STANDARD PRACTICE FOR THE DESIGN AND CONSTRUCTION OF HIGH DENSITY POLYETHYLENE PIPE (HDPE)

PART 1: GENERAL

1.01 SCOPE

A. This standard practice covers the design and construction of High Density Polyethylene (HDPE) pipe for use in installations within the ________________.

B. Buried HDPE pipes are a composite structure consisting of a plastic tube and the surrounding soil envelope. Both the plastic tube and soil envelope play a vital part in the structural design requirements for HDPE pipes. It is essential that the designer and installer recognize that the composite soil-pipe interaction in a typical trench installation is comprised of the select embedment zone soils immediately surrounding the pipe and the native trench wall soils. The interaction of these materials can play a significant role in the overall pipe's structural performance.

C. Part 2 presents the design method for HDPE pipe design using the standard installation configurations that are specified herein. The limit states design method presented herein evaluates the pipe for deflection, thrust, strain, localize buckling and global buckling.

D. Part 3 presents the construction requirements for thermoplastic pipe designed and installed in accordance with this standard practice.

E. This standard practice shall be used as a reference by ACPA Infrastructure Market Teams to assist in modifying existing agency standard specifications or specific project specifications. It is not intended to be shared with specifying agencies.

F. The design procedures given in this standard are intended for use by engineers who are familiar with the concept of soil-pipe interaction and of the factors that may impact both the performance of the pipe and of the soil envelope. Before using the design procedures given in Part 2, the engineer should review the guidance and requirements given in other sections of this standard practice and its accompanying commentary.
G. The values of dimensions and quantities are expressed in English unit values.

1.02 APPLICABLE DOCUMENTS

A. AASHTO (American Association of State Highway and Transportation Officials)
   AASHTO LRFD Bridge Construction Specifications
   AASHTO LRFD Bridge Design Specifications
   M43 Standard Specification for Sizes of Aggregate for Road and Bridge Construction
   M145 Standard Specification for Classification of Soils and Soil-Agginate Mixtures for Highway Construction Purposes
   M294 Standard Specification for Corrugated Polyethylene Pipe, 300 to 1500 mm (12 to 60 in.) Diameter
   PP63-09 Standard Practice for Pipe Joint Selection for Highway Culvert and Storm Drains

B. AREMA (American Railway Engineering and Maintenance-of-Way Association)
   AREMA Manual for Railway Engineering

C. ASTM (ASTM International)
   C923 Standard Specification for Resilient Connectors Between Reinforced Concrete Manhole Structures, Pipes, and Laterals
   D420 Standard Guide to Site Characterization for Engineering Design and Construction Purposes
   D698 Standard Test Methods for Laboratory Compaction Characteristics of Soil Using Standard Effort
   D1586 Standard Test Method for Standard Penetration Test (SPT) and Split-Barrier Sampling of Soils
   D2412 Standard Test Method for Determination of External Loading Characteristics of Plastic Pipe by Parallel-Plate Loading
   D2487 Standard Practice for Classification of Soils for Engineering Purposes (Unified Soil Classification System)
   D3350 Standard Specification for Polyethylene Plastics Pipe and Fittings Materials
   F477 Standard Specification for Elastomeric Seals (Gaskets) for Joining Plastic Pipe
   F894 Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe
D. AWWA (American Water Works Association)
M45 Manual of Practice for Fiberglass Pipe Design

E. OSHA (Occupational Safety and Health Standards)
29 CFR Part 1926, OSHA Standards for the Construction Industry

1.03 DEFINITIONS

Figure 1 illustrates the definitions and limits of the terms: foundation, bedding, haunching, initial backfill, final backfill, pipe zone, pipe embedment, pipe width, excavated trench width and springline as used in this standard practice.

Note: Drawing not to scale.

Figure 1 – Standard Terminology

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1.04 SUMMARY OF STANDARD PRACTICE APPROACH

A. The design approach of this standard practice is based upon the assumptions inherent in the original Spangler load distribution for flexible pipe. In this approach, the vertical reaction on the bottom of the pipe is equal to the vertical load on the top of the pipe and is equally distributed over the bedding. Passive horizontal pressures on the sides of the pipe have a parabolic distribution over the middle 100 degrees of the pipe (see Figure 2).

![Figure 2 – Load Distribution Based on Spangler](image)

B. Earth load effects are computed based upon the pressure distributions presented herein. While both embankment loading and trench loading nomenclature are presented for clarity, all design is based upon developing full prism loads as opposed to Marston load theory.

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C. Soil stiffness values (modulus of soil reaction, $E'$) for material in the embedment zone are based upon the research of Duncan and Hartley\textsuperscript{4} and McGrath\textsuperscript{5}. The soil stiffness values to be utilized in design are based upon a direct substitution of the one-dimensional constrained modulus, $M_s$, for $E'$. In the absence of direct measurement of constrained modulus values, the design values presented in Table 12.12.3.5-1 of the AASHTO LRFD Bridge Design Specifications are recommended for use herein.

D. The soil stiffness values should be further modified, if required, based on the trench width and the nature and properties of native soils encountered in accordance with the procedure articulated in AWWA Manual of Practice M45\textsuperscript{6}. Leonhardt Factor.

E. Lastly, the Modified Iowa formula, as developed by Spangler-Watkins, should be corrected to solve for vertical as opposed to horizontal deflection in accordance with the procedure proposed by Masada\textsuperscript{7} and reproduced herein and the recommendations presented in Part 2 of the Standard Practice.

PART 2: DESIGN

2.01 GENERAL

A. Design criteria and methodology shall conform to the applicable sections of this standard practice.

B. The designer shall carry out design checks in accordance with this standard practice to ensure that the maximum localized distortion and net tension strain of the installed thermoplastic pipe shall not exceed the specified limits based upon the pipe selected for use, the embedment material properties specified, the native soil conditions that are anticipated to be encountered, and the installation configuration specified.

C. The native soil component can significantly impact both short and long-term pipe performance, and its impact may vary with both trench configuration and embedment material selection. The designer shall clearly indicate the combination of native soils, embedment soils, and installation configuration assumed in design. This information shall be provided to the installer in the manner prescribed by Article 2.02, Paragraph B.

2.02 DESIGN REQUIREMENTS

A. General Design Approach

1. The performance limits for thermoplastic pipe include: wall crushing (stress), localized wall buckling, reversal of curvature (over-deflection), excessive deflection (i.e., deflection that compromises functional performance), strain limits, longitudinal stresses, shear loadings, and fatigue.

2. The designer should understand that he alone is responsible for carrying out all necessary performance limit checks for each specific design situation.

3. The three parameters that are essential in flexible pipe design include: load (design fill height, surcharge loads and live loads), soil stiffness in the pipe zone (both embedment and native soil), and pipe stiffness.

4. Soil is a major component in developing soil-pipe interaction. The designer must take this into account during design and properly communicate/specify the soil requirements to the installer and field inspector. Should the installer or field inspector identify soil conditions in the field differing from those specified by the designer, the design should be modified to account for the actual field conditions.

5. The design process, therefore, consists of:
   a. Determining external loading conditions,
   b. Assessing whether any special design conditions other than conventional trench and/or embankment loadings will govern in design,
   c. Determining or estimating in-situ soil conditions based on either site specific geotechnical investigations or experience,
   d. Selection of the desired balance of soil and pipe stiffness to meet the anticipated loading conditions for the duration of the design period, and
e. Articulating the assumptions utilized in design to the installer to ensure that any conditions that arise or become apparent during construction that are at variance with the design assumptions can be reviewed to confirm whether the design is still valid or requires some modification to meet the design objective.

B. Minimum Information Transfer to Contractor and Contract Administrator: The minimum level of information transfer to the installer for each design where the use of flexible thermoplastic pipe is contemplated includes:

1. Pipe material and minimum pipe stiffness
2. Assumed installation configuration
3. Embedment material and required placement density
4. Assumed embedment width and assumed native soil characteristics (qualitative description and $E'_{\text{native}}$ value)

2.03 PIPE MATERIAL REQUIREMENTS

A. Pipe material requirements are general pipe material requirements to conform to this Standard Practice. They are not to be construed as general approval for the use of these products within the ______________. Specific products approvals are addressed by the ______________ on a product-by-product basis outside of this Standard Practice.

B. Polyethylene (PE) Profile Wall Products

1. Closed profile and open profile PE pipe products and fittings shall conform to latest version of ASTM D3350 for all basic material requirements and manufactured quality and dimensional tolerance for sanitary and storm sewer applications in accordance with AASHTO M294 and ASTM F894.

2. Materials used for pipe and fabricated fittings shall come from a single compound manufacturer and shall be made from virgin polyethylene compounds having the minimum cell classifications as provided in Table 1:

<table>
<thead>
<tr>
<th>Product</th>
<th>Outside Profile, Corrugations Inside</th>
<th>Lining, Waterway Wall</th>
</tr>
</thead>
<tbody>
<tr>
<td>Storm Sewer and Fabricated Fittings</td>
<td>324432 C, or 324432 E</td>
<td>324432 C, or 324432 E</td>
</tr>
<tr>
<td>Sanitary Sewer and Fabricated Fittings</td>
<td>324432 C, or 324432 E</td>
<td>324432 C, or 324432 E</td>
</tr>
</tbody>
</table>

3. Resin compounds shall be tested for slow crack growth resistance in accordance with Appendix SP-NCTL in ASTM Standard D5397.

2.04 BEDDING AND FOUNDATION MATERIAL REQUIREMENTS
A. Classification of Materials: Materials for use as foundation, embedment, and backfill are classified in Table 2. They include natural, manufactured, and processed aggregates and the soil types classified according to ASTM Test Method D2487.

Table 2 – Classes of Embedment and Backfill Materials

<table>
<thead>
<tr>
<th>ASTM D2321</th>
<th>ASTM D 2487</th>
<th>AASHTO M 43</th>
<th>AASHTO M 145</th>
<th>Percent Passing</th>
<th>Limits</th>
<th>formity</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>Class</td>
<td>Description</td>
<td>Symbol</td>
<td>Description</td>
<td>ASTM D 2321</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>I</td>
<td>Crushed rock, angular&lt;sup&gt;a&lt;/sup&gt;</td>
<td>None</td>
<td>Angular, crushed stone or rock, crushed gravel, broken coral, crushed slag, cinders or shells; large void content, contain little or no fines.</td>
<td>#5, #56&lt;sup&gt;c&lt;/sup&gt;, #57&lt;sup&gt;c&lt;/sup&gt;, #8, #67</td>
<td>None</td>
<td>100% ≤ 25% ≤ 15% &lt; 12%</td>
<td>Non Plastic</td>
</tr>
<tr>
<td>II</td>
<td>Coarse-Grained Soils; clean.</td>
<td>GW</td>
<td>Well-graded sands and gravelly sands; little or no fines.</td>
<td>#5</td>
<td>&lt; 50% of coarse fraction</td>
<td>&gt; 4</td>
<td>1 to 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GP</td>
<td>Poorly-graded sands and gravelly sands; little or no fines.</td>
<td>#56, #57, #67</td>
<td>100%</td>
<td>&lt; 5%</td>
<td>Non Plastic</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SW</td>
<td>Well-graded sands and gravelly sands; little or no fines.</td>
<td>A1, A3</td>
<td>&gt; 50% of coarse fraction</td>
<td>&gt; 6</td>
<td>1 to 3</td>
</tr>
<tr>
<td></td>
<td></td>
<td>SP&lt;sup&gt;c&lt;/sup&gt;</td>
<td>Poorly-graded sands and gravelly sands; little or no fines.</td>
<td>None</td>
<td>Varies 5% to 12%</td>
<td>Non Plastic</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Coarse-Grained Soils; borderline clean w/ fines.</td>
<td>e.g., GW-GC, SP-SM</td>
<td>Sands and gravels which are borderline between clean and with fines.</td>
<td>None</td>
<td>100%</td>
<td>Varies 5% to 12%</td>
<td>Same as for GW, GP, SW and SP.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Class I materials allow for a broader range of fines than previous versions of ASTM D2321. When specifying Class I material for infiltration systems, the engineer shall include a requirement for an acceptable level of fines.

