CITY OF CALGARY

STANDARD PRACTICE FOR THE DESIGN AND CONSTRUCTION OF FLEXIBLE THERMOPLASTIC PIPE IN THE CITY OF CALGARY 071221

Prepared for

City of Calgary

Prepared by

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December 21, 2007 0082-242-00

John Sealy
Senior Research Engineer
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Dear John:

Re: Standard Practice for the Design and Installation of Flexible Thermoplastic Pipe in the City of Calgary

Please find enclosed the Final Standard Practice for the Design and Installation of Flexible Thermoplastic Pipe in the City of Calgary, revised in accordance with comments received over the course of last winter.

We thank you for the opportunity to work on this very interesting and challenging assignment for the City of Calgary.

Sincerely,

UMA Engineering Ltd.

PROFESSIONAL ENGINEER
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21 DECEMBER 2007
ALBERTA

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cc: Mark Ruault, P. Eng.
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PART I: GENERAL

1.0 Scope

1.1 This standard practice covers the design and construction of flexible thermoplastic pipe for use in installations within the City of Calgary. While the Standard Practice is primarily focused on the use of PVC pipe, it does address HDPE pipe products to illustrate some of the subtle differences between the two thermoplastics that must be addressed in design.

1.2 When buried, it must be recognized that thermoplastic pipes are a composite structure made up of the plastic ring of the pipe and the soil envelope around them, and that both materials play a vital part in the structural design requirements for the pipe. It also essential that the designer and installer recognize that the soil envelope in typical trench installations is composed of two components – the embedment zone soil and the native soil and that the interaction of these materials can play a significant role in pipe performance.

1.3 Part II of this standard practice presents the proposed design method for flexible pipe design using the standard installation configurations that are specified herein. This design method is predicated on the principle that controlling deflection to within acceptable limits will be sufficient to meet both structural requirements of the pipe based on the materials specifically covered in this standard and the standard installations detailed herein, and the functional requirements of pipe performance such as joint integrity, connections to other structures, etc. in the majority of design situations. This does not preclude the fact that the designer should carry out the appropriate structural design checks as detailed in Part II of the standard practice to ensure that performance limiting factors other than deflection do not control in any site specific design.

1.4 Part III of this standard practice presents the construction requirements for thermoplastic pipe designed and installed in accordance with this standard practice.

1.5 This standard practice shall be used as a reference by the owner or owner's engineer in preparing project specifications within the City of Calgary based on the standard design and installation practices specified herein.

1.6 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 II, the engineer should review the guidance and requirements given in other sections of this standard practice and its accompanying commentary.

1.7 The values of dimensions and quantities are expressed in SI unit values with conversions expressed in inch-pound (English) units for convenience.

2.0 Applicable Documents

2.1 ASTM (American Society for Testing and Materials)

2.1.1 D420-98 Guide to Site Characterization for Engineering, Design, and Construction Purposes

2.1.2 D2321-00 Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications

2.1.3 D2487-00 Standard Classification of Soils for Engineering Purposes (Unified Soil Classification System)

2.1.4 D2488-00 Standard Practice for Description and Identification of Soils (Visual-Manual Procedure)

2.1.5 D3034-00 Standard Specification for Type PSM Poly(Vinyl Chloride) (PVC) Sewer Pipe and Fittings

2.1.6 D3212-96a Standard Specification for Joints for Drain and Sewer Plastic Pipes Using Flexible Elastomeric Seals

2.1.7 D3350-02a Standard Specification for Polyethylene Plastics Pipe and Fittings Materials

2.1.8 F679-01 Standard Specification for Poly(Vinyl Chloride) (PVC) Large-Diameter Plastic Gravity Sewer Pipe and Fittings

2.1.9 F794-99 Standard Specification for Poly(Vinyl Chloride) (PVC) Profile Gravity Sewer Pipe and Fittings Based on Controlled Inside Diameter

2.1.10 F894-98a Standard Specification for Polyethylene (PE) Large Diameter Profile Wall Sewer and Drain Pipe

2.2 CSA (Canadian Standards Association)

2.2.1 B182.2, PVC Sewer Pipe and Fittings (PSM Type)

2.2.2 B182.4, Profile PVC Sewer Pipe and Fittings

2.2.3 B182.6, Profile Polyethylene Sewer Pipe and Fittings for Leak-Proof Sewer Applications

2.2.4 B182.8, Profile Polyethylene Storm Sewer and Drainage Pipe and Fittings

2.2.5 B182.11, Recommended Practice for the Installation of Thermoplastic Drain, Storm, and Sewer Pipe and Fittings

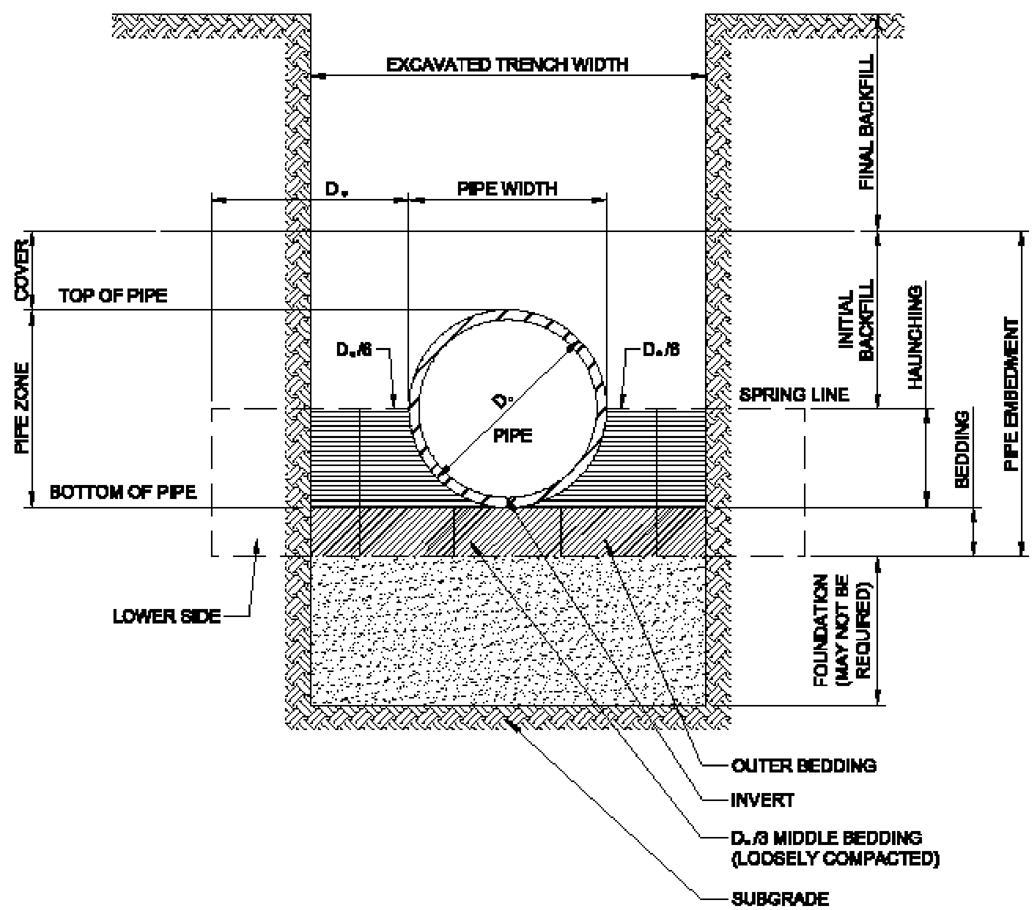
2.3 AWWA (American Water Works Association)

2.3.1 AWWA M45, Fiberglass Pipe Design Manual

3.0 Definitions

3.1 Figure 1 illustrates the definitions and limits of the terms, foundation, subgrade, bedding, haunch, lower side, initial backfill, pipe zone, embedment zone, backfill or overfill, invert, crown, springline, top of pipe, and bottom of pipe as used in this standard practice.

Figure 1 Standard Terminology



4.0 Notations

A = cross sectional area (m^2)

B_c = width of pipe (m)

B_d = width of trench (m)

C_c = coefficient of curvature (unitless)

C_u = coefficient of uniformity (unitless)

D, d = pipe diameter (m)

Δx = horizontal deflection (m)

Δy = vertical deflection (m)

D_L = deflection lag factor (unitless)

E = flexural modulus of elasticity (kPa)

E' = modulus of soil reaction (kPa)

E'_b = modulus of soil reaction - embedment soils (kPa)

E'_{design} = modulus of soil reaction - composite design value (kPa)

E'_{native} = modulus of soil reaction - native soils (kPa)

ϵ = bending strain (mm/mm)

Γ = soil density

H = height of cover (m)

I = moment of inertia

I_f = impact factor (unitless)

J = Masada's bedding angle/bedding factor constant

K = bedding factor (unitless)

LL = liquid limit

M = bending moment

ν = Poisson's Ratio

P = external load expressed as a pressure (kPa)

P_{cr} = critical buckling pressure (kPa)

PI = plasticity index

PS = pipe stiffness (kPa)

q_u = unconfined compressive strength

R = radius

S_c = composite soil support factor (unitless)

σ_y = yield point stress

SPD = standard Proctor dry density

SPT = standard penetration test blow count

t = wall thickness

W = total load (kN/m)

W_D = earth load (kN/m)

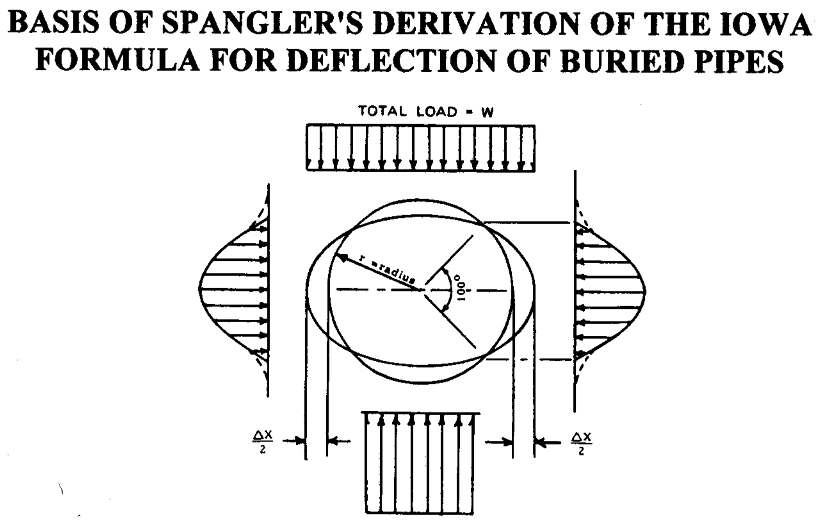
W_L = live load (kN/m)

$\mathrm{w_L}$ = live load pressure (kN/m^2)

5.0 Summary of Standard Practice Approach

5.1 The design approach of this standard practice is based upon the assumptions inherent in the original Spangler load distribution[1] 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[2]



5.2 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.

5.3 Soil stiffness values (modulus of soil reaction, *E'*,) for material in the embedment zone are based upon the research of Duncan and Hartley[3] and McGrath[4]. 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 determined by McGrath's research are recommended for use herein.

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[1] Watkins, R.K. and M.G. Spangler, "*Some Characteristics of the Modulus of Passive Resistance of Soil – A Study in Similitude",* Highway Research Board Proceedings, 1958.

[2] Uni-Bell PVC Pipe Association, *:Handbook of PVC Pipe – Design and Construction",* 3rd Edition September 1991, pp. 204

[3] Hartley, J.D. and J.M. Duncan, *"E' and Its Variation with Depth",* Journal of Transportation Engineering, September 1987.

[4] McGrath, T.J., *"Replacing E' with the Constrained Modulus in Flexible Pipe Design",* Proceedings of the Pipeline Division Conference, San Diego, ASCE, 1998.

5.4 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[5].

5.5 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[6] and reproduced herein and the recommendations presented in Part II of the standard practice.

[5] American Water Works Association, *"Manual of Water Supply Practices – M45; Fiberglass Pipe Design"*, 1st Edition, 1996.

[6] Masada, T., *"Modified Iowa Formula for Vertical Deflection of Buried Pipe",* Journal of Transportation Engineering, September/October 2000.

PART II: DESIGN METHOD FOR FLEXIBLE PIPE DESIGN USING CITY OF CALGARY SPECIFIED INSTALLATION CONDITIONS

6.0 General

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

6.2 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.

