methodology for selecting or verifying the minimum wall thickness consistent with withstanding the installation loads in mini-HDD applications, based upon reasonable assumptions and approximations.*(**11**)

7.2 *Minimum Wall Thickness Based upon Depth*

During the back-reaming and pullback operations (Figure 2), the mini-HDD drilling fluid creates a relatively dense slurry that applies hydrostatic pressure symmetrically around the pipe circumference. Under sufficient hydrostatic pressure, in combination with local drilling fluid pressure, the pipe may deform and collapse. Appendix B provides the collapse strength of HDPE (PE4710) pipe for various wall thicknesses (DR) values, under idealized conditions, and also describes the basis for estimating the corresponding allowable (reduced) mini-HDD depths for practical applications. The criteria are based upon a consideration of the installation phase as well as the post-installation (but pre-operational) phase, and incorporate reductions consistent with various degradations described in ASTM F1962, as well as a "safety" (i.e., uncertainty) factor of approximately 2-to-1 to account for deviations from the simplified model.

The information in Appendix B indicates that essentially all the **commonly used wall thicknesses, with the possible exception of DR 17 pipe, would be sufficiently strong for depths considerably greater than 15 ft,** , the typical limit for mini-HDD installations. DR 17 pipe should generally be limited to less than 10 ft depth, although 15 ft may also be acceptable in some cases (see Section B.3.6.). For depths significantly greater than 15 ft, the adequacy of the product for the application should be verified using the information in Appendix B. In general, the use of very thin-walled product pipe (e.g., > DR 17) is not recommended for typical mini-HDD installations.

As discussed in Section 7.1, the pipe should be independently analyzed by the owner, or its engineering consultant, to verify sufficient strength during the operational phase for withstanding long-term soil and surface loads (e.g., for relatively shallow buried pipe), such as may be imposed for conventional installations, using accepted industry practices.

The allowable depths as determined in Appendix B, and indicated above, assume an **empty pipe** during the installation and pre-operational phase, in the absence of possible subsequent internal fluids or pressure, which would offset the effects of the external pressure due to drilling fluid/slurry. Although some HDD installations, such as more complex maxi-HDD installations, or possibly some midi-HDD applications, may deliberately allow the pipe to be temporarily filled with water or drilling fluid in order to reduce pull loads due to buoyancy effects, as well as the net effective hydrostatic pressure, during installation, such practices are not typically employed in mini-HDD operations; see Appendix B. For water applications, however, the beneficial effects, will be present during the later operational phase, and may be reflected in the design considerations by the facility owner.

7.3 *Minimum Wall Thickness Based upon Pulling Load*

7.3.1 *Safe Pipe Pull Tension* – Table 2 and Table 3 provide the safe pull tension for HDPE (**PE4710**) pipe for a variety of sizes, for the IPS and DIPS systems, respectively. The pulling load (lbs) is based upon a safe tensile stress of 1,400 psi(**1**), considering a minimum tensile yield strength of 3,500 psi x 0.4 factor at 80°F, as applied to the pipe cross-section. This characteristic accounts for the effective cumulative tensile load duration on the pipe, assumed to be 1 hour, and a significant reduction relative to the nominal tensile test strength of HDPE to limit non-recoverable viscoelastic deformation.(**12**) The quantitative values shown are based on the minimal required wall thickness, as opposed to that of the actual manufactured product, and therefore underestimate the average safe pull tension by approximately six percent.

Table 2 Safe Pull Tension (lbs), HDPE (PE4710) Pipe, 1 hour*
IPS

Nominal Size	Pipe Diameter to Thickness Ratio (DR)				
	7	9	11	13.5	17
2-in.	3,038	2,450	---	---	---
3-in.	6,597	5,321	---	---	---
4-in.	10,906	8,796	7,361	6,109	4,931
6-in.	23,638	19,066	15,954	13,240	10,687
8-in.	40,064	32,315	27,040	22,441	18,114
10-in.	62,237	50,200	42,006	34,861	28,140
12-in.	87,549	70,616	59,090	49,039	39,584

* PE4710 with minimum tensile yield strength 3500 psi x 0.4 factor = 1400 psi at 80°F

Table 3 Safe Pull Tension (lbs), HDPE (PE4710) Pipe, 1 hour*
DIPS

Nominal Size	Pipe Diameter to Thickness Ratio (DR)				
	7	9	11	13.5	17
3-in.	8,445	6,812	---	---	---
4-in.	12,408	10,008	8,375	6,950	5,610
6-in.	25,641	20,681	17,306	14,362	11,593
8-in.	44,109	35,578	29,771	24,707	19,943
10-in.	66,356	53,522	44,786	37,168	30,002

12-in.	**93,838**	**75,689**	**63,335**	**52,562**	**42,428**

* PE4710 with minimum tensile yield strength 3500 psi x 0.4 factor = 1400 psi at 80°F

7.3.2 *Peak Tension* – Appendix C provides details regarding the technical basis and development for the following equations and simplified methodology, including Equation 2 which provides an estimate of the peak force applied to the pipe as it is pulled throughout the bore hole:

$$\textbf{Tension (lbs) = [Bore Length (ft) x Buoyant Weight (lbs/ft) x (1/3)] x } (1.6)^n \qquad (2)$$

The buoyant weight may be conveniently (approximately) determined as

$$\textbf{Buoyant Weight (lbs/ft) = ½ [Pipe Outer Diameter (in.)]}^2 \textbf{ – Pipe Weight (lbs/ft)} \qquad (3)$$

and n is equal to the number (or fraction) of 90° route bends due to cumulative route curvature, or

$$n = n_1 + n_2 \qquad (4)$$

The quantity **n_1 is the effective number of *deliberate/planned* 90° route bends**, and n_2 is the cumulative curvature (90° route bends) due to the unplanned undulations. For example, as illustrated in Figure 6, if a deliberate horizontal (planar) bend of 45° to the right, in order to avoid an obstacle or follow a utility right-of-way, is followed by another 45° horizontal bend to the left, each 45° bend is equal to half of a 90° bend, corresponding to a total of ½ + ½ = 1 full 90° bend; i.e. $n_1 = 1$. The quantity **n_2** is described in Section 7.3.2.1.

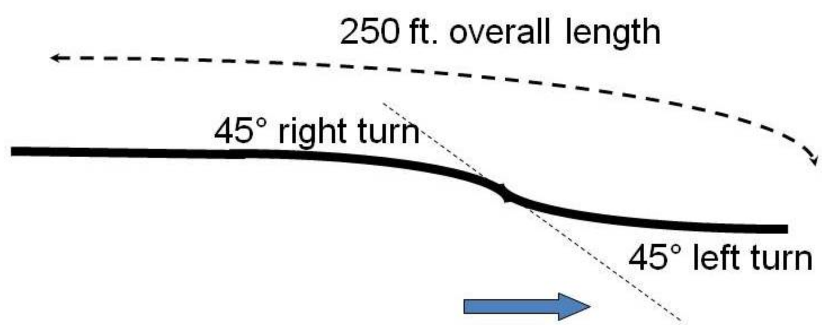

Figure 6 Deliberate/Planned and Unplanned Path Curvature

The pipe weight (lbs per foot) in Equation 3 is available from the manufacturer (based upon the diameter and DR rating), or may be determined by weighing a sample length. Alternatively, Figure 7 may be used to determine the approximate buoyant weight for use in Equation 2, recognizing that, for a given pipe size (nominal diameter), the actual buoyant will be somewhat larger for the lower DR (thicker wall, heavier) pipes than the larger DR (thinner wall, lighter) pipes

Figure 7 shows slightly greater buoyant weights for the DIPS system than the IPS system, due to the somewhat larger outer diameters, for the same nominal pipe size. This results in correspondingly greater predicted tensions, which are offset by the similarly larger safe pull tensions in Table 3, allowing the same potential placement distances (see Figure 9).[3]

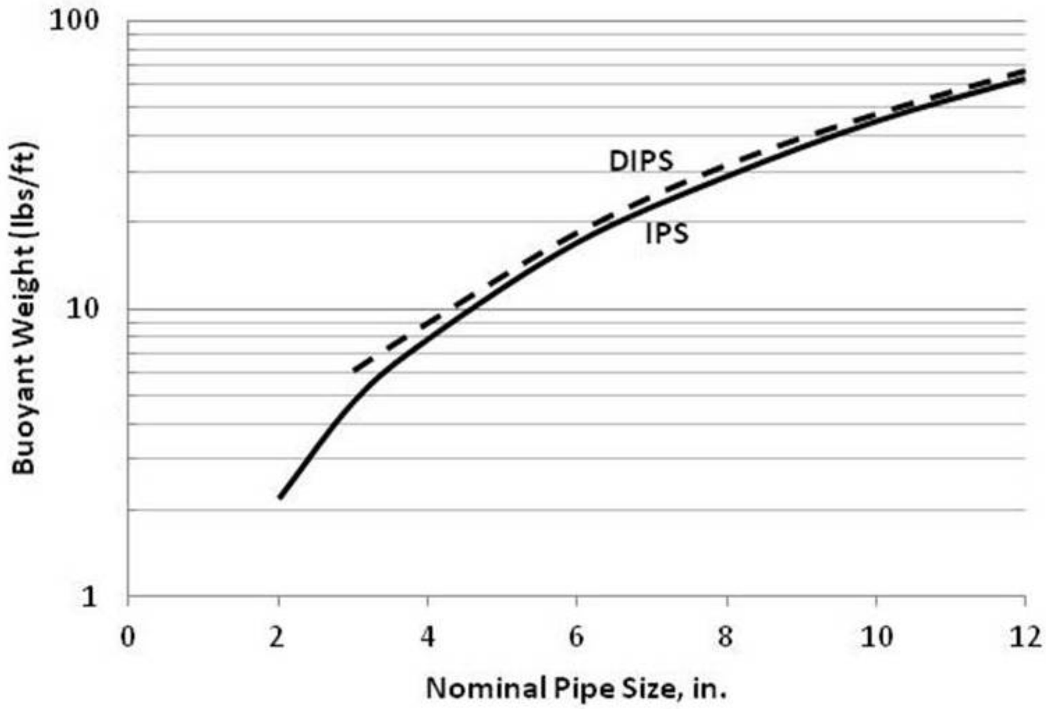

Figure 7 Buoyant Weight of HDPE Pipe
(Source: Outside Plant Consulting Services, Inc.)

7.3.2.1 *Unplanned Path Curvature* – The quantity **n_2 is the effective cumulative *unplanned* curvature**, due to path corrections, and resulting bore hole undulations. Although such a quantity will obviously vary among installations due to soil conditions, expertise of the crew, etc., the following rule may be used to provide a reasonable estimate for a mini-HDD operation using typical **2-inch drill rods**:

$$n_2 = \text{Bore Length (ft)} / 500 \text{ ft} \tag{5}$$

i.e., there may be assumed to be effectively one 90° bend, due to path corrections, for each 500 ft of path length. For the path illustrated in Figure 6, the application of Equation 5 results in additional effective route curvature n_2 = 250 ft / 500 ft = ½. Thus, the total route curvature is calculated as $n = n_1 + n_2 = 1 + ½ = 1½$.

7.3.2.2 *Drill Rod Diameter* – The magnitude of unplanned path curvature provided by Equation 5 is intended to be applicable to a typical mini-HDD operation using steel drill rods of approximately 2-inch diameter. Larger diameter drill rods are stiffer and therefore result in more gradual path deviations and corrections, resulting in a reduced level of path undulations. Thus,

[3] For a given DR value, the buoyant weight, predicted pull tension (Equation 2), and strength of the pipe are both proportional to the square of the outer diameter, allowing the same maximum placement distances,, for a specified route geometry.

when applying the above procedures to mini- (or midi-) HDD equipment employing **different diameter (larger or smaller) rods**, the following value of n_2 should be used

n_2 =[Bore Length (ft) / 500 ft] **x** [2-in / Rod Diameter (in.)] (6)

For example, a 4-inch diameter drill rod would correspond to one 90° bend every 1,000 ft. The results of Equation 6 are illustrated in Figure 8.

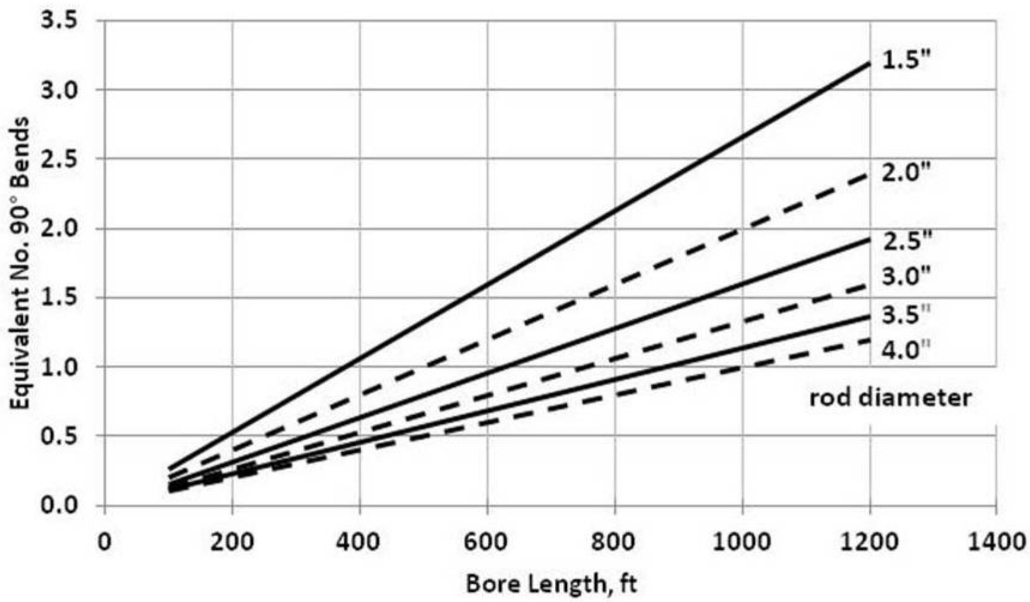

Figure 8 Unplanned Curvature, n_2
(Source: Outside Plant Consulting Services, Inc.)

Although, in principle, this same rule, for estimating unplanned path curvature, may be extrapolated to maxi-HDD, using corresponding large diameter drill rods, it is considered excessively conservative for such well-planned, well-controlled installations, as discussed below.

7.3.3 *Pipe Selection* – The estimated tension as calculated from Equation 2 must be compared to the safe pulling load of Table 2 or Table 3, for which it is required that the former not exceed the latter; i.e.,

Tension (Equation 2) ≤ Safe Pull Tension (Table 2 or Table 3) (7)

Appendix D provides examples of its application.

The use of Equation 7 provides a reasonable estimate of practical placement distances using mini-HDD, and is analogous to the procedure incorporated in ASTM F1962 for maxi-HDD installations. *The present mini-HDD calculations, however, will generally result in considerably shorter possible placement distances than that corresponding to application of the methodology and equations provided in ASTM F1962, which may also include the use of anti-buoyancy techniques to reduce buoyant weight to significantly reduce required pull loads. The shorter placement distances for mini-HDD are also due to the increased drag ("capstan effect") generated by the additional route curvature characteristic of mini-HDD installations, especially* *that due to path corrections[4] (Equations 5 and 6), which are more likely and of greater magnitude and significance than that encountered in typically well-controlled maxi-HDD installations. (See IMPORTANT NOTE.)*

In general, therefore, the preceding formulas and methodology are recommended for estimating pull loads for mini-HDD installations. Other methods for determining pulling loads, including software tools (e.g. Boreaid, www.boreaid.com, www.ppiboreaid.com), are typically based on well-controlled maxi-HDD installations and not representative of actual mini-HDD applications with respect to anticipated pull loads.

> **IMPORTANT NOTE**
>
> The indicated mini-HDD allowable bore lengths in Figure 9 are significantly lower than that achievable with typical maxi-HDD operations. The estimated mini-HDD pull loads assume (1) the absence of water ballast within the pipe, which otherwise greatly reduces the buoyant weight and associated frictional drag, and (2) the presence of additional route curvatures due to path corrections characteristic of typical mini-HDD operations. The latter phenomenon, for example, would significantly reduce practical placement distances for pipes of any material. Thus, the implementation of anti-buoyancy measures and/or avoidance of unnecessary path curvatures, such as representative of well-planned and executed maxi-HDD installations, correspond to practical placement distances several times that shown in Figure 9. ASTM F1962 may be used to determine such practical placement distances.

7.4 *Results*

As discussed above, Equation 7 may be used to predict the pulling load as a fraction of the safe pull tension, as a function of route length, for various route geometries and applications. Figure 9 illustrates the results for a nominally straight bore (i.e., $n_1 = 0$), for various HDPE (PE4710) pipe strengths (DR values), independent of diameter, for typical 2-inch drill rods. For example, based upon pull load only, the DR 11 pipe may be installed in a segment length of 1,000 ft, well beyond the nominal upper limit of mini-HDD capability, without anticipated problems. Based upon the allowable depth information in Appendix B, the same pipe may be installed as deep as 55 ft, again well beyond the capability of mini-HDD equipment. These results indicate that DR 11 HDPE pipe should have adequate physical strength for essentially all practical mini-HDD applications. DR 11 pipe should also be readily capable of withstanding reasonable field handling, which is not directly considered by the analyses. Maximum recommended lengths would be reduced for routes with additional planned bends ($n_1 > 0$); see Appendix D.

Furthermore, based on Figure 9, all the DR values indicated would be acceptable for the nominal limit (600 ft) of mini-HDD, and beyond, assuming the corresponding depth limits are satisfied (Appendix B).

[4] Due to the quantitative significance of the unplanned path curvatures due to path corrections – and the wide variability of such effects – in some cases it may be considered desirable to apply a load factor of > 1.0, or possibly < 1.0, to the tension predicted by Equation 2, depending on the experience and judgment of the contractor,; see Appendix C.4 and Appendix D.

