Vitrified Clay Pipe Engineering Manual

Since 1917

NCPI

NATIONAL CLAY PIPE INSTITUTE

A Century Of Leadership

- In service in the U.S. for over 200 years
- Over 5 Billion linear feet of VCP installed
- The longest-lasting, most sustainable pipe material

Vitrified Clay Pipe Engineering Manual

FOREWORD

The *Vitrified Clay Pipe Engineering Manual* has been prepared by the National Clay Pipe Institute (NCPI) and is offered by the member manufacturers of the Institute as an aid to those requiring engineering reference data applicable to the design, construction and testing of sewer systems and other projects in which Vitrified Clay Pipe (VCP) should be used.

Design and construction techniques encountered throughout the country are many and varied. Those described here are based on recognized standards and are considered sound. Technical data presented are considered reliable, but no guarantee is made or liability assumed. The recommendations in this Manual should not be substituted for the judgment of a professional engineer experienced in sanitary sewer design as to the best way of achieving specific requirements.

The Engineering Staff of NCPI and of its member companies are available to assist the reader.

An electronic version of this document, including links to reference materials, is available for download at *ncpi.org.*

The National Clay Pipe Institute

The National Clay Pipe Institute (NCPI), established in 1917 by clay pipe manufacturers, has developed an unmatched expertise in the use of clay pipe for gravity sanitary sewers. As a result of this focus and decades of research and development, the organization is an invaluable resource for engineers.

NCPI led the development of factory applied, flexible compression joints and the low pressure air test to verify proper installation and performance of those joints. Today, NCPI is the resource for technical expertise and practical experience in using VCP for open-cut as well as trenchless installations. Research, development, testing and educational outreach continue to be the driving forces for NCPI.

The organization has defined best practices for, designing and installing projects with vitrified clay pipe and represents clay pipe manufacturers on the ASTM International (ASTM) C04 Committee on Clay Pipe.

History

For at least 6,500 years, clay pipe has been used in sanitary sewers. The design standards and planned functions have changed significantly over the last six millennia, but the knowledge base acquired over that period is an important part of the development of clay pipe of the 21st century.

Clay pipe has been used in the construction of combined sewers, storm sewers and sanitary sewers in American cities since the early 1800’s. Much of the early pipe was terra cotta and should not be confused with today’s vitrified clay pipe. Vitrification is a critical difference.

“Vitrification by definition is the progressive reduction and elimination of porosity of a ceramic composition with the formation of a glass phase as a result of heat treatment,” according to G. Bickley Remmey in his book Firing Ceramics. He goes on to say, “The firing process encompasses chemical and physical changes in the ceramic body accompanied by a loss of porosity and a subsequent increase of density.” The ultimate purpose of firing is to achieve the mechanical bonding of particles (for strength) and consolidation or reduction in porosity (e.g., for impermeability to fluids).

In 1915, almost 100-years after clay pipe was introduced in the sewers of major U.S. cities, ASTM accepted the recommendations of the C04 committee as the first tentative specification for sewer design and construction, designated C12, Recommended Practice for Laying Sewer Pipe. For the preceding 100-years there were no accepted standard practices, so the quality of installation was very much determined by individual engineers and their construction teams. It is a testament to those individuals and the clay pipe manufacturers of the day that 200-years later some of those sewers are still in service.

100 – 200 Years of Service in the U.S.
(As of 2015)

Years in Service	Year Installed	Location		
200 Years	1815	Washington, DC		
175 - 199 Years	1829	Boston, MA	Philadelphia, PA	
150 - 174 Years	1850	Clinton, IA		
	1856	Chicago, IL		
	1861	Cleveland, OH		
	1866	New York, NY		
125 – 149 Years	1868	Erie, PA		
	1869	Grand Rapids, MI	St. Louis, MO	
	1870	Hartford, CT		
	1872	Indianapolis, IN		
	1873	Los Angeles, CA Portland, OR	New Haven, CT Raleigh, NC	St. Paul, MN
	1874	Lawrence, KS		
	1875	Baltimore, MD	Portland, ME	
	1876	San Francisco, CA St. Joseph, MO	Jacksonville, FL	Albany, GA
	1877	Davenport, IA Bucyrus, OH	Kansas City, MO	New Bedford, MA
	1878	Omaha, NE		
	1879	Camden, NJ Providence, RI	Memphis, TN Nashville, TN	Parkersburg, WV
	1880	Rome, GA Sioux City, IA Fargo, ND Napa, CA	Rockford, IL Red Wing, MN Dallas, TX Sacramento, CA	Terre Haute, IN Reno, NV Denver, CO Woodland, CA
	1881	Kalamazoo, MI		
	1884	Le Mars, IA		
	1888	Salt Lake City, UT		
	1890	San Jose, CA		
	1892	Phoenix, AZ	Massillon, OH	
100 – 124 Years	1895	Highlands, NJ	Atlanta, GA	Santa Cruz, CA
	1904	New Castle, DE		
	1915	Seattle, WA		

The National Clay Pipe Institute and its member companies are proud of their history as early leaders in the acceptance of and participation in ASTM. More than a century of working with the engineering community has led to the development of stringent standards for the manufacture, testing and installation of VCP sanitary sewer pipe. Clay pipe manufacturers today provide a pipe system that is leak-free resulting in the most sustainable and longest-life sanitary sewer product available.

For more information about the history of sewers, visit sewerhistory.org.

Acknowledgements

The National Clay Pipe Institute wishes to acknowledge the following subject matter experts and members of the NCPI Technical Services Committee who have contributed to this edition, both individually and collectively.

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Vitrified Clay Pipe Engineering Manual

Table of Contents

For the most up-to-date information and live links to related materials, see our manual on line at ncpi.org.

CHAPTER 1: VITRIFIED CLAY PIPE

Figure 1-1: *Modern Vitrified Clay Pipe (VCP) with factory-applied, compression joints, which "shall not leak," per ASTM C425.*

Properties

Vitrified Clay Pipe (VCP) is uniquely suited for gravity sanitary sewers and is the longest lasting sewer pipe available. No other pipe material can match the properties or deliver the long-term value of VCP.

Vitrified Clay Pipe attributes:

- Rigid Strength
- Flexible Watertight Joints
- Sustainable
- Inert

Rigid Strength

VCP is categorized as a rigid conduit, which means it has inherent structural strength in the pipe itself. The common method to determine structural strength is a three-edge bearing test, which is measured in pounds of load per linear foot of pipe length. Three-edge bearing capacities increase with larger pipe diameters. Minimum strengths

Figure 1-2: *Three-edge bearing testing for inherent structural strength.*

per pipe diameter are included in the standard ASTM C700 *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated.*

Flexible Watertight Joints

VCP compression joints shall not leak in accordance with ASTM C425 *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings.* The joint test for VCP includes subjecting an assembled deflected joint to a 10-ft head of water pressure with a shear load applied. The pipe joint is deflected to simulate a curvilinear alignment and the applied shear force simulates settlement and lack of proper support. The minimum shear load applied to the unsupported pipe end is 150-pounds per inch of nominal diameter. With all of these loads applied for a total test period of 1 hour, the joint **"shall not leak."** VCP compression joints are designed to allow angular deflection while retaining joint integrity. See Table 1-1 for the limits of joint deflection and page 2-4 for designing curvilinear sewers with deflected joints.

Nominal Diameter (inches)	Deflection of Pipe, inches/linear ft.
3 to 12	1⁄2
15 to 24	3⁄8
27 to 36	1⁄4
39 and 42	3⁄16
48	1⁄8

Table 1-1: *Joint Deflection limits*

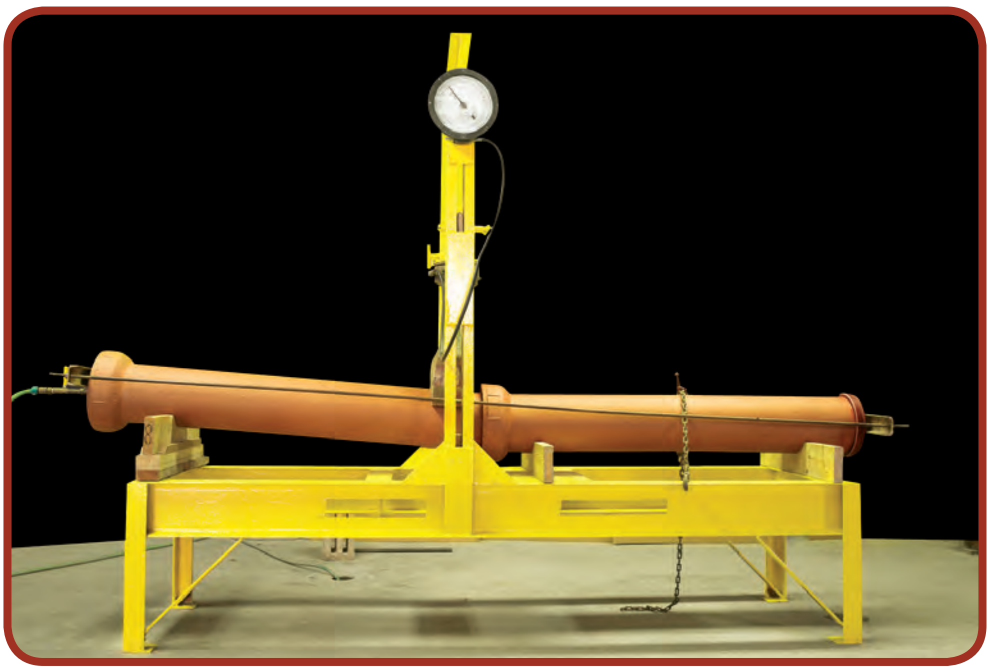


Figure 1-3: *Compression joint test simulates joint performance under conditions of shear load and angular deflection.*

Sustainable

Vitrified Clay Pipe is the most sustainable sewer pipe manufactured today. The documented lifecycle of VCP, coupled with naturally occurring, abundant raw materials makes it the most sustainable pipe product ever made.

The raw materials for the manufacture of VCP are clays and shales. These earthy mineral aggregates are the end products of nature's weathering forces.

VCP manufactured by the member companies of National Clay Pipe Institute (NCPI) has been independently certified as environmentally friendly based on an ISO 14001-compliant life cycle assessment. This review included critical evaluation of the raw materials, sourcing, manufacture and expected product lifecycle as they impact human health and the environment over both the short and long term. To see the scorecard from this assessment, visit the sustainability page of the NCPI website (ncpi.org).

Inert

Through centuries, soluble and reactive minerals have been leached from rock and soil, leaving an inert material. This chemically inert material is transformed into a dense, hard, homogeneous clay body through firing in kilns at temperatures of about 2000°F (1100°C). "Vitrification" occurs as the clay mineral particles become mechanically bonded into an inert, chemically stable compound, integrally bonded by its very nature.

Figure 1-4: *Firing at about 2000° F (1100°C) is critical to achieving vitrification which creates a solid pipe body.*

VCP will not rust, corrode, shrink, elongate, bend, deflect, erode, oxidize or deteriorate over time.

Pipe Specification Considerations

Each municipality has its own set of special challenges, but there are some universal concerns that should be addressed when specifying any pipe material for sanitary sewers.

- Life expectancy: No other pipe material can match the 200-years of proven service life in the United States.
- Chemical attack: VCP is inert and therefore resistant to internal and external attack from solvents, acids, alkalis, gases, etc.
- Flow characteristics: Low friction coefficient.
- Structural integrity: Inherent load bearing capacity.
- Joint tightness: Factory applied flexible compression joints that "shall not leak."
- Abrasion resistance: Exceptional resistance to abrasion and scour.
- Availability: Available in a full range of sizes, fittings and adapters.
- Environmental impact: No other pipe material can come close to the natural environmentally responsible credentials of VCP.
- Economics: Best total value considering cost of material, installation, maintenance and useful life.
- Durability.

Manufacturing Process

Vitrified Clay Pipe is one of man's most enduring materials. Manufacturers blend specially selected clays and shales to develop the inherent strength and load bearing capacities of the pipe. The principal steps in the manufacture of clay pipe are:

- Mining
- Grinding
- Extruding
- Drying
- Firing
- Testing the Pipe and Joint

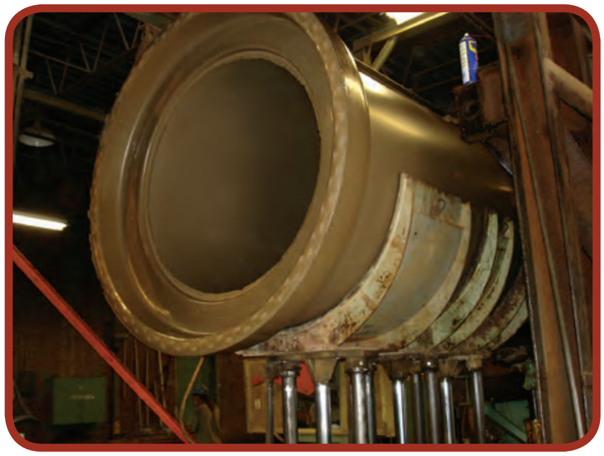


Figure 1-5: *Modern manufacturing methods enable production of larger diameter pipe.*

To see a video of the VCP Manufacturing process from the *How It's Made* Science Channel episode, visit our YouTube channel.

Mining

Only specialized clays, found in hydrous alumina silicates, are suitable for the manufacture of Vitrified Clay Pipe. These clays must have an appropriate level of plasticity (essential for forming the pipe), suitable vitrification properties and stability at high temperatures (to achieve the desired strength during firing). Laboratory tests determine that all raw materials used meet these qualifications and ensure that the resultant pipe meets the rigorous standards of ASTM.

Grinding

The clay mixture is ground in heavy, perforated metal pans by large crushing wheels. The mixture is then sent through fine, heated, vibrating screens to assure proper particle size.

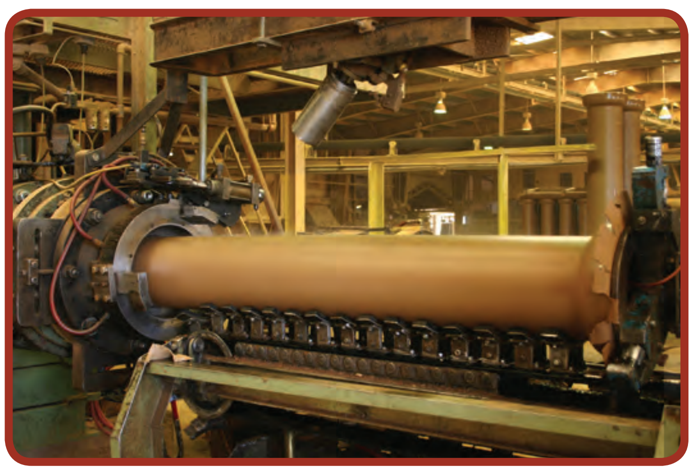


Figure 1-6: *More powerful extrusion equipment produces stronger pipe bodies and longer pipe lengths.*

Extruding

Ground raw materials are mixed with water in a pug mill. This material is forced through a vacuum, de-airing chamber to produce a smooth, dense mixture. The moistened clay is extruded under high pressure to form the pipe. Because the pressure is extreme, voids and laminations are not a concern in modern VCP.