6.3 As 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 and articulate this information to the installer in the manner prescribed by Section 7.2.

7.0 Design Requirements

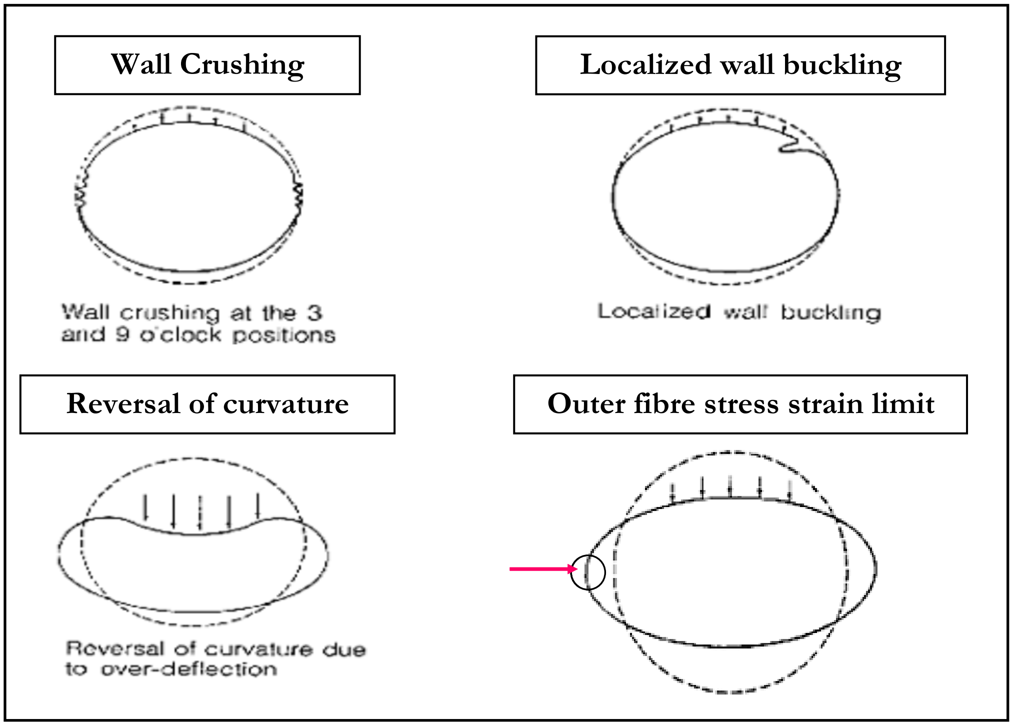
7.1 General Design Approach

The performance limits for thermoplastic pipe can 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 (see typical examples of most common modes in Figure 3).

In practice, limiting deflection to within tolerable limits is satisfactory to meet all performance requirements for PVC thermoplastic pipe products in the vast majority of non-pressure applications. The designer is encouraged to determine the conditions under which other performance limits will govern in design to facilitate streamlining the design process. However, the designer should understand that he alone is responsible for carrying out all necessary performance limit checks for each specific design situation.

Both low DR and solid-wall and HDPE thermoplastic pipe products should be reviewed by the designer for the full range of design checks before applying the design principles articulated in this Standard Practice so that the designer is fully cognizant of the performance limiting factors that will govern in design.

Figure 3 - Typical Performance Limiting Modes for Gravity Thermoplastic Pipe



The three parameters that are most essential to consider in all flexible pipe design include load (primarily driven by depth of bury), soil stiffness in the pipe zone (both embedment and native soil), and pipe stiffness.

Soil is obviously a major component of the soil-pipe interaction system and is actually the component that supports the load. While the designer must take this into account in developing his design assumptions, the installer ultimately must be aware of those design assumptions, such that soil conditions in the field that are at variance with the design assumptions can be readily identified and the design, if necessary, modified to account for actual field conditions.

The design process, therefore, consists of:

- Determining external loading conditions,
- Assessing whether any special design conditions other than conventional trench loading will govern in design,
- Determining or estimating in-situ soil conditions based on either site specific geotechnical investigations or experience,

- Selection of the desired balance of soil and pipe stiffness to meet the anticipated loading conditions for the duration of the design period, and

- 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.

7.2 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:

7.2.1 Pipe material and minimum pipe stiffness

7.2.2 Assumed installation configuration

7.2.3 Embedment material and required placement density

7.2.4 Assumed trench width and assumed native soil characteristics (qualitative description and E'_{native} value)

8.0 Pipe Material Requirements

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 City of Calgary. Specific products approvals are addressed by the City on a product-by-product basis outside of this Standard Practice.

8.1 Smooth-wall PVC Products

8.1.1 Smooth wall PVC pipe products and fittings shall conform to Sections 4 and 5 of CSA Standard B182.2 for all basic material requirements and manufactured quality and dimensional tolerance.

8.1.2 Materials used for pipe shall come from a single compound manufacturer and shall have a cell classification of 12454-B, 12454-C, or 12364-C as defined in ASTM Standard D 1784. Materials used for moulded fittings shall come from a single compound manufacturer and shall have a cell classification of 12454-B, 12454-C, or 13343-C as defined in ASTM Standard D 1784.

8.1.3 Notwithstanding the requirements of Section 4 of CSA Standard B182.2, compounds with different cell classifications than that noted above shall not be used without the prior approval of the City of Calgary.

8.2 Profile PVC Products

8.2.1 Closed profile, dual-wall corrugated, and open profile PVC pipe products and fittings shall conform to Sections 4 and 5 of CSA Standard B182.4 for all basic material requirements and manufactured quality and dimensional tolerance.

8.2.2 Materials used for pipe and fittings shall come from a single compound manufacturer and shall have a cell classification of 12454-B, 12454-C, or 12364-C as defined in ASTM Standard D 1784.

8.2.3 Notwithstanding the requirements of Section 4 of CSA Standard B182.4, compounds with different cell classifications than that noted above shall not be used without the prior approval of the City of Calgary.

8.3 Polyethylene (PE) Profile Wall Products

8.3.1 Closed profile and open profile PE pipe products and fittings shall conform to Sections 4 and 5 of CSA Standards B182.6 and B182.8 for all basic material requirements and manufactured quality and dimensional tolerance for sanitary and storm sewer applications, respectively.

8.3.2 Materials used for pipe and fabricated fittings shall come from a single compound manufacturer and shall be made from virgin polyethylene compounds having the following minimum cell classifications as defined in ASTM Standard D3350:

Product	Outside Profile, corrugations	Inside lining, waterway wall
Storm Sewer and Fabricated Fittings	324420 C or 324420 E	321120C or 321120E
Sanitary Sewer and Fabricated Fittings	324430 C or 324430 E	324430 C or 324430 E

8.3.3 Resin compounds shall be tested for slow crack growth resistance in accordance with Appendix SP-NCTL in ASTM Standard D5397 as modified in Clause 8.8 of CSA B182.8.

9.0 Bedding and Foundation Material Requirements

9.1 Classification of Materials

Materials for use as foundation, embedment, and backfill are classified in Table 1. They include natural, manufactured, and processed aggregates and the soil types classified according to ASTM Test Method D 2487.

9.2 Installation and Intended Use of Materials

Table 2 provides recommendations on installation and use based on class of soil or aggregates and their location in the trench.

Class I, Class II, and Class III materials are suitable for use as foundation material and in the embedment zone subject to the limitations noted herein and in Table 2.

Class IV-A materials should only be used in the embedment zone in special design cases, as they would not normally be construed as a desirable embedment material for flexible pipe.

Class IV-B, Class V Soils, and Frozen Materials are not recommended for embedment, and should be excluded from the final backfill except where specifically allowed by project specifications.

9.3 Description of Embedment Material

Sections 9.3.1 through 9.3.7 describe characteristics of materials recommended for use in the embedment zone.

Table 1 – Classes of Embedment and Backfill Materials[7]

				Percentage Passing Sieve Sizes			Atterberg Limits		Coefficients	
Class	Type	Soil Group Symbol D2487	Description	20 mm (3/4 in)	4.75 mm (No. 4)	0.075 mm (No. 200)	LL	PI	Uniformity C_U	Curvature C_C
IA	Manufactured Aggregates: open-graded, clean.	None	Angular, crushed stone or rock, crushed gravel, broken coral, crushed slag, cinders or shells; large void content, contain little or no fines.	100%	≤10%	<5%	Non Plastic			
IB	Manufactured, Processed Aggregates; dense-graded, clean.	None	Angular, crushed stone (or other Class 1A materials) and stone/sand mixtures with gradations selected to minimize migration of adjacent soils; contain little or no fines (see commentary in Appendix B).	100%	≤50%	<5%	Non Plastic			
II	Coarse-Grained Soils, clean	GW	Well-graded gravels and gravel-sand mixtures; little or no fines.	100%	<50% of “Coarse Fraction”	<5%	Non Plastic		>4	1 to 3
		GP	Poorly-graded gravels and gravel-sand mixtures; little or no fines.						<4	<1 or >3
		SW	Well-graded sands and gravelly sands; little or no fines.		>50% of “Coarse Fraction”				>6	1 to 3
		SP	Poorly-graded sands and gravelly sands; little or no fines.						<6	<1 or >3
	Coarse-Grained Soils, borderline clean to w/fines	e.g. GW-GC, SP-SM	Sands and gravels which are borderline between clean and with fines.	100%	Varies	5% to 12%	Non Plastic		Same as for GW, GP, SW and SP	
III	Coarse-Grained Soils With Fines	GM	Silty gravels, gravel-sand-silt mixtures.	100%	<50% of “Coarse Fraction”	12% to 50%		<4 or <”A” Line		
		GC	Clayey gravels, gravel-sand-clay mixtures.					<7 and >”A” Line		
		SM	Silty sands, sand-silt mixtures.		>50% of “Coarse			>4 or <”A” Line		

[7] Table excerpt from D2321-00 Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications. Maximum aggregate size modified.

				Percentage Passing Sieve Sizes			Atterberg Limits		Coefficients	
Class	Type	Soil Group Symbol D2487	Description	20 mm (3/4 in)	4.75 mm (No. 4)	0.075 mm (No. 200)	LL	PI	Uniformity C_U	Curvature C_C
		SC	Clayey sands, sand-clay mixtures.		Fraction”			>7 and >”A” Line		
IVA[A]	Fine-Grained Soils (inorganic)	ML	Inorganic silts and very fine sands, rock flour, silty or clayey fine sands, silts with slight plasticity.	100%	100%	>50%	<50	<4 or <”A” Line		
		CL	Inorganic clays of low to medium plasticity, gravely clays, sandy clays, silty clays, lean clays.					>7 and >”A” Line		
IVB	Fine-Grained Soils (inorganic)	MH	Inorganic silts, micaceous or diatomaceous fine sandy or silty soils, elastic silts.	100%	100%	>50%	>50	<”A” Line		
		CH	Inorganic clays of high plasticity, fat clays					>”A” Line		
V	Organic Soils	OL	Organic silts and organic silty clays of low plasticity.	100%	100%	>50%	<50	<4 or <”A” Line		
		OH	Organic clays of medium to high plasticity, organic silts.				>50	<”A” Line		
	Highly Organic	PT	Peat and other high organic soils.							

[A]Includes Test Method D2487 borderline classifications and dual symbols depending on plasticity index and liquid limits.

NOTE – “Coarse Fraction” as used in this table is defined as material retained on a 0.075 mm (No. 200) sieve.

