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BASIC AND ENGINEERED INSTALLATION OF HDPE PIPE

Amster Howard
Civil Engineering Consultant.
1562 S Yank St,
Lakewood CO, USA

SHORT SUMMARY (*One paragraph, ~6 sentences maximum*)
The Second Edition (2020) of AWWA M55 PE Pipe – Design and Installation contains significant changes of interest to users of buried HDPE pressure pipe. The revisions include updating terminology, soil modulus values, use of uniform soil classes, and installation in poor soils. The manual addresses these applications as related to PE 4710 HDPE pipe. This paper concentrates on the part related to basic and engineered installation.

KEYWORDS (*Mandatory, please give ~3-5 keywords)*
HDPE, AWWA M55, PE 4710, design, installation, geotechnical, soil modulus, deflection

ABSTRACT

Deeper pipe burial, less expensive and environmentally friendly backfill, uniform language for contractors and inspectors, simplified installations for smaller pipe, and allowable construction in poor soil conditions are highlights in the latest edition of AWWA M55 and all benefit the users of HDPE pressure pipe.

This paper summarizes the significant updates to the design and installation recommendations in the Second Edition of AWWA (American Water Works Association) Manual M55 PE Pipe – Design and Installation to be published in 2020. For design, these updates include higher E' (Modulus of Soil Reaction) values, use of composite E' values, use of Uniform Soil Classes, use of geotextiles, and terminology. For installation, there is revised information on trench width, flowable fill, inspection and soil testing, and compaction requirements. These changes reflect the recent revisions to ASTM D2774 Standard Practice for Underground Installation of Thermoplastic Pressure Piping. The changes are applicable to all pipe diameters and to all pipe stiffness values.

The Second Edition of M55 encourages the use of basic installation and engineered installation for buried pressure PE pipe. The basic installation is for HDPE pipe stiff enough to not need special bedding and embedment, for shallow burial with no live load, 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, compressive strength, and buckling requirements. The engineered installation approach *recommends an uncompacted bedding and an uncompacted padding zone over the top of the pipe.*

INTRODUCTION

Deeper pipe burial, less expensive and environmentally friendly backfill, uniform language for contractors and inspectors, simplified installations for smaller pipe, and allowable construction in poor soil conditions as presented in the latest edition of AWWA M55 all benefit the users of HDPE pressure pipe

AWWA Manual of Water Supply Practices, M55 *PE Pipe – Design and Installation*, 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. The Second Edition is expected to be published in 2020 and contains significant updates that users need to be aware of. Many of the changes reflect recent modifications to ASTM D2774 *Practice for Underground Installation of Thermoplastic Pressure Piping*. The updates are applicable to all pipe diameters and to all pipe stiffness values. For design, these revisions include:

- Change in trench section terminology
- Change in classification and descriptions of soils
  (use of Uniform Soil Classes)
- 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
  (using 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 uncompacted bedding to lay the pipe on
- Use of flowable fill for embedment and backfill

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

New M55 information is also provided for PE4710, Seismic Performance, Marine Applications, and Trenchless Construction. Model specifications have been added along with actual case histories of HDPE installations and PE4710 Pipe Data. Refer to AWWA M55 for details.

DISCUSSION
PE4710

The new Manual will include PE4710 compounds that have been added in the ANSI/ AWWA C901 and C906 standards. PE4710 is a new material that was not available when the first edition was published. The second edition contains material properties pertaining only to PE4710. Pipe made with PE4710 have higher pressure ratings (or reduced wall thickness) and a higher resistance to rapid crack propagation. The higher resistance is due to increased ductility and higher impact resistance.

TRENCH CROSS-SECTION TERMINOLOGY

The new terminology for the trench cross section is shown in Figure 1.