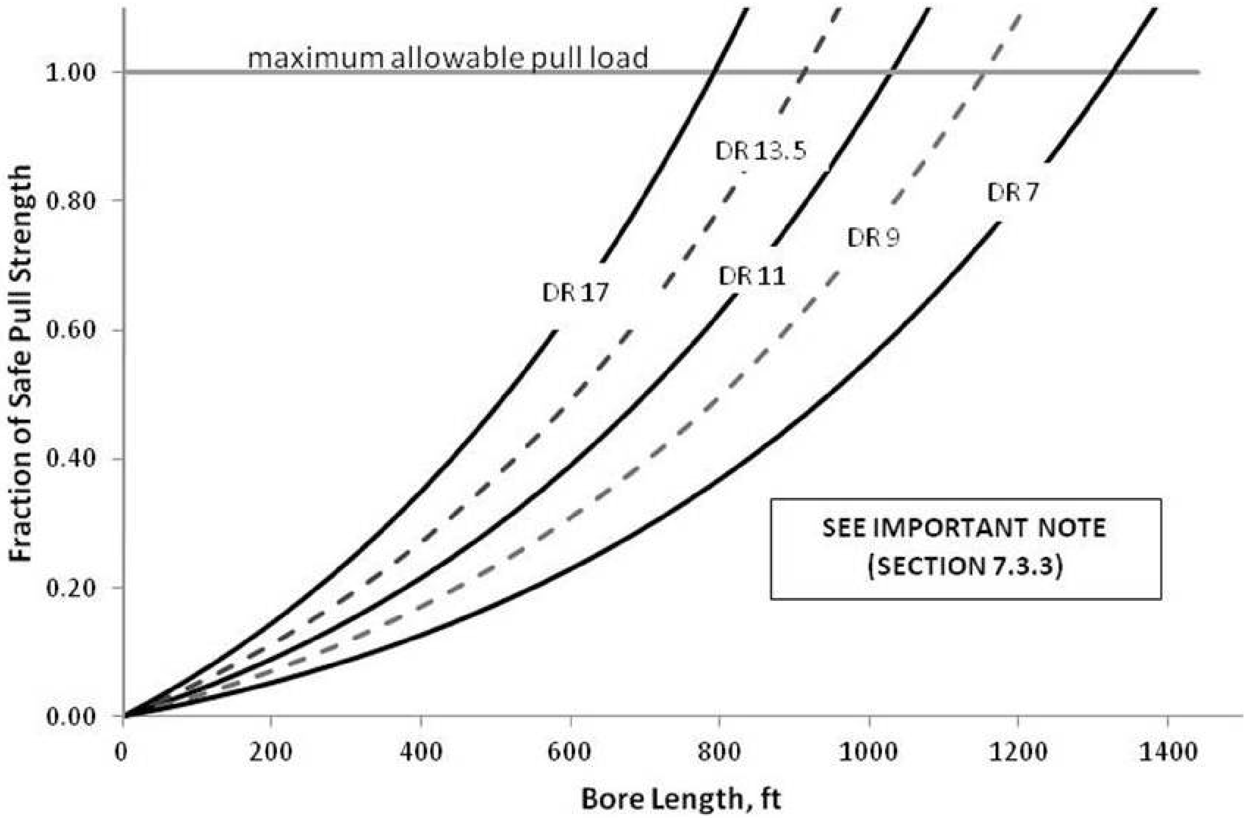

Figure 9 Predicted Mini-HDD Pull Load vs. Safe Pull Tension, HDPE (PE4710) Pipe Nominally Straight Path, 2-inch Drill Rods

(Source: Outside Plant Consulting Services, Inc.)

7.5 *Comments*

A determination that the selected pipe (DR) meets the design criteria as described in Section 7 should not be misconstrued to encourage or allow reduced care or skill in the recommended industry practices, such as summarized in other sections of this guide. The selection procedures are based upon the assumption that proper drilling procedures are followed. For example, a prematurely collapsed bore hole may impose pipe loads significantly greater than those assumed in the present analyses, leading to an unsuccessful installation. Conversely, the determination that a particular pipe size and strength does not meet the present design criteria for a desired bore route does not necessarily indicate that the installation will fail. The methodology is based upon a degree of inherent conservatism (see Appendix C) such that it would be expected that, in many cases, individual selected pipes falling short of the criteria would nonetheless be successfully installed by the mini-HDD process, albeit in the absence of the greater assurance provided by the present design practices.

8. Bore Path Planning and Drill Rig Setup

Section 8 addresses the planning of the bore path, consistent with meeting the requirements of the project owner, including placement depth, as well as corresponding drill rig setup information, which is dependent upon the equipment parameters (e.g., allowable drill rod curvature). The information provided supports the design of the bore path in both the vertical and horizontal planes. Commercially available software tools may also be used to help perform these functions.(**13**)

The information provided in this section comprises elements of the design (e.g., planning bore path trajectory) and actual construction or implementation operations, both of which are typically performed by the contractor for mini-HDD installations. For more complex HDD operations, such as maxi-HDD installations, these functions would typically be performed separately, by different individuals or organizations, including engineers, and utilizing software tools such as Boreaid®.**(8)**

8.1 *General Considerations*

8.1.1 *Bore Path Planar (Horizontal Plane) Trajectory* – The owner or its representative (engineer) will provide the general requirements for the path of the product pipe, including position within the right-of-way, identification of road or local obstacle crossings (e.g., laterals or service lines to residence or building), etc. The precise location for each segment, however, will be determined on-site, in advance of the operations, by the selected contractor and utility engineer, depending upon the location of existing utilities and other site specific conditions, consistent with the procedures of Section 6.

8.1.2 *Specified Depths* – The nominal desired depth of placement will also be specified by the owner, including minimum and maximum, consistent with that of existing utilities. The general depths of existing facilities may be initially judged based upon the preliminary investigations, at a corresponding level of confidence, but in critical cases, such as planned crossings of other lines, depths must be visually confirmed (Sections 6.2.3 and 6.4.4). A minimum depth of cover of 36 inches is typically desired to reduce the likelihood for surface movement or displacement, drilling fluid penetration to the surface, as well as a tendency for the drill head to rise to the free surface during the initial pilot boring operation, thereby complicating the steering operation, although greater depths are generally recommended depending upon the bore hole size, as discussed below. Excessive depths, however, may not be practical for future maintenance activities.

8.1.3 *Minimum Depth of Cover* –Typical industry guidelines recommend a minimum ratio of approximately 10-to-1 for depth of cover to final bore hole diameter to avoid surface heaving effects, for a compaction process in appropriate (compatible) soil conditions.(**15**) The use of pneumatic penetrating missiles ("moles") is an example of a compaction process. In such cases, spoils disposal is absent or minimized and the displaced soil is compacted into the surrounding walls of the hole. Similarly, for mini-HDD installations creating a final bore hole diameter of less than 4-inches, the hole is also primarily formed by a compaction process, with a relatively small amount of soil removed by the drilling fluid. In contrast, for larger holes, the mini-HDD operation utilizes drilling fluid techniques to remove at least a portion of the spoils during the initial boring or reaming operations. A disproportionally greater volume of drilling fluid would be required to remove the soil from the bore hole in a soil removal process, in comparison to a compaction process. It is the responsibility of the contractor to understand and utilize drilling fluid technology properly, including to form the bore hole without surface heaving, and with little or no fluid penetration at the surface.

Figure 10 shows recommended depth of cover for conditions compatible with the nominal 10-to-1 ratio for a compaction process, as well as a 5-to-1 ratio for a mini-HDD spoils removal process, at a minimum of 36 inches, as a function of final bore hole diameter. It is noted that the final bore hole size for mini-HDD operations is nominally recommended to be at least 50% greater than the pipe outer diameter(s). Such recommendations for depth of cover are recognized as only a guide, since the tendency for subsequent ground movement, as well as penetration of drilling fluid to the surface, and other possible effects, are dependent upon local soil characteristics and construction variables.(**4**, **15**) However, if a lower depth of cover than that indicated in Figure 10 is necessary, it is recommended that the final bore hole size be gradually enlarged using several (one or more) pre-reaming passes, prior to the final pullback of the pipe, accompanied by careful monitoring of the drilling fluid pressure; see Section 9.3.1.

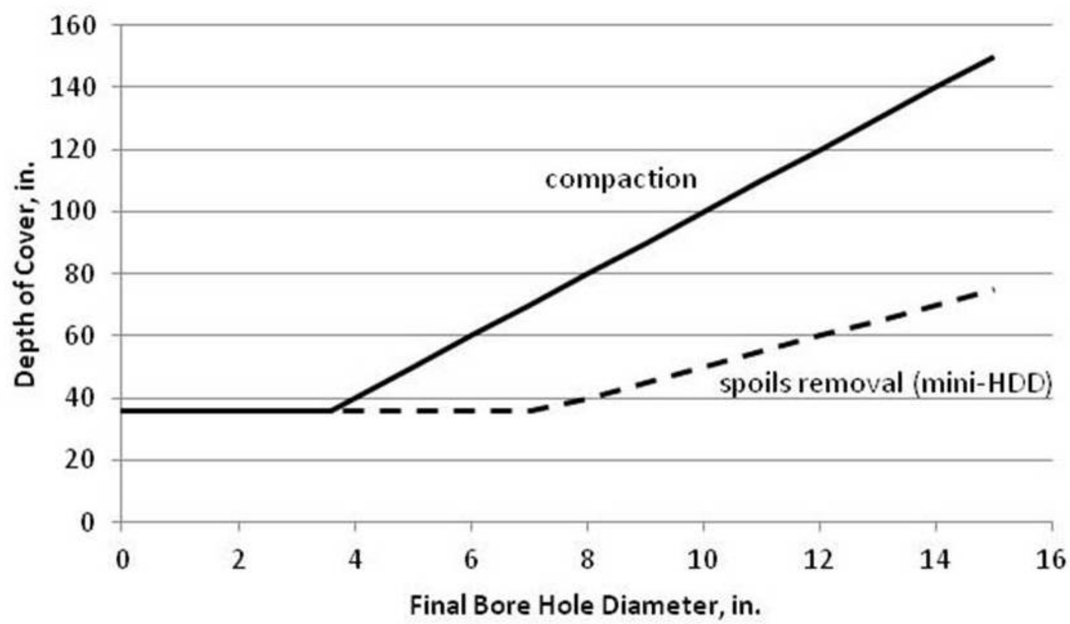

Figure 10 Recommended Minimum Depth of Cover
(Source: Outside Plant Consulting Services, Inc.)

8.2 *Steering & Drill Rod Constraints*

The planned path must be consistent with the steering capability of the drill string, based upon the allowable radius of curvature (bend radius) of the steel drill rods, including the presence of joints, as specified by the manufacturer of the rods; see Section 3.3. The bending limitation considers the yield strength of the steel material, as well as the fatigue characteristics of the rods at lower stress levels. A drill rod may be able to withstand a single bend cycle corresponding to a relatively sharp radius of curvature, but the rotation of the rod during the boring operation results in repeated flexure which may eventually cause fatigue failure due to the cumulative effect of a large number of such cycles. The diameter of the drill rod is the primary parameter affecting its allowable bend radius, and corresponding steering capability. The specific drill rod characteristics are reflected in the detailed information provided in Section 8.4.

8.3 *Product Pipe Constraints*

The allowable radius of curvature (bend radius) of the product pipe will be provided by the pipe manufacturer. For pipe constructed from plastic or other very flexible material, the bend radius limitation of the drill rods is generally sufficiently large to be compatible with that of the product pipe. In particular, HDPE pipe is sufficiently flexible such that the corresponding bends and path curvatures imposed on the pipe during an HDD installation will not be significant.

8.4 *Bore Path Profile (Vertical Plane)*

Figure 11 illustrates a typical mini-HDD bore profile trajectory, including occasional pits along the route. These pits may be required for pipe splicing, completing lateral connections, or to expose existing utilities. The pits may also be useful for collecting drilling fluid from the boring or reaming operations. The characteristics of the drill rod, as described in Section 3.3, including bending capability and rod length, and the entry angle of the rod to ground surface, will determine the minimum depth achievable at the beginning of the bore path. Although Figure 11 is conveniently shown for a level ground surface, the information presented may be readily interpreted relative to a uniformly sloped uphill or downhill surface.

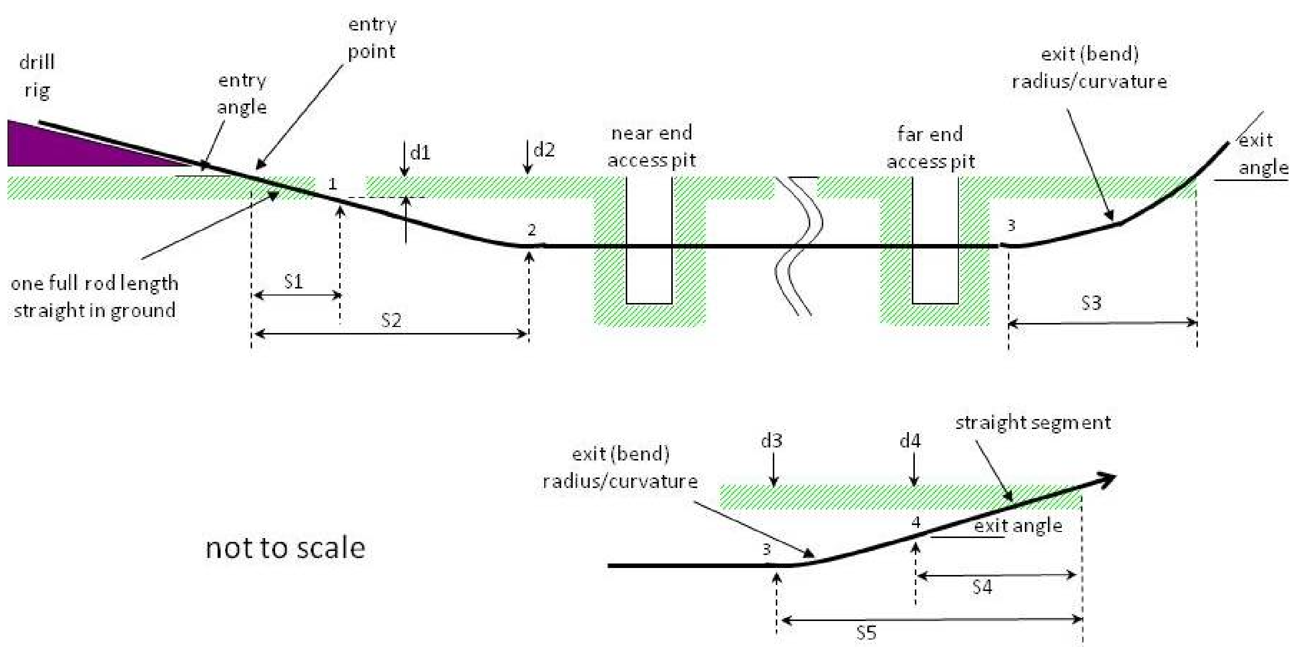

Figure 11 Drill Rig Setup and Related Distances
(Source: Outside Plant Consulting Services, Inc.)

8.4.1 *Angle Measurement* – In HDD operations, the angle of the drill rig (entry angle) relative to the surface, as well as the local angles established at the drill head during the pilot boring process, determine the path of the bore hole. The angles may be in a vertical plane (elevation), such as the drill rod entry angle, or in a horizontal plane (azimuth), during turns, or a combination of both directions. The angle may be commonly measured in degrees or, for elevation angle, in percent grade (vertical rise or drop per unit horizontal distance, times 100). **The angle in degrees is approximately equal to half the percent grade**, as illustrated in Figure 12. Typical drill racks allow an entry angle in the range of 5° – 25° (10% – 45% grade).

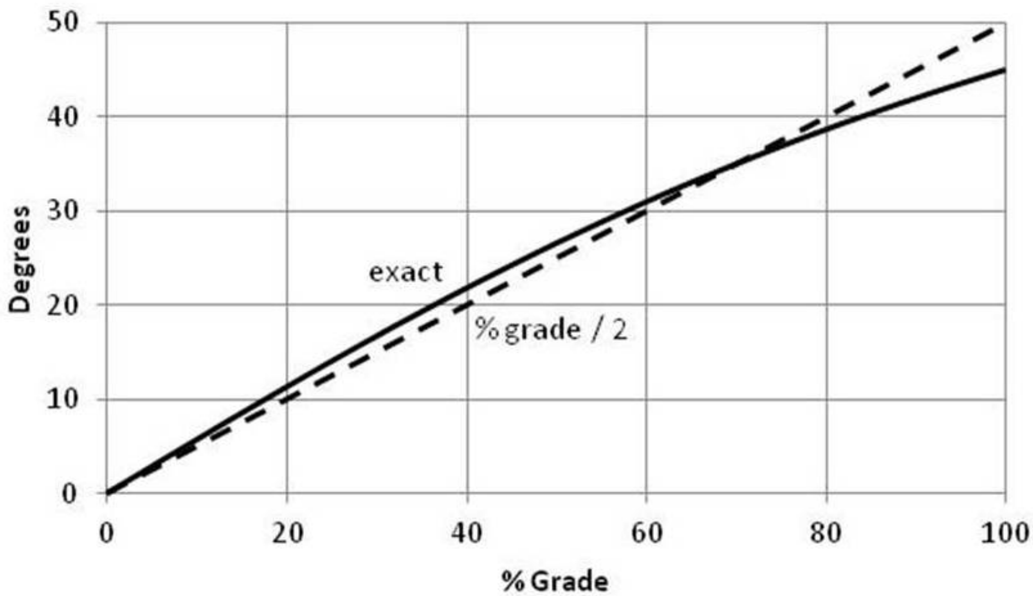

Figure 12 Degrees vs. Percent Grade

8.4.2 *Setback Distance* – In order to achieve a specified depth at a particular point towards the beginning of a pilot bore operation, the front of the drill rig must be located an appropriate distance rearward from the point of interest. This setback distance depends not only upon the depth at the point of interest, but also on the desired orientation (percent grade) of the bore at that point. In Figure 11, point 1 is directly along the entry path of the drill rod, at which the resulting bore path is inclined at the entry angle, and for which the setback distance corresponding to reaching the depth d1 is designated as S1. S1 represents the minimal setback distance for achieving a specified depth, independent of the orientation of the bore path, beyond which the trajectory may become level.

Knowledge of such minimum setback requirements is important with respect to determining the location and position of the drill rig, consistent with available space or feasible or convenient setup locations.

8.4.2.1 *Setback Distance to Level Trajectory* – Beyond point 1, the drill rods are steered such that the bore path trajectory becomes level at point 2, correspond to a depth d2 and setback distance S2. The distance S2 is significantly greater than the corresponding to S1, assuming the same depth of interest. The greater distance is required to allow the drill rods to establish an upward curvature consistent with achieving a horizontal orientation. In this case, it is also assumed that the bore is initiated along a straight path, at the entry angle, without any curvature or steering for a distance equal to one full drill rod length (e.g., 10 ft, for typical mini-HDD equipment) in the ground.(**16**) This is a recommended practice to avoid bearing loads at the front of the drill rig. The upward desired curvature is introduced during the placement of subsequent drill rods.

8.4.2.2 *Minimum Depth for Level Trajectory* – Due to the recommendation that the first drill rod be placed in the ground without any curvature or steering, and the subsequent path curvature consistent with the bending capability of the rod, there is a minimum depth at which the trajectory will become level, depending upon the entry angle and rod characteristics. This depth is designated as $(d2)_{min}$.