Table 2 – Recommendations for Installation and Use of Soils and Aggregates for Foundation, Embedment and Backfill[8]

Soil Classes (see Table 1)[A]					
	Class IA	Class IB	Class II	Class III	Class IV-A
General Recommendations and Restrictions	Do not use where conditions may cause migration of fines from adjacent soil and loss of pipe support. Suitable for use as a drainage blanket and underdrain in rock cuts where adjacent material is suitably graded (see Commentary in Appendix B)	Process materials as required to obtain gradation which will minimize migration of adjacent materials (see Commentary in Appendix B). Suitable for use as drainage blanket and underdrain.	Where hydraulic gradient exists, check gradation to minimize migration. "Clean" groups suitable for use as drainage blanket and underdrain	Do not use where water conditions in trench may cause instability.	Obtain geotechnical evaluation of proposed material. May not be suitable under high earth fills, surface applied wheel loads, and under heavy vibratory compactors and tampers. Do not use where water conditions in trench may cause instability.
Foundation	Suitable as foundation and for replacing over-excavated and unstable trench bottom as restricted above. Install and compact in 150 mm maximum layers.	Suitable as foundation and for replacing over-excavated and unstable trench bottom. Install and compact in 150 mm maximum layers.	Suitable as a foundation and for replacing over-excavated and unstable trench bottom as restricted above. Install and compact in 150 mm maximum layers.	Suitable as foundation and for replacing over-excavated trench bottom as restricted above. Do not use in thicknesses greater than 300 mm total. Install and compact in 150 mm maximum layers.	Suitable only in undisturbed condition and where trench is dry. Remove all loose material and provide firm, uniform trench bottom before bedding is placed.
Bedding	Suitable as restricted above. Install in 150 mm maximum layers. Level final grade by hand. Minimum depth 100 mm (150 mm in rock cuts).	Install and compact in 150 mm maximum layers. Level final grade by hand. Minimum depth 100 mm (150 mm in rock cuts).	Suitable as restricted above. Install and compact in 150 mm maximum layers. Level final grade by hand. Minimum depth 100 mm (150 mm in rock cuts).	Suitable only in dry trench conditions. Install and compact in 150 mm maximum layers. Level final grade by hand. Minimum depth 100 mm (150 mm in rock cuts).	Suitable only in dry trench conditions and when optimum placement and compaction control is maintained. Install and compact in 150 mm maximum layers. Level final grade by hand. Minimum depth 100 mm (150

[8] Table excerpt from D2321-00 Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity-Flow Applications. Minimum initial backfill and embedment compaction values modified.

Soil Classes (see Table 1)[A]					
	Class IA	Class IB	Class II	Class III	Class IV-A
					mm in rock cuts).
Haunching	Suitable as restricted above. Install in 150 mm maximum layers. Work in around pipe by hand to provide uniform support.	Install and compact in 150 mm maximum layers. Work in around pipe by hand to provide uniform support.	Suitable as restricted above. Install and compact in 150 mm maximum layers. Work in around pipe by hand to provide uniform support.	Suitable as restricted above. Install and compact in 150 mm maximum layers. Work in around pipe by hand to provide uniform support.	Suitable only in dry trench conditions and when optimum placement and compaction control is maintained. Install and compact in 150 mm maximum layers. Work in around pipe by hand to provide uniform support.
Initial Backfill	Suitable as restricted above. Install to a minimum of 150 mm above pipe crown.	Install and compact to a minimum of 150 mm above pipe crown.	Suitable as restricted above. Install and compact to a minimum of 300 mm above pipe crown.	Suitable as restricted above. Install and compact to a minimum of 300 mm above pipe crown.	Suitable as restricted above. Install and compact to a minimum of 300 mm above pipe crown.
Embedment Compaction	Place and work by hand to insure all excavated voids and haunch areas are filled. For high densities use vibratory compactors.	Minimum density 90% Std. Proctor Use hand tampers or vibratory compactors.	Minimum density 90% Std. Proctor Use hand tampers or vibratory compactors.	Minimum density 95% Std. Proctor Use hand tampers or vibratory compactors. Maintain moisture content near optimum to minimize compactive effort.	Minimum density 95% Std. Proctor Use hand tampers or impact tampers. Maintain moisture content near optimum to minimize compactive effort..
Final Backfill	Compact as required by the Engineer.	Compact as required by the Engineer.	Compact as required by the Engineer.	Compact as required by the Engineer.	Suitable as restricted above. Compact as required by the Engineer.

[A]Class IV-B (MH-CH) and Class V (OL, OH, PT) Materials are unsuitable as embedment. They may be used as final backfill as permitted by the Engineer.

[B]When using mechanical compactors avoid contact with pipe. When compacting over pipe crown maintain a minimum of 150 mm cover when using small mechanical compactors. When using larger compactors maintain minimum clearances as required by the Engineer (see Commentary in Appendix B).

[C]The minimum densities given in the table are intended as the compaction requirements for obtaining satisfactory embedment stiffness in most installation conditions (see Section 13).

9.3.1 Class IA Materials

Class IA materials provide maximum stability and pipe support for a given density due to angular interlock of particles. With minimum effort these materials can be installed at relatively high densities over a wide range of moisture contents. In addition, the high permeability of Class IA 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 IA materials (see commentary in Appendix B).

9.3.2 Class IB Materials

Class IB materials are processed by mixing Class IA and natural or processed sands to produce a particle size distribution that minimizes migration from adjacent materials that contain fines (see commentary in Appendix B). They are more densely graded than Class IA materials and thus require more compactive effort to achieve the minimum density specified. When properly compacted, Class IB materials offer high stiffness and strength and, depending on the amount of fines, may be relatively free draining.

9.3.3 Class II Materials

Class II materials, when compacted, provide a relatively high level of pipe support. In most respects, they have all the desirable characteristics of Class IB materials when densely graded. However, open graded groups may allow migration and the sizes should be checked for compatibility with adjacent material (see commentary in Appendix B). Typically, Class II materials consist of rounded particles and are less stable than angular materials unless they are confined and compacted.

9.3.4 Class III Materials

Class III materials provide less support for a given density than Class I or Class II materials. High levels of compactive effort may be required unless moisture content is controlled. These materials provide reasonable levels of pipe support once proper density is achieved.

9.3.5 Class IV-A Materials

Class IV-A materials require a geotechnical evaluation prior to use and are only permitted to be used in special design applications such as in cut-off walls or in areas where a short section of low permeability soil is required by design.

Moisture content must be near optimum to minimize compactive effort and achieve the required density. Properly placed and compacted, Class IV-A materials can provide reasonable levels of pipe support; however, these materials may not be suitable under high fills, surface applied wheel loads, or under heavy vibratory compactors and tampers. Do not use where water conditions in the trench may cause instability and result in uncontrolled water content.

9.3.6 Moisture Content of Embedment Material

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 IVA, and some borderline Class II soils), moisture content is normally required to be held to +3% of optimum (see ASTM Test Methods D 698). 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).

9.3.7 Maximum Particle Size

Maximum particle size for embedment is limited to material passing a 20 mm (3/4 in.) sieve (see Table 1). To enhance placement around small diameter pipe and to prevent damage to the pipe wall, a smaller maximum size may be required (see commentary in Appendix B). When final backfill contains rocks, cobbles, etc., the Engineer may require greater initial backfill cover levels (see Figure 1).

10.0 Characterization of Native Soil Conditions

10.1 Characterization of Native Soils

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.

10.2 Implication of Native Soils versus Embedment Material Selection

Short-term performance shall be evaluated to determine whether the modulus of soil reaction in design, E'_{design}, needs to be adjusted based on native soil conditions in accordance with Section 13.2.1.6.

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 2.

11.0 Standard Installation Configurations

Standard installation configurations are presented on Figure 10, Figure 11, and Figure 12 in Part III of this Standard Practice for narrow, sub-ditch, and wide trenches.

12.0 External Loads

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 Section 12.3.

12.1 Dead Load Design Requirements

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

$$W_D = \gamma * H * B_c \quad (1)$$

where $\gamma = \rho * g$

The minimum density (ρ) used in design shall be 2165 kg/m^3 (135 lb/ft^3), and the acceleration of gravity (g) used shall be 9.8064 m/s^2. Should an engineered backfill be utilized with densities 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.

12.2 Minimum Live Load Requirements

12.2.1 Minimum live load requirements shall be the live load generated by a CL-800 truck as defined by Canadian Highway Bridge Design Code (CAN/CSA-S6-00). 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 CL-800 trucks.

12.2.2 Where pipes cross or could be impacted by railway loads, live loads shall be estimated based on the AREA 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.

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

12.3 Special Design Considerations

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. There can exist, in design, a number of conditions that warrant special consideration as unique design conditions that are beyond the scope of the design checks suggested by Section 13.0. This could include:

i) Shallow Parallel pipes subjected to heavy surface loads

ii) Parallel trenches

iii) Sloped trench walls

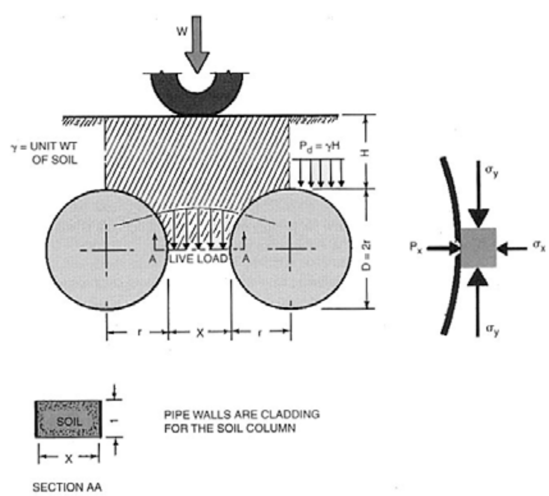
iv) Situations involving longitudinal bending, support spacing, and thermal contraction and expansion.

A brief discussion on each of these situations follows complete with references to additional resources to evaluate these unique design situations.

12.3.1 Shallow Parallel Pipes subjected to Heavy Surface Loads

Where buried pipes are installed in parallel as illustrated in Figure 4 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].

Figure 4– Shallow Parallel Pipes, Heavy Surface Loads

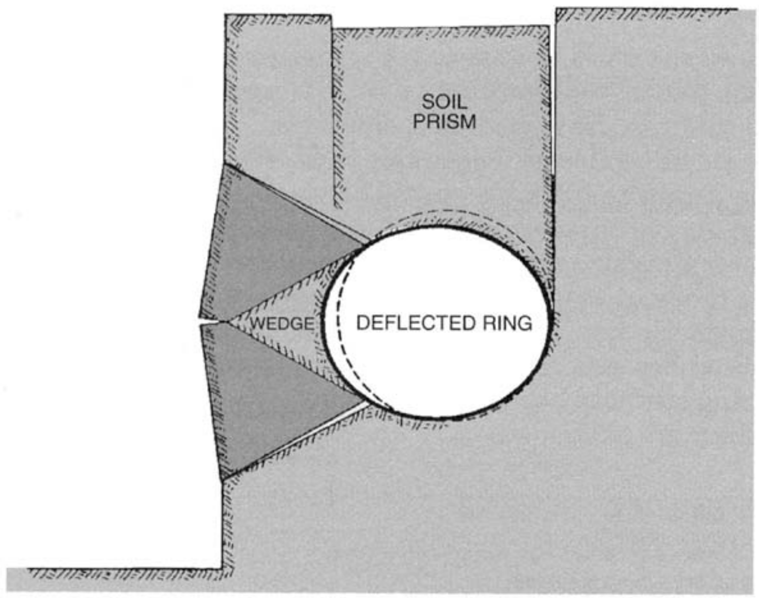


[9] A.P. Moser, *Buried Pipe Design – 2nd Edition",* published by McGraw-Hill, 2001, pp. 121.

12.3.2 Parallel trenches to Existing Flexible Pipes

Where a parallel trench is cut adjacent 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 5). A suitable analytical technique for this analysis is presented in Moser[10].

Figure 5 – Vertical Trench Parallel to Flexible Pipe Initiating Active Soil Wedge



12.3.3 Sloped trench walls

Where sloped trench walls are cut adjacent to flexible pipes at deeper heights of cover (see Figure 6), 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[11].

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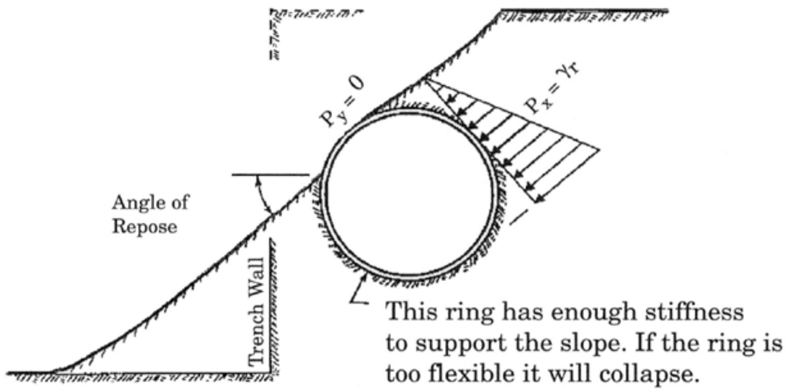
[10] A.P. Moser, *Buried Pipe Design – 2nd Edition",* published by McGraw-Hill, 2001, pp. 130.

[11] A.P. Moser, *Buried Pipe Design – 2nd Edition",* published by McGraw-Hill, 2001, pp. 132.