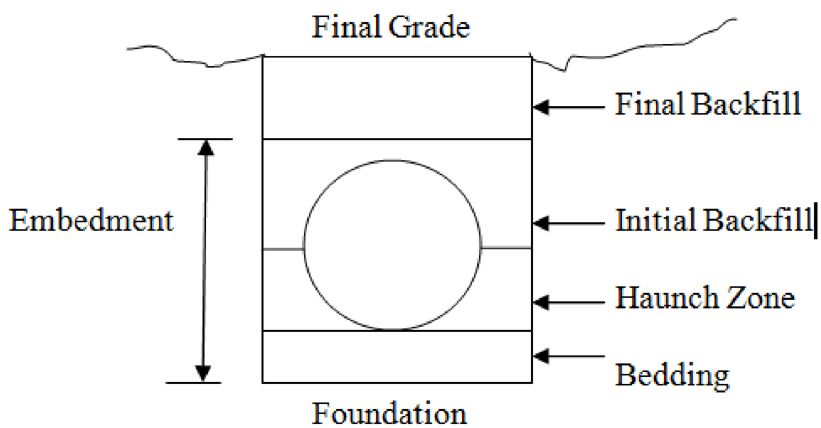

Figure 1 Trench Terminology

- *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. The bedding 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 inches (300 mm) above the top of the pipe. The initial backfill combined with the haunch zone act as lateral support for the pipe. The support may also include the native trench walls.
- *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 PVC pipe), M55 (pressure PE pipe), M45 (fiberglass pipe), and are planned for inclusion in a revised edition of 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 soils are usually considered cohesive and are best compacted with pressure, impact, or kneading. Class V soils are considered cohesive but are not recommended for use in pipe installation (Howard 2015).

Table 1 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	**USCS** (Note 1)
Class II	**Clean, coarse grained soils** or any soil beginning with one of these symbols (can contain up to 12% fines) (Note 2)	**GW GP** **SW SP**
Class III	**Coarse grained soils with fines** S**andy 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. Soil classification in accordance with ASTM D 2487 or D 2488.
2. Uniform fine sands (SP) (SP-SC) (SP-SM) with more than 50% passing a #100 sieve should be
   treated as Class III material.
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.

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.

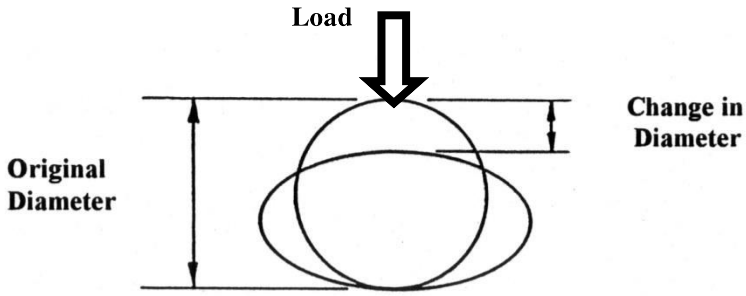

Figure 2 Flexible Pipe Deflection

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:

$$\text{Deflection} = \frac{\text{Load}}{\text{Pipe Stiffness} + \text{Soil Stiffness}} \qquad \text{(Eq. 1)}$$

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. Under most installation conditions, PE pressure pipe tends to deflect minimally into an elliptical shape. The horizontal and vertical deflections may be considered equal in the range of deflections typically allowed for PE pipe.

The equation in M55 (both editions) is:

(Eq. 2)

$$\%\frac{\Delta Y}{D_M} = \frac{k(T_L W_E + W_L + W_S)}{\frac{2E}{3(DR - 1)^3} + 0.061E'}(100)$$

Where:

$\%\frac{\Delta Y}{D_M}$ = vertical deflection, %

ΔY = vertical change in diameter, inches.

D_M = mean diameter, inches. (D_o - t)

Do = outside pipe diameter

t = pipe wall thickness

k = bedding constant, use 0.1

T_L = time-lag factor use 1.0, 1.5, or 2.0 (see discussion)

W_E = earth load pressure, psi
W_L = live load pressure, psi
W_S = surcharge pressure, psi
E = apparent modulus of elasticity of pipe material, psi
DR = dimension ratio (D_o/t)
E′ = modulus of soil reaction, psi

Time Lag._The previous edition recommended a Time-Lag value of 1.5. That has been revised in the Second Edition.

Buried flexible pipe continue to deflect after the pipe have been initially backfilled. The time lag factor, T_L, relates the initial deflection of the pipe to the deflection of the pipe after many years. The primary cause of increasing pipe deflection with time is the increase in backfill load. The full backfill load is not realized until about 3 to 12 months after completion of backfilling (or longer). A secondary cause of increasing pipe deflection is the time-related consolidation of the embedment and in some cases, the trench walls. The soil consolidation is generally of much less significance than the increasing load.

When the operating internal pipe pressure equals or exceeds the external load, assume that the pipe will tend to re-round. For pipelines that are pressurized within 3 months of installation, a time-lag factor of 1.0 can be used. Otherwise, a time-lag factor of 1.5 should be used to estimate the deflection that may occur while the pipe is not pressurized. If the pipe will not be pressurized for several years, a time-lag factor of 2.0 should be used to estimate the deflection until pressurized.

E', Modulus of Soil Reaction. Table 2 is an updated version of the First Edition table and contains some higher values which allows for deeper burial (Howard 2006).

