SAFE PULL STRENGTH CALCULATIONS FOR CONDUIT: INCLUDING DERATING FACTORS

TN-63

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Foreword

This technical note was developed and published with the technical help and financial support of the members of the Plastics Pipe Institute. The members have shown their interest in quality products by assisting independent standard-making and user organizations in the development of standards, and also by developing reports on an industry-wide basis to help engineers, code officials, specifying groups, and users.

This technical note has been prepared to provide guidance, to those responsible for the selection and installation of HDPE conduit, on the appropriate selection of conduit based on installation considerations. This document was not intended to provide system design information. The reader is referred to the PPI website at www.plasticpipe.org for system design documents.

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PPI intends to revise this report from time to time, in response to comments and suggestions from users of this note. Please send suggestions for improvements to PPI. Information on other publications can be obtained by contacting PPI directly or visiting the web site.

The Plastics Pipe Institute, Inc.

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**SAFE PULL STRENGTH CALCULATIONS FOR CONDUIT:
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1.0 OVERVIEW

One of the most commonly used methods for installation of high-density polyethylene (HDPE) conduit is to pull it into place. Examples where HDPE conduit is pulled into place would be when it is installed as an innerduct or into an open trench or directly into the ground using a trenchless method such as either the pull plow method or by Horizontal Directional Drilling (HDD). When pulling HDPE conduit into place, an increasing axial tensile load will be exerted on the conduit.

The purpose of this technical note is to provide designers and end users criteria for determining the "Safe Pull Strength" (SPS). SPS is the calculated maximum tensile load that should be placed on a conduit, of a given diameter and wall type, as it is being pulled into place.

The following sections are provided in the document:

- **SPS Calculation** showing the calculation method and calculation results
- **Physical Behavior of Conduit Under Load** explaining the physical basis of the calculation
- **Conduit Installation Considerations**
- **Other Resources**
- **Appendix A** providing temperature compensations factors
- **Appendix B** providing metric conversions for all tables

2.0 SPS CALCULATION

As a short-term pulling stress is placed on HDPE conduit it will stretch slightly but will fully recover provided the tensile load is limited to 40% of the materials rated tensile yield strength. The 40% tensile load limit is incorporated into the SPS calculation as F_Y. The SPS should not be exceeded to assure that the conduit is not damaged during installation.

The SPS can be calculated as shown using Equation 1:

$$SPS = \pi \cdot D^2 \cdot F_Y \cdot F_t \cdot F_T \cdot \left[\frac{1}{DR} - \frac{1}{DR^2}\right] \qquad \text{Equation 1}$$

Where

SPS	=	Safe pull strength, lbs.
π	=	3.1415 (i.e., the value *Pi*)
D	=	Conduit outside diameter, in.
F_Y	=	Tensile yield design stress (psi), see Table 1
F_t	=	Time under tension design factor, see Table 2
F_T	=	Conduit temperature compensation factor (see **Appendix A**) (at approximately 73 °F, F_T = 1.00)
DR	=	Conduit standard dimension ratio (DR or SDR), where DR is equal to the nominal conduit OD divided by the minimum wall thickness.

Two types of HDPE compound are typically used for extruding conduit: they are standard industry strength PE conduit compound or higher strength PE conduit compound (see Note 1). The SPS can be derived from the minimum tensile yield strength for each compound type. Table 1 provides minimum Tensile Yield Design Stress (F_Y) values at 73 °F (23 °C).

The SPS may require further downrating for the time under tension and for the conduit temperature while under tension. Factors F_t and F_T in Equation 1 address each of these concerns, respectively.

- Table 2 provides the Time Under Tension Design Factor, F_t.
- The Conduit Temperature Compensation Factor, F_T, is 1.0 or greater, at temperatures lower than 80 °F. **Appendix A** provides the factors, F_T, for conduit installation at other temperatures, from -20 to 140 °F.