Drying

The pipe is transferred to large, heated drying rooms to remove moisture. Drying time can vary based on the size of the pipe and the level of ambient humidity

Figure 1-7: *Drying rooms capture excess heat from the kilns to help make VCP the most environmentally responsible sanitary sewer pipe product.*

Firing

The temperature in the kiln is gradually increased to approximately 2000°F (1100°C). The first phase of firing must take place slowly so that the shape of the pipe is set before the ramp-up to the higher temperatures required for vitrification. At the highest temperatures the interior portions of the pipe body are almost liquefied to create the solid ceramic structure. Cooling also has to happen in a controlled, slow process to prevent damage. Firing times vary by raw materials and pipe size.

Testing the Pipe & Joint

Every pipe exiting the kiln is visually and physically inspected. Representative samples from each firing are tested for bearing strength (in accordance with ASTM C700 *Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*). The final test per ASTM C425 *Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings* includes shear load, deflection and hydrostatic pressure to simulate the most extreme conditions in the field.

Figure 1-8: *Aggressive testing of the joint ensures long-term, leak-free performance.*

Perforated Pipe

Figure 1-9: *Perforated clay pipe is an environmental alternative for drainage applications.*

Perforated clay pipe are used in a variety of drainage applications including leachate detection and transmission. Normal use requires that the pipe be installed on a controlled grade with the perforations placed down. The surrounding materials should be properly sized to prevent migration of fines or blockage of the perforations. A filter fabric which restricts the passage of fines may be required in certain installations. Refer to ASTM C700 *Standard Specification of Vitrified Clay Pipe Extra Strength, Standard Strength, and Perforated,* and ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe Lines.*

Vitrified Clay Pipe ASTM Specification & Testing Standards

ASTM C12	*Standard Practice for Installing Vitrified Clay Pipe Lines*
ASTM C301	*Standard Test Methods for Vitrified Clay Pipe*
ASTM C425	*Standard Specification for Compression Joints for Vitrified Clay Pipe and Fittings*
ASTM C700	*Standard Specification for Vitrified Clay Pipe, Extra Strength, Standard Strength, and Perforated*
ASTM C828	*Standard Test Method for Low-Pressure Air Test of Vitrified Clay Pipe Lines*
ASTM C896	*Standard Terminology Relating to Clay Products*
ASTM C1091	*Standard Test Method for Hydrostatic Infiltration Testing Of Vitrified Clay Pipe Lines*
ASTM C1208/1208M	*Standard Specification for Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting, and Tunnels*

CHAPTER 2: GRAVITY SEWER DESIGN

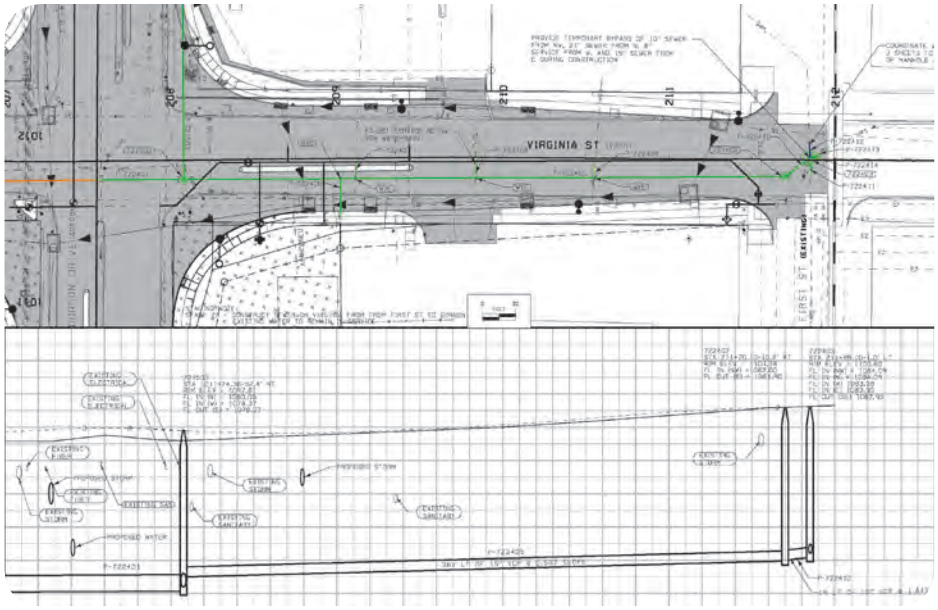


Figure 2-1: *Sample plan and profile illustration*

Planning and Layout

Sewer Planning

Sufficient lead time to formulate economic proposals, secure approvals, arrange financing, design, construct and place in operation the necessary sewers to carry domestic, commercial and industrial wastewater from a community to a point of treatment is required for projects. Most agencies have Sewer System Master Plans in place to be used in the design of pipe sizing and locations.

Design Period

A design period must be chosen and sewer capacity planned that will be adequate. Population and land use changes for more than 20 years into the future are sometimes difficult to predict and plan. However, when planning, designing, financing and construction are compared to the relatively minor additional cost of providing extra capacity, a minimum design life of 50-years should be considered and when possible, a design life of 100-years or more is recommended. Planners should design for ultimate development where special conditions exist such as remote areas near the boundary of a drainage area. Also to be considered are areas where special construction, such as pump stations and inverted siphons may be required. The cost of additional capacity is minimal compared to the cost of relief lines installed at a later date.

Mainline sewers should be designed for the population density expected in the areas served, since the quantity of domestic sewage is a function of the population and of water consumption. Trunk and interceptor sewers should be designed for the tributary areas, land use and the projected population. For these larger sewers, past and future trends in population, water use and sewage flows must be considered. The life expectancy of the pipe is critical. Clay pipe has a demonstrated life expectancy in excess of 200 years.

Design Flows

A sanitary sewer has two main functions:

1. to carry the maximum design flow, and
2. to transport suspended solids so that deposits in the sewer are kept to a minimum.

It is essential therefore that the sewer has adequate capacity for the maximum design flow and that it function properly at minimum flow as well.

Maximum design flow determines the hydraulic capacity of sewers, pump stations, and treatment plants. Minimum flows must be considered in design of sewers and inverted siphons to insure reasonable cleansing velocities.

Extraneous Flows

Sanitary sewer design quantities should include consideration of the various non-sewage components, which can become a part of the total flow. These non-sewage components have been greatly reduced as sanitary sewers have been separated from storm sewers, but a consideration factor for these flows is still seen as advisable.

The cost of transporting, pumping and treating sewage obviously increases as the quantity of flow delivered to the pumps or treatment facility increases. Thus, extraneous flow should be eliminated to the extent possible by proper design and construction practices and adequately enforced connection regulations.

Inflow

A very few illicit roof drains connected to the sanitary sewer can result in a surcharge of smaller sewers. For example, a rainfall of 1 in. per hour on 1,200 ft^2 of roof area, would contribute more than 12 gpm.

Connection of roof, yard and foundation drains to sanitary sewers should be legally prohibited and steps taken to eliminate them. Most municipalities have now enacted, or are in the process of enacting laws to accomplish this. Water from these sources and surface run off should be directed to a storm drainage system.

Tests indicate that leakage through manhole covers may be from 20 to 70 gpm with a depth of 1 in. of water over the cover. Such leakage may contribute amounts of storm water exceeding the average sanitary flow.

Infiltration

Prominent sources of excessive infiltration can be poorly constructed manholes and/or connections and improperly laid house laterals. In a given system, laterals frequently have a total length greater than the collecting system. House connections should receive the same specifications, construction and inspection as public sewers.

Prior to 1972 and the passage of the Clean Water Grant Act, sewer designers allowed higher amounts of infiltration to aid in transporting solids. "Dilution is the Solution to Pollution" was the phrase used to illustrate the design theory of the time. The cost involved in treating infiltration in modern systems means that it must now be prevented.

Advantages of Flexible Compression Joints

Probably the largest misconception about VCP surrounds the jointing system. VCP is the most widely used pipe material for gravity sanitary sewer pipe over the last few centuries. As a result, many people think of the early field-made joints from the 1900's and not the factory-made flexible compression joints that were first introduced in the late 1950s. The problems with the old jointing system were twofold. The first issue was a leaky joint and the resultant root intrusion and material loss outside the pipe both affecting structural integrity of a pipeline. The second was created by having a joint incapable of adjusting to minor movement after installation. While cement mortar, oakum, and asphaltic joints are a thing of the past there are many miles of pipelines with this antiquated joint system still in service.

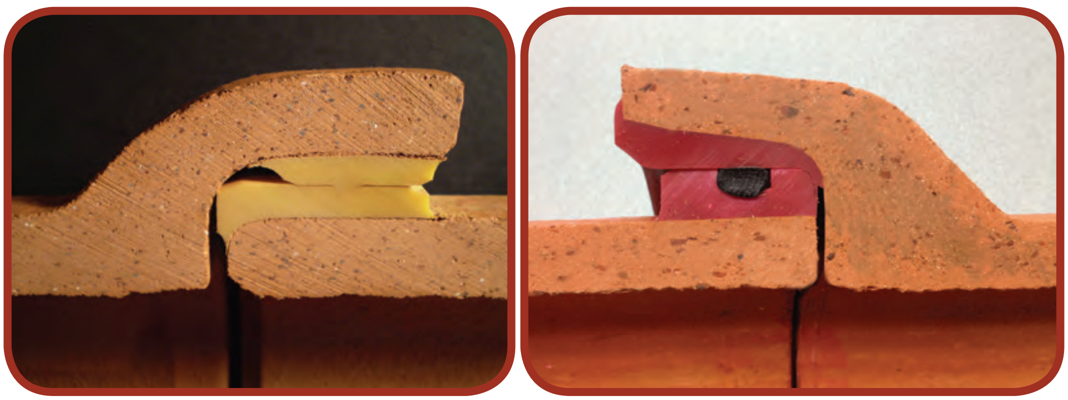


Figure 2-2: *Polyurethane (left) and O-ring and polyester (right) flexible compression joints.*

Flexible compression joints conforming to ASTM C425 provide a tight and flexible joint whether the sewer is above or below ground water. Modern, flexible compression joints use polyester or polyurethane materials and are factory applied to both the bell and spigot of every pipe (see Figure 2-2). Another jointing system option is plain end pipe barrels joined with rubber compression couplings with stainless steel tightening bands (see Figure 2-3). All of these jointing systems allow the clay pipe to shift or move with any minor changes in earth conditions without damaging the pipe. This provides a measure of forgiveness during installation and for the life of the line.

Figure 2-3: *Rubber compression couplings with stainless steel tightening bands.*

Curvilinear Sewers

The factory applied joints of modern VCP pipe are designed to allow some angular deflection while retaining joint integrity. ASTM C425 prescribes the limits of joint deflection as shown in Table 2-1. A smaller curve radius can be created using shorter lengths of pipe.

Radius of Curvature & Angle of Deflection							
Pipe Diameter (inches)	**Maximum Deflection**		**Equation for r***	**Minimum Radius of Curvature (r*)**			
	In./LF	**Angle Θ**		**Pipe Length L (feet)**			
				4	**6**	**8**	**10**
3 – 12	1/2	(2.4°)	r = 24(L)	96	144	192	----
15 – 24	3/8	(1.8°)	r = 32(L)	128	192	256	320
27 – 36	1/4	(1.2°)	r = 48(L)	192	288	384	480
39 – 42	3/16	(0.9°)	r = 64(L)	256	384	512	640
48	1/8	(0.6°)	r = 96(L)	384	576	768	960
* r = Minimum radius in feet							

Table 2-1: *Radius of Curvature & Angle of Deflection*

The equation for use in determining radius, deflection angle per joint or the length of pipe in feet can be stated as follows:

$$r = (360°/\theta)(L/2\pi)$$

The equation for determining the distance each pipe section needs to be deflected from a straight line (measured in inches) can be stated as:

$$\Delta d = \tan \theta \, (L)(12)$$

Where:

- r = Radius of the curved sewer in feet
- θ = Deflection angle per joint
- L = Length of pipe in feet
- Δd = Deflection measured in inches per joint

Example 2-1: Finding the Maximum Pipe Length

The planned curve of a street and location of other utilities has tentatively been planned to call for a 125 foot radius. The service demand in this area will require an 8-inch pipe. Referring to Table 2-1, the maximum allowable angular deflection for 8-inch pipe is 2.4°.

$$r = (360°/\theta)(L/2\pi)$$

$$125 = (360°/2.4°)(L/2\pi)$$

$$L = (125)(2.4)(2\pi)/360$$

$$L = 5.24'$$

A standard 5 foot pipe length should be used.

Example 2-2: Finding Angle of Deflection for Each Pipe

If the design radius of the proposed 15-inch diameter sewer will be 220 feet, determine the deflection angle of each piece of pipe.

Determine that the design radius of 220 feet is larger than the minimum prescribed in Table 2-1: r = 32(6) = 192.

$$r = (360°/\theta)(L/2\pi)$$

$$220 = (360°/\theta)(6/2\pi)$$

$$\Theta = (360)(6)/(220)(2\pi)$$

$$\Theta = 1.56°$$

For ease of installation, determine the distance each 6-foot length of pipe needs to be deflected from a straight line in inches.

$$\Delta d = \tan\theta\,(L)(12)$$

$$\Delta d = \tan 1.56°\,(6)(12)$$

$$\Delta d = 1.96''$$

Flow Monitoring

A sewer flow-monitoring program is necessary to determine when existing sewers will reach hydraulic design capacity. Monitoring methods vary from high water markers that record maximum depths to hand held mechanical tools or electronic devices. With a history of flow data, projections can forecast the year the peak flow will reach the design capacity of the sewer.

Sewer line modeling computer programs are available to analyze existing systems and establish quantities for the design of relief sewers.

Basic Premises for Calculating Flow in Sewers

This section on hydraulics of sewers deals only with uniform flow. Standard hydraulic handbooks should be consulted for special conditions.

Since the flow characteristics of sewage and water are similar, the surface of the sewage will seek to level itself when introduced into a channel with a sloping invert. This physical phenomenon induces movement known as gravity flow. Most sewers are of this type.