Figure 6 – Slope Adjacent Trench Wall – Pressure Distribution



12.3.4 Longitudinal bending, Support spacing, and Thermal contraction and expansion

12.3.4.1 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. Analytical procedures and performance limitations for PVC pipe are presented in the PVC pipe Handbook[12].

12.3.4.2 Support Spacing

In buried applications, a flexible pipe's strength in longitudinal bending is rarely, if ever, 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. Support spacing requirements for both solid wall and profile wall PVC products are presented in the PVC pipe Handbook[13].

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[12] Uni-Bell PVC Pipe Association, *"Handbook of PVC Pipe – Design & Construction"*, 4th edition, August 2001.

[13] Uni-Bell PVC Pipe Association, *"Handbook of PVC Pipe – Design & Construction"*, 4th edition, August 2001.

12.3.4.3 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. Where flexible thermoplastic pipes, however, are installed in buried applications, even with shallow cover, there is typically enough skin friction to overcome axial contraction and expansion (e.g. about 600 mm of cover is generally sufficient to overcome axial movement in smooth wall HDPE pipe). Where thermoplastics are installed in special design situations without the benefit of skin friction, such as in encasement pipes, the effects of thermal contraction and expansion should be reviewed closely.

13.0 Specific Design Approach

13.1 Design Objective

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:

- Avoid reversal of curvature
- Limit bending and strain
- Avoid pipe flattening
- Maintain hydraulics
- Maintain hydrostatic integrity at joints

Controlling deflection will be a function of the load, pipe stiffness, and soil stiffness. In practice, deflection can readily be controlled to within acceptable limits with:

- Proper material selection (both pipe and embedment material)
- Proper construction techniques

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).

13.2 Deflection and Deflection Limits

For PVC pipe materials specified in Sections 8.1 and 8.2, short and long-term deflection shall meet the requirements of Table 3. HDPE deflection limits will vary with DR and will be identified at a later date.

Table 3 – Short and Long-Term Deflection Requirements

Maximum Allowable Deflection	
Short-term	**Long-term**
5.00%	7.50%

Short-term deflection shall be deemed to be any deflection measured not sooner than 30 days after backfilling an installation up to 1 year after backfilling an installation.

Long-term deflection shall be deemed to be any deflection measured after 1 year of backfilling.

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.

13.2.1 Modified Iowa Formula

The modified Iowa formula in the following form shall be used to estimate horizontal deflection (expressed as a percent change in original diameter):

$$\frac{\Delta x}{d}(\%) = \frac{100 D_L K P}{0.149(PS) + 0.061 E'_{design}} \qquad (2)$$

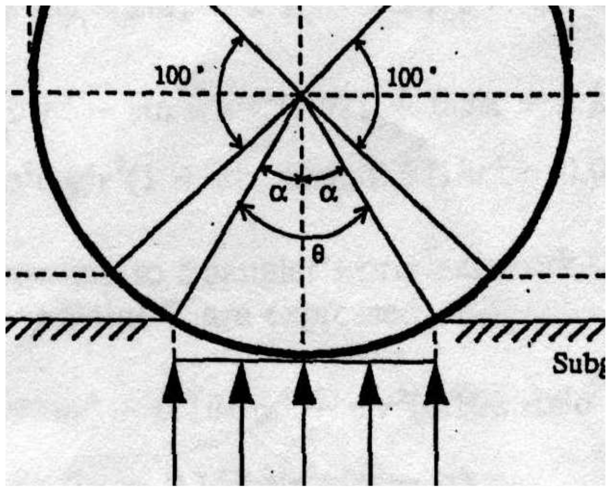
13.2.1.1 Deflection Lag Factor, D_L

A deflection lag factor, D_L, of 1.0 shall be used in all analysis where long-term loading has been estimated based on prism load theory.

13.2.1.2 Bedding Factor, K

A bedding factor, K, 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 60-75 degrees are readily achievable in practice with adherence to good pipe installation practices (see Figure 7 for an illustration of bedding angle).

Figure 7 - Bedding Angle θ, a measure of the pipe's interface with the Bedding Material



13.2.1.3 External Load, *P*

External loads shall be estimated as detailed in Section 12.0 for the appropriate dead and live loading condition. For use in the modified Iowa formula, dead and live loads shall be converted to the equivalent overburden pressure acting over the pipe as follows:

$$P = \frac{(W_D + W_L)}{B_c} \qquad (3)$$

13.2.1.4 Pipe Stiffness, *PS*

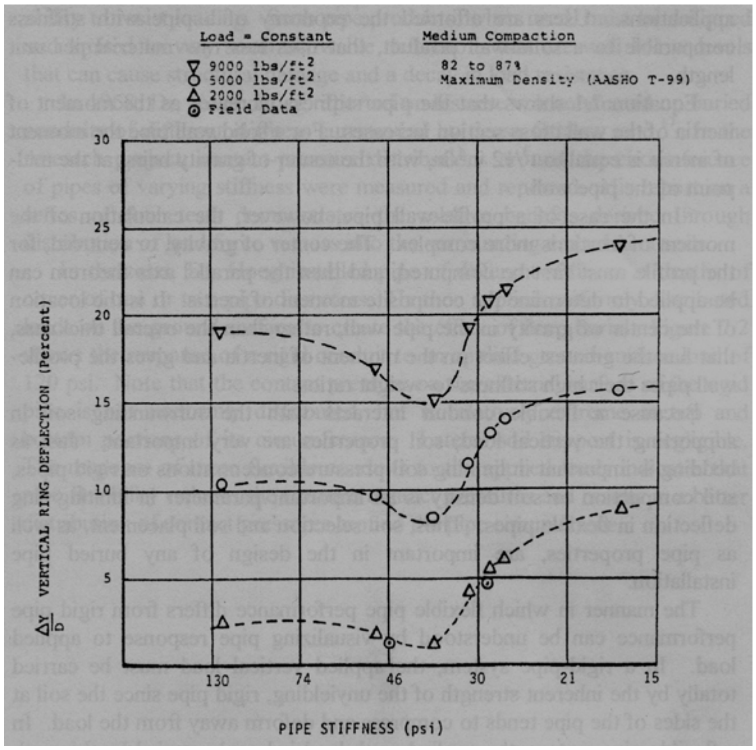
Pipe stiffness, *PS*, shall be the load required to deflect the pipe to 5% deflection as measured in an ASTM D2412 parallel-plate loading test. The pipe stiffness value is calculated by dividing the force per unit length by the deflection. While these values are commonly reported in units of kilopascals (kPa) in SI and pounds per inch^2 (psi) in the inch-pound system, the values do not represent an equivalent resisting force and should not be construed as such.

The minimum *PS* recommended by this Standard Practice is 320 kPa (46 psi).

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 320 kPa (46 psi) *PS*, to employ only Class I embedment material.

In carrying out analytical checks for pipes with *PS* values less than 320 kPa (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 *PS* values less than 260 kPa (37 psi). This fact is illustrated in Figure 8 based on research carried out at the Utah State.

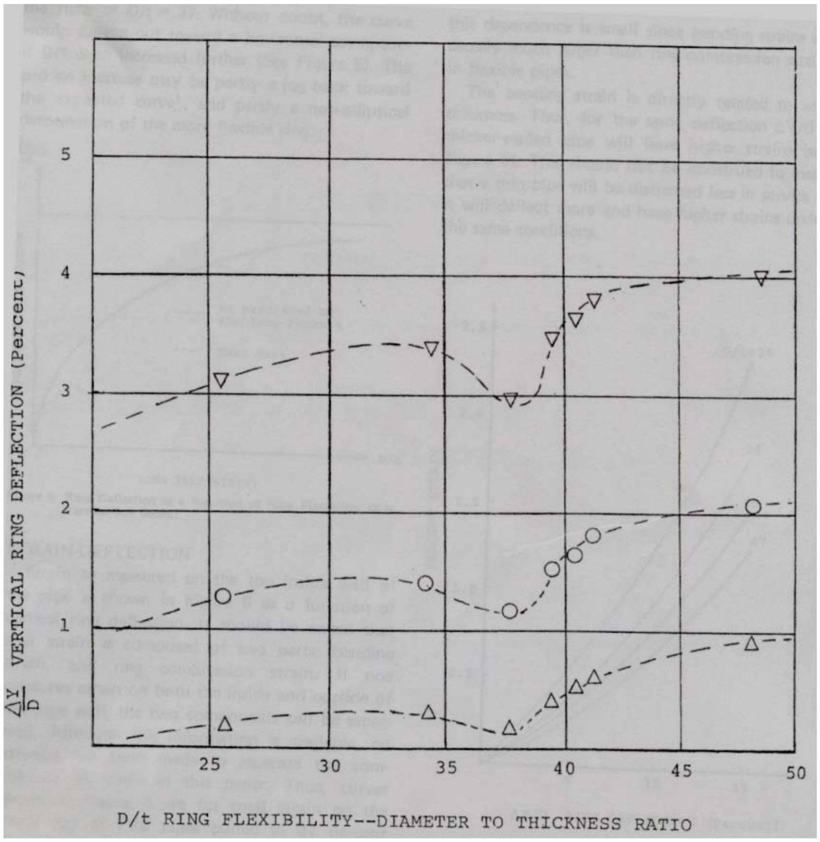
Figure 8 – Observed Vertical Ring Deflection in Buried Plastic Pipe as a Function of Pipe Stiffness[14]



Note that Figure 8 represents medium embedment compaction conditions (approximately 85% Standard Proctor Density). Under similar loading conditions, denser embedment conditions have a significant impact on the observed vertical deflection for pipe with *PS* values less than 260 kPa (37 psi). This is evident from Figure 9, representing compaction density of approximately 90-94% Standard Proctor Density.

[14] Uni-Bell PVC Pipe Association, *"Handbook of PVC Pipe – Design & Construction",* 4th edition, August 2001.

Figure 9 – Observed Vertical Ring Deflection in Buried Plastic Pipe as a Function of Pipe Stiffness, Denser Embedment Compaction (Note Loading and Embedment Conditions as per Figure 8)[15]



13.2.1.5 Modulus of Soil Reaction, *E'b* – Embedment Soils

The values for modulus of soil reaction for embedment soils may be estimated based upon a direct substitution of the one-dimensional constrained modulus, M_s, for E'. The values published by McGrath have been related to embedment materials permitted for use in the City of Calgary by this standard practice and are reproduced in Table 4 below. These values may be utilized in design subject to the cautionary notes below.

[15] A.P. Moser, R.K. Watkins, and R.R. Bishop, *"The Structural Response of Buried PVC Pipe"* , Utah State University, 1972

Table 4 – E'$_b$ Values for Embedment Soil based on McGrath

Height of Cover	Class I, II Embedment			Class III Embedment			Class IVA Embedment		
	95% SPD	90% SPD	85% SPD	95% SPD	90% SPD	85% SPD	95% SPD	90% SPD	85% SPD
0-2 m (3-6 ft)	13.8 (2000)	8.8 (1300)	3.2 (500)	9.8 (1400)	4.6 (700)	2.5 (400)	3.7 (500)	1.8 (300)	0.9 (100)
2-4 m (6-13 ft)	17.9 (2600)	10.3 (1500)	3.6 (500)	11.5 (1700)	5.1 (700)	2.7 (400)	4.3 (600)	2.2 (300)	1.2 (200)
4-8 m (13-26 ft)	20.7 (3000)	11.2 (1600)	3.9 (600)	12.2 (1800)	5.2 (800)	2.8 (400)	4.8 (700)	2.4 (300)	1.4 (200)

Note 1: E' in MPa (psi rounded to nearest 100 in brackets)

Note 2: Use E' values for 4-8 m of cover and for all heights of cover greater than 8 m.

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

- Class IV-A materials (fine grained soils, CL and ML) are only permitted as embedment materials in specialized design situations (such as cut-off walls, for example). In practice, obtaining uniform densities greater than 85% with fine-grained materials is very difficult to attain unless considerable quality control efforts are exercised and moisture is tightly controlled during construction.

- 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, densities of 90% or more are readily achieved with moderate compactive effort with Class II materials. The practitioner is encouraged to review the Commentary in Appendix B, Section B7 to determine the appropriate methods of compaction for each embedment class.

- In practice, it is requires considerable compactive effort to consistently achieve densities of 95% or higher in the embedment zone unless Class I materials are utilized. In situations where site conditions and design requirements truly require the consistent development of densities as high 95% SPD, the designer would be wise to require the use of Class I embedment materials.