Table 1: Tensile Yield Design Stress, F_Y

Temperature	Compensating Multiplier (F_T)	Standard Strength HDPE Conduit	Higher Strength HDPE Conduit
73 °F (23 °C)	1.00	1200 psi	1400 psi

Table 2: Time Under Tension Design Factor, F_t

Time Under Tension (Hours)	Design Factor (F_t)
≤1	1
>1 to 12	0.95
>12 to 24	0.91

Note 1: Industry standards for HDPE conduit, such as ASTM F2160, NEMA TC 7, and UL 651A, require a standard minimum PE compound cell classification of PE334480C or PE334480E, as defined by specification ASTM D3350. The fourth digit of the cell class corresponds to the specified minimum yield strength, specifying a minimum yield strength of 3,000 psi (21 MPa) for standard strength conduit compound. Occasionally a higher strength grade may be specified or needed for the installation. If using a higher strength grade, the fourth digit of the cell class will be greater than 4, typically 5 corresponding to a minimum yield strength of 3,500 psi (24 MPa). The conduit print line is not required to include the PE cell class (only the general term HDPE is included); if needed (e.g., for tensile calculations), contact the conduit manufacturer for the conduit compound strength.

Using the values for each conduit type from Table 1, calculations can be made for SPS for the commonly used conduit diameters and wall types. Those values for each diameter and wall type are provided below in Tables 3 through 8. **All of these calculations have been done based on the conduit temperature of 73 °F (23 °C) and with a 1-hour or less time under tension design factor (i.e., both F_T and F_t equal to 1.00). For deviations from these conditions, apply the appropriate factors for F_T and F_t per Equation 1.** Metric conversions of all tables are provided in **Appendix B**.

Table 3: SDR Types, Safe Pull Strength for Standard Strength HDPE Conduit (lbs)

Trade Size	Standard Dimension Ration (SDR)				
	9	11	13.5	15.5	17
½	298	244	208	208	203
¾	442	374	319	286	265
1	682	581	487	433	403
1 ½	1,077	910	766	681	632
1 ½	1,413	1,187	996	886	818
2	2,211	1,853	1,539	1,359	1,258
2 ½	3,233	2,709	2,257	1,961	1,819
3	4,801	4,018	3,338	2,944	2,703
4	7,932	6,646	5,519	4,860	4,469
5	12,119	10,166	8,524	7,434	6,814
6	17,187	14,400	11,978	10,530	9,683

Table 4: SDR Types, Safe Pull Strength for Higher Strength HDPE Conduit (lbs)

Trade Size	Standard Dimension Ration (SDR)				
	9	11	13.5	15.5	17
½	348	285	243	243	237
¾	516	436	372	333	310
1	795	678	568	505	470
1 ¼	1,256	1,061	893	794	737
1 ½	1,648	1,385	1,162	1,034	954
2	2,580	2,161	1,795	1,586	1,468
2 ½	3,772	3,160	2,633	2,288	2,123
3	5,602	4,688	3,894	3,435	3,154
4	9,254	7,753	6,439	5,670	5,214
5	14,139	11,861	9,945	8,673	7,950
6	20,052	16,800	13,975	12,285	11,297

Table 5: Schedules 40 and 80, Safe Pull Strength (lbs)

Trade Size	Schedule 40		Schedule 80	
	Standard Strength	Higher Strength	Standard Strength	Higher Strength
½	323	377	404	472
¾	430	501	548	639
1	632	737	804	938
1 ¼	854	996	1,113	1,298
1 ½	1,020	1,190	1,349	1,574
2	1,367	1,595	1,367	1,595
2 ½	2,156	2,515	2,848	3,322
3	2,824	3,295	3,815	4,450
4	4,021	4,691	5,576	6,505
5	5,454	6,363	7,741	9,031
6	7,085	8,266	10,648	12,423

Table 6: True Sizes, Safe Pull Strength (lbs)

Trade Size	Standard Strength		Higher Strength	
	True 9	True 11	True 9	True 11
½	133	108	155	126
¾	281	226	328	263
1	499	405	583	472
1 $^{1}/_{8}$	633	506	739	590
1 ¼	783	630	913	735
1 $^{3}/_{8}$	945	761	1,102	888
1 ½	1,126	898	1,313	1,048
2	1,997	1,605	2,329	1,873