The flow in a pipe with a free water surface is defined as open channel flow. Steady flow means a constant quantity of flow and uniform flow means a steady flow in the same size conduit with the same depth and velocity. Although these conditions seldom occur in practice, it is necessary to assume uniform flow conditions in order to simplify the hydraulic design.

There are times when sewers become surcharged, encounter obstacles requiring an inverted siphon or require pumping. Under these conditions the sewer line will flow full and be under head or internal pressure.

The Flow Characteristics Diagram (Figure 2-4) demonstrates the theory and terminology applied to flow in open channels. To simplify the diagram, all slopes are subcritical and it is assumed that

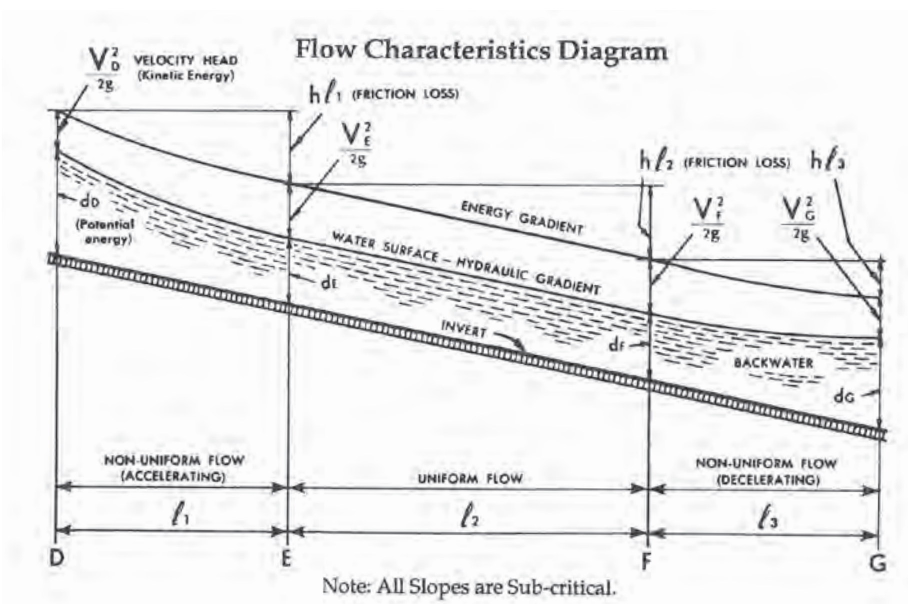


Figure 2-4: Flow Characteristics theory and terminology illustrated

at point D a constant supply of water or sewage is being supplied. Between D and E the slope of the conduit is greater than is required to carry the water at its initial velocity, and is greater than the retarding effect of friction, which causes acceleration to occur. At any point between E and F, the potential energy of the water equals the loss of head due to friction and the velocity remains constant. This is uniform flow. Between F and G the effect of downstream conditions are causing a decrease in the velocity.

The Hydraulic Profile

Three distinct slope lines are commonly referred to in hydraulic design of sewers as shown in Figure 2-4.

1. The Slope of the Invert of the Sewer. This is fixed in location and elevation by construction. Except in rare cases, the invert slopes downstream in the direction of flow.
2. The Slope of the Hydraulic Gradient (H.G.). This is sometimes referred to as the water surface. In open channel flow, this is the top surface of the liquid flowing in the sewer. Except for a few cases, the hydraulic gradient slopes downstream in the direction of flow.
3. The Energy Gradient (E.G.). This is located above the hydraulic gradient, a distance equal to the velocity head, which is the velocity squared divided by two times the acceleration due to gravity ($v^2/2g$). This slope is always downstream in the direction of flow. For uniform flow, the slope of the energy gradient, the slope of the hydraulic surface and the slope of the invert are parallel to one another but at different elevations.

Design Requirements

In sewer system design the following hydraulic requirements must be met:

1. The velocity must be sufficiently high to prevent the deposition of solids in the pipe but not high enough to induce excessive turbulence. The minimum scouring velocity is 2 feet per second. Clay pipe is being used successfully where velocities exceed 20 feet per second.
2. Where changes are made in the horizontal direction of the sewer line, in the pipe diameter, or in the quantity of flow, invert elevations must be adjusted so that the change in the energy gradient elevation allows for the head loss.
3. Sanitary sewers up to 15-inches in diameter should be designed to run half-full at peak flow and larger sewers designed to run three-quarters full at peak flow. This also provides necessary air space to transfer sewer gases.

After flow estimates have been prepared, including all allowances for future increases and the layout of the system has been determined, the next step is to establish the slope for each line. Profile sheets show the surface elevations, subsurface structures and any other control points, such as house connections and other sewer connections. A typical profile for sewer design is shown on page 2-1.

Using the profile sheet, a tentative slope of the sewer is determined beginning at the lower end and working upstream between street intersections or control points. The slope is located as shallow as possible to serve the adjacent area and tributary areas with consideration to street grade and any control points or obstructions.

Determination of Pipe Sizes

Knowing the peak flow and the tentative slope, a tentative pipe size can be selected for each reach using the Design Capacity Graph shown on page 2-12. A diagram based on Manning's Equations showing quantity, slope, pipe size and velocity can be used to find pipe sizes. The diagram shows quantities for one-half depth for small pipe through 15-in. diameter and three-quarters depth for 18-in. and larger sizes. The "n" values can range from 0.006 to 0.013. Enter the diagram with Q and slope and read the larger pipe size. Except for cases where there are large head losses, the tentative pipe size will be the final pipe size.

Selecting the Sizes for the New Sewer Line

Once design flows (Q_d), the slope of the line and the "n" value to be used are determined, the required pipe sizes may be selected.

The slope is obtained by drawing a preliminary profile showing control points, such as, sewers to be intercepted, major substructures, ground lines, outlet sewer, etc. The "n" value is selected by the specifying agency or is defined by regional standards.

Example 2-3: Determination of the Required Pipe Size Using a Design Capacity Graph

For a given project, flow estimating calculations resulted in the values below.

Estimated Average & Maximum Flows (cfs) for Project Reaches A - G							
MH	A	B	C	D	E	F	G
Q_{av}	0.37	0.59	1.21	1.98	2.14	4.47	9.19
Q_d	0.96	1.53	2.80	4.50	4.80	9.40	18.00

If the available slope is 0.4 ft. per 100 ft. along this reach and the coefficient of friction (n) is 0.013, determine the required pipe size for the reach downstream from MH A, using the Design Capacity Graph shown on page 2-12.

- Locate the intersection of the 0.004 slope and Q_d of 0.96 cfs
- Read the larger pipe size. This Q_d intersects the 0.004 slope between a 10-in. and a 12-in. pipe.

The larger pipe is usually selected.

In the reach downstream from MH B, the Q_d is 1.53 cfs, indicating that a 15-in. pipe will be required.

Further downstream, the outflow from MH F is 9.4 cfs, and a 21-in. pipe is necessary.

As a final check, plot the pipelines on the profile, set the outlet elevation and work upstream through each confluence, making sure there is adequate clearance for substructures and that the line meets all other controls. The pipe size will have to be rechecked if the slope has been changed for any reason.

Knowing the quantity of flow and the pipe size, the velocity can be calculated using the Manning Equation, the Velocity Variation Table (page 2-10) or the Design Capacity Graph (page 2-12). The velocity head can be calculated to give the energy gradient.

In many cases, especially with large diameter sewers, it is necessary to carefully plot the energy gradient of the sewer to determine that the hydraulic design requirements are met.

In these cases, start at the downstream end of the profile and mark the energy gradient at that point. Where the flow enters another sewer it will be the energy gradient of that sewer.

A line to represent a tentative location for the energy gradient for the first section of sewer being designed is then drawn upstream following the available surface slope to the next control point on the profile. As discussed earlier, this could be a point where flow is added, a street intersection, an abrupt change in surface slope or other control points. Care must be taken to see that the final design of the sewer provides adequate cover and that the sewer clears all subsurface obstructions. The profile can now be finalized.

Quantity and Velocity Equations

The following equations are provided to show the basis for flow diagrams and to supply equations for more accurate hydraulic calculations. Precise calculations of hydraulic data are not possible except under controlled conditions.

The Manning Equations

The most commonly used velocity and quantity equations are:

$$V = \frac{1.486}{n} r^{2/3} s^{1/2}$$

$$Q = \frac{1.486}{n} ar^{2/3} s^{1/2}$$

Where:

"***V***" = the velocity of flow (averaged over the cross-section of the flow) measured in feet per second. For sewers flowing at design depth, "V" should exceed 2 feet per second to prevent settlement of solids in the pipe. Conversely, velocities exceeding 20 feet per second should be avoided where possible. Clay Pipe can handle high velocities without damage, however, manholes, structures and angle points must be designed carefully to avoid problems.

"***Q***" = the quantity of flow measured in cubic feet per second.
"***n***" = a coefficient of roughness which is used in Manning's Equation to calculate flow in a pipe. (See the following discussion of "n" values.)
"***a***" = the cross-sectional area of the flowing water in square feet.
"***r***" = the hydraulic radius of the wetted cross-section of the pipe measured in feet. It is obtained by dividing "a" by the length of the wetted perimeter.
"***s***" = the slope of the energy gradient. It is numerically equal to the slope of the invert and the hydraulic surface in uniform flow.

Velocity Variations From Design Depths
(To Convert Depth/Diameter to % of Velocity)

d/D	% V.5D	% V.75D	d/D	% V.5D	% V.75D	d/D	% V.5D	% V.75D	d/D	% V.5D	% V.75D
.05	26	23	.30	78	69	.55	104	92	.80	114	101
.10	40	35	.35	84	74	.60	107	95	.85	114	100
.15	52	46	.40	90	80	.65	110	97	.90	112	99
.20	62	54	.45	95	84	.70	112	99	.95	110	97
.25	70	62	.50	100	88	.75	113	100	1.00	100	88

Table 2-2: *Velocity Variations*

Discussion of Values for "n"

The value of "n" for smooth bore pipe is affected by depth of flow, velocity of flow and quality of construction. In controlled experiments, using clean water, values of "n" under 0.009 have consistently been obtained for vitrified clay pipe and some other sewer materials. Many design engineers recommend that a more conservative value of "n" be used in design because of:

1. the variations in "n" due to variable flow conditions,
2. the deposition of debris, grit and other foreign materials which find their way into a sewer system,
3. the build-up of slime and grease on all pipe surfaces, see Figure 2-5 on page 2-11,
4. the loss of hydraulic capacity of flexible pipe due to ring deflection and
5. misalignment due to construction or settlement.

Based upon current data, "n" values of 0.009 - 0.013 can be applied to all types of smooth bore pipe. After pipelines have been in place for several years, measurements may indicate "n" values that differ from the design value. These new values can be used for future flow calculations. Field-testing of lines in service for 10-years have reported values as low as 0.006, validating the use of 0.013 as a conservative value for Manning's "n". Factors for determining Q's when using the conservative "n" value of 0.013 are shown on the Design Capacity Graph on page 2-12.

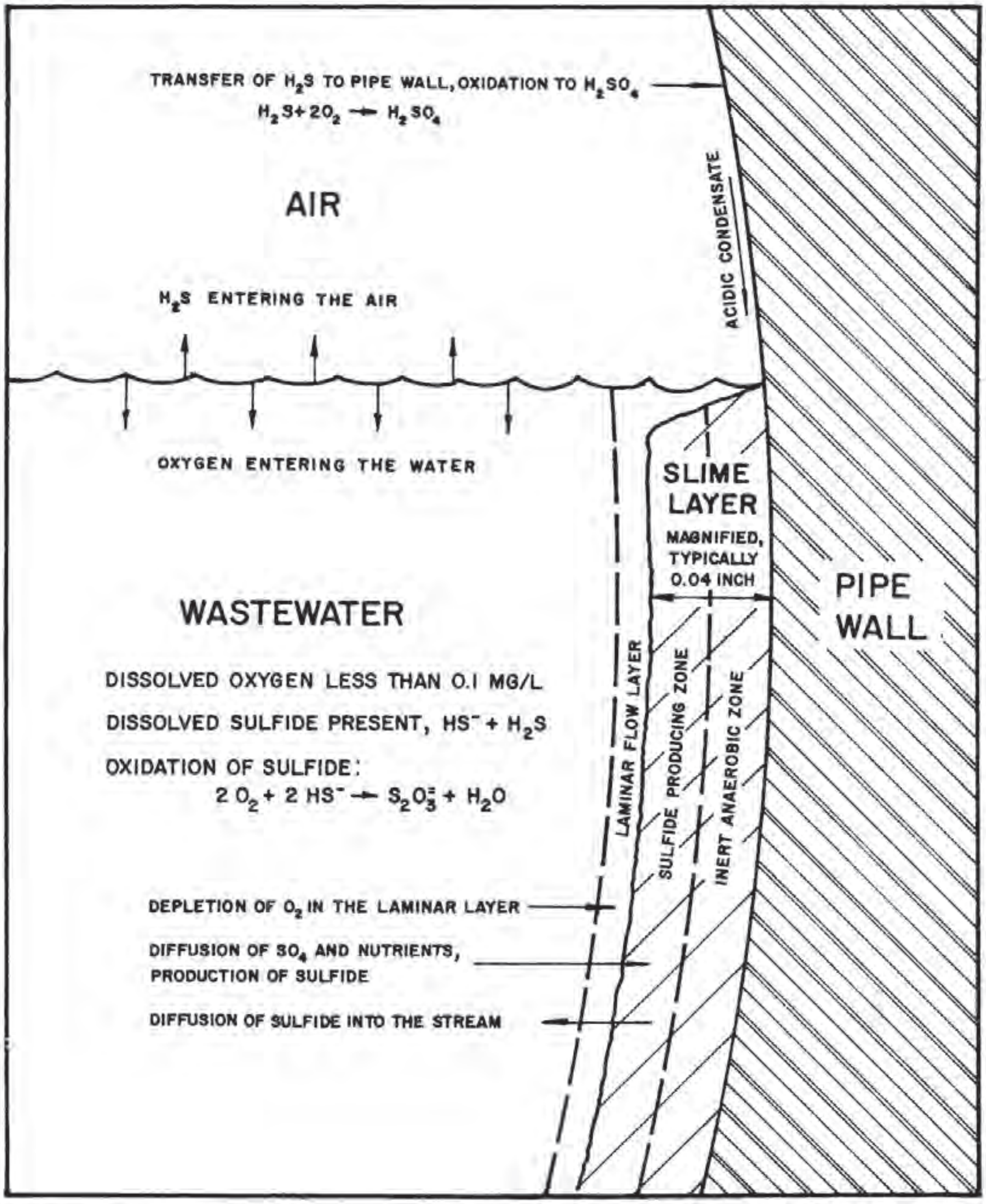


Figure 2-5: *Processes occurring in sewer under sulfide buildup conditions.*
Source: *Environmental Protection Agency, Process Design Manual for Sulfide Control in Sanitary Sewers, Richard D. Pomeroy, October, 1974.*