<sup>b</sup> All particle faces shall be fractured.

<sup>c</sup> Assumes less than 25% passes the 3/8” sieve.

<sup>d</sup> Class IV materials require a geotechnical evaluation prior to use and should only be used as backfill under the guidance of a qualified engineer.
Table 2 – Classes of Embedment and Backfill Materials (continued)

<table>
<thead>
<tr>
<th>Class</th>
<th>Description</th>
<th>ASTM D2321</th>
<th>ASTM D 2487</th>
<th>AASHTO M 43 Symbol</th>
<th>AASHTO M 145 Symbol</th>
<th>ASTM D 2321 Percent Passing</th>
<th>Limits</th>
<th>formity</th>
<th>Curvature</th>
</tr>
</thead>
<tbody>
<tr>
<td>III</td>
<td>Coarse-Grained Soils; with fines.</td>
<td>GM</td>
<td>Silty gravels, gravel-sand-silt mixtures.</td>
<td>Gravel &amp; sand with &lt; 10% fines</td>
<td></td>
<td>1-1/2&quot;*</td>
<td>3/8&quot;</td>
<td>No. 200</td>
<td>LL</td>
</tr>
<tr>
<td></td>
<td></td>
<td>GC</td>
<td>Clayey gravels, gravel-sand-clay mixtures.</td>
<td>A-2-4, A-2-5, A-2-6, or A-4 or A-6 soils with more than 30% retained on the #200 sieve</td>
<td></td>
<td>12% to 50%</td>
<td>N/A</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SM</td>
<td>Silty sands, sand-silt mixtures.</td>
<td></td>
<td></td>
<td>&gt; 50% of coarse fraction</td>
<td>N/A</td>
<td>&gt; 7 &amp; &gt;&quot;A&quot; Line</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>SC</td>
<td>Clayey sands, sand-clay mixtures.</td>
<td></td>
<td></td>
<td>100%</td>
<td>N/A</td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td></td>
<td>Fine-Grained Soils; inorganic.</td>
<td>ML</td>
<td>Inorganic silts and very fine sands, rocks flour, silty or clayey fine sands, silts with slight plasticity.</td>
<td></td>
<td></td>
<td>&gt; 30% (retained)</td>
<td>&lt; 4 or &lt; &quot;A&quot; Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CL</td>
<td>Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.</td>
<td></td>
<td></td>
<td>&gt; 50%</td>
<td>&gt; 7 &amp; &gt;&quot;A&quot; Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td>IVF</td>
<td>Fine-Grained Soils; inorganic.</td>
<td>ML</td>
<td>Inorganic silts and very fine sands, rocks flour, silty or clayey fine sands, silts with slight plasticity.</td>
<td>N/A</td>
<td></td>
<td>A-2-7 or A-4 or A-6 soils with 30% or less retained on #200 sieve</td>
<td>&lt; 4 or &lt; &quot;A&quot; Line</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td>CL</td>
<td>Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, silty clays, lean clays.</td>
<td>N/A</td>
<td></td>
<td>100%</td>
<td>&lt; 7 &amp; &gt;&quot;A&quot; Line</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Uniform fine sands (SP) with more than 50% passing a 100 sieve behave like silts and should be treated as Class III soils if allowed.
Table 2 – Classes of Embedment and Backfill Materials (continued)

<table>
<thead>
<tr>
<th></th>
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<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>F</td>
<td>Fine-Grained Soils; inorganic.</td>
<td>MH</td>
<td>Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.</td>
<td>100%</td>
<td>100%</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Organic Soils</td>
<td>CH</td>
<td>Inorganic clays of high plasticity, fat clays.</td>
<td>100%</td>
<td>100%</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td>Highly Organic Soils</td>
<td>OL</td>
<td>Organic silts and organic silty clays of low plasticity.</td>
<td>100%</td>
<td>100%</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>OH</td>
<td>Organic clays of medium to high plasticity, organic silts.</td>
<td>100%</td>
<td>100%</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
<tr>
<td>V</td>
<td></td>
<td>PT</td>
<td>Peat and other high organic soils.</td>
<td>100%</td>
<td>100%</td>
<td>&gt; 50</td>
<td>&gt; 50</td>
<td>&gt; &quot;A&quot; Line</td>
<td></td>
<td></td>
<td></td>
<td>N/A</td>
<td></td>
</tr>
</tbody>
</table>

F Class V materials shall not be permitted as bedding and backfill material.

B. Installation and Intended Use of Materials

1. Table 3 provides recommendations on installation and use based on class of soil or aggregates and their location in the trench.

2. Class I (manufactured crushed stone) and Class II (AASHTO A1 and A3) materials are highly preferred for use in the foundation and embedment zones. When properly placed, these materials provide a high degree of stiffness and strength in limiting long term pipe deflection as compared to Class III and Class IV materials. Depending on the gradation and the in situ conditions, the user is advised that geotechnical fabric may be warranted to prevent the migration of fines.

3. Class III (AASHTO A2-4, A2-5, A2-6, A-4 and A-6) materials contain a percentage of clays and silts. Being such, Class III materials are sensitive to moisture, require a high degree of compactive effort and control. As compared to Class I and Class II materials, Class III materials are less stiff and offer less strength in limiting long term pipe deflection.

4. Class IV (AASHTO A2-7, A-4 and A-6) materials contain a percentage of clays and silts. Compared to Class III materials, Class IV materials are highly sensitive to moisture, require a higher degree of compactive effort and control. Class IV material are less stiff and offer less strength in limiting long term pipe deflection.

5. Class V (AASHTO A5 and A7) Soils, and frozen materials are not recommended for embedment. These types of materials should be excluded and avoided from the embedment zone.
Table 3 – Recommendations for Installation and Use of Soils and Aggregates for Foundation, and Pipe-Zone Embedment

<table>
<thead>
<tr>
<th>Soil Classes (See Table 2)</th>
<th>Class I&lt;sup&gt;a&lt;/sup&gt;</th>
<th>Class II</th>
<th>Class III</th>
<th>Class IV</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>General Recommendations and Restrictions</strong></td>
<td>Acceptable and common where no migration is probable or when combined with a geotextile filter media. Suitable for use as a drainage blanket and under drain where adjacent material is suitably graded or when used with a geotextile filter fabric.</td>
<td>Where hydraulic gradient exists check gradation to minimize migration. Clean groups are suitable for use as a drainage blanket and underdrain (see Table 2). Uniform fine sands (SP) with more than 50% passing a #100 sieve (0.006 in.) behave like silts and should be treated as Class III soils.</td>
<td>Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less.</td>
<td>Difficult to achieve high-soil stiffness. Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi or less.</td>
</tr>
<tr>
<td><strong>Foundation Bedding</strong></td>
<td>Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above.</td>
<td>Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above. Install and compact in 12 in. maximum layers.</td>
<td>Suitable for replacing over-excavated trench bottom as restricted above. Install and compact in 6 in. maximum layers.</td>
<td>Suitable for replacing over-excavated trench bottom for depths up to 12 in. as restricted above. Use only where uniform longitudinal support of the pipe can be maintained, as approved by the engineer. Install and compact in 6 in. maximum layers.</td>
</tr>
<tr>
<td><strong>Bedding</strong></td>
<td>Suitable as restricted above. Work material under pipe to provide uniform haunch support.</td>
<td>Suitable as restricted above. Work material under pipe to provide uniform haunch support.</td>
<td>Suitable as restricted above. Difficult to place and compact in the haunch zone.</td>
<td>Suitable as restricted above. Difficult to place and compact in the haunch zone.</td>
</tr>
<tr>
<td><strong>Minimum Recommended Percent Compaction, SPD&lt;sup&gt;d&lt;/sup&gt;</strong></td>
<td>See Note&lt;sup&gt;c&lt;/sup&gt;</td>
<td>85% (SW and SP soils) For GW and GP soils, see Note&lt;sup&gt;e&lt;/sup&gt;</td>
<td>90%</td>
<td>95%</td>
</tr>
<tr>
<td><strong>Relative Compactive Effort Required to Achieve Minimum Percent Compaction</strong></td>
<td>low</td>
<td>moderate</td>
<td>high</td>
<td>very high</td>
</tr>
<tr>
<td><strong>Compaction Methods</strong></td>
<td>vibration or impact</td>
<td>vibration or impact</td>
<td>impact</td>
<td>impact</td>
</tr>
<tr>
<td><strong>Required Moisture Content</strong></td>
<td>none</td>
<td>none</td>
<td>Maintain near optimum to minimize compactive effort.</td>
<td>Maintain near optimum to minimize compactive effort.</td>
</tr>
</tbody>
</table>

<sup>a</sup> Class V materials are unsuitable as embedment. They may be used as final backfill as permitted by the engineer.<br><sup>b</sup> Class I materials have higher stiffness than Class II materials, but data on specific soil stiffness values are not available at the current time. Until such data are available the soil stiffness of placed, uncompacted Class I materials can be taken equivalent to Class II materials compacted to 95% of maximum standard Proctor density (SPD95), and the soil stiffness of compacted Class I materials can be taken equivalent to Class II materials compacted to 100% of maximum standard Proctor density (SPD100).
Even if placed uncompacted (that is, dumped), Class I materials should always be worked into the haunch zone to assure complete placement.

Suitable compaction typically achieved by dumped placement (that is, uncompacted but worked into haunch zone to ensure complete placement).

SPD is standard Proctor density as determined by Test Method D698.

C. Description of Embedment Material

1. The characteristics of materials recommended for use in the embedment zone are classified as follows:

a. Class I Materials: These materials provide maximum stability and pipe support for a given percent compaction due to the low content of sand and fines. With minimum effort these materials can be installed at relatively high-soil stiffnesses over a wide range of moisture contents. In addition, the high permeability of Class I materials may aid in the control of water, and these materials are often desirable for embedment in rock cuts where water is frequently encountered. However, when ground-water flow is anticipated, consideration should be given to the potential for migration of fines from adjacent materials into the open-graded Class I materials. (see commentary in Appendix B).

b. Class II Materials: When compacted, these materials provide a relatively high level of pipe support. However, open graded groups may allow soils migration and the sizes should be checked for compatibility with adjacent material (see commentary in Appendix B).

c. Class III Materials: These materials provide less support for a given density than Class I or Class II materials. Higher levels of compactive effort are required and moisture content must be near optimum to minimize compactive effort and achieve the required percent compaction. These materials provide reasonable levels of pipe support once proper percent compaction is achieved.

d. Class IV Materials: These materials require a geotechnical evaluation prior to use. Moisture content must be near optimum to minimize compactive effort and achieve the required percent compaction. Properly placed and compacted, Class IV materials can provide reasonable levels of pipe support; however, these materials may not be suitable under high fills, surface-applied wheel loads, or under high-energy-level vibratory compactors and tampers. Do not use where water conditions in the trench may prevent proper placement and compaction.

