

**Pipe Stiffness and Flattening Tests in
Coilable HDPE Conduit; and Its
Relationship to Burial Depth in Conduit
Applications
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FOREWORD

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The purpose of this technical report is to provide important information available to PPI on design factors and design coefficients recommended for thermoplastic pressure piping applications. These recommendations are based on discussions with several internationally recognized technical experts in the plastic pipe industry. More detailed information on its purpose and use is provided in the document itself.

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Introduction

Continuous length, coilable HDPE conduit has enjoyed tremendous growth not only as a protection for electrical cable, but in large part due to the huge expansion of the telecommunications industry in the US and abroad to protect fiber optic cable. Its availability in long lengths combined with HDPE's ductility, strength and durability make it ideally suitable for the "long haul" and trenchless installation technologies such as HDD (horizontal directional drilling) installations in the power and telecom industries. Buried cables installed in conduit provide long term and improved protection from damage caused by storms and vandalism when compared to aerial cables. Conduit also extends the life and reliability of underground cables by providing added protection from ground movement or poor soil conditions. These permanent raceways allow for easier and less costly future cable replacements.

HDPE conduit has been used for decades with great success due to its low coefficient of friction, resistance to corrosion, excellent chemical resistance and ability to remain ductile (flexible) even at low temperatures. Because the properties of HDPE result in a wide range of flexibility, HDPE conduit can be provided on coils or on steel reels in long lengths specifically for trenchless or plowing technologies (i.e. a reel of 1 ¼" diameter HDPE conduit could hold as much as an 8,500 ft continuous length). Larger diameter HDPE conduit such as 8" or greater is available in sticks up to 50-ft. An alternative plastic used in the conduit industry is PVC where typical lengths are limited to 20-ft.

When HDPE conduit is considered for underground installations, there have been cases where PS (pipe stiffness) and the term "Crush Strength" are used to determine strength relative to other materials regardless of their property differences. (In reality, "Crush Strength" is a term misapplied to thermoplastic,

flexible pipes (i.e. HDPE and PVC). Crush Strength implies a brittle failure, where flexible pipes can deflect in excess of 20% with no signs of wall buckling, cracking or splitting. Flattening is the correct and more appropriate engineering term to measure how much deflection a flexible pipe can take without damage.) When HDPE is compared to PVC at similar diameters and wall thicknesses, PVC will inherently have a higher PS attributed to the modulus being more than twice that of standard HDPE conduit materials¹. However, this in no way indicates how HDPE will ultimately perform compared to PVC conduit.

PS has applicability in calculations of burial depth but it should not be used to compare dissimilar materials. Also, too often, engineers consider “Crush Strength” or Flattening to determine allowable burial depth. Flattening does not relate to burial depth and should be considered a quality control test. Finally, the national specifications calculate PS inconsistently. This technical note provides the reader with detailed information showing that HDPE conduit’s PS is more than adequate at typical burial depths. Furthermore, because of the inconsistencies in the national specifications, PS and Flattening should be considered only as quality control tests.

Specifications

The inconsistencies of existing national specifications referencing stiffness and flattening have created confusion even for comparable materials. PS in ASTM D-2412 titled, “Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading”, is defined as the force per unit length of the test specimen, loaded at a prescribed loading rate, at a prescribed percentage deflection (0.5” per minute, typically 5% deflection). The test measures the conduit’s resistance to ring deflection as it is being compressed between two steel plates. This parallel plate test empirically determines PS where as an alternative “calculated” method uses the materials modulus and SDR (dimension ratio). This shows the usefulness of PS as a Quality Control Test. Requirements referenced in several applicable national specifications are as

follows where PS and Flattening are both used as quality assurance tests. Note: “Crush Strength” does not have a defined formula in the ASTM standards.

1. HDPE conduit for power and telecom applications is manufactured in accordance with standard ASTM F-2160, a standard written specifically for solid wall conduit based on controlled outside diameter. ASTM F-2160 specifies the material, dimensional, manufacturing, and quality assurance testing requirements for HDPE Conduit.
2. ASTM F-512 is the Standard Specification for PVC Conduit for Underground Installation. It uses PS as a quality control test at 5% deflection with a modulus of 500,000 psi (the minimum allowed by the material specifications).
3. ASTM D-1785 is the Standard Specification for PVC pipe in Schedule 40, 80 and 120. This is a pressure pipe specification. The test method only includes a flattening test with no load requirement. The requirement is a pass/fail on visual inspection.
4. NEMA (National Electrical Manufacturers Association) are specifications for conduit used in electrical applications. The following are pipe stiffness requirements for HDPE and PVC:
 - NEMA TC 7 for HDPE Electrical Conduit (Various Types)
 - Minimum load at 5% deflection
 - Compression and recovery test to 50% with 85% diameter recovery
 - NEMA TC 6 & 8 for PVC Plastic Utilities Duct (Type EB/DB Ducts)
 - Minimum load at 5% deflection
 - NEMA TC 2 for PVC Electrical Conduit (Type Schedule 40/80)
 - Minimum load required (no deflection limit indicated)
 - Flattening test to 40% with no visible cracking
5. Underwriters Laboratory UL 651 is a specification used for both PVC and HDPE conduits housing electrical cables in accordance with the NEC (National Electric Code published by NFPA):

