Designation: ~~F1962 – 20~~ F1962 – 22

Standard Guide for
Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings[1]

This standard is issued under the fixed designation F1962; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

1. Scope*

1.1 This guide describes the design, selection considerations, and installation procedures for the placement of polyethylene (PE) pipe or conduit below ground using maxi-horizontal directional drilling equipment. The pipes or conduits may be used for various applications including telecommunications, electric power, natural gas, petroleum, water lines, sewer lines, or other fluid transport.

1.2 Horizontal directional drilling is a form of trenchless technology. The equipment and procedures are intended to minimize surface damage, restoration requirements, and disruption of vehicular or maritime traffic with little or no interruption of other existing lines or services. Mini-horizontal directional drilling ~~(min-HDD)~~(mini-HDD) is typically used for the relatively shorter distances and smaller diameter pipes associated with local utility distribution lines. In comparison, maxi-horizontal directional drilling (maxi-HDD) is typically used for longer distances and larger diameter pipes common in major river crossings. Applications that are intermediate to the mini-HDD or maxi-HDD categories may utilize appropriate "medi" equipment of intermediate size and capabilities. In such cases, the design guidelines and installation practices would follow those described for the mini- or maxi-HDD categories, as judged to be most suitable for each situation.

1.3 The values stated in inch-pound units are to be regarded as standard. The values given in parentheses are mathematical conversions to SI units that are provided for information only and are not considered standard.

1.4 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety, health, and environmental practices and determine the applicability of regulatory limitations prior to use.* Section 6 contains general safety information related to the use of maxi-horizontal directional drilling equipment.

1.5 *This international standard was developed in accordance with internationally recognized principles on standardization established in the Decision on Principles for the Development of International Standards, Guides and Recommendations issued by the World Trade Organization Technical Barriers to Trade (TBT) Committee.*

2. Referenced Documents

2.1 *ASTM Standards:*[2]

D420 Guide for Site Characterization for Engineering Design and Construction Purposes

---

[1] This guide is under the jurisdiction of ASTM Committee F17 on Plastic Piping Systems and is the direct responsibility of Subcommittee F17.67 on Trenchless Plastic Pipeline Technology.

Current edition approved ~~Nov. 1, 2020~~Nov. 15, 2022. Published ~~November 2020~~December 2022. Last previous edition approved in ~~2011~~2020 as F1962~~–11 which was withdrawn July 2020 and reinstated in November 2020. DOI: 10.1520/F1962-11.~~–20. DOI: 10.1520/F1962-22.

[2] For referenced ASTM standards, visit the ASTM website, www.astm.org, or contact ASTM Customer Service at service@astm.org. For *Annual Book of ASTM Standards* volume information, refer to the standard's Document Summary page on the ASTM website.

***A Summary of Changes section appears at the end of this standard**

D422 Test Method for Particle-Size Analysis of Soils (Withdrawn 2016)[3]
D1586 Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils
D1587 Practice for Thin-Walled Tube Sampling of Fine-Grained Soils for Geotechnical Purposes
D2113 Practice for Rock Core Drilling and Sampling of Rock for Site Exploration
D2166 Test Method for Unconfined Compressive Strength of Cohesive Soil
D2435 Test Methods for One-Dimensional Consolidation Properties of Soils Using Incremental Loading
~~D2447 Specification for Polyethylene (PE) Plastic Pipe, Schedules 40 and 80, Based on Outside Diameter (Withdrawn 2010)[3]~~
D2513 Specification for Polyethylene (PE) Gas Pressure Pipe, Tubing, and Fittings
D2850 Test Method for Unconsolidated-Undrained Triaxial Compression Test on Cohesive Soils
D3035 Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Controlled Outside Diameter
D4186 Test Method for One-Dimensional Consolidation Properties of Saturated Cohesive Soils Using Controlled-Strain Loading
D4220 Practices for Preserving and Transporting Soil Samples
D4318 Test Methods for Liquid Limit, Plastic Limit, and Plasticity Index of Soils
D4767 Test Method for Consolidated Undrained Triaxial Compression Test for Cohesive Soils
D5084 Test Methods for Measurement of Hydraulic Conductivity of Saturated Porous Materials Using a Flexible Wall Permeameter
F714 Specification for Polyethylene (PE) Plastic Pipe (DR-PR) Based on Outside Diameter
F1804 Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
F2160 Specification for Solid Wall High Density Polyethylene (HDPE) Conduit Based on Controlled Outside Diameter (OD)
F2620 Practice for Heat Fusion Joining of Polyethylene Pipe and Fittings

2.2 *Other Standards:*
ANSI Preferred Number Series 10
ANSI/EIA/TIA-590 Standard for Physical Location and Protection of Below-Ground Fiber Optic Cable Plant[4]
AWWA C901 Polyethylene (PE) Pressure Pipe and Tubing, 3/4 in. (19 mm) through 3 in. (76 mm), for Water Service[5]
AWWA C906 Polyethylene (PE) Pressure Pipe and Fittings, 4 in. thru 65 in. (100 mm through 1650 mm), for Waterworks[5]
OSHA-3075 Controlling Electrical Hazards[6]
~~TR-NWT-000356~~GR356 Generic Requirements for Optical Cable Innerduct[7]

3. Terminology

3.1 *Definitions:*

3.1.1 *horizontal directional drilling, HDD, n*—a technique for installing pipes or 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.