2. The moisture content of embedment materials must be within suitable limits to permit placement and compaction to required levels with reasonable effort. For non-free draining soils (that is, Class III, Class IV, and some borderline Class II soils), moisture content is normally required to be held to +3% of optimum (see ASTM Test Methods D698). The practicality of obtaining and maintaining the required limits on moisture content is an important criterion for selecting materials, since failure to achieve required density, especially in the pipe zone, may result in excessive deflection. Where a chance for water in the trench exists, embedment materials should be selected for their ability to be readily
densified while saturated (that is, free-draining, cohesionless granular materials).

3. The maximum particle size for embedment is a function of the pipe diameter and wall corrugation. However, in no case should the maximum particle size exceed the ¼-inch sieve. The annular space between wall corrugation is a function of pipe diameter. Smaller diameter pipes (e.g. 10 inch to 15 inch) tend to have a small corrugated annular space as compared to larger diameter pipes (e.g. 48 inch to 60 inch). As such, to enhance placement around the corrugated plastic pipe and to completely fill the annular space between the wall corrugations so as to eliminate voids and to limit long term deflection, the designer should specify the maximum particle size as a function of pipe diameter and the annular space between the wall corrugation.

2.05 CHARACTERIZATION OF NATIVE SOIL CONDITIONS

A. Native soils must be characterized to determine their potential impact on both short and long-term pipe performance. Soil characterization to evaluate short-term implications shall be geared towards assessing the impact of native soils on the modulus of soil reaction, $E'$. Soil characterization to evaluate potential long-term implications shall be geared towards assessing the potential for migration of native soils into the embedment material or other conditions that may cause degradation of the embedment material’s performance with time.

B. Implication of Native Soils versus Embedment Material Selection

1. Short-term performance shall be evaluated to determine whether the modulus of soil reaction in design, $E'_{\text{design}}$, needs to be adjusted based on native soil conditions in accordance with Article 2.08, Sub-paragraph B.3.b.6).

2. Potential native soil impact on long-term pipe performance shall be assessed in accordance with the recommendations for matching various embedment classes to native soil conditions in Table 3.

2.06 STANDARD INSTALLATION CONFIGURATIONS

Standard installation configurations are presented on Figure 7, Figure 8, and Figure 9 in Part 3 of this Standard Practice for narrow, sub-ditch, and wide trenches.

2.07 EXTERNAL LOADS

A. The designer shall evaluate external loads in response to both dead and live loads. Based upon the specifics of the installation, the designer may be required to assess specialized loading conditions such as those noted in Article 2.07, Paragraph D.

B. Dead Load Design Requirements

1. The earth load from fill over the pipe shall be calculated based on the prism load as determined by:

$$W_D = \gamma H B_c$$

(1)

where:
\[ W_D = \text{earth load (lb/ft)} \]
\[ \gamma = \text{backfill unit weight (lb/ft}^3) \]
\[ H = \text{height of cover (ft)} \]
\[ B_c = \text{width of pipe (ft)} \]

2. The minimum backfill unit weight for use in design shall be 120 lb/ft\(^3\). Should an engineered backfill be utilized with unit weights markedly higher or lower than this value, the designer shall review the specifics of the material’s long-term performance characteristics with the Approving Authority to seek approval for use of alternate design values.

C. Minimum Live Load Requirements

1. Minimum live load requirements shall be the live load generated by the HL-93 Highway Load as defined by AASHTO LRFD Bridge Design Specifications. Where warranted based on traffic volumes, sewer alignment, and the nature of the traffic route, the designer shall review the possible impact of dual or passing HS-20 loads.

2. Where pipes cross or could be impacted by railway loads, live loads shall be estimated based on the AREMA designated Cooper E-series loads. The minimum live load for consideration in design shall be a Cooper E-80 live load, unless the Approving Authority indicates that a greater live load needs to be accommodated.

3. Requirements for aircraft or other live loads shall be as required by Approving Authority in each specific design.

4. Minimum cover (depth of backfill above top of pipe) shall be at least 24 in. or one pipe diameter, whichever is larger, for Class IA and IB embedment, and a cover of at least 36 in. or one pipe diameter, whichever is larger, for Class II and III embedment.

D. Special Design Considerations

1. The designer shall note that the primary design checks articulated in this Standard Practice relate to dead and live loads acting on a single conduit in a variety of conventional trench configurations.

2. In design, there can exist several conditions that warrant special consideration as unique design conditions that are beyond the scope of the design checks suggested by Article 2.08. This could include:
   a. Shallow Parallel Pipes Subjected to Heavy Surface Loads: Where buried pipes are installed in parallel as illustrated in Figure 3 below, the principles of analysis for single pipes still apply. The design of parallel pipes, however, subjected to heavy surface loads requires additional analysis to determine minimum cover requirements. The designer should consult a suitable reference to conduct this analysis such as the analytical technique proposed by Moser\(^9\).

---

b. Parallel Trenches: Where a parallel trench is cut adjacent to an in-place flexible pipe, the width of sidefill soil beside the flexible pipe should be reviewed to ensure that it is sufficiently thick to maintain adequate side support for the pipe (see Figure 4). A suitable analytical technique for this analysis is presented in Moser\textsuperscript{10}.

Figure 4 – Vertical Trench Parallel to Flexible Pipe Initiating Active Soil Wedge

c. Sloped Trench Walls: Where sloped trench walls are cut adjacent flexible pipes at deeper heights of cover (see Figure 5), the pipe ring stiffness should be reviewed to determine that it is sufficient to withstand the resulting pressure distribution that is imposed upon the pipe. A suitable analytical technique is presented in Moser\textsuperscript{11}.

d. Longitudinal Bending, Support Spacing, and Thermal Contraction and Expansion

1) Longitudinal Bending: Where flexible pipe is required by design to be subjected to horizontal alignment modifications without the use of bends, deflection typically occurs as a result of longitudinal pipe bending as opposed to individual joint offsets. Where the designer or installer intends to accomplish horizontal offsets in this manner they should review the analytical method and performance limitations of the specific products in use.

2) Support Spacing: In buried applications, a flexible pipe's strength in longitudinal bending is rarely a performance limiting design feature. Where flexible pipe is required to be supported either temporarily or in permanent free span installations such as pipe installed within encasement pipes, its strength in longitudinal bending must be reviewed in greater detail. This is particularly true for some profile wall configurations that provide equivalent strength in terms of equivalent ring stiffness to solid wall products but markedly lower strength in longitudinal bending.

3) Thermal Contraction and Expansion: Flexible thermoplastic materials have markedly higher coefficients of thermal contraction and expansion than most rigid pipe materials. This is particularly true for thermoplastics such as HDPE. To avoid damage to the overlying pavement, minimum cover over the thermoplastic pipe should be 2 feet or one-half the pipe diameter, whichever is greater.

2.08 SPECIFIC DESIGN APPROACH
A. Design Objective

1. While deflection is required in flexible pipe installations to transfer overburden load to the adjacent soils, deflection must be controlled within tolerable limits to meet both structural and functional requirements for the pipe installation. Controlling deflection to acceptable levels will:
   a. Avoid reversal of curvature
   b. Limit bending and strain
   c. Avoid pipe flattening
   d. Maintain hydraulics
   e. Maintain hydrostatic integrity at joints

2. Controlling deflection will be a function of the load, pipe stiffness, and soil stiffness. In practice, deflection can be controlled to within acceptable limits with:
   a. Proper material selection (both pipe and embedment material)
   b. Proper construction techniques

3. While the designer has limited control over the use of proper construction techniques, he can have a greater assurance that his design will be successfully implemented in practice by ensuring that the design is practical and achievable with adherence to normal good pipe installation practices. Any design that requires the use of specialized materials or an unusual level of installer effort to assure success should have those additional requirements clearly articulated to the installer as an output of the design process, to ensure that the installer can make the appropriate adjustments to their normal construction method(s).

B. Deflection and Deflection Limits

1. The design long term deflection (i.e. reduction of the internal pipe diameter) or "final" deflection due to earthen backfill, surcharge and live load shall not exceed 5%.

2. Allowable deflection limits for specific pipe materials shall be measured as indicated in Appendix A, which incorporates the appropriate allowances for out-of-roundness and other manufacturing tolerances permitted by this Standard Practice.

3. Modified Iowa Formula – Horizontal Deflection
   a. The modified Iowa formula in the following form shall be used to estimate horizontal deflection:

   \[ \frac{\Delta x}{d} \text{ (%) } = \frac{100D_k K P}{0.149 (PS) + 0.061 E'} \]  

   where:

   \[ \Delta x = \text{ horizontal deflection of pipe (in.)} \]
\[ d = \text{diameter of un-deformed pipe (in.)} \]

\[ D_L = \text{deflection lag factor} \]

\[ K = \text{bedding factor (see Table 6)} \]

\[ P = \text{vertical pressure on the pipe (lb/in.)} \]

\[ PS = \text{pipe stiffness (lb/in./in.)} \]

\[ E' = \text{horizontal modulus of soil reaction (psi)} \]

b. Additional information on the properties involved in the modified Iowa formula is provided below:

1) Deflection Lag Factor, \( D_L \): A deflection lag factor of 1.0 shall be used for Class I and II soils and DL of 1.5 shall be used for class III and IV soils where long-term loading has been estimated based on prism load theory.

2) Bedding Factor, \( K \): A bedding factor of 0.10 shall be utilized in design, for all standard installation configurations specified herein. This is based on the assumption that bedding angles of 60 to 75 degrees are readily achievable in practice with adherence to good pipe installation practices.

3) External Load, \( P \)
   a) External loads shall be estimated as detailed in Article 2.07 for the appropriate dead and live loading condition.
   b) For use in the modified Iowa formula, dead and live loads shall be converted to the equivalent overburden pressure acting over the pipe in pounds per linear inch as follows:

\[
P = \frac{W_D + W_L}{12}
\]

where:

\[ W_L = \text{live load (lb/ft)} \]

4) Pipe Stiffness, \( PS \)
   a) Pipe stiffness shall be the load required to deflect the pipe to 5% deflection as measured in an ASTM D2412 parallel-plate loading test. The pipe stiffness value is calculated by dividing the force per unit length by the deflection (lbs per inch of deflection per inch of length (lbs/in/in)). While these values are commonly reported in units of pounds per inch\(^2\) (psi), the values do not represent an equivalent resisting force and should not be construed as such.
   b) The minimum \( PS \) required by this Standard Practice is 46 psi.
   c) Optimally, a pipe stiffness of 46 lbs/in/in should be utilized (See Commentary). However, many HDPE corrugated
drainage pipes are not provided with pipe stiffnesses this high. If lower pipe stiffness materials are used the designer should exercise considerable caution, carry out all necessary design checks, and carefully consider all contributing factors that may impact pipe-soil interaction. It would be prudent if using pipe materials with less than 46 psi $PS$, to employ only Class I embedment material.

d) In carrying out analytical checks for pipes with $PS$ values less than 46 psi, the designer should note that the analytical model proposed herein may no longer be valid as experimental load cell tests have shown markedly greater observed vertical deflection for pipe products with lower $PS$ values.