Table 2 – E' Values, 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 or D2488 (Unified Soil Classification System)
2. Percent compaction based on ASM D4253 or D7382 (vibratory tests) for Class I and II soils
3. Percent compaction based on ASM 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, SP-SM) with more that 50% passing a #100 sieve should be treated as Class III material.
7. E' values only valid for cover depths of 50 ft or less.

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 and their stiffness should be combined with the stiffness of the embedment soil to calculate a composite E′ to be used for estimating deflection (Howard 2015).

The composite E′ varies depending on the soil type and the degree of compaction of the embedment material, the native soil stiffness, the pipe diameter, and the 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:

$$E' = S_c E'_E \qquad \text{(Eq 3)}$$

Where:

E' = composite modulus of soil reaction, psi
S_c = soil support combining factor
E'_E = modulus of soil reaction of the embedment material

In the manual, tables of Sc 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. A revised table of native soil E'_N values is included in the new Second Edition. This new table is shown here as Table 3.

Table 3 E'_N based on SPT Values, psi

Soil description and classification - USCS	N Value from SPT test (number of blows/foot)					
	0 – 4	5	10	20	30	≥50
Clays and silts with less than 30% Sand/gravel CL ML	zero	500	750	1250	1500	2500
Sandy silts, clays With more than 30% sand CL ML Silty or Clayey sand SM SC	zero	700	1000	1500	2000	3000
Normally consolidated sands SP, SP-SM, SP-SC	zero	1000	1500	2500	3000	5000
Over-consolidated sands SP, SP-SM, SP-SC	zero	2000	3000	4000	5000	8000
Gravels, soils with gravel	zero	Typically higher than sands but SPT test very unreliable, use another method				

Notes: Unified Soil Classification based on ASTM D2487 or D2488
SPT = Standard penetration test per ASTM D1586.

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 pipe may be used for construction without performing the verification calculations in this chapter 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 inches or less.
- DR is equal to or less than 26.
- Depth of cover is 15 ft or less
- Natural ground water level is below pipe.
- There will be no live load nor surcharge load for cover depths less than 6 feet.
- 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 of 5 psi (ASTM D2166), a N value of at least 5 from the Standard Penetration Test (ASTM D1586), 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

For Final Backfill, the maximum particle size is limited to 3 inches per ASTM D2774

An engineered installation should be used when any of these conditions are not met. In 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′ ≥ 400 psi if moderately compacted. The embedment soil must be compacted to at least 85% (D698).

Class I or II soils, whether native or imported, can provide an embedment E′ ≥ 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 the 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 ground water, selection of embedment material, increased compaction, time before pipeline is pressurized, live load, and surcharge load. Construction may require imported embedment material, placing a 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 however, 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 trench width that was assumed for design.

Maximum Particle Size. As shown in Table 4, the allowable maximum particle size for soils adjacent to the pipe reflect the values from D2774.

Table 4- Maximum Particle Size in Embedment

Pipe Diameter	Maximum Particle Size in Embedment
Up to 4 inch	½ inch
6 to 8 inch	¾ inch
10 to 16 inch	1 inch
18 inch and greater	1.5 inch

Soil Compaction. The soil support for the pipe is dependent on the degree of compaction, referred to as *percent compaction*. Percent compaction is defined by ASTM D653 as the ratio of the field density 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. For soil classes I or II, the laboratory maximum density is determined using a vibratory compaction test* ASTM D7382 or D4253.

> **ASTM D 7382 is a new procedure using a vibratory hammer to obtain a maximum density and is considered more reliable than D 4253.*

Use of the term *percent compaction* is recommended in ASTM D653. 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% (D 698) means that the in-place density should be equal to or higher than 95 percent of the maximum density obtained using D 698.

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 four inches thick for pipe less than 60 inches in diameter and six inches thick for 60 inch and larger pipe. If the bottom of the trench is rock or contains cobbles or boulders, the bedding thickness should be increased at least two inches.

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 (1) flowable fill, or (2) compacting Class I or Class II soils with saturation and vibration, as recommended in ASTM F 1668. 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. ASTM has several standards relating to the mixing, placing, and testing of flowable fill. ASTM refers to flowable fill as controlled low strength material (CLSM). The hardened flowable fill is typically about 2 to 5 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 inches (see ASTM D6103) and the hardened flowable fill should have a compressive strength of 40 to 80 psi, according to ASTM D4832.

Many contractors have developed equipment and methods for using the soils excavated from the trench and mixing on site. This provides considerable cost savings compared to ordering from a ready-mix plant. While sandy soils are best, soils such as Fat Clays (CH) 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 is 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.

ACKNOWLEDGMENTS
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