Open Cut High-Density Polyethylene Pipe Installations per Updates in the Second Edition of AWWA Manual M55

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The Second Edition of AWWA Manual M55, *High-Density Polyethylene Pipe – Design and Installation*, was published in 2020. In this edition, there are significant updates to the design and installation recommendations that users of high-density polyethylene pipe (HDPE) for water pipe should be aware of.

For design, the new manual will now include PE4710 compounds that have been added in the ANSI/AWWA C901 and C906 standards. Design updates also include higher E′ (modulus of soil reaction) values, use of composite E′ values, use of Uniform Soil Classes, and terminology. For installation, M55 contains revised information on trench width, flowable fill, inspection and soil testing, and compaction requirements. These changes reflect the recent revisions to the ASTM D2774, Standard Practice for Underground Installation of Thermoplastic Pressure Piping[1].

The M55 encourages the use of HDPE using two types of open cut methods: basic installation and engineered installation. The basic installation is for HDPE pipe (up to 24 in. nominal diameter) that is stiff enough (with SDR <=21) to avoid the need for special bedding and embedment, for burial up to 10 ft. with no live load within 6 ft or less, and for stable trench wall support. In this case, the HDPE pipe can be laid on the trench bottom and backfilled with compacted soil from the excavation. This covers the majority of HDPE pressure pipe installations. For other conditions, the engineered installation means selecting an HDPE pipe and corresponding installation details to meet deflection, buckling, and compressive stress requirements.

In addition, M55 has a new chapter describing trenchless technology and has new appendices on model specifications, seismic performance, marine applications, case studies, and PE4710 pipe data.

This article will focus on HDPE external load design and commensurate open cut installation methods as presented in Chapters 5 and 8 within M55.

Background

Deeper pipe burial, less expensive and environmentally friendly backfill, uniform language for contractors and inspectors, simplified installations for common pipe sizes, and allowable construction in poor soil conditions are presented in the latest edition of M55, and all benefit the designers and owners of HDPE pressure piping systems.

The M55 was first published in 2006. The manual covers engineering properties, design procedures, underground installation, acceptance testing, and maintenance for solid-wall HDPE pipe used in pressure applications.

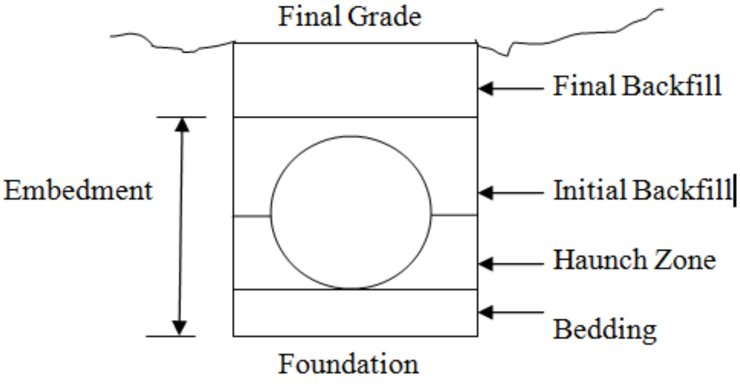

Figure 1. Trench Terminology

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The revised manual includes:

- Change in trench section terminology
- Change in classification and descriptions of soils
- Revision of equation for estimating pipe deflection due to dead and live loads
- New table of E′ values, the modulus of soil reaction of supporting soils (use of Uniform Soil Classes)
- Use of composite E′ for incorporating effect of weak trench walls
- Use of basic installation and engineered installation

For installation, the changes include:

- Trench width requirements
- Compaction methods and testing
- Use of flowable fill for embedment and backfill
- Use of uncompacted bedding to lay the pipe on

In the interest of uniformity, similar changes were made in 2020 to AWWA Manual M23, *Polyvinyl Chloride Pipe – Design and Installation*.

New information is also provided for PE4710. Model specifications have been added, along with actual case histories of HDPE installations and PE4710 pipe data. Refer to M55 for details.

Terminology

Trench Cross Section

The new terminology for the trench cross section is shown in Figure 1, with definitions as follows:

- *Foundation*. The foundation is the native soil in the bottom of the excavation. If the foundation is unsuitable, remediation will be required to provide a stable trench bottom.

- *Bedding*. The bedding is the soil placed in the bottom of the trench on top of the foundation and serves as a cushion for the pipe.
- *Haunch Zone*. The haunch zone is from the bottom of the pipe up to the springline. The haunch zone and the initial backfill provide the side support for the pipe that resists deflection.
- *Initial Backfill*. The initial backfill extends from the top of the haunch zone to 12 in. above the top of the pipe. The initial backfill, combined with the haunch zone, acts as lateral support for the pipe.
- *Embedment*. The embedment includes the bedding, haunch zone, and initial backfill.
- *Final Backfill*. The final backfill extends from the top of the initial backfill to the final grade.

