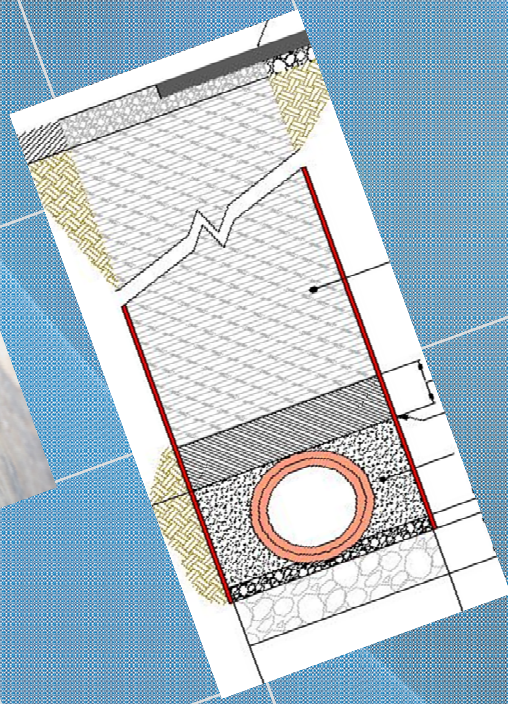
Buried Pipe Installation Trench Design Workshop

Coachella Valley Water District

Ed Kampbell, PE
Luis Roberto Leon, PE, BCEE

April, 2015



WATER DISTRICT

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INTRODUCTION

MARK JOHNSON, PE
DIRECTOR OF ENGINEERING

Agenda

- CVWD Guidelines & Resources
  - District-specific Guidelines
  - Buried Pipe Design Resources for the Practicing Engineer
- Brief History of the Art of Buried Pipe Design
- Soil-Structure Interaction Theory
  - Soils Investigations
  - Buried Structures relationship with the surrounding soils
  - Groundwater
- Buried Pipe Design Approaches
  - Rigid Pipe
    - Narrow Trench Loads
    - Load or bedding factors for standard trenches
    - Effect of Trench Width
  - Flexible Pipe
    - Trench Load on pipe
    - Pipe Embedment
    - Effect of Trench Width
  - Other Design Considerations
    - Trench Safety
    - Pipe Trench Foundation design
    - Pipe Burial below the Phreatic Surface
- Construction Observation
  - Design Factor of Safety
  - Changed Conditions

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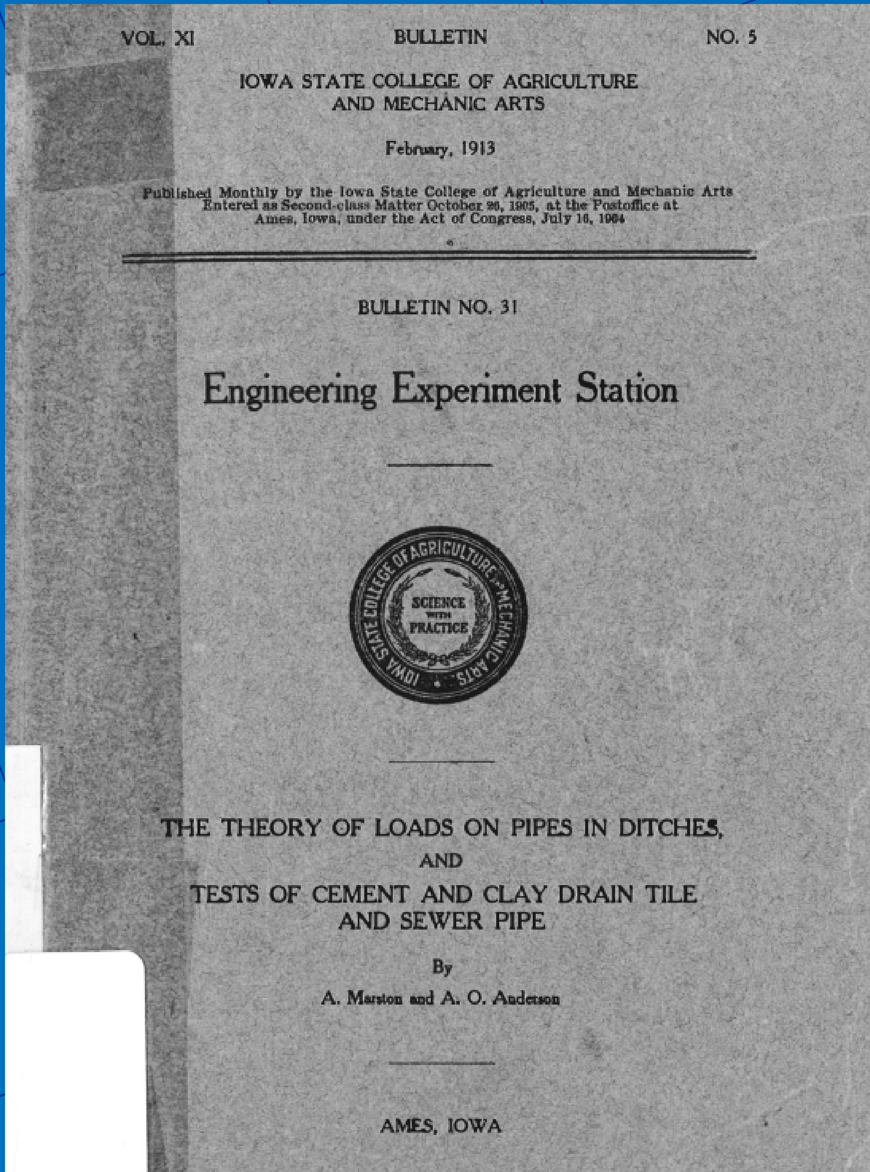
CVWD Guidelines

- Geotechnical Investigation Guidelines for Pipeline Projects
- Pipe Materials for Non-Pressurized Pipeline Projects
- Pipe Materials for Pressurized Pipeline Projects
- Specification for Dewatering

Buried Pipe Design Resources

- Flexible Pipe Design standards integration
  - AWWA M11 Steel Pipe Guide (2013)
  - AWWA M23 PVC Pipe Design & Installation (2003)
  - AWWA M45 Fiberglass Pipe Design (2014)
  - Uni-Bell Handbook of PVC Pipe (2012)
  - PPI Plastic Pipe Handbook (2012)
  - Design of Ductile Iron Pipe, DIPRA (2012)
  - Welded Steel Pipe Design Manual, AISI (2007)
  - Thickness Design of Ductile Iron Pipe, AWWA C150
- Rigid Pipe Design standards integration
  - Concrete Pipe Design Manual (2007)
  - Clay Pipe Engineering Manual (2014)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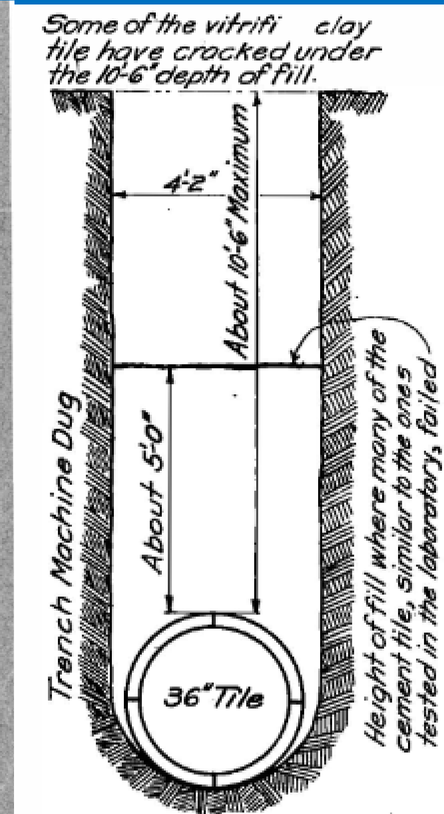
Engineering Experiment Station

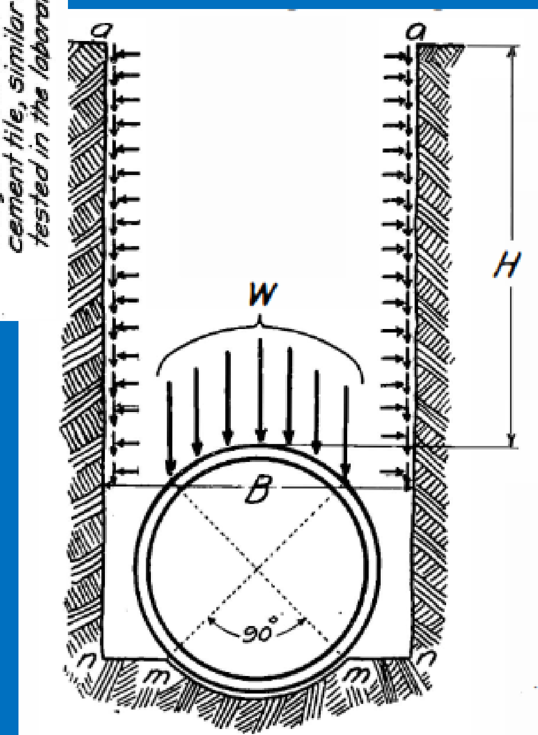
IOWA STATE COLLEGE OF AGRICULTURE AND MECHANIC ARTS
SCIENCE WITH PRACTICE

THE THEORY OF LOADS ON PIPES IN DITCHES,
AND
TESTS OF CEMENT AND CLAY DRAIN TILE
AND SEWER PIPE

By
A. Marston and A. O. Anderson

AMES, IOWA





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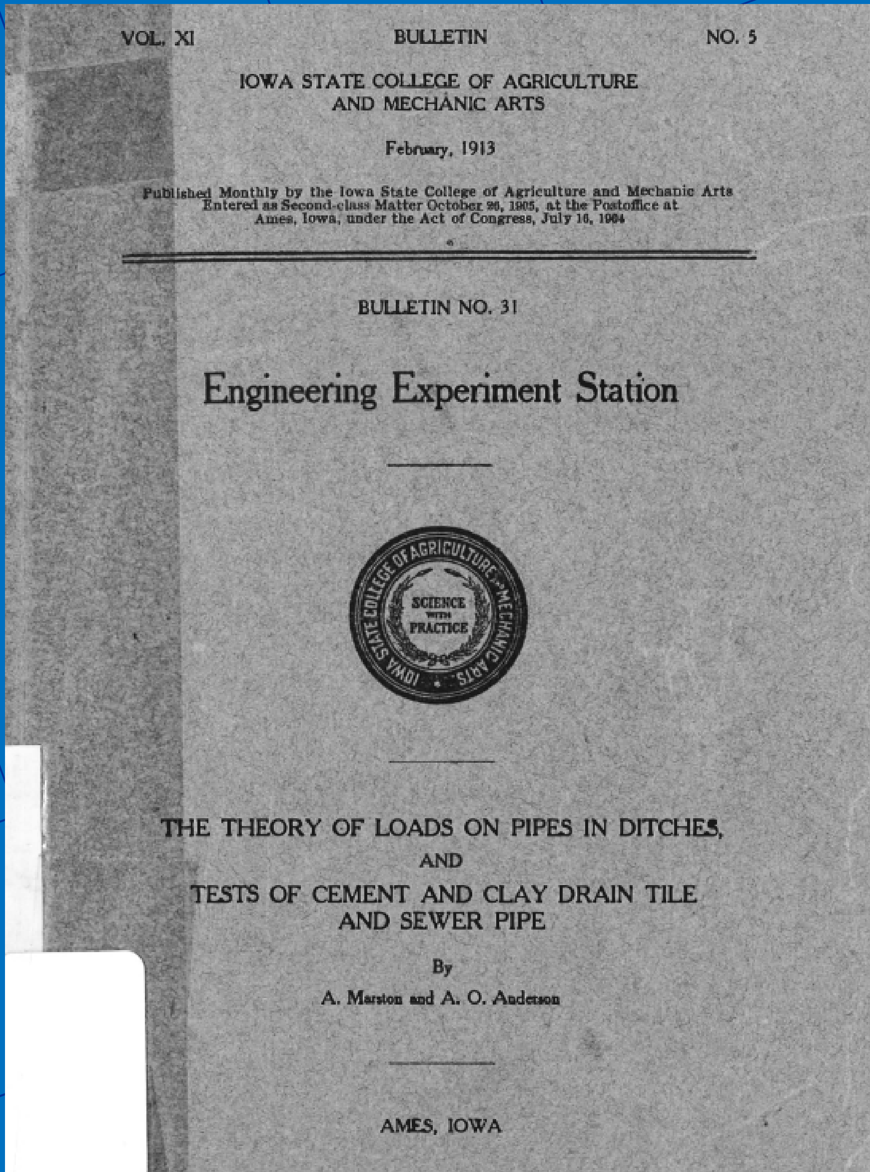

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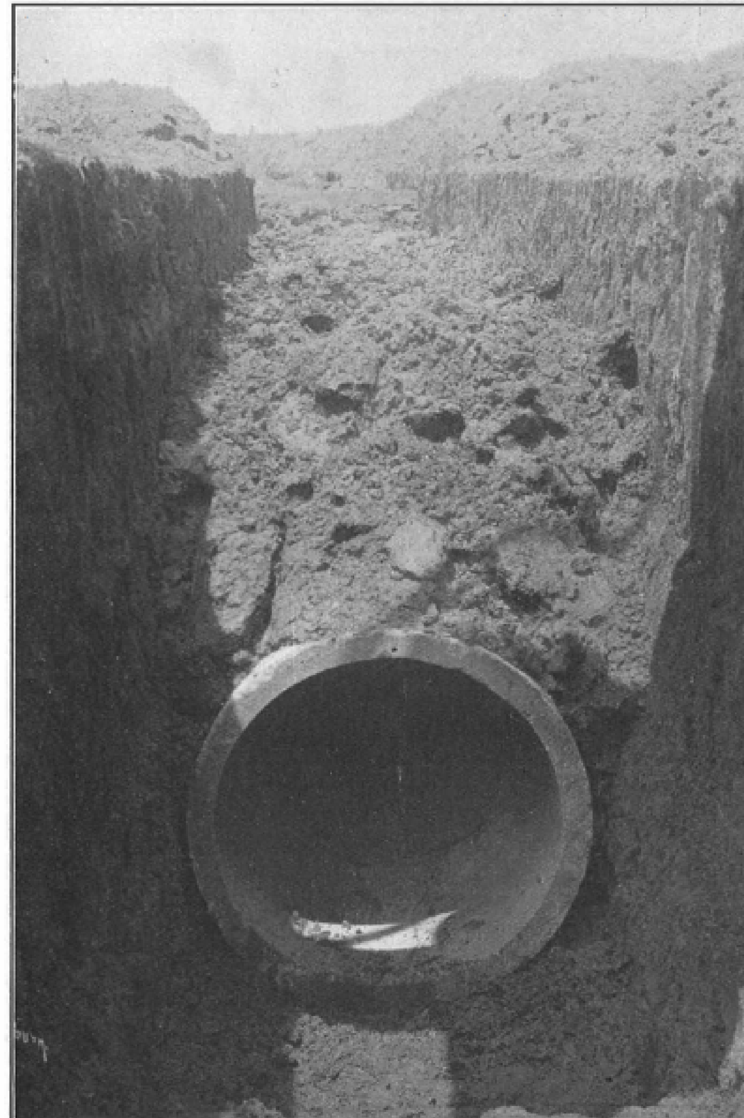

Fig. 22. Photograph Showing Typical Actual Field Conditions of Bedding and Loading of Pipes in Ditches.

The bottom of the pipes are bedded for about 90 degrees of the circumference. There is practically no side support. The load of ditch filling material is supported mainly by the top 90 degrees of the circumference.

Photograph was of the pipe being laid when the photographer came upon the work without previous notice.