Table 7: SIDR Sizes, Safe Pull Strength for Standard Strength HDPE Conduit (lbs)

Trade Size	SIDR - Standard Inside Dimension Ratios		
	SIDR 15	SIDR 11.5	SIDR 9
1	339	436	561
1 ¼	568	738	945
1 ½	761	994	1,280
2	1,234	1,624	2,123
2 ½	1,743	2,316	-
3	-	3,567	-
4	-	6,150	-
5	-	9,458	-

Table 8: SIDR Sizes, Safe Pull Strength Higher Strength HDPE Conduit (lbs)

Trade Size	SIDR - Standard Inside Dimension Ratios		
	SIDR 15	SIDR 11.5	SIDR 9
1	395	509	654
1 ¼	663	861	1,103
1 ½	887	1,159	1,493
2	1,440	1,895	2,477
2 ½	2,033	2,702	-
3	-	4,162	-
4	-	7,175	-
5	-	11,035	-

3.0 PHYSICAL BEHAVIOR OF CONDUIT UNDER LOAD

It is important to understand HDPE conduit's strain response to being placed under a short-term stress. The primary reason for discussing elongation and recovery is so that installers compensate for any contraction that is likely to occur after the axial tension is released by leaving sufficient additional slack after pulling the conduit. The axial tension applied to HDPE conduit by a pulling load causes it to elongate. The amount of change in length is dependent upon the amount of axial tension being applied and duration of the time under tension and all of the other variables in the SPS formula (e.g., compound type, diameter, wall thickness, temperature). Limiting the maximum short-term stress to 40% or less of the conduit's maximum tensile yield stress strength will keep its elongation within the recoverable range, where the conduit may fully recover, with time, to its original length when the load is removed.

Note that some recovery after installation may be restricted due to frictional forces of the surrounding earth, or casing for innerduct, but this will not harm the conduit. See the next section for guidance on the suggested slack and recovery allowances.

If the SPS is exceeded during installation, the conduit may yield and the increased length of the conduit due to the tensile load will not recover. The maximum tensile stress for HDPE conduit is derived from the minimum rated tensile yield stress values of 3,000 psi for conduit manufactured using standard industry strength compound or 3,500 psi when manufactured from higher strength compound (See Note 1). As illustrated in Figure 1, manufacturers conduct tensile and elongation testing in accordance with test method ASTM D638 where tensile load is measured at a separation rate of 2 inch/minute, recording the conduit's tensile yield stress and, ultimately, its elongation at tensile break. Failure is the point at which the conduit yields but its length will continue elongating to 400% or more and may exhibit very little tensile load change prior to breaking.

Figure 1 shows a length of conduit tested in accordance with ASTM D638 pulled to the breaking point. Notice how the conduit, as it has passed the yield point, elongates and reduces in diameter prior to reaching the breaking point. In the test, the elongation has been taken beyond the conduit's recovery (yield) point, the ID has been reduced, commonly referred to as "necked down" and will not recover. This means, if the conduit during installation has been pulled to beyond its yield, the point along the conduit where it begins to permanently elongate and neck down will become an obstruction within the conduit. When the cable is later pulled into place, it may be blocked from passing beyond this section.