5) Modulus of Soil Reaction, $E'$ (Embedment Soils)

a) The values for modulus of soil reaction for embedment soils may be estimated based upon a direct substitution of the one-dimensional constrained soil modulus, $M_o$, for $E'$. The values published by McGrath and incorporated into Section 12 of the AASHTO LRFD Bridge Design Specifications have been reproduced in Table 4 below. These values may be utilized in design subject to the cautionary notes below.

Table 4 – $E'$ Values$^a$ for Embedment Soil Based on McGrath

<table>
<thead>
<tr>
<th>Height of Cover$^b$</th>
<th>Class I and II Embedment</th>
<th>Class III Embedment</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>95% SPD</td>
<td>90% SPD</td>
</tr>
<tr>
<td>3 - 6 ft</td>
<td>2,000</td>
<td>1,300</td>
</tr>
<tr>
<td>&gt;6 - 13 ft</td>
<td>2,600</td>
<td>1,500</td>
</tr>
<tr>
<td>&gt;13 - 26 ft</td>
<td>3,000</td>
<td>1,600</td>
</tr>
</tbody>
</table>

$^a$ $E'$ values are provided in units of psi, rounded to the nearest 100.

$^b$ Use $E'$ values for 13 – 16 ft of cover for all heights of cover greater than 26 ft.

b) The following commentary is provided to the designer in terms of selection of appropriate design values from the above table:

- In practice, consistently obtaining densities higher than 90% is very difficult to achieve with the use of Class III materials (standard bedding sand with greater than 12% fines). Where greater values are required to facilitate design, the designer is encouraged to review the feasibility of utilizing a higher standard of embedment material to achieve a more practical, readily achievable design for the installer.
• In practice, it is very difficult to consistently achieve densities of 95% or higher, even with the use of the highest embedment materials available (Class I and II). Further, it would be wise to advise the installer in all circumstances where densities greater than 90% are required by design and to limit embedment materials to Class I quality in these cases.

• The designer is further advised to exercise caution for any construction to be carried out under winter conditions, as the use of frozen embedment materials can preclude achieving any of the density values noted irrespective of the level of compactive effort exercised due to the difficulties in generating free moisture in the embedment material under winter construction conditions.

c) Influence of Native Soils (Determining Composite $E'$ Values)

• The $E'$ value to be utilized in design shall be a composite $E'_{design}$ value, based upon the $E'_{b}$ of the embedment material as indicated in Article 2.08, Sub-paragraph B.3.b.5) and the designer’s understanding of both native soil conditions, $E'_{native}$ and specified trench width.

• $E'_{native}$ values can be estimated based upon Table 5 below.

### Table 5 – $E'_{native}$ for Various Native Soil Conditions\(^{12}\)

<table>
<thead>
<tr>
<th>Granular</th>
<th>Cohesive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>SPT (Blows / ft)(^{b})</strong></td>
<td><strong>Description</strong></td>
</tr>
<tr>
<td>&gt;0 - 1</td>
<td>very, very loose</td>
</tr>
<tr>
<td>1 - 2</td>
<td>very loose</td>
</tr>
<tr>
<td>2 - 4</td>
<td>0.25 - 0.50</td>
</tr>
<tr>
<td>4 - 8</td>
<td>loose</td>
</tr>
<tr>
<td>8 - 15</td>
<td>slightly loose</td>
</tr>
<tr>
<td>15 - 30</td>
<td>compact</td>
</tr>
<tr>
<td>30 - 50</td>
<td>dense</td>
</tr>
<tr>
<td>&gt; 50</td>
<td>very dense</td>
</tr>
</tbody>
</table>

\(^{A}\) The modulus of soil reaction $E'_{native}$ for rock is $\geq 50,000$ psi.

\(^{b}\) Standard penetration test per ASTM D1586.

• The designer shall determine an $E'_{\text{design}}$ based upon the combined interaction of the embedment soils specified, the native soils anticipated, and the specified trench width. The value for $E'_{\text{design}}$ shall be determined from the expression:

$$E'_{\text{design}} = S_c E'_b$$

and $S_c$ is determined by:

$$S_c = \frac{1.667}{\Delta f + (1.667 - \Delta f) \frac{E'_b}{E'_n}}$$

and $\Delta f$ is determined by:

$$\Delta f = \frac{\left(\frac{E_d}{E_c} - 1\right)}{[0.982 + 0.283 \left(\frac{E_d}{E_c} - 1\right)]} < 1.667$$

where:

- $S_c$ = Leonhardt correction factor
- $E'_b$ = modulus of soil reaction of the pipe embedment (psi)
- $E'_n$ = modulus of soil reaction of the native soil at pipe springline (psi)
- $B_d$ = trench width at pipe springline (ft)
- $B_c$ = pipe diameter at springline (ft)

4. Calculation of Vertical Deflection
   
a) Computed values for horizontal deflection shall be converted to vertical deflection based on Masada's\(^{13}\) integration of the modified Iowa formula in the following form:

$$\left| \frac{\Delta y}{\Delta x} \right| = \left| \left( \frac{J}{K} \right) + \left[ 0.0595 + 0.061 \left( \frac{J}{K} \right) \right] \frac{E'}{0.149 \ (PS)} \right|$$

where:

The value for \( J \) in the above expression is directly related to the bedding angle and bedding factor. As previously noted, bedding angles of 60 - 75 degrees are readily achievable with standard construction practice and would normally be recommended for use in design.

c) \( J \) can be calculated directly using the following equation:

\[
J = -0.434 + 0.25\alpha + 0.318 \cos \alpha + \frac{0.08\alpha}{\sin \alpha} + \frac{0.167(\cos \alpha - 1)}{\sin \alpha} - \frac{\sin 2\alpha}{\sin \alpha} (0.04 + 0.125 \sin \alpha) + \sin \alpha (-0.25 + 0.159 \alpha + 0.333 \cos \alpha)
\]

where:

\[\alpha = \text{angle (see Figure 2) equal to one-half the bedding angle (radians)}\]

C. Strain Limits

1. Strain as described herein is total circumferential strain, which is comprised of bending strain, ring compression strain, hoop strain due to internal pressure, and strain due to Poisson’s effect. In gravity sewer applications, bending strain should be combined with ring compression strain and compared to the allowable compression and tension limits. The allowable strain limits are as shown in the table below.

<table>
<thead>
<tr>
<th>HDPE Pipe Strain Limits</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tension</td>
</tr>
<tr>
<td>5.0%</td>
</tr>
</tbody>
</table>

2. Bending strain shall be calculated as follows:

\[
\varepsilon_{bi} = SF D_f \left( \frac{e_i}{r} \right) 0.05 \quad \text{For strain at inner surface}
\]

\[
\varepsilon_{bo} = SF D_f \left( \frac{e_o}{r} \right) 0.05 \quad \text{For strain at outer surface}
\]

and \( D_f \) is determined by:
$$D_f = \frac{3.33 RS + 0.00136}{1.1 RS + 0.000151} \quad (10)$$

and $RS$ is determined by:

$$RS = \frac{E_{50} I}{D_m^3 M_s} \quad (11)$$

where:

- $SF$ = safety factor = 1.5
- $D_f$ = shape factor
- $c_i$ = distance from the neutral axis of the profile to the inner wall surface (in.)
- $c_o$ = distance from the neutral axis of the profile to the outer wall surface (in.)
- $r$ = radius of pipe (in.)
- 0.05 = allowable deflection ratio
- $RS$ = pipe-soil stiffness ratio
- $E_{50}$ = long term (50-year) modulus of elasticity of the plastic (psi)
- $I$ = moment of inertia of pipe wall cross-section per unit length (in.$^4$/in.)
- $D_m$ = mean diameter of pipe (in.)
- $M_s$ = constrained soil modulus (psi)

3. Wall Crushing
   a. Wall crushing describes the condition of localized yielding for a ductile material or cracking failure for brittle materials. The performance limit for HDPE pipe is reached when the in-wall stress reaches a maximum value of 900 psi for a 50-year design life. For installations where the applied loads are short term, the allowable stress may be adjusted based on the application of an appropriate time-dependent modulus for a strain level of 4.1% as established in Table XXX. Ring compression stress is the primary contributor to this performance limit, where:

$$\text{Ring Compression} = \frac{P D}{2 A} \quad (12)$$

where,

- $D$ = diameter of pipe (in.)
- $A$ = actual area of pipe wall (in.$^2$/ft)

b. However, wall crushing can also be influenced by bending stresses, where:

$$\text{Bending Stress} = \frac{M t}{2 I} \quad (13)$$

where,
\[ M = \text{bending moment per unit length (lb*in./in.)} \]
\[ t = \text{pipe wall thickness (in.)} \]

c. Thus, the total compression stress for wall crushing should include ring compression plus bending compression.

4. General Wall Buckling: Long term critical buckling stress shall be checked using the following equation:

\[
 f_{cr} = 9.24 \left( \frac{R}{A} \right) \sqrt{\frac{B M_s E_{50} I}{0.149 R^3}} 
\]

(14)

where:

\[ B = 1 - \frac{0.33 H_w}{H} \]

(15)

and,

\[ f_{cr} = \text{critical buckling stress (psi)} \]
\[ R = \text{effective radius of pipe (in.)} \]
\[ H_w = \text{height of water surface above top of pipe (ft)} \]

PART 3: CONSTRUCTION

3.01 GENERAL

A. The soil-flexible thermoplastic pipe system shall be in configurations that conform to the requirements of Figure 7, Figure 8, and Figure 9, the criteria and design concepts presented in Parts 1 and 2, and to the line and grade designated on the plans and the Standard Specifications.
Figure 7 – Typical Trench Not Under Pavement
Figure 8 – Typical Trench Under Pavement

Figure 9 – Wide Trench
B. Owners are advised to provide for, or require, adequate inspection of the pipe installation at the construction site.

3.02 SAFETY

Safety requirements for construction shall be in accordance with the applicable federal, state, and local standard regulations.

3.03 EXCAVATION

A. The maximum earth load on flexible pipes results from the consolidated prism of soil directly over the pipe, which has been considered in design by this Standard Practice.

B. The load on the pipe will not increase beyond these values with increasing trench width. The installer, therefore, shall construct the trench as wide as is dictated by practical and economic considerations, but in all cases wide enough to permit proper placement of the material in the embedment zone.

3.04 TRENCH CONSTRUCTION

A. General

1. Standard OSHA construction practices requires all excavations and trenches to be designed and constructed so as to protect employees from cave-ins by adequate protective systems. Trench excavations that are 5 feet in depth or made in entirely of stable rock are exempt provided site soil conditions warrant such. Trench construction necessitates the use of supported, or unsupported trench walls, or combination thereof in variations of narrow, benched, wide or sloped trench configurations. Excavations exceeding 20 feet in depth must be designed and certified by an Engineer.

2. Per OSHA 1926.652, unsupported trenches include:
   a. Sloped Trench: Trench walls having a slope no greater than 1 ½ horizontal to 1 vertical dependent upon site soil conditions.
   b. Benched Trench: Trench wall is stepped along a maximum slope no greater than ¾ horizontal and 1 vertical dependent upon site soil conditions.