3.1.1.1 *Discussion—*
The drill string creates a pilot bore hole in an essentially horizontal path or shallow arc which may subsequently be enlarged to a larger diameter during a secondary operation which typically includes reaming and then pullback of the pipe or utility line. Tracking of the initial bore path is accomplished by a manually operated overhead receiver or a remote tracking system. Steering is achieved by controlling the orientation of the drill head which has a directional bias and 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. The procedure uses fluid jet or mechanical cutting, or both, with a low, controlled volume of drilling fluid flow to minimize the creation of voids during the initial boring or backreaming operations. The drilling fluid helps stabilize the bore hole, remove cuttings, provide lubricant for the drill string and plastic pipe, and cool the drill head. The resultant slurry surrounds the pipe, typically filling the annulus between the pipe and the bored cavity.

3.1.2 *maxi-horizontal directional drilling, maxi-HDD, n*—a class of HDD, sometimes referred to as directional drilling, for boring holes of up to several thousand feet in length and placing pipes of up to 48 in. (1¼ m) diameter or greater at depths up to 200 ft (60 m).

3.1.2.1 *Discussion—*
Maxi-HDD is appropriate for placing pipes under large rivers or other large obstacles (Fig. 1). Tracking information is provided

---

[3] The last approved version of this historical standard is referenced on www.astm.org.
[4] Available from the Electronics Industries Association, 2001 Pennsylvania Ave., N.W., Washington, DC, 20006.
[5] Available from American Water Works Association (AWWA), 6666 W. Quincy Ave., Denver, CO 80235, http://www.awwa.org.
[6] Available from the Occupational Health and Safety Administration, 200 Constitution Ave. N.W. Washington, DC 20210.
[7] Available from ~~Bellcore, 60 New England Ave., Room 1B252, Piscataway, NJ, 08854-4196.~~Ericsson, Ericsson Information Superstore, https://telecominfo.njdepot.ericsson.net.

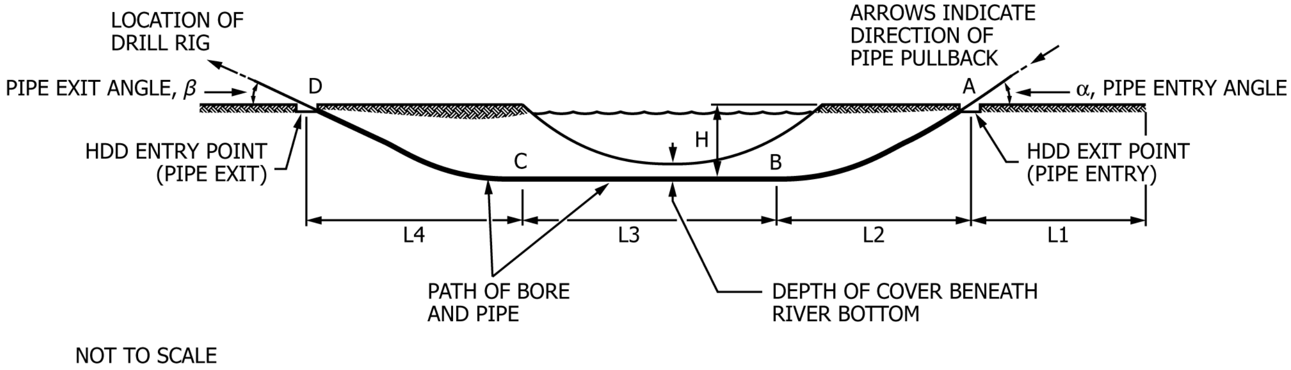

FIG. 1 Maxi-HDD for Obstacle (for example, River) Crossing

remotely to the operator of the drill rig by sensors located towards the leading end of the drill string. Cutting of the pilot hole and expansion of the hole is typically accomplished with a bit or reamer attached to the drill pipe, which is rotated and pulled by the drilling rig.

3.1.3 *mini-horizontal directional drilling, mini-HDD, n*—a class of HDD, sometimes referred to as guided boring, for boring holes of up to several hundred feet in length and placing pipes of typically 12 in. (300 mm) or less nominal diameter at depths typically less than 25 ft (7 m).

3.1.3.1 *Discussion*—

Polyethylene pipe selection and usage for mini-HDD is discussed extensively ~~in the Plastics Pipe Institute's (PPI) TR-46,~~ MAB-7 2020, "Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of ~~High Density Polyethylene Pipe."~~ HDPE (PE4710) for Municipal Applications", published by the Municipal Advisory Board of the Plastics Pipe Institute (PPI) (**1**)[8]

3.1.3.2 *Discussion*—

Mini-HDD is appropriate for placing local distribution lines (including service lines or laterals) beneath local streets, private property, and along right-of-ways. The creation of the pilot bore hole and the reaming operations are typically accomplished by fluid jet cutting or the cutting torque provided by rotating the drill string, although mud motors powered by the drilling fluid are sometimes used for hard or rocky soil conditions. The use of such mud motors would only be applicable for the larger mini-HDD machines. The locating and tracking systems typically require a manually operated overhead receiver to follow the progress of the initial pilot bore. The receiver is placed above the general vicinity of the drill head to allow a determination of its precise location and depth, indicate drill head orientation for determining steering information to be implemented from the drill rig.

3.1.4 *pipe dimension ratio, DR, n*—the average specified diameter of a pipe divided by the minimum specified wall thickness.