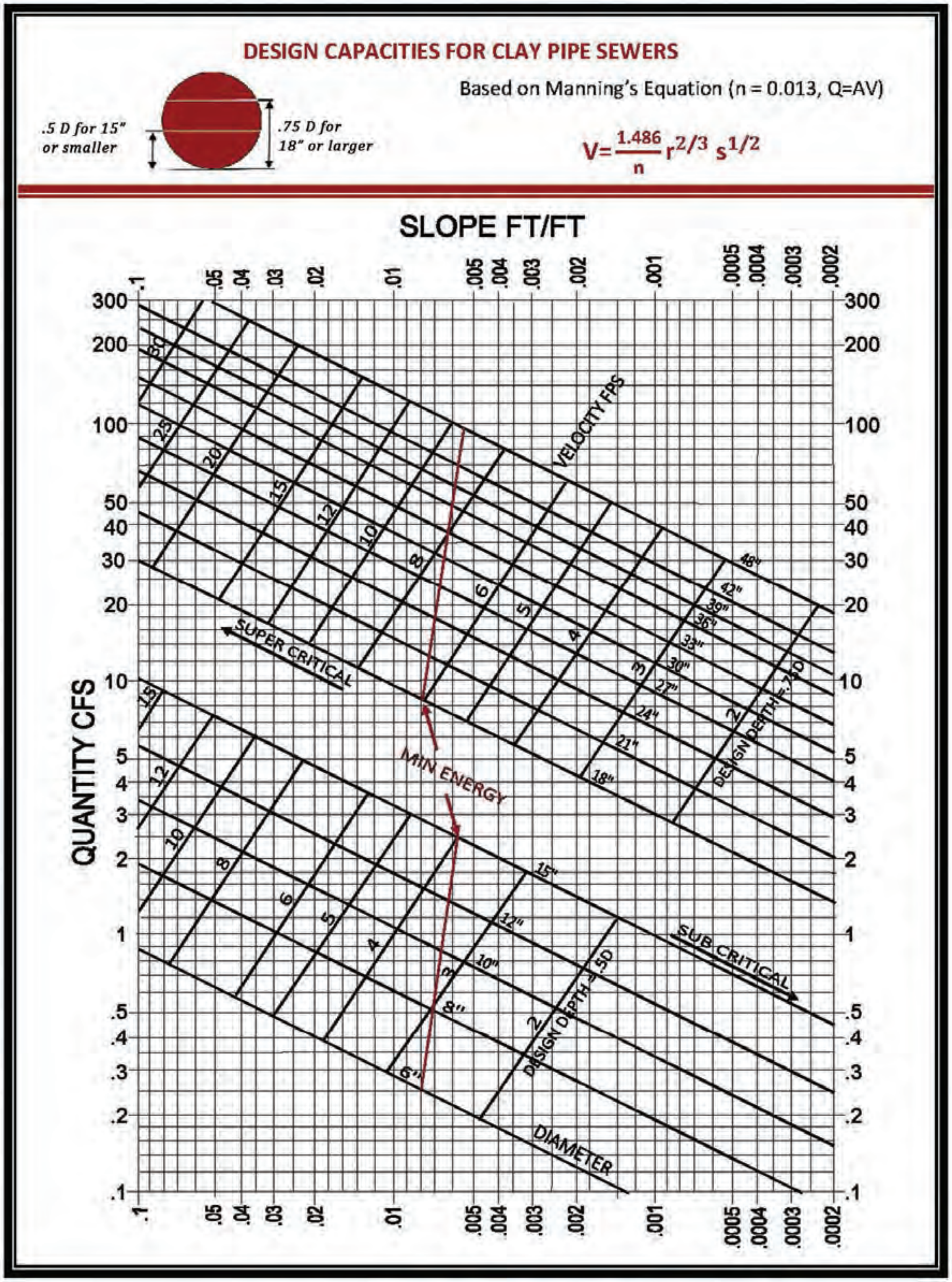


Figure 2-6: Design Capacities for Clay Pipe Sewers using a friction coefficient of n = 0.013.

Computer Aided Design

The National Clay Pipe Institute offers a hydraulic design program, Hyflow, which uses Manning's Equations to assist engineers in selecting pipe size, flow quantities or velocity in gravity flow sanitary sewers. It is available online at ncpi.org/toolbox/hyflow.

Examples 2-4 and 2-5 demonstrate two uses of the Hyflow program.

Example 2-4: Determination of the Required Pipe Size and Velocity Using Hyflow

Determine the required pipe size and velocity when flowing full, given:

Coefficient of Friction (n):	0.013
Flow Rate:	11.0 cfs
Slope:	0.28 ft. per 100 ft.

- Enter the Hyflow program from the Toolbox page of the NCPI website.
- On the Flow Data tab, enter the Manning's n of 0.013 and select an alternate "Design Depth of Flow."
- On the Pipe Diameter Solutions tab, enter 100 in the Liq. Depth (%) box.
- Enter 11.0 in the Flow Quantity box (make sure that cfs is selected for the units of measure).
- Enter the drop of 0.28 and run of 100.
- Click the "Get Pipe Diameter Results" button.

Pipe Slope:	0.0028
Coefficient of Friction (n):	0.013
Design Quantity:	11 cfs
Liquid Depth:	100.0%

Pipe Dia. (in.)	Velocity (fps)	Quantity (cfs)
15	2.81	3.44
18	3.17	5.59
21	3.51	8.43
24	**3.83**	**12.03**
27	4.14	16.45
30	4.44	21.77
33	4.72	28.05

From the Hyflow results above, read a **24-inch** pipe size is needed to achieve a flow rate of 11 cfs or more (or 12.03 cfs). Read the velocity of **3.83 fps** when flowing full.

Example 2-5: Determination of the Required Pipe Size and Velocity Using Hyflow

Determine the required pipe size and velocity flowing at a liquid depth to pipe diameter ratio of 0.50, given:

Coefficient of Friction (n):	0.013
Flow Rate:	1.0 cfs
Slope:	1.2 ft. per 100 ft.

- Enter the Hyflow program from the Toolbox page of the NCPI website.
- On the Flow Data tab, enter the Manning's n of 0.013 and select an alternate "Design Depth of Flow."
- On the Pipe Diameter Solutions tab, enter 50 in the Liq. Depth (%) box and 1.0 in the Flow Quantity box (make sure that cfs is selected for the units of measure).
- Enter the drop of 1.2 and run of 100.
- Click the "Get Pipe Diameter Results" button.

Pipe Slope:	0.012
Coefficient of Friction (n):	0.013
Design Quantity:	1 cfs
Liquid Depth:	50.0%

Pipe Dia. (in.)	Velocity (fps)	Quantity (cfs)
6	3.17	0.31
8	3.84	0.67
10	**4.45**	**1.21**
12	5.02	1.97
15	5.81	3.57
18	6.55	5.79

From the Hyflow results above, read a **10-inch** pipe size is needed to achieve a flow rate above the minimum of 1.0 cfs required (1.21 cfs). Read the velocity of **4.45 fps** when flowing at a liquid depth to pipe diameter ratio of 0.50.

Conveyance Factors

Conveyance Factors equal Q/Q_d expressed as a percent. Q is the amount of flow at any depth and Q_d is the amount of flow when the depth is at design depth. Design depth for pipe 15-in. and smaller, is one-half full (.5D) and for pipe 18-in. and larger, three-quarters full (.75D). Depths are expressed in terms of d/D, where "d" is the depth and "D" is the diameter. The Conveyance Factor Tables are shown on page 2-19.

Example 2-6 demonstrates the use of the .5D Table for pipe 15-in. and less in diameter. Example 2-7 demonstrates the use of the .75D Table for pipe 18-in. and larger in diameter.

Example 2-6: Determination of Percentage of Design Capacity and Flow of an Existing Sewer

Compute the percentage of design capacity ($\%Q_d$) and flow (Q), given:

Pipe Size:	10 in. = .83 ft.
Coefficient of Friction (n):	0.013
Measured Depth of Flow:	.35 ft.
Slope:	1.2 ft. per 100 ft.

d/D = Depth of flow/pipe diameter (ft)

d/D = 0.35/0.83

d/D = 0.42

- Use the .5D Table to find $\%Q_d$ (Table 2-3 on page 2-19.)
- Enter table with 0.42 (0.40 on the vertical axis and 0.02 horizontal axis) and read 73%.

This pipe is flowing at 73% of its design capacity (Q_d).

Use the Hyflow Calculator to determine the actual design capacity:
- Enter the Hyflow program from the Toolbox page of the NCPI website.
- On the Flow Data tab, enter the Manning's n of 0.013.
- On the Flow Solutions tab, select 10-in. from the drop down menu.
- Enter drop of 1.2 and run of 100 (make sure cfs is selected for the units of measure).
- Click the "Get Flow Results" button.

The results appear on page 2-16.

Example 2-6 (Continued): Determination of Percentage of Design Capacity and Flow of an Existing Sewer

From the results below; for flowing 50% full, read the design capacity Q_d = 1.21 cfs. Since the pipe is flowing at 73% of its design capacity; multiply Q_d by 0.73 to find Q.

$$Q = Q_d \times \%Q_d$$

$$Q = 1.21 \times .73$$

$$Q = 0.88 \text{ cfs}$$

Pipe Diameter:	10 in.
Pipe Slope:	0.012
Coefficient of Friction (n):	.013
Selected Output Unit:	cfs

Percent of Pipe Dia.	Depth Liq (in)	Velocity (fps)	Quantity (cfs)
5	0.5	1.16	0.01
10	1.0	1.80	0.05
15	1.5	2.31	0.12
20	2.0	2.75	0.21
25	2.5	3.13	0.33
30	3.0	3.46	0.48
35	3.5	3.75	0.64
40	4.0	4.02	0.82
45	4.5	4.25	1.01
50	**5.0**	**4.45**	**1.21**
55	5.5	4.62	1.42
60	6.0	4.77	1.63
65	6.5	4.88	1.83
70	7.0	4.97	2.03
75	7.5	5.03	2.21
80	8.0	5.06	2.37
85	8.5	5.05	2.50
90	9.0	4.99	2.58
95	9.5	4.86	2.60
100	10.0	4.45	2.43

Example 2-7: Determination of Percentage of Design Capacity and Flow of an Existing Sewer

Compute the percentage of design capacity ($\%Q_d$) and flow (Q), given:

Pipe Size:	21 in. = 1.75 ft.
Coefficient of Friction (n):	0.013
Measured Depth of Flow:	1.12 ft.
Slope:	.4 ft. per 100 ft.

d/D = Depth of flow/pipe diameter (ft)

d/D = 1.12/1.75

d/D = 0.64

- Use the .75D Table to find $\%Q_d$ (Table 2-4 on page 2-19).
- Enter table with 0.64 (.6 on the vertical axis and 0.04 horizontal axis) and read 81%.

This pipe is flowing at 81% of its design capacity (Q_d).

Use the Hyflow Calculator to determine the actual design capacity:
- Enter the Hyflow program from the Toolbox page of the NCPI website.
- On the Flow Data tab, enter the Manning's n of 0.013.
- On the Flow Solutions tab, select 21-in. from the drop down menu.
- Enter drop of .4 and run of 100 (make sure that cfs is selected for the units of measure).
- Click the "Get Flow Results" button.

Pipe Diameter:	21 in.
Pipe Slope:	0.004
Coefficient of Friction (n):	0.013
Selected Output Unit:	cfs

Example 2-7 (Continued): Determination of Percentage of Design Capacity and Flow of an Existing Sewer

Percent of Pipe Dia.	Depth Liq (in)	Velocity (fps)	Quantity (cfs)
5	1.1	1.09	0.05
10	2.1	1.70	0.21
15	3.2	2.18	0.49
20	4.2	2.59	0.89
25	5.3	2.95	1.39
30	6.3	3.26	1.98
35	7.4	3.54	2.65
40	8.4	3.78	3.40
45	9.5	4.00	4.20
50	10.5	4.19	5.04
55	11.6	4.35	5.90
60	12.6	4.49	6.77
65	13.7	4.60	7.61
70	14.7	4.69	8.43
75	**15.8**	**4.74**	**9.18**
80	16.8	4.77	9.84
85	17.8	4.76	10.37
90	18.9	4.70	10.73
95	20.0	4.58	10.82
100	21.0	4.19	10.08

From the results shown above; for flowing 75% full, read the design capacity Q_d = 9.18 cfs.

Since the pipe is flowing at 81% of its design capacity; multiply Q_d = 9.18 cfs. by 0.81 to find **Q = 7.44 cfs.**

CONVEYANCE FACTOR TABLES										
.5D TABLE FOR PIPE 15" AND SMALLER For pipe 15" and smaller, Q_d = Q at a depth of .5 Diameter										
d/D	**.00**	**.01**	**.02**	**.03**	**.04**	**.05**	**.06**	**.07**	**.08**	**.09**
.0	%	0	0	0	1	1	1	2	3	3
.1	4	5	6	7	8	10	11	13	14	16
.2	18	19	21	23	25	27	30	32	34	37
.3	39	42	44	47	50	52	55	58	61	64
.4	67	70	73	77	80	83	86	90	93	96
.5	100	103	106	110	113	117	120	124	127	131
.6	134	138	141	144	148	151	154	158	161	164
.7	167	170	173	176	179	182	185	188	190	193
.8	195	197	200	202	204	206	207	209	210	212
.9	213	214	214	215	215	215	214	213	211	208
1.0	200									
Example: If the depth of flow in a 8" sewer is measured at .21' d/D = .21/.67 = .31. Enter table for smaller sewers with d/D = .31 and read 42% Q design. Q design is read from Design Capacity Charts.										

Table 2-3: *Conveyance Factors for Pipe up to 15 inches in diameter*

CONVEYANCE FACTOR TABLES										
.75D TABLE FOR PIPE 18" AND LARGER For pipe 18" and larger, Q_d = Q at a depth of .75 Diameter										
d/D	**.00**	**.01**	**.02**	**.03**	**.04**	**.05**	**.06**	**.07**	**.08**	**.09**
.0	%	0	0	0	1	1	1	1	1	2
.1	2	3	3	4	5	5	6	7	8	9
.2	10	11	12	13	14	15	16	17	19	20
.3	21	23	2	26	27	29	30	32	34	35
.4	37	39	40	42	44	46	48	49	51	53
.5	55	57	59	60	62	64	66	68	70	72
.6	74	76	77	79	81	83	85	87	88	90
.7	92	94	95	97	99	100	102	103	105	106
.8	107	109	110	111	112	113	114	115	116	116
.9	117	118	118	118	118	118	118	117	116	114
1.0	110									
Example: If the depth of flow in a 18" sewer is measured at 1.02' d/D = 1.02/1.5 = .68. Enter table with d/D = .68 and read 88% Q design. Q design is read from Design Capacity Charts.										