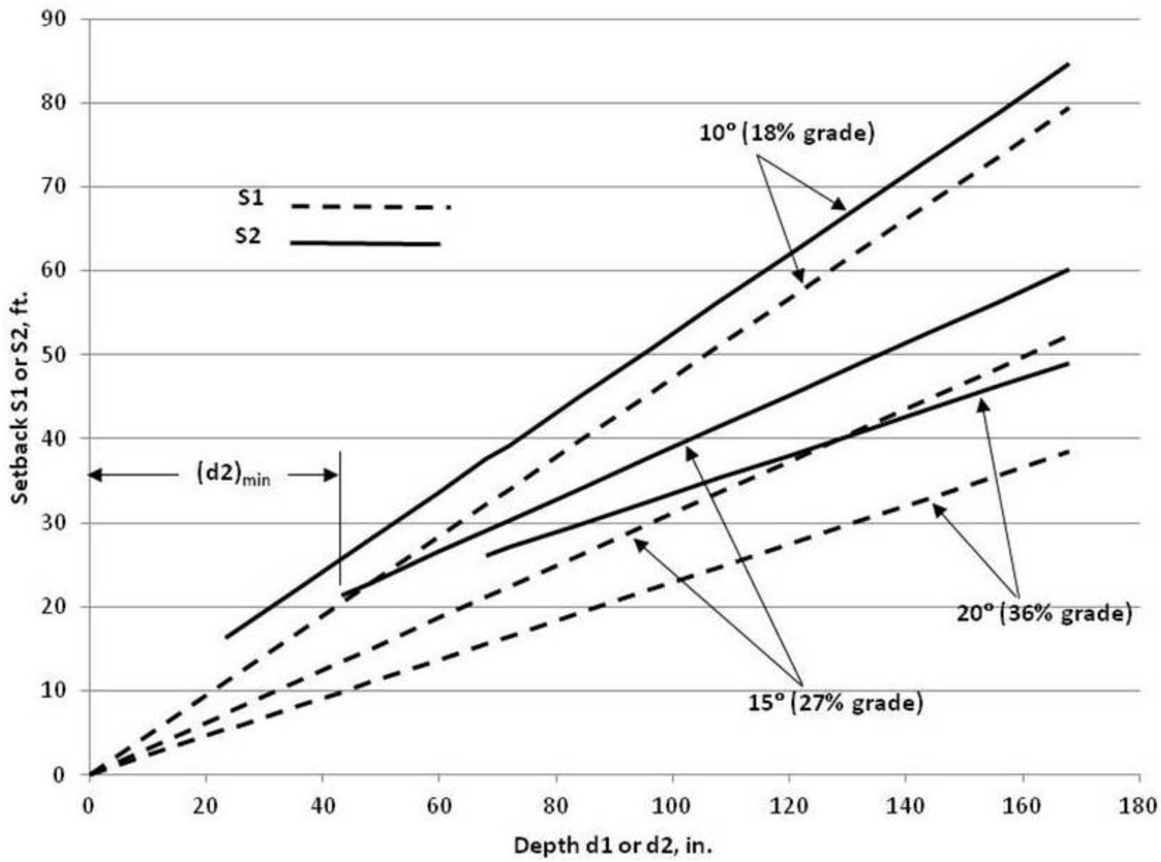

Figure13 Drill Rig Setback Distance
Drill Rods: 6 ft Long, 60 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.3 *Setback Guidelines* – The above setback distances S1 and S2, as a function of depth, d1 or d2, respectively, are shown in Figures 13, 14 and 15 for several drill rods, including lengths of 6 ft, 10 ft and 15 ft, with corresponding allowable radii of curvature of 60 ft, 100 ft and 150 ft. These figures also indicate the minimum depth $(d2)_{min}$, and corresponding minimum setback distance S2, at which the trajectory may become level. Thus, for the typical 10 ft drill rods of Figure 14 and an entry angle of 15°, a depth d1 of 72 inches will be achieved at a setback distance S1 of 22 ft based upon an inclined (non-level) trajectory. In comparison, a setback distance S2 of 36 ft is required to reach the same depth (72 inches) at a level trajectory. Figure 14 also indicates that this particular drill rod (10 ft length and 100 ft allowable radius of curvature) and entry angle are not consistent with achieving a level trajectory at depths shallower than 72 inches. If it is necessary to be at a shallower depth, a lower entry angle and/or sharper bend radius would be required. If necessary, the trajectory could exceed the desired depth at the beginning of the bore, and rise to the proper depth further along the path, at a correspondingly greater setback distance.

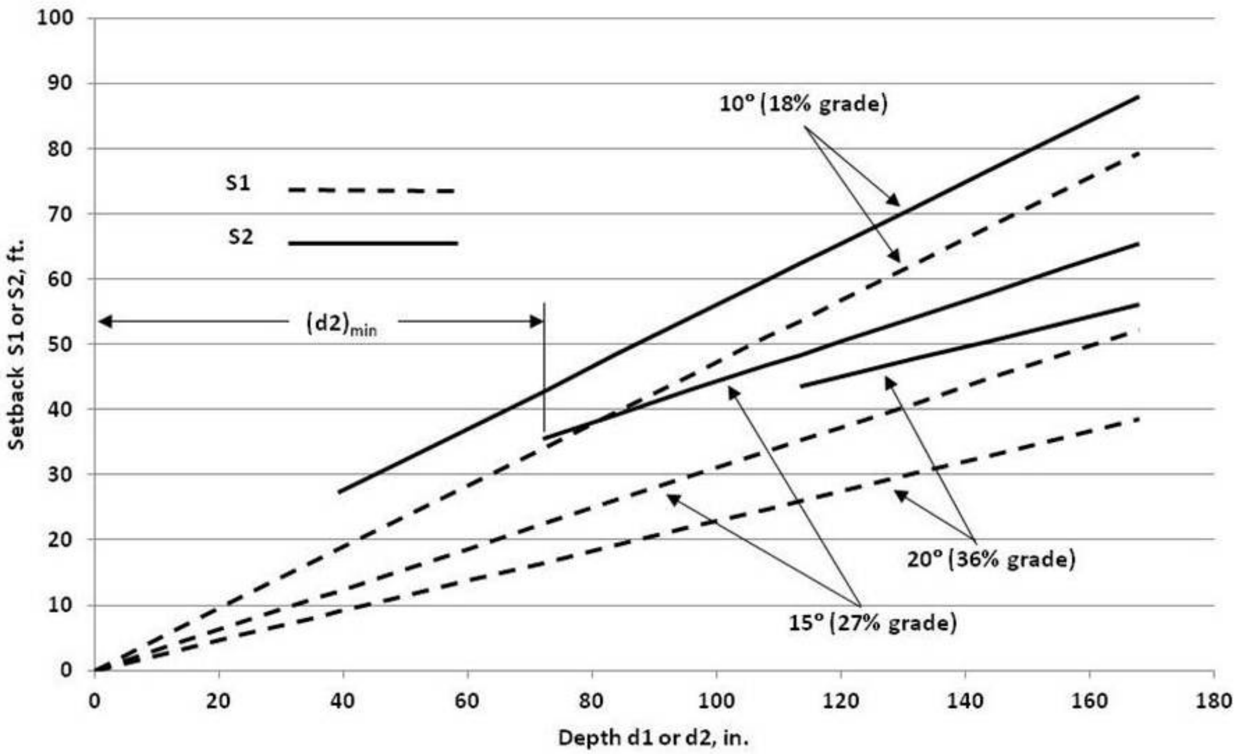

Figure 14 Drill Rig Setback Distance
Drill Rods: 10 ft Long, 100 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

Appendix E provides additional information on setback distances, including formulae that may be used to generate additional setback guidelines for drill rods with differing characteristic than those considered in Figures 13 – 15. Appendix F provides examples of their application.

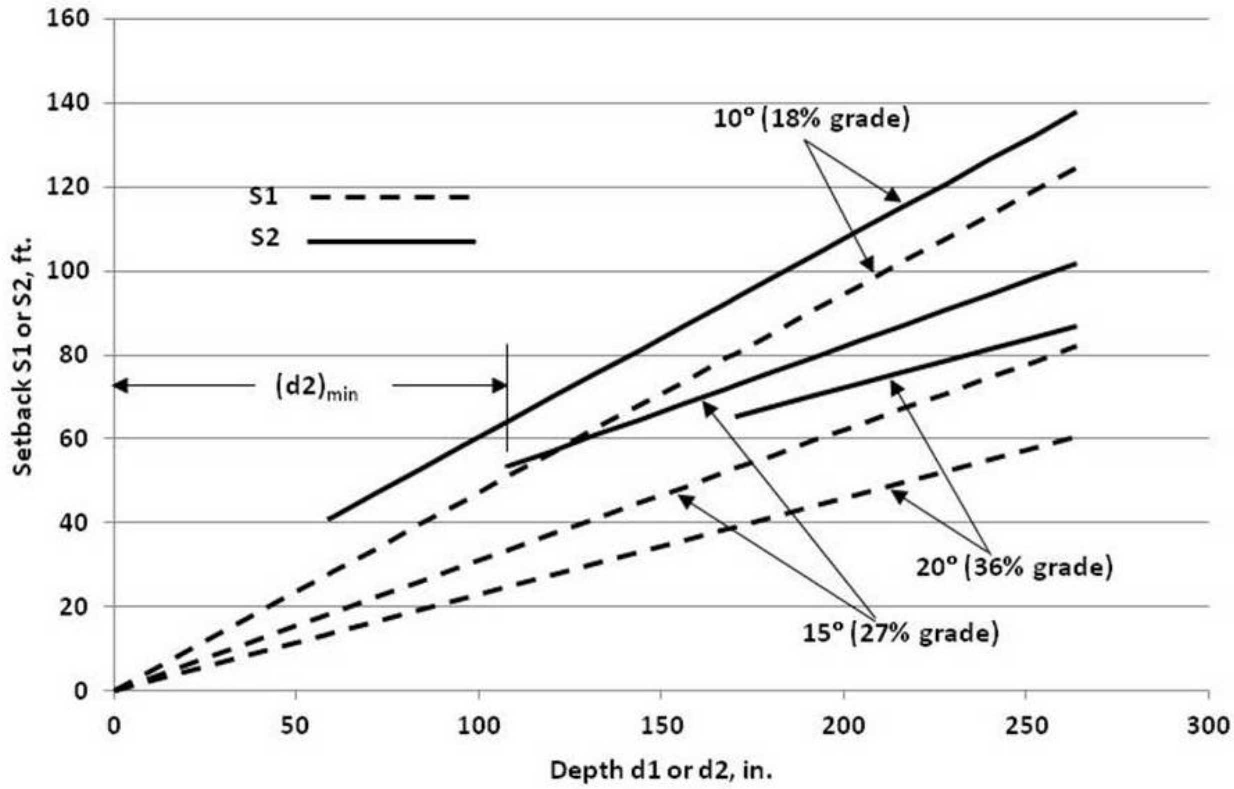

Figure 15 Drill Rig Setback Distance
Drill Rods: 15 ft Long, 150 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.4 *Depth/Setback Implications* – If the determined setback distances or drill rod angle consistent with the project *maximum* depth specifications are not practical, consideration should be given to receiving approval from the owner allowing increased depths in the vicinity of the entry point, with a gradual transition to the preferred depth along the balance of the route. If necessary, smaller diameter, more flexible, drill rods (e.g., Figure 13) may be considered if consistent with anticipated thrust and torque loads. Smaller bend radii than that recommended by the rod manufacturer may be considered by the contractor if it is recognized that reduced service life may result for the drill rods. If the steering conditions in the soil preclude a sufficiently sharp upward turn, mechanical assistance may be provided at the entry pit to apply an upward bending moment on the rod.

8.4.5 *Distance to Rise to Surface from Level Trajectory* – Figures 16 – 18 show the horizontal distances required for the head of the drill string to reach the surface from a point 3, on a level trajectory, from its present depth d3, as indicated in Figure 11. The minimum distance to reach the surface, designated S3, corresponds to that of steering upward at the minimum allowable radius of curvature of the drill rod. Alternatively, if it is desired to exit the ground at a specific angle, a greater horizontal distance will generally be required. For example, it may be desired to exist at a relatively low angle to facilitate the subsequent pipe entry into the bore path, which will require a greater horizontal rise distance, designated S5, than for a larger angle.

Knowledge of such distances is important with respect to determining the location for feeding of the product pipe into the bore path during the pullback phase. Such locations must be compatible with available space at the far end of the bore path.

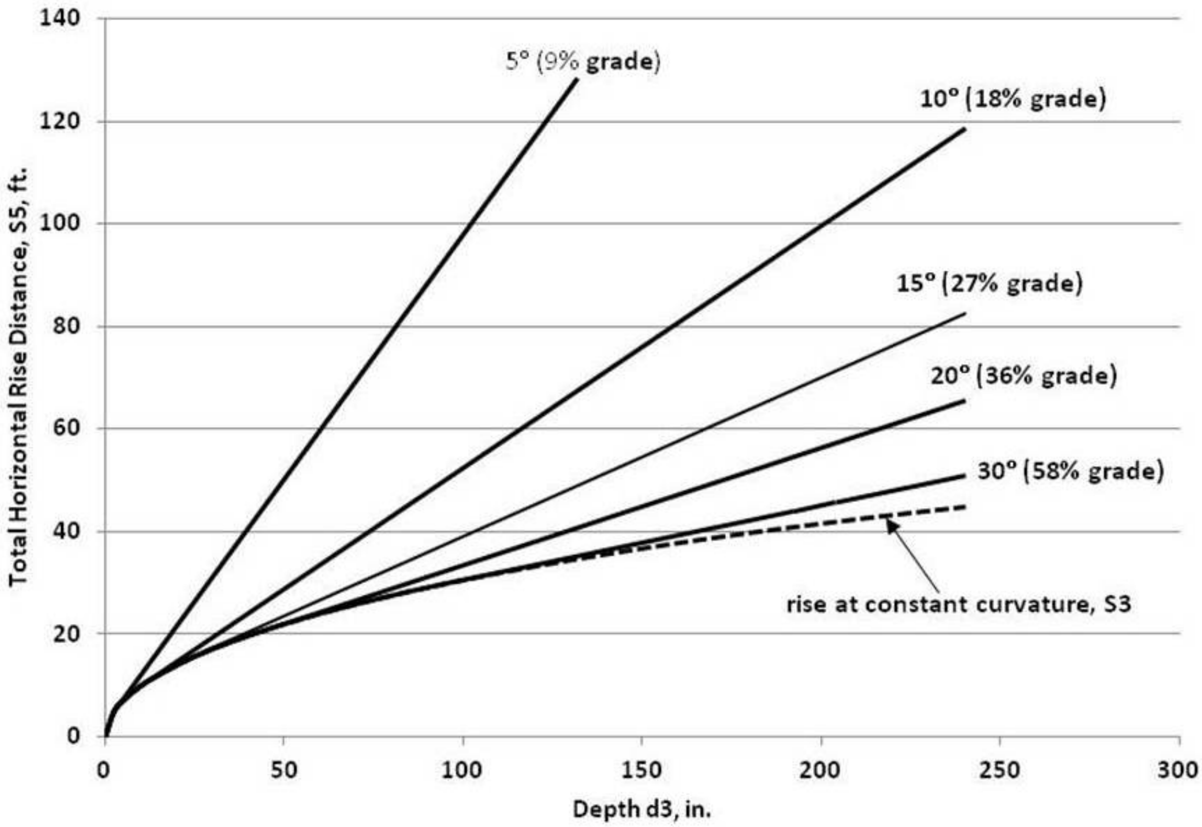

Figure 16 Distance to Rise to Surface
Drill Rods: 60 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

Assuming the typical drill rod of Figure 17 (100 ft allowable radius of curvature[5]), the shortest rise distance, S3, from a level trajectory at 100 inches depth, d3, is approximately 40 ft, in comparison to approximately 100 ft (S5) for an desired exit angle of only 5°; see Figure 11. The maximum possible exit angle is limited by the depth. For this drill rod, relatively high exit angles (e.g., greater than 20°), are not possible at depths less than approximately 72 inches. Figure 19 illustrates exit angles for a rise at the indicated constant curvature.

[5] The rod length is not a factor for the distance to rise to surface.

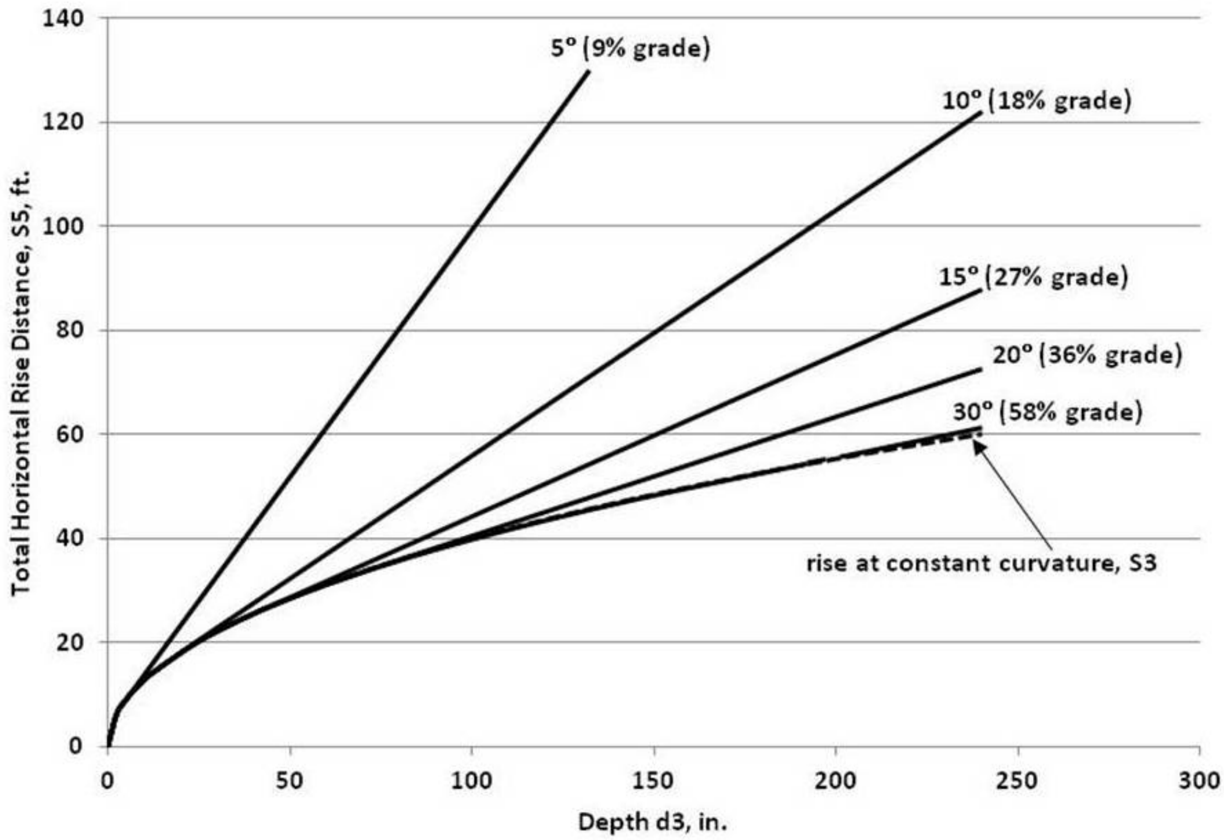

Figure 17 Distance to Rise to Surface
Drill Rods: 100 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