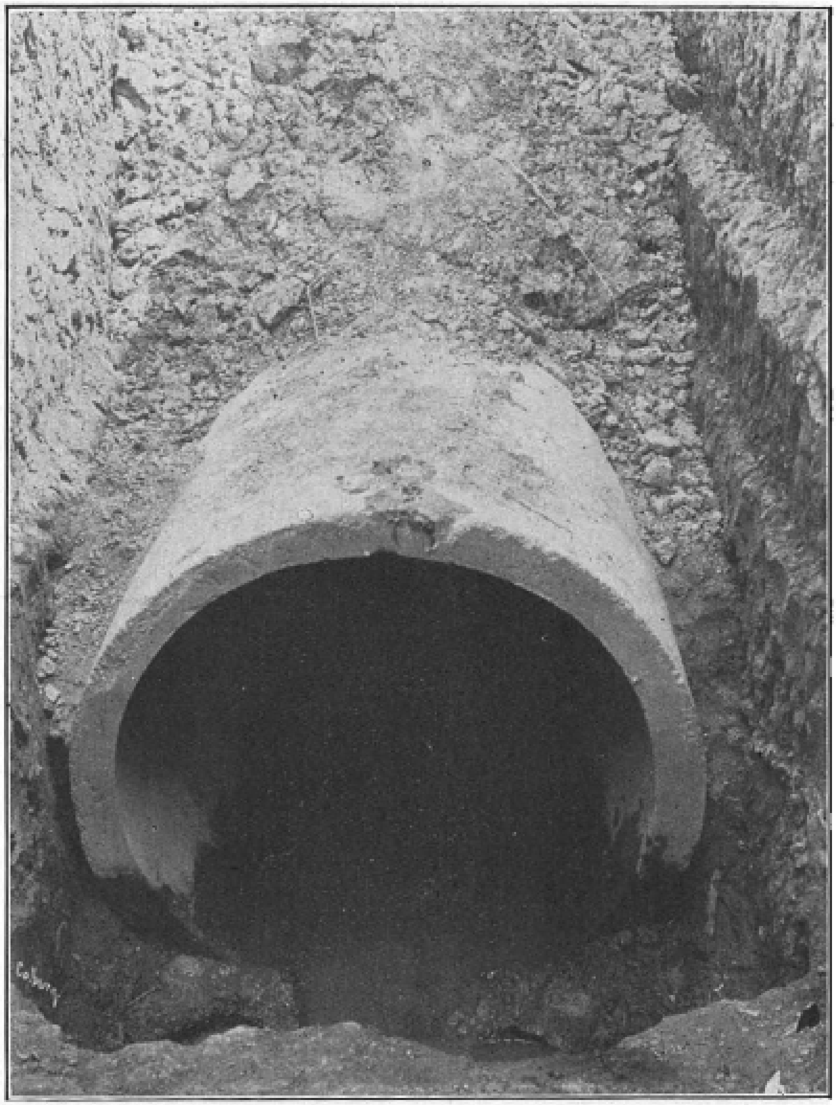

Fig. 23. Photograph Showing the very Best Possible Bedding of Pipes in Ditches.

The bottom of the ditch has been shaped to fit the 36 in. pipe and the bottoms of the pipes bedded in a layer of granular material. The side filling has been carefully tamped around the pipe.

In spite of this care in laying all the pipe cracked under about 9 ft. of fill.

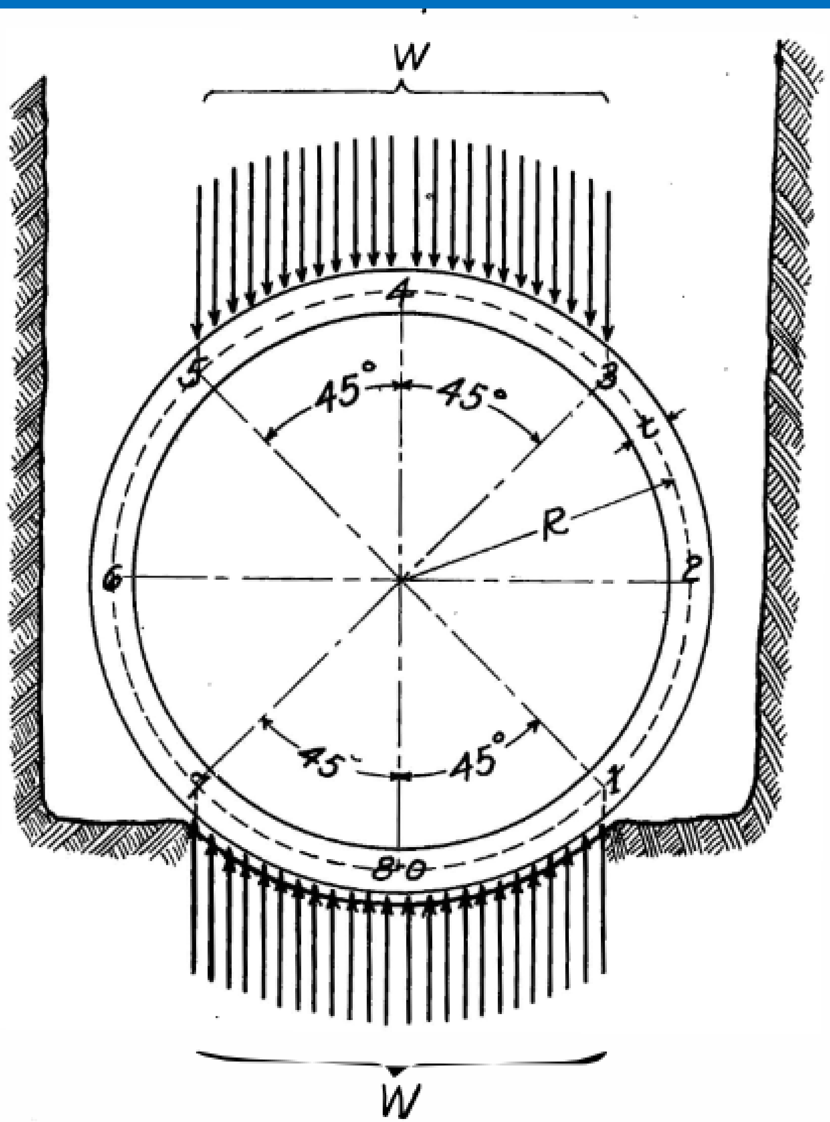

Fig. 24. Diagram Illustrating the Calculation of the Modulus of Rupture, and Showing the Approximate Loading on Drain Tile and Sewer Pipe from Ordinary Ditch Filling, and from the Loads Applied in Iowa Standard Laboratory Tests of Bearing Strength.

In the Laboratory tests the pipe are bedded in sand for 90 degrees of the circumference at the bottom, and the same amount at the top.

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SOIL ENGINEERING

Second Edition

MERLIN GRANT SPANGLER

Research Professor of Civil Engineering
Iowa State University

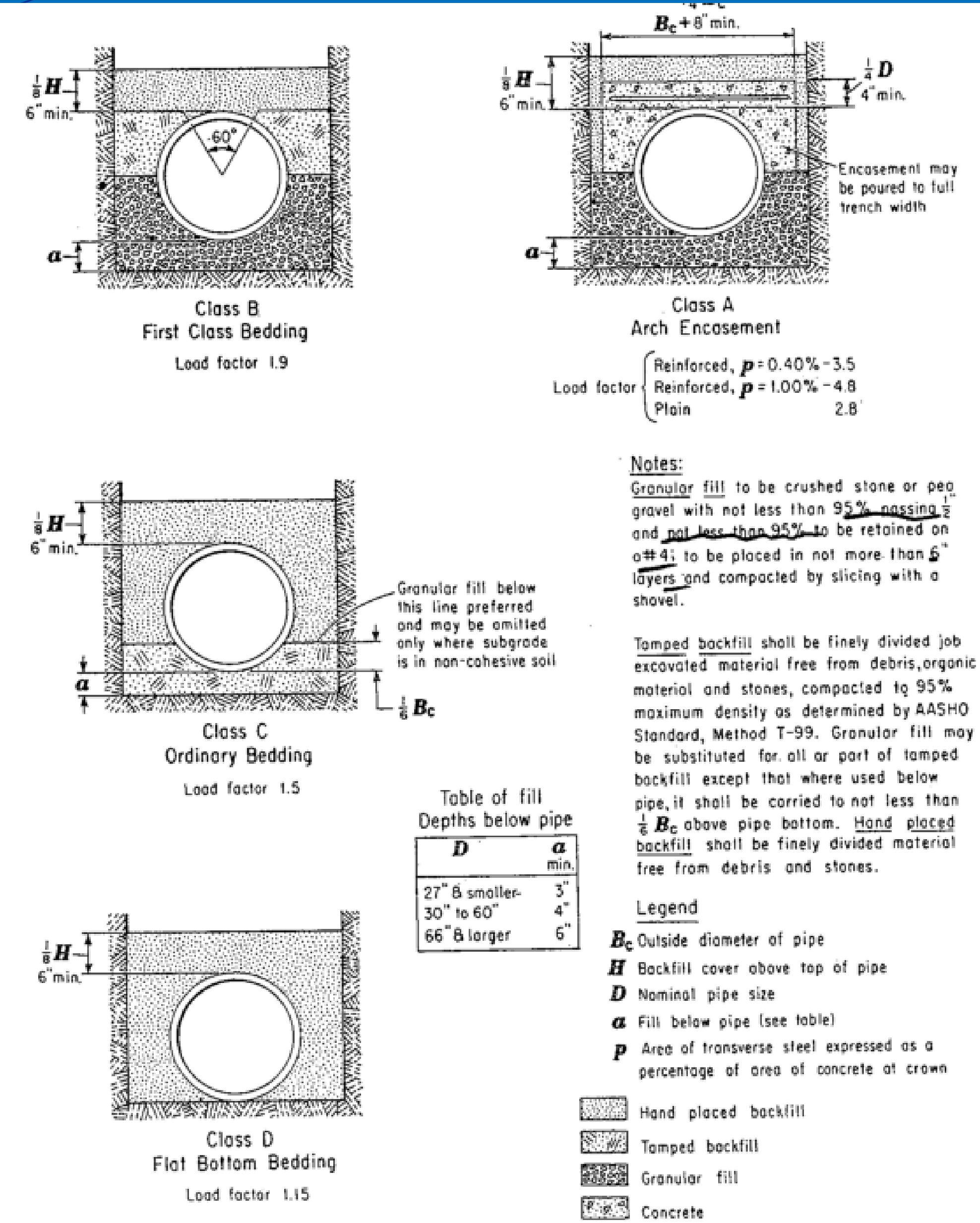


Fig. 25-3. Beddings and Load Factors for Rigid Conduits in Trenches

Impermissible bedding

Method of bedding a ditch conduit in which little or no care is exercised to shape the foundation to fit the lower part of the conduit exterior or to refill all spaces under and around the conduit with granular materials at least partially compacted

Ordinary bedding

- Method of bedding a ditch conduit in which the conduit is bedded with "ordinary" care in an earth foundation shaped to fit the lower part of the conduit exterior with reasonable closeness for a width of at least 50% of the conduit breadth; and in which the remainder of the conduit is surrounded to a height of at least 0.5 feet above its top by granular materials that are shovel-placed and shovel-tamped to completely fill all spaces under and adjacent to the conduit.
- All this work must be done under the general direction of a competent engineer.

First-class bedding

- Method of bedding a ditch conduit in which the conduit is carefully bedded on fine granular materials in an earth foundation that is carefully shaped to fit the lower part of the conduit exterior for a width of at least 60% of the conduit breadth; and in which the remainder of the conduit is entirely surrounded to a height of at least 1.0 ft. above its top by granular materials that are carefully placed to fill all spaces under and adjacent to the conduit and that are thoroughly tamped on each side and under the conduit as far as practicable in layers not exceeding 0.5 ft. in thickness
- All work must be done under the direction of a competent engineer represented by a competent inspector who is constantly present during the operation.

Soil-Structure Interaction Theory

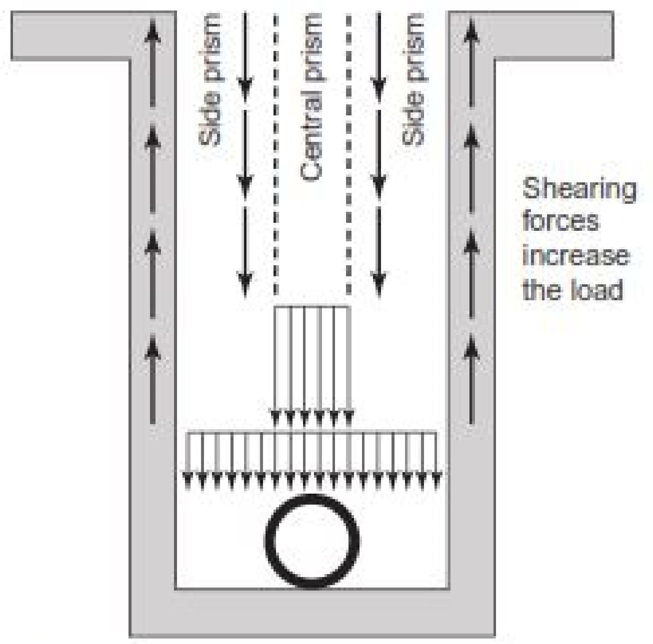


Fig. 6.2 Downward shearing forces over rigid pipe.

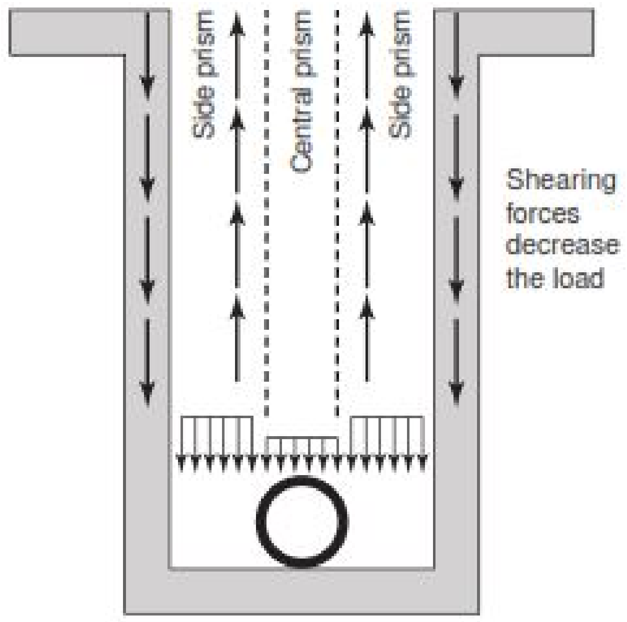
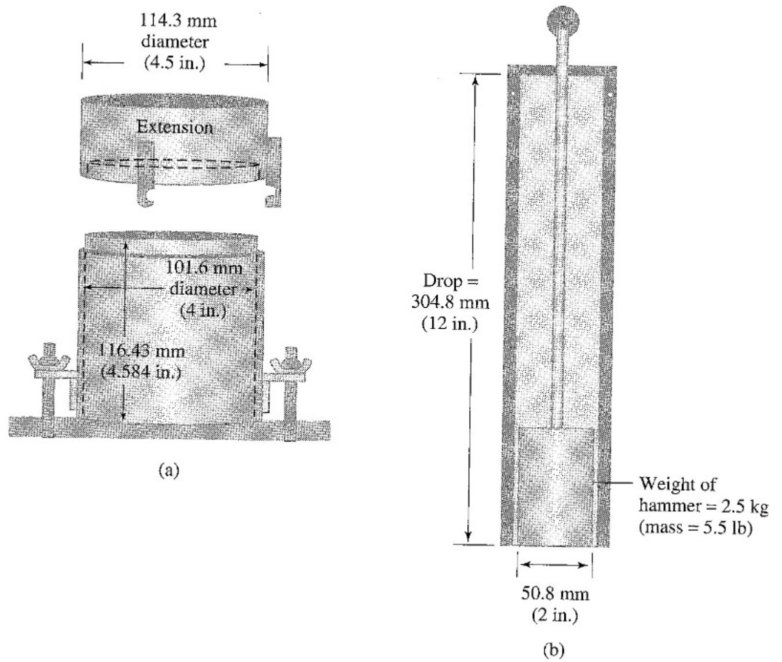
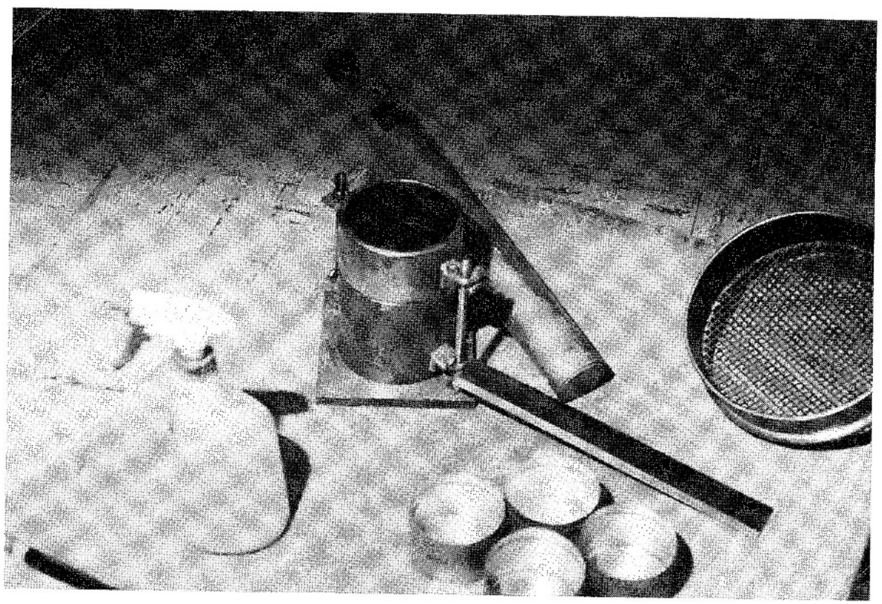


Fig. 6.3 Upward shearing forces over flexible pipe.