- The designer is encouraged not to arbitrarily specify an unreasonably high level of compactive effort unless that level of effort is required by design. As illustrated in Appendix B and the design examples of Appendix C, consistently achieving composite E'_{design} values in excess of 1000 MPa is what is truly required for adequate long term performance in the vast majority of design situations.

- 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.

13.2.1.6 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 Section 13.2.1.5 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

In-situ Soils				
Granular		Cohesive		E'_{native}
SPT (Blows/0.3 m)	Description	Unconfined Compressive Strength q_u(kPa)	Description	kPa (psi)
>0-1	very, very loose	>0-12	very, very soft	345 (50)
1-2	very loose	12-24	very soft	1380 (200)
2-4		24-48	soft	4825 (700)
4-8	loose	48-96	medium	10,340 (1,500)
8-15	slightly loose	96-192	stiff	20,680 (3,000)
15-30	compact	192-383	very stiff	34,470 (5,000)
30-50	dense	383-575	hard	68,940 (10,000)
>50	very dense	>575	very hard	137,880 (20,000)

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

$$E'_{design} = S_c \times E'_b \tag{4}$$

where, S_C is determined interpolation of the values provided in Table 6 below.

Table 6 – Values of S_c, Versus E'_b and E'_{native}

E'_{native}/E'_b	B_d/B_c	B_d/B_c	B_d/B_c	B_d/B_c	B_d/B_c	B_d/B_c
	1.5	2	2.5	3	4	5
0.1	0.15	0.30	0.60	0.80	0.90	1.00
0.2	0.30	0.45	0.70	0.85	0.92	1.00
0.4	0.50	0.60	0.80	0.90	0.95	1.00
0.6	0.70	0.80	0.90	0.95	1.00	1.00
0.8	0.85	0.90	0.95	0.98	1.00	1.00
1.0	1.00	1.00	1.00	1.00	1.00	1.00

13.2.1.7 Calculation of Vertical Deflection

Computed values for horizontal deflection shall be converted to vertical deflection based on Masada's[16] simplified integration of the modified Iowa formula:

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094E'_{design}}{(PS)} \qquad (5)$$

13.3 Strain Limits

Strain is more commonly a performance limiting factor in thermosetting (e.g. fiberglass, CIPP, GRP) as opposed to thermoplastic (e.g. PVC, HDPE) materials. 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 is by far the largest and other components are typical small in comparison. Therefore, if bending strains approach the materials strain limit, a more comprehensive review would be warranted.

13.3.1 Bending Strain

Bending strain in the hoop direction may be reasonably approximated by the following expression:

$$\in \approx \frac{t}{D} * \frac{3\dfrac{\Delta y}{D}}{1 - 2\dfrac{\Delta y}{D}} \qquad (6)$$

[16] Masada, T., *"Modified Iowa Formula for Vertical Deflection of Buried Pipe",* Journal of Transportation Engineering, September/October 2000.

13.3.2 Wall Crushing

Wall crushing describes the condition of localized yielding for a ductile material or cracking failure for brittle materials. The performance limit is reached when the in-wall stress reaches the yield stress or ultimate stress of the pipe material. Ring compression stress is the primary contributor to this performance limit, where:

$$RingCompression = \frac{PD}{2A} \qquad (7)$$

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

$$BendingStress = \frac{\frac{Mt}{2}}{I} \qquad (8)$$

Wall crushing is typically performance limiting in only rigid or brittle pipe products. In flexible thermoplastic pipes, it is not usually performance limiting unless stiffer pipes are subjected to very deep cover, in highly compacted backfill.

13.3.3 Localized Wall Buckling

Localized wall buckling is not normally performance limiting in conventionally buried gravity sewer pipes. Localized buckling may govern in the design of flexible pipes subjected to internal vacuum, high external hydrostatic pressure, or in instances where pipe is subjected to high soil pressures in very highly compacted soil. Localized buckling typically governs in flexible pipes installed as close-fitting liners and should be reviewed more closely in profile wall applications, dependent on the design of the profile section, and particularly in instances when HDPE profile pipe is utilized to its lower flexural modulus.

For long circular tubes subjected to plain strain, the critical buckling pressure is determined by:

$$P_{cr} = \frac{Et^3}{4(1-\nu^2)R^3} \qquad (9)$$

For buckling in the inelastic range (materials with a pronounced yield point), the critical buckling point in terms of the materials yield point is:

$$P_{cr} = \frac{t}{R} * \frac{\sigma_y}{\dfrac{1+\sigma_y R^2}{Et^2}} \qquad (10)$$

However, critical buckling pressures can be significantly impacted by the geometry of the deflected conduit and the nature of the medium that the pipe is buried in. Calculated critical buckling pressure should be modified to account for geometric effects and should be reviewed to assess the impact, if any, of the surrounding medium[17].

In restrained buckling situations, such as in close-fitting liner pipe installations, the flexural modulus is also impacted by phenomenon of creep and the use of the apparent long-term flexural modulus as determined by ASTM D2990[18] is more appropriate than use of the short term modulus.

For a thorough review of localized buckling in soil situations the designer should review Moser[19] and for the use of thermoplastics as close-fitting liners the designer should review the recommended design procedure in Appendix X1 of ASTM Standard F1216[20].

[17] F1216-07b Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube, pp 5

[18] D2990-01 Standard Test Methods for Tensile, Compressive, and Flexural Creep and Creep-Rupture of Plastics

[19] A.P. Moser, *Buried Pipe Design – 2nd Edition",* published by McGraw-Hill, 2001, pp. 110, pp 470

[20] F1216-07b Standard Practice for Rehabilitation of Existing Pipelines and Conduits by the Inversion and Curing of a Resin-Impregnated Tube

PART III: CONSTRUCTION OF SOIL/FLEXIBLE PIPE SYSTEMS

14.0 General

14.1 The soil-flexible thermoplastic pipe system shall be in configurations that conform to the requirements of Figure 10, Figure 11, and Figure 12, the criteria and design concepts presented in Parts I and II, and to the line and grade designated on the plans and the City of Calgary Standard Specifications. Owners are advised to provide for or require adequate inspection of the pipe installation at the construction site.

15.0 Safety

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

16.0 Excavation

16.1 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. 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.

17.0 Trench Construction

17.1 General

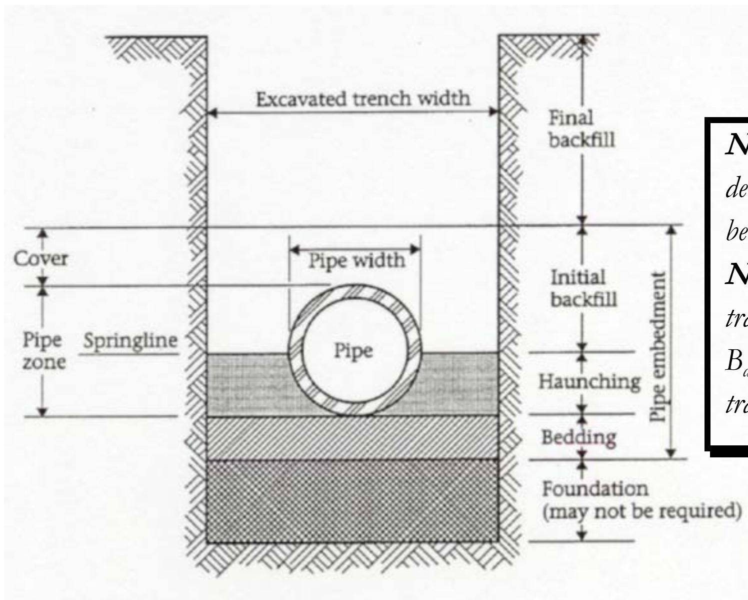
Standard construction practices may necessitate the construction of supported or unsupported trenches in variations of narrow or wide trench configurations.

17.1.1 Unsupported trenches include

- Narrow, unsupported vertical-walled trenches;
- Sub-ditch trenches; and
- Wide trenches

17.1.2 Supported trenches may involve the construction of either narrow vertical-walled trenches or sub-ditch trenches but as supported trenches with the appropriate movable sheeting, trench boxes, shields, or other protective apparatus in place to facilitate construction.

Figure 10 – Narrow Unsupported Trench – Typical



Note 1: *Do not over densify middle-third of bedding under pipe.*
Note 2: *Technical transition to wide trench at $B_d/D_o > 5$. Practical transition at $B_d/D_o > 3$.*

Figure 11 – Sub-ditch Trench Configurations - Typical

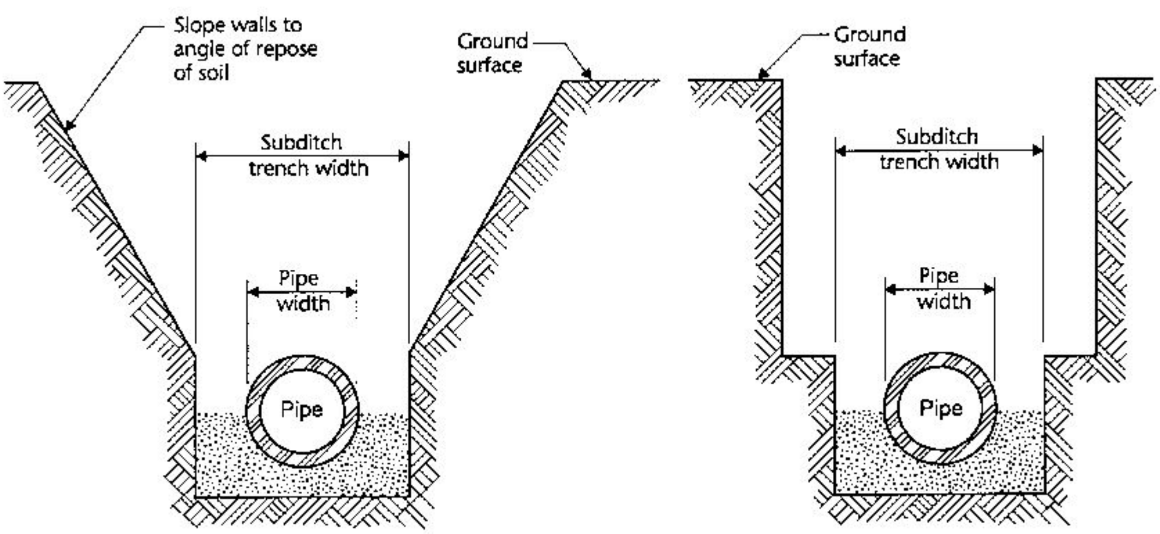
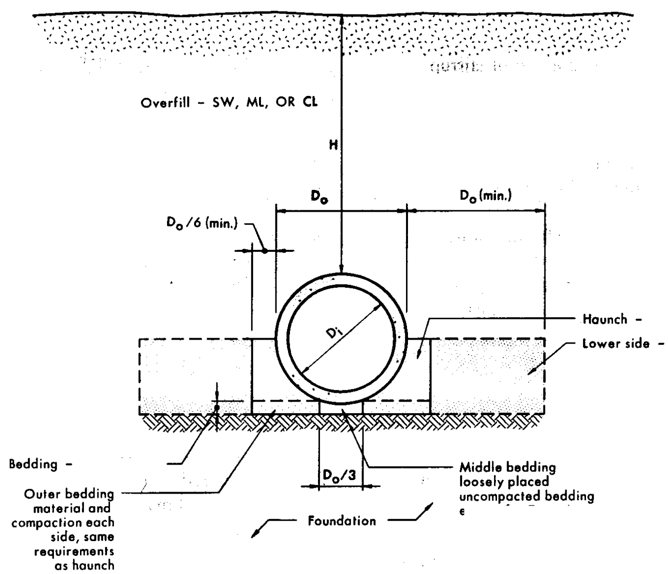


Figure 12 – Wide Trench –Typical



Note 1: *Do not over densify middle-third of bedding under pipe.*
Note 2: *Technical transition to wide trench at* $B_d/D_o > 5$. *Practical transition at* $B_d/D_o > 3$.

17.1.3 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 the values reprinted in Table 6 of Part II of this Standard Practice to gain an appreciation for conditions under which native soils may impact embedment soils in a deleterious manner.

17.2 Narrow, unsupported vertical-walled trenches

17.2.1 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.

17.2.2 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 Table 6 of Part II). The installer, therefore, should pay particular attention to the designer of record's 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.

17.3 Unsupported sub-ditch trenches

17.3.1 Sub-ditch trenches are variations of the narrow vertical wall trenches, where the vertical-walled portion above the pipe has been backcut or sloped. The minimum width of the lower trench for sub-ditch trenches shall conform to the requirements of 17.2.1.