3.1.4.1 *Discussion*—

For pipes manufactured to a controlled outside diameter (OD), the DR is the ratio of pipe outer diameter to minimum wall thickness. The standard dimension ratio (SDR) is a specific ratio of the outside diameter to the minimum wall thickness as specified by ANSI Preferred Number Series 10.

NOTE 1—Lower DR values correspond to ~~thicker, stronger pipes.~~thicker pipe walls for a given diameter.

4. Preliminary Site Investigation

4.1 *General Considerations*—A maxi-HDD project, such as that associated with a river crossing, is a major event that will require extensive and thorough surface and subsurface investigations. Qualified geotechnical engineers should perform the work for the owner in preparation for planning and designing of the bore route. The information should also be provided to the potential contractors to provide guidance for the bidding stage and subsequent installation. The contractor may perform additional investigations, as desired. Since typical maxi-HDD projects represent river crossings, the following procedures are described in terms of the specific investigations and issues arising in such cases. The general procedures, however, may be appropriately interpreted to also apply to non-river crossings, such as under land-based obstacles including highways, railways, etc.

4.2 *Surface Investigation* (**2**, **3**)

---

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

4.2.1 *Topographic Survey*—A survey should be conducted to accurately define the working areas described in 4.1 for the proposed crossing site. Horizontal and vertical references must be established for referencing hydrographic and geotechnical data. The survey should typically include overbank profiles on the anticipated path center-line, extending about 150 ft (75 m) landward of the bore entry point to the length of the (pre-fabricated) pull section landward of the bore exit point. The survey information should be related to topographical features in the vicinity of the proposed crossing. Existing topographical information may be available from the U.S. Geological Survey, or Federal, state, or county publications. Aerial photographs or ordnance surveys may be useful, especially for crossing land-based obstacles in urban areas, since these may indicate the presence of demolished buildings and the possibility of old foundations, as well any filled areas **(4)**. It is also necessary to check available utility records to help identify the precise location of existing below-ground facilities in the vicinity, including electric power, natural gas, petroleum, water, sewer, or telecommunications lines. The presence of existing pipelines, support pilings, etc., containing significant steel mass should be noted since this may cause interference with magnetically sensitive equipment guidance or location instrumentation.

4.2.1.1 *Drill Rig (Bore Entry) Side*—The available area required on the side of the drill rig must be sufficient for the rig itself and its ancillary equipment. In general, the size of the required area on the rig side will depend upon the magnitude of the operation, including length of bore and diameter of pipe to be placed. Typically, a temporary workspace of approximately 150 ft (45 m) width by 250 ft (75 m) length will be sufficient. These dimensions may vary from 100 by 150 ft (30 by 45 m) for shorter crossings of 1000 ft (300 m) or less, to 200 by 300 ft (60 by 90 m) for medium or long crossings.

4.2.1.2 *Water Supply*—Water storage and facilities for mixing, storing, and pumping drilling fluid will require significant space. Although it is standard practice to draw fresh water found at the location for mixing the drilling fluid, alternate water supplies may be required to obtain proper drilling fluid characteristics. Hard or salty water is undesirable, although additives may be used to create the proper pH value. It may be necessary to provide access for trucks to transport water or to provide for the installation of a relatively long surface pipe or hose connecting a remote hydrant.

4.2.1.3 *Pipe (Bore Exit) Side*—Assuming the pipe to be placed is too large a diameter to be supplied on a reel (for example, larger than 6 in. (150 mm)), sufficient space is required at the side opposite that of the drill rig, where the bore will exit and the pipe be inserted, to accommodate a continuous straight length of pre-fabricated pipe. The space for the straight length will begin approximately 50 to 100 ft (15 to 30 m) from the anticipated bore exit and extend straight landward at a width of 35 to 50 ft (10 to 15 m), depending upon the pipe diameter. In the immediate vicinity of the bore exit (pipe entry), an area of typically 50 ft (15 m) width by 100 ft (30 m) length is required; for relatively large diameter pipes (larger than 24 in. (600 mm), or in cases of difficult soil conditions, an area of 100 ft (30 m) width by 150 ft (45 m) length should be provided.

4.2.2 *Hydrographic/Potamological Survey*—For crossing significant waterways, a survey should be conducted to accurately describe the bottom contours and river stability to establish suitability for the design life of the pipeline. Typically, depths should be established along the anticipated center-line, and approximately 200 ft (60 m) upstream and downstream; closer readings may be required if it is necessary to monitor future river activity. Consideration should be given to future changes in river bank terrain. Washouts, bank migrations, or scour can expose pipe.

4.2.3 *Drilling Fluid Disposal*—The means for disposal of the drilling fluid wastes must be considered. The volume of drilling fluid used will depend upon the soil characteristics but is typically on the order of 1 to 3 times the volume of removed soil. Most drilling fluids use bentonite or polymer additives which are not generally considered to be hazardous. However, local regulations should be followed regarding disposal.

4.2.3.1 *Drilling Fluid Recirculation* —Occasionally, drilling fluid recirculation is used to reduce overall material and disposal costs. If drilling fluid recirculation is contemplated, a means must be considered for transporting any fluid exhausted from the opposite (bore exit) side, during the pullback operation, to the rig side. This may be accomplished by truck, barge, or a temporary recirculation pipe line on the bottom of the waterway (for river-crossings). The recirculation line must be adequate to prevent accidental discharge into the waterway.