Table 2-4: *Conveyance Factors for Pipe 18 inches in diameter and larger*

CHAPTER 3: CORROSION, SOLVENT-BASED CHEMICALS, ABRASION & HIGH TEMPERATURE APPLICATIONS IN SANITARY SEWERS

Figure 3-1: Both bell and spigot pipe and plain-end pipe joined with rubber compression couplings (seen here) have demonstrated a superior resistance to all chemicals commonly found in sewers.

Corrosion – Vitrified Clay Pipe is Chemically Inert

Vitrified Clay Pipe is not vulnerable to damage due to domestic sewage, order control chemicals, sulfide attack, most industrial wastes and solvents or aggressive soils. The only known chemicals that may damage clay pipe are Hydrofluoric Acid (used in glass etching) and Caustic Soda at temperatures exceeding 200°F. Vitrified Clay Pipe is the most chemically resistant pipe material available and the only one to have a proven life span in excess of 100 years.

Hydrogen Sulfide

The relationship between the chemistry of sewage to the pipe materials conveying it is of primary concern in the design of sanitary sewer systems. A brief outline of the factors involved in the ever-present generation of hydrogen sulfide gas is provided to point out the variety of conditions, which can exist and must therefore be anticipated in sanitary sewers. The protection of the sewer system from the ravages of sewer gas attack is of fundamental importance in designing and providing permanent, trouble-free lines. Failure to fully and properly evaluate any of the contributing factors may lead to subsequent failure of the sewer line.

Factors contributing to sulfide generation and evolution are:

1. Temperature of sewage
2. Strength of sewage
3. Velocity of flow
4. Age of sewage
5. pH of sewage
6. Sulfate concentration

Sulfides are generated in the slime layer which forms between the sewer pipe and the flowing sewage. The sulfides form hydrogen sulfide gas which first diffuses into the sewage and then, unless destroyed or neutralized, escapes into the sewer atmosphere.

The sulfuric acid collects on the exposed arch of the pipe and begins a chemical attack unless the pipe material is chemically inert and invulnerable to corrosive acid action. See Figure 3-2 showing the results of chemical attack on an exposed arch in a sanitary environment on a pipe susceptible to corrosion.

Figure 3-2: *Concrete pipe degraded over years in the corrosive environment of a sanitary sewer.*

High velocity may also be damaging if any hydrogen sulfide is present in a stream of sewage. The rate of sulfide release increases with increased flow rate. Turbulence, due to junctions, changes of pipe size, drops, etc. will cause a relatively rapid release of hydrogen sulfide gas. One of the major causes for the increasing sulfide damage in modern sewer systems is the dumping of vast quantities of organic matter from household garbage disposals. This condition increases deposits in sewer lines, thus retarding the flow and providing a source of increased sulfide generation. It also substantially increases the Biochemical Oxygen Demand (BOD) which increases the difficulty of meeting the oxygen required to limit sulfide build-up.

Force mains are a cause of sulfide problems in sewers, particularly if the sewage is retained for any appreciable length of time. High sulfide concentrations will not damage the interior of the filled pipe, but may cause odor nuisances and damage to downstream structures.

When corrodible pipe materials are attacked by sulfuric acid, disintegration begins on the upper surface of the pipe leaving a soft residue. Sometimes the soft or pasty material is washed away by high water exposing new surfaces to corrosive attack. Even when this does not occur, acid formed at the exposed surface continues to diffuse through this residue and attacks the underlying pipe material. When the pipe is too weak to support the earth load, it collapses and the sewer becomes inoperable.

Acid Resistance

Vitrified Clay Pipe is commonly tested with 1 N solutions of sulfuric (H2SO4), hydrochloric (HCl), nitric (HNO3), or acetic (CH3COOH) acids and allowed zero weight loss. Test procedures to determine the acid resistant qualities and other properties of vitrified clay pipe are outlined in ASTM C301 *Standard Test Methods for Vitrified Clay Pipe.*

Aggressive Soils and Other Hostile Environments

Some sanitary sewers are subject to constant attack by a multitude of wastes from industry, homes and businesses. Ordinary domestic sewage includes detergents, drain cleaners, scouring powders, bleaches and other household chemicals. From business and industry come other and more aggressive chemicals, solvents, acids and alkalis.

Sanitary sewer pipe may also be subject to corrosion from acidic or alkaline soils, electrolytic decomposition attack and temperature induced damage. Different pipe materials display various levels of resistance to these factors. Cement bonded and metallic pipe materials normally require special protection.

Temperature and solvent sensitive plastic materials should be avoided where the potential exists for these factors to occur.

Former industrial sites, commonly referred to as brownfields, are another area where soil conditions have a high potential for contaminants that may corrode or damage non-clay pipe materials.

Preliminary soils and site investigation should be required if conditions in the area selected for installation are unknown or suspected to cause damage to candidate materials.

Abrasion

Ceramics are among the most abrasion-resistant materials known. As a ceramic, VCP is the most abrasion-resistant commonly-used sanitary sewer pipe material. This abrasion resistance has always been an important material property of VCP, but it has become essential as modern cleaning methods intensify the concern. For more on the impact of these methods, see Chapter 12: Operations & Maintenance.

Figure 3-3: NCPI accelerated abrasion testing of various 8-inch pipe materials.

Various 8-in sewer pipe were tested for abrasion resistance. The test accelerated normal abrasion rates. Based on test results, the pipes were ranked in order of highest resistance to abrasion as shown in Table 3-1.

The test results were obtained by rotating pipe sections at 2.5 feet per second for 500 hours. The abrasive charge consisted of 7 pounds #67 crushed stone and 6.6 pounds of water which was changed every 48 hours.

Pipe (All 8-in Diameter)	Wall Thickness Δ (Inches)	Abraded Percent
Vitrified Clay	.003	0.3
Certain-Teed (PVC)	.027	10.5
Carlon Prime (PVC)	.043	19.4
Corrugated (PVC)	.048	100.0[a]
PVC Truss	.059	100.0[a]
ABS Truss	.067	100.0[a]
a - 100% indicates complete abrasion through the pipe body or in the case of Truss pipe through the inner pipe wall.		

Table 3-1: Abrasion test results

Pipe	Pipe Stiffness Test (ASTM D 2412)		
	Min. Req.	After Abrasion	% Decrease
Carlon Prime (ASTM F 789)	46 psi	19.2 psi	58.3%
Certain-Teed (ASTM D 3034)	46 psi	32.1 psi	30.2%
ABS Truss (ASTM D 2680)	200 psi	143.5 psi	28.3%
PVC Truss (ASTM D 2680)	200 psi	152.6 psi	23.7%
A-2000[b]	46 psi	28.6 psi	37.8%
[b] – *Manufacturers' Requirement*			

Table 3-2: Post abrasion testing, pipe stiffness test results

Following the abrasion test, 6-inch sections were cut from each of the plastic pipe. A standard 5% pipe stiffness test was run. The vitrified clay was subjected to a three-edge bearing test Results for the thermoplastic pipe and the vitrified clay are listed in Tables 3-2 and 3-3.

Pipe	ASTM C700 Standard	Actual Bearing Strength After Abrasion	Over ASTM Standard
Vitrified Clay	2,200 lbs /ft.	4,067 lbs /ft.	84.9%

Table 3-3: *Post abrasion testing, three-edge bearing test results*

Abrasion Testing Summary

1. Vitrified clay pipe demonstrated superior abrasion resistant qualities compared to the plastic pipe tested.
2. The most abrasion resistant plastic pipe abraded at a rate which was nine times greater than vitrified clay.
3. Three of the four plastic pipe made of PVC abraded at essentially the same rate whereas the Carlon Prime PVC pipe abraded at a markedly faster rate. The Carlon Prime pipe abraded at a rate nearly 40% faster than the next highest PVC pipe. The Carlon PVC tested contained a substantial amount of filler.
4. All of the plastic pipe demonstrated a substantial decrease in pipe stiffness following abrasion.
5. The loss of plastic pipe stiffness due to abrasion may affect its long-term load supporting capability.
6. All non-solid wall plastic pipe consisting of thin inner and outer walls experienced total abrasion of the inner wall within the 500 hour test time.
7. The bearing strength of vitrified clay pipe after abrasion greatly exceeded the ASTM minimum requirement of 2,200 lbs per linear foot.

This abrasion test is not intended to duplicate actual field conditions or to predict longevity. It does determine the relative abrasion resistance qualities of each product tested.

Most of the plastic pipe tested have established maximum velocity limits. Vitrified clay should be used where high velocity or water borne abrasive particulate are anticipated.

Solvent Based Chemical Applications

In industrial areas, resistance to solvent-based chemicals can be critical to the long-term performance of the pipe. Certain commonly used pipe materials are susceptible to attack from various chemicals. VCP is resistant to attack from any chemicals legally found in sewers today.

The elastomeric coupling gasket jointing materials have proven to perform well for the vast majority of sanitary sewer applications. However, there are rare occasions where exposure to solvent based chemicals as well as strong oxidizing mineral and organic acids may require the use of elastomeric materials resistant to the anticipated chemicals or other non-elastomeric jointing systems such as specialty mortars.

High Temperature Applications

Vitrified Clay Pipe can withstand extreme temperatures. However, a rapid change of temperature produces thermal gradients in the pipe wall which may damage the pipe. This is commonly referred to as thermal shock. Proper system design should consider, at least, the following factors: temperature of the effluent, rate and depth of flow, wall thickness of the pipe, temperature of the pipe, temperature of the soil, and the volume of the effluent. The number of variables makes it difficult to predict behavior of the pipe under all conditions. The polyester, polyurethane and rubber gasket jointing materials have shown good high-temperature resistance for short time periods. However, long term exposure to high temperatures is likely to affect the sealing capability of these materials. Other jointing systems such as mortars and high temperature couplings are available and will perform better over the long-term for these applications. Pipe and Joint samples may be evaluated for suitability for this application.

With thermoplastic materials, the more times they are heated, the more the physical properties change. Subsequent heat cycles can break the chemical bonds within the polymer chains, changing the physical properties of the pipe.

CHAPTER 4: STRUCTURAL ANALYSIS OF RIGID CONDUITS, UNDERGROUND

Figure 4-1: Soil characteristics and bedding are critical to structural stability.

This chapter deals with the examination and evaluation of all those forces, which affect or influence the structural stability and useful life of vitrified clay pipe.

Methods are outlined by which trench loads may be considered and analyzed for the purpose of accomplishing required structural support.

Predetermining Loads Accurately

There is a tendency to think of sewer pipe from the hydraulic standpoint only and to neglect the importance of pipe as a structural element. It must, above all else, maintain structural stability.

Nearly all building codes impose legal standards upon designers to insure against the failure of building structures. Standard practice in highway work and railroad work also provides for predetermined structural safety.

Computer Design

The National Clay Pipe Institute has developed Trench Load, an online program, which can be used to determine backfill loads, safety factors and bedding classes. It is available at ncpi.org/toolbox/trenchload/.

Trench Load is available from any internet-connected device. The values provided by this program are based on the equations presented in this chapter and are conservative.

Loads Can Be Accurately Determined

Just as the safety of ordinary structural members involves the application of “mechanics” to cases of calculated live loadings, the safety in underground pipe work involves application of “soil mechanics” for determining the load on the pipe. The amount of load to be supported by the pipe can be computed and the result will be safe and accurate in the same sense that predetermination of strength is safe and accurate.

Complete reference tables are included in Chapter 5 to provide engineers with a convenient method of predetermining loads and strength requirements for clay pipe. These tables show the predicted load according to pipe size, trench depth and width and type of backfill. Chapter 6 provides data for determining the effect of the type of bedding or support given to the pipe.

Trench Load

To determine a reliable equation for computing the relationship between various kinds of loads and the required test strength of pipe, a series of studies were made at the Engineering Experiment Station of Iowa State College (now the Iowa State University). The result is the Marston Equation named for its originator, Anson Marston, who was the first Dean of Engineering at Iowa State and President of the American Society of Civil Engineers. First published in 1930 as part of The Iowa Engineering Experiment Station Bulletin 96, it is a widely recognized, conservative equation for computing trench loads on pipe.

An understanding of the Marston Equation, and the factors involved, is helpful when using the trench load tables.

Figure 4-2: *Pipe and bedding class are critical to support the backfill load.*

Essentially, any structure installed below the surface of the earth supports the weight of all the materials above it, depending upon certain characteristics of the trench backfill. These characteristics, (principally internal soil friction) tend to increase or diminish the backfill load on the pipe structure.

This is true for both trench and embankment loads. Considering a structure of circular cross-section such as a sewer pipe, the backfill material directly above the pipe is that material which lies between vertical planes tangent to the outside of the pipe barrel (Figure 4-3). The net load on the pipe exclusive of live load, is the actual weight of such backfill material plus or minus an amount which depends on whether internal soil friction assists in the support of the mass of backfill over the pipe or not.

Figure 4-3 illustrates the cross-section of a typical sewer trench showing the location of planes tangent to the sides of the pipe. These are called the primary planes. When the backfill in a trench is compacted uniformly, uniform settlement (further compaction) can be expected with the passage of time. The depth of the backfill between the primary tangent planes will be reduced through such settlement by a fairly definite amount, depending upon the nature and compaction of the original backfill.

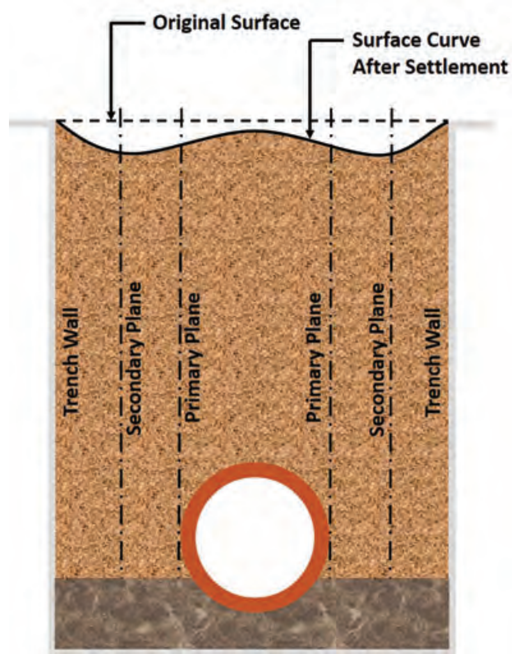


Figure 4-3: *Cross-section of a sewer trench illustrates expected pattern of settlement.*

The backfill between the trench walls and the primary planes on either side of the pipe will also settle in time.