SC1, SC2, SC3, SC4, and SC5….

Native Backfill Soil Classification (NBSC)	Group name	Approximate Weight	Average Weight	$K\mu'$	Soil Stiffness	
Crushed Rock	Man-Made		130	0.192	SC 1	≤15% Sand, max 25% passing ⅜-in Sieve, max 5% passing No. 200 Sieve
GW	Well-Graded Sand	119-128	124	0.165	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
GP	Poorly-Graded Gravel	104-128	122	0.165	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
GM	Silty Gravel	87-133	113	0.165	SC 3	Coarse-Grained Soils With More Than 12% Fines
GC	Clayey Gravel	96-129	117	0.165	SC 3	Coarse-Grained Soils With More Than 12% Fines
SW	Well-Graded Sand	118-135	126	0.150	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
SP	Poorly Graded Sand	106-135	116	0.150	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
SM	Silty Sand	93-133	117	0.150	SC 3	Coarse-Grained Soils With More Than 12% Fines
SC	Clayey Sand	104-132	119	0.150	SC 3	Coarse-Grained Soils With More Than 12% Fines
CL, ML	With Sand Or Gravel	90-121	109	0.130	SC 3	Sandy Or Gravelly Fine-Grained Soils With More Than 30% Retained On The No. 200 Sieve
Fine-Grained Soils -1		82-126	103	0.130	SC 3	Sandy Or Gravelly Fine-Grained Soils With More Than 30% Retained On The No. 200 Sieve (Cl-Ml, Cl/Ml, Ml/Cl)
Fine-Grained Soils -2		82-107	95	0.110	SC 4	Fine-Grained Soil With 30% Or Less Retained On The No. 200 Sieve (Cl-Ml, Cl/Ml, Ml/Cl)
MH, CH, OL, OH, PT		83-89	85	0.110	SC 5	Highly Plastic And Organic Soils





Standard Proctor Density Test
> 3 layers of soil
> 25 hammer blows per layer
> 5.5 lb. hammer
> 12 inch drop

Modified Proctor Density Test
> 5 layers of soil
> 25 hammer blows per layer
> 10 lb. hammer
> 18 inch drop

Buried piping is based upon the Standard Proctor Density because of the size of the equipment, need to not disturb the pipe, need not to damage the pipe, etc…

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Buried piping is based upon the Standard Proctor Density because of the size of the equipment, need to not disturb the pipe, need not to damage the pipe, etc…

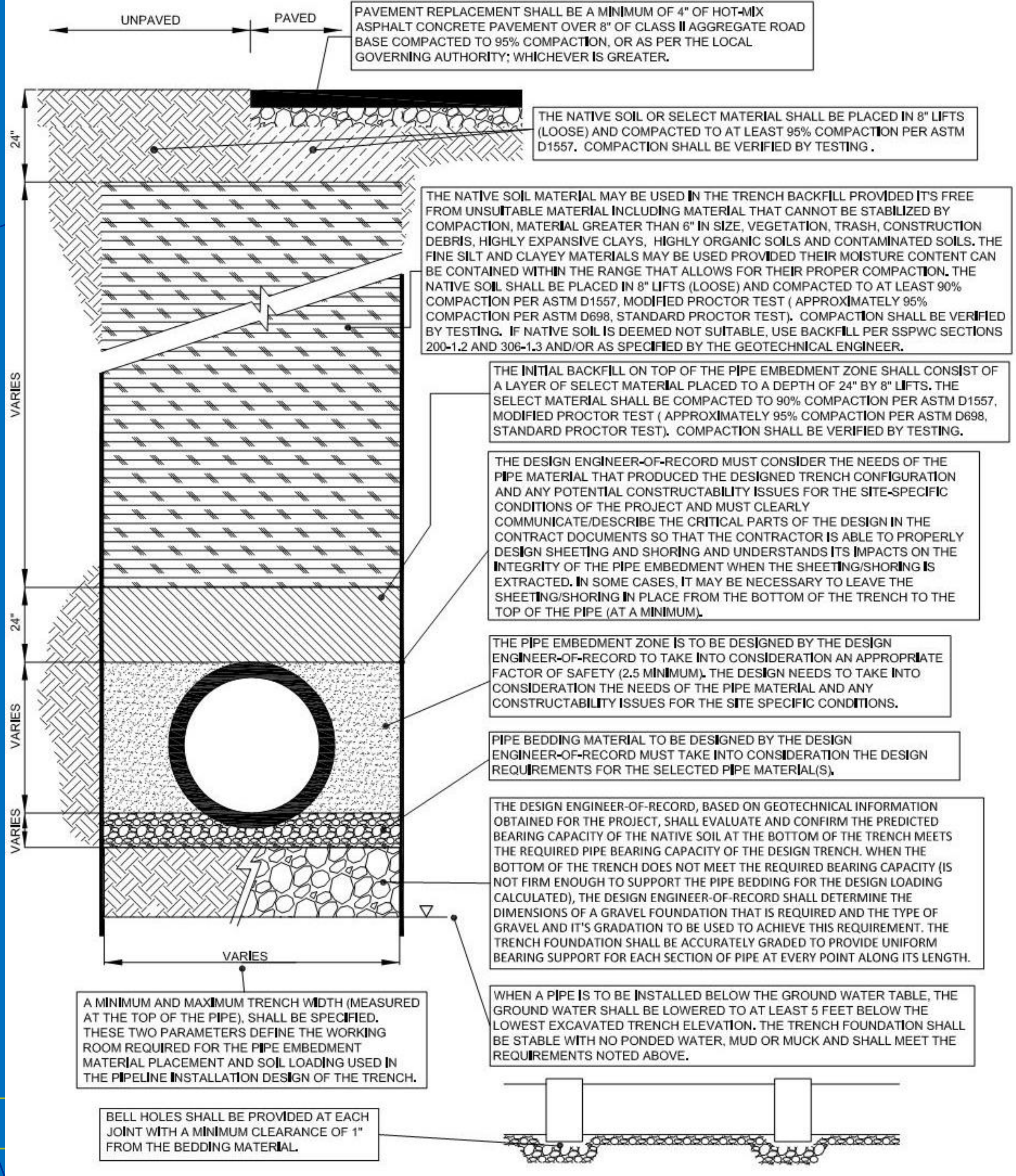
Why use a safety factor? How is it settled on?

The assignment of a factor of safety is done by accounting for:

- the magnitude of damages related to any potential loss of life or property damage,
- the relative cost of increasing or decreasing the FS,
- relative change in the probability of a failure by changing the FS,
- the reliability of the soil data,
- construction tolerances,
- changes in the soil properties due to the anticipated construction operations,
- the accuracy (or approximations used) in developing the design/analysis methods.

CVWD's minimum recommended factor of safety is 2.5 for H/D ≥ 2, or 3.0 for H/D < 2

(Where H is the height in feet of the fill over the pipe and D is the O.D. of the pipe in feet)


UNPAVED
PAVED
PAVEMENT REPLACEMENT SHALL BE A MINIMUM OF 4" OF HOT-MIX ASPHALT CONCRETE PAVEMENT OVER 8" OF CLASS II AGGREGATE ROAD BASE COMPACTED TO 95% COMPACTION, OR AS PER THE LOCAL GOVERNING AUTHORITY; WHICHEVER IS GREATER.
THE NATIVE SOIL OR SELECT MATERIAL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 95% COMPACTION PER ASTM D1557. COMPACTION SHALL BE VERIFIED BY TESTING.
24"
THE NATIVE SOIL MATERIAL MAY BE USED IN THE TRENCH BACKFILL PROVIDED IT'S FREE FROM UNSUITABLE MATERIAL INCLUDING MATERIAL THAT CANNOT BE STABILIZED BY COMPACTION, MATERIAL GREATER THAN 6" IN SIZE, VEGETATION, TRASH, CONSTRUCTION DEBRIS, HIGHLY EXPANSIVE CLAYS, HIGHLY ORGANIC SOILS AND CONTAMINATED SOILS. THE FINE SILT AND CLAYEY MATERIALS MAY BE USED PROVIDED THEIR MOISTURE CONTENT CAN BE CONTAINED WITHIN THE RANGE THAT ALLOWS FOR THEIR PROPER COMPACTION. THE NATIVE SOIL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING. IF NATIVE SOIL IS DEEMED NOT SUITABLE, USE BACKFILL PER SSPWC SECTIONS 200-1.2 AND 306-1.3 AND/OR AS SPECIFIED BY THE GEOTECHNICAL ENGINEER.
VARIES
THE INITIAL BACKFILL ON TOP OF THE PIPE EMBEDMENT ZONE SHALL CONSIST OF A LAYER OF SELECT MATERIAL PLACED TO A DEPTH OF 24" BY 8" LIFTS. THE SELECT MATERIAL SHALL BE COMPACTED TO 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING.
THE DESIGN ENGINEER-OF-RECORD MUST CONSIDER THE NEEDS OF THE PIPE MATERIAL THAT PRODUCED THE DESIGNED TRENCH CONFIGURATION AND ANY POTENTIAL CONSTRUCTABILITY ISSUES FOR THE SITE-SPECIFIC CONDITIONS OF THE PROJECT AND MUST CLEARLY COMMUNICATE/DESCRIBE THE CRITICAL PARTS OF THE DESIGN IN THE CONTRACT DOCUMENTS SO THAT THE CONTRACTOR IS ABLE TO PROPERLY DESIGN SHEETING AND SHORING AND UNDERSTANDS ITS IMPACTS ON THE INTEGRITY OF THE PIPE EMBEDMENT WHEN THE SHEETING/SHORING IS EXTRACTED. IN SOME CASES, IT MAY BE NECESSARY TO LEAVE THE SHEETING/SHORING IN PLACE FROM THE BOTTOM OF THE TRENCH TO THE TOP OF THE PIPE (AT A MINIMUM).
24"
THE PIPE EMBEDMENT ZONE IS TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD TO TAKE INTO CONSIDERATION AN APPROPRIATE FACTOR OF SAFETY (2.5 MINIMUM). THE DESIGN NEEDS TO TAKE INTO CONSIDERATION THE NEEDS OF THE PIPE MATERIAL AND ANY CONSTRUCTABILITY ISSUES FOR THE SITE SPECIFIC CONDITIONS.
VARIES
PIPE BEDDING MATERIAL TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD MUST TAKE INTO CONSIDERATION THE DESIGN REQUIREMENTS FOR THE SELECTED PIPE MATERIAL(S).
VARIES
THE DESIGN ENGINEER-OF-RECORD, BASED ON GEOTECHNICAL INFORMATION OBTAINED FOR THE PROJECT, SHALL EVALUATE AND CONFIRM THE PREDICTED BEARING CAPACITY OF THE NATIVE SOIL AT THE BOTTOM OF THE TRENCH MEETS THE REQUIRED PIPE BEARING CAPACITY OF THE DESIGN TRENCH. WHEN THE BOTTOM OF THE TRENCH DOES NOT MEET THE REQUIRED BEARING CAPACITY (IS NOT FIRM ENOUGH TO SUPPORT THE PIPE BEDDING FOR THE DESIGN LOADING CALCULATED), THE DESIGN ENGINEER-OF-RECORD SHALL DETERMINE THE DIMENSIONS OF A GRAVEL FOUNDATION THAT IS REQUIRED AND THE TYPE OF GRAVEL AND IT'S GRADATION TO BE USED TO ACHIEVE THIS REQUIREMENT. THE TRENCH FOUNDATION SHALL BE ACCURATELY GRADED TO PROVIDE UNIFORM BEARING SUPPORT FOR EACH SECTION OF PIPE AT EVERY POINT ALONG ITS LENGTH.
VARIES
A MINIMUM AND MAXIMUM TRENCH WIDTH (MEASURED AT THE TOP OF THE PIPE), SHALL BE SPECIFIED. THESE TWO PARAMETERS DEFINE THE WORKING ROOM REQUIRED FOR THE PIPE EMBEDMENT MATERIAL PLACEMENT AND SOIL LOADING USED IN THE PIPELINE INSTALLATION DESIGN OF THE TRENCH.
WHEN A PIPE IS TO BE INSTALLED BELOW THE GROUND WATER TABLE, THE GROUND WATER SHALL BE LOWERED TO AT LEAST 5 FEET BELOW THE LOWEST EXCAVATED TRENCH ELEVATION. THE TRENCH FOUNDATION SHALL BE STABLE WITH NO PONDED WATER, MUD OR MUCK AND SHALL MEET THE REQUIREMENTS NOTED ABOVE.
BELL HOLES SHALL BE PROVIDED AT EACH JOINT WITH A MINIMUM CLEARANCE OF 1" FROM THE BEDDING MATERIAL.