- UL (Underwriters Laboratories) 651A is for PVC or HDPE provided in stick lengths.
 - Minimum load during 30% deflection
- UL (Underwriters Laboratories) 651B for HDPE (Various Types)
 - Minimum load during 30% deflection through 1” diameter and during 25% deflection for 1 ¼” and larger. In this specification, the test loads for HDPE conduit are usually greater than those for PVC conduit.

Since HDPE and PVC are different materials, corresponding values in specifications should be determined independently for each material. Further, the field performance of a particular conduit material may be independent of its PS.

Buried Flexible Pipe Design

Both HDPE and PVC use flexible pipe design methodology⁴ as oppose to rigid pipe design used for materials such clay or concrete. Flexible pipe or conduit deflects and as they deflect, they mobilize the surrounding soil, and with the materials inherent stiffness, resist further deflection. A full discussion of the methodology of calculating burial depth in flexible pipe is not germane to this paper; however, a general discussion will assist the reader in determining that PS and Flattening should not be the overriding variables in choosing which material is suitable for protection of fiber and power cable in conduit applications.

Simplified, the four calculations for buried flexible pipe are as follows which are applicable for HDPE conduit as well²:

1. Ring Deflection: The deflection of the pipe due to earth and live loads is calculated to determine if the deflection exceeds the recommended values. The formula to calculate ring deflection, the Spangler Modified Iowa Formula does use a form of pipe stiffness

$$PS = EI/0.149r^3 \quad Eq (1)$$

where

E = material modulus

I = moment of inertia

r = pipe radius

2. Compressive Ring Thrust: The radial compressive force around the circumference of the pipe. Failure occurs when the compressive stress in the wall exceeds the yield stress of the material. PS does not have any direct application in compressive ring thrust.
3. Buckling: Excessive compressive stress along the pipe wall may cause the pipe wall to buckle. Although the buckling calculation does involve the modulus and moment of inertia, it is not directly related to the pipe stiffness calculation. Buckling will rarely be a determining factor in burial depth for conduit applications, as HDPE conduit is heavier than SDR 21 and burial depths are much less than 25-ft^(note 3).
4. Flexibility Factor (FF): FF is the stiffness of the pipe required to adequately and properly backfill the structure. It is important in large diameter (above 12”), light walls and profile pipe in deep fill applications. It is not a controlling factor in conduit applications as it uses heavier walls compared to drainage pipe and it is buried at depths much less than 25-ft.

Burial Depths for HDPE Conduit

Although pipe stiffness plays an important factor in one of the design requirements of HDPE conduit, other variables often override it as the critical factor. For example, in the majority of telecom and power installations the burial depth is relatively shallow and the “installation stresses” frequently dictate the strength requirements rather than in-situ earth loading. HDPE conduit is generally installed using three distinct methods: open cut or continuous trench, plowing, or HDD (horizontal directional drilling).

Open Cut/Continuous Trench:

Open cut trenching is a commonly used method in the installation of telecom and power conduits. Since the physical application of the installation method does not change, we can apply the same principles in determining the anticipated earth loading strength requirements of HDPE conduit when they are being installed using open cut, as for other common flexible pipe applications.

The Plastic Pipe Institute (PPI) handbook for “PE Pipe-Design and Installation”, describes a design window³, where constrained buckling becomes the determining factor in choosing the pipe strength and depth of cover allowed. PE pipe is limited to SDR 21 or heavier and no calculations are required because critical buckling for this wall thickness passes with a safety factor of 2. Coiled HDPE conduit for power and telecom applications is rarely manufactured lighter than SDR 15.5 in small diameters, and SDR 13.5 in larger diameters (4-6”) because of the potential for excessive ovality and kinking as it is coiled or wound on the reel during manufacturing. In this case, the manufacturing process dictates a heavier wall in order to properly wind the conduit.

Note: Schedule 40 HDPE conduit through 3” has a wall thickness greater than SDR 15.5. Schedule 40 HDPE conduits in diameters above 3” and Schedule 80 in 6” have wall thickness ranges that are less than SDR 15.5, for this reason these types are not recommended for coiling due to ovality and kinking concerns.