4.3 *Subsurface Investigation*—The overall technical and economic feasibility of the maxi-HDD process is highly dependent upon the properties of the soil formation through which the penetration will be accomplished. Thus, an accurate and thorough geotechnical investigation must be performed by a qualified engineer, including review of existing information and site specific studies for the proposed location. This information will be used to produce design drawings (including final bore route, pipe design, and bore design), construction specifications, and permit applications as well as to provide information for the contractors upon which to select appropriate tools and methods for the actual construction. While the guidelines given in the following sections point out general procedures or types of information, or both, which could be developed, unforeseeable site-specific variables make the thoroughness and accuracy of any site characterization study directly dependent on the skill, experience, and inquisitiveness of the investigating engineer. Therefore, the investigator should define the configuration, extent, and constituency of the investigation. Site characterization information must go beyond just defining soil conditions along the bore path to include a forecast of future conditions (that is, river meanders and scours) and to anticipate the ~~affect~~effect of the maxi-HDD process on site conditions.

4.3.1 *Preliminary Study*—The subsurface investigation should begin with a review of existing data such as may be obtained from published soil reports (for example, Soil Conservation Service Report, U.S. Geological Survey, U.S. Army Corps of Engineers reports, etc.) or records from previous construction projects. In particular, data from nearby pipe or cable river-crossings, or bridge foundation construction should be examined. The results of this study will be used to define the initially recommended bore penetration profile path.

4.3.2 *Test Borings* (**2, 3, 5**)—Site-specific data must be obtained to fully characterize and verify the conditions through which the proposed bore path will be created. Refer to Guide D420, Test Method D1586, Test Method D1587, Test Method D2113 and Practice D4220. Data collection should be aimed at identifying earth materials at the site and at exploring subsurface stratification (including identification of the boundary between rock and other strata, presence of cobbles or boulders and other anomalies such as old tree stumps and fill debris). The location, depth, and number of borings should be determined by the engineer based on the preliminary study, anticipated future changes in site conditions (river meanders, scours, etc.), and modifications of soil conditions during construction. These borings should be located at a sufficient lateral distance (to either side) from the proposed bore path to avoid boring into the test hole, and the holes should be sealed with grouting to avoid potential leakage paths for drilling fluid during the actual installation. Following completion of the detailed route design (Section 7), additional test borings may be desirable at critical points such as bends.

NOTE 2—In environmentally and other sensitive areas, possible restrictions may exist on the location or number of test borings.

4.3.3 In addition to test borings, dynamic cone testing or developing non-intrusive techniques such as ground penetrating radar or sonar may be used to identify stratification and areas with anomalies. Such probing techniques may be applied in the proximity of known conditions determined by a boring to obtain proper calibration, and then extended towards untested areas at relatively close intervals to identify irregularities between borings. If needed, additional borings may then be made at intermediate points of interest (**4, 5**).

4.3.4 *Soil Analysis* (**3, 6, 7**)—The geotechnical study should evaluate several parameters, including soil classifications, (Refer to Test Methods D4318 and D422.) strength and deformation properties, (Refer to Test Methods D1586, D2166, D2435, D2850, D4186, and D4767.) and groundwater table behavior. (Refer to Test Method D5084.) Although some field evaluation and in-situ testing should be included, the geotechnical investigation should emphasize laboratory testing in order to obtain more accurate and meaningful quantitative results. If rock is encountered, the borings should penetrate sufficiently to verify whether or not it is bedrock. The relevant soil testing methods listed in Section 2 should be followed. In general, the following specific data should be obtained from the borings:

4.3.4.1 Standard classification of soils, (Refer to Test Method D4318),

4.3.4.2 Gradation curves for granular soils, as described in Test Method D422,

4.3.4.3 Standard penetration test values, as described in Test Method D1586,

4.3.4.4 Cored samples of rock with rock quality designation (RQD) and percent recovery,

4.3.4.5 Unconfined compressive strength, as described in Test Method D2166,

4.3.4.6 Moh's hardness for rock samples,

4.3.4.7 Possible contamination (hazardous waste),

4.3.4.8 Groundwater location, type, and behavior, and

4.3.4.9 Electrical resistivity or mineralogical constituents.

4.3.5 For river crossings, the results from the preliminary study and site specific tests should be combined in a comprehensive report describing the geotechnical subsurface conditions beneath the river bottom plus the stream's potential for meandering and scouring. The results must then be considered by the owner, the engineer, and potential contractors, with regard to compatibility with the state-of-the-art of directional drilling technology for cost-effectively completing the task. If necessary, the crossing location may be altered to a more favorable crossing site. In this case, many of the surface and subsurface investigations may have to be repeated for the new proposed crossing location and bore path.

4.3.6 *Feasibility*—Soil conditions are a major factor affecting the feasibility and cost of using maxi-HDD in a given geographic area. 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 (**4, 6**). The "generally suitable" category presumes knowledgeable, experienced contractors or personnel using appropriate equipment. Such contractors are assumed to have a minimum of one year field experience and completed approximately 30 000 ft (10 km) of construction in related projects. The size and type machines considered appropriate for particular installations are a function of bore length, final hole diameter, and soil conditions. Various type drill heads, mud motors, reamers, and drilling fluid capabilities are available for various ground conditions. The conditions under which "difficulties may occur" may require modifications of routine procedures or equipment, such as the use of special purpose drill heads or optimized drilling fluids. Some cases will entail "substantial problems" and may not be economically feasible for directional drilling using present technology. The potential for problems to occur increases with the presence of gravels, boulders, or cobbles or with transitions from non-lithified material into solid rock. In such cases, other drilling locations or construction alternatives should be considered unless special circumstances dictate the need for directional drilling at the present location, even at high costs associated with special rock drilling techniques, etc.