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Rigid Pipe Installation Design

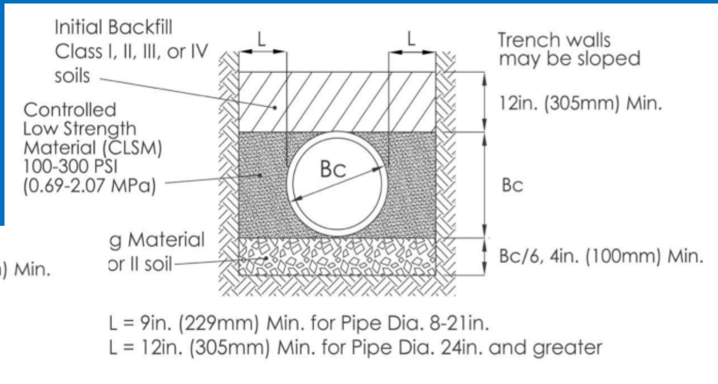
- Manufactured strength of the material
- Field strength of the material
  - Pipe embedment configuration
  - Width of the pipe trench
    - Minimum
    - Maximum
- Foundation of the installation
- Impact of using trench wall support systems

Rigid Pipe – Manufactured Strengths

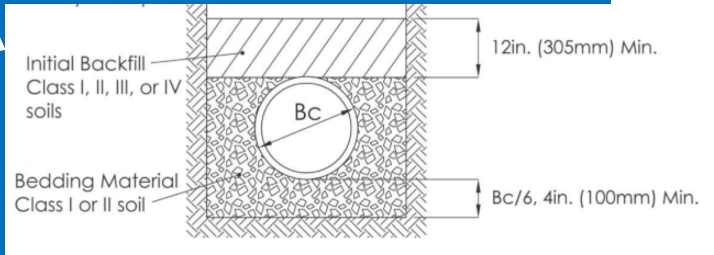
Size	SS VCP	ES VCP	CP I	CP II	CP III	RCP I	RCP II	RCP III	RCP IV	RCP V
8	1400	2200	1500	2000	2400	---	---	---	---	---
10	1600	2400	1600	2000	2400	---	---	---	---	---
12	1800	2600	1800	2250	2600	---	1000	1350	2000	3000
15	2000	2900	2000	2600	2900	---	1000	1350	2000	3000
18	2200	3300	2200	3000	3300	---	1000	1350	2000	3000
21	2400	3850	2400	3300	3850	---	1000	1350	2000	3000
24	2600	4400	2600	3600	4400	---	1000	1350	2000	3000
27	2800	4700	---	---	---	---	1000	1350	2000	3000
30	3300	5000	---	---	---	---	1000	1350	2000	3000
33	3600	5500	---	---	---	---	1000	1350	2000	3000
36	4000	6000	---	---	---	---	1000	1350	2000	3000
39	---	6600	---	---	---	---	1000	1350	2000	3000
42	---	7000	---	---	---	---	1000	1350	2000	3000

Rigid Pipe – Field Strength

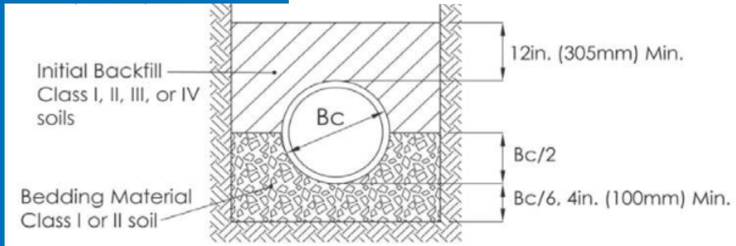
Manufactured strengths versus installed strengths…



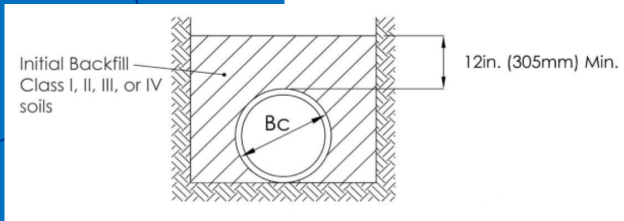
Load Factor 2.8



Load Factor 2.2



Load Factor 1.9



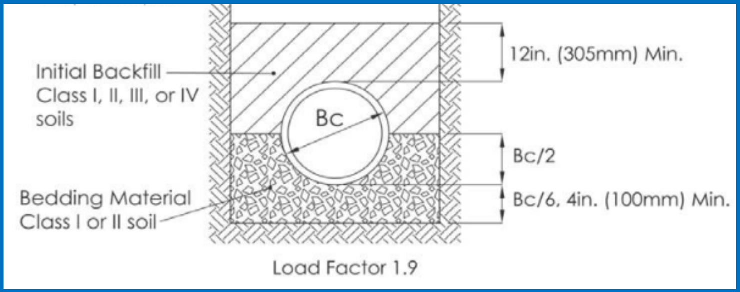
Load Factor 1.1

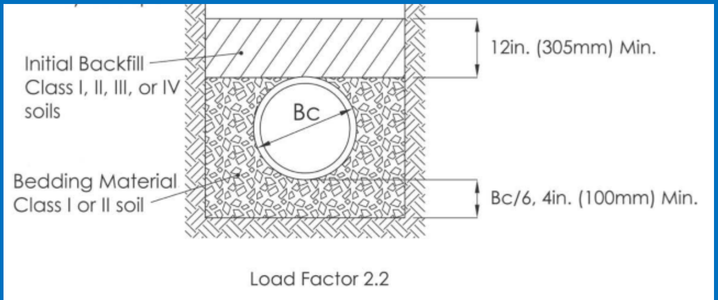
$$FS_{Actual} = \frac{Field\ Supporting\ Strength\ of\ the\ Pipe\ Material}{Total\ of\ the\ Actual\ Load\ Acting\ on\ the\ Pipe}$$

Figure 6-11: Load factor development at the NCPI Research laboratory

Table 6-2 Allowable Bedding Material and Initial Backfill per Bedding Class

Allowable Bedding Material & Initial Backfill per Bedding Class					
Bedding Class	**Allowable Bedding Material**			**Allowable Initial Backfill**	
	Table 1	**Gradation**	**Size**	**Class**	**Particle Size**
Class D	N/A	N/A	N/A	I, II, III or IV	1" (25mm)
Class C	I or II		1" (25 mm)	I, II, III or IV	1½" (38 mm)
Class B	I or II	- 100% passing a 1" (25 mm) sieve - 40 – 60% passing a ¾" (19 mm) sieve - 0 – 25% passing a 3/8" (9.5 mm) sieve	1" (25 mm)	I, II, III or IV	1½" (38 mm)
Crushed Stone Encasement	I or II	- 100% passing a 1" (25 mm) sieve - 40 – 60% passing a ¾" (19 mm) sieve - 0 – 25% passing a 3/8" (9.5 mm) sieve	1" (25 mm)	I, II, III or IV	1½" (38 mm)
CLSM	I or II	- 100% passing a 1" (25 mm) sieve - 40 – 60% passing a ¾" (19 mm) sieve - 0 – 25% passing a 3/8" (9.5 mm) sieve	1" (25 mm)	I, II, III or IV	1½" (38 mm)
Cradle	N/A	N/A	N/A	I, II, III or IV	





Rigid Pipe Design Considerations

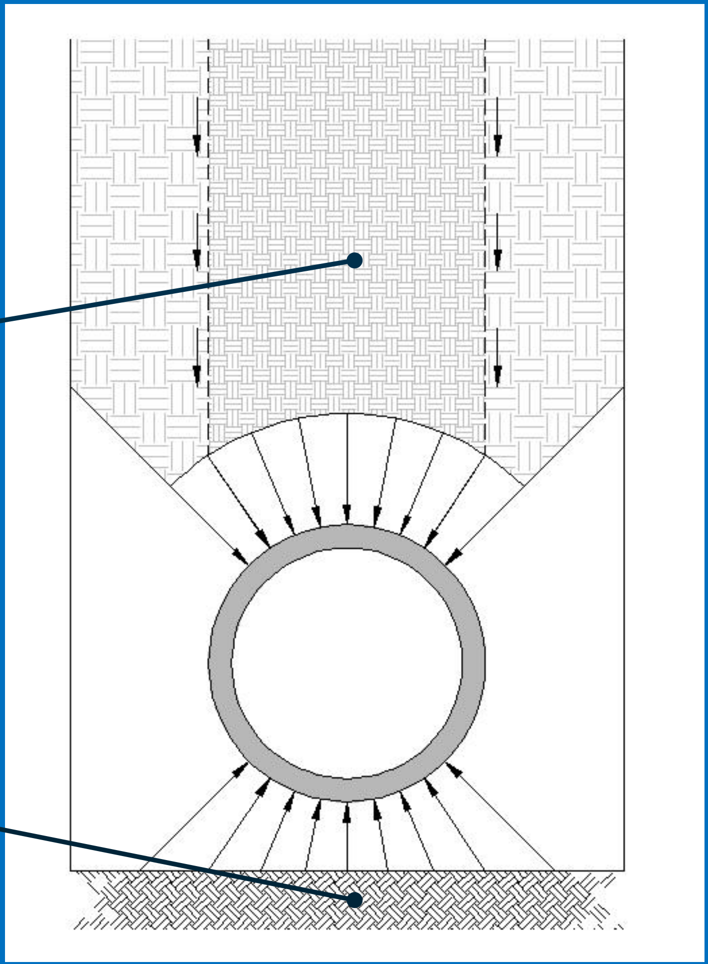
Trench design elements that impact the rigid pipe's in ground performance…

Trench width…

$$W_d = C_d w B_d^2 + \frac{D_o^2(4-\pi)}{8} w$$

Foundation design…

$$Bearing\ Capacity = \frac{W_d + W_{pipe}}{B_c}$$



Trench Width versus Trench Load on Pipe…

12" LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS 12"

(In Pounds Per Linear Foot)

12" VITRIFIED CLAY PIPE

100 Pounds Per Cubic Foot Backfill Material*

Italicized figures represent maximum loads on pipe at and beyond transition trench width.
Transition Width Column represents the trench width where trench loads reach a maximum and are equal to the embankment load.

GRAVELS (GW, GP, GM, GC)

Kμ' = 0.165

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	680	920	*950*					2.57'
6	760	1040	*1140*					2.68'
8	890	1240	*1530*					2.90'
10	980	1390	1820	*1910*				3.10'
12	1050	1510	2000	*2290*				3.29'
14	1090	1600	2150	*2670*				3.46'
16	1130	1660	2250	2890	*3060*			3.63'
18	1150	1720	2350	3040	*3450*			3.79'
20	1160	1760	2430	3150	*3830*			3.94'
22	1180	1790	2480	3250	4060	*4210*		4.09'
24	1190	1820	2540	3330	4180	*4600*		4.23'
26	1200	1840	2570	3390	4280	*4980*		4.37'
28	1200	1850	2600	3450	4360	5340	*5360*	4.51'
30	1200	1850	2630	3490	4440	5450	*5740*	4.64'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	700	940	*950*					2.51'
6	790	1070	*1140*					2.62'
8	930	1290	*1520*					2.83'
10	1030	1450	1890	*1900*				3.01'
12	1110	1590	2100	*2300*				3.19'
14	1170	1700	2260	*2680*				3.35'
16	1210	1780	2390	3040	*3060*			3.51'
18	1240	1840	2500	3210	*3440*			3.66'
20	1270	1900	2590	3350	*3830*			3.80'
22	1290	1940	2670	3460	*4210*			3.94'
24	1300	1970	2730	3570	4450	*4600*		4.08'
26	1300	1990	2770	3640	4570	*4980*		4.21'
28	1310	2010	2820	3710	4680	*5370*		4.34'
30	1320	2030	2850	3770	4770	*5750*		4.46'

SILTS AND CLAYS (CL, ML)

Kμ' = 0.130, L.L. Less Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	730	*950*						2.44'
6	830	1120	*1140*					2.54'
8	990	1360	*1520*					2.72'
10	1120	1560	*1910*					2.89'
12	1220	1720	2240	*2290*				3.05'
14	1290	1840	2430	*2670*				3.20'
16	1350	1950	2600	*3060*				3.34'
18	1390	2030	2730	*3440*				3.48'
20	1420	2100	2850	3640	*3820*			3.61'
22	1460	2160	2950	3790	*4220*			3.74'
24	1470	2210	3030	3920	*4600*			3.86'
26	1480	2240	3100	4020	*4980*			3.98'
28	1500	2270	3160	4120	5160	*5370*		4.10'
30	1510	2300	3210	4210	5270	*5750*		4.21'

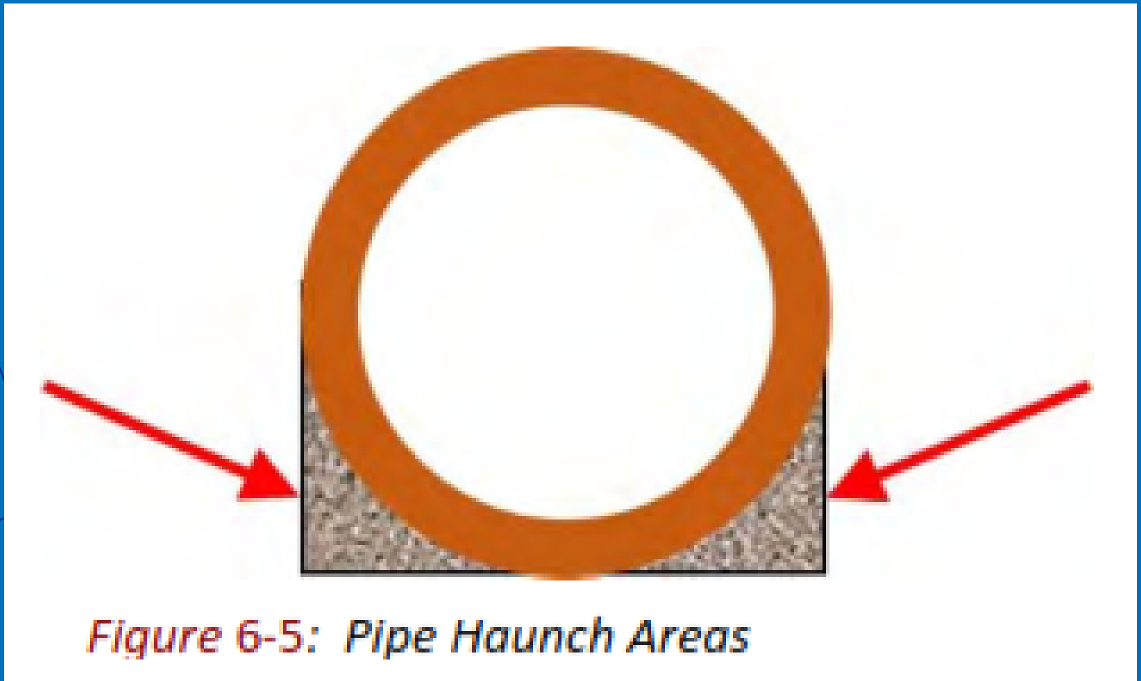
SILTS AND CLAYS (CH, MH)

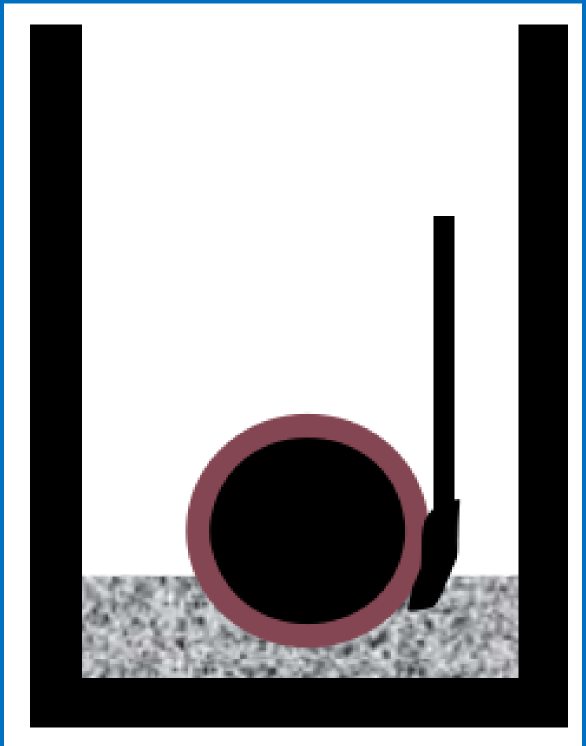
Kμ' = 0.110, L.L. Greater Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	770	*950*						2.37'
6	880	*1140*						2.45'
8	1060	1440	*1520*					2.62'
10	1220	1660	*1910*					2.77'
12	1330	1850	*2290*					2.91'
14	1430	2020	2620	*2680*				3.04'
16	1510	2150	2820	*3060*				3.17'
18	1570	2260	3000	*3450*				3.29'
20	1620	2350	3150	*3830*				3.41'
22	1650	2430	3280	4170	*4220*			3.52'
24	1690	2500	3380	4340	*4600*			3.63'
26	1720	2550	3490	4480	*4980*			3.74'
28	1740	2600	3570	4610	*5360*			3.84'
30	1750	2640	3640	4720	*5750*			3.95'

*Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 in NCPI's *Vitrified Clay Pipe Engineering Manual*, page 4 – 18)

Bedding the Pipe to carry the Load





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Bedding the Pipe to carry the Load

Figure 6-7: Shovel-slicing the bedding material into the haunches of the pipe is essential if the total load factor is to be realized.