Uniform Soil Classes

The other major change in terminology is the use of Uniform Soil Classes, as shown in Table 1. These soil classes have now been adopted for use in ASTM C12 (clay pipe), D2321 (thermoplastic gravity pipe), D2774 (thermoplastic pressure pipe), D3839 (fiberglass pipe), AWWA M23 (pressure polyvinyl chloride [PVC] pipe), M55 (pressure PE pipe), and M45 (fiberglass pipe), and are planned for inclusion in a revised edition of Manual M9 (concrete pressure pipe).

The soil classes, Class I to Class V, are in descending order of stiffness when the soil is compacted. Class I and Class II soils are usually considered cohesionless and are best compacted using vibration; Class III and Class IV are usually considered cohesive and are best compacted with pressure, impact, or kneading; and Class V soils are considered cohesive, but are not recommended for use in pipe installation[2].

Soil Compaction

The soil support for the pipe is dependent on the degree of compaction, referred to as "percent compaction," which is defined by ASTM D653[5] as the ratio of the field compaction to the laboratory maximum density, expressed as a percent. The field compaction is measured by in-place density tests, such as sand cone or nuclear gauge. For soil classes III, IV, or V, the laboratory maximum density is determined using the standard Proctor compaction test ASTM D698[6]. For soil classes I or II, the laboratory maximum density is determined using a vibratory compaction test* ASTM D7382[7] or D4253[8].

Table 1. Uniform Soil Classes for Pipe Installation

Class I	**Crushed Rock** 100% passing 1-1/2-in. sieve, ≤ 25% passing 3/8-in. sieve, ≤ 15% passing #4 sieve, ≤ 12% fines	
Class II	**Clean, Coarse-Grained Soils** Or any soil beginning with one of these symbols; can contain up to 12% fines (Note 1)	GW GP SW SP
Class III	**Coarse Grained Soils With Fines** **Sandy or Gravelly Fine-Grained Soils** With ≥ 30% retained on #200 sieve	GM GC SM SC ML CL
Class IV	**Fine-Grained Soils** With < 30% retained on #200 sieve	ML CL
Class V	**Fine-Grained Soils, Organic Soils** High-compressibility silts and clays, organic soil	MH CH OL OH Pt

Notes:

1. Uniform fine sands (SP, SP-SC, and SP-SM) with more than 50 percent passing a #100 sieve should be treated as Class III material.
2. Soil classification in accordance with ASTM D2487[3] or D2488[4].
3. Fines are soil particles that pass a #200 sieve.
4. Class I: crushed rock particles should have all-fractured faces.
5. Recycled concrete, slag, and shells should be considered Class II.

GW = well-graded gravel
SW = well-graded sand
SP-SC = poorly graded sand with clay
GM = silty gravel
SM = silty sand
ML = silt
MH = elastic silt
OL = organic silt
Pt = peat

GP = poorly graded gravel
SP = poorly graded sand
SP-SM = poorly graded sand with silt
GC = clayey gravel
SC = clayey sand
CL = lean clay
CH = fat clay
OH = organic clay

*ASTM D7382 is a new procedure using a vibratory hammer to obtain a maximum density and is considered more reliable than D4253.

Use of the term percent compaction is recommended in ASTM D653[5]. The percent of the maximum density of the soil is followed by the ASTM test procedure used to determine the maximum density. For example, 95 percent (D698) means that the in-place density should be equal to or higher than 95 percent of the maximum density obtained using D698[6].

Estimating Deflection

Flexible pipe derives its load-carrying capacity from the soil-structure interaction of the installation. As illustrated in Figure 2, the pipe tends to deflect due to load, thereby developing passive soil support at the sides of the pipe. At the same time, soil arching over the pipe due to the deflection transfers a portion of the vertical load to the soil at the sides of the pipe. Installed correctly, the strength of the pipe-soil system can be very effective.

The deflection of the pipe is the change in vertical diameter divided by the original diameter, stated as a percent. Conceptually, the relationship between load and deflection may be expressed as:

$$\text{Deflection} = \frac{\text{Load}}{\text{Pipe Stiffness} + \text{Soil Stiffness}}$$

(Equation 1)

The soil stiffness depends on the soil classification and the soil compaction. The soil stiffness is referred to as E′, the modulus of soil reaction.

E′, Modulus of Soil Reaction

Table 2 is an updated version of the First Edition table and contains some higher values, which allow for deeper burial.

Composite E′ (Soil Stiffness)

While the embedment soil is normally the primary source for the passive resistance, support for the pipe may also be influenced by the trench walls. Very weak or very stiff native trench wall soils can affect the pipe deflection,

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and their stiffness should be combined with the stiffness of the embedment soil to calculate a composite E′ to be used for estimating deflection.