5. Safety and Environmental Considerations

5.1 *General Considerations*—Injury to personnel may result from the mechanical and hydraulic machine operations directly related to the drilling operation or from striking of electric power lines or buried pipelines. In addition, the scale of maxi-HDD operations may involve additional equipment and accessories required for the lifting and handling of heavy drill rods, drill heads, reamers, etc., as well as the product pipe or conduit. Additional precautions relating to specific auxiliary equipment must be followed, but is beyond the scope of this standard. Non-essential personnel and bystanders should not be allowed in the immediate vicinity of the maxi-HDD equipment. Barriers and warnings should be placed a minimum of 30 ft (10 m) from the edge of the equipment or associated hardware. Safety precautions are to be followed by all personnel and at both ends of the bore path. Inadvertent contact with electric power, natural gas, or petroleum lines may result in hazards to personnel or contamination. If

TABLE 1 Soil Conditions and Suitability of Horizontal Directional Drilling[A]

Soil Conditions	Generally Suitable	Difficulties May Occur	Substantial Problems
Soft to very soft clays, silts, and organic deposits		X	
Medium to very stiff clays and silts	X		
Hard clays and highly weathered shales	X		
Very loose to loose sands above and below the water table (not more than 30 % gravel by weight)		X	
Medium to dense sands above or below the water table (not more than 30 % gravel by weight)	X		
Very loose to dense gravelly sand, (30 % to 50 % gravel by weight)		X	
Very loose to dense gravelly sand (50 % to 85 % gravel by weight)			X
Very loose to very dense gravel			X
Soils with significant cobbles, boulders, and obstructions			X
Weathered rocks, marls, chalks, and firmly cemented soils	X		
Slightly weathered to unweathered rocks		X	

[A] For additional information, see Ref. (**6**).

possible, any in-service pipeline in the proximity of the bore should be de-activated during the construction. In general, the possibility of injury or environmental impact caused by damage to working or powered subsurface facilities or pipelines during the initial boring or backreaming operations is reduced by appropriate adherence to regulations and damage prevention procedures, as outlined in Section 6.

5.2 *Work Clothing*—**Warning—**Loose clothing or jewelry should not be worn since they may snag on moving mechanical parts. Safety glasses or OSHA approved goggles, or both, and OSHA approved head gear should be worn at all times. Protective work shoes and gloves must be worn by all personnel.

5.3 *Machine Safety Practices*—Contractors must comply with all applicable OSHA, state, and local regulations, and accepted industry practices. All personnel in the vicinity of the drill rig or at the opposite end of the bore must be properly trained and educated regarding the potential hazards associated with the maxi-HDD equipment. For electrical hazards, see OSHA 3075. Personnel ~~shall~~must be knowledgeable of safe operating procedures, safety equipment, and proper precautions. Courses and seminars are available in the industry, including training provided by the equipment suppliers.

5.3.1 The operation of the drill rig requires rotation and advancement or retraction of the drill rods. Drill rig operation is typically accomplished using chain drives, gear systems, and vises which may potentially lead to personal injury due to the moving mechanical components. All safety shields or guards must be properly mounted. The equipment must be checked at the beginning of each work day to verify proper operation.

5.3.2 *Hydraulic Fluid*—The hydraulic oil lines powering the drill rig operate under pressures of several thousand psi (hundreds of bars). The hoses and connectors must be properly maintained to avoid leaks.

5.3.2.1 **Warning—**If a leak is suspected, it should be checked by using a piece of cardboard or other object, but not hands or any other part of the body. The high pressure hydraulic fluid can penetrate the skin, burn, or cause blood poisoning. Before disconnecting any hydraulic lines, the system pressure should be relieved.

5.3.3 *Drilling Fluid*—Drilling fluid pressures will vary depending upon the equipment design and operator preference; pressures of several thousand psi (hundreds of bars) are possible. The hoses and connections must be properly maintained to avoid leaks.

5.3.3.1 **Warning—**Suspected leaks should be checked by using a piece of cardboard or other object. Avoid the use of hands or any other part of the body to check for a leak. Before individual drill rods are inserted or removed from the drill string, it must be verified that the drilling fluid pressure has been shut off and allowed to decrease; otherwise, high pressure fluid will squirt from the joint and possibly cause injury to personnel. The drilling fluid pressure gage must be checked to verify the pressure has been relieved before disconnecting any rods.

NOTE 3—If the pressure does not decrease in a short interval following pressure shut off, the fluid jet openings at the drill head may be clogged. Special care must then be made when disconnecting the rod. It may be necessary to retract the drill string or expose the drill head to clear the jets before continuing the operation. To avoid injury from the drill head and drilling fluid, all personnel should maintain a safe distance from the exit point of the bore as the drill head surfaces. The pressure should be shut off as soon as the drill head exits.

5.4 *Construction Effects on Site*—It is assumed that the preliminary site investigations included analyses to verify the stability of embankments, roads, or other major features to be traversed. It is necessary to ensure that the maxi-HDD operation will not negatively impact the site upon completion. In many cases, it will be appropriate to use grouting to seal the final bore path hole or the end portions of the hole following the installation of the pipe to prevent future flow or environmental contamination. Particularly sensitive areas include statutorily designated areas, such as wetlands, natural and scenic waterways, or contaminated or waste disposal sites. If the bore will pass through, or in close proximity to, a contaminated area, special spoils monitoring and disposal procedures must be followed, consistent with applicable Federal, state, or local regulations.