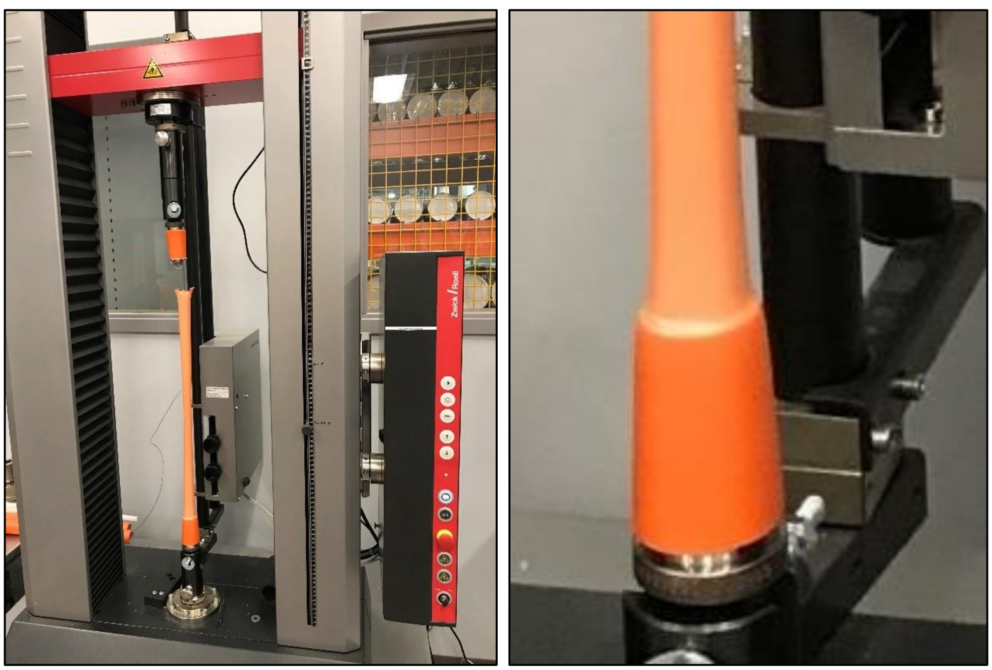

Figure 1: Example of Conduit Pulled Past Yield Point (Left: Full test Rig after Elongation/Break, Right: Closeup of Transition from Unyielded to Yielded Conduit)

4.0 CONDUIT INSTALLATION CONSIDERATIONS

The amount of tensile load placed on the conduit during installation must be controlled and should not exceed the allowable values for each diameter and wall type listed in Tables 3 through 8. Additionally, it may be necessary to make adjustments to the values in Tables 3 through 8 based on duration of the pull times and conduit temperature from Table 2 and Appendix A - Table A1, respectively. Most installation equipment used for various pulling operations are capable of exerting tensile loads that can exceed the conduit's SPS. It is important that appropriate precautions during installation are taken so that a clear pathway through the conduit remains after installation. Below are several additional installation techniques to help installers assure a successful installation.

4.1. General, Pulled into Place:

1. The leading end of the conduit or conduits should be sealed to prevent the ingress of water or debris as it is being pulled into place.
2. The reel should turn freely and it is advisable to assist the reel to reduce the amount of back tension as the conduit is being pulled into place.
3. The proper size grip or pulling eye, correctly assembled per the supplier's instructions, should be used.
4. The conduit should never be pulled over the sharp edge of a handhole, manhole or pit.
5. For smaller diameters use a device that monitors pulling tension, like an in-line-tensiometer, as it is being pulled into place.
6. Use a breakaway link sized appropriately for the conduit and installation conditions.
7. Use a swivel to avoid twisting of conduit or conduit bundle.

4.2. Open Trench, Pulled into Place:

1. If there are horizontal changes in direction to the pathway, then corners should be rounded larger than the minimum bend radius for the diameter of conduit (see PPI Handbook on Polyethylene Pipe, Chapter 14).
2. The conduit should be monitored at all locations where a change in direction is to occur to make sure it is not being damaged as it is being pulled around the bend.
3. The trench bottom should be flat and free of obstructions.
4. The conduit should be payed out from the bottom of the reel and not pulled over any sharp edges as it enters or exits the trench.

4.3. Horizontal Directional Drill (HDD), Pulled into Place:

1. A properly sized entry and exit pit should be dug in order to allow for the appropriate entry and exit angles.
2. The diameter of the bore hole that the conduit is being pulled into should be a minimum of 1.5 times the outside diameter of the conduit or conduit bundle that is being installed.

3. Manufacturer suggested boring fluid mixtures should be used that are appropriate for the soil conditions to help assure formation of a stable bore hole and to reduce pulling friction.
4. The conduit installation should be coordinated and observed at both the feed and exit locations to assure it is traveling at the same rate of speed at both ends. If the feed end begins to slow or become erratic in relation to the pull speed then friction may be causing a significant increase in pulling tension, which could result in exceeding the SPS and damaging the conduit.
5. Additional HDD information can be found in the “Other Resources” section of this technical note.