17.3.2 The installer should note that sub-ditch trenches, by design, have the narrowest of trench widths within the embedment zone and, therefore, pipe performance will be significantly impacted by native soil characteristics in all sub-ditch trench applications. As noted in 17.2.2, the installer shall promptly notify the Engineer in all cases where the conditions encountered are at variance with the stated design assumptions.

17.4 Wide trenches – See Figure 6

17.4.1 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.

17.4.2 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.

17.5 Supported trenches

17.5.1 Support of Trench Walls

Where required based on safety regulations, field conditions, or design, the pipe shall be installed in a supported trench.

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.

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.

17.5.2 Supports Left in Place

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. When top of sheeting is to be cut off, make cut 500 mm 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. 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.

17.5.3 Movable Trench Wall Support

Do not disturb the installed pipe and its embedment when using movable trench boxes and shields. Movable supports shall not be used below the top of the pipe zone unless an approved method is used to maintain the integrity of the embedment material. 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.

17.5.4 Removable Trench Wall Support

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

18.0 Foundation

18.1 The foundation soil shall be moderately firm to hard in situ soil, stabilized soil, or compacted fill material.

18.2 When unsuitable or unstable material is encountered, the foundation shall be stabilized.

18.3 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.

19.0 Bedding and Initial Backfill Requirements

19.1 Verification that Proposed Construction Method is Consistent with Design Intent

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.

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.

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.

19.2 Placement of Bedding Materials

19.2.1 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.

19.2.2 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.

19.2.3 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.

19.3 Placement of Haunch and Initial Backfill Materials

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

19.3.2 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.

19.3.3 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.

19.3.4 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.

19.3.5 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 Section 22.0.

20.0 Change in Native Soil Conditions

20.1 The designer will apprise the installer of the assumed in-situ soil conditions that the design was based on. As noted in Part II 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, such that the validity of the original design concept can be reviewed by the designer of record. If necessary, the design will be modified to suit the actual conditions encountered in the field.

20.2 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.

20.3 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.

21.0 Backfill (Overfill) Materials

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

21.2 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.

21.3 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.

22.0 Minimum Cover Requirements for Construction Loads

22.1 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.

22.2 The minimum depth of cover should be established by the project engineer based on the specific project requirements.

22.3 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 as noted in Table 2:

- Provide minimum cover of at least 600 mm or one pipe diameter (whichever is larger) where Class I embedment materials have been utilized, or

- Provide minimum cover of at least 900 mm or one pipe diameter (whichever is larger) where Class II or lower embedment materials have been utilized, and

- Allow at least 1200 mm of cover before using a hydrohammer for compaction directly over the pipe, and

- Where construction loads may be excessive (e.g. cranes, earth moving equipment, etc.) consult with the project engineer to determine minimum operating cover requirements.

23.0 Connection of Flexible Pipe to Manholes

23.1 The installer shall use flexible water stops, resilient connectors, or other flexible systems approved by the project engineer to make watertight connections to manholes and other structures.

23.2 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.

24.0 Completion of Construction Criteria and Acceptance Testing

24.1 Vertical and Horizontal Alignment Tolerances

The pipe shall be installed to the line and grade noted on the construction drawings. Acceptance variance shall be:

- 6 mm plus 20 mm per m of diameter for vertical grade, and
- within 150 mm of the designated alignment for horizontal grade of pipes up to 900 mm in diameter or 50 mm per 300 mm of diameter of the designated alignment for pipes greater than 900 mm in diameter, and

No variance from grade shall be permitted that results in individual joint deflections in excess of the manufacturer's recommended value to maintain hydrostatic integrity to the limits specified herein.

24.2 Infiltration/Exfiltration Limits

Elastomeric gasket joints for pipe and fittings shall meet the requirements of ASTM D3212, except that the internal hydrostatic pressure shall be 100 kPa (15 psi).

24.3 CCTV Inspection

All pipe up to and including 900 mm shall be inspected by CCTV Inspection methods as per Section 403.13.05 CCTV Video Inspection, of the City of Calgary Standard Specifications Sewer Construction latest edition. Pipes larger than 900 mm shall be inspected by man-entry methods as per Section 403.13.05.

24.4 Deflection Testing

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 Section 13.2, Appendix A and the City of Calgary Standard Specifications Sewer Construction latest edition. Deflection tests shall not be carried out sooner than 30 days after installation and backfilling completion to assess short-term deflection and not sooner than 1 year to assess long-term deflection.

APPENDIX A: MANDREL REQUIREMENTS FOR DEFLECTION TESTING

APPENDIX A: MANDREL REQUIREMENTS FOR DEFLECTION TESTING

A1.0 Scope

Appendix A covers the technical requirements for deflection testing of flexible thermoplastic pipe installations within the City of Calgary designed and constructed in accordance with this standard practice.

A2.0 Inspection Method

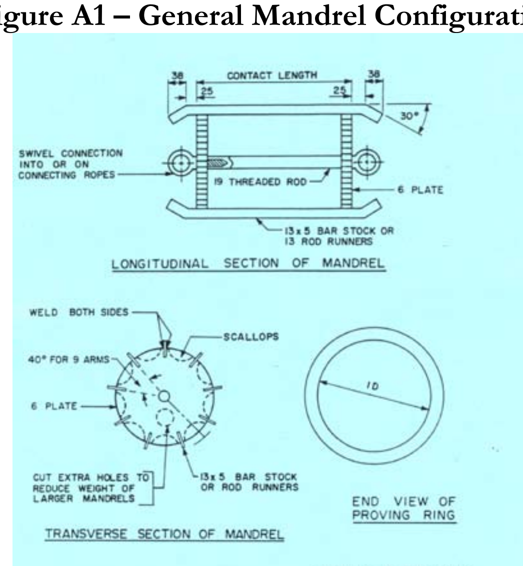
All pipe up to and including 900 mm NPS diameter shall be inspected with "go/no-go" mandrel device as described herein. Pipe larger than 900 mm NPS diameter shall be inspected with a suitable proving device to confirm that vertical deflection does not exceed either the maximum allowable short or long term deflection limits stipulated by Section 13.2.

The mandrel or proving device shall be pulled through the pipe 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.

Deflection testing shall be performed in conjunction with a closed circuit television inspection. The mandrel shall be located in front of, and in clear view of, the television camera. An appropriate distance is typically from 1.5 to 2.5 pipe diameters in front of the television camera.

The mandrel shall be cylindrical in shape, constructed with 9 evenly spaced arms and shall generally conform to Figure A1.

Figure A1 – General Mandrel Configuration



Mandrels larger than 450 mm in diameter shall be constructed of special breakdown devices to facilitate entry through access manholes.

A3.0 Mandrel Dimensional Requirements

The minimum diameter of the circle scribed around the outside of the Mandrel arms shall be equal to the values indicated in Section A4 for each specific pipe material, within a tolerance of +/- 0.25 millimetres. The contact length of the Mandrel shall be measured between the points of contact on the Mandrel arm as indicated on Figure A1. Prior to each use the outside radius of the Mandrel arms shall be checked for conformance with these specifications with a certified Proving Ring.

Either a dual purpose Go/No Go Proving Ring, sized as noted below, must be used, or two separate Proving Rings, one an 'Oversize Ring' which the mandrel must pass through and the second an 'Undersize Ring' which the mandrel must not pass through.

An Oversized Proving Ring shall be manufactured to a diameter equal to the outside diameter of the Mandrel plus 1 millimetre. The Proving Ring shall be manufactured to within 0.25 millimetres of the specified size. The Proving Ring shall be fabricated from 6 millimetre thick steel minimum. Required Mandrel radii are given in Section A4 and Sheet 63 of The City of Calgary Standard Specifications Sewer Construction latest edition.

An Undersized Proving Ring shall be manufactured to a diameter between 0.10 and 0.30 millimetres less than the diameter of a circle that would be scribed by the specified Mandrel size.

The Ring must be stamped with the NAME of the manufacturer or an agreed abbreviation and a unique SERIAL NO. formatted as follows: >**CC**< >daymonthyear of manufacture< >nominal diameter< >**mm**< >5.0% or 7.5%< >Ring No. on the day of manufacture< >SW and/or +PW< (for solid wall or profile wall) >Oversize or Undersize< (if not a Go/No Go Ring).

Also see Section 403.13.04 and Sheet 63 of The City of Calgary Standard Specifications Sewer Construction latest edition.

A4.0 Acceptance Test Limits

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 Section 13.2. Deflection shall be measured versus the appropriate base inside diameter for each specific pipe material as indicated in the following sections.

Base inside diameter for the purposes of this Standard Practice is the base inside diameter as defined by the appropriate CSA Standard than governs manufacture of the specific pipe being tested.

The base inside diameter is the minimum inside pipe diameter prior to calculating allowable deflection and is derived by subtracting a statistical tolerance package from the pipe's average inside diameter. The tolerance package includes allowances for variation in outside diameter, over-thickened walls, and initial out-of-roundness.

A4.1 Solid Wall DR35

Spec	*CSA B182.2*					
Solid Wall PVC						
DR	*35*		*Allowable Vertical Deflection (mm)*			
NPS	*Average Inside Diameter (mm)*	*Base Inside Diameter (BID) (mm)*	*Short Term 5.00%*	*Long Term 7.50%*	*Radius of Mandrel Arm (r) (mm) Short term*	*Long term*
100	100.57	98.40	93.5	91.0	*47.0*	*45.9*
150	149.73	146.50	139.2	135.5	*70.0*	*68.3*
200	200.42	196.11	186.3	181.4	*93.7*	*91.4*
250	250.55	245.16	232.9	226.8	*117.1*	*114.3*
300	298.27	291.86	277.3	270.0	*139.4*	*136.0*
375	365.09	357.25	339.4	330.5	*170.6*	*166.5*
450	446.23	436.64	414.8	403.9	*208.5*	*203.5*
525	526.08	514.77	489.0	476.2	*245.8*	*239.9*
600	591.84	579.11	550.2	535.7	*276.6*	*269.9*
675	666.99	652.64	620.0	603.7	*311.7*	*304.2*
750	763.57	747.68	710.3	691.6	*357.1*	*348.5*
900	913.89	894.77	850.0	827.7	*427.3*	*417.0*
1050	1061.84	1039.51	987.5	961.5	*496.4*	*484.5*
1200	1212.14	1186.60	1127.3	1097.6	*566.7*	*553.0*

A4.2 Profile Wall PVC Pipe

Spec	CSA B182.4					
Profile PVC Pipe						
PS	320 kPa		Allowable Vertical Deflection (mm)			
NPS	Average Inside Diameter	Base Inside Diameter (BID)	Short Term	Long Term	Radius of Mandrel Arm (mm)	
	(mm)	(mm)	5.00%	7.50%	Short term	Long term
100	100.71	98.54	93.6	91.1	47.1	45.9
150	149.71	146.51	139.2	135.5	70.0	68.3
200	200.41	196.11	186.3	181.4	93.7	91.4
250	250.55	245.19	232.9	226.8	117.1	114.3
300	298.13	291.75	277.2	269.9	139.4	136.0
375	365.09	357.28	339.4	330.5	170.6	166.5
450	448.31	438.70	416.8	405.8	209.5	204.5
525	527.05	515.75	490.0	477.1	246.3	240.4
600	596.90	584.17	555.0	540.4	279.0	272.3
675	673.10	659.49	626.5	610.0	314.9	307.4
750	749.30	734.14	697.4	679.1	350.6	342.1
900	901.70	883.46	839.3	817.2	421.9	411.7
1050	1054.10	1032.79	981.2	955.3	493.2	481.3
1200	1206.50	1182.12	1123.0	1093.5	564.5	550.9

APPENDIX B: COMMENTARY

APPENDIX B: COMMENTARY[21]

B.1 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.2 *General* – Sub-surface conditions should be adequately investigated prior to construction, in accordance with Practice D 420, 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.3 *Load/Deflection Performance* – 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. 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.4 *Pipe Deflection* – Pipe deflection is the diametral 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. 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.

B.4.1 *Construction Deflection* – 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. Compaction of the side fill may result in negative vertical deflections (that is, increases in pipe vertical diameter and decreases in horizontal diameter).

B.4.2 *Load-Inducted Deflection* – Load-induced deflections result from backfill loads and other superimposed loads that are applied after the pipe is embedded.

[21] Modified from ASTM 2321-00, Standard Practice for Underground Installation of Thermoplastic Pipe for Sewers and Other Gravity Applications

B.4.3 *Short-term Deflection* – 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. 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.