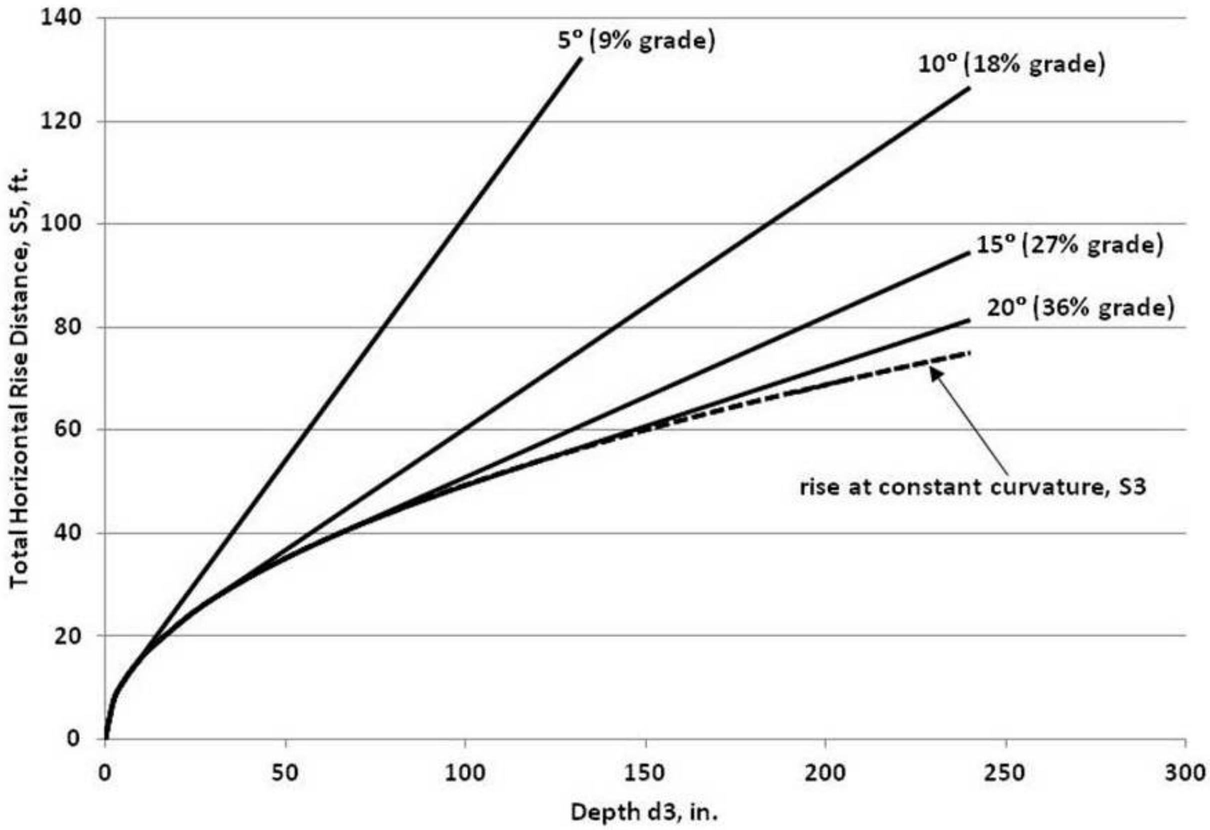

Figure 18 Distance to Rise to Surface
Drill Rods: 150 ft Radius of Curvature
(Source: Outside Plant Consulting Services, Inc.)

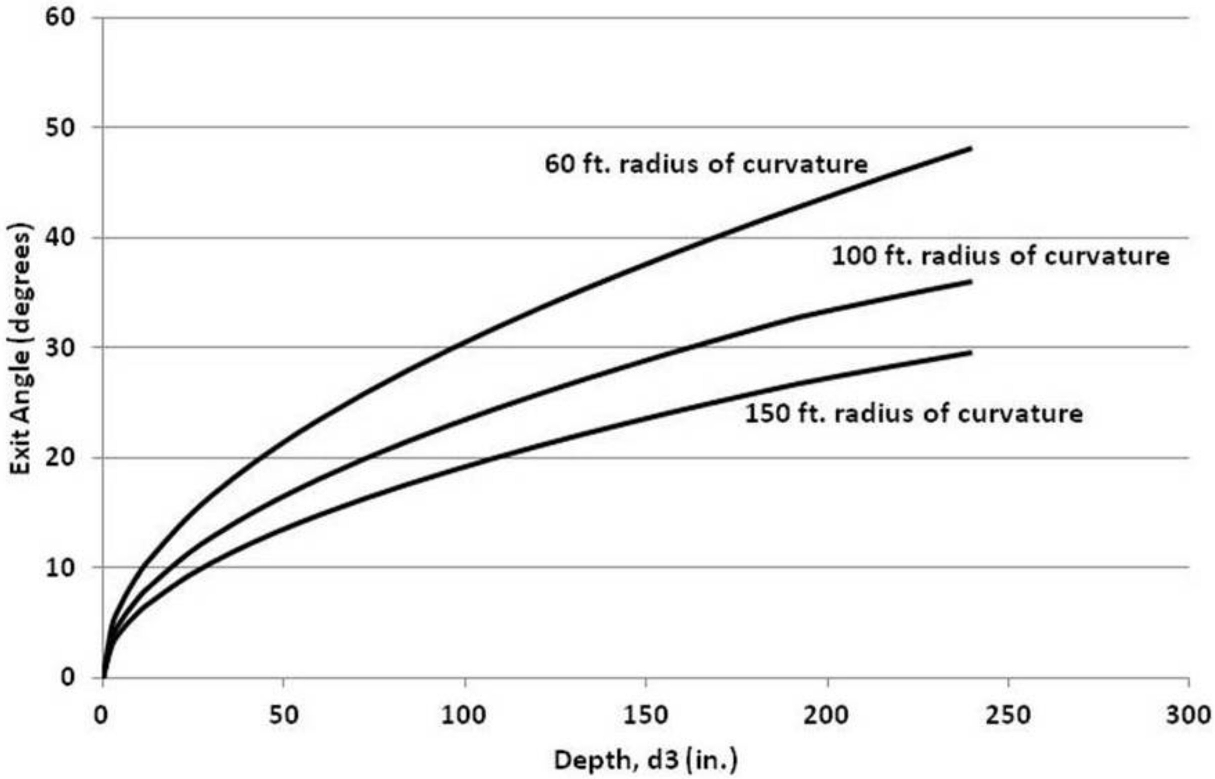

Figure 19 Exit Angle for Rise at Constant Curvature
(Source: Outside Plant Consulting Services, Inc.)

8.4.6 *Distance to Exit at Specified Grade* – Considering a drill head oriented at an upward grade, Figure 20 shows the horizontal distance, S4, required for the head of the drill string to reach the surface from a point 4, on an inclined path, from its present depth d4; see Figure 11. The information may also be used to determine the horizontal distance corresponding to a specified rise distance from any point on an inclined path. The present d4 and elevation angle is available from the drill head locating system. The vertical rise results in Figure 20 directly correspond to the local percent grade (fraction of horizontal distance) of the trajectory.

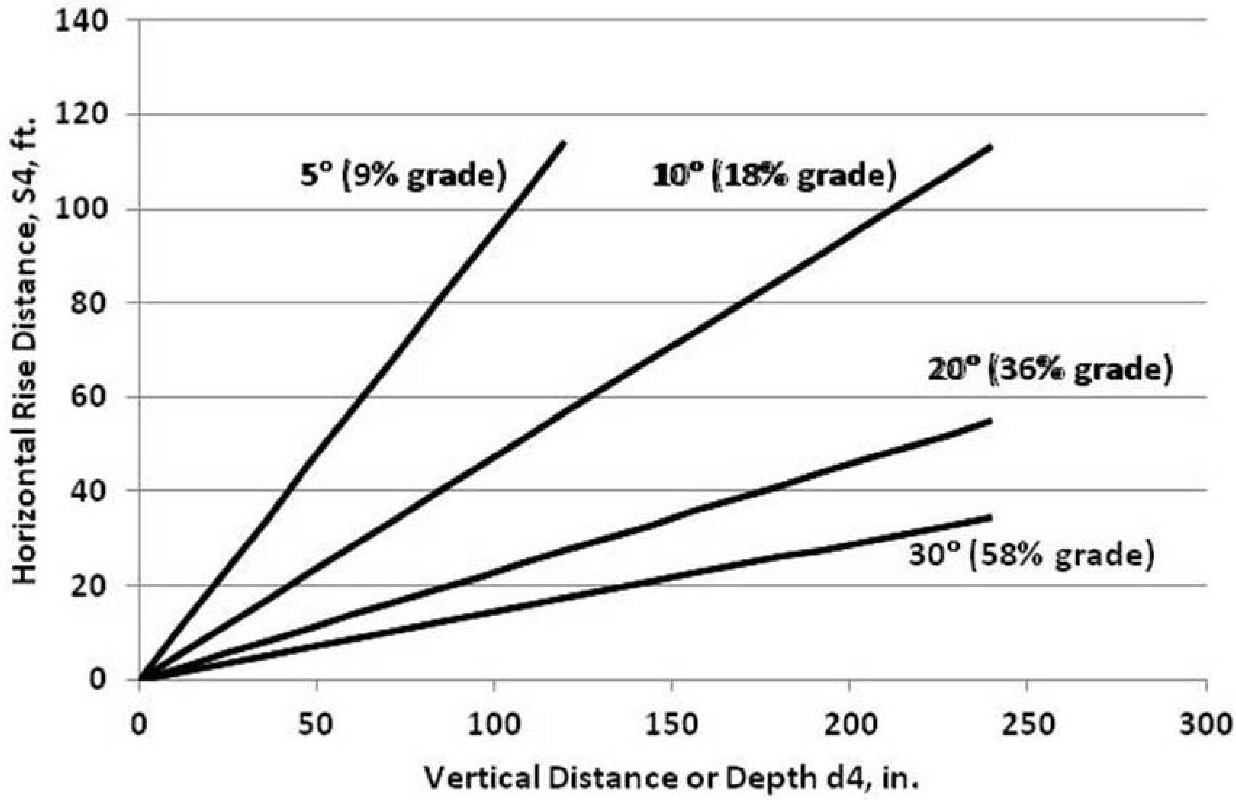

Figure 20 Horizontal Distance to Rise Vertical Distance or to Surface

Appendix E provides additional details and formulae that may be used to generate guidelines for cases not explicitly considered in Figures 16 – 20. Appendix F provides examples in their application.

8.5 *Bore Route (Horizontal Plane)*

In plan view, the bore path should be as direct as possible, consistent with available right-of-way, utility architecture, existing utilities and other obstacles, as well as the capability of the mini-HDD system, considering the recommended bend radius of the drill rods and ability to steer within the soil. This includes paths for pipes for distribution lines or for services to individual residences or structures. In many cases, a visual survey and simple sketch may be sufficient for defining the bore route. In more complicated situations, a transit or other type survey may be required. In general, a proposed bore path plan view and profile layout should be prepared indicating the surface grade and important surface features, location of existing below ground utility lines, reference points, etc. The bore path layout should also show anticipated access pits for utility connections or lateral service lines, and the bore depth of the pipe to be placed, especially at critical points such as access pits, and at other reference points along the route.

8.5.1 *Surface Grade* – For convenience, previous discussions (Section 8.4) are based upon a level grade. For relatively regular surfaces, the actual (average) grade may be approximately determined using a taut string, or a series of such, spanning the distance between the entry and exit points. The string may also provide a reference for verifying the proper depth during the actual operation in the presence of minor surface depressions or irregularities (compared to depth), and serves as a basis from which to interpret the guidelines of Section 8.4, which assume a uniform level surface grade. In general, the bore should attempt to follow a path at the nominal specified depth below the average surface profile. For large surface depressions or mounds (e.g., of height greater than the depth of interest and extending over a long expanse, on the order of the drill rod bend radius or greater), including peaks and valleys, the bore should attempt to follow a path at the specified depth below the local average surface grade.

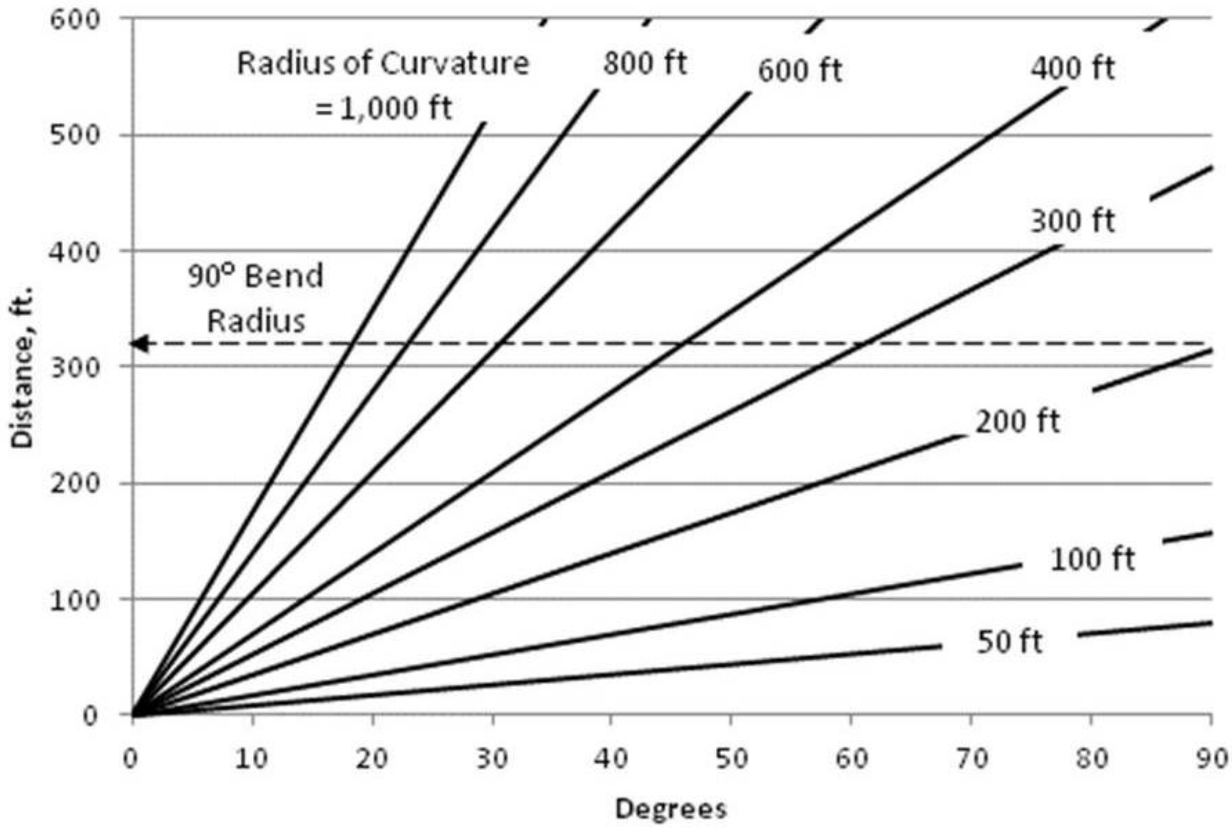

Figure 21 Radius of Curvature for Angle and Distance
(Source: Outside Plant Consulting Services, Inc.)

8.5.2 *Path Curvature* – Although the presence of obstacles or ROW geometry may impose deliberate path curvature (Figure 6), the bore plan should attempt to minimize such deliberate bends and curves, whether left/right or up/down. Such trajectories are difficult to follow and may lead to over-steering and excessive bends, resulting in increased stresses in the drill rods and greater required pulling forces during the installation of the pipe; see Section 7.3. The average radius of curvature, or 90° bend radius (see Section 3.3), of a path segment may be estimated based upon the distance along the path segment and the angular change, as follows:

Radius of Curvature (ft) = 57.3 x Distance (ft) / Angle (deg) (8a)

90° Bend Radius (ft) = 90 x Distance (ft) / Angle (deg) (8b)

Thus, a change of 20° along a 100 ft path segment corresponds to a path radius of curvature of 287 ft and a path 90° bend radius of 450 ft. Figure 21 illustrates the radius of curvature corresponding to the angular change and distance along the path. The 90° bend radius, defined as the distance for accomplishing a 90° angle, is equal to the radius of curvature multiplied by 1.57; see Section 3.3.4, Equation 1b. For example, the 90° bend radius corresponding to a 200 ft radius of curvature is equal to 200 ft x 1.57 = 314 ft, which is seen to agree with the distance traversed for a 90° bend, as indicated in Figure 21.

8.5.3 *Proposed Bore Path* – While more convenient methods and tools are now available for preparing a bore plan(**13**), it is instructive to consider the conventional manual procedure, such as illustrated in Figure 22. This figure shows a sample bore plan, comprising a straight path in the planar view, which may be used as the basis of subsequent as-built drawings, illustrated in Figure 24.(**16**) Although not explicitly shown in the sample, reference points should be included.