Frictional Forces in the Backfill

Since the depth of the backfill between the pipe and the trench sidewalls is greater than the depth of the backfill directly over the pipe, it will settle or compact more than the material directly over the pipe. This movement will be restricted by friction between the backfill particles on each side of the primary tangent planes. The increased settlement of the backfill on both sides of the pipe tends to transfer load to that portion of the backfill located directly above the pipe, thereby transmitting additional load to the pipe.

Secondary vertical planes are assumed to be between the primary planes and the walls of the trench as shown in the drawing. As mentioned previously, the backfill between the primary and secondary planes is prevented from settling to a maximum amount by the action of frictional forces along the primary vertical planes. This increases the load supported by the pipe in the trench condition.

The remainder of the backfill, which lies between the secondary planes and the trench walls is supported in part by friction along the trench walls. This reduces the load on the pipe.

The Effect of Trench Width

It will be seen that, as the secondary plane is moved away from the pipe, the differential settlement on opposite sides of the plane will become less. It is therefore possible to locate a definite position where the differential settlement on opposite sides of the secondary plane is so small that no frictional forces are transmitted across it. When this location is within the cross section of the trench, the weight of backfill between the secondary plane and trench wall can add nothing to the load on the pipe. In other words, the trench width may be increased beyond this point without adding to the load on the pipe.

The minimum distance, which meets the above qualifications, is called the **transition width** of the trench. It is the trench width at which further widening will have no effect on the load on the pipe.

When the actual width is less than the **transition width**, friction in the plane of the trench wall tends to support part of the load and to lessen the load on the pipe. This phenomenon is illustrated by the curve marked surface curve after settlement as shown in Figure 4-3. Wherever this curve deflects downward from its origin directly over the center of the pipe, internal friction in the backfill transmits weight to the pipe. Where the curve deflects upward (as alongside the trench wall) backfill weight is transmitted to the sidewall of the trench.

Marston Equation

The Marston Equation applies the preceding reasoning to the calculation of loads on pipes. Actual tests have been performed on many types of soil to determine the weight, frictional characteristics and the relative settlement of each type. These measurable quantities have been combined into a single expression to produce for each case a computation of the total load supported by the pipe.

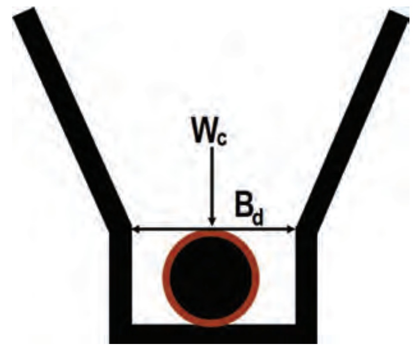


Figure 4-4: *The Marston Equation for pipe in narrow trenches.*

The factors taken into consideration in the following Marston Equation are:

- Depth of backfill cover over the top of the pipe.
- Width of trench measured at the level of the top of the pipe.
- Unit weight of backfill.
- Values for frictional characteristics of the backfill material.

The Marston Equation for pipe in narrow trenches is:

$$W_c = C_d \omega B_d{}^2$$

Where:

W_c = The vertical external load on a closed conduit due to fill materials (lb/ ft. of length),
C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),
ω = The unit weight of fill materials, (lb/ ft.^{3}) and
B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft.).

By substitution of available data in the Marston equation, a direct result is obtained for the load on the pipe in terms of pounds per linear foot. The computation of loads is simplified by the use of this equation and the Computation Diagram (Figure 4-5 on page 4-6), which represents the plotted solution of the "Load Calculation Coefficient" equation shown below:

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

Where:

- C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),
- e = 2.7182818 which equals base of natural logarithms, an abstract number,
- K = Ratio of active horizontal pressure at any point in the fill to the vertical pressure which caused the active horizontal pressure, an abstract number,
- μ' = The "coefficient of sliding friction" between the fill material and sides of the trench, an abstract number,
- H = Vertical height from top of conduit to the upper surface of fill in feet, and
- B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft.).

The Computation Diagram is based on various types of soil conditions, and may be used to obtain the values of the load calculation coefficient C_d.

The Trench Load Tables in Chapter 5 have been compiled using the Marston Equation previously described. The soil weights are based upon an arbitrary value of 100 lbs/ ft^3. When the actual soil weight is known to vary from 100 lbs/ ft^3, the tabulated loads may be adjusted up or down by direct ratio.

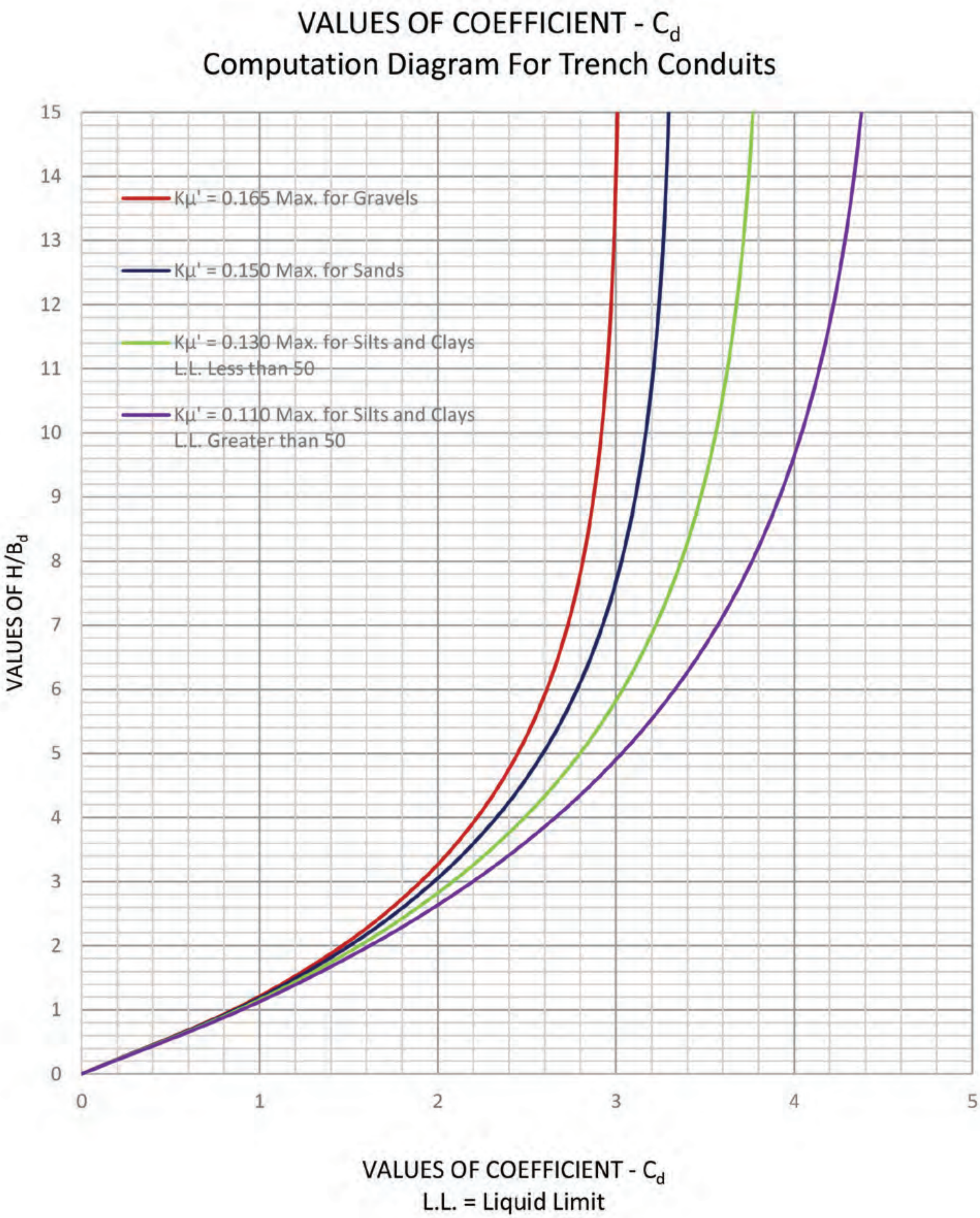


Figure 4-5: *Computation Diagram for Trench Conduits (completely buried in trenches).*

Backfill Soils Classification Chart

	Criteria For Assigning Group Symbols And Group Names		Soil Classification*		Weight (lbs.ft³)	
			Group Symbol	Group Name	Approximate Soil Weight	Average
COARSE-GRAINED SOILS More than 50% retained on No. 200 sieve	**GRAVELS** More than 50% of coarse fraction retained on No. 4 sieve Kμ' 0.165	**CLEAN GRAVELS** Less than 5% fines	GW	Well-graded gravel	119 - 128	124
			GP	Poorly graded gravel	104 – 128	122
		GRAVELS WITH FINES More than 12% fines	GM	Silty gravel	87 – 133	113
			GC	Clayey gravel	96 – 129	117
	SANDS 50% or more of coarse fraction passes No. 4 sieve Kμ' 0.150	**CLEAN SANDS** Less than 5% fines	SW	Well-graded sand	93 – 133	117
			SP	Poorly graded sand	104 – 132	119
		SANDS WITH FINES More than 12% fines	SM	Silty sand	93 – 133	117
			SC	Clayey sand	104 – 132	119
FINE-GRAINED SOILS 50% or more passes the No. 200 sieve	**SILTS AND CLAYS** Liquid limit less than 50 Kμ' 0.130	**INORGANIC**	CL	Lean clay	90 – 121	109
			ML	Silt	82 - 126	103
	SILTS AND CLAYS Liquid limit 50 or more Kμ' 0.110	**INORGANIC**	CH	Fat clay	82 – 107	95
			MH	Elastic silt	83 – 89	85
HIGHLY ORGANIC SOILS		Primarily organic matter, including landfill waste, organic clays and silts, peat, etc.			Soil weight will vary – use appropriate geotechnical soils data	

* Reference – ASTM D2487, *Standard Practice for Classification of Soils for Engineering Purposes* (Unified Soil Classification System)

Table 4-1: *Backfill Soils Classification Chart*

Embankment Loads

Although the Trench Load Tables (Chapter 5) show loads on pipe in trenches, they are equally applicable for pipe installed under embankment or "wide trench" conditions. As the width of the trench increases, other factors remaining constant, the load on the pipe increases until it reaches a limiting value equal to the embankment load on the pipe. This limiting value is called the load at transition width. The transition widths shown in the Trench Load Tables have been calculated using the equation for positive projecting conduits in wide trenches.

Modified Marston Equation When Designing with CLSM

Marston factored the consolidation of the soil prism along both sides of the pipe as inducing load on the rigid pipe dependent upon the soil type, soil weight and trench width. Arching or inverted arching of the prism of soil directly above the pipe via shear of the exterior soil prisms above the sidefills is an inherent principle in the Marston Theory.

He theorized that the material at the sides of rigid pipe was so loose compared to the rigidity of the pipe that the support of any backfill load by the sidefill would be negligible. The presumed inability of the sidefills to carry a significant share of the backfill load is not applicable when Controlled Low Strength Material (CLSM) bedding is used since it neither settles nor compacts or shrinks significantly.

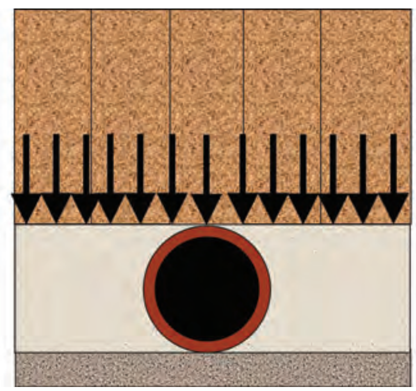


Figure 4-6: *CLSM sidefills support a portion of the load from the soil prism directly above the rigid pipe as well as the adjacent prisms.*

With the experience gained by testing flexible corrugated metal pipe at Iowa State, Professor Spangler realized that the full trench backfill load was not actually applied to flexible pipe with compacted sidefills. Since it was common practice to compact the material at the sides of the corrugated steel pipe to keep it in shape, he reasoned that this compacted material not only reduced deflection of the pipe but it also must be supporting some of the backfill load.

Professor Spangler made the following statement in his classic 1951 textbook, Soil Engineering: "For the case of a flexible pipe conduit and thoroughly tamped sidefills having essentially the same degree of stiffness as the pipe itself, the value of given by equation (25-3)(rigid pipe equation) might be multiplied by the ratio $\frac{B_c}{B_d}$ [Breadth of conduit / Breadth of ditch]." As a result, the flexible pipe load equation was generated.

This flexible pipe load equation takes the form:

$$W_c = C_d \omega B_c B_d$$

Where:

- W_c = The vertical external load on a closed conduit due to fill materials (lbs/ LF)
- C_d = Load calculation coefficient for conduits completely buried in ditches, abstract number (see Computation Diagram – Figure 4-5 on page 4-6),
- ω = The unit weight of backfill (lbs/ ft^3)
- B_c = The width of conduit (O.D.), (ft.)
- B_d = Breadth of Ditch (trench width measured at top of pipe barrel, ft)

Where clay pipe is installed with CLSM sidefills from the bottom of the pipe to the top of the pipe barrel; the clay pipe is rigid and, when set sufficiently prior to backfill, CLSM is also rigid. The backfill load is distributed with reasonable uniformity across the top of the pipe and the sidefills.

Applying the Spangler principal, the load on a clay pipe can be reduced by the ratio $\frac{B_c}{B_d}$. The standard Marston rigid pipe trench load equation becomes:

$$W_c = C_d \omega \mathrm{B}_d{}^2 \left(\frac{B_c}{B_d}\right)$$

which can be simplified to:

$$W_c = C_d \omega B_c B_d$$

resulting in a modification to the standard Marston Equation.

The main reason for the high computed loads on rigid pipe is the presumed inability of the sidefills to carry any significant share of the backfill load. In CLSM installations, the CLSM neither settles nor compacts or shrinks significantly. It will support a large portion of the load that would otherwise be carried by the pipe. It only requires sufficient strength so that it does not move downward any distance greater than the top of the pipe when loaded.

For additional information, see *CLSM as a Pipe Bedding: Computing Predicted Load using the Modified Marston Equation* paper presented at 2013 ASCE Pipelines Conference.

Example 4-1: Modified Marston CLSM Design Computation

A 24-inch sewer is to be installed in an area of CL lean clay $K\mu'$ = 0.130 with an average weight of 120 lbs/ ft^3. The top of the pipe is 40 ft. below ground surface and the trench width is 84 in. At this cover depth and trench width; CLSM side fills will be utilized. Determine the factor of safety.