B.4.4 *Time Dependent Factors* – 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. Time dependent factors are accounted for in this Standard Practice by adjusting acceptable short-term deflection limits by a factor of 1.5.

B.4.5 *Long-term Deflection* – Long-term deflection is the total long term deflection of the pipe. It consists of initial deflection adjusted for time dependent factors as noted. While acknowledged the time-dependent deflection can occur for many years, the experience has shown that the vast majority of long-term deflection (typically 90% or more) has occurred after the first year of installation. For the purposes of this Standard Practice, therefore, the long-term deflection shall be considered to be any deflection measured one year or later after backfilling.

B.5 *Deflection Criteria* – Deflection criteria are the limits set for the design and acceptance of buried flexible pipe installation. Deflection limits for specific pipe systems may be derived from both structural and practical considerations. Structural considerations include pipe cracking, yielding, strength, strain, and local distortion. Practical considerations include such factors as flow requirements, clearance for inspection and cleaning, and maintenance of joint seals. Acceptable short and long-term deflection limits are presented for all pipes addressed by this Standard Practice in Appendix A.

B.6 *Deflection Control* – Embedment materials should be selected, placed, and compacted so as to minimize total deflections and, in any event, to maintain installed deflections within specific limits. Methods of placement, compaction, and moisture control should be selected based on soil types given in Table 1 of Part II of this Standard Practice and on recommendations given in Table 2 of Part II of this Standard Practice. 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.

B.6.1 *Embedment at Pipe Haunches* – 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. A key objective during installation of flexible thermoplastic pipe (or any 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.

B.6.2 *Embedment Density* – 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. The minimum densities given in Table 2 are based on attaining an average modulus of soil reaction (E') of greater than 6.9 MPa (1000 psi) except under special circumstances where Class IVA embedment material is used. 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.7 *Compaction Methods* – 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. 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 A. 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.8 *Migration* – 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. 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 B.8.1 below). In general, where significant ground water flow is anticipated, avoid placing coarse, open-graded materials, such as Class IA, 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. 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 B.10.

B.8.1 The following filter gradation criteria may be used to restrict migration of fines into the voids of coarser material under a hydraulic gradient:

B.8.1.1 $D_{15}/d_{85} < 5$ 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.

B.8.1.2 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 of the coarser material is well-graded (see Test Method D 2487).

B.8.1.3 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 B.8.1.1: D_{15} < 15% by weight of the coarser material.

Note – Materials selected for use based on filter gradation criteria, such as in B.8.1, should be handled and placed in a manner that will minimize segregation.

B.9 *Maximum Particle Size* – Limiting particle size to 20 mm (¾ in.) or less enhances placement of embedment material for nominal pipe sizes 200 mm (8 in.) through 375 mm (15 in.). For smaller pipe, a particle size of about 10% of the nominal pipe diameter is recommended.

B.10 *Embedment Width for Adequate Support* – 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. Under these conditions, for small diameter pipe (12 in (300mm) or less), embedment should be placed and compacted to a point at least 2.5 pipe diameters on either side of the pipe. For pipe larger than 12 in. (300mm), 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.11 *Other Design and Construction Criteria* – The design and construction of the pipe system should recognize conditions that may induce excessive shear, longitudinal bending, or compression loading in the pipe. 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. Other sources of loads on buried pipes are: freezing and thawing of the ground in the vicinity of the pipe, rising and falling of the ground water table, hydrostatic pressure due to ground water, and localized differential settlement loads occurring next to structures such as manholes and foundations. Where external loads are deemed to be excessive, the pipe should be installed in casing pipe or other load limiting structures.

APPENDIX C: DESIGN EXAMPLES

Appendix C - Design Examples

This Memorandum provides a couple of design examples to compute deflection based on the application of the analytical model recommended by this Standard Practice.

The design method recommended by this Standard Practice is comprised of the following basic steps:

1. Determine external loading (both Dead and Live Loading). Dead loading is directly related to the height of cover, while live loading will be a function of the height of cover and the anticipated live loading vehicle (e.g. standard truck loads, railway loads, and/or airport loading).

2. Evaluate whether any special design conditions need to be evaluated and evaluate them independently.

3. Determine a representative Modulus of Soil Reaction, *E'*. The effective or composite Modulus of Soil Reaction will be a function of the embedment soil we select, native soil conditions, and trench width.

4. Select the remaining Modified Iowa Formula parameters including the deflection lag factor (D_L), bedding factor (*K*), and pipe stiffness (*PS*).

5. Calculate horizontal deflection utilizing the Modified Iowa Formula.

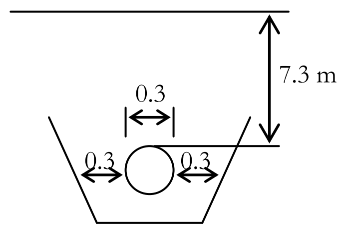
6. Calculate the vertical deflection using Masada's simplified integration of the Modified Iowa Formula. Review the answer versus our performance limits for deflection to determine whether we need to carry out additional iterations with modified bedding conditions, increased trench width, etc.

This is intended to be a relatively simple set of examples, and purposely has omitted reviews of any evaluation of specialized design conditions. Here goes…

EXAMPLE NO. 1

A 300 mm PVC pipe is to be installed with a maximum of 7.3 m of cover. Proposed material for use as bedding and initial backfill is standard City of Calgary bedding sand. This material has been confirmed to have a fines content in the 5-12% range.

The trench configuration is anticipated to be a wyed sub-ditch type of trench with a trench width of O.D. plus 0.6 m at pipe depth (0.9 m).



The installation location is within the right-of-way of a typical residential subdivision within the City of Calgary.

Based on geotechnical investigations carried out in the area, native soils in the pipe zone are predominately comprised of cohesive soils with visual descriptions varying from soft to very soft. Grain size approaches silt or varved silts in clay. Based on the borehole investigations these soils are reported to have unconfined compressive strengths on the order of 15-20 kPa at anticipated pipe depth.

Design computations would include:

1. Dead and Live Load

a. Dead Load (as per Clause 12.1 of the Standard Practice)

$$W_D = \rho * g * H * B_c$$

$$W_D = (2100 kg/m^3) * (9.8064 m/s^2) * 7.3m * 0.3m * (1kN/1000N)$$

$$= 45.10\ kN/m$$

b. Live Load

We'll use the AASHTO Live Load calculation method for simplicity. As this is a residential street we'll assume only 1 large truck as opposed multiple passing trucks. Using this method average pressure is calculated (in SI units) by:

$$w_L = \frac{AxleLoad}{(2.34m + 1.75H)(0.25m + 1.75H)}$$

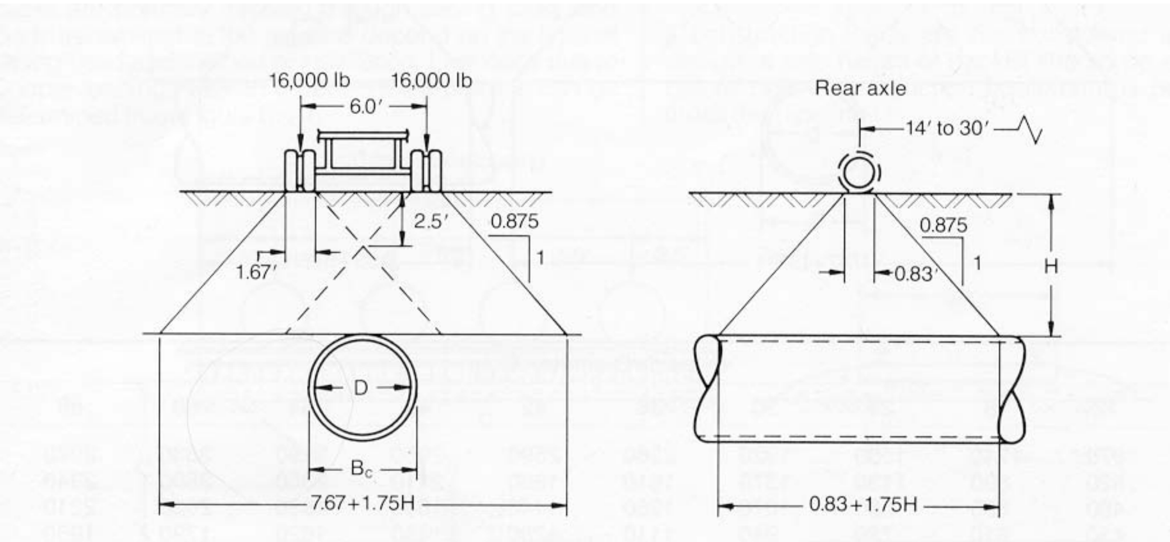
Total live load per unit length of pipe is then calculated by:

$$W_L = w_L B_C (1 + I_f),$$

where I_f = Impact factor

Typical Impact factors (I_f) range from 0.5 at 0.3 m of cover to 0 at 1.8 m of cover or greater.

The AASHTO method is calculating an average stress at pipe depth based on the load distribution assumptions noted in the Figure below.



We'll use an AASHTO HS 20 vehicle (depicted above in Imperial units), which has a total axle load of 142.34 kN (32,000 lbf).

Using SI units, live load pressure is then:

$$w_L = \frac{142.34kN}{(2.34m + 1.75 * 7.3m)(0.25m + 1.75 * 7.3m)} = 0.72kN/m^2 = 0.72kPa$$

Total live load is therefore,

$$W_L = 0.72kN/m^2 * 0.3m(1+0) = 0.22kN/m$$

c. Total Dead + Live Load as a Pressure

As per Clause 13.2.1.3 of our Standard Practice:

$$P = \frac{W_D + W_L}{B_C}$$

Therefore, our total live + dead load is:

$$P = \frac{45.10kN/m + 0.22kN/m}{0.3m} = 151.06kN/m^2 = 151.06kPa$$

We now move on to the Iowa Formula.

2. Evaluate Special Design Conditions

Based on a review of Section 12.3 of the Standard Practice, none present.

3. Determine Modulus of Soil Reaction E'_{design}

E'_{design} will be a function of our embedment material, E'_b, native soil conditions, E'_{native}, and our selected trench width, B_D.

Standard City of Calgary bedding sand with less than 12% fines, is a Class II embedment material (Table 1 on pp 13 of the Standard Practice). We'll assume a minimum of 90% of the maximum standard Proctor dry density (SPD) will be achieved. Based on Table 4 on pp 28 of the Standard Practice, E'_b at all heights of cover greater than 4 m is 11.2 MPa or **11,200 kPa.**

The native soil conditions, E'_{native}, can be estimated based on the geotechnical data. Based on Table 5 of the Standard Practice on pp 29, unconfined compressive strengths of 15-20 kPa for the native soils do indeed correspond to the visual descriptor very soft. The native E'_{native}, can read from Table 5 as **1380 kPa.**

The composite value for E'_{design} can be estimated by determining the modifying factor, S_c, from Table 6 on pp 30 of the Standard Practice by knowing:

$$\frac{E'_{native}}{E'_b} = \frac{1380kPa}{11{,}200kPa} = 0.12$$, and

$$\frac{B_D}{B_C} = \frac{0.9m}{0.3m} = 3$$

Interpolating from the table, S_c, = 0.81, E'_{design} can be calculated by:

$$E'_{design} = S_c \times E'_b = 0.81 * 11{,}200kPa = 9090kPa$$

4. Select remaining parameters for the Modified Iowa Formula

We will need values for:

$$DeflectionLag = D_L = 1.0,$$

(Clause 13.2.1.1 of the Standard Practice) where a Prism Load is used in design, and

$$BeddingFactor = K = 0.10$$

as per Clause 13.2.1.2 of the Standard Practice for 60-75 degree bedding angle, and

$$PipeStiffness = PS = 320kPa$$

for a DR 35 PVC pipe as per Clause 13.2.1.4 of the Standard Practice.