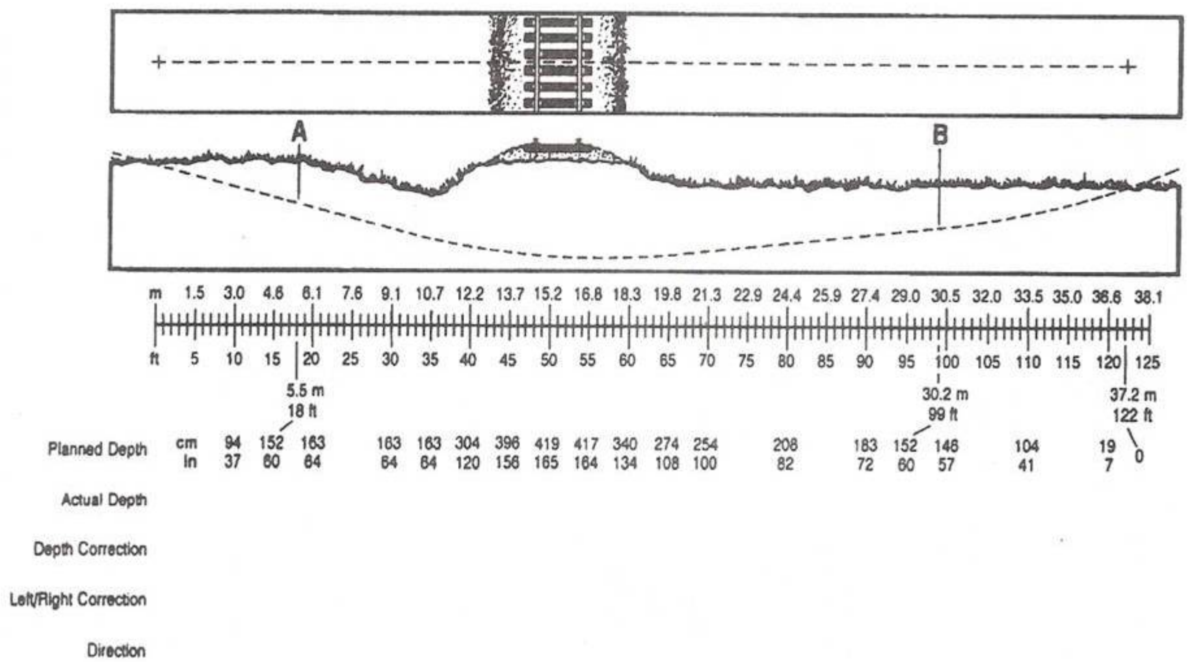

Figure 22 Initial Bore Plan
(Source: Ditch Witch®)

8.5.4 *Accuracy and Tolerance* – Section 6.3 (Figure 5) discusses the tolerance zone, with respect to existing facilities, which must be avoided by any part of the drill or reamer. To help maintain the required separation, it is recommended that the proposed bore path, including the outer edge of the cutter/reamer, be an additional 18 inches laterally offset from the outer edges of the tolerance zone, corresponding to a total 36-inch initially planned separation. For the case of the bore path crossing an exposed utility, adequate physical separation may be visually verified as the drill head or reamer passes above or beneath the existing line. In the rare event in which it is not feasible to expose an existing utility at a crossing, the position of the line must be otherwise accurately established or verified and the proposed bore path must **provide a minimum of 24-inches separation, or greater if required by State or local regulations**, between the outer edge of the cutter/reamer and the closest portion of the utility, whose depth has been determined as well as reasonably possible during the identification and location process (Sections 6.2 and 6.4). The owner may place additional restrictions on the allowed deviation from the proposed bore, in both vertical and horizontal directions. (See Section 9.5.1.) Soil conditions, including cobbles and other encountered obstacles, as well as attempts to conform to relatively sharp bends, may result in unintentional bore path deviations. More frequent verification of the position of the drill head during the pilot bore phase will help detect potential discrepancies as soon as possible, and facilitate path corrections; see Section 9.4.3.

9. Implementation

Section 9 discusses the overall sequence of operations, and appropriate procedures, during the actual pipe installation. These operations include drill rig positioning, pilot boring, tracking, steering, reaming and pullback. It is beyond the scope of these guidelines to provide detailed operational procedures for the various mini-HDD and auxiliary equipment. It is therefore assumed that the contractor has provided evidence of proficiency (see Section 5.9).

9.1 *Drill Rig Positioning*

The drill rig unit is positioned as determined in Section 8, consistent with the desired product pipe depth and bore route. The unit must be properly secured, typically by means of anchors driven into the ground, by impact or screwing, located at the front of the machine. Proper anchoring is especially important for soft or sandy soils. It is important to ensure that there are no utility lines or other facilities (service lines, sprinkler systems, ...) that may be damaged immediately beneath the anchors, which are driven several feet into the ground.

9.2 *Pilot Bore*

Figure 1 illustrates the initial pilot bore operation, including the drill head and assembly of drill rods. The actual size and type drill head selected should be appropriate for the soil conditions, considering the ability to penetrate and accomplish the desired steering. Depending upon the mini-HDD equipment, soil penetration is accomplished using high pressure, low volume fluid jets and/or mechanical cutting. Section 3.3, Section 8.2 and Appendix A discuss bending limitations of the drill rods and their implications for a mini-HDD operation. Overly aggressive steering corresponds to excessive bending of the rods, which may shorten their life due to cumulative fatigue as the drill rods rotate in a bent configuration. In addition, in order to minimize lateral bearing loads at the front of the rig, and avoid potential difficulties in the insertion of additional rods, steering should not be attempted until one rod length (e.g., 10 ft) has been inserted straight (while rotating) into the ground. Proper care and handling of the drill rods is important to avoid damage during the insertion or removal of rods from the drill string, and should conform to the manufacturer's guidelines. In general, the threads must be coated ("greased") when inserted into the drill string. Improper torque during connection may result in loosened, and possibly disconnected, rods.

9.3 *Drilling Fluid Usage*

Drilling fluids are used to remove cuttings and spoils and help support and stabilize the bore hole, as well as to provide possible cutting assistance during the boring or back-reaming operations. The fluids provide lubrication during the various phases of the HDD process (pilot boring, reaming, pullback), to reduce the required torque and thrust or pullback loads imposed on the equipment. Reduced friction is an important factor in minimizing the required tensile forces applied to the product pipe (Appendix C). The drilling fluid also cools the drill head to avoid premature damage to the cutters and/or failure of the internal transmitter. The volume of fluid required depends upon the size of the pilot bore and especially that of the subsequent expanded hole (Section 9.6), and on the role of the fluid in accomplishing the ground penetration. If mud motors are required, such as for rocky conditions, considerably greater volumes of drilling fluid will be required, for which the use of drilling fluid recirculating systems is recommended. An important element in the proficiency of the crew is an adequate understanding of the proper use of drilling fluids, and the appropriate types for various ground conditions.(**4**, **17**)

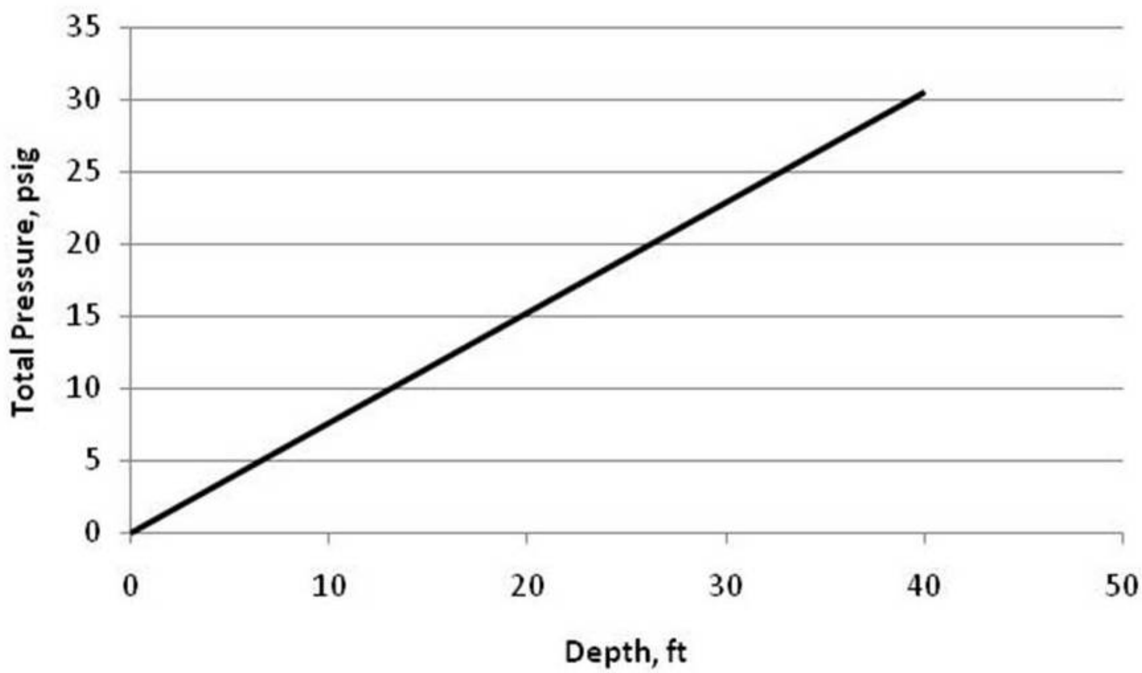

Figure 23 Recommended Limit on Total Drilling Fluid Pressure
(Source: Outside Plant Consulting Services, Inc.)

9.3.1 *Drilling Fluid Pressure* – A possible problem in HDD operations is the appearance of drilling fluid at undesired surface locations, or possible heaving, sometimes as a result of excessive drilling fluid pressures. Excessive applied drilling fluid pressures may also contribute to premature pipe collapse (Appendix B). Figure 23 may serve as a guide for the upper limit on the total pressure to be maintained within the bore hole, including that due to the weight of the drilling fluid/slurry and the incremental pressure applied at the drill head or back-reamer (Section B.3.4). Additional information and recommendations may be obtained from other industry sources.(**3**)

9.3.2 *Inadvertent Fluid at Surface* – Due to the combination of drilling fluid pressure and possible local fissures in the soil, it is possible that fluid may penetrate to the surface at an intermediate point along the bore path. In such cases, the material should be promptly remediated or removed. In order to avoid uncontrolled surface penetration in sensitive areas, several deliberately placed vertical holes from the surface to the bore hole can serve as a vent to locally relieve the fluid pressure. Such procedures may be appropriate at the edges of paved areas including driveways. Any vented fluid should be cleaned immediately after completion of the installation of the pipe, and the vent holes re-filled. See Section 9.10 for additional information.

9.3.2.1 *High Risk Situations*(**19**) – Extra caution should be employed in situations with a high risk of inadvertent returns:

- Fractured rock (pre-existing flow paths or presence of joints)
- Coarse grained permeable soils (gravel, cobble and boulders)
- Considerable elevation differences between the entry side and pipe side
- Areas where HDD vertical depth of cover is insufficient
- Artificial features (existing exploratory bore holes).

9.4 *Tracking and Steering*

9.4.1 *Communications* – During the pilot boring operation, the primary responsibilities are those of the drill rig operator and the locator, possibly using a walkover receiver manually, as indicated in Figure 1. The locator provides information to the operator on an ongoing basis to allow path corrections to follow the planned bore path, possibly aided by available software tools.(**13**) For systems that provide remoting of the locating information directly to a display at the drill rig, including "target steering"(**20**), much of this function is accomplished automatically, but communications are still required to coordinate operations and avoid hazardous situations. Radio communications should be used for distances exceeding that for convenient voice communication (e.g., 50 ft) or when out of sight. If communications are disrupted, the drilling operation must be halted until communications are restored. See Section 9.4.4.

9.4.2 *Interfering Signals* – To the extent possible, potential sources of interference to the tracking system should be identified and eliminated. For example, electronic signals previously applied to existing utility lines or tracer wires to facilitate their location (Section 6.2) should be removed prior to the boring operation. It is also possible that some existing lines, such as dielectric (non-metallic) fiber-optic cables, may utilize a tracer wire that continuously carries a characteristic signal to facilitate cable location. If suspected to be present, and in the same frequency band used by the mini-HDD tracking system, the responsible facility owner should be contacted to temporarily remove such signals. Rebar is a common source of passive interference, but may be mitigated by use of recently developed tracking systems.(**21**)

9.4.3 *Location Interval* – For manual tracking, the actual bore path should be visibly marked at each location point. In order to accurately follow the planned path, the bore head position should typically be determined at least once each rod addition. More frequent determinations (e.g., each half rod length) are recommended when negotiating turns or path corrections, or in sensitive areas such as the vicinity of other utilities. Since the drill head position (e.g., roll angle) may vary somewhat immediately after soil penetration, it may be beneficial to rotate the drill string in place (without thrust, with fluid flow) for several rotations before taking a reading.

9.4.4 *Steering* – In areas with cobbles or other obstacles that may divert the drill head, and when not using remote or target steering, measurements should be made whenever contact with such obstacles is suspected. Such incidents can lead to significant departures from the intended path, possibly towards adjacent facilities, which may require immediate correction. If not acceptable to gradually steer back to the desired path, it may be possible to retract the rod somewhat and attempt to pursue a path closer to that intended.

9.5 *Records*

9.5.1 *Pilot Bore Position* – Figure 24 shows the actual "as-built" path of the pilot bore based upon the tracking information, corresponding to the original bore plan of Figure 22.(**16**) The deviations from the intended path in both the horizontal and vertical directions are provided. This information, and/or related drawings and supplemental information, may be used to provide a record of the installation, to be submitted to the owner; see Section 10.4. The drawings should reference permanent existing structures or features (e.g., curbing), and preferably indicate the relationship to existing utilities, especially at crossings of such lines. Unforeseen obstacles encountered during the drilling process should also be indicated. Similar to the availability of more convenient (less manual) methods and tools available for preparing the original bore plan (Section 8.5.3), software tools are also available for facilitating the preparation of the information or drawings, including the ability to "Log-While-Drilling".(**13**, **20**)

9.5.2 *Other Information* – Figure 24 also includes information related to the actual boring operation such as steering commands (drill head orientation). Additional information related to the boring or reaming operation, such as type and size (diameter) drill head, reamer and/or compactor; drilling fluid type and volume; duration of pilot bore and/or back-reaming operation, may be useful for subsequent operations in the project area (see Section 4.4.3). In general, a daily log book, or equivalent, should be maintained by the contractor to provide a permanent record of the operation, including the above information.(**4**)

9.5.3 *Product Pipe Position* – The recorded path information is based upon the tracking information obtained during the pilot bore operation, and assumes that the reamer closely follows the original path. In practice, however, it is not uncommon for the reamer to deviate somewhat from the pilot bore path, due to various effects, including a tendency for the reamer to cut corners as it is pulled around curves and bends. Although such discrepancies may be significant in cases of very close proximity to other utilities, it is not generally considered to be a major issue, similar to the tendency of the installed product pipe to float above (or sit below) the centerline of the final bore hole corresponding to the difference in their diameters.

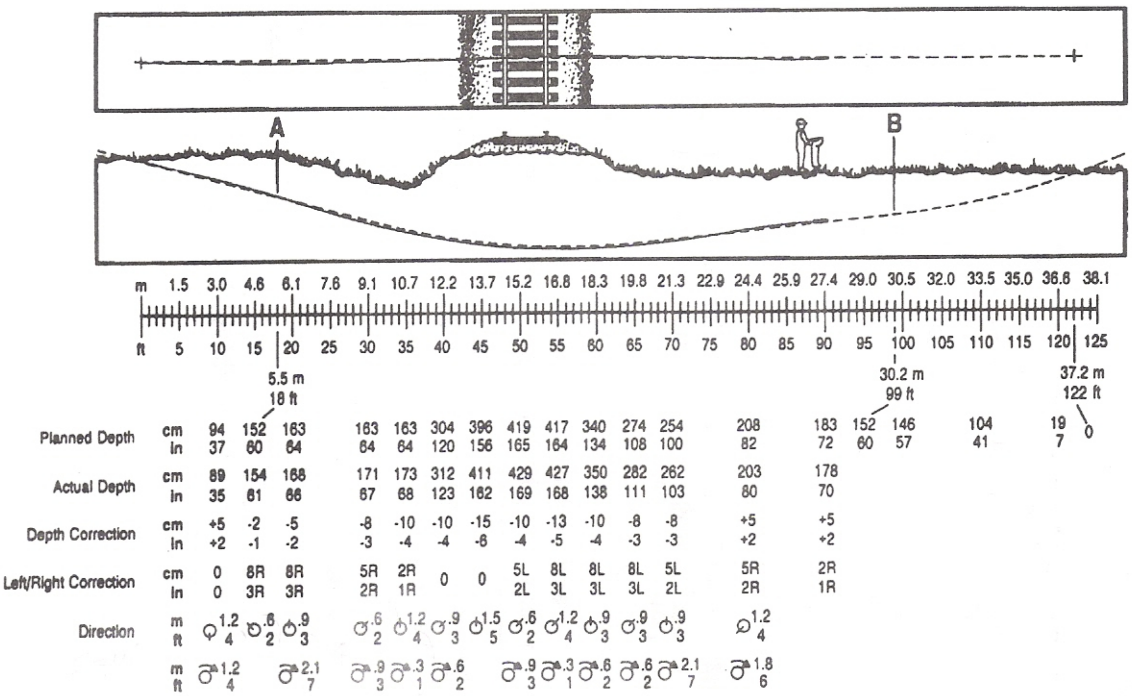

Figure 24 Final "As-Built" Pilot Bore Path
(Source: Ditch Witch®)

9.6 *Reaming*

9.6.1 *Final Hole Diameter* – With the exception of very small diameter pipes, such as 1- to 1½-inch HDPE duct, most mini-HDD operations require the expansion of the initial pilot bore hole, as illustrated in Figure 2. The increased size is necessary to accommodate the relatively large diameter of the pipe, including pulling grips, as well as to facilitate spoils removal and avoid unnecessarily large pullback forces on the pipe. A final hole diameter at least 50% greater than the outer diameter of the pipe (or pipe bundle) is recommended. The back-reaming and pullback operation typically requires greater time, machine load, and drilling fluid volume than the initial pilot bore due to the creation of the larger hole. The soil conditions will determine the appropriate type of reamer.

9.6.2 *Pre-Reaming* – In some cases, the mini-HDD operation requires more than the two stages illustrated in Figures 1 and 2. A simultaneous back-reaming/pullback operation is adequate for product pipes up to approximately 4-inch nominal size. For larger sizes, however, a pre-reaming operation(s) is recommended, allowing relatively large holes to be created in stages. Although time-consuming, this procedure reduces the required torque and thrust loads at the mini-HDD equipment, and reduces the likelihood of subsurface voids, surface heaving or settlement, and undesirable drilling fluid appearance at the surface. The hole diameter should be expanded in increments of 6 inches or less during a single pass. In order to maintain the original path during the pre-reaming operation, drill rods must be available at the pilot bore exit and connected to a swivel at the rear of the reamer and pulled into the hole. Due to potential hazards associated with expanding the hole in the presence of existing electrical facilities lines, it is important to closely adhere to the electrical safety aspects discussed in Section 5.5.2 to avoid electrical shock at the bore exit end where the rods are added, as well as at the drill rig.

9.7 *Connecting the Product Pipe*

9.7.1 *Assembly* – A major advantage of polyethylene pipe is its availability in continuous lengths on a reel, or in a coil, for a wide range of diameters (possibly 6-inches or greater). For HDPE products not available in continuous lengths, discrete lengths of HDPE pipe may be readily fused in the field, without an appreciable loss in the tensile capability required for HDD pulling operations.[6] In the latter case, the pipe should be assembled prior to the pullback operation to maintain continuity during the pipe placement process and avoid unnecessary delays. Significant interruptions may lead to increased drag and resulting pulling forces, including eventual loss of integrity and collapse of the bore hole, preventing further movement of the pipe.