3. Per OSHA 1926.652 supported trenches involve the construction of either narrow vertical-walled trenches or sub-ditch trenches with the appropriate movable sheeting, trench boxes, shields, or other protective apparatus in place to facilitate construction and protection of employees.

4. For the purposes of this guide document, a wide trench is defined as any trench whose width at the top of the pipe measures wider than 5 pipe diameters. By inference, all trenches less than 5 pipe diameters are narrow trenches. From a practical perspective, the influence of native soils on embedment soils diminishes rapidly at trench widths beyond 3 pipe diameters. Installers should review Part 2 of this Standard Practice to gain an appreciation for conditions under which native soils may impact embedment soils in a deleterious manner.
B. Narrow, Unsupported Vertical-walled Trenches
   1. Where site conditions and safety regulations permit, the trench may be constructed as a narrow, unsupported vertical-walled trench. The width of trench under these conditions shall be the minimum required for a worker to safely place and compact material within the embedment zone in accordance with the specified installation requirements and the compaction equipment and methods required to achieve the specified embedment densities.

   2. The installer should note that the embedment soil support in all narrow trench installations is impacted by native soil characteristics. At trench widths less than 3 pipe diameters, native soil characteristics have an increasingly significant impact on embedment soil support (see Part 2). The installer, therefore, should pay particular attention to the designer of records design assumption for native soils in all narrow trench installations and report soils at variance with the design assumptions to the Engineer in a prompt manner to determine what design modifications, if any, are required to be implemented.

C. Unsupported Sub-ditch Trenches
   1. Sub-ditch trenches are variations of the narrow vertical wall trenches, where the vertical-walled portion above the pipe has been back-cut or sloped. The minimum width of the lower trench for sub-ditch trenches shall conform to the requirements of Article 3.04, Sub-paragraph B.1.

   2. The installer should note that sub-ditch trenches, by design, have the narrowest of trench widths within the embedment zone. Therefore, pipe performance will be significantly impacted by native soil characteristics in all sub-ditch trench applications. As noted in Article 3.04, Sub-paragraph B.2, the installer shall promptly notify the Engineer in all cases where the conditions encountered are at variance with the stated design assumptions.

D. Wide Trenches (see Figure 9)
   1. Where design or field conditions dictate that a wide trench configuration be utilized the minimum width of embedment zone densification shall extend for a distance of 2.5 pipe diameters on either side of the pipe. The designer may permit a narrower width of embedment zone densification if it can be demonstrated that the composite embedment zone structure will produce acceptable pipe functional and structural behavior. In these cases the requirements for material type and density outside the embedment zone shall be clearly articulated to the installer.

   2. In instances where wide trench construction is employed, the installer is not required to inform the Engineer of native soil condition characteristics that are at variance with the design assumptions.

E. Supported Trenches
   1. Support of Trench Walls
      a. Where required based on safety regulations, field conditions, or design, the pipe shall be installed in a supported trench.

      b. Where unstable or flowing soil conditions are encountered in the trench wall, such as may be encountered in excavations below the water table
and/or in weak non-cohesive soils, the unstable soils shall be stabilized prior to proceeding with pipe installation.

c. When supports such as trench sheeting, trench jacks, trench shields, or boxes are used, ensure that support of the pipe and its embedment is maintained throughout installation. Ensure that sheeting, where required, is sufficiently tight to prevent washing out of the trench wall from behind the sheeting. Provide tight support of trench walls below existing utilities or other obstructions that restrict driving of sheeting.

2. Supports Left in Place

   a. Unless otherwise directed by the Engineer, sheeting driven into or below the pipe zone should be left in place to preclude loss of support of foundation or embedment zone material.

   b. When top of sheeting is to be cut off, make cut 20 inches or more above the crown of the pipe. Leave rangers, whalers, and braces in place as required to support cutoff-sheeting and the trench wall in the vicinity of the pipe zone.

   c. Timber sheeting to be left in place is considered a permanent structural member and shall be treated against biological degradation as necessary, and against decay if above the groundwater table. Certain preservative and protective compounds react adversely with thermoplastics, and their use should be avoided in proximity to the pipe material.

3. Movable Trench Wall Support

   a. Do not disturb the installed pipe and its embedment when using movable trench boxes and shields.

   b. Movable trench supports shall extend within 2 feet of the trench bottom (OSHA 1926.652e) while maintaining the integrity of the embedment material.

   c. Before moving supports, place and compact embedment to sufficient depths to ensure protection of the pipe. As supports are moved, finish placing and compaction of embedment material.

4. Removable Trench Wall Support

   a. Where sheeting or other trench wall supports are used within or below the pipe zone, ensure the foundation and embedment materials are not disturbed by support removal.

   b. Fill any voids left on removal of supports and compact all material to required densities.

3.05 FOUNDATION

   A. The foundation soil shall be moderately firm to hard in situ soil, stabilized soil, or compacted fill material. When unsuitable or unstable material is encountered, the foundation shall be stabilized.

   C. Where groundwater and soil characteristics may contribute to the migration of soil fines into or out of the foundation, embedment soils, sidefill, and/or backfill
materials, methods to prevent migration shall be provided. Commentary on the potential and means to preclude migration of soil fines are presented in Appendix B of this Standard Practice.

3.06 BEDDING AND INITIAL BACKFILL REQUIREMENTS

A. Verification that Proposed Construction Method is Consistent with Design Intent

1. Project specific design requirements for the in-place density of outside bedding material, haunch material, and initial backfill shall be noted on the plans or in the project specifications. As the precise measurement of these densities in-place during construction is often not technically feasible, the installer shall demonstrate to the Engineer for the project that their proposed method of placement of these materials is sufficient to achieve the specified results, through a trial compaction demonstration.

2. Should the materials proposed for use in the embedment zone change during the course of the works the installer shall notify the Engineer and carry out additional compaction trials, sufficient to demonstrate that their proposed method of placement is consistent with achieving the specified requirements.

3. The trial compaction demonstration shall in no way relieve the installer from their contractual requirement of meeting the minimum performance criteria for completed installations as specified herein.

B. Placement of Bedding Materials

1. The bedding shall be constructed as required by the project specifications and in accordance with the installer’s proposed construction method as verified in the compaction trial demonstration. Bedding shall be placed in such a manner to maximize the bedding angle achieved, to provide uniform load-bearing reaction, and to maintain the specified pipe grade.

2. The bedding layer shall be placed as uniformly as possible to the required density, except that loose, un-compacted material shall be placed under the middle third of the pipe, prior to placement of the pipe.

3. Bell holes shall be excavated in the bedding when installing pipe with expanded bells such that the barrel and not the pipe bells support the pipe.

C. Placement of Haunch and Initial Backfill Materials

1. Placement of haunching and initial backfill embedment materials shall be carried out by methods that will not disturb or damage the pipe.

2. Work in and tamp the haunching material in the area between the bedding and the underside of the pipe before placement and compaction of the remainder of the material in the embedment zone.

3. Use compaction equipment and methods that are compatible with the materials used, the location in the trench, and the in-place densities required. In addition to the requirements of the compaction trial demonstration, review commentary in Appendix B of this Standard Practice.

4. The primary purpose of initial backfill is to protect the pipe from any impact damage that may arise from the placement of overfill materials. Minimum thickness of the initial backfill layer shall be as indicated on the standard
installation drawings. In instances where overfill material contains large objects or is required to be deposited from very high heights, initial backfill shall be extended to such additional height above the pipe as is necessary to prevent damage from occurring to the pipe during backfilling operations.

5. Before using heavy compaction or construction equipment directly over the pipe, ensure that sufficient backfill has been placed over the pipe to prevent damaging either the pipe or the embedment zone materials as indicated in Artie 3.09.

3.07 CHANGE IN NATIVE SOIL CONDITIONS

A. The designer will apprise the installer of the assumed in-situ soil conditions that the design was based on. As noted in Part 2 of this standard practice, in-situ soil properties can significantly impact both short and long-term pipe performance in narrow trench and sub-ditch type trench configurations. Should a change in site conditions be observed that would result in impacting either short or long-term pipe and/or embedment soil performance, the installer shall notify the Engineer. If necessary, the design will be modified to suit the actual conditions encountered in the field.

B. Where such modifications are required, they shall be addressed as a change in site conditions and valued for payment in accordance with the requirements of the specific contract provisions for changed site conditions. Where no adjustments are required, there shall be no adjustments in contract price.

C. In all instances where the designer of record’s input is sought, it shall be provided in as expeditious a manner as possible so as to minimize the impact on construction progress.

3.08 BACKFILL (OVERFILL) MATERIALS

A. Construction of the backfill zone shall be as specified in the specific project requirements.

B. The soil shall be approved material containing no debris, organic matter, frozen material, or large stones or other object that may be detrimental to the pipe or the embedment materials. The presence of such material in the embedment may preclude uniform compaction and result in excessive localized deflections.

C. The installer shall ensure that there is sufficient cover over the pipe and embedment zone materials to facilitate all construction operations associated with the placement and compaction of overfill material.

3.09 MINIMUM COVER REQUIREMENTS FOR CONSTRUCTION LOADS

A. To preclude damage to the pipe and disturbance to the embedment zone, a minimum depth of backfill should be maintained before allowing vehicles or heavy construction equipment traverse the pipe trench.

B. The minimum depth of cover should be established by the Project Engineer based on the specific project requirements.

C. In the absence of such a detailed investigation, the installer shall meet the following minimum cover requirements before allowing vehicles or construction equipment to
traffic the trench surface, assuming that the minimum embedment zone densities are as noted in Table 3:

1. Provide minimum cover of at least 24 inches or one pipe diameter (whichever is larger) where Class I embedment materials have been utilized, or
2. Provide minimum cover of at least 36 inches or one pipe diameter (whichever is larger) where Class II or lower embedment materials have been utilized, and
3. Allow at least 48 inches of cover before using a hydro-hammer for compaction directly over the pipe, and
4. Where construction loads may be excessive (e.g. cranes, earth moving equipment, etc.) consult with the project engineer to determine minimum operating cover requirements.

3.10 CONNECTION OF FLEXIBLE PIPE TO MANHOLES

A. The installer shall use flexible water stops, resilient connectors in accordance with ASTM C923, or other flexible systems approved by the project engineer to make watertight connections to manholes and other structures.

B. The designer should review the structural requirements associated with installing flexible pipes within manholes and should ensure that sufficient manhole structure is provided to accommodate the installation of a flexible pipe.

3.11 COMPLETION OF CONSTRUCTION CRITERIA AND ACCEPTANCE TESTING

A. Vertical and Horizontal Alignment Tolerances: The pipe shall be installed to the line and grade noted on the construction drawings. Acceptance variance shall be:

1. 0.25 inch plus 0.80 inch per yard of diameter for vertical grade, and
2. Within 6 inches of the designated alignment for horizontal grade of pipes up to 36 inches in diameter or 3 inches per 12 inches of diameter of the designated alignment for pipes greater than 36 inches in diameter, and
3. No variance from grade shall be permitted which results in individual joint pulls in excess of the manufacturer’s recommended value to maintain hydrostatic integrity to the limits specified herein.