The composite E′ varies depending on the soil type and the degree of compaction of the embedment material, native soil stiffness, pipe diameter, and trench width. To find the composite E′, the E'_E of the embedment material and the E'_N of the native soil are combined, similar to calculating footing settlement on layered soil.

The composite E′ is calculated as follows:

$$E' = S_c E'_E$$

(Equation 2)

Where:

E′ = composite modulus of soil reaction (psi)

S_c = soil support combining factor

E'_E = E'_E of the embedment

In the manual, tables of S_c values and E'_N are presented to help determine the composite stiffness value. The composite E′ can be higher or lower than the embedment E′, depending on how stiff or weak the trench walls are.

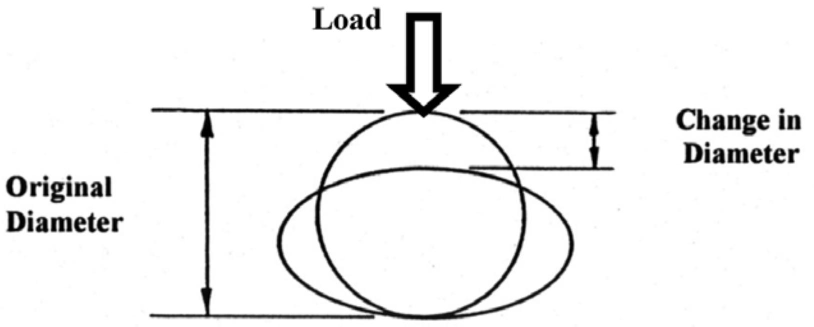

Figure 2. Flexible Pipe Deflection

Table 2. E′ Values, Pounds Per Sq In. (psi)

Soil Group USCS	**Uncompacted**	**Compacted**	
		Moderate 85%- 90% compaction	**High** ≥ 95% compaction
Class I Crushed rock	1000	6000	
Class II GW GP SW SP	500	2000	4000
Class III GC GM SC SM. CL ML (≥30% sand/gravel)	200	1000	2500
Class IV CL ML	100	400	1500
Class V CH MH OH OL Pt	Do Not Use		

Notes:

1. Soil classification based on ASTM D2487 (Unified Soil Classification System).
2. Percent compaction based on ASTM D4253 or D7382 (vibratory tests) for Class I and II soils.
3. Percent compaction based on ASTM D698 (standard proctor) for Class III and IV soils.
4. Class I crushed rock particles should have all-fractured faces.
5. Recycled concrete, slag, shells, and coral should be considered Class II.
6. Uniform fine sands (SP, SP-SC, and SP-SM) with more that 50 percent passing a #100 sieve should be treated as Class III material.

Basic Installation and Engineered Installation

There are some combinations of pipe selection, external loads, and soil stiffness that may not need design verification for deflection, buckling, and compressive stress. Accordingly, the design and construction may be divided into basic installations and engineered installations.

Basic Installation

Under certain conditions, some installations using pipe with an adequate stiffness will not exceed the specified deflection limits, will have a safety factor of at least two against buckling, and will not exceed the allowable wall compressive stress. These pipes may be used for construction without performing the verification calculations in this manual and may be installed with minimum soil support.

Typically, the embedment material is the soil excavated from the trench. The pipe can be laid directly on the trench bottom, and minimal testing and inspection are required. Basic installation is frequently suitable for rural transmission and distribution lines.

A basic installation can be used for the following conditions:

- Pipe diameter is 24 in. or less.
- Dimension ratio (DR) is equal to or less than 21.
- Depth of cover is 10 ft or less.
- Natural groundwater level is below pipe.
- There will be no live load or surcharge load for cover depths less than 6 ft.
- Final backfill does not need to be compacted.
- Embedment soil stiffness, E′, will be at least 200 psi.
- The foundation and trench walls are stable and have a minimum unconfined compressive strength[9] of 5 psi, a N value of at least 5 from the Standard Penetration Test[10], or an E′ of at least 400 psi.
- The foundation does not consist of expansive clays, collapsing soils, or landfills.
- The soils in the foundation and used for the embedment do not contain rock particles larger than the maximum particle size, as shown in Table 3.

An engineered installation should be used when any of these conditions are not met. In

Table 3. Maximum Particle Size in Embedment

Pipe Diameter	**Maximum Particle Size in Embedment***
Up to 4 in.	½ in.
6 to 8 in.	¾ in.
10 to 16 in.	1 in.
18 in. and greater	1 ½ in.

* For final backfill, the maximum particle size is limited to 3 in. per ASTM D2774.

some cases where live or surcharge loads may occasionally occur, such as road crossings, the pipeline may consist of a combination of basic installation and engineered installation.