9.7.2 *Gripping* – Appropriate gripping hardware and utilization should be compatible with the inherent safe pulling load (Section 7.3.1) of the product during the pullback operation and also ensure that debris or slurry does not enter the pipe. Improper gripping may result in slippage or premature pipe rupture at the grip connection. One option is to use a pulling head that is fused to the product pipe; see also Section 9.7.4. Although some, more sophisticated, HDD operations, including maxi-HDD, may deliberately allow drilling fluid to enter the cavity to minimize or eliminate buoyancy effects, which tend to increase pulling loads (Section 7), as well as to offset the effects of external pressure, typical mini-HDD installations do not employ this procedure.

9.7.2.1 *Hardware* – A relatively convenient gripping method, appropriate for a relatively wide range of pipe sizes, utilizes a wire mesh grip that squeezes the outer surface of the pipe as tension is applied, and is properly used in combination with an internal dowel inserted into the pipe to prevent crushing as well as the entry of debris or slurry. (If the dowel or equivalent is not employed, the exposed end of the duct must be taped closed.) The wire mesh grip should be initially taped to the pipe outer surface to prevent initial loosening until tension is applied. Although convenient to use, such grips may not be fully compatible with the safe pulling load of the pipe. Another type of gripping hardware utilizes a tapered threaded shaft, in the appropriate size range, that engages the interior surface of the pipe. A particularly effective hardware design grips both the interior and exterior surfaces of the pipe. Using any hardware type, several pipes in a bundle may be pulled simultaneously. A separate grip should be used for each pipe, and the position of the grips should be staggered, to avoid a large bulge.

9.7.3 *Swivel* – In order to prevent the transmission of torsional loads to the pipe(s) due to the rotating drill rods or back-reamer, a swivel should be mounted behind the rods or reamer, to which the pulling line(s) and gripping hardware are connected; see Figure 2. The swivel must be appropriate for drilling operations, compatible for use in soil and slurry. For non-breakaway type swivels (Section 9.7.4.2 discusses breakaway swivels), the load rating should be at least as large as the total safe pulling loads of the bundle of pipes to be installed, but not excessively greater. Inefficiencies in overly large swivels may impose significant torque on small pipes.

9.7.4 *Breakaway Link or Thinner-Walled Pipe Connection* – Section 7 provides a methodology for selecting the pipe strength (wall thickness, DR) for a mini-HDD operation, providing confidence that the product pipe will safely withstand the installation stresses. Nonetheless, for some applications it may be desirable to ensure that the integrity of the product pipe has not been compromised by excessive tensile loads, especially when using product pipe

[6] See ASTM F1055, ASTM F2620, ASTM F3190, MAB-01 and MAB-02.

thinner than DR 11. In general, attempting to monitor the pulling load on the pipe by observing the hydraulic pressure at the control panel, which reflects the pulling load imposed on the drill rig, is not appropriate. Such loads are not necessarily experienced by the pipe, but include the pullback force necessary to ream or compact the hole, or pull the drill rods through the path. A commonly used procedure would be to install a breakaway link between the main swivel and the grip at the pipe, to ensure that the allowable tensile strength is not exceeded. The rating of the breakaway link should be compatible (i.e., slightly lower than) with the safe pulling load of the product pipe. Alternatively, it is possible to fuse a short segment of thinner-walled pipe to the product pipe, to serve as a "weak link". In the event of a broken or ruptured link, due to excessive pull load, the pipe should attempted to be withdrawn from the pipe entry end. The likely reason for failure should be determined and, assuming the predicted pull load is verified to be acceptable (Section 7), the installation repeated. If necessary, a new bore path may have to be created.

9.7.4.1 *Multiple Pipes* – When installing a bundle of pipes, the pull loads may not be equally or proportionally distributed among the individual units, and an individual pipe may experience excessive stress. Thus, it is preferable to use an individual breakaway link connected to each pipe, rather than a single link rated at the cumulative strength of the bundle.

9.7.4.2 *Breakaway Swivel* – When pulling a single pipe, if a breakaway swivel is used as the breakaway link, and is not specifically designed for direct exposure to soil, the use of such a breakaway swivel does not reduce the need for the main swivel described in Section 9.7.3. When pulling multiple pipes in a bundle and individual breakaway swivels are used for each pipe (Section 9.7.4.1), a separate main swivel behind the reamer is again required to prevent twisting of the bundle itself.

9.8 *Handling the Pipe*

The following procedures should be followed when handling or installing the pipe during the mini-HDD operation:

- Avoid supporting pipe on surface that may cause abrasion during pullback
- Minimize back tension on pipe, to prevent escalating effects at pulling end
- Avoid pulling around sharp bends, to avoid pipe collapse (kinking); see comments below
- Pull additional 3 - 4% length at pipe exit to allow for temporary elongation (stretch) and subsequent recovery.

When exposed to sharp bends, the pipe is vulnerable to local collapse. For example, the pipe is vulnerable when it is fed directly out of an access pit (Figure 11) where it may be desired to interface with aboveground communications or power equipment. Special care should be used, including local support of the pipe as it is bent. In general, the pipe is particularly vulnerable when pulled around bends while under tension. Thus, the procedure of using the tensile capability of the drill rig (or other equipment) to pull the pipe out of an access pit, directly from the surface, requires caution, and should be avoided, if possible. If necessary, sharp bearing corners should be cut and relieved to reduce the degree of curvature where the pipe is pulled around the corners of the pit.

To account for possible recovery ("relaxation") of temporary elongation in the polyethylene pipe, an additional amount of pipe equal to 3% – 4% of the bore length should be pulled from the pipe exit, with a similar amount left at the entrance. The pipe should not be cut or terminated for several hours, or approximately the time required for the actual pullback operation.(**1**)

9.9 *Potential Causes of Failure or Problems*

HDD operations should only be performed by trained and experienced contractors (Section 5.9). Nonetheless, such operations may encounter various difficulties, including:

- Loss of drilling fluid or loss of circulation (flow)
- Obstructions (cobbles, debris, foundations, ...)
- Hydrolock[7]
- Line and Grade Problems
- Bore hole collapse
- Failure of drill rods or downhole tooling
- Surface collapse or heaving
- Inadvertent drilling fluid returns (surface, waterways, ...); see Section 9.10
- Striking or damaging existing utility
- Product pipe failure or damage
- Product pipe stuck in bore hole.

Practices and contingency plans and methods for avoiding or mitigating such problems are available in industry guidelines.(**4**, **19, 22**)

9.10 *Containment of Inadvertent Drilling Fluid Returns*

In the event of inadvertent, uncontrolled returns, there are a variety of containment measures that may prove useful, depending upon the anticipated volume, access, environmental sensitivity of the area contaminated and adjacent areas and soil and weather conditions. Possible methods include the use of silt fencing, hay or straw bales, or sand bags. If insufficient, additional techniques are available.(**19**)

10. Completion

Following installation of the pipe, it is necessary to confirm the viability of the new facility, as well as to provide a permanent record of the actual placement location. Section 10 addresses these practices and also indicates the need for final site cleanup.

10.1 *Inspection*

It is assumed that the owner, or its representative, of the pipeline facility being installed, has had an inspector on-site, or has regularly visited the area, to verify the progress of the operation and that the construction is consistent with recommend practices, such as those provided herein or

[7] "Hydrolock" occurs when the pressure acting on the leading end of the reamer, during the pullback process, exceeds the pullback capability of the drill rig.

available from the industry.(**4**, **5**)[8] It is essential that pipeline facility being installed be visibly inspected prior to filling the various pits that may be present. In particular, the route should be inspected at openings or pits provided for access, as well as any areas where existing utilities have been exposed, such as at crossings with the new pipe. The depth of the pipe may be conveniently verified at such locations.

10.2 *Pipe Testing*

The integrity of the pipes should be appropriately verified. Any mud or debris that may have entered the pipe should be expelled, and the pipe flushed if necessary. The assembled pipe line should be checked for leakage, pressurized as necessary, consistent with its subsequent usage (e.g., potable water).

10.3 *Site Cleanup*

After approval by the owner, the pits should be filled as soon as possible, the soil compacted, and the surface area restored, as reasonable. Surface mud and drilling fluid must be cleaned from the site and be properly disposed (Section 5.8). All equipment, tools, and miscellaneous debris must be removed.

10.4 *Certified Record ("As-Built") Drawings*[9]

Information showing the final "as-built" location of the pipe must be submitted to the owner, who should confirm that all appropriate information is included (Section 9.5.1). The information should be sufficient to create a certified record of the new utility pipe. The drawings provided by the contractor may be used to verify the pipe was placed at the proper location and depth, or within acceptable limits. Ideally, the information provided should correspond to the actual position of the pipe within the final expanded bore hole. This position can differ from the final pilot bore path (Figure 24) due to possible deviation of the reamer during the expansion of the bore hole, as well as movement of the pipe within the oversized bore hole. The accurate determination of the final pipe position may be expensive, requiring exposure at discrete points or use of special surveying tools inserted within the pipe. Such accuracy may not be required by the owner. As a minimum, however, deviations of the pipe (center) position from the planned bore path (Figure 22) should be provided if exceeds 6 inches vertically or 12 inches laterally.(**5**) However, as a check on the general quality of the installation, the owner may elect to verify the approximate location or depth at several discrete points along the path by careful digging, or by use of an internal transmitter placed within the pipe path in combination with a surface locator.

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[8] HDD training and/or certification courses are available from various sources, including the Center for Underground Infrastructure Research and Education at the University of Texas at Arlington, the Centre for Advancement of Trenchless Technologies at the University of Waterloo, Bowling Green State University, the Trenchless Center at Louisiana Tech University, and the North American Society for Trenchless Technology.

[9] A new document, *Standard Guideline for Recording and Exchanging Utility Infrastructure Data* is under preparation by the ASCE to provide a common means for communicating the positional accuracy of utility assets.

APPENDICES

A. Drill Rod Bending or Steering Capability

A.1 *Typical Characteristics*

The bending capability of the drill rod may be specified by various parameters, including those described Section 3.3. In general, the degree of allowable bending or curvature will depend upon the characteristics of the steel drill rod, including yield and fatigue resistance, as well as the capability of the threaded joints to withstand the associated bending stresses. In general, the allowable radius of curvature or 90° bend radius will be proportional to the outer diameter of the drill rod.

Consider the following **example**: The manufacturer of a 10 ft long drill rod, of 2-inch diameter, specifies an allowable "90° bend radius" of 157 ft. Equation 1b then indicates that the "radius of curvature" may be calculated as:

Radius of Curvature (ft) = 90° Bend Radius (ft) / 1.57
= 157 ft / 1.57
= 100 ft

Thus, the distance from the center of the circle to the perimeter (100 ft) is considerably less than the minimum allowable distance around a 90º quadrant; see Figure 3. A misunderstanding of the difference between these two terms may lead to overstressing of the rods; e.g., if bent to create a circular path of only 100 ft around a 90º quadrant. Conversely, assuming that the distance from the center of the circle to the perimeter must be a minimum of 157 ft is under-utilizing the steering capability.

For the same drill rod, Equation 1a may be rearranged to quantify the maximum angular change per drill rod:

Angular Change (deg/rod) = 90 x Rod Length (ft) / 90° Bend Radius (ft)
= 90 x 10 ft / 157 ft
= 5.7º / rod

A similar result may be obtained by rearrangement of Equation 1c:

Angular Change (deg/rod) = 57.3 x Rod Length (ft) / Radius of Curvature (ft)
= 57.3 x 10 ft / 100 ft
= 5.7º / rod

These values describing the bending -- or maximum steering -- characteristics of the postulated 2 ft x 10 ft drill rod are representative of the capability of typical mini-HDD machines; see Section A.2. These limitations apply to bends in a horizontal (plan) or vertical (profile) plane, as well as an inclined plane or three-dimensional path.

A.2 *Significance of Rod Dimensions*

As an approximate guide, longer drill rods, of the same size (diameter) and design as that considered in the above example, would typically be characterized by the same (minimum) radius of curvature or 90° bend radius, but proportionally greater allowable angular change per rod. Alternatively, similar designed drill rods of the same length, but larger diameter, would correspond to a proportionally greater required (minimum) radius of curvature or 90° bend radius.

Thus, considering another **example**, for an assumed drill rod of 15 ft length and $2^7/_8$-inch diameter, the radius of curvature or 90° bend radius would be expected to be greater than that of the previous (Section A.1) 2 ft x 10 ft rod by a factor of 2.875 ÷ 2.0, or approximately 1.44, corresponding to 226 ft or 144 ft, respectively. The angular change per rod, which is inversely proportional to the radius of curvature or 90° bend radius, would be reduced by a factor of **1.44**, but increased by a factor of 15 ft ÷ 10 ft, or **1.5**, to account for the greater length, resulting in

Angular Change (deg/rod) = 5.7º / rod x **1.5** / **1.44**
= 5.9º / rod

In practice, the actual limits may be somewhat different, due to the design details, including the capability of the threaded joints.

It is noted that the bending limits as described above are more liberal than the industry rule of thumb (ASTM F1962) that the radius of curvature (feet) for a steel pipe or rod should not be less than 100 times the diameter (inches), corresponding to 200 ft minimum for the 2-inch drill rod of the first example. This is considerably more restrictive than the manufacturer allowed minimum radius of curvature of 100 ft.

B. Maximum Allowable Depth (Pipe Collapse/Buckling) – Theoretical Development

The following methodology, for application to mini-HDD installations, is based upon techniques similar to that provided in "Simplified Methodology for Selecting Polyethylene Pipe for Mini (or Midi) – HDD Applications", by Slavin(**11**), which are derived from the procedures provided in ASTM F1962.

B.1 *Allowable Net External Pressure*

ASTM F1962 provides the basic equation for determining the critical (buckling) pressure, P_{cr} :

$$P_{cr} = 2\,E \cdot f_o \cdot f_R / \{(1 - \mu^2) \cdot (DR - 1)^3\} \qquad \text{(B-1)}$$

where E is the material modulus of elasticity, μ the Poisson's ratio, f_o the ovality compensation (reduction) factor, and f_R the tensile stress reduction factor. Poisson's ratio may be is assumed to be 0.45 (**1**), while the effective modulus E for the viscoelastic HDPE pipe depends upon the load duration. The factor f_o accounts for initial or subsequent out-of-roundness due to imposed loads on the pipe (buoyancy, longitudinal bending, possible soil pressure, ...), and f_R recognizes a potential reduction in collapse strength in the presence of significant tensile loads, such as during the mini-HDD installation phase. The critical pressure is independent of the pipe diameter, and is therefore applicable to both IPS and DIPS systems.

B.2 *Idealized Allowable Head of Water*

The critical pressure, P_{cr} , as given above may be expressed in terms of an equivalent hydrostatic head (ft) of water, for idealized conditions in which the ovality reduction factor, f_o , and tension reduction factor, f_R , are assumed equal to 1.0, and at a nominal temperature of 73°F. Since the (effective) material stiffness, E, is dependent upon the load duration, the critical pressure is also dependent upon duration. Table B.1 is based upon the corresponding HDPE (PE4XXX) characteristics provided in The Handbook of Polyethylene Pipe.(1) The values shown are based on the minimal required wall thickness, as opposed to that of the actual manufactured product, and therefore underestimate the average collapse pressure (water head) of each pipe by more than twenty percent. The indicated depths assume an **empty pipe**, in the absence of internal fluids or pressure, which would more than offset the effect of the external pressure. Although some HDD installations, such as more complex maxi-HDD installations, may deliberately allow the pipe to be filled with water or drilling fluid during installation, to reduce the buoyant weight and corresponding tensions, as well as avoid possible initial collapse, such practices are not typically employed in mini-HDD operations. Depending on the application, however, the beneficial effects may be present during the later operational phase, such as for potable water supply, or other pressurized applications, with the depth limited by potential collapse during the installation itself.

Table B.1 Ideal Critical Pressure (Water Head, ft) for Unconstrained HDPE (PE4710) Pipe (73°F)

Duration	Pipe Diameter to Thickness Ratio (DR)				
	7	9	11	13.5	17
"Short Term"	3,350	1,415	725	370	175
1 hr	2,090	880	450	230	110
10 hrs	1,740	735	375	195	92
100 hrs	1,475	620	320	165	78
1,000 hrs	1,230	520	265	135	65
1 yr	1,070	450	230	120	57
50 yrs	775	330	170	86	41
100 yrs	750	315	160	83	40

B.3 *Adjusted Allowable Depths*

Since the drilling fluid is of significantly greater density than water, the idealized pressure head (ft) values of Table B.1 must be reduced by a factor equal to the specific gravity of the drilling fluid/slurry relative to water. A specific gravity of 1.5 is conservatively assumed for the mud slurry. The values must be further adjusted (reduced) for possible initial elevated temperature as well as the aforementioned ovality and tensile load factors. Furthermore, the effect of the local hydrokinetic pressure of the drilling fluid during the pullback process, in addition to the hydrostatic pressure corresponding to the head (depth), should be considered.(ASTM F1962) As discussed above, since the depths in Table B.1 are based upon differential pressure, the addition of water within the pipe during the installation (and pre-operational) phase would have a dramatic impact, essentially tripling the corresponding final allowable depths. Although such practices are not typical for mini-HDD installations, they may be advantageously employed for special cases; e.g., some midi-HDD applications.

B.3.1 *Short-term Collapse* – There are two phases to be considered with regard to possible short-term collapse of the pipe, as associated with the installation process. During the actual installation phase, the relatively high 1 hour strength, corresponding to the effective cumulative tensile load duration on the pipe, would be appropriate, in combination with anticipated values of f_o and f_R during this period, as well as the local hydrokinetic pressure of the drilling fluid. For the post-installation (but pre-operational) phase, a relatively low 1,000 hour collapse strength is conveniently employed as the maximum period during which the drilling fluid is assumed to apply hydrostatic pressure on the pipe, subsequent to which it is assumed to thicken and set sufficiently to provide adequate lateral support for the pipe.(**23**, **24**) For this post-installation phase, the tension reduction factor, f_R , is equal to 1.0, in the absence of significant tensile load, and there is no hydrokinetic pressure increment. The effect of possible initial elevated material temperatures, due to conditions at the surface prior to installation, is ignored, assuming the pipe adjusts to local belowground temperatures during the installation process.

B.3.2 *Ovality Factor*– Based upon the ovality reduction factor provided in ASTMF 1962, and consistent with the present simplified approach, it is reasonable to assume a maximum overall value of f_o of approximately 0.65 to account for ring deformation due to initial ovality plus that induced during installation (e.g., buoyancy or longitudinal bending, aggravated by tension-induced wall bearing pressure), or possibly due to some degree of soil-induced loads. This corresponds to an ovality of approximately 5%, a reasonable ring deflection limit.(**1**)

B.3.3 *Tension Reduction Factor* – ASTM F1962 provides the tensile stress reduction factor f_R as a function of the average stress on the pipe cross-section. For stress levels corresponding to that of the safe pulling load (Table 2 or Table 3), f_R is equal to 0.65. However, for tensile loads that are significantly less than the safe load, as would be typically experienced, f_R would be closer to the 1.0 level. For the present purposes, the likelihood of experiencing a tensile load equal to the predicted value (i.e., equal to the safe pull tension), based on placement at the somewhat conservatively determined maximum recommended length, simultaneously with placement at the maximum recommended depth, is assumed to be low.