B. Infiltration/Exfiltration Limits: Elastomeric gasket joints for pipe and fittings shall meet the requirements of ASTM D3212, F477, F2487, and AASHTO PP 63-09, except that the internal hydrostatic pressure shall be 15 psi.

C. CCTV Inspection

1. All pipe up to and including 48-inch diameter shall be inspected by CCTV inspection methods.
2. All pipes larger than 48-inch diameter shall be inspected by man-entry methods. 100 percent of the pipeline shall be inspected.

D. Deflection Testing

1. Deflection testing shall be carried out in accordance with the procedures of Appendix A of this Standard Practice to confirm that the installed pipe meets
the requirements for either short or long-term deflection limits as per Article 2.08, Paragraph B and Appendix A.

2. An initial deflection test shall be carried out no sooner than 30 days after placing the final backfill, but prior to placing pavements to assess short-term deflection. A second deflection test shall be conducted no sooner than 1 year to assess long-term deflection prior to final project acceptance.
APPENDIX A: MANDREL REQUIREMENTS FOR DEFLECTION TESTING

A.01 SCOPE

Appendix A covers the technical requirements for deflection testing of flexible thermoplastic pipe installations designed and constructed in accordance with this Standard Practice.

A.02 INSPECTION METHOD

A. All pipe up to and including 36-inch diameter shall be inspected with go/no-go mandrel device as described herein. Pipe larger than 36-inch diameter shall be inspected directly with a suitable measuring device such as a tape measure to confirm that vertical deflection does not exceed either the maximum allowable short or long-term deflection limits stipulated by Article 2.08, Paragraph B.

B. The mandrel or proving device shall be pulled through the pipe by hand and in such a manner so as to ensure that excessive force is not used to advance the device through any deflected portion of the pipe.

C. The mandrel shall be cylindrical in shape, constructed with 9 or more (odd number) evenly spaced legs.

D. Mandrels larger than 18 inches in diameter shall be constructed of special breakdown devices to facilitate entry through access manholes.

A.03 TESTING FOR EXCESSIVE DEFORMATION

A. HDPE pipe shall be tested for excessive deformation. The test shall be performed by the Contractor in the presence of the Engineer. Testing shall be conducted no fewer than 30 days after the completion of all fill over the pipe.

B. The Contractor shall conduct the test by pulling a nine (or more, odd number) point mandrel through the entire length of the pipe by hand.

C. The mandrel shall meet the following requirements:
   1. It shall be made of steel or aluminum;
   2. It shall have an effective diameter of 95% of the nominal inside diameter of the pipe;
   3. It shall be at least as long as the diameter of the pipe;
   4. It shall be fitted with pulling rings at each end;
   5. It shall be stamped or engraved on some segment other than a runner with the pipe size and mandrel outside diameter.

D. Prior to testing, the Contractor shall provide the Engineer with a proving ring to verify the mandrel size.

E. The deformation is unacceptably excessive if the mandrel cannot be pulled through the pipe by hand without damaging the pipe. If the deformation is unacceptably excessive, the pipe shall be replaced without extra compensation.

F. There will be no direct payment for testing.

A.04 ACCEPTANCE TEST LIMITS
A. Mandrel or visual walk-through proving devices shall be sized to confirm that either short or long-term vertical deflection limits are not in excess of the appropriate allowance as dictated by Article 2.08, Paragraph B.

B. Deflection shall be measured versus the nominal diameter.
APPENDIX B: COMMENTARY\(^1\)

B.01 GENERAL

A. Those concerned with the service performance of a buried flexible pipe should understand factors that can affect this performance. Accordingly, key considerations in the design and execution of a satisfactory installation of buried flexible thermoplastic pipe that provided a basis for the development of this practice are given in this Appendix.

B. Sub-surface conditions should be adequately investigated prior to construction, in accordance with Practice D420, as a basis for establishing requirements for foundation, embedment and backfill materials and construction methods. The type of pipe selected should be suited for the job conditions.

B.02 LOAD / DEFLECTION PERFORMANCE

A. The thermoplastic pipes considered in this practice are classified as flexible conduits since in carrying load they deform (deflect) to develop support from the surrounding embedment. This interaction of pipe and soil provides a pipe-soil structure capable of supporting earth fills and surface live loads of considerable magnitude.

B. The design, specification and construction of the buried flexible pipe system should recognize that embedment materials must be selected, placed and compacted so that pipe and soil act in concert to carry the applied loads without excessive strains from deflections or localized pipe wall distortions.

B.03 PIPE DEFLECTION

A. Pipe deflection is the diametrical change in the pipe-soil system resulting from the process of installing the pipe (construction deflection), static and live loads applied to the pipe (load-induced deflection), and time dependent soil response (deflection lag). Construction and load induced deflections together constitute initial pipe deflection.

B. Additional time dependent deflections are attributed primarily to changes in embedment and in-situ soils, and trench settlement. The sum of initial and time dependent deflections constitutes total deflection. The analytical methods proposed in this Standard Practice are intended to limit total deflection to within acceptable limits.

C. Construction Deflection

1. Construction deflections are induced during the process of installing and embedding flexible pipe, even before significant earth and surface loads are applied. The magnitude of construction deflections depends on such factors as the method and extent of compaction of the embedment materials, type of embedment, water conditions in the trench, pipe stiffness, uniformity of embedment support, pipe out-of-roundness, and installation workmanship in general. These deflections may exceed the subsequent load-induced deflections.

2. Compaction of the side fill may result in negative vertical deflections (that is, increases in pipe vertical diameter and decreases in horizontal diameter).

3. Construction deflection of 5% shall not be exceeded when the pipe is measured at any location across its diameter. If local distortions are present, a more detailed analysis of the strain at that location shall be performed to determine if the pipe is acceptable.

D. Load-Induced Deflection: Load-induced deflections result from backfill loads and other superimposed loads that are applied after the pipe is embedded.

E. Short-term Deflection
   1. Short-term deflection is the deflection in the installed and backfilled pipe. It is the total of construction deflections and load-induced deflections determined after a sufficient portion of the long-term load has developed on the pipe.
   2. For the purposes of this Standard Practice the short-term deflection shall be total deflection as measured after a time period not shorter than 30 days after backfilling.
   3. Total short-term deflection of 3% shall not be exceed when the pipe is measured at any location across its diameter.

F. Time Dependent Factors
   1. Time dependent factors include changes in soil stiffness in the pipe embedment zone and native trench soils, as well as loading changes due to trench settlement over time. These changes typically add to the short-term deflection. The time involved varies from a few days to several years depending on soil types, their placement, and initial compaction.
   2. Time dependent factors are accounted for in this Standard Practice by adjusting acceptable short-term deflection limits by a factor of 1.5.

G. Long-term Deflection
   1. Long-term deflection is the total long-term deflection of the pipe. It consists of initial deflection adjusted for time dependent factors as noted.
   2. While acknowledging the time-dependent deflection can occur for many years, experience has shown that the vast majority of long-term deflection (typically 90% or more) has occurred after the first year of installation. Therefore, for the purposes of this Standard Practice, the long-term deflection shall be considered to be any deflection measured one year or later after backfilling.
   3. Total long-term deflection of 5% shall not be exceeded when the pipe is measured at any location across its diameter.

B.04 DEFLECTION CRITERIA

A. Deflection criteria are the limits set for the design and acceptance of buried flexible pipe installation.

B. Deflection limits for specific pipe systems may be derived from both structural and practical considerations.
1. Structural considerations include pipe cracking, yielding, strength, strain, and local distortion.

2. Practical considerations include such factors as flow requirements, clearance for inspection and cleaning, and maintenance of joint seals.

C. Acceptable short and long-term deflection limits are presented for all pipes addressed by this Standard Practice in Appendix A.

B.05 DEFLECTION CONTROL

A. Embedment materials should be selected, placed, and compacted to minimize total deflections and maintain installed deflections within specific limits.

B. Methods of placement, compaction, and moisture control should be selected based on soil types given in Table 2 of Part 2 of this Standard Practice and on recommendations given in Table 3 of Part 2 of this Standard Practice.

C. The amount of load-induced deflection is primarily a function of the stiffness of the pipe and soil embedment system. Other factors that are important in obtaining deflection control are outlined below.

1. Embedment at Pipe Haunches
   a. Lack of adequate compaction of embedment material in the haunch zone can result in excessive deflection, since it is this material that supports the vertical loads applied to the pipe. It may also result in local distortions in the bottom of the pipe.
   b. A key objective during installation of flexible thermoplastic pipe is to work in and compact embedment material under pipe haunches, to ensure complete contact with the pipe bottom, and to fill voids below the pipe.

2. Embedment Density
   a. Embedment density requirements should be determined by the engineer based on deflection limits established for the pipe, pipe stiffness, and installation quality control, as well as the characteristics of the in-situ soil and compatibility characteristics of the embedment materials used.
   b. The minimum densities given in Table 3 are based on attaining an average modulus of soil reaction ($E'$) of greater than 1000 psi, except under special circumstances where Class IV embedment material is used.
   c. Where higher modulus of soil reaction values are required, the designer should refer to Table 4 as well as making the appropriate adjustments if necessary to account for the impact of native soils that may have modulus values lower than the proposed embedment soils.

B.06 COMPACITION METHODS
A. Achieving desired densities for specific types of materials depends on the methods used to impart compactive energy. Coarse-grained, clean materials such as crushed stone, gravels, and sand are more readily compacted using vibratory equipment, whereas fine materials with high plasticity require kneading and impact force along with controlled water content to achieve acceptable densities.

B. In pipe trenches, small, hand-held or walk-behind compactors are required, not only to preclude damage to the pipe, but to ensure thorough compaction in the confined areas around the pipe and along the trench wall. As examples, vibratory plate tampers work well for coarse grained materials of Class I and Class II, whereas hand tampers or air driven hand-held impact rammers are suitable for the fine-grained, plastic groups of Class III and IV.

C. Gas or diesel powered jumping jacks or small, walk-behind vibratory rollers impart both vibratory and kneading or impact force, and hence are suitable for most classes of embedment and backfill material.

B.07 MIGRATION

A. When coarse and open-graded material is placed adjacent to a finer material, fines may migrate into the coarser material under the action of hydraulic gradient from ground water flow. Significant hydraulic gradients may arise in the pipeline trench during construction when water levels are being controlled by various pumping or well-pointing methods, or after construction when permeable under drain or embedment materials act as a French drain under high ground water levels.

B. Field experience shows that migration can result in significant loss of pipe support and continuing deflections that may exceed design limits. The gradation and relative size of the embedment and adjacent materials must be compatible in order to minimize migration (see Article B.07, Paragraph D below). In general, where significant ground water flow is anticipated, avoid placing coarse, open-graded materials, such as Class I, above, below, or adjacent to finer materials, unless methods are employed to impede migration such as the use of an appropriate stone filter or filter fabric along the boundary of the incompatible materials.

C. To guard against loss of pipe support from lateral migration of fines from the trench wall into open-graded embedment materials, it is sufficient to follow the minimum embedment width guidelines in Article B.09.

D. The following filter gradation criteria may be used to restrict migration of fines into the voids of coarser material under a hydraulic gradient:

1. \( D_{15}/d_{85} < 5 \) where \( D_{15} \) is the sieve opening size passing 15% by weight of the coarser material and \( d_{85} \) is the sieve opening six passing 85% by weight of the finer material.