Native materials that are Class III or Class IV soils can provide an embedment $E' \geq 400$ psi if moderately compacted. The embedment soil must be compacted to at least 85 percent (D698).

Class I or II soils, whether native or imported, can provide an embedment $E' \geq 400$ psi when dumped in place beside the pipe without any compaction. Class V soil is not recommended for embedment.

Engineered Installation

When the basic installation is not appropriate, the pipe design will require additional checks for deflection, buckling, and compressive stress, as prescribed in the manual. An engineered installation design may need to consider the trench wall support, the effects of groundwater, selection of embedment material, increased compaction, time before the pipeline is pressurized, live load, and surcharge load. Construction may require imported embedment material, placing bedding for the pipe, soil testing requirements, and more-stringent inspection. Where the pipeline would cross under any kind of pavement, pipeline, cable, or waterway, an engineered installation should be used.

Installation

Trench Width

Rather than recommended values, the manual states that the excavated trench should have a width based on the excavation equipment used by the contractor, but this width must allow for clearance between the pipe and trench wall (as applicable) for joining the pipe, snaking the pipe, shovel slicing, compacting the embedment, testing the percent compaction, and checking the joints. In poor soils, the width may need to be increased to properly support the pipe; therefore, if the installation was designed using composite E', then the pipeline must be constructed using the design trench width.

Bedding for Engineered Installation

A layer of Class I or Class II material should be placed on the trench bottom and left uncompacted. The bedding should be 4 in. thick for pipe, less than 60 in. in diameter, and 6 in. thick for 60-in. and larger pipe. If the bottom of the trench is rock or contains cobbles or boulders, the bedding thickness should be increased at least 2 in.

Haunch Compaction for Engineered Installation

A successful installation depends on the correct placement and compaction of soil in the haunch zone of the pipe. The first few lifts should be placed so that the soil can be shovel-sliced into the haunches. The thickness and compaction of the remaining lifts should be appropriate for the type of material and the compaction requirements. Preferred options to shovel slicing are flowable fill or compacting Class I or Class II soils with saturation and vibration, as recommended in ASTM F 1668[2]. If flowable fill is used in the haunch zone, it should also be used as the bedding.

Flowable Fill

Flowable fill is a fluid mixture of Portland cement, soil, and water that hardens into a solid mass. There are several ASTM standards relating to the mixing, placing, and testing of flowable fill; they refer to flowable fill as controlled low-strength material (CLSM). The hardened flowable fill is typically about two to five times stiffer than compacted soil and thus provides good support for buried pipe. Flowable fill can range from material obtained from a concrete batch plant to a mixture using the native soils excavated from the trench or borrow source. The fresh flowable fill should have a spread of 8 to 12 in. and the hardened flowable fill should have a compressive strength of 40 to 80 psi[2].

Many contractors have developed equipment and methods for using the soils excavated from the trench and mixing onsite, which provides considerable cost savings when compared to ordering from a ready-mix plant. While sandy soils (such as in Florida) are best, soils, such as fat clays, have been successfully used with the proper processing.

The E' for flowable fill depends on the amount of cementitious material, the aggregate, and the time after placement. Unless it's a high early-strength mixture, flowable fill should not be backfilled until the day after placement. Flowable fill gains strength after placement, so the stiffness for estimating deflection will depend on when the backfill load is placed over the pipe and the flowable fill.

References

1. ASTM D2774, *Standard Practice for Underground Installation of Thermoplastic Pressure Piping*, ASTM International, West Conshohocken, Penn.
2. Howard, Amster, *Pipeline Installation* 2.0, Relativity Publishing, 2015.
3. ASTM D2487, *Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)*, ASTM International, West Conshohocken, Penn.
4. ASTM D2488, *Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)*, ASTM International, West Conshohocken, Penn.
5. ASTM D653, *Standard Terminology Relating to Soil, Rock, and Contained Fluids*, ASTM International, West Conshohocken, Penn.
6. ASTM D698, *Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort (12,400 ft-lbf/ft^3 (600 kN-m/m^3))*, ASTM International, West Conshohocken, Penn.
7. ASTM D 7382, *Standard Test Methods for Determination of Maximum Dry Unit Weight and Water Content Range for Effective Compaction of Granular Soils Using a Vibrating Hammer*, ASTM International, West Conshohocken, Penn.
8. ASTM D4253, *Standard Test Methods for Maximum Index Density and Unit Weight of Soils using a Vibratory Table*, ASTM International, West Conshohocken, Penn.
9. ASTM D2166, *Standard Test Method for Unconfined Compressive Strength of Cohesive Soil*, ASTM International, West Conshohocken, Penn.
10. ASTM D1586, *Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils*, ASTM International, West Conshohocken, Penn.