5.4.1 *Drilling Fluid*—The most common drilling fluid additive is bentonite, a naturally occurring clay. When added to water, the resulting fluid provides desired properties including viscosity, low density, and lubricity. The bentonite material used should be National Sanitation Foundation (NSF) certified. Disposal should be in accordance with local laws and regulations. The bentonite-water slurry is not a hazardous material unless it becomes mixed with toxic pollutants. The waste material is usually considered as typical excavation spoils and can be disposed or by means similar to other spoils. If other additives are of concern or hazardous material disposal is required, 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.

5.4.2 The utility access pits which may be present at both ends of the bore are convenient receptacles for collecting used drilling fluid. If not present for utility access, small pits should be provided at both ends to serve as such receptacles. Depending upon soil permeability, the pits may be lined with an appropriate material or membrane. The pits should be emptied as necessary. Some maxi-HDD systems use drilling fluid recirculating systems to reduce the volume of spoils. If the geotechnical investigation revealed the existence of soil conditions conductive to fluid migration, such as through pre-fractures in surrounding clay or soil mass permeability, this condition must be anticipated and accounted for in the drilling operation.

6. Regulations and Damage Prevention

6.1 *General Considerations*—The owner of the proposed pipeline should obtain any required drilling permits and is responsible for obtaining approvals from the Federal, state, or local jurisdictions or other agencies that may be affected by the work. The preliminary investigations (Section 4) should identify appropriate site locations and paths, including safe separations from other facilities such as electric power, natural gas, or petroleum lines. If the constraints for a particular maxi-HDD bore are such as to be in the vicinity of known facilities, the affected owners must be contacted and strict procedures for location and marking followed. If a maxi-HDD bore interconnects points under the jurisdiction of several states or governing bodies, then the regulations of all parties must be considered, including relevant permits. Special restrictions may exist, including restoration regulations, in environmentally sensitive habitat areas.

6.2 *Environmental, Health, and Safety Plan*—When required, each contractor that will work on the project must submit an environmental, health, and safety plan. Items to consider are the responsibilities of the plan, reporting, employee training, MSDS sheets for materials being used, emergency telephone numbers for police, fire department, and medical assistance, fire prevention, sanitation, and industrial hygiene.

6.3 *Environmental and Archaeological Impact Study*—Most projects using maxi-HDD will require procurement of various environmental permits. When an environmental permitting plan must be prepared, it should include a list of required permits (for example, USAE, USEPA), the time needed to prepare permits, and an estimated date of issuance. Items to consider are solid and hazardous materials and waste management, wetlands, burial grounds, land use, air pollution, noise, water supply and discharge, traffic control and river and railroad transportation.

6.4 *Waterways* (see ANSI/EIA/TIA-590)—The U.S. Army Corps of Engineers (USAE) regulates activities involving interstate bodies of water, including marshes and tributaries, as well as intrastate waters which could affect interstate or foreign commerce. The organization is responsible for work affecting such waterways, including to the headwaters of freshwater streams, wetlands, swamps and lakes. The Regional District Engineer of the USAE will advise applicants of the types of permits required for such proposed projects. In addition, a state or local, or both, agency environmental review and permit may be required.

6.5 *Railroad Crossings* (see ANSI/EIA/TIA-590)—The chief engineer of the railroad should be consulted for the approved methods of crossing the railroad line. For spur tracks or sidings, the tract owner should be consulted. Railroads normally require cased pipes at crossings to prevent track washouts or damage in the event of pipeline rupture. (At the time of writing of this standard, an American Railway Engineering Association (AREA) committee is studying the use of HDD for uncased and cased crossing of railroads for both plastic and steel gas pipelines.)

7. Bore Path Layout and Design

7.1 *General Considerations*—For maxi-HDD projects, such as river crossings, the bore path should be designed and specified by the engineer representing the owner prior to the contractor bidding process. Based upon the preliminary surface and subsurface investigations, the path will be selected to place the pipe within stable ground and isolated from river activities for the design life of the utility line. The ground through which the path will traverse must be compatible with maxi-HDD technology. In general, for maxi-HDD projects, the design path will lie within a vertical plane. If necessary, lateral curvature is possible, consistent with the capabilities of the equipment and the product pipe. The path should be clearly designated in an integrated report summarizing the results of the surface and subsurface investigations, and should be used for pricing, planning, and executing the operation.

7.2 *Steering and Drill Rod Constraints*—The planned path must be consistent with the steering capability of the drill string and the allowable radius of curvature of the steel drill rods based upon the corresponding bending stresses in the steel rods and joints. Although some soil conditions will inhibit sharp steering maneuvers, path limitations will often be based upon fatigue strength considerations of the rods. A given 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 flexural cycles which may eventually cause cumulative fatigue failure. The diameter of the drill rod is an important parameter affecting its stiffness, steering capability, and the allowable bend radii. A conservative industry guideline indicates the minimum bend radius should be approximately:

$$(R_{rod})_{\min} = 1200\, D_{rod} \tag{1}$$

where:

$(R_{rod})_{min}$ = medium recommended bend radius of drill rod, in. (mm), and
D_{rod} = nominal diameter of drill rod, in. (mm).

This applies to bends in horizontal (plan) or vertical (profile) planes.