Pipe diameter =	24-inch
t (wall thickness) =	3 in.
B_c =	24 + 2t = 24 + 6 = 30 in. or 2.5 ft
H =	40 ft
B_d =	84 in. or 7 ft
ω =	120 lbs. / ft^3 ($K\mu'$ = 0.130)
24 in. pipe bearing strength	4,400 lbs/ LF
H/B_d	40 ft./ (84/12) = 5.71
C_d*	[1- $e^{-2(0.130)(5.71)}$] / 2(0.130) = 2.97
* For C_d Equation, see page 4-5	

Example 4-1 (Continued): Modified Marston CLSM Design Computation

$$W_c = C_d \omega B_c B_d$$

W_c = (2.97)(120 lbs / ft^3)(2.5 ft.)(7 ft.)

W_c = 6237 lbs/ LF.

Safety Factor = [Bearing strength of pipe X Load Factor] / [Backfill Load]

Safety Factor = [4,400 lbs/ LF. X 2.8] / [6,237 lbs/ LF.]

Safety Factor = 1.98

Earth Load on Jacked Pipe

When modified to include soil cohesion, the Marston Equation is used to compute earth load on a jacked pipe through undisturbed soil. In the case of Vitrified Clay Jacking Pipe (VCP-J), the applicable trenchless methods are pilot tube and slurry microtunneling installations (See Chapter 8). Typically, the greatest load on these pipes is the axial compressive force exerted during installation. When computing earth load for pipe in a tunnel, the Marston Equation takes the form:

$$W_t = C_t B_t (\omega B_t - 2c)$$

Where:

W_t = earth load on the tunneled pipe (lbs/ LF.)
C_t = coefficient for tunnels (see Figure 4-8)
B_t = tunnel diameter (Pipe OD + overcut) (ft.)
ω = weight of backfill (lbs/ ft^3)
c = "safe values" for soil cohesion (psf)

Recommended Safe Values for Soil Cohesion	
Material	**Values of c (psf)**
Clay, very soft	40
Clay, medium	250
Clay, hard	1,000
Sand, loose dry	0
Sand, silty	100
Sand, dense	300
Top soil, saturated	100

Table 4-2: *Safe Values for Soil Cohesion*

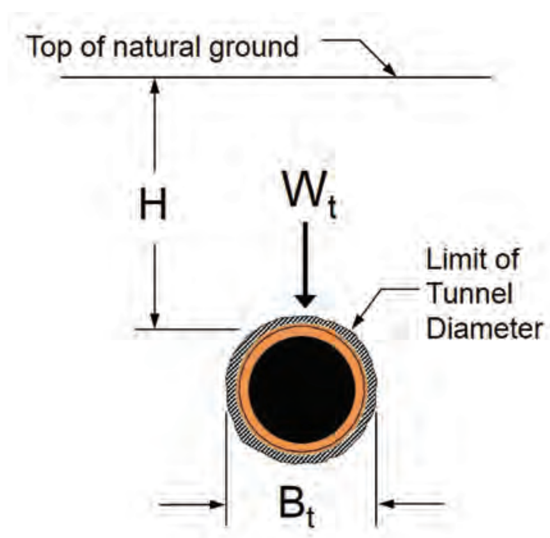


Figure 4-7: *Jacked pipe in tunnel*

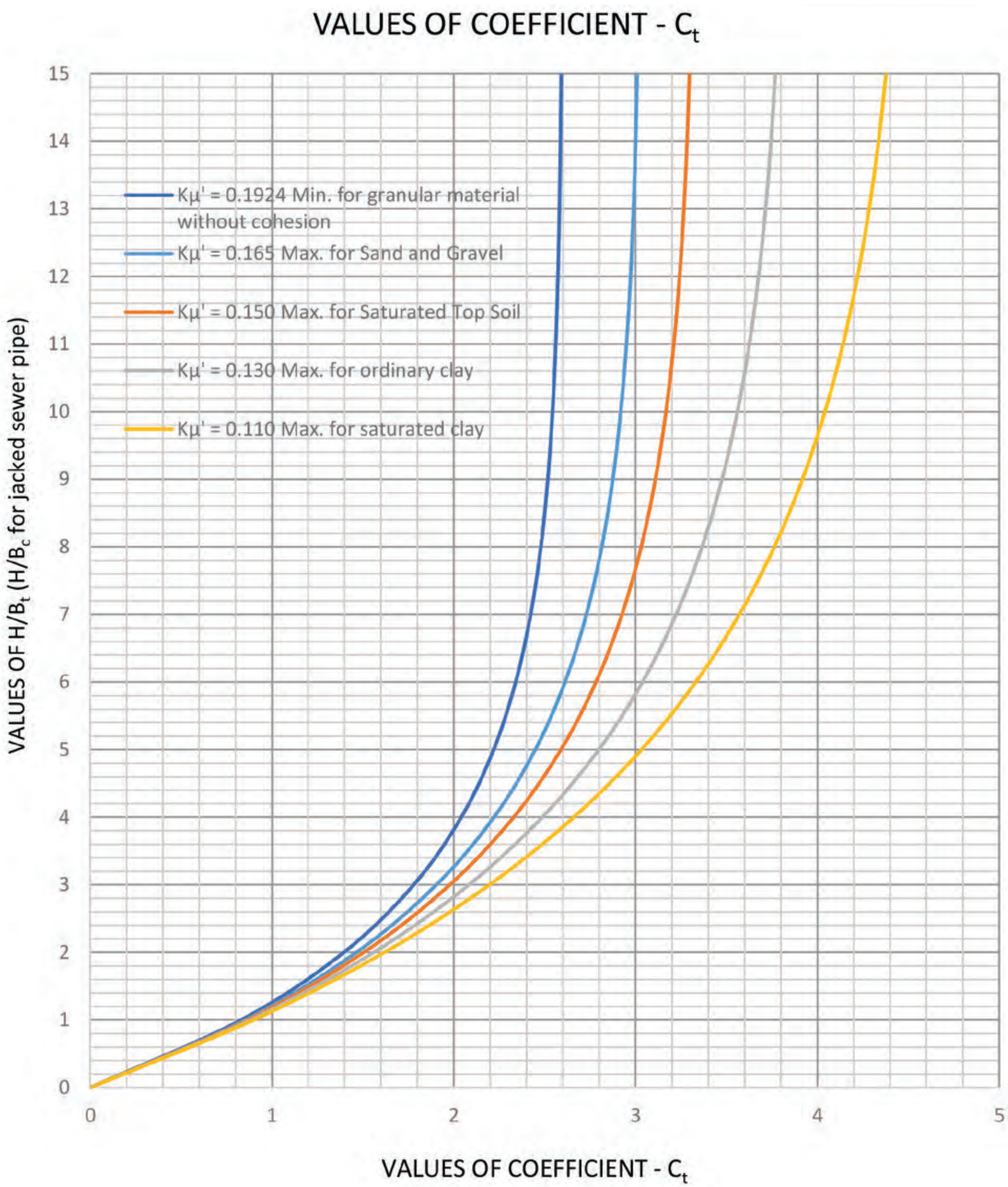


Figure 4-8: *Jacked sewer pipe or tunnels in undisturbed soil.*

Example 4-2: Computing Earth Load On A Jacked Pipe

A 12-inch Vitrified Clay Jacking Pipe installed via Pilot Tube Method. It is to be installed in an area with 25 ft. of cover. The soils are lean clay, native soils at 120 lbs/ ft^3.

B_t = (Pipe O.D. + overcut)/12 =	(15.8 in. + 1 in.)/12 = 1.4 ft.
$K\mu'$ =	0.130
H/B_t =	25.0 ft./ 1.40 ft. = 17.86

Using computation diagram (Figure 4-8 on page 4-11) with H/B_t = 17.86 and $K\mu'$ = 0.130, therefore, C_t = the limiting value of $1/(2\,K\mu')$ = 3.85

Using Table 4-2 (on page 4-10) find the value of c: c = 40 psf (clay, very soft)

Inserting the above values into the Marston Equation modified for soil cohesion:

$$W_t = C_t B_t(\omega B_t - 2c)$$

$$W_t = (3.85)(1.40\text{ ft.})[(120\text{ lbs/ ft}^3)(1.40\text{ ft.}) - (2)(40\text{ lbs/ ft}^2)]$$

$$W_t = (3.85)(1.40\text{ ft.})[168.0\text{ lbs/ ft}^2 - 80\text{ lbs/ ft}^2]$$

$$W_t = 474\text{ lbs/ LF}$$

Superimposed Loads

Concentrated and distributed superimposed loads should be considered in the structural design of sewers, especially where the depth of earth cover is less than 8 ft. Where these loads are anticipated, they are added to the predetermined trench load. Superimposed loads are calculated by use of Holl's and Newmark's modifications to Boussinesq's equation.

Concentrated Loads

Holl's integration of Boussinesq's solution leads to the following equation for determining loads due to superimposed concentrated load, such as a truck wheel load (Figure 4-9):

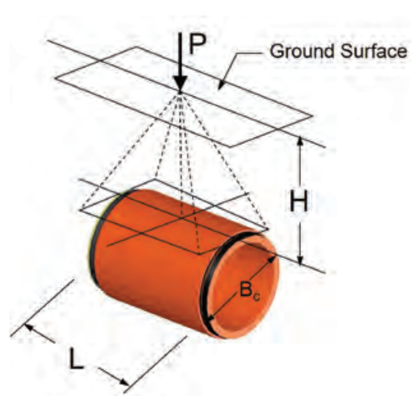


Figure 4-9: *Concentrated superimposed load vertically centered over sewer pipe.*

$$W_{sc} = C_s \frac{PF}{L}$$

Where:

- W_{sc} = The load on the conduit (lbs/ LF)
- P = The concentrated load (lbs)
- F = The impact factor
- C_s = The load coefficient, a function of $\frac{B_c}{(2H)}$ and $\frac{L}{(2H)}$

Where:

- H = The height of fill from the top of conduit to ground surface in ft.
- B_c = The width of conduit (O.D.), (ft.)
- L = The effective length of conduit (ft.)

For values of C_s see Table 4-3 on page 4-15. For values of *F*, see Table 4-5 on page 4-17.

An effective length, *L*, equal to 3 ft. for pipe greater than 3 ft. long, and the actual length for pipe shorter than 3 ft. is recommended. H-20, H-25 wheel loadings are standard for highway and bridge design and are applicable for estimating traffic loads on sewers. However, engineers and contractors must also consider construction loads imposed upon sewers subsequent to their installation. Large earthmoving equipment traveling over sewers and construction activities from subsequent installation of nearby structures should be reviewed for additional imposed loads on installed pipes. Wheel loads from large construction equipment may exceed 50,000 lbs.

Notes: *H-20 (as defined by the American Association of State Highway and Transportation Officials, or AASHTO) refers to wheel loading resulting from the passage of trucks having a gross weight of 40,000 lbs., 32,000 lbs. (80%) of which is on the rear axle; each rear wheel carrying one half this load or 8 tons (16,000 lbs.) without impact.*

H-25 (as defined by the American Association of State Highway and Transportation Officials, or AASHTO) refers to wheel loading resulting from the passage of trucks having a gross weight of 50,000 lbs., 40,000 lbs. (80%) of which is on the rear axle; each rear wheel carrying one half this load or 10 tons (20,000 lbs.) without impact.

Example 4-3: Calculating Load

Determine the load on a 15-inch, 6 ft. length of pipe with 5 ft. of cover caused by a concentrated H-20 wheel load. For pipe greater than 3 ft. long, use 3 ft. as the effective length, *L*.

P =	16,000 lbs
F =	1.5 (Highway)
L =	3.0 ft.
d (pipe I.D.) =	15 in.
t (wall thickness)=	1.5 in.
Therefore B_c = 15 + 3 = 18 inches = 1.5 ft.	
H =	5.0 ft.
$\frac{B_c}{2H}$ =	1.5/10 = 0.15
$\frac{L}{2H}$ =	3/10 = 0.30
C_s =	0.078
(C_s found by interpolation of the values in Table 4-3)	

$$W_{sc} = C_s \frac{PF}{L}$$

Inserting the known values in the equation:

$$W_{sc} = \frac{(0.078)(16{,}000 \text{ lbs})(1.5)}{3.0 \text{ ft.}}$$

$$W_{sc} = 624 \text{ lbs/ LF}$$

If the concentrated load is not centered vertically over the pipe, but is displaced laterally and longitudinally, the load on the pipe can be computed by adding the effect of the concentrated load. Dividing the tabular values of C_s by 4 will give the result for this condition.

An alternative method of determining concentrated or superimposed loads on a buried conduit is to use the Percentages of Wheel Loads shown in Table 4-4 (on page 4-16). These percentages have been determined directly from data contained in "Theory of External Loads on Closed Conduits," Bulletin 96, published by the Engineering Experiment Station at Iowa State College. Note that an allowance for impact must be added to the percentage figures shown in the table. The table does not apply to distributed superimposed loads.

Example 4-4: Calculating Load Using the Simplified Equation

Using the same case as Example 4-3,

P =	16,000 lbs
F =	1.5 (Highway)
Percentage of load 15-in. pipe with 5 ft. depth of cover =	2.6% (0.026)
(from the Percentage of Wheel Load Table (Table 4-4))	

Inserting the known values in the equation:

$$W_{sc} = PF(\%) = 16{,}000 \text{ lbs } (1.5)(0.026)$$

$$W_{sc} = 624 \text{ lbs/ LF}$$

Values of Load Coefficients, C_s
for Concentrated and Distributed Superimposed Loads Vertically Centered Over Conduit*

$\frac{D}{2H}$ OR $\frac{B_c}{2H}$	$\frac{M}{2H}$ or $\frac{L}{2H}$													
	0.1	**0.2**	**0.3**	**0.4**	**0.5**	**0.6**	**0.7**	**0.8**	**0.9**	**1.0**	**1.2**	**1.5**	**2.0**	**5.0**
0.1	0.019	0.037	0.053	0.067	0.079	0.089	0.097	0.103	0.108	0.112	0.117	0.121	0.124	0.128
0.2	0.037	0.072	0.103	0.131	0.155	0.174	0.189	0.202	0.211	0.219	0.229	0.238	0.244	0.248
0.3	0.053	0.103	0.149	0.190	0.224	0.252	0.274	0.292	0.306	0.318	0.333	0.345	0.355	0.360
0.4	0.067	0.131	0.190	0.241	0.284	0.320	0.349	0.373	0.391	0.405	0.425	0.440	0.454	0.460
0.5	0.079	0.155	0.224	0.284	0.336	0.379	0.414	0.441	0.463	0.481	0.505	0.525	0.540	0.548
0.6	0.089	0.174	0.252	0.320	0.379	0.428	0.467	0.499	0.524	0.544	0.572	0.596	0.613	0.624
0.7	0.097	0.189	0.274	0.349	0.414	0.467	0.511	0.546	0.584	0.597	0.628	0.650	0.674	0.688
0.8	0.103	0.202	0.292	0.373	0.441	0.499	0.546	0.584	0.615	0.639	0.674	0.703	0.725	0.740
0.9	0.108	0.211	0.306	0.391	0.463	0.524	0.574	0.615	0.647	0.673	0.711	0.742	0.766	0.784
1.0	0.112	0.219	0.318	0.405	0.481	0.544	0.597	0.639	0.673	0.701	0.740	0.774	0.800	0.816
1.2	0.117	0.229	0.333	0.425	0.505	0.572	0.628	0.674	0.711	0.740	0.783	0.820	0.849	0.868
1.5	0.121	0.238	0.345	0.440	0.525	0.596	0.650	0.703	0.742	0.774	0.820	0.861	0.894	0.916
2.0	0.124	0.244	0.355	0.454	0.540	0.613	0.674	0.725	0.766	0.800	0.849	0.894	0.930	0.956

*Influence coefficients for solution of Holls' and Newmark's Integration of the Boussinesq Equation for vertical stress.