5. Calculate Horizontal Deflection

Using the Modified Iowa formula calculate maximum anticipated long term horizontal deflection (Clause 13.2.1 of the Standard Practice):

$$\frac{\Delta x}{d}(\%) = \frac{100 D_L K P}{0.149(PS) + 0.061E'_{design}} = \frac{100 * 1.0 * 0.10 * 151.06kPa}{0.149 * 320kPa + 0.061 * 9090kPa} = 2.51\%$$

6. Calculate Vertical Deflection

Calculate the deflection ratio with Masada's simplified formula as follows (Clause 13.2.1.7 of the Standard Practice):

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094E'_{design}}{(PS)}$$

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094(9090kPa)}{(320kPa)} = 1.27$$

Therefore, anticipated long-term vertical deflection equals:

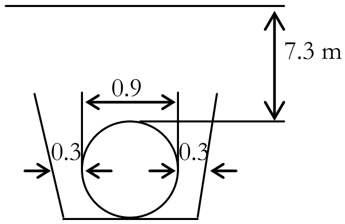
$$\frac{\Delta y}{d} = \frac{\Delta x}{d} * 1.27 = 2.51\% * 1.27 = 3.18\%$$

Which is less than our long-term acceptable limit of 7.50% as per Table 3 on pp 24 of the Standard Practice, and is O.K.

EXAMPLE NO. 2

A 900 mm PVC pipe is to be installed with a maximum of 7.3 m of cover. Proposed material for use as bedding and initial backfill is standard City of Calgary bedding sand. This material has been confirmed to have a fines content in the 5-12% range.

The trench configuration is anticipated to be a wyed sub-ditch type of trench with a trench width of O.D. plus 0.6 m at pipe depth (1.5 m).



The installation location is within the busier right-of-way that may encounter multiple passing trucks.

Based on geotechnical investigations carried out in the area, native soils in the pipe zone are predominately comprised of cohesive soils as per Example No. 1 with visual descriptions varying from soft to very soft. Grain size approaches silt or varved silts in clay. Based on the borehole investigations these soils are reported to have unconfined compressive strengths on the order of 15-20 kPa at anticipated pipe depth.

Design should determine:

1. Dead and Live Load

a. Dead Load (as per Clause 12.1 of the Standard Practice)

$$W_D = \rho * g * H * B_c$$

$$W_D = (2100kg/m^3) * (9.8064m/s^2) * 7.3m * 0.9m * (1kN/1000N)$$

$$= 135.30kN/m$$

b. Live Load

We'll use the AASHTO Live Load calculation method for multiple passing trucks. Using this method average pressure is calculated (in SI units) by:

$$w_L = \frac{AxleLoad}{(5.39m + 1.75H)(0.25m + 1.75H)}$$

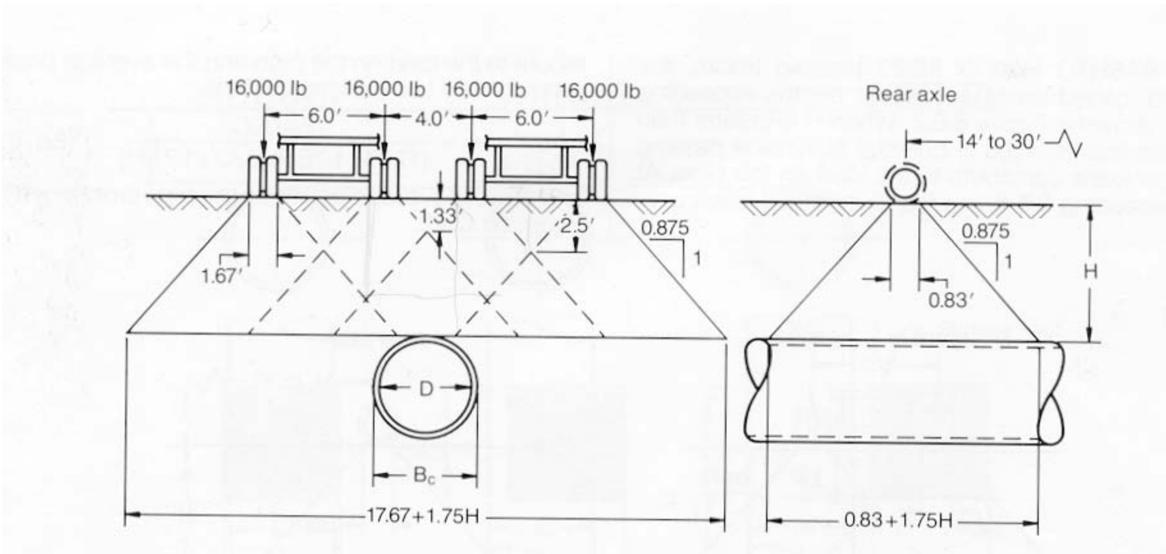
Total live load per unit length of pipe is then calculated by:

$$W_L = w_L B_C (1 + I_f),$$

where I_f = Impact factor

Typical Impact factors (I_f) range from 0.5 at 0.3 m of cover to 0 at 1.8 m of cover or greater.

The AASHTO method for multiple trucks is calculating an average stress at pipe depth based on the load distribution assumptions noted in the Figure below.



We'll continue to use an AASHTO HS 20 vehicle (depicted above in Imperial units), which has a total axle load of 142.34 kN (32,000 lbf) per truck for a total load of 284.69 kN (64,000 lbf).

Using SI units, live load pressure is then:

$$w_L = \frac{284.69kN}{(5.39m + 1.75 * 7.3m)(0.25m + 1.75 * 7.3m)} = 1.20kN/m^2 = 1.20kPa$$

$$W_L = 1.20kN/m^2 * 0.9m(1+0) = 1.08kN/m$$

Total live load is therefore,

c. Total Dead + Live Load as a Pressure

As per Clause 13.2.1.3 of our Standard Practice:

$$P = \frac{W_D + W_L}{B_C}$$

Therefore, our total live + dead load is:

$$P = \frac{135.30kN/m + 1.08kN/m}{0.9m} = 151.54N/m^2 = 151.54kPa$$

We now move on to the Iowa Formula.

2. Evaluate Special Design Conditions

Based on a review of Section 12.3 of the Standard Practice, none present.

3. Determine Modulus of Soil Reaction E'_{design}

E'_{design} will be a function of our embedment material, E'_b, native soil conditions, E'_{native}, and our selected trench width, B_D.

Standard City of Calgary bedding sand with less than 12% fines, is a Class II embedment material (Table 1 on pp 13 of the Standard Practice). We'll assume a minimum of 90% of the maximum standard Proctor dry density (SPD) will be achieved. Based on Table 4 on pp 28 of the Standard Practice, E'_b at all heights of cover greater than 4 m is 11.2 MPa or **11,200 kPa.**

The native soil conditions, E'_{native}, can be estimated based on the geotechnical data. Based on Table 5 of the Standard Practice on pp 29, unconfined compressive strengths of 15-20 kPa for the native soils do indeed correspond to the visual descriptor very soft. The native E'_{native}, can read from Table 5 as **1380 kPa.**

The composite value for E'_{design} can be estimated by determining the modifying factor, S_c, from Table 6 on pp 30 of the Standard Practice by knowing:

$$\frac{E'_{native}}{E'_b} = \frac{1380kPa}{11{,}200kPa} = 0.12$$, and

$$\frac{B_D}{B_C} = \frac{1.5m}{0.9m} = 1.67$$

Interpolating from the table, S_c, = 0.23, E'_{design} can be calculated by:

$$E'_{design} = S_c \times E'_b = 0.23 * 11{,}200kPa = 2630kPa$$

4. Select remaining parameters for the Modified Iowa Formula

We will need values for:

$$DeflectionLag = D_L = 1.0,$$

(Clause 13.2.1.1 of the Standard Practice) where a Prism Load is used in design, and

$$BeddingFactor = K = 0.10$$

as per Clause 13.2.1.2 of the Standard Practice for 60-75 degree bedding angle, and

$$PipeStiffness = PS = 320kPa$$

for a DR 35 PVC pipe as per Clause 13.2.1.4 of the Standard Practice.

5. Calculate Horizontal Deflection

Using the Modified Iowa formula, calculate the maximum anticipated long term horizontal deflection (Clause 13.2.1 of the Standard Practice):

$$\frac{\Delta x}{d}(\%) = \frac{100 D_L K P}{0.149(PS) + 0.061 E'_{design}} = \frac{100 * 1.0 * 0.10 * 151.54kPa}{0.149 * 320kPa + 0.061 * 2630kPa} = 7.28\% < 7.50\%$$

6. Calculate Vertical Deflection

Calculate the deflection ratio with Masada's simplified formula as follows (Clause 13.2.1.7 of the Standard Practice):

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094 E'_{design}}{(PS)}$$

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094(2630kPa)}{(320kPa)} = 1.08$$

Therefore, anticipated long-term vertical deflection equals:

$$\frac{\Delta y}{d} = \frac{\Delta x}{d} * 1.08 = 7.28\% * 1.08 = 7.84\% > 7.50\%$$

◄ **Exceeds long-term deflection limit**

This is greater than our long-term acceptable limit of 7.50% (see Table 3 on pp 24 of the Standard Practice) and is not O.K. We could either increase minimum trench width or upgrade the density requirements for the backfill material. We're going to try increasing minimum density requirements to 95% SPD. If this is truly required as a minimum density our Standard Practice recommends we utilize Class I embedment materials, which in this application would well be advised to be a crushed, well-graded aggregate material to prevent long-term soil migration.

This changes things as follows:

$E_b^{'} = 20.7MPa = 20{,}700kPa$ based on Table 4.

$$\frac{E_{native}^{'}}{E_b^{'}} = \frac{1380kPa}{20{,}700kPa} = 0.07$$

$$\frac{B_D}{B_C} = \frac{1.5m}{0.9m} = 1.67$$

By interpolating in Table 6 using a $\frac{E_{native}^{'}}{E_b^{'}}$ value of 0.1, we get:

$$E'_{design} = S_c \times E'_b = 0.20 * 20{,}700kPa = 4140kPa$$

Horizontal deflection becomes:

$$\frac{\Delta x}{d}(\%) = \frac{100 D_L K P}{0.149(PS) + 0.061 E'_{design}} = \frac{100 * 1.0 * 0.10 * 151.54kPa}{0.149 * 320kPa + 0.061 * 4140kPa} = 5.05\%$$

Our deflection ratio becomes:

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094(4140kPa)}{320kpa} = 1.12$$

Anticipated long-term vertical deflection then becomes

$$\frac{\Delta y}{d} = \frac{\Delta x}{d} * 1.12 = 5.05\% * 1.12 = 5.66\% < 7.50\%$$

.

An alternative to upgrading embedment material would be to increase trench width. Upgrading the trench width to 2.5 * B_C may not only be more effective at reducing deflection but more practical than changing embedment materials. Let's see how it would fair. Our design E' becomes:

$$\frac{E_n^{'}}{E_b^{'}} = \frac{1380kPa}{11{,}200kPa} = 0.12$$

$$\frac{B_D}{B_C} = 2.5$$

$$E'_{design} = S_c \times E'_b = 0.62 * 11{,}200 = 6980kPa$$

Horizontal deflection becomes:

$$\frac{\Delta x}{d}(\%) = \frac{100 D_L K P}{0.149(PS) + 0.061 E'_{design}} = \frac{100 * 1.0 * 0.10 * 151.54kPa}{0.149 * 320kPa + 0.061 * 6980kPa} = 3.20\%$$

Our deflection ratio becomes:

$$\left|\frac{\Delta y}{\Delta x}\right| = 1 + \frac{0.0094(6980kPa)}{320kPa} = 1.21$$

Anticipated long-term vertical deflection now becomes:

$$\frac{\Delta y}{d} = \frac{\Delta x}{d} * 1.21 = 3.20\% * 1.21 = 3.86\%$$

This level of anticipated long-term deflection is O.K.

From this analysis it is evident that increasing trench width is more effective at reducing deflection than increasing densities in the embedment zone. It also doesn't require acquiring a brand new bedding material or force a contractor to achieve densities that are, from a practical perspective, much harder to achieve.

CLOSURE

Both design examples purposely used very poor native soil examples. Native soils in most areas of Calgary are better than this, however, we have seen unconfined compressive strengths as low as these in previous test hole logs, particularly in areas with native soils similar to the IPC area.

When native soil conditions yield values higher than your embedment soil E', we do not as a rule increase the design modulus of soil reaction, even though it would be technically a correct reflection of pipe-soil interaction.

What is importantly illustrated by the two examples from a practical perspective, are the subtle differences between small diameter and intermediate to larger diameter pipe design and trench width, particularly in situations when native soils turn ugly. Even though we're a big proponent of upgrading bedding material in these installations, it is important to note that increasing trench width will minimize the deleterious impact of poor native soils on our embedment material more effectively than upgrading embedment densities alone. From a practical perspective, however, utilizing Class I embedment materials may be the only way to consistently achieve densities even as high as 90% SPD when native ground conditions are very wet.

Respectfully Submitted,

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