B.3.4 *Hydrokinetic Pressure* – ASTM F1962 assumes the incremental hydrokinetic pressure applied at the drill head or back-reamer to be as much as 10 psi (equivalent to 23 ft of water head). However, the actual value should also be limited to that which would avoid heaving or fluid leakage at the surface due to the total pressure, including that due to the hydrostatic pressure head. In general, the lower the mud slurry density, the greater the allowable hydrokinetic fluid pressure that may be applied. Thus, although a specific gravity of 1.5 is conservatively assumed for the mud slurry for the purposes of these guidelines, lower values are recommended in practice.(**4**) Figure 23 shows recommended total pressure based upon the simplified assumption that the pressure due to the drilling fluid/slurry may be as high as the overburden pressure due to the soil(OPSS 450), with an assumed density of 110 lbs/ft^3, but also no greater than 10 psi above that due to the hydrostatic pressure of the drilling fluid/slurry. Excessive pressures may also contribute to premature pipe collapse.

B.3.5 *Maximum Allowable Depth* – Both the 1 hour installation and the 1,000 hour post-installation strengths should be considered relative to the applied loads, as described above. Based upon the above discussions, and considering the various factors and their applicability, the **1,000 hour** installation conditions are assumed to be the more restrictive. Thus, these values, as reduced by the slurry density (1.5) and ovality factor (0.65), plus a suggested “safety” (i.e., uncertainty) factor of 2-to-1, to account for deviations from the above assumptions, provide the allowable maximum depths based upon the short-term (installation and pre-operational) considerations. These factors correspond to a **net reduction of 4.6** for the values indicated in Table B.1, and result in estimated allowable depths ranging from greater than 250 ft. for thick-walled DR 7 to slightly less than 15 ft for relatively thin-walled DR 17, with significantly greater (20%) average values due to the oversize effect of actual manufactured product.

B.3.6 PPI Boreaid (www.ppiboreaid.com) – The Plastics Pipe Institute BoreAid™ software tool is intended to apply to maxi-HDD applications, and allows a more precise determination of the maximum allowable depth, considering both short-term (e.g., installation) or long-term loads, and, based on the specific application (pressurized vs non-pressurized) and soil characteristics. A consideration of a variety of possible combinations indicates that the allowable depths, as estimated by the above simplified procedure, are remarkably consistent with that of Boreaid, as applied to analogous maxi-HDD installations, with the exception of DR 17 pipe, which appears to be limited to lesser depths, due to collapse during initial installation. The DR 17 pipe may be conservatively placed at less than 10 ft, although a greater depth, such as 15 ft, may be justified for installation tensions less than the maximum allowable, (e.g., a relatively short bore), and in consideration of the 20% additional margin described above.

C. Pulling Tension Prediction – Theoretical Development

The following methodology, for application to mini-HDD installations, is based upon the techniques provided in "Simplified Methodology for Selecting Polyethylene Pipe for Mini (or Midi) – HDD Applications"(**11**), which are derived from the procedures provided in ASTM F1962.

C.1 *Maxi-HDD Geometry*

Figure C.1 illustrates a typical geometry for a maxi-HDD installation, corresponding to a river crossing, consistent with ASTM F1962. The overall path includes the three segments spanning the pipe entry to exit point (L_2, L_3, L_4). An additional "excess" length (L_1) corresponds to that remaining after the span has been accomplished. Thus, the projected length of the actual crossing, L_{bore}, is given by

$$L_{bore} = L_2 + L_3 + L_4$$

In some cases, the intermediate horizontal segment, L_3, may be of zero length. In general, the depth of the crossing, H, is small compared to distances $L_2 + L_4$, due to the typically low pipe entry angle, α, and exit angle, β.

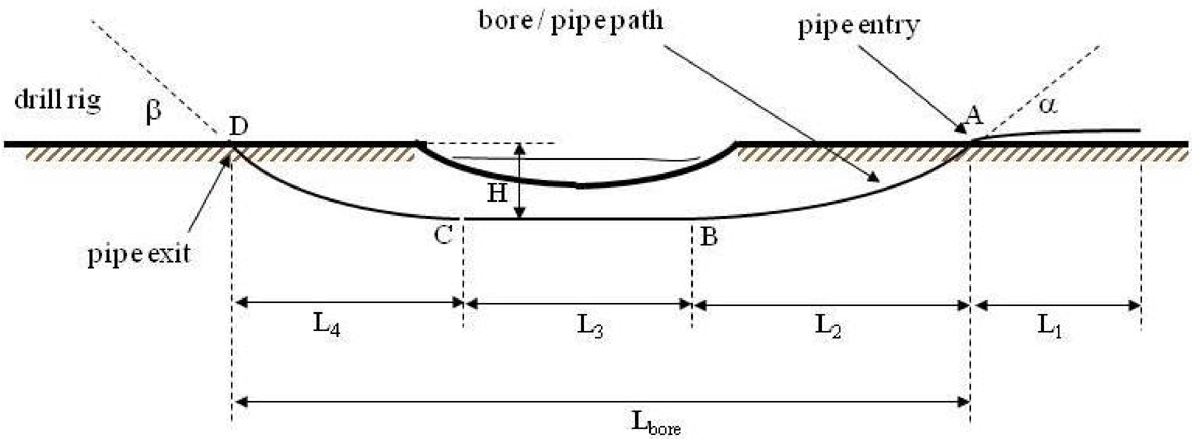

Figure C.1 Nominal Maxi-HDD Route (River Crossing)
(Source: Outside Plant Consulting Services, Inc.)

C.2 *Pull Load Equations*

Using the above terminology, ASTM F1962 provides a set of equations to estimate the required pull force as the pipe traverses the route. Thus, T_A, T_B, T_C, and T_D correspond to the predicted pull forces with the leading end of the pipe at points A, B, C and D (Figure C.1):

$$T_A = e^{\nu a\, \alpha} \cdot \nu_a \cdot w_a \cdot (L_1 + L_2 + L_3 + L_4) \qquad \text{(C-1a)}$$

$$T_B = e^{\nu b\, \alpha} \cdot (T_A + \nu_b \cdot |w_b| \cdot L_2 + w_b \cdot H - \nu_a \cdot w_a \cdot L_2 \cdot e^{\nu a\, \alpha}) \qquad \text{(C-1b)}$$

$$T_C = T_B + \nu_b \cdot |w_b| \cdot L_3 - e^{\nu b\, \alpha} \cdot (\nu_a \cdot w_a \cdot L_3 \cdot e^{\nu a\, \alpha}) \qquad \text{(C-1c)}$$

$$T_D = e^{\nu b\, \beta} \cdot (T_C + \nu_b \cdot |w_b| \cdot L_4 - w_b \cdot H - e^{\nu b\, \alpha} \cdot [\nu_a \cdot w_a \cdot L_4 \cdot e^{\nu a\, \alpha}]) \qquad \text{(C-1d)}$$

where w_a and w_b are the empty (above ground) and buoyant weights of the pipe, respectively, and ν_a and ν_b. are the corresponding coefficients of friction; the angles α and β are expressed in radians[10]. For HDD installations for which the buoyant forces dominate – i.e., in the absence of anti-buoyancy techniques, such as filling the product pipe with water or drilling fluid to serve as ballast-- the peak required tension will tend to occur towards the end of the installation. Thus, as described below, for the present purposes, an estimate of T_D is sufficient for determining the appropriate pipe strength.

C.2.1 *Coulomb Friction Model* – Equations C-1 are based upon conventional Coulomb friction. In this mathematical model, drag forces on the pipe are proportional to the local normal bearing pressure applied at the pipe surface, with the proportionality constant designated as the "coefficient of friction". Bearing pressures are due to the combination of several effects, including the dead (empty) weight of the pipe where above ground, the buoyant weight of the submerged pipe (possibly reduced by anti-buoyancy measures), or bending forces associated with pulling a stiff pipe around a curved surface. For the case of HDPE pipe, of low bending stiffness relative to that of the steel drill rods that created the gradually curved bore hole path, the corresponding bearing and drag forces are not significant.

C.2.2 *Capstan Effect* – There is, however, another important source of bearing pressure acting at bends that is independent of the pipe stiffness, or weight or buoyant forces, and is due to the local tension tending to pull the pipe against the inner surface of the curved path. This phenomenon is referred to as the "capstan effect" (i.e., the operating principle of the "capstan winch") and is the basis of the exponential terms in Equations C-1. Such effects are independent of the direction of curvature, or the sharpness of the bend (radius of curvature) and accumulate exponentially along the path. The capstan effect results in a local amplification factor at each discrete bend of finite angle, or, for a gradual bend, an amplification effect distributed along the path, with magnitude dependent upon the total cumulative traversed angle. For an idealized weightless, perfectly flexible pipe:

$$F_2 = F_1 \cdot e^{\nu \theta} \qquad \text{(C-2)}$$

F_1 represents the axial tension at the entry point of a bend of magnitude θ (radians), ν is the local coefficient of friction between the product pipe and bore hole wall surface, and F_2 is the required axial tension at the exit point of the bend. In practice, the effect of the actual weight, or possible stiffness, of the pipe, is reflected in the preceding tension, F_1. Due to the exponential compounding character of the tension increase, discrete route bends or gradual accumulating curvature, may represent the dominant source of drag, essentially controlling practical placement distances.

C.3 *Simplification for Mini-HDD*

Equations C-1, and the ASTM F1962 procedures in general, were originally developed for use by experienced or knowledgeable engineers, for application to a maxi-HDD project. However, the application of these methods to most mini-HDD projects would not be practical or appropriate. Thus, the reduction of these equations to a relatively simple calculation, although at a possible loss of precision, is desired.

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[10] The angle in radians is equal to the angle in degrees x (π / 180). For relatively small angles, such as typical HDD bore entry or exit, the angle in radians is approximately equal to the percent grade divided by 100.

C.3.1 *Simplifying Assumptions* –Equations C-1 may be simplified for the present case of interest -- i.e., typical mini-HDD installations of HDPE pipe – based upon the following assumptions:

- No anti-buoyancy techniques employed
- Coefficients of friction, ν_a and ν_b, equal to 0.5 and 0.3 respectively
- Pipe entry angle, α, and exit angle, β, equal to 20°
- Depth of crossing, H, small compared to overall bore length, L_{bore}
- Peak pull force, T_D, occurs at the end of the installation.

These assumptions are reasonable and/or conservative, and result in a simplification of Equation C-1d:

$$T_D \approx L_{bore} \cdot w_b \cdot (1/3) \qquad \text{(C-3)}$$

Although it is possible, under appropriate conditions and actual installations, that the pull force may achieve its maximum level prior to point D, based upon the above assumptions, the predicted tension at point D would be the maximum, or reasonably close in magnitude to a previously occurring (predicted) maximum value.

C.3.2 *Additional Path Curvature* – Equations C-1 and C-2 account for the capstan effect due to the deliberate route bends illustrated in Figure C.1 for a well controlled maxi-HDD installation. However, mini-HDD installations tend to be accompanied by additional path curvature due to possible planned course deviations to avoid previously identified obstacles, as well as inevitable unplanned path corrections, depending upon the operator skill and soil conditions. The above estimate of T_D by Equation C-3 must therefore be modified to account for a corresponding increase in the required pull force. These effects may be conservatively included in the analysis by applying the exponential term in Equation C-2 to Equation C-3, such that

$$T_D^1 = T_D \cdot e^{\nu b\,\theta} \qquad \text{(C-4)}$$

where T_D^1 represents the net final tension, and the angle θ is equal to the total additional route curvature. The angle θ is conveniently expressed as an equivalent number of 90° route bends, n, or fraction thereof, where each 90° route bend is equal to $(\pi/2)$ radians; thus,

$$\theta = n \cdot (\pi/2) \qquad \text{(C-5)}$$

Using the previously assumed value of ν_b of 0.3, combining Equations C-3, C-4 and C-5 yields

$$\mathbf{T_D^1 \approx [L_{bore} \cdot w_b \cdot (1/3)] \cdot (1.6)^n} \qquad \text{(C-6)}$$

which corresponds to Equation 2 (Section 7.3.2).

C.3.2.1 *Effective Number of Route Bends* – The total number of effective 90° route bends may be expressed as

$$n = n_1 + n_2 \qquad \text{(C-7)}$$

where n_1 is the number of deliberate/planned 90° route bends, and n_2 is the cumulative effective number of 90° bends due to the unplanned undulations. See Section 7.3.2 and Figure 6 for a further description of the interpretation and determination of the effective number of route bends.

C.3.2.2 *Unplanned Route Curvature* – It is noted that the cumulative effective number of 90° bends due to the unplanned undulations, n_2 , is difficult to predict since this will obviously vary among installations due to soil conditions, expertise of the crew, … The final effective curvature experienced by the product pipe during the pullback operation may also be impacted by the reaming process, which may tend to straighten the path somewhat, and by the amount of clearance between the product pipe and bore hole diameter, with greater clearances reducing the imposed pipe curvature. The suggested values provided by Equations 5 and 6 are intended to represent the general magnitude of the unplanned curvature experienced by the product pipe, as based upon limited experiences, including analyses of sample as-built data provided in mini-HDD equipment operator manuals.(**16**, **25**) These levels are not necessarily intended to be conservative for such mini-HDD applications, and significant variability may be anticipated.

C.3.2.3 *Drill Rod Size* – The linear dependence of the unplanned route curvature, n_2 , on rod diameter, as indicated in Equation 6, is consistent with maintaining an equivalent stress level in the steel rod, and corresponds to approximately one-third that typically allowed by bending specifications provided by drill rod manufacturers, as illustrated in Appendix A. Although, in principle, this same rule may be extrapolated to maxi-HDD, using corresponding large diameter drill rods, it is considered excessively conservative for such well-planned, well-controlled installations.

C.3.3 *Buoyant Weight* – In order to apply Equation C-6 (or Equation 2, Section 7.3.2), it is necessary to determine the buoyant weight, w_b , of the portion of the HDPE pipe submerged in the drilling fluid, along route segments L_2, L_3, and L_4 (Figure C.1). ASTM F1962 provides general formulae for calculating the buoyant weight of the pipe under various conditions, including empty, filled with water, and filled with drilling fluid. For the present mini-HDD case of interest, for which the pipe is assumed to be **empty**, and, as suggested in ASTM F1962, the specific gravity of the drilling fluid (mud), γ_b, is conservatively assumed equal to 1.5, the formula for calculating the buoyant weight reduces to Equation 3, Section 7.3.2.

C.4 *Application*

The guidelines for maxi-HDD provided in ASTM F1962 require that the predicted peak tensile stress be no greater than the corresponding safe pull stress, without the imposition of any additional explicit design/safety factor. However, the corresponding determination of the peak tensile stress includes that due to the average tensile load applied across the pipe cross-sectional area, as predicted by Equations C-1, plus the bending stresses at path bends, as well as the stress increment due to hydrokinetic pressure from the drilling fluid flow along the length of the pipe. In comparison, the simplified methodology as provided in the present mini-HDD guide does not account for the latter two effects. For this reason, and the acknowledged lower degree of control in mini-HDD operations, including anticipated wide variability in unplanned path curvature (Appendix C.3.2.2), as well as the various simplifications used to arrive at above Equation C-6 (or Equation 2), an additional load factor (> 1.0) may be applied to the tension term on the left side of Equation 2 or Equation C-6 for those applications in which a more conservative design may be desired. This would effectively reduce the recommended maximum placement distances; see Appendix D.

D. Examples of Load Prediction and Pipe Selection

D.1 *Load Prediction (Comparison to Field Data)*

The best measure of the validity of the presented simplified methodology for predicting the pull load on a PE pipe during a mini-HDD operation is a comparison to actual field data. The ideal field data would be that directly measured by an in-line force gauge at the leading end of the pipe, as it is installed during a mini-HDD (or midi-HDD) operation. Fortunately, such data is conveniently available.

D.1.1 *Case 1* – One source provides data obtained during a trial of a commercial product[11] for monitoring tension at the leading end of the pipe.(**18**) In particular, a detailed plot of force vs. installed length is provided for a 6-inch DR 11 (IPS) HDPE pipe installed in a nominally straight, 460 ft route. The data shows a monotonically increasing tension, reaching a peak load of approximately 3,500 lbs at the completion of the installation. In this case, a drill rig, with 15 ft long, 3.5-in. diameter drill rods was employed, and Equation 6 (vs. Equation 5) must be used to estimate the unplanned path curvature. The following physical properties and characteristics define the installation:

Bore Length	=	460 ft
Drill Rod Diameter	=	3.50 inches
Pipe Outer Diameter	=	6.625 inches
Pipe Weight	=	4.97 lbs/ft
Buoyant Weight	=	½ [Pipe Outer Diameter (in.)]^2 – Pipe Weight (lbs/ft)
	=	½· (6.625 in.)^2 – 4.97 lbs/ft
	=	17.0 lbs/ft
n_1	=	0 (no deliberate route bends)
n_2	=	[Bore Length / 500 ft] x [2-in. / Rod Diameter]
	=	[460 ft / 500 ft] · [2-in./ 3.5-in.]
	=	0.53 (additional equivalent number of 90° bends)
n	=	$n_1 + n_2$
	=	0.53

Thus, Equation 2 predicts a peak pull load of

Tension (lbs)	=	[Bore Length x Buoyant Weight x (1/3)] x $\mathbf{(1.6)^n}$
	=	[460 ft x 17.0 lbs/ft x (1/3)] x $(1.6)^{0.53}$
	=	3,344 lbs

which is within 5% of the measured load.

In general, such precision cannot be expected in most cases, and the present agreement is considered to be somewhat fortuitous. The methodology used is an over-simplification of a complicated process, which in many cases would be expected to result in pull loads deviating to a significantly greater extent from the levels predicted. It is also interesting to consider the

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11 This product is no longer commercially available.

impact of the unplanned curvature effect, reflected in the n_2 (or n) term. Ignoring this term (i.e., assuming $n_2 = 0$) would result in a predicted tension of less than 2,607 lbs -- underestimating the measured load by 25%. The results are illustrated in Figure D.1 (Case 1).