Nearly all conduit installations, even open cut, are significantly less than 20’ depth which is well within the parameters of the allowable design window established in PPI’s, handbook. Other design window parameters that can be found in the handbook are:

- HDPE Conduit like pressure rated HDPE pipe is manufactured from HDPE resin in accordance with ASTM D-3350. The modulus and tensile properties of the specified cell classification for conduit resin from ASTM F-2160 is designated as 4 or 5. Because these cell values are the same as pressure rated resin the resulting mechanical properties for the finished conduit will be the same as those of pressure pipe.

- No surcharge loading
- Acceptable embedment materials are typically coarse-grained, compacted to a minimum of 85% proctor yielding an E' of 1000 psi assuming prism loading. The native soil also must be stable. (These parameters are important! It is assumed in an open cut application the conduit will be backfilled properly as it should be for drainage pipes. It should be noted these backfill conditions are easily achieved.)
- Unit weight of soil does not exceed 120-pcf. (Some soils and gravels can exceed 120-pcf)
- Installed in accordance with ASTM D-2321 (Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications).

For open cut, HDPE conduit typically has a wall thickness that is heavier than SDR 17 due to manufacturing considerations or “construction survivability” requirements, so the height of cover table shown below is extremely conservative.

Table 1: Design Window Maximum & Minimum Depth of Cover*2

DR	Min. Depth of Cover With H2O Load	Min. Depth of Cover Without H2O Load	Maximum Depth of Cover
7.3	3 ft	2 ft	25 ft
9	3 ft	2 ft	25 ft
11	3 ft	2 ft	25 ft
13.5	3 ft	2 ft	25 ft
17	3 ft	2 ft	25 ft
21	3 ft	2 ft	25 ft

**Limiting depths where no additional calculations are required, due to earth loading with properly followed installation techniques. Conduits are suitable for deeper burial depth provided a sufficient E' is accomplished during installations. Calculations would be required for depths greater than 25 ft.*

Direct Plow Method of Installation:

The second method of installing HDPE conduit is via plowing. Chute plowing is where a static or vibratory “shoe” cuts through the ground, splitting and compressing the soil to make a pathway for the conduit. The method feeds the conduit over the machine, making the long continuous length, flexibility and bend radius of HDPE pipe both a feature and requirement. Plowing can expose rocks and other obstructions, so SDR 13.5 or heavier conduit is normally specified due to these “installation stresses”. After the shoe passes, the soil is expected to subside and consolidate around the pipe.

The “Modified Spangler Formula”^{5,6} is the standard calculation that can be used to determine whether a pipe has sufficient strength to withstand earth and live loads (refer to the previous discussion of burial depth calculations). If one assumes no contribution from the soil (an extremely conservative approach), meaning $E' = 0$, the formula reverts to Watkins and Anderson⁵.

Modified Spangler Formula:

$$y/D = 0.0125P / (E/12(DR-1))^3 \quad \text{Eq (2)}$$

Where:

- y = horizontal deflection (inches)
- D = mean diameter (inches)
- P = vertical load (lb/ft²)
- E = material modulus
- DR = dimension ratio

Using a 5% deflection limit and E (modulus) of 50 yr at 28,200 psi (very conservative assumptions) the height of cover can be calculated:

- SDR 15.5
 - Height of cover = 3.7 feet
- SDR 13.5

- Height of cover = 5 feet
- SDR 11
 - Height of cover = 11'

As stated above, most power and electrical conduit are specified to be buried at three feet, especially in plowed applications as they are cross country networks or along highway right-of-ways. Rarely are they expected to be deeper than four feet. So even with the most conservative equation assumptions, HDPE conduit, in SDR 13.5 is more than adequate in nearly all plowed applications in regard to the earth load forces and PS (pipe stiffness). It should be noted, designers and contractors sometimes choose SDR 11 conduit either to be conservative, or because of severe installation stresses due to soil conditions (rocks).

HDD (Horizontal Directional Drilling):

HDD is the last installation method, but in some ways the most popular and one of the reasons HDPE conduit is so successful. HDD has enjoyed explosive growth over the past 15 years as the technology has allowed power and telecom cable to be installed with minimal traffic disruption and surface damage. HDPE is the material of choice because of its long lengths which significantly reduce the number of required joints over typical pulling distances. The tensile strength and modulus allows pull lengths of many feet. Thousand foot bores are not uncommon. Furthermore, the flexibility of HDPE allows the conduit to move around underground obstructions,

Design of the pipe weight for HDD applications can be complex and is determined by many variables. The one parameter related to the pipe stiffness would be a collapsed or deformed borehole. Loads are defined by either a deformed/collapsed borehole or an open borehole (no earth load on the pipe). In the case of a deformed or collapsed hole, the soil above will mobilize arching, In this case there will be no additional (beyond the mud pressure) loading on the pipe. In a severe collapse, the upper limit of earth pressure will be the soil prism

above the pipe. Prism loads are most likely to develop under shallow applications; therefore the earth loads will be minimal.