Depending upon how much tension was placed on the conduit and the length of time to complete the pull during the installation, the conduit will have elongated slightly. Due to this elongation, it is advisable to pull about 3 to 5 % excess slack to allow for the amount of retraction that will take place as the conduit recovers to its original length. Once the conduit has been pulled into place it is important to allow the conduit time to relax prior to making any final terminations. The conduit should be allowed to relax at least the same amount of time it has taken to complete the pull. If possible, let the conduit relax overnight before cutting the pulled end to the desired finished length or making any joints or terminations. As long as the conduit’s SPS has not exceeded during installation it will, with time, fully recover its original length.

Additional information is available from the Plastics Pipe Institute’s website or consult with your conduit supplier.

5.0 OTHER RESOURCES

Other conduit pulling related resources that may be of interest to the reader:

- **Conduit Design Calculator** – **www.conduitcalc.com** – The PPI Power and Communications Division (PCD) has developed an online calculator for mini-HDD calculations to aid in determining the most appropriate wall thickness of HDPE conduit installed via horizontal directional drilling (HDD) techniques. This calculator will address the majority of conduit applications with limitations of up to 12 inch diameter, 1,000 feet pull distance, 15 feet depth, and assuming a conduit temperature of approximately 73 °F. Beyond these limits, PPI offers **http://ppiboreaid.com/**.
- **TN-48** - Guidelines for Choosing Wall Thickness for HDPE Conduit Based on "Mini-HDD" (Horizontal Directional Drilling)
- **MAB-7** - MAB Guidelines for Use of Mini-Horizontal Directional Drilling for Placement of HDPE (PE4710) Pipe in Municipal Applications
- **TN-50** - Guide to Specifying HDPE Conduit
- **TN-58** - HDPE Conduit and Duct Handling Guide
- **TN-61** - Coilable HDPE Conduit Ovality and Coil-Set
- **PPI Handbook of PE Pipe**
    - Chapter 3 - Material Properties
    - Chapter 7 - Underground Installation of PE Piping
    - Chapter 12 - Horizontal Directional Drilling
    - Chapter 14 - Duct and Conduit
- **ASTM D638** - Standard Test Method for Tensile Properties of Plastics
- **ASTM F1804** - Standard Practice for Determining Allowable Tensile Load for Polyethylene (PE) Gas Pipe During Pull-In Installation
- **ASTM F1962** - Standard Guide for Use of Maxi-Horizontal Directional Drilling for Placement of Polyethylene Pipe or Conduit Under Obstacles, Including River Crossings

APPENDIX A – TEMPERATURE COMPENSATION FACTORS

The Temperature Compensation Multiplier, F_T, shown in Table A1 may be applied to the SPS to account for conduit temperature at the time of pulling.

Suggested field practices to reduce the temperature of the conduit before pulling includes removing the conduit from direct sun exposure, shading it with an opaque tarp or timing the pull in the earlier, cooler hours before the sun heats the conduit.

Table A1: Temperature Compensation Multiplier

Maximum Sustained Temperature of the Conduit while under Tension during Installation °F	Maximum Sustained Temperature of the Conduit while under Tension during Installation °C	Temperature Compensating Multiplier F_T
≤ 80	≤ 27	1.0
> 80 – 90	> 27 – 32	0.9
> 90 – 100	> 32 – 38	0.8
> 100 – 110	> 38 – 43	0.8
> 110 – 120	> 43 – 49	0.7
> 120 – 130	> 49 – 54	0.7
> 130 – 140	> 54 – 60	0.6

Source: Derived from PPI Handbook of PE Pipe, Errata 6/24/2020 of Chapter 3 Table A.2

APPENDIX B – METRIC CONVERSIONS

This appendix provides the metric conversations for tables within the main body.