2. \( D_{50}/d_{50} < 25 \) where \( D_{50} \) is the sieve opening size passing 50% by weight of the coarser material and \( d_{50} \) is the sieve opening size passing 50% by weight of the
finer material. This criterion need not apply if the coarser material is well-graded (see Test Method D 2487).

3. If the finer material is a medium to highly plastic clay without sand or silt partings (CL or CH), then the following criterion may be used in lieu of Article B.07, Sub-paragraph D.1: \( D_{15} < 15\% \) by weight of the coarser material.

4. Materials selected for use based on filter gradation criteria, such as in Article B.07, Paragraph D, should be handled and placed in a manner that will minimize segregation.

B.08 MAXIMUM PARTICLE SIZE

A. Limiting particle size to 0.8 inch or less enhances placement of embedment material for nominal pipe sizes 8 inch through 15 inch.

B. For smaller pipe, a particle size of about 10\% of the nominal pipe diameter is recommended.

B.09 EMBEDMENT WIDTH FOR ADEQUATE SUPPORT

A. In certain conditions, a minimum width of embedment material is required to ensure that adequate embedment stiffness is developed to support the pipe. These conditions arise where in-situ lateral soil resistance is negligible, such as in very poor native soils (for example, peat, muck, or highly expansive soils) or along highway embankments.

B. Under these conditions, for small diameter pipe (12 inch or less), embedment should be placed and compacted to a point at least 2.5 pipe diameters on either side of the pipe.

C. For pipe larger than 12 inch, the engineer should establish the minimum embedment width based on an evaluation of parameters such as pipe stiffness, embedment stiffness, nature of in-situ soil, and magnitude of construction and service loads.

B.10 OTHER DESIGN AND CONSTRUCTION CRITERIA

A. The design and construction of the pipe system should recognize conditions that may induce excessive shear, longitudinal bending, or compression loading in the pipe.

B. Live loads applied by construction and service traffic may result in large, cumulative pipe deflections if the pipe is installed with a low-density embedment and shallow cover.

C. Other sources of loads on buried pipes are: freezing and thawing of the ground in the vicinity of the pipe, rising and falling ground water table levels, hydrostatic pressure due to ground water, and localized differential settlement loads occurring next to structures such as manholes and foundations.
D. Where external loads are deemed to be excessive, the pipe should be installed in casing pipe or other load limiting structures.

*** END OF STANDARD PRACTICE ***
Commentary
C1.04.A In the AASHTO LRFD Bridge Design Specifications, the vertical deformation is based on the bending deflection roughly following the Spangler method, while incorporating additional vertical deformation from hoop compression of the pipe. This document treats deflection a little differently than the AASHTO Specifications. It acknowledges that Spangler’s deflection equation is for horizontal deflection, and incorporates the correction factor from Masada to develop the vertical deflection. Answers from the two different methods may not necessarily agree. The critical item to note, is that merely using the basic deflection equation by Spangler will under-predict the vertical field deflection.

C1.04.B When determining the loads to be used for the calculation of strain in the pipe, this specification utilizes the Spangler loads, while the AASHTO LRFD Bridge Design Specifications reduce the soil loads below prism load based on the assumption that the hoop compression of the pipe causes it to shrink away from the soil and reduce the load.

C1.04.D AWWA Manual of Practice M45 is for Fiberglass Pipe Design. This practice took the original equations for determining a combined soil modulus, as determined by Leonhardt, and put the values in tabular form. The tabular values are typically less conservative than if the actual equations are used. Both options will be discussed later in this commentary.

C2.03B ASTM D3350, “Standard Specification for Polyethylene Plastics Pipe and Fitting Materials” is a standard for designating and testing the material properties of plastics used in the pipe. It is not a standard for the production of the finished pipe.

Table 1 of this document requires that the profile and the liner be made of resins with the same material properties.

There are six digits in the cell classification system of D3350. They represent the following:

- The first digit represents the density of the resin. This standard has a designation of “3”, whereas AASHTO M294 designates a “4”, which is a slightly higher density (>0.947 – 0.955 g/cm³) versus (>0.940 – 0.947 g/cm³). Higher densities are associated with higher strengths, but also more brittle material.

- The second digit represents the melt index. This standard has a designation of “2”, whereas AASHTO M294 designates a “3”, which is a slightly lower melt index (1 to 0.4) versus (<0.4 to 0.15).

- The third digit represents the flexural modulus. This standard has a designation of “4”, whereas AASHTO M294 designates a modulus of “5”, (80,000 to 110,000 psi) versus (110,000 to < 160,000).

- The fourth digit represents the tensile strength of the resin. This standard, and AASHTO M294 both have a designation of “4” (3,000 to < 3500 psi). This is the short-term strength of the time-dependent material.

- The fifth digit represents the testing requirements for slow-crack growth. This standard uses a designation of “3”, while AASHTO M294 uses a designation of “0”. The “3” designation requires the resin to be tested for 192 hours following ASTM D1693. AASHTO uses the “0” designation because the producers of HDPE drainage pipe wanted to get away from the standard test methods for slow-crack growth and develop a different test where they could control the requirements. Instead of referencing
one of the test methods designated in ASTM D3350, they use ASTM F2136, which they developed specifically for their pipe. Prior to getting AASHTO to agree to F2136, they utilized D1693 with a testing time of 24 hours. Thus, there has never been an AASHTO M294 pipe that could meet a “3” designation, although stress crack resistance is considered a key component in a reliable thermoplastic pipe.

The sixth digit is for the hydrostatic strength designation. This standard uses a designation of “2”, which requires that the pipe material be tested for a long-term hydrostatic design strength of 1,000 psi. HDPE pipe producers used the argument that gravity pipe is not the same as pressure pipe to convince AASHTO to eliminate this testing requirement from their cell class by using a designation “0”. Interestingly enough, although the long-term strength of AASHTO M294 pipe is not tested, the AASHTO LRFD Bridge Design Specifications utilize a long-term design strength of 900 psi, as a rough correlation to what a designation of “2” would give them.

C2.07B This standard utilizes the soil prism load for all the soil design limit states for which the pipe is analyzed. The AASHTO LRFD Bridge Designs Specifications utilizes the soil prism load for the service load deflection calculation, but uses a reduced load for evaluating the ultimate load conditions of thrust, strain, and buckling. While AASHTO assumes that HDPE pipe is so weak that it compresses and thereby shrinks away from the load, this standard assumes that the reduction in pipe strength as it compresses only exacerbates the problem, and the soil load will not reduce as quickly as the pipe stiffness.

The use of a soil pressure below the soil prism load in AASHTO generally results in higher allowable fill heights when performing an AASHTO design versus a design per this standard. Additionally, while this standard reveals the deflection criteria to be critical, deflection limits are very seldom the limiting state when performing an AASHTO design, which is not consistent with the multitude of excessive deflections seen in the field.

2.08B.3.b.2 The equation for K is shown below. When going from a bedding angle of 30 degrees to 90 degrees, the K factor only reduces from 0.107 to 0.095. Thus, in the basic deflection equation, the vertical bedding reaction has much less to do with the calculated deflection than does the lateral support from the surrounding soil. Thus, a K value of 0.1 is considered sufficient for bedding angles above 60 degrees.

\[
K = 0.5\sin(\alpha) - 0.082\sin(\alpha)^2 + 0.08\left(\frac{\alpha}{\sin(\alpha)}\right) - 0.16\sin(\alpha)(\pi - \alpha) - 0.04\left(\frac{\sin(2\alpha)}{\sin(\alpha)}\right) + 0.318\cos(\alpha) - 0.208
\]

2.08B.3.b.4 Research carried out at Utah State has shown that pipe deflection values increase considerably for installed pipes with stiffness values less than 37 psi versus pipes with higher pipe stiffness values, all other things being equal. (See Figure below). At lower pipe stiffnesses, the lateral constraint of the surrounding soil does little to reduce the vertical deflection of the pipe.
In pipe produced in accordance with AASTHO M294, only the 12-inch pipe size has a minimum stiffness equal to or greater than 46 psi. (See Figure Below) Pipe Stiffness values decrease rapidly as the size of the pipe increases, with a 60 inch pipe having a minimum required pipe stiffness of 15 lbs/in/in per ASTM D2412. The pipe stiffness per D2412 is typically what is used in Equation (2). However, the Engineer is cautioned that HDPE is a time-dependent material, and the pipe stiffness values will have a marked decrease after being subjected to constant load for one year’s time (See PS365 graph below). Thus, appropriate caution in the use of the pipe stiffness value, and selection of a deflection lag factor and applied safety factors is warranted.
2.08B.3.b.5.a The Modulus of Soil Reaction ($E'$) is a semi-empirical parameter representing the strength of the embedment soil surrounding the installed pipe. The Modulus of Soil Reaction is not a measurable stiffness, and most tables of $E'$ are based on back-calculated values from measured deflections of numerous flexible pipe installations. The constrained soil modulus ($M_s$) of a soil can be determined through testing, and has been incorporated into the deflection equation as a direct substitute for $E'$ in many standards.

Table 4 For a more detailed analysis, the $M_s$ values may be taken directly from the AASHTO table (see below) with linear interpolation for the overburden stresses between the values given in the first column.
The E’ values in Table 4 are based on the Constrained Soil Modulus values (M<sub>s</sub>) in AASHTO’s Table 12.12.3.5-1. M<sub>s</sub> and E’ values are considered equivalent, when used in the deflection equation. The E’ values in Table 4 were developed through taking the lower bound fill height in the first column, and using a unit soil weight of 120 pcf to determine an appropriate overburden pressure in which to pull the information from the AASHTO Table. For example, at 6 feet of fill, the overburden pressure would be 6 x 120 pcf = 720 psf = 5 psi. According to Table 12.12.3.5-1 from AASHTO, the M<sub>s</sub> value for a 95% compacted granular material (Sn) at this overburden pressure would be 2600 psi, which is the value given in Table 4 for 95% SPD between 6 and 13 feet. Thus, Table 4, as provided in this standard conservatively uses the lower bound values for the fill height increments, and stops at an overburden of approximately 10 psi rather than carry out the constrained soil modulus values to extremely high values.

2.0883.b.5.c Leonhardt Factor As a simplification to the Leonhardt factor, S<sub>c</sub> may be determined by interpolation of the values in Table X1 below, which is what is used in AASHTO.

Table X1 – Values of S<sub>c</sub>, Versus E’b and E’ native
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Table X1 above is directly taken from AWWA Manual M45, Fiberglass Pipe Design Manual. It is a simplified tabular form of Leonhardt Factor for a composite $E'$. For comparison purposes, an exact Leonhardt factor table is included below.