On long HDD applications, the tensile forces of pullback are perhaps the most critical variable in choosing the pipe strength. Along with the frictional and mud pressure forces, the pipe has bending forces (the pipe has deflected laterally to avoid obstructions, or from the depth of the bore to the ground surface) requiring high tensile strength, with flexibility.

For HDD projects, selecting the proper strength HDPE conduit takes due consideration and a full design (see ASTM F-1962 and PPI report TR-46 for detail design criteria related to very long difficult bores with larger diameter pipe^{7:8}). PPI report TR-46, states that commonly used wall thicknesses DR 7.0 – DR 17 would be sufficiently strong for depths to 15-ft. Conduit wall thicknesses lighter than DR 13.5 is rarely used in power and telecom applications. PS has minimal relevance in these cases. HDD installations are not conducive to PVC's short lengths, so a comparison to PVC pipe stiffness seems immaterial. HDD contractors are often the best judge of what DR pipe is required as the end performance of the pipe pull often is directly related to their boring expertise, the soil conditions, and contractor's equipment capabilities.

Conclusion

PS and Flattening can be useful for manufacturing quality control and assurance. However, the values should be related to the specific material (HDPE or PVC) and wall thickness, not a single arbitrary target. PS testing for HDPE pipe should be at 5% deflection in accordance with ASTM D-2412, Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel Plate Loading. Test values should be compared to calculated values at the minimum modulus (80,000 psi) specified for the HDPE materials in ASTM F-2160. These test conditions have precedence in many flexible pipe specifications, including PVC Conduit ASTM F-512, NEMA TC 7 and AASHTO

M-294 for Corrugated PE Pipe. The appropriate values in psi at 5% deflection are listed below:

Table 2: Recommended Minimum Pipe Stiffness Values for HDPE Conduit

Conduit Size	SDR 9	SDR 11	SDR 13.5	SDR 15.5	Schedule 40	Schedule 80
1"	700	360	180	120	510	1400
1 ¼"	700	360	180	120	280	790
2"	700	360	180	120	200	580
2 ½"	700	360	180	120	160	430
3"	700	360	180	120	100	290
4"	700	360	180	120	60	190
5"	700	360	180	120	40	130
6"	700	360	180	120	30	120

Furthermore, flattening certainly is not an indication of the allowable burial depth of pipe, as no one would design flexible pipe for deflections of 15% let alone 40% or greater. It does, however, give an indication of the flexibility of pipe, so if specified, it makes logical sense to use it as a pass/fail to indicate the flexibility and recovery characteristics of HDPE pipe. Any deflection in excess of 30% seems excessive even if HDPE conduit can be deflected in the range of 50%. A visual inspection for cracking or splitting is adequate.

HDPE conduit has enjoyed great success as a protector of our country's power and telecom infrastructure. It has very strong features and benefits making HDPE ideal for conduit applications. In all of these applications the "installation stress", not the pipe stiffness or depth of cover, is the dictating factor in choosing pipe strength. Certainly, arbitrarily requiring HDPE conduit to meet a certain pipe stiffness based on a PVC design fails to take advantage of the competitive aspects of an alternate, yet proven product.

References:

1. ASTM D-3034 for PVC specifies a cell class indicating a modulus for PVC at 400,000 to 440,000 psi. ASTM F-2160 specified a modulus for HDPE used in conduit at 80,000 to 160,000 psi.
2. Plastic Pipe Institute (2009), *“Design of PE Piping Systems”*, Chapter 6, 2nd Ed.
3. Plastic Pipe Institute (2009), *“Design of PE Piping Systems”*, Chapter 14, 2nd Ed.
4. Plastic Pipe Institute (2009), *“Design of PE Piping Systems”*, Chapter 7, 2nd Ed.
5. Spangler, M.G. (1941), *“The Structural Design of Flexible Pipe Culverts”*, Bulletin 153, Iowa Engineering Experiment Station, Ames, IA.
6. Watkins, R.K. & Spangler, M.G. (1958), *“Some Characteristics of the Modulus of Passive Resistance of Soil-A Study in Similitude”*. Highway Research Board Proceedings 37: 576-583, Washington.
7. Plastic Pipe Institute Report TR-46, *“Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of High Density Polyethylene Pipe”*
8. ASTM F-1962, *“Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings”*.