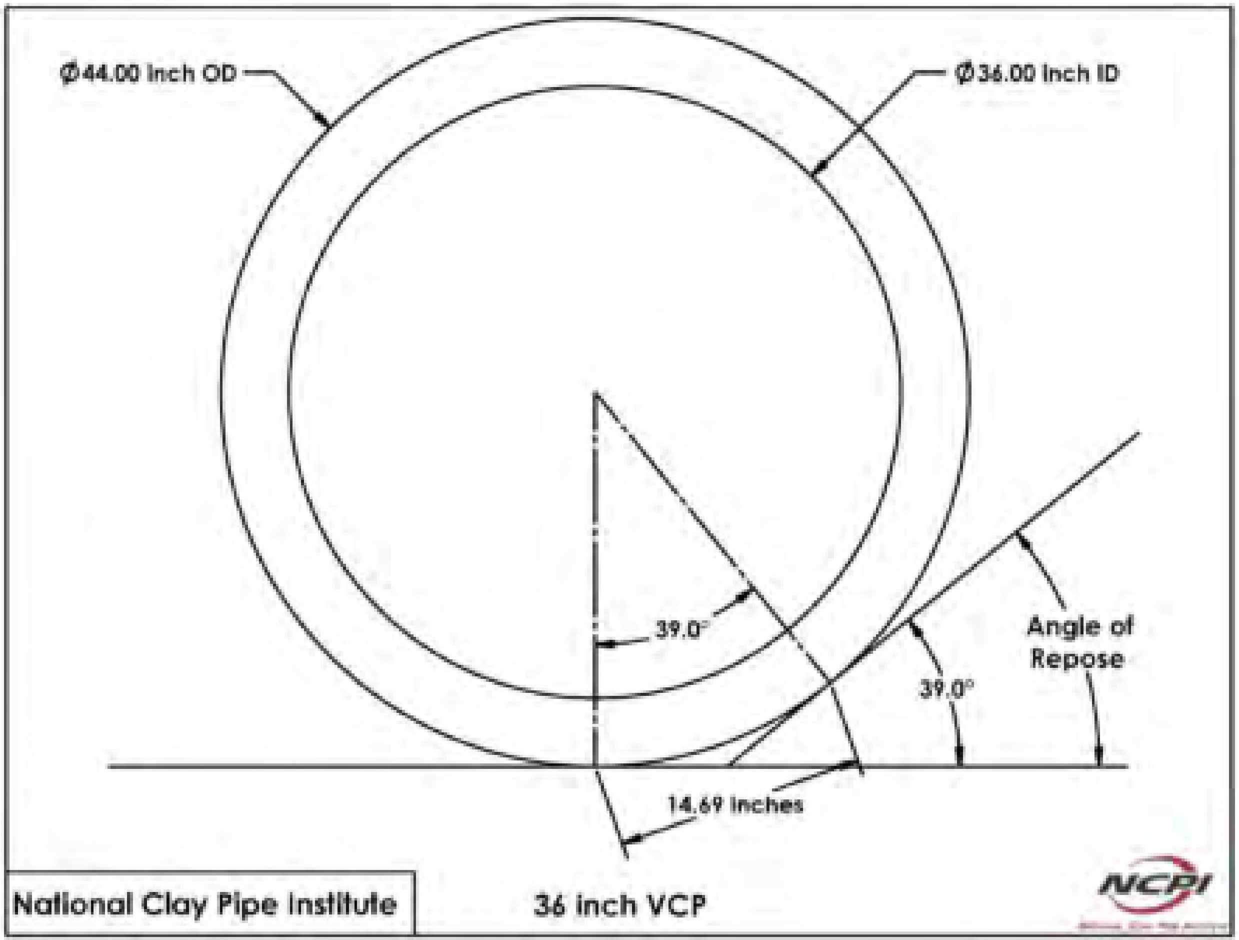

Figure 6-9: Illustration of the void space left in the haunches of a 44-in OD pipe when the bedding material angle of repose is 39 degrees and dumped.

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Figure 6-10: In testing, daylight was visible on the other end of a length of pipe.

Good haunch support:

- Significantly increases the load carrying capacity of buried pipe
- Requires compacting the soil in the haunch area, or using flowable fill
- Is not attained by dumping gravels and crushed rock beside the pipe
- Can be attained by pipe settling into uncompacted bedding to mobilize the strength of the haunch soil

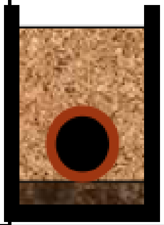
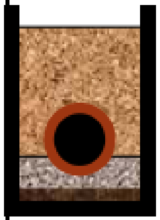
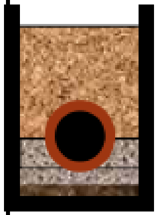
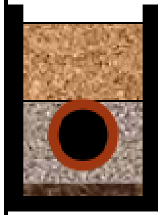
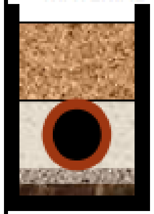
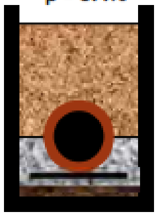
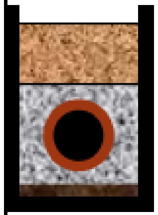
An internal inspection of an 11-ft diameter RCP conduit constructed in the mid 1970's found severe invert longitudinal cracks and spalling of the cover over the steel reinforcing. The exterior was excavated and companion longitudinal cracking was observed at the springline (shown in Figure 11). The pipe was laid directly on the trench bottom (no bedding) and compacted embedment was specified up to 0.375 OD (dotted line in figure).

Table 6-3: Bearing Strength, Load Factors and Field Supporting Strength for 6-in to 48-in VCP

FIELD SUPPORTING STRENGTH OF EXTRA STRENGTH VITRIFIED CLAY PIPE

(Pounds Per Linear Foot of Pipe)

Field Supporting Strength = 3 Edge Bearing Strength x Load Factor

	THREE-EDGE BEARING STRENGTH Minimum* Based on ASTM C700	CLASS D 	CLASS C 	CLASS B 	CRUSHED STONE ENCASEMENT 	CONTROLLED LOW STRENGTH MATERIAL 	CLASS A-I CONCRETE CRADLE p = 0.4%** 	CLASS A-II FULL CONCRETE ENCASEMENT 
NOMINAL SIZE INCHES	LBS/LINEAR FT.	LOAD FACTOR 1.1	LOAD FACTOR 1.5	LOAD FACTOR 1.9	LOAD FACTOR 2.2	LOAD FACTOR 2.8	LOAD FACTOR 3.4	Design by a Structural Engineer
6	2000	2200	3000	3800	4400	5600	6800	
8	2200	2420	3300	4180	4840	6160	7480	
10	2400	2640	3600	4560	5280	6720	8160	
12	2600	2860	3900	4940	5720	7280	8840	
15	2900	3190	4350	5510	6380	8120	9860	
18	3300	3630	4950	6270	7260	9240	11220	
21	3850	4235	5775	7315	8470	10780	3090	
24	4400	4840	6600	8360	9680	12320	14960	
27	4700	5170	7050	8930	10340	13160	15980	
30	5000	5500	7500	9500	11000	14000	17000	
33	5500	6050	8250	10450	12100	15400	18700	
36	6000	6600	9000	11400	13200	16800	20400	
39	6600	7260	9900	12540	14520	18480	22440	
42	7000	7700	10500	13300	15400	19600	23800	
48	8000	8800	12000	15200	17600	22400	27200	

* Check with local manufacturers for bearing strengths available in a particular area

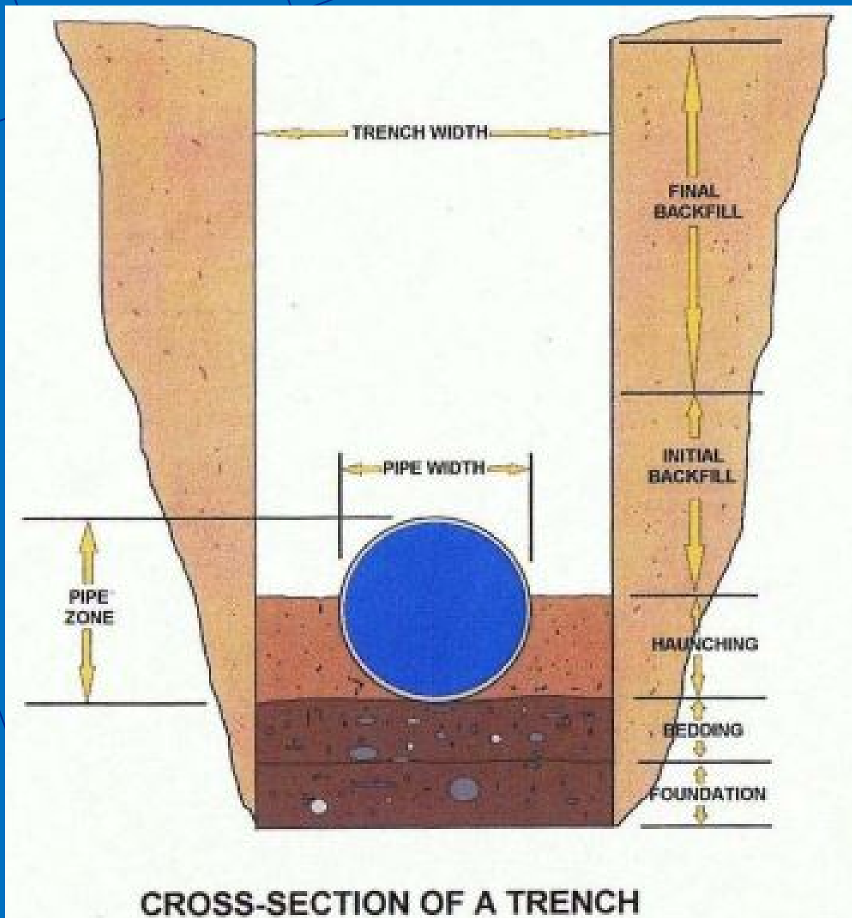
** Refer to page 6-15 for definition of p

Figure 6-8: Provide uniform and continuous support of pipe barrel between bell or coupling holes for all classes of bedding.

Rigid Pipe Installation Trench Design Example

- Design installation trench for a 12-inch VCP with a cover of 8-12 ft.
- Soils report indicates the existing soil along the alignment for this pipe is:
  - From TG to a depth of 5 feet soil is ML with in place density of 105 pcf
  - From 5-15 ft. the soil is a SM material with in place density of 108 pcf
  - The bearing capacity is estimated by the soils engineer to be 1500 psf in the zone between 8 and 12 ft. deep
  - No water was encountered in the soil borings, taken to 25 ft.
- The surface improvements constructed along this alignment is a parking lot that will be constructed with a 6-in. asphaltic concrete (HMAC) underlain with 8-in. of crushed stone

Vertical or sloped side walls?



The loading on the pipe will consist of the dead load from the soil and the live load from the vehicular traffic…

Soil Load →

$$W_d = C_d w B_d^2 + \frac{D_o^2(4-\pi)}{8} w$$

12" LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS **12"**

(In Pounds Per Linear Foot)

12" VITRIFIED CLAY PIPE

100 Pounds Per Cubic Foot Backfill Material*

Italicized figures represent maximum loads on pipe at and beyond transition trench width.
Transition Width Column represents the trench width where trench loads reach a maximum and are equal to the embankment load.

GRAVELS (GW, GP, GM, GC) Kμ' = 0.165

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	680	920	950					2.57'
6	760	1040	1140					2.68'
8	890	1240	1530					2.90'
10	980	1390	1820	1910				3.10'
12	1050	1510	2000	2290				3.29'
14	1090	1600	2150	2670				3.46'
16	1130	1660	2250	2890	3060			3.63'
18	1150	1720	2350	3040	3450			3.79'
20	1160	1760	2430	3150	3830			3.94'
22	1180	1790	2480	3250	4060	4210		4.09'
24	1190	1820	2540	3330	4180	4600		4.23'
26	1200	1840	2570	3390	4280	4980		4.37'
28	1200	1850	2600	3450	4360	5340	5360	4.51'
30	1200	1850	2630	3490	4440	5450	5740	4.64'

SANDS (SW, SP, SM, SC) Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	700	940	950					2.51'
6	790	1070	1140					2.62'
8	930	1290	1520					2.83'
10	1030	1450	1890	1900				3.01'
12	1110	1590	2100	2300				3.19'
14	1170	1700	2260	2680				3.35'
16	1210	1780	2390	3040	3060			3.51'
18	1240	1840	2500	3210	3440			3.66'
20	1270	1900	2590	3350	3830			3.80'
22	1290	1940	2670	3460	4210			3.94'
24	1300	1970	2730	3570	4450	4600		4.08'
26	1300	1990	2770	3640	4570	4980		4.21'
28	1310	2010	2820	3710	4680	5370		4.34'
30	1320	2030	2850	3770	4770	5750		4.46'

SILTS AND CLAYS (CL, ML) Kμ' = 0.130, L.L. Less Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	730	950						2.44'
6	830	1120	1140					2.54'
8	990	1360	1520					2.72'
10	1120	1560	1910					2.89'
12	1220	1720	2240	2290				3.05'
14	1290	1840	2430	2670				3.20'
16	1350	1950	2600	3060				3.34'
18	1390	2030	2730	3440				3.48'
20	1420	2100	2850	3640	3820			3.61'
22	1460	2160	2950	3790	4220			3.74'
24	1470	2210	3030	3920	4600			3.86'
26	1480	2240	3100	4020	4980			3.98'
28	1500	2270	3160	4120	5160	5370		4.10'
30	1510	2300	3210	4210	5270	5750		4.21'

SILTS AND CLAYS (CH, MH) Kμ' = 0.110, L.L. Greater Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 24	30	36	42	48	54	60	Transition Width
5	770	950						2.37'
6	880	1140						2.45'
8	1060	1440	1520					2.62'
10	1220	1660	1910					2.77'
12	1330	1850	2290					2.91'
14	1430	2020	2620	2680				3.04'
16	1510	2150	2820	3060				3.17'
18	1570	2260	3000	3450				3.29'
20	1620	2350	3150	3830				3.41'
22	1650	2430	3280	4170	4220			3.52'
24	1690	2500	3380	4340	4600			3.63'
26	1720	2550	3490	4480	4980			3.74'
28	1740	2600	3570	4610	5360			3.84'
30	1750	2640	3640	4720	5750			3.95'

*Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 in NCPI's *Vitrified Clay Pipe Engineering Manual*, page 4 – 18)

$$C_d = \frac{1 - e^{-2K\mu'\left(\frac{H}{B_d}\right)}}{2K\mu'}$$

$$C_d = \frac{1 - e^{-2\times 0.130\left(\frac{12}{3}\right)}}{2 \times 0.130} = 2.48$$

$$W_d = 2.48 \times 109 \times 3^2 + \frac{1.21^2\,(4-\pi)}{8} 109 = 2457 \text{ lbs./lf}$$

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Possible Design Trench Configurations and the resulting Safety Factor…

Trench Class	Load Factor	Field Supporting Strength	Estimated Load on Pipe	Factor of Safety
D	1.1	2860	2457	1.16
C	1.5	3900	2457	1.59
B	1.9	4940	2457	2.01
Encasement	2.2	5720	2457	2.32
CLSM	2.8	7280	2457	2.96

Min. required Factor of Safety is 2.5… Choices are to use the CLSM, narrow the trench width to 2.0 feet (maximum) and try and compact stone under and around the pipe, or narrow the trench width to 2.75 feet and use CLSM; the FS are 2.96, 3.9, and 8.0.