**Leonhardt Factor**

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<td>0.236</td>
<td>0.41</td>
<td>0.649</td>
<td>0.806</td>
<td>0.917</td>
<td>1</td>
</tr>
<tr>
<td>0.6</td>
<td>0.331</td>
<td>0.526</td>
<td>0.748</td>
<td>0.87</td>
<td>0.947</td>
<td>1</td>
</tr>
<tr>
<td>0.8</td>
<td>0.866</td>
<td>0.936</td>
<td>0.975</td>
<td>0.989</td>
<td>0.996</td>
<td>1</td>
</tr>
<tr>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
<td>1</td>
</tr>
</tbody>
</table>

A graphical representation of the Leonhardt Factor is included below.
2.08B.4 The Modified Iowa Equation was developed for the calculation of the horizontal deflection of flexible pipe products. In initial evaluations, using flexible pipe with higher pipe stiffnesses, such as steel pipe, little difference was seen between horizontal and vertical deflections. However, subsequent research on the flexible pipes now allowed by AASHTO and ASTM with much lower pipe stiffnesses, has shown that the vertical deflection can be significantly higher than the horizontal deflection if the pipe is too weak to push out into the soil horizontally. Equation 7, is taken from an analysis performed by Dr. Masada from the University of Ohio.
Table 6: Values of J versus K

<table>
<thead>
<tr>
<th>Bedding Angle (degrees)</th>
<th>K</th>
<th>J</th>
<th>J/K</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.1100</td>
<td>-0.1160</td>
<td>-1.0545</td>
</tr>
<tr>
<td>15</td>
<td>0.1092</td>
<td>-0.1152</td>
<td>-1.0549</td>
</tr>
<tr>
<td>30</td>
<td>0.1075</td>
<td>-0.1129</td>
<td>-1.0502</td>
</tr>
<tr>
<td>45</td>
<td>0.1050</td>
<td>-0.1095</td>
<td>-1.0429</td>
</tr>
<tr>
<td>60</td>
<td>0.1020</td>
<td>-0.1054</td>
<td>-1.0333</td>
</tr>
<tr>
<td>75</td>
<td>0.0986</td>
<td>-0.1010</td>
<td>-1.0243</td>
</tr>
<tr>
<td>90</td>
<td>0.0951</td>
<td>-0.0966</td>
<td>-1.0158</td>
</tr>
<tr>
<td>105</td>
<td>0.0919</td>
<td>-0.0927</td>
<td>-1.0087</td>
</tr>
<tr>
<td>120</td>
<td>0.0890</td>
<td>-0.0893</td>
<td>-1.0034</td>
</tr>
<tr>
<td>135</td>
<td>0.0868</td>
<td>-0.0865</td>
<td>-0.9965</td>
</tr>
<tr>
<td>150</td>
<td>0.0852</td>
<td>-0.0846</td>
<td>-0.9930</td>
</tr>
<tr>
<td>165</td>
<td>0.0844</td>
<td>-0.0837</td>
<td>-0.9917</td>
</tr>
<tr>
<td>180</td>
<td>0.0843</td>
<td>-0.0829</td>
<td>-0.9834</td>
</tr>
</tbody>
</table>

Incorporating Equation 7 with the assumption that J/K = -1 results in the simplified form of:

\[ C_f = \left| \frac{\Delta y}{\Delta x} \right| \]

\[ C_f = 1 + \frac{0.0094M_s}{PS} \]

Where:

\[ C_f = \text{Factor to correct horizontal deflection into vertical deflection} \]

As an example of the significant difference between horizontal and vertical deflections for a 48-inch plastic pipe with a pipe stiffness of 30 psi installed in a soil with a constrained soil modulus of 1,580 psi (granular soil with 90% compaction at 10 feet of fill) the resulting correction factor would be:

\[ C_f = 1 + \frac{0.0094(1580)}{30} = 1.5 \]

In other words, the vertical deflection would be 50 percent more than the horizontal deflection in a 48-inch pipe installed 10 feet deep with granular material.

The AASHTO LRFD Bridge Design Specifications do not incorporate a correction factor for vertical versus horizontal deflection. However, AASHTO incorporates an additional term in the deflection equation to...
account for the pipe experiencing hoop compression. Using the AASHTO design method, and following the example above, if the horizontal deflection is calculated for the 48-inch pipe at 10 foot of cover with 95% compaction of a granular material, it would be approximately 1.6%. If the hoop compression term in AASHTO is incorporated, it would add an additional vertical deflection of 1.8%, resulting in a total deflection of 3.4%. Whereas the deflection calculated using this standard would be 1.6 x 1.5 = 2.4% vertical deflection.

However, the above comparison is based on the short-term pipe stiffness, which is what AASHTO promotes. Long term pipe stiffness is roughly 20 percent of the short-term stiffness. If the long-term stiffness of 6 psi is properly utilized in accordance with this standard, the vertical deflection would be 5.78%, and the pipe would not be acceptable at 10 feet of fill, unlike its acceptance by AASHTO at these conditions.

Even if the long-term pipe stiffness were to be used in the AASHTO method, it would only result in a total deflection of 3.5% since the soil modulus is the critical support in the horizontal deflection equation, and the effective area of the pipe wall is not changed. In contrast, the Cr factor is a function of the soil modulus over the pipe stiffness, and jumps from 1.5 to 3.6 when such a low pipe stiffness is used in the denominator.

The use of the long-term pipe stiffness per this standard appropriately evaluates the property of the pipe with respect to its installed condition. Additionally, the correction factor accounts for the fact that while pipe with lower pipe stiffnesses will have increased deflection vertically, they have insufficient strength to continue to push out into the much stronger soil horizontally.

2.08C.1 Strain Limits The strain limits provided in Table XXX are taken from the requirements in the AASHTO LRFD Bridge Design Specifications. There is little information elsewhere on allowable values for HDPE drainage pipe. The strain values for tension and compression are based on the general location of the stress-strain curve where the behavior of the material becomes nonlinear. The strain limit for combined compression strain from hoop compression and bending strain is 50% higher than it is for hoop compression strain alone. AASHTO’s rationalization for this is that the web elements in the corrugated profile will not experience strain levels as high as the extreme fibers under bending, and are thus less likely to buckle.

2.08C.2 Bending Strain Bending strain in a pipe can be calculated by the equation:

\[
\varepsilon_b = \left(\frac{1}{R} - \frac{1}{r}\right) c
\]

where:

\[R = \text{initial radius of the pipe (in)}\]
\[r = \text{final radius of the pipe (in)}\]
c = distance to the neutral axis of the pipe wall from the extreme fiber

The change in radius of the pipe is dependent upon the deflection of the pipe and the shape that the pipe takes when deflected. Equation 9 is a modification to the equation above, with the incorporation of the maximum allowable deflection of 5% (0.05), and a shape factor that is dependent upon the stiffness of the pipe versus the stiffness of the surrounding soil. As mentioned above in the discussion of vertical deflection versus horizontal deflection, low stiffness pipes lack the strength to push out into the surrounding soil. These pipes, therefore, tend to square and develop smaller radiuses of curvature in the haunch areas, and thus higher strains (higher shape factor). Thus, higher shape factors are associated with low stiffness pipes in high stiffness soils.

The equations in this standard were taken from AS/NZ, “Buried Flexible Pipelines, Part 1, Structural Design” xxxxx. Section 12 of the AASHTO LRFD Bridge Design Specifications provides a table with shape factors (shown below).

<table>
<thead>
<tr>
<th>Pipe Stiffness \ (EI/0.149 R²)</th>
<th>Pipe Zone Embedment Material and Compaction Level</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Dumped to Slight (3)</td>
</tr>
<tr>
<td>0.009</td>
<td>5.5</td>
</tr>
<tr>
<td>0.018</td>
<td>4.5</td>
</tr>
<tr>
<td>0.036</td>
<td>3.8</td>
</tr>
<tr>
<td>0.072</td>
<td>3.3</td>
</tr>
</tbody>
</table>

1. GW, GP, GW-GC, GW-GM, GP-GC and GP-GM per ASTM D2487 (includes crushed rock).
2. SW, SP, SM, SC, GM and GC or mixtures per ASTM D2487.
3. <85% of maximum dry density per AASHTO T 99, <40% relative density (ASTM D4253 and D4254).
4. ≥85% of maximum dry density per AASHTO T 99, ≥40% relative density (ASTM D4253 and D4254).

Consistent with the approach they have taken throughout the plastic pipe design process, AASHTO takes a liberal approach with the shape factors it utilizes as well. In many cases, calculating the shape factor per AASHTO provides a lower shape factor than what would be calculated using the equations in this standard. This is particularly true for pipe installed in Gravels. AASHTO places emphasis on the effort required to compact the soil surrounding the pipe. For weaker soils that require higher compactive effort, it is assumed that the compactive effort will result in an initial upward deflection of the pipe prior to its final downward deflection, and this will cause an increase in the change in radius and result in higher strains. This concern is valid. However, while incorporating this into the shape factor, they greatly reduce the concern for the strength of the soil itself, and its lateral stiffness. As mentioned, the lack of concern for the soil’s constrained modulus results in values that are often lower than what would be calculated by this standard, even after the construction effects have been taking into account by AASHTO.

The graph below represents the shape factors calculated from the equations in this standard for the same 48-inch, 6 psi pipe that was used for discussion regarding deflection. Whereas the highly compacted gravel materials would provide the highest constrained soil modulus, the highest shape factor in the AASHTO table is for sands, and not gravels.
Additionally, AASHTO allows the engineer to subtract a value of 1.0 from the shape factor for profile wall polyethylene pipe. This is based on the assumption that the low hoop stiffness of PE pipes allows them to compress within themselves (which is taken into account through the compressive strain calculation) before they would bend, thus, lessening the bending strain. This standard does not believe that the pipe will compress prior to bending, and no such reduction in the shape factor is allowed.

![Shape Factor for a 6 psi Pipe Stiffness](image)

**2.08C.3 Wall Crushing**  
Because of its time-dependent properties, the proper design of HDPE pipe should be based on allowable strain levels for the pipe material. With time dependent properties, a constant strain level results in a reduced allowable stress level over time. Most engineers are more comfortable using a stress based design, and thus an allowable wall crushing stress of 900 psi is required for long-term design. This value is the resultant of a 50-year elastic modulus ($E_{50}$) for the HDPE pipe material (22,000 psi) being applied to the allowable compressive strain of 4.1% ($0.041 \times 2,000 = 900$ psi). The initial modulus of HDPE pipe material is 110,000 psi. For time durations other than short-term testing, or long-term installed loads, the elastic modulus of the HDPE pipe material may be adjusted using the following equation from Hashash and Selig.

$$E_{int} = 664 \times T^{-0.0859} \times 145.0377$$

Where:

$E_{int} =$ intermediate modulus of elasticity for HDPE pipe material (psi)
T = time in minutes

B.03 Deflection  HDPE pipes experience short-term deflection from the initial backfill load after installation, as well as long-term deflection after load lag and deflection lag affect the pipe. Additionally, the pipes will often experience an upward vertical load during installation.

The construction deflection limit of 5% is incorporated to avoid excessive vertical ovaling in the pipe from the soil compaction efforts on the sides of the pipe. Large upward vertical deflections can result in squaring and large strain values in the pipe once the backfill load exerts downward pressure on the pipe. This is to be avoided.

Once backfilling of the soil over the pipe is complete, it experiences both short-term and long-term deflection. It will take time for the backfill to settle due to its own weight and any additional moisture absorbed into the soil. Beyond this, the vertical deflection will increase further due to the long-term consolidation of the soil and the time dependent properties of the pipe (see Figure below). As noted in B.03b, the analytical methods in this standard are intended to limit total deflection within acceptable limits. The acceptable limit for total deflection in design has been established as 5% throughout 2.08 of this standard. To ensure a total deflection of 5%, and thereby acceptable levels of stress/strain in the pipe wall for a 50-year design life, the short-term deflection should not exceed 3%. 