Table B1: Tensile Yield Design Stress, *F_Y*

Temperature	Temperature Compensating Multiplier	Standard Strength HDPE Conduit	Higher Strength HDPE Conduit
23 °C	1.00	8.4 MPa	9.6 MPa

Table B2: SDR Types, Safe Pull Strength for Standard Strength HDPE Conduit (Newtons)

Trade Size	Standard Dimension Ration (SDR)				
	9	11	13.5	15.5	17
½	1,326	1,087	927	927	904
¾	1,966	1,664	1,420	1,271	1,181
1	3,032	2,583	2,168	1,925	1,792
1 ¼	4,791	4,047	3,406	3,027	2,811
1 ½	6,283	5,282	4,429	3,941	3,638
2	9,837	8,241	6,845	6,046	5,597
2 ½	14,380	12,049	10,039	8,722	8,093
3	21,357	17,875	14,848	13,095	12,024
4	35,284	29,562	24,549	21,619	19,881
5	53,909	45,222	37,918	33,068	30,311
6	76,453	64,054	53,283	46,838	43,071

Table B3: SDR Types, Safe Pull Strength for Higher Strength HDPE Conduit (Newtons)

Trade Size	Standard Dimension Ration (SDR)				
	9	11	13.5	15.5	17
½	1,547	1,269	1,082	1,082	1,055
¾	2,293	1,941	1,656	1,483	1,378
1	3,537	3,014	2,529	2,245	2,090
1 ¼	5,589	4,722	3,973	3,532	3,279
1 ½	7,331	6,162	5,167	4,598	4,244
2	11,476	9,615	7,985	7,054	6,530
2 ½	16,776	14,057	11,713	10,176	9,441
3	24,917	20,854	17,322	15,278	14,028
4	41,165	34,488	28,640	25,222	23,194
5	62,894	52,759	44,238	38,580	35,363
6	89,196	74,730	62,163	54,644	50,250

Table B4: Schedules 40 and 80, Safe Pull Strength (Newtons)

Trade Size	Schedule 40		Schedule 80	
	Standard Strength	Higher Strength	Standard Strength	Higher Strength
½	1,439	1,679	1,798	2,098
¾	1,912	2,231	2,437	2,843
1	2,810	3,279	3,577	4,173
1 ¼	3,798	4,431	4,949	5,774
1 ½	4,536	5,292	6,001	7,001
2	6,081	7,094	6,081	7,094
2 ½	9,590	11,189	12,667	14,779
3	12,561	14,655	16,969	19,797
4	17,885	20,865	24,803	28,937
5	24,260	28,303	34,432	40,171
6	31,517	36,769	47,365	55,259

Table B5: True Sizes, Safe Pull Strength (Newtons)

Trade Size	Standard Strength		Higher Strength	
	True 9	True 11	True 9	True 11
½	591	480	689	560
¾	1,251	1,005	1,460	1,172
1	2,222	1,801	2,592	2,101
1 $^{1}/_{8}$	2,816	2,251	3,286	2,626
1 ¼	3,481	2,802	4,062	3,269
1 $^{3}/_{8}$	4,203	3,386	4,903	3,950
1 ½	5,007	3,994	5,842	4,660
2	8,882	7,141	10,362	8,332

Table B6: SIDR Sizes, Safe Pull Strength for Standard Strength HDPE Conduit (Newtons)

Trade Size	SIDR - Standard Inside Dimension Ratios		
	SIDR 15	SIDR 11.5	SIDR-9
1	1,508	1,939	2,494
1 ¼	2,526	3,281	4,204
1 ½	3,384	4,421	5,694
2	5,491	7,224	9,446
2 ½	7,752	10,302	-
3	-	15,867	-
4	-	27,356	-
5	-	42,073	-

Table B7: SIDR Sizes, Safe Pull Strength for Higher Strength HDPE Conduit (Newtons)

Trade Size	SIDR - Standard Inside Dimension Ratios		
	SIDR 15	SIDR 11.5	SIDR-9
1	1,759	2,263	2,910
1 ¼	2,947	3,828	4,905
1 ½	3,947	5,158	6,643
2	6,406	8,428	11,020
2 ½	9,044	12,019	-
3	-	18,512	-
4	-	31,915	-
5	-	49,085	-