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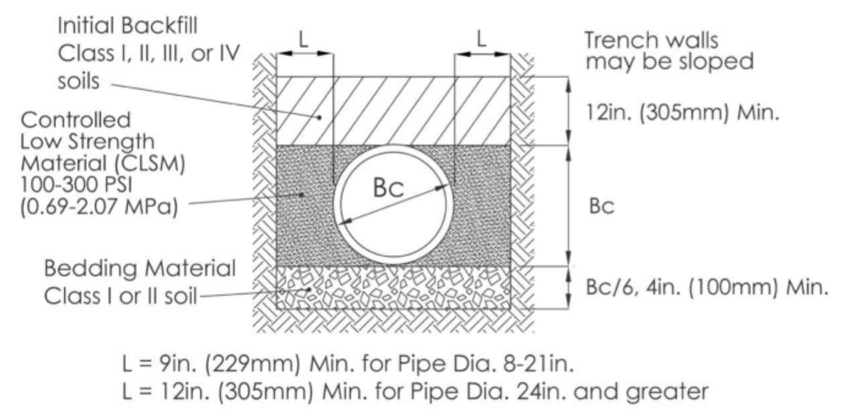
Foundation Load

$$W_{bd} = \frac{W_d + W_p}{B_c}$$

- Given our bearing capacity of 1500 psf at the bottom of the excavation…
- 3.0 ft. wide trench with rock produces a W_{bd} = 2163 psf → 6.0 inches of foundation
- 2.0 ft. wide trench with rock produces a W_{bd} = 1242 psf → no foundation required
- 2.75 ft. wide trench using CLSM produces a W_{bd} = 795 psf → no foundation required

$$W_d = C_d w B_d^2 + \frac{D_o^2(4-\pi)}{8} w$$

$$W_d = C_d w B_d B_c$$



Load Factor 2.8

Break time! 15 minutes

Live Load

$$W_L = \frac{M_p P I_f}{L_1 L_2}$$

$$I_f = 1 + 0.33\left[\frac{96 - h}{96}\right] \geq 1.0$$

$$L_1 = t_l + \text{LLDF}(h)$$

For L_2 … If $h \leq h_{int}$

$$L_2 = t_w + \text{LLDF}(h)$$

If $h > h_{int}$

$$L_2 = \frac{[t_w + 72 + \text{LLDF}(h)]}{2}$$

$h_{int} = (72 - t_w)/\text{LLDF}$

W_L = live load on pipe, psi
M_p = multiple presence factor = 1.2
P = wheel load magnitude
= 16,000 lb. for AASHTO H20 truck
= 20,000 lb. for H25 truck
I_f = impact factor
L_1 = load width parallel to direction of travel, in.
L_2 = load width perpendicular to direction of travel, in.
h = depth of cover, in.
h_{int} = depth at which load from wheels interact, in.
t_l = length of tire footprint = 10 in.
t_w = width of tire footprint = 20 in.
LLDF = factor to account for live load distribution with depth of fill
= 1.15 for Class 1 and Class 2 soil backfills
= 1.0 for all other backfill soils

Flexible Pipe Installation Design

- Selecting the right pipe stiffness
- Pipe embedment design
  - Knowing the native soil(s) strengths/weakness
  - Selecting a complimentary embedment material
  - Selecting the necessary min. trench width
    - Placement of the embedment material selected
    - Achieving the needed effective M_S to deliver the FS
- Foundation design
- Confirming the long-term deflection performance

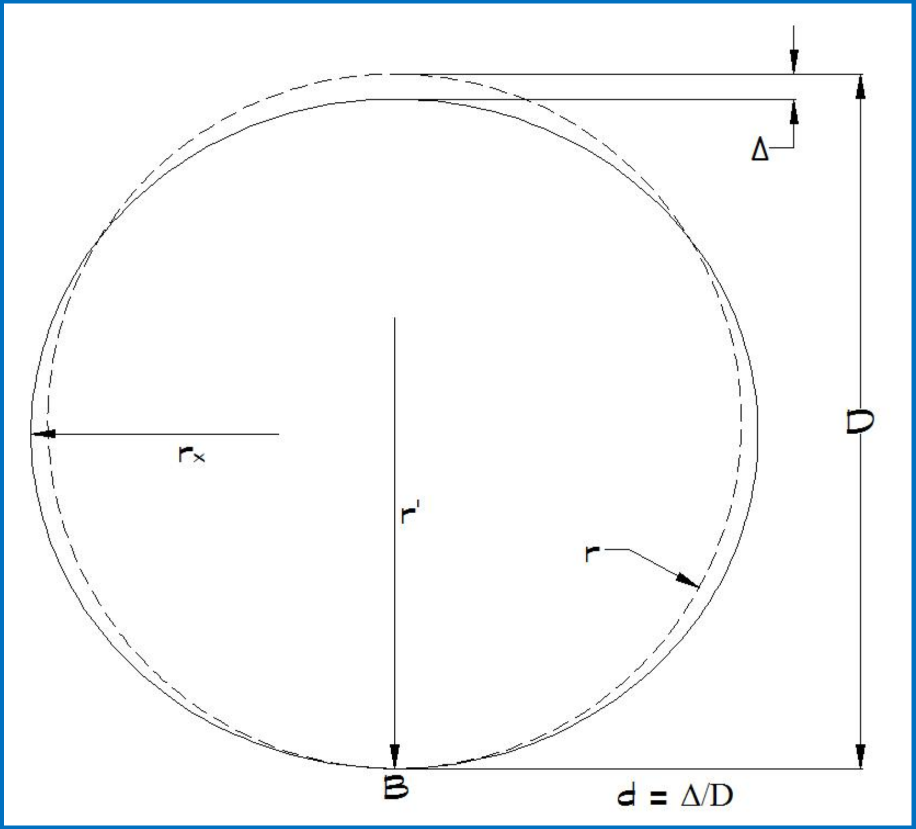
Flexible Pipe Stiffness

$$PS = \frac{F}{\Delta} = 53.77\left(\frac{EI}{D^3}\right)$$

$$\frac{\Delta}{D} = \frac{(D_L W_C + W_L)K_X}{0.149PS + 0.061M_S}$$

$$\downarrow$$

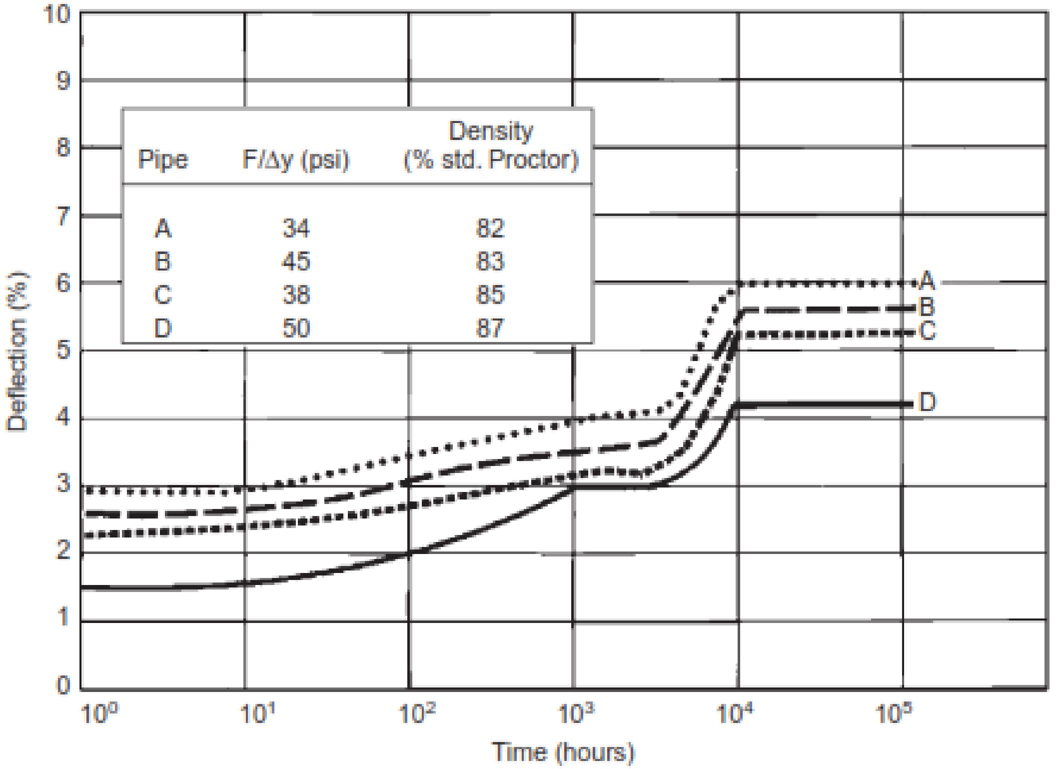
$$\frac{\Delta}{D} = \frac{\textit{Soil Load} + \textit{Live Load}}{\textit{Pipe Stiffness} + \textit{Soil Stiffness}}$$



Soil Classification	Vertical Stress Level psi	Compaction, % maximum Standard Proctor Density				
		Dumped psi	100 psi	95 psi	90 psi	85 psi
I	1	2000	2350	2000		
I	5	2600	3450	2600		
I	10	3000	4200	3000		
I	20	3450	5500	3450		
II	1		2350	2000	1275 (1085)	470 (330)
II	5		3450	2600	1500 (1275)	520 (365)
II	10		4200	3000	1625 (1380)	570 (400)
II	20		5500	3450	1800 (1530)	650 (455)
III	1			1415 (708)	670 (335)	360 (180)
III	5			1670 (835)	740 (370)	390 (195)
III	10			1770 (885)	750 (375)	400 (200)
III	20			1880 (940)	790 (395)	430 (215)
IV *	1			530 (159)	255 (77)	130 (39)
IV *	5			625 (188)	320 (96)	175 (53)
IV *	10			690 (207)	355 (107)	200 (60)
IV *	20			740 (222)	395 (119)	230 (69)

Native Backfill Soil Classification (NBSC)	Group name	Approximate Weight	Average Weight	Kμ'	Soil Stiffness	
Crushed Rock	Man-Made		130	0.192	SC 1	≤15% Sand, max 25% passing ⅜-in Sieve, max 5% passing No. 200 Sieve
GW	Well-Graded Sand	119-128	124	0.165	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
GP	Poorly-Graded Gravel	104-128	122	0.165	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
GM	Silty Gravel	87-133	113	0.165	SC 3	Coarse-Grained Soils With More Than 12% Fines
GC	Clayey Gravel	96-129	117	0.165	SC 3	Coarse-Grained Soils With More Than 12% Fines
SW	Well-Graded Sand	118-135	126	0.150	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
SP	Poorly Graded Sand	106-135	116	0.150	SC 2	Clean, Coarse-Grained Soils With 12% Or Less Passing The No. 200 Sieve
SM	Silty Sand	93-133	117	0.150	SC 3	Coarse-Grained Soils With More Than 12% Fines
SC	Clayey Sand	104-132	119	0.150	SC 3	Coarse-Grained Soils With More Than 12% Fines
CL, ML	With Sand Or Gravel	90-121	109	0.130	SC 3	Sandy Or Gravelly Fine-Grained Soils With More Than 30% Retained On The No. 200 Sieve
Fine-Grained Soils -1		82-126	103	0.130	SC 3	Sandy Or Gravelly Fine-Grained Soils With More Than 30% Retained On The No. 200 Sieve (Cl-Ml, Cl/Ml, Ml/Cl)
Fine-Grained Soils -2		82-107	95	0.110	SC 4	Fine-Grained Soil With 30% Or Less Retained On The No. 200 Sieve (Cl-Ml, Cl/Ml, Ml/Cl)
MH, CH, OL, OH, PT		83-89	85	0.110	SC 5	Highly Plastic And Organic Soils

Flexible Pipe Stiffness vs. Defl'n



Pipe	F/Δy (psi)	Density (% std. Proctor)
A	34	82
B	45	83
C	38	85
D	50	87

Fig. 7.11 Deflection vs. time for 10-in. diameter PVC sewer pipe (22-ft deep embankment, installed September 1975).

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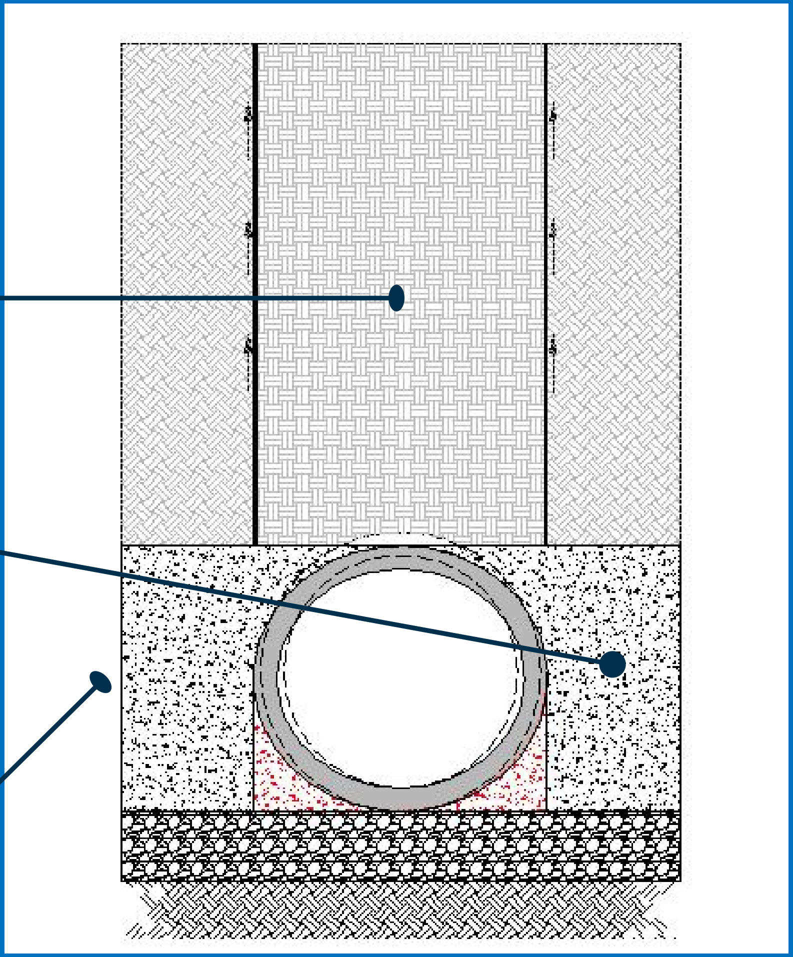
Flexible Pipe Design Checks

Parametric considerations for Flexible Pipe Installation design

1. The load on the pipe does not change with increasing the trench width
2. The resistance to deflection can be improved with increasing the trench width…

   $M_S = S_c \times \quad M_{sb}$
3. Small amount of deflection (1-2%) is okay for flexible pipes.
4. Maximum deflection is a function of the pipe wall strain
5. Pipe sizes larger than 24" will require special design consideration when trench shoring is required



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Flexible Pipe Embedment Design

Table 6-2 Recommendations for installation and use of soils and aggregates for foundation and pipe zone embedment