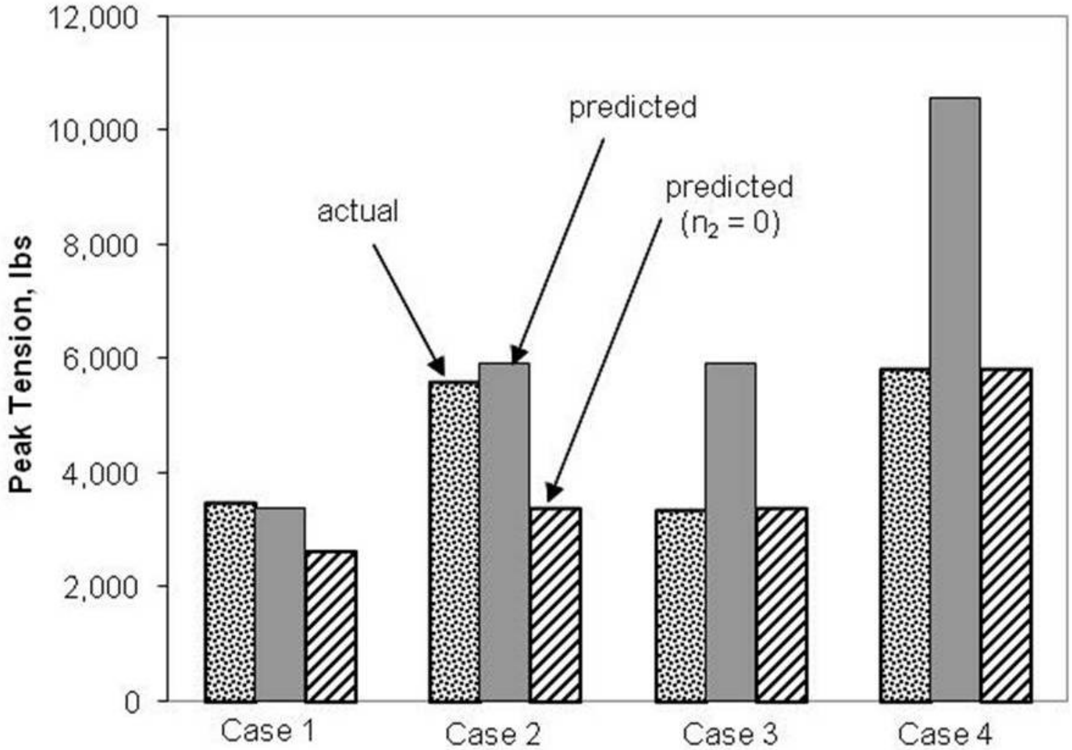

Figure D.1 Actual vs. Predicted Tension for Mini-HDD Installations

D.1.2 *Cases 2, 3, 4* – Another source provides data obtained during a series of three experimental installations, using and reusing the same 590 ft long nominally straight bore hole path, pre-reamed as necessary to approximately 50% greater than the outer diameter of the pipe.(**26**) Two of the installations placed a 6-inch DR 11 (IPS) MDPE[12] pipe (Case 2 and Case 3) and the third placed an 8-inch DR 17 (IPS) HDPE pipe (Case 4). The installations were accomplished using drill rods assumed to be of approximately 2-in. diameter. The recorded peak pull loads were 5,620 lbs., 3,372 lbs., and 5,845 lbs., in the sequence described, and in general were experienced prior to the end of the operations. These loads compare to predicted levels of 5,924, 5924, and 10,580 lbs., using the present methodology in a manner similar to that of Case 1. The results for the three sets of data are also illustrated in Figure D.1.

D.1.3 *Discussion* – The results demonstrate that the proposed simplified model is able to predict the general magnitude of the experienced peak tensile load during a mini (or midi) - HDD operation, within a factor of two or better, based upon the limited sample size. In general, the degree of agreement is excellent, depending upon whether the additional tensile load due to unplanned bore path curvature (n_2) is included in the estimate. In some cases (Case 1 and Case 2), such considerations result in outstanding agreement, while in other cases (Case 3 and Case 4) the agreement is excellent without considering the additional tension due to this effect. A

[12] The methodology (Equation 2) for estimating the pull load does not depend upon the type of PE pipe.

possible explanation for the latter is the repeated use of the same bore hole, for the purposes of the three field experiments, with subsequent reaming/pullback operations resulting in a somewhat straighter path than that corresponding to the estimated magnitude of unplanned curvature, more likely to be present in practical applications.

In spite if the demonstrated good-to-excellent agreement in the sample cases above, a wide variability must be anticipated when considering mini-HDD installations in general, due to the complexity of the soil-pipe interaction, variable soil conditions, operator skill, ... Such factors, for example, will impact the degree of unplanned path curvatures, demonstrated to be of importance in some cases, but only roughly estimated by Equations 5 and 6. The possible use of a load or safety factor (> 1.0) applied to the tension, as discussed in Appendix C.4, attempts to account for the wide variability associated with such effects in mini-HDD (and some midi-HDD) installations; see design example of Appendix D.2.

D.2 *Pipe Selection (Design Example)*

The appropriate wall thickness of an HDPE pipe, for a given diameter, may be conveniently determined by the application of the method provided in Sections 7.2 and 7.3. As an example, consider the feasibility of using typical mini-HDD equipment to install a relatively long 700 ft segment of 4-inch DR 11 (DIPS) HDPE pipe along a route including one deliberate 90° planar bend, and placed at a relatively large depth of 30 ft.[13]

D.2.1 *Pull Strength* – The following physical properties and characteristics define the proposed installation:

Bore Length = 700 ft

Drill Rod Diameter = 2.0 inches

Pipe Outer Diameter = 4.80 inches (DIPS)

Pipe Weight = 2.61 lbs/ft

Buoyant Weight = ½ [Pipe Outer Diameter (in.)]^2 – Pipe Weight (lbs/ft)
= ½· (4.80 in.)^2 – 2.61 lbs/ft
= 8.9 lbs/ft

Alternatively, using Figure 7, an approximate buoyant weight of 9.0 lbs/ft, independent of DR rating, is conveniently employed for the present purposes.

n_1 = 1.0 (one deliberate 90° bend)

n_2 = [Bore Length / 500 ft] x [2-in. / Rod Diameter]
= [700 ft / 500 ft] · [2-in./2-in.]
= 1.4 (additional equivalent 90° bend)

n = $n_1 + n_2$
= 2.4

[13] These distances exceed the nominal limits for typical mini-HDD installations, but are used to illustrate the proposed design procedure.

Thus, Equation 2 predicts a peak pull load of

$$\text{Tension (lbs)} = [\text{Bore Length x Buoyant Weight x (1/3)}] \times \mathbf{(1.6)^n}$$
$$= [700 \text{ ft x } 9.0 \text{ lbs/ft x } (1/3)] \times (1.6)^{2.4}$$
$$= 6{,}488 \text{ lbs}$$

Equation 7 then requires that this predicted installation load, approximately 6,500 lbs, be no greater than the relevant safe pull tension (nominal 4-inch pipe, DR 11) indicated in Table 3 for HDPE pipe, which corresponds to 8,375 lbs. The DR 11 pipe therefore has an apparent safety factor equal to 8,375 lbs / 6,500 lbs, or 1.3. Table 3 also indicates that a DR 13.5 pipe should have adequate tensile strength, but with a lower safety factor (< 1.1). Considering the potential issues discussed above (Appendix C.4 and D.1.3), the responsible engineer may decide to select the thicker wall DR 11 product.

Whereas the present example specifically considers a 4-inch DIPS pipe, for a given DR value, the predicted pull load and the safe pull tension are both proportional to the square of the outer diameter. The conclusions are therefore independent of the pipe diameter, including for IPS designated pipes. It is noted that the use of the DR 11 pipe in a nominally straight route of more than 1,000 ft-- significantly beyond the generally accepted limit for mini-HDD applications -- is also predicted to be acceptable based on estimated pull loads (see Section 7.4 and Figure 9).

D.2.2 *Collapse Strength* – Regarding the potential vulnerability to collapse during the installation or post-installation (but pre-operational) phase, while it is subject to the hydrostatic pressure due to the drilling fluid/slurry, prior to its assumed "solidification", Appendix B indicates that DR 11 HDPE pipe may be placed at a depth of 58 ft (= 265 ft / 4.6), independent of pipe diameter. Thus, the relatively high 30 ft proposed installation depth is well within the capability of the DR 11 wall thickness. -The allowable depth of a DR 13.5 pipe (= 135 ft / 4.6), or slightly less than 30 ft, would be marginal, suggesting the need for the DR 11 product.

D.2.3 *Discussion* – The relatively difficult, aggressive mini-HDD installation of the design example demonstrates that a DR 11 HDPE pipe represents a reliable selection for essentially all mini-HDD (as well as many midi-HDD) applications. Thinner walled pipe (higher DR rating) may also be a reasonable selection in many cases, but should be verified by specific calculations for the route of interest. It is emphasized, however, that the present methodology for pipe DR selection does not ensure that a weaker, thinner-walled pipe would not be successful in practice in individual installations, but, as in most design procedures, the methodology provides reasonable or conservative estimates of the capability of the pipe to withstand the application, and serves as a warning that a weaker product may be marginal or inadequate.

E. Drill Rod Characteristics and Implications – Theoretical Development

The physical characteristics of the drill rods, in combination with the geometry associated with the drill rig entry and desired bore path exit angle, provide restrictions on the bore path configuration and mini-HDD operation. These include required minimum setback distances as well as horizontal distances required to rise to the surface.

E.1 *Setback Distance*

In order to achieve a specified depth at a particular point at the beginning of a bore, the front of the drill rig must be located an appropriate distance rearward ("setback") from the point of interest, designated as point 1 or point 2 in Figure 10. The depth d1, at point 1, is achieved with the bore path on a downward trajectory at the bore entry angle β[14], with the drill rig setback a corresponding distance S1. The both greater depth d2 and associated setback distance S2 correspond to point 2, at which the bore path has achieved a horizontal trajectory. The distance S1 depends upon the entry angle established by the drill rig, but the distance S2 is also dependent upon the drill rod characteristics, including bending capability (allowable radius of curvature) and individual drill rod length.

E.1.1 *Setback Distance S1 along Non-Level Trajectory* – Setback distance S1 corresponds to a bore path segment comprising a straight line extending from the entry point of the drill rod directly towards the point of interest, point 1 (Figure 11):

$$S1 = d1 / \tan\beta$$
$$\approx d1 / \beta \qquad \text{(E-1)}$$

where the bore entry angle β is expressed in radians. This formula corresponds to a drop at a constant grade angle, and is shown as the dotted lines (S1) in Figures 13 – 15. The depth of the bore path will continue to increase beyond point 1, over the distance required for the drill rods to develop a concave-upward curvature to achieve a horizontal trajectory, as determined below.

E.1.2 *Setback Distance S2 at Level Trajectory* – As a general industry recommendation, the bore path should be initiated without any curvature or steering for a minimum distance equal to one full drill rod length in the ground.(**16**, **25**) This practice is intended to avoid or minimize lateral bearing loads at the front of the drill rig. Steering may be introduced following the placement of subsequent drill rods, including the introduction of concave upward curvature to achieve the desired level trajectory at point 2, at depth d2. The minimum setback distance for S2 corresponds to a path with the first drill rod(s) inserted such as to continue the straight (sloping) trajectory, to descend as rapidly as possible, and the subsequent rods placed with the leading rod then creating a path at the minimum allowable radius of curvature, or

$$S2 = \ell \cos\beta + R_{rod} \cdot \sin\beta + [d2 - \ell \sin\beta - R_{rod} (1 - \cos\beta)] / \tan\beta$$
$$\approx R_{rod} \cdot \beta / 2 + d2 / \beta \qquad \text{(E-2)}$$

where ℓ is the length of the drill rod length and R_{rod} its minimum radius of curvature. Equation E-2 is the basis of the distances S2 presented in Figures 13 – 15.

E.1.3 *Minimum Depth to Level Trajectory* – Based on the geometric restraints established by the bore entry angle and allowable minimum radius of curvature of the drill rods, as well as

[14] The bore path entry angle β corresponds to the pipe exit angle, as illustrated in Figure C.1.

the recommendation that the first rod be placed in the ground in a straight configuration, there is a minimum depth at which the trajectory may be able to become level. The minimum possible depth for d2 may be calculated by:

$$(d2)_{min} = \ell \sin\beta + R_{rod} \cdot (1 - \cos\beta)$$
$$\approx \ell \beta + R_{rod} \cdot \beta^2 / 2 \qquad \text{(E-3)}$$

This value is explicitly indicated in Figures 13 – 15, for various drill rods, for the case of a 15° (27% grade) bore entry angle.

E.2 *Horizontal Distance to Rise to Surface*

The geometric restraints associated with the allowable minimum radius of curvature of the drill rods again dictates the rate at which the bore path can divert from its present horizontal trajectory (e.g., point 3, Figure 11) at depth d3 to reach the ground surface.

E.2.1 *Rise at Constant Curvature* – Assuming the drill rods are steered consistent with their maximum bending capability (minimum radius of curvature), the minimum distance S3 to reach the surface is given by:

$$S3 = \sqrt{2 \cdot d3 \cdot R_{rod}} \times \sqrt{1 - \frac{d3}{2 \cdot R_{rod}}}$$
$$\approx \sqrt{2 \cdot d3 \cdot R_{rod}} \qquad \text{(E-4)}$$

These values are shown as the dotted lines (S3) in Figures 16 – 18. The resulting bore exit angle α[15]will be determined by the depth d3, as given by:

$$\alpha = \arccos\left[1 - d3/R_{rod}\right]$$
$$\approx \sqrt{2 \cdot d3 / R_{rod}} \qquad \text{(E-5)}$$

Corresponding exit angles based upon this equation are provided in Figure 19.

E.2.2 *Exit at Specified Angle* – The distance S3 is shorter than that corresponding to the distance S5 indicated in Figure 11. The latter distance corresponds to a path that rises from the depth d3 partially on an arc and then (from point 4) continues along a straight path at a specified bore exit angle (grade) α:

$$S5 = R_{rod} \cdot \sin\alpha + [d3 - R_{rod}(1 - \cos\alpha)] / \tan\alpha$$
$$\approx R_{rod} \cdot \alpha + [2 \cdot d3 - R_{rod} \cdot \alpha^2)] / 2\alpha \qquad \text{(E-5)}$$

These values are also shown in Figures 16 – 18, as a function of the specified exit angle, for which the maximum possible exit angle is limited by the depth d3, consistent with Figure 19.

E.2.3 *Horizontal Rise Distance along Fixed Grade* – For a drill head oriented at an upward angle α, the horizontal distance S4 to rise to the surface from a point 4 (Figure 11) from a depth d4 is

$$S4 = d4 / \tan\alpha$$

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[15] The bore path exit angle α corresponds to the pipe entry angle, as illustrated in Figure C.1.

$$\approx d4 / \alpha \qquad \text{(E-6)}$$

Analogous to Equation E-1, this formula corresponds to a rise at a constant grade, and is shown in Figures 20, for various angles.

Appendix F provides examples in the application of the above equations, as reflected in Figures 13 – 20.

F. Example of Drill Rig Setup and Bore Path Geometry

F.1 *Drill Rig Setup*

The information provided in Section 8, including Figures 10 – 20, may be used to help plan the drill rig setup, and verify the feasibility of performing the operation within the local space restraints. For example, consider a utility requiring several hundred foot section of six inch pipe to be placed along a right-of-way using HDD equipment, with the following product, placement and site characteristics:

Pipe Outer Diameter (IPS) = 6.625 inches

Drill Rods = 15 ft long x 150 ft allowable radius of curvature

Uniform Depth of Cover = 60 inches

Available setback distance (S2, preceding point 2, Figure 11) = 35 ft

Available rise distance (S3 or S5, beyond point 3, Figure 11) = 40 ft

Desired Exit Angle = 5°

F.1.1 *Required Setback Distance* – The utility specified depth of cover is consistent with that recommended in Section 8.1.3. This may be verified by considering a final bore hole diameter of approximately 50% greater than the pipe outer diameter, or approximately 10 inches (6.625 x 1.50), and comparing the specified 60 inches to the minimum cover of 50 inches indicated in Figure 10.

Considering the shallowest entry angle (10°) indicated in Figure 15, the minimum depth $(d2)_{min}$ required to achieve a level trajectory is approximately equal to the 60 inches desired[16]. However, the corresponding setback distance S2 of approximately 40 ft exceeds the available space of 35 ft. Increasing the entry angle in an attempt more rapidly reach the desired depth is not a solution since the minimum depth to achieve a level trajectory, at greater entry angles, will now be greater than that desired. Unnecessarily deep placement is undesirable with respect to possible future repair and maintenance activities.

One possible solution is to use a smaller HDD rig, utilizing drill rods of 10 ft length and 100 ft allowable radius of curvature (Figure 14), for which the setback distance S2 at low entry angle (10°) is approximately equal to the 35 ft available. The shorter drill rig also increases the available setback distance by approximately 5 ft.

Another alternative would be to gain permission for the pipe to be somewhat shallower than the desired 60 inches towards the entry point of the path, with the desired (level trajectory) depth achieved slightly further along the route. Thus, for the original 15 ft drill rods, Figure 15 indicates that the available 35 ft space is approximately 5 ft less than the approximately 40 ft necessary to achieve the level trajectory, and that a slightly shallower (non-level trajectory) depth will be experienced for this short segment.

[16] For the present purposes, the difference between the centerline of the bore path, as indicated in Figure 13, and the reduced depth of cover corresponding to the pipe protruding above the centerline, is ignored.

Still another alternative is for the utility to agree that the objective depth may be exceeded towards the beginning of the bore, beyond which the path may be adjusted to gradually rise to the desired 60 inch depth. In this case, the 60 inch depth may be achieved along a path at the entry grade after a setback distance S1 of only 30 ft (Figure 13).

F.1.2 *Required Horizontal Distance to Rise* – Figure 17 (and Figure 19) indicates that steering the 150 ft radius of curvature drill rods such that they rise from the 60 inch level depth at their maximum recommended bending capability, will result in an exit angle of 15°. Based upon the information in Figure 18, this rise to the surface may be accomplished within a horizontal distance S3 approximately equal to the 40 ft available space. Such a large exit angle is, however, significantly greater than that originally specified (5°). In order to exit at the desired 5° angle, an available distance S5 of more than 60 ft would be required (Figure 18). In this case, the use of a smaller drill rig, with more flexible rods, would provide only a minor reduction in the required horizontal rise distance S5 (Figures 16 and 17), and not represent a practical solution.

As a result of the above considerations, additional discussions with the utility may be warranted, in order to obtain a better understanding of the space restriction at the pipe entry (bore exit) end of the installation. It is possible that the utility had originally specified a low bore exit angle, as well as reserved additional space at that end, in order to accommodate relatively rigid (non polyethylene) pipe products. In such cases, significant longitudinal space is required to facilitate assembly, layout and/or feeding of the pipe product into the completed bore hole. The use of HDPE may therefore alleviate the problem, due to its possible availability in continuous lengths, or convenient fusing into required lengths, greater physical flexibility and easier handling. For example, the relatively large (15°) bore exit angle, achievable within the originally specified 40 ft, should not be an issue with an HDPE product.

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