7.3 The proposed path should avoid unnecessary bends. Such trajectories may be difficult to follow and may lead to oversteering and excessive bends, resulting in increased stresses in the drill rods and greater required pulling forces during the installation of the pipe. The local radius of curvature of the path at any point may be estimated by:

$$R = \frac{\Delta S}{\Delta \varphi} \tag{2}$$

where:

R = local radius of curvature along path segment, ft (m),
ΔS = distance along path, ft (m), and
$\Delta\varphi$ = angular change in direction, rad.

NOTE 4—The angle in radians is equal to the angle in degrees × 0.0175. (One radian equals 57.3°.)

Thus, if ΔS is selected to be equal to 30 ft (10 m) (for example, one rod length for some maxi-HDD machines) a change of 0.1 rad (6°) corresponds to a radius of curvature of 300 ft (100 m).

7.4 *Bore Paths Profile (Vertical Plane) Trajectory* (**2, 3**) —A typical obstacle crossing, such as that represented by a river is illustrated in Fig. 1.

7.4.1 The following parameters must be specified in defining the bore path:

7.4.1.1 Bore entry (pipe exit) point,

7.4.1.2 Bore exit (pipe entry) point,

7.4.1.3 Bore entry (pipe exit) angle,

7.4.1.4 Bore exit (pipe entry) angle,

7.4.1.5 Depth of path, (for example, depth of cover of pipe beneath river bottom), and

7.4.1.6 Path curvatures.

7.4.2 *Bore Entry (Pipe Exit)*—The bore entry point must be accurately specified consistent with the pipe route, equipment requirements, and preliminary topographical investigations. Bore entry angles should be in the range of 8 to 20° (0.15 to 0.35 rad) from the ground surface, preferably 12 to 15° (0.20 to 0.25 rad) from the ground surface. These angles are compatible with typical equipment capabilities.

7.4.3 *Bore Exit (Pipe Entry)*—The bore exit point must also be accurately specified consistent with the pipe length and topographical investigations. Bore exit angles should be relatively shallow, preferably less than 10° (0.15 rad). A shallow angle will facilitate the insertion of the pipe into the bore hole while maintaining the minimum radius of curvature requirements. Relatively steep angles will require greater elevation of the pipe to maintain the required bend radii.

7.4.4 *Path Profile*—The proposed path should optimally lay within a vertical plane including the bore entry and exit points. The arcs of the bore path and straight sections (that is, after achieving desired depth) must be defined, including the radii of curvature and approximate points of tangency of curved and straight segments. The curvatures must be compatible with both the steel drill rods (Eq 1) and the PE pipe or conduit (Section 8). It should be noted that even larger bend radii (lower curvatures) will further reduce lateral flexural bending loads on the pipe and drill rods as they traverse the route, thereby helping avoid additional increases in tensile loads associated with their stiffness effects. Typically, the path should ensure a minimum depth of cover of 15 ft (5 m) beneath the river bottom as projected over the design life of the pipe line, including allowance for scouring (**3, 5**). This will overcome buoyancy effects and help overcome the tendency for the drill head to rise towards the free surface, thereby complicating the steering operation.

NOTE 5—The Directional Crossing Contractors Associations (DCCA) (**8**) recommends a minimum depth of 20 ft beneath the river bottom.

7.4.4.1 *Average Radius of Curvature* —The average radius of curvature for a path segment (that is, A-B or C-D in Fig. 1) reaching to or from a depth required to pass beneath an obstacle, may be estimated from the bore exit or entry angle, respectively, and the depth of the bore:

$$R_{avg} = \frac{2H}{\theta^2} \tag{3}$$

where:

R_{avg} = average radius of curvature along path segment, ft (m),
θ = bore exit or entry angle to surface, rad, and
H = depth of bore beneath surface, ft (m).

The corresponding horizontal distance required to achieve the depth or rise to the surface may be estimated by:

$$L = \frac{2H}{\theta} \tag{4}$$

where:

L = horizontal transition distance, ft (m).

It must be noted that departures from a uniform radius will result in locally smaller radii.

7.4.4.2 The resultant path will determine the stresses to be exerted upon the pipe during the installation and service life. The product pipe design must therefore be analyzed based upon the final selected path, following the pipe design and selection procedures given in Section 8.

8. Pipe Design and Selection Considerations

8.1 *General Guidelines:*

8.1.1 Maxi-HDD applications typically require detailed analysis of the pipe or conduit in relation to its intended application. Due to the large, anticipated pulling loads and potentially high external pressure, a careful analysis of the PE pipe must be performed, subject to the route geometry, to verify or determine an appropriate DR (or pipe wall thickness). The analysis should consider both the installation forces occurring during pull-back and the long-term operational loads.

8.1.2 *PE Pipe*—Pipes made from either high density polyethylene (HDPE) or medium density polyethylene (MDPE) are suited for directional drilling. PE pipe specifications include Specifications ~~D2447,~~ D2513, D3035, F2160~~and~~, F714~~.~~, AWWA C901, and AWWA C906. If such pipe is provided in short segments, the individual units should be joined using a butt-fusion technique in accordance with Practice F2620. This will allow the inherent strength of the PE pipe to be maintained during the placement process and when subjected to other operational stresses. Small diameter pipe of continuous length may be provided on reels. Table X1.1 gives modulus and strength values for typical pressure-rated HDPE and MDPE resins.