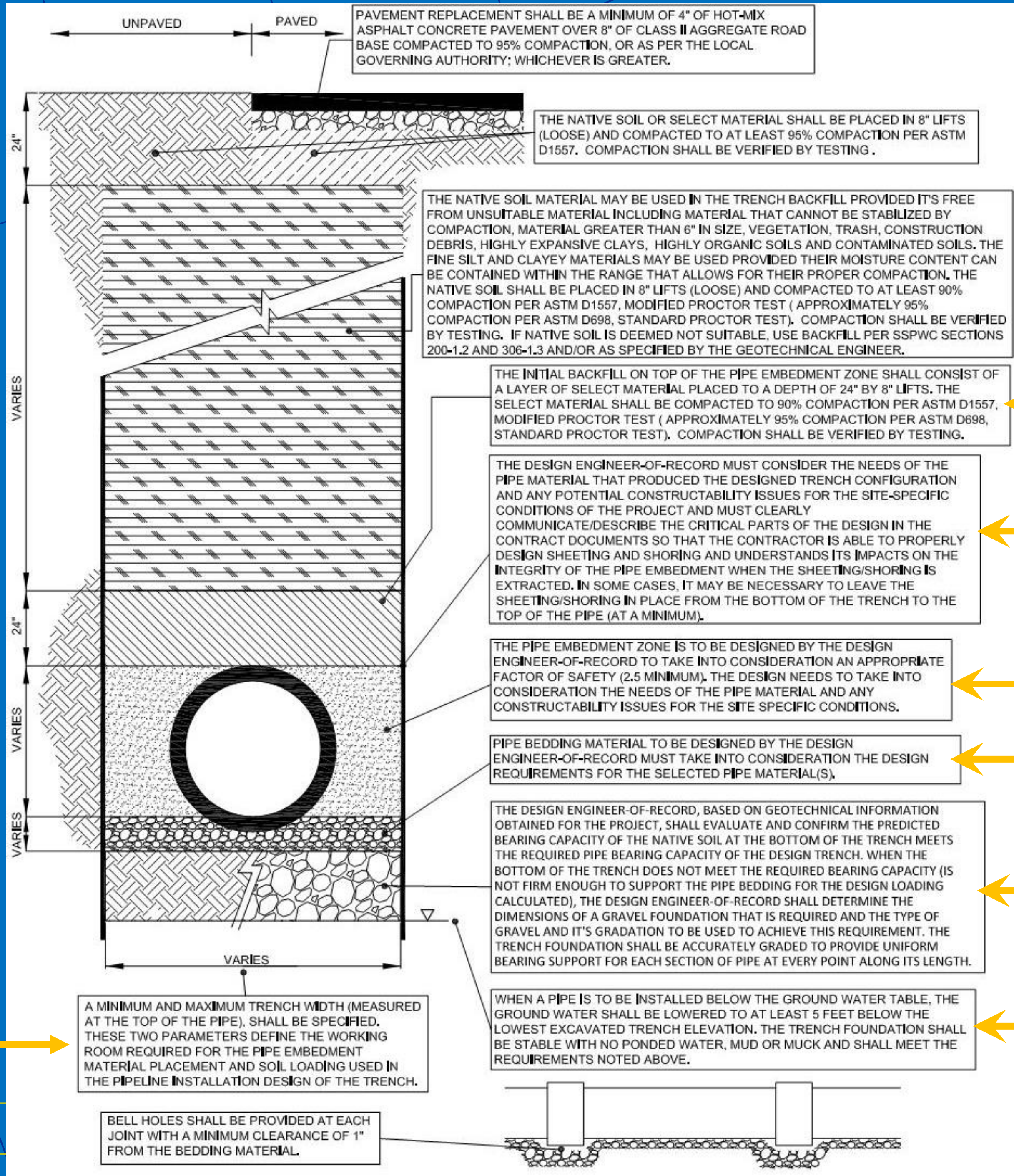
Soil Classes*	Class I	Class II	Class III	Class IV
General recommendations and restrictions	Acceptable and common where no migration is probable or when combined with a geotextile filter media. Suitable for use as a drainage blanket and under-drain where adjacent material is suitably graded or when used with a geotextile filter fabric (see Sec. 6.5.2).	Where hydraulic gradient exists, check gradation to minimize migration. Clean groups are suitable for use as a drainage blanket and underdrain (see Table 5-3). Uniform fine sands (SP) with more than 50% passing a No. 100 sieve (0.006 in., 0.15 mm) behave like silts and should be treated as Class III soils.	Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi (62 kPa) or less.	Difficult to achieve high soil stiffness (see Sec. 6.5.1). Do not use where water conditions in trench prevent proper placement and compaction. Not recommended for use with pipes with stiffness of 9 psi (62 kPa) or less.
Foundation	Suitable as foundation and for replacing overexcavated and unstable trench bottom as restricted above.	Suitable as foundation and for replacing overexcavated and unstable trench bottom as restricted above. Install and compact in 12-in. (300-mm) maximum layers.	Suitable for replacing overexcavated trench bottom as restricted above. Install and compact in 6-in. (150-mm) maximum layers.	Not suitable.
Pipe zone embedment	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Work material under pipe to provide uniform haunch support.	Suitable as restricted above. Difficult to place and compact in the haunch zone.	Suitable as restricted above. Difficult to place and compact in the haunch zone.
Embedment compaction				
Minimum recommended density, SPD†	Minimum density typically achieved by dumped placement.	85%	90%	95%
Relative compactive effort required to achieve minimum density	Low	Moderate	High	Very high
Compaction methods	Vibration or impact	Vibration or impact	Impact	Impact
Required moisture control	None	None	Maintain near optimum to minimize compactive effort.	Maintain near optimum to minimize compactive effort.

Class of material is chosen by…

1. Compatible with native soil
2. Equal to or greater than native soil's stiffness; needed net level of stiffness
3. Level of effort required to get it properly placed
4. Level of construction observation to be provided

Soil combining factor, SC

M_{sn}/M_{sb}	$B_d/D = 1.25$	$B_d/D = 1.50$	$B_d/D = 1.75$	$B_d/D = 2.0$	$B_d/D = 2.5$	$B_d/D = 3.0$	$B_d/D = 4.0$	$B_d/D = 5.0$
0.005	0.02	0.05	0.08	0.12	0.23	0.43	0.72	1.00
0.01	0.03	0.07	0.11	0.15	0.27	0.47	0.74	1.00
0.02	0.05	0.10	0.15	0.20	0.32	0.52	0.77	1.00
0.05	0.10	0.15	0.20	0.27	0.38	0.58	0.80	1.00
0.1	0.15	0.20	0.27	0.35	0.46	0.65	0.84	1.00
0.2	0.25	0.30	0.38	0.47	0.58	0.75	0.88	1.00
0.4	0.45	0.50	0.56	0.64	0.75	0.85	0.93	1.00
0.6	0.65	0.70	0.75	0.81	0.87	0.94	0.98	1.00
0.8	0.84	0.87	0.90	0.93	0.96	0.98	1.00	1.00
1.0	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
1.5	1.40	1.30	1.20	1.12	1.06	1.03	1.00	1.00
2	1.70	1.50	1.40	1.30	1.20	1.10	1.05	1.00
3	2.20	1.80	1.65	1.50	1.35	1.20	1.10	1.00
≥5	3.00	2.20	1.90	1.70	1.50	1.30	1.15	1.00


UNPAVED
PAVED
PAVEMENT REPLACEMENT SHALL BE A MINIMUM OF 4" OF HOT-MIX ASPHALT CONCRETE PAVEMENT OVER 8" OF CLASS II AGGREGATE ROAD BASE COMPACTED TO 95% COMPACTION, OR AS PER THE LOCAL GOVERNING AUTHORITY; WHICHEVER IS GREATER.
THE NATIVE SOIL OR SELECT MATERIAL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 95% COMPACTED PER ASTM D1557. COMPACTION SHALL BE VERIFIED BY TESTING.
24"
VARIES
THE NATIVE SOIL MATERIAL MAY BE USED IN THE TRENCH BACKFILL PROVIDED IT'S FREE FROM UNSUITABLE MATERIAL INCLUDING MATERIAL THAT CANNOT BE STABILIZED BY COMPACTION, MATERIAL GREATER THAN 6" IN SIZE, VEGETATION, TRASH, CONSTRUCTION DEBRIS, HIGHLY EXPANSIVE CLAYS, HIGHLY ORGANIC SOILS AND CONTAMINATED SOILS. THE FINE SILT AND CLAYEY MATERIALS MAY BE USED PROVIDED THEIR MOISTURE CONTENT CAN BE CONTAINED WITHIN THE RANGE THAT ALLOWS FOR THEIR PROPER COMPACTION. THE NATIVE SOIL SHALL BE PLACED IN 8" LIFTS (LOOSE) AND COMPACTED TO AT LEAST 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING. IF NATIVE SOIL IS DEEMED NOT SUITABLE, USE BACKFILL PER SSPWC SECTIONS 200-1.2 AND 306-1.3 AND/OR AS SPECIFIED BY THE GEOTECHNICAL ENGINEER.
THE INITIAL BACKFILL ON TOP OF THE PIPE EMBEDMENT ZONE SHALL CONSIST OF A LAYER OF SELECT MATERIAL PLACED TO A DEPTH OF 24" BY 8" LIFTS. THE SELECT MATERIAL SHALL BE COMPACTED TO 90% COMPACTION PER ASTM D1557, MODIFIED PROCTOR TEST (APPROXIMATELY 95% COMPACTION PER ASTM D698, STANDARD PROCTOR TEST). COMPACTION SHALL BE VERIFIED BY TESTING.
4
THE DESIGN ENGINEER-OF-RECORD MUST CONSIDER THE NEEDS OF THE PIPE MATERIAL THAT PRODUCED THE DESIGNED TRENCH CONFIGURATION AND ANY POTENTIAL CONSTRUCTABILITY ISSUES FOR THE SITE-SPECIFIC CONDITIONS OF THE PROJECT AND MUST CLEARLY COMMUNICATE/DESCRIBE THE CRITICAL PARTS OF THE DESIGN IN THE CONTRACT DOCUMENTS SO THAT THE CONTRACTOR IS ABLE TO PROPERLY DESIGN SHEETING AND SHORING AND UNDERSTANDS ITS IMPACTS ON THE INTEGRITY OF THE PIPE EMBEDMENT WHEN THE SHEETING/SHORING IS EXTRACTED. IN SOME CASES, IT MAY BE NECESSARY TO LEAVE THE SHEETING/SHORING IN PLACE FROM THE BOTTOM OF THE TRENCH TO THE TOP OF THE PIPE (AT A MINIMUM).
3
24"
VARIES
THE PIPE EMBEDMENT ZONE IS TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD TO TAKE INTO CONSIDERATION AN APPROPRIATE FACTOR OF SAFETY (2.5 MINIMUM). THE DESIGN NEEDS TO TAKE INTO CONSIDERATION THE NEEDS OF THE PIPE MATERIAL AND ANY CONSTRUCTABILITY ISSUES FOR THE SITE SPECIFIC CONDITIONS.
2
VARIES
PIPE BEDDING MATERIAL TO BE DESIGNED BY THE DESIGN ENGINEER-OF-RECORD MUST TAKE INTO CONSIDERATION THE DESIGN REQUIREMENTS FOR THE SELECTED PIPE MATERIAL(S).
1
THE DESIGN ENGINEER-OF-RECORD, BASED ON GEOTECHNICAL INFORMATION OBTAINED FOR THE PROJECT, SHALL EVALUATE AND CONFIRM THE PREDICTED BEARING CAPACITY OF THE NATIVE SOIL AT THE BOTTOM OF THE TRENCH MEETS THE REQUIRED PIPE BEARING CAPACITY OF THE DESIGN TRENCH. WHEN THE BOTTOM OF THE TRENCH DOES NOT MEET THE REQUIRED BEARING CAPACITY (IS NOT FIRM ENOUGH TO SUPPORT THE PIPE BEDDING FOR THE DESIGN LOADING CALCULATED), THE DESIGN ENGINEER-OF-RECORD SHALL DETERMINE THE DIMENSIONS OF A GRAVEL FOUNDATION THAT IS REQUIRED AND THE TYPE OF GRAVEL AND IT'S GRADATION TO BE USED TO ACHIEVE THIS REQUIREMENT. THE TRENCH FOUNDATION SHALL BE ACCURATELY GRADED TO PROVIDE UNIFORM BEARING SUPPORT FOR EACH SECTION OF PIPE AT EVERY POINT ALONG ITS LENGTH.
5
VARIES
WHEN A PIPE IS TO BE INSTALLED BELOW THE GROUND WATER TABLE, THE GROUND WATER SHALL BE LOWERED TO AT LEAST 5 FEET BELOW THE LOWEST EXCAVATED TRENCH ELEVATION. THE TRENCH FOUNDATION SHALL BE STABLE WITH NO PONDED WATER, MUD OR MUCK AND SHALL MEET THE REQUIREMENTS NOTED ABOVE.
6
7
A MINIMUM AND MAXIMUM TRENCH WIDTH (MEASURED AT THE TOP OF THE PIPE), SHALL BE SPECIFIED. THESE TWO PARAMETERS DEFINE THE WORKING ROOM REQUIRED FOR THE PIPE EMBEDMENT MATERIAL PLACEMENT AND SOIL LOADING USED IN THE PIPELINE INSTALLATION DESIGN OF THE TRENCH.
BELL HOLES SHALL BE PROVIDED AT EACH JOINT WITH A MINIMUM CLEARANCE OF 1" FROM THE BEDDING MATERIAL.

Flexible Pipe Design Example

- 12-inch diameter SDR 35 PVC pipe with depth of cover between 8-ft. and 12.0-ft.
- The soils report indicates that the existing soil along the alignment for this pipe is as follows
  - From T.G. to a depth of 5.0 feet soil is ML with in place density of 105 pcf
  - From 5.0 - 15 ft. the soil is SM material with in place density of 108 pcf
  - The bearing capacity is estimated by the soils engineer to be 1500 psf in the zone between 8 and 12 ft. deep
  - No water was encountered in the soil borings, taken to 25 ft.
- The surface improvement constructed along this alignment is a parking lot that will be constructed with a 6-in. asphaltic concrete (HMAC) underlain with 8-in. of crushed stone

Deflection Performance

- D_L, the deflection lag factor is small for pipes buried in relatively stiff native soils with dense granular embedment ad for such conditions should be taken near 1.0. For poor native soils and/or loose embedment increases in deflection over time can be significant and D_L may approach 1.5. The high potential value for D_L clearly demonstrates the need to control backfill quality and construction practices such that the design conditions are achieved.

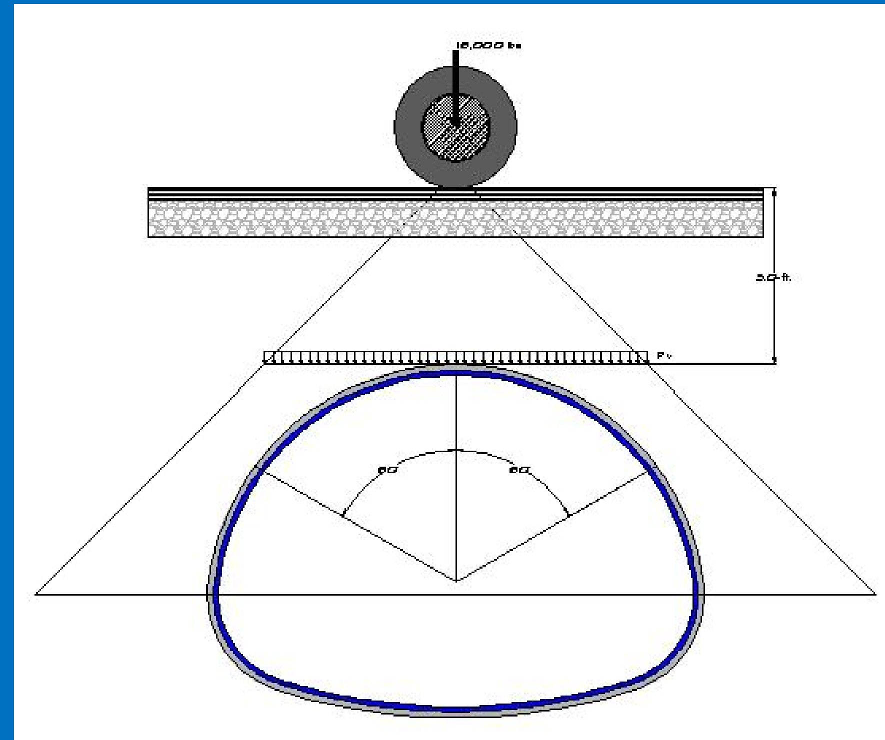
- K_x is the bedding coefficient which reflects the degree of support provided by the soil at the bottom of the pipe and over which the bottom reaction is distributed. Assuming an inconsistent haunch achievement (typical direct bury condition), a K_x value of 0.1 should be used. For a uniform shaped bottom support, a K_x value of 0.083 is appropriate.

Calculating the deflection ….

$$W_c = \frac{\delta_s h}{144} = \frac{109 \times 12}{144} = 9.1psi$$

W_L =0.8 psi

$$M_s = 0.92 \times 3000 = 2752psi$$



$$\frac{\Delta y}{D} = \frac{(D_L W_c + W_L)K_x}{0.149PS + 0.061M_s} = \frac{\big((1.1 \times 9.1) + 0.8\big)0.1}{(0.149 \times 46) + (0.061 \times 2752)} = 0.006$$

If the native soil had been only 90% SPD … Δy/D = 0.007 For B_d=2 → Δy/D = 0.010

If the native soil had been only 85% SPD … Δy/D = 0.008 For B_d=2 → Δy/D = 0.014

Soil Classification	Vertical Stress Level psi	Compaction, % maximum Standard Proctor Density				
		Dumped psi	100 psi	95 psi	90 psi	85 psi
I	1	2000	2350	2000		
I	5	2600	3450	2600		
I	10	3000	4200	3000		
I	20	3450	5500	3450		
II	1		2350	2000	1275 (1085)	470 (330)
II	5		3450	2600	1500 (1275)	520 (365)
II	10		4200	3000	1625 (1380)	570 (400)
II	20		5500	3450	1800 (1530)	650 (455)
III	1			1415 (708)	670 (335)	360 (180)
III	5			1670 (835)	740 (370)	390 (195)
III	10			1770 (885)	750 (375)	400 (200)
III	20			1880 (940)	790 (395)	430 (215)
IV *	1			530 (159)	255 (77)	130 (39)
IV *	5			625 (188)	320 (96)	175 (53)
IV *	10			690 (207)	355 (107)	200 (60)
IV *	20			740 (222)	395 (119)	230 (69)

The allowable deflection is based on the long-term ring-bending strain capacity of the pipe material reduced by an appropriate factor of safety....

$$\varepsilon_b = D_f\left(\frac{\Delta y_a}{D}\right)\left(\frac{t_t}{D}\right) \leq \frac{S_b}{\mathrm{DF}} \longrightarrow \frac{\Delta y_a}{D} \leq \frac{D S_b}{D_f t_t \mathrm{DF}}$$

	Pipe Zone Embedment Material and Compaction			
	Gravel*		Sand†	
Pipe Stiffness	< 85% SPD	≥ 85% SPD	< 85% SPD	≥ 85% SPD
psi	Shape Factor, D_f, (dimensionless)			
9	5.5	7.0	6.0	8.0
18	4.5	5.5	5.0	6.5
36	3.8	4.5	4.0	5.5
72	3.3	3.8	3.5	4.5

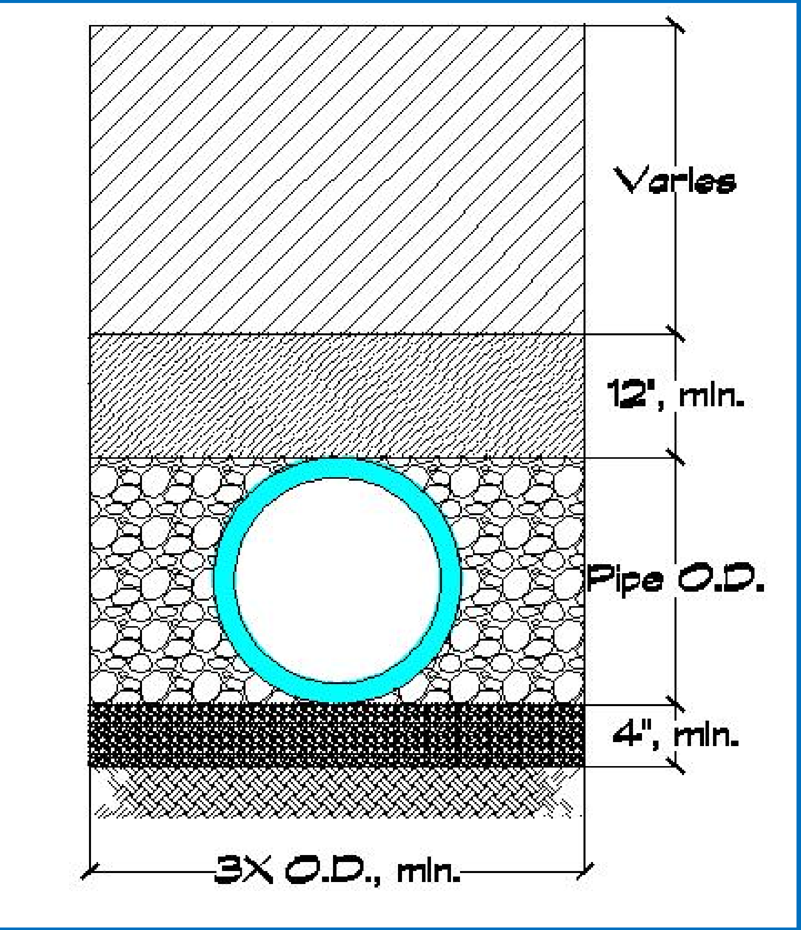
* GW, GP, GW-GC, GW-GM, GP-GC, and GP-GM per ASTM D2487 (includes crushed rock)

† SW, SP, SM, GM, and GC or mixtures per ASTM D 2487

$$\frac{\Delta y_a}{D} \leq \frac{DS_b}{D_f t_t \mathrm{DF}} = \frac{12.14 \times 0.05}{4.3 \times 0.36 \times (\frac{1}{2.0})} = 0.78 \quad \rightarrow 22\%$$

DF = 1/FS

Load acting on the bottom of the trench is 9.9 psi (1425 psf); which is less than the bearing capacity of the soil which is 1500 psf. No foundation under the bedding material will be required.



Temporary Trench Wall Supports

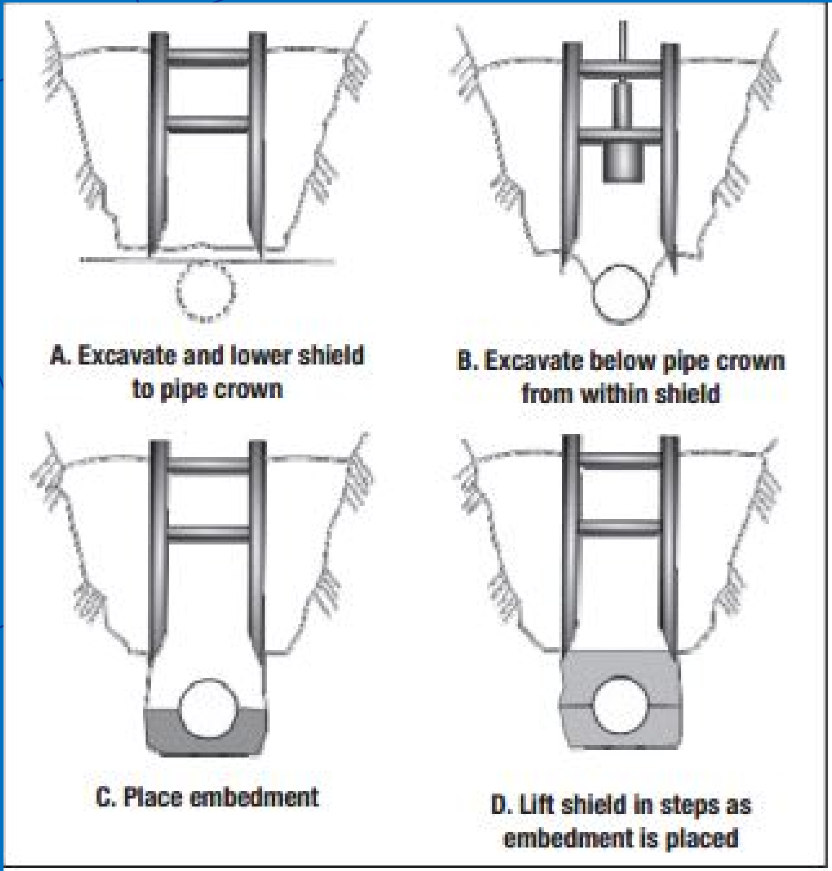
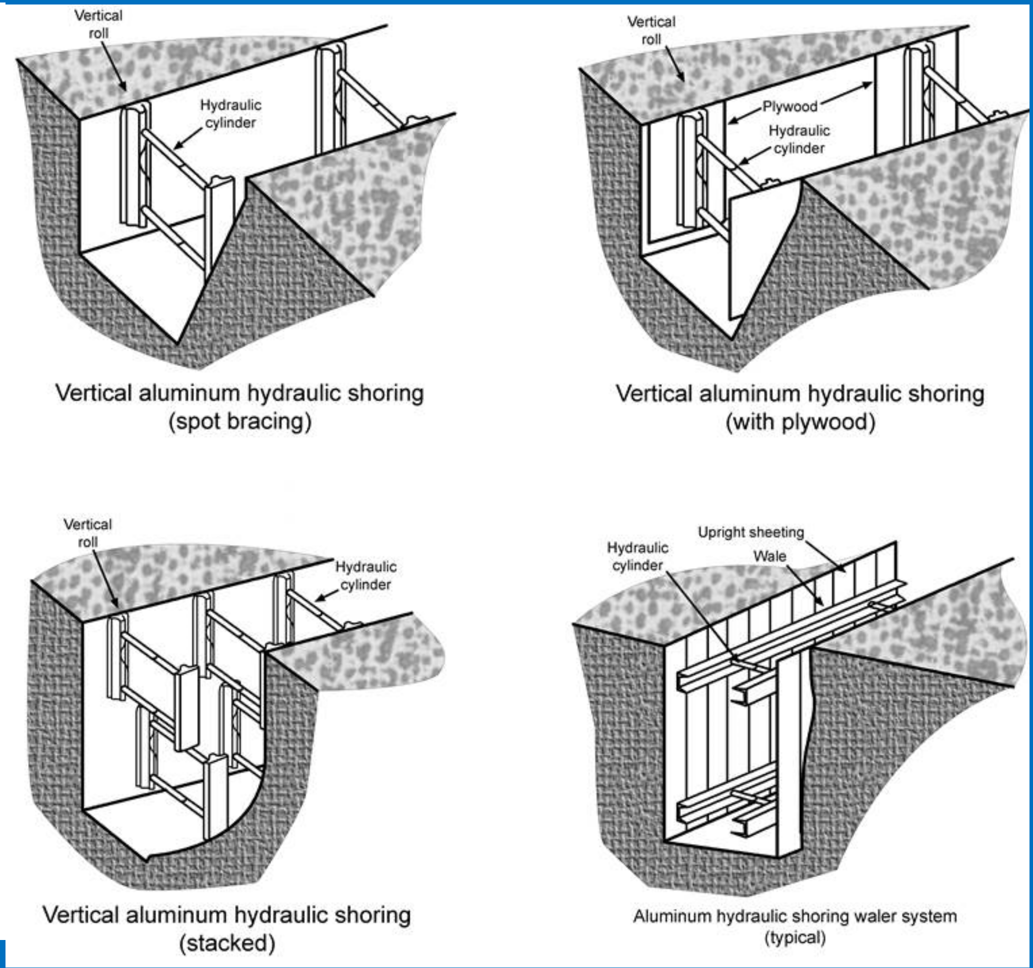
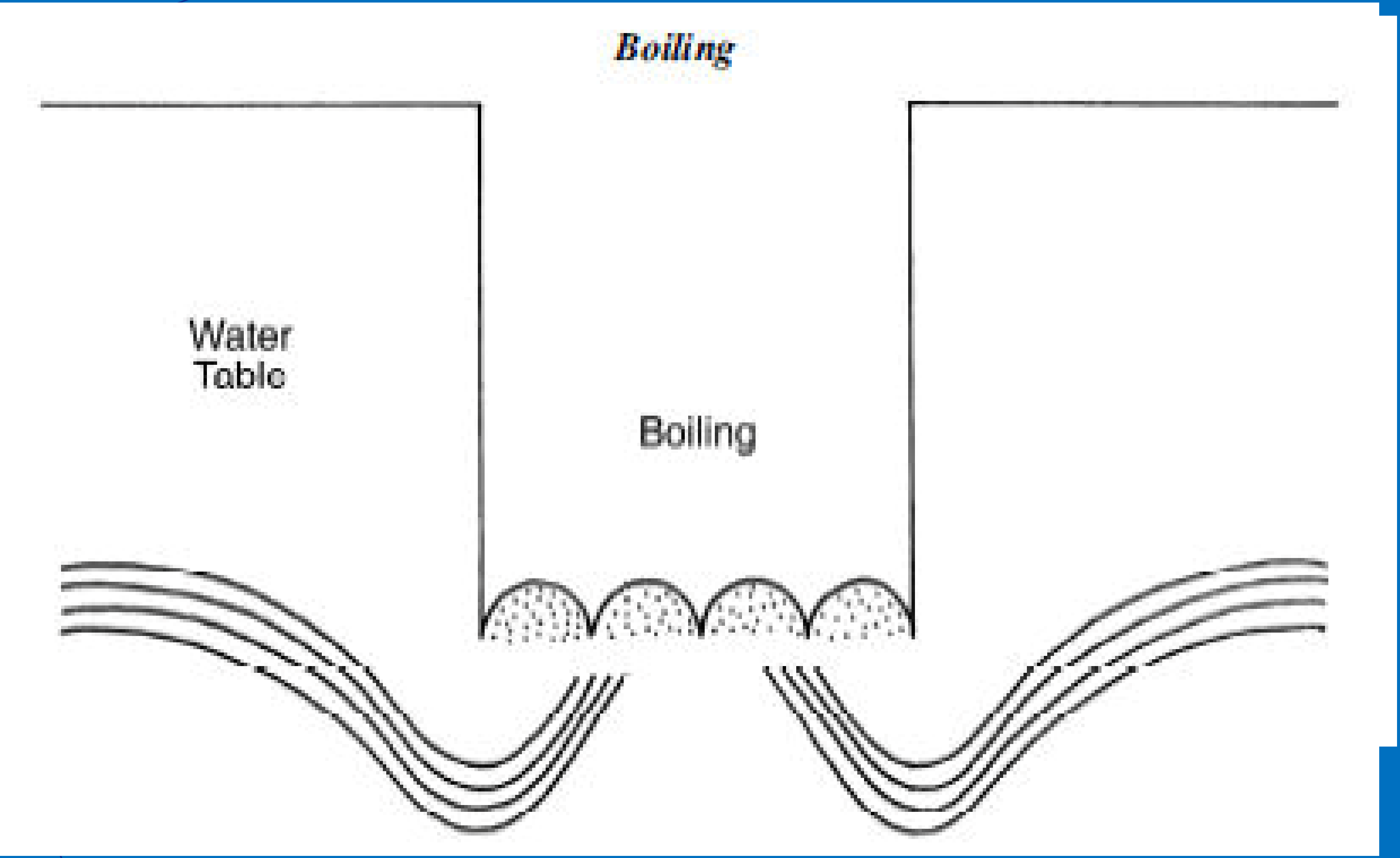


Figure 5 Installing PE Pipe with a Portable Trench Shield



Temporary Trench Wall Supports

Water Table



Summary

- Soil-Structure Interaction
  - Rigid Pipes
  - Flexible Pipes
- Recognizing the signs of significant deviation from the design
  - Guidance Detail
  - Changed Conditions
- Taking appropriate actions based on the severity of the deviant conditions occurring on site
- Confirming quality of the installation with an inspection of the pipe before the warranty period ends!

THANK YOU

WATER
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