8.1.3 *Cable Conduit Applications* —For cable conduit applications, including electric power and telecommunications, small diameter pipe may be supplied on a continuous reel including internal pull line or the cable itself, as pre-installed by the manufacturer. In addition, the pipe may be provided with the interior surface pre-lubricated. Such features will be in accordance with that specified by the owner or engineer. Requirements for telecommunications applications, including HDPE pipe with various internal surface profiles, including smoothwall or ribbed are specified in ~~TR-NWT-000356.~~GR356.

8.2 *Pipe Loading:*

8.2.1 *Operational and Installation Loads*—The pipe will be subject to loads during its long-term operation and during the installation process. It is the responsibility of the owner (or the owner's contractor or engineer) to determine the design and selection of the pipe to serve the function intended and withstand the operational stresses at the directionally drilled section as well as at other sections along the pipe line. This practice deals primarily with the loads imposed during the directional drilling process and earth and groundwater loads during operation (post-installation).

8.2.2 *Internal (Operational) Pressure Loads*—It is the responsibility of the owner (or owner's contractor or engineer) to determine the nominal diameter and wall thickness appropriate for the intended application. For example, if the pipe will be used for the pressurized flow of liquids or gases, it is necessary to determine the nominal diameter based on flow capacity requirements and the minimum wall thickness (or DR) to withstand the corresponding circumferential stresses on a long term basis. Specification D2513, D3035, F714~~or~~, ~~F714~~F2160, AWWA C901, and AWWA C906 may be used to determine an initial estimate of the corresponding maximum dimension ratio (DR) for PE pipe.

8.2.3 *External (Operational) Hydraulic and Earth Loads*—The pipe will be subjected to hydrostatic external pressure due to the height of water or drilling fluid (or slurry) above the maximum depth of placement relative to the entry or exit point, and earth loads and ~~liveloads~~ live loads due to load transfer through the deformation of the soil around the borehole (**9**). If borehole deformation is minimal (such as in rock) or does not deform the pipe, the only loading applied to the pipe is the hydrostatic external pressure. When earth load does reach the pipe, load reductions from the geostatic stress (arching) may be anticipated. The reductions may be significant when the in situ soil is normally- or over-consolidated. On the other hand, in under-consolidated soils such as river deposits, the earth load on the pipe may equal the prism load (adjusted for buoyancy in the case of a river crossing). The external pressure applied to the pipe equals the total stress, that is, it is the sum of the effective earth pressure, reduced for arching, and the hydrostatic pressure. In some cases, the mud-slurry pressure will offset the earth pressure. As the earth load applied to directional drilled pipe is dependent on the depth of cover, borehole diameter, mud-slurry properties, drilling and back-reaming techniques, and the in situ soil properties, among other things, a geotechnical engineer should be consulted. See X2.2 for a discussion earth load calculations. ~~Liveload~~ Live load pressure can be transmitted to shallow directional drilled pipe. For shallow applications, it is likely that the pipe is subjected to the same liveload and earth pressures as an entrenched pipe.

8.2.3.1 *Net External Pressure*—The net external pressure, P_{net}, is the differential pressure between the inside and outside of the pipe. The external operational load applied to the pipe may be decreased or totally off-set by internal pressure occurring within the pipe. Likewise, the external load may increase with the occurrence of negative pressure (vacuum) inside the pipe. The net external pressure may vary at different times in the life of the pipeline. For instance, during pressurized flow, the net external pressure may be zero but during a shut-down or prior to service, considerable external pressure may be applied. An analysis should be made of all potential external loadings, internal pressurization or vacuum events, and of their duration of occurrence, so that the net external pressure and its duration is determined for each cycle of the pipeline's service life.

8.2.4 *Pipe Resistance to External Loads*—The pipe must be of sufficient thickness (or DR ratio) to withstand the net external pressure without collapsing or deflecting unduly during each cycle of the operational life of the pipeline. (The effects of external hydrosatic loads applied during the installation phase are discussed in 8.2.9.)

NOTE 6—Spangler's Iowa Formula is typically not applicable to directional drilled pipes as the mud-slurry (unless cemented) on setting develops only the consistency of a soft clay which will not provide significant side-support for the pipe.

8.2.4.1 *Pipe Deflection (Ovality)*—Deflection reduces the pipe's resistance to external collapse pressure. Earth loads, longitudinal bending (bore path curvature), and buoyancy forces during installation will produce ring deflection in the pipe. Formulas for calculating earth load deflection, buoyancy deflection, and curvature-induced deflection along with permissible deflection limits are given in Appendix X2. When bore path curvature is limited to the guidelines given in Note 7 and the DR is 21 or less, ovality due to longitudinal bending can generally be ignored. Filling the pipe with water during the placement operation will reduce the buoyancy force (see 8.2.6) and greatly eliminate the possible short-term collapse. The effective external pressure would then be equal to that corresponding to the actual external differential pressure due to the head of drilling slurry minus the internal pressure due to that of the water inside the pipe.

8.2.4.2 *Unconstrained Collapse*—The following version of Levy's equation may be used to determine the allowable external pressure for directional drilled pipe:

$$P_{ua} = \frac{2E}{(1-\mu^2)}\left(\frac{1}{DR-1}\right)^3 \frac{f_o}{N} \tag{5}$$

where:

P_{ua} = allowable external collapse pressure, psi (kPa),

E = apparent (time-corrected) modulus, psi (kPa), for the grade of material used to manufacture the pipe, and time and temperature of interest,