Table 4-3: *C_s values for Concentrated and Distributed Superimposed Loads Vertically Centered Over Conduit*

Percentage of Wheel Loads Transmitted to Underground Pipes*

Depth of Backfill Over Top of Pipe in Feet	Pipe Size in Inches													
	6	8	10	12	15	18	21	24	27	30	33	36	39	42
	Outside Diameter of Pipe in Feet (Approx.)													
	.64	.81	1.0	1.2	1.5	1.8	2.1	2.4	2.7	3.0	3.3	3.5	3.9	4.2
1	12.8	15.0	17.3	20.0	22.6	24.8	26.4	27.2	28.0	28.6	29.0	29.4	29.8	29.9
2	5.7	7.0	8.3	9.6	11.5	13.2	15.0	15.6	16.8	17.8	18.7	19.5	20.0	20.5
3	2.9	3.6	4.3	5.2	6.4	7.5	8.6	9.3	10.2	11.1	11.8	12.5	12.9	13.5
4	1.7	2.1	2.5	3.1	3.9	4.6	5.3	5.8	6.5	7.2	7.9	8.5	8.8	9.2
5	1.2	1.4	1.7	2.1	2.6	3.1	3.6	3.9	4.4	4.9	5.3	5.8	6.1	6.4
6	0.8	1.0	1.1	1.4	1.8	2.1	2.5	2.8	3.1	3.5	3.8	4.2	4.3	4.4
7	0.5	0.7	0.8	1.0	1.3	1.6	1.9	2.1	2.3	2.6	2.9	3.2	3.3	3.5
8	0.4	0.5	0.6	0.8	1.0	1.2	1.4	1.6	1.8	2.0	2.2	2.3	2.5	2.6

*These figures make no allowance for impact. See Impact Factor values in Table 4-5.

Table 4-4: *Percentage of Wheel Loads Transmitted to Underground Pipes*

Distributed Loads

For determining loads on pipe due to superimposed loads distributed over a surface area (Figure 4-10) the following equation was developed:

$$W_{sd} = C_s P F B_c$$

Where:

W_{sd} = The load on the conduit in lbs/ ft. of length

P = The intensity of distributed load in psf.

F = The impact factor

B_c = The width of the conduit (ft.)

C_s = The load coefficient, a function of $\frac{D}{(2H)}$ and $\frac{M}{(2H)}$

Where:

H = The height from the top of the conduit to the ground surface (ft.)

D = The width of the area over which the distributed load acts (ft.)

M = The length of the area over which the distributed load acts (ft.)

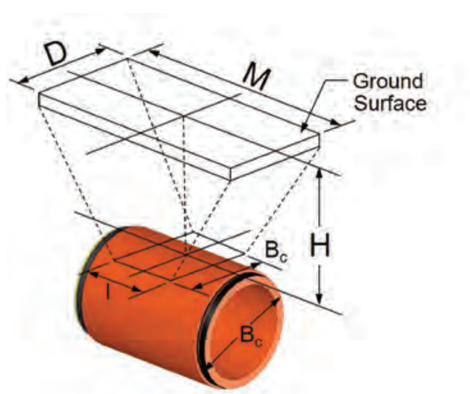


Figure 4-10: *Superimposed distributed load vertically centered over pipe.*

For values of C_s see Table 4-3 on page 4-15. For values of F, see Table 4-5 on page 4-17.

If the area of the distributed superimposed load is not centered vertically over the pipe, but is displaced laterally and longitudinally, the load on the pipe can be computed by adding algebraically the effect of various rectangles of loaded area. It is more convenient to work in terms of load under one corner of a rectangular loaded area rather than at the center. Dividing the tabular values of C_S by 4 will give the effect for this condition.

Impact Loads

Impact factors must be considered to account for the influence of impact loading due to traffic and construction activities after sewer installation.

Extremely high impact loads can be transmitted to the pipe especially when wheeled construction equipment travels over the trench. The engineer and contractor need to consider construction impact loads during the initial project and any subsequent construction.

Suggested Impact Factor (F) Values	
Traffic	**Impact Factor**
Highway	1.50
Railway	1.75
Runways/Airfield	1.00
Taxiways, aprons, hardstands	1.50

Table 4-5: *Suggested values of Impact Factors (F)*

Trench Width, Depth of Fill and Soil Characteristics

To properly approach the analysis of loads imposed on the pipe, it is necessary to decide, for each size of pipe, what the minimum practicable design trench width at the top of the pipe is to be and still permit good workmanship. The design trench width, the depth of fill over the pipe, and the soil characteristics of the fill, will produce the load which must be supported by the pipe and its bedding. This load is readily available from either the Trench Load Tables in Chapter 5 or the NCPI trench load online program when the above factors are known.

Using Trench Load Tables

The correct use of the Trench Load Tables, which are given in Chapter 5, is demonstrated by the following hypothetical case where a designer wants to calculate the trench load imposed.

Example 4-5: Using Trench Load Tables

A 12-inch sewer is to be installed in an area of gravel $K\mu'$ = 0.165 with an average weight of 120 lbs/ ft^3. The top of the pipe is 8 ft. below ground surface and the trench width is 30 in. To determine the trench load use the Trench Load Tables for 12-inch pipe in Chapter 5 on page 5-5.

Pipe diameter =	12-inch
$K\mu'$=	0.165 Backfill gravel
B_d =	30 in.
H =	8 ft.
ω =	120 lbs / ft^3

W_c = 1,240 lbs/ LF x 120/100 = 1,488 lbs/ LF

Example 4-6: Using Calculated Live Load

Plans call for the installation of a 15-inch sewer line with 5 ft. of cover in a 3 ft. wide trench of silt and clay $K\mu'$= 0.110 weighing 95 lbs/ ft^3 and that construction equipment wheel loads of 16,000 lbs. each will pass over the backfilled trench before the pavement is placed. This is the maximum loading condition. What is the total load on the pipe? To determine the trench load use the Trench Load Tables for 15-inch pipe in Chapter 5 on page 5-6.

Pipe size	15 in.
Backfill – silt and clay	$K\mu'$= 0.110
Trench width	36 in.
Backfill weight	95 lbs/ ft^3
Backfill load	(1,170 lbs / LF x 95/100) = 1,112 lbs/ LF
(The live load has been calculated. See Examples 4-3 and 4-4 on page 4-14)	
Live load	624 lbs/ LF
Total trench load	1,736 lbs/ LF

CHAPTER 5: TRENCH LOAD TABLES

Figure 5-1: 30-inch pipe installed in a vee trench in Linda, CA.

The load tables are based on Marston's Equations for loads on rigid conduit. The tables show the loads imposed upon pipe by four primary soil groups. Loads are calculated using 100 lbs/ft^3 soil weight (See Table 4-1 on page 4-7).

When the actual soil weight is known, the tabulated loads may be adjusted by direct ratio.

The tables list loads on pipe diameters of 6- through 48-inches. (For a discussion on embankment loads, see page 4-8).

"TRENCH LOAD," a Computer Design Trench Load Program

NCPI has developed an online application for trench load design (TRENCH LOAD) based upon the Marston Equations and the pipe bedding classes described in ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe Lines.*

"TRENCH LOAD" accepts project specific input data and yields safety factors for combinations of trench depth and width, soil types and densities. Live loads and impact factors may also be included at trench depths less than 8 feet.

"TRENCH LOAD" is available online at ncpi.org/toolbox.

6" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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) 18	24	30	36	42	Transition Width
5	450	500				1.59'
6	500	600				1.69'
8	560	800				1.86'
10	600	980	990			2.02'
12	640	1050	1190			2.17'
14	650	1090	1390			2.31'
16	660	1130	1590			2.44'
18	670	1150	1720	1790		2.56'
20	670	1160	1760	1990		2.68'
22	670	1180	1790	2190		2.80'
24	680	1190	1820	2390		2.91'
26	680	1200	1840	2570	2590	3.01'
28	680	1200	1850	2600	2790	3.12'
30	680	1200	1850	2630	2990	3.22'

SANDS (SW, SP, SM, SC)
Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 18	24	30	36	42	Transition Width
5	480	500				1.55'
6	520	600				1.64'
8	600	790				1.80'
10	650	990				1.95'
12	680	1110	1190			2.09'
14	700	1170	1390			2.22'
16	720	1210	1590			2.34'
18	730	1240	1790			2.46'
20	740	1270	1900	1990		2.57'
22	740	1290	1940	2190		2.68'
24	750	1300	1970	2390		2.79'
26	750	1300	1990	2590		2.89'
28	750	1310	2010	2790		2.98'
30	750	1320	2030	2850	2990	3.08'

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) 18	24	30	36	42	Transition Width
5	500					1.49'
6	560	590				1.57'
8	650	790				1.72'
10	720	990				1.85'
12	760	1190				1.98'
14	790	1290	1390			2.10'
16	810	1350	1590			2.21'
18	820	1390	1790			2.32'
20	840	1420	1990			2.42'
22	850	1450	2160	2190		2.52'
24	850	1470	2210	2390		2.62'
26	860	1480	2240	2590		2.71'
28	860	1500	2270	2790		2.80'
30	860	1510	2300	2990		2.89'

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) 18	24	30	36	42	Transition Width
5	490					1.42'
6	590					1.49'
8	710	790				1.63'
10	780	990				1.75'
12	850	1190				1.86'
14	890	1390				1.97'
16	920	1510	1590			2.07'
18	950	1570	1790			2.17'
20	970	1620	1990			2.26'
22	980	1650	2190			2.35'
24	990	1690	2390			2.44'
26	1000	1720	2550	2590		2.52'
28	1010	1740	2660	2790		2.60'
30	1010	1750	2640	2990		2.68'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

8" VCP

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

Bold 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)
$K\mu' = 0.165$

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 18	24	30	36	42	48	Transition Width
5	450	650					1.93'
6	500	760	780				2.03'
8	560	890	1040				2.22'
10	610	980	1300				2.40'
12	640	1050	1510	1560			2.56'
14	650	1090	1600	1830			2.71'
16	660	1130	1660	2090			2.86'
18	670	1150	1720	2350			3.00'
20	670	1160	1760	2430	2610		3.13'
22	670	1180	1790	2480	2870		3.26'
24	680	1190	1820	2540	3140		3.38'
26	680	1200	1840	2570	3400		3.50'
28	680	1200	1850	2600	3450	3650	3.62'
30	680	1200	1850	2630	3490	3920	3.73'

SANDS (SW, SP, SM, SC)
$K\mu' = 0.150$

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 18	24	30	36	42	48	Transition Width
5	480	650					1.88'
6	520	780					1.98'
8	600	930	1040				2.16'
10	650	1030	1300				2.32'
12	680	1110	1570				2.47'
14	700	1170	1700	1830			2.62'
16	720	1210	1780	2090			2.76'
18	730	1240	1840	2350			2.89'
20	740	1270	1900	2590	2610		3.01'
22	740	1290	1940	2670	2870		3.13'
24	750	1300	1970	2730	3130		3.25'
26	750	1300	1990	2770	3390		3.36'
28	750	1310	2010	2820	3660		3.47'
30	750	1320	2030	2850	3770	3920	3.58'

SILTS AND CLAYS (CL, ML)
$K\mu' = 0.130$, L.L. Less Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 18	24	30	36	42	48	Transition Width
5	500	650					1.81'
6	560	770					1.90'
8	650	990	1040				2.06'
10	720	1120	1300				2.21'
12	760	1220	1570				2.35'
14	790	1290	1820				2.48'
16	810	1350	1950	2080			2.61'
18	820	1390	2030	2350			2.73'
20	840	1420	2100	2610			2.84'
22	850	1450	2160	2870			2.95'
24	850	1470	2210	3030	3130		3.06'
26	860	1480	2240	3100	3390		3.16'
28	860	1500	2270	3160	3660		3.26'
30	860	1510	2300	3210	3920		3.36'

SILTS AND CLAYS (CH, MH)
$K\mu' = 0.110$, L.L. Greater Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 18	24	30	36	42	48	Transition Width
5	530	650					1.75'
6	600	780					1.82'
8	710	1040					1.97'
10	780	1220	1300				2.10'
12	850	1330	1560				2.23'
14	890	1430	1820				2.34'
16	920	1510	2080				2.46'
18	950	1570	2260	2350			2.56'
20	970	1620	2350	2610			2.67'
22	980	1650	2430	2870			2.77'
24	990	1690	2500	3130			2.86'
26	1000	1720	2550	3390			2.95'
28	1010	1740	2600	3570	3650		3.04'
30	1010	1750	2640	3640	3920		3.13'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

10" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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	Transition Width
5	680	800					2.25'
6	760	950					2.36'
8	890	1240	1280				2.56'
10	980	1390	1600				2.75'
12	1050	1510	1930				2.92'
14	1090	1600	2150	2250			3.09'
16	1130	1660	2250	2560			3.25'
18	1150	1720	2350	2890			3.40'
20	1160	1760	2430	3150	3210		3.54'
22	1180	1790	2480	3250	3540		3.68'
24	1190	1820	2540	3330	3850		3.81'
26	1200	1840	2570	3390	4170		3.94'
28	1200	1850	2600	3450	4360	4500	4.07'
30	1200	1850	2630	3490	4440	4820	4.19'

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	Transition Width
5	700	790					2.20'
6	790	960					2.30'
8	930	1280					2.49'
10	1030	1450	1600				2.67'
12	1110	1590	1920				2.83'
14	1170	1700	2240				2.99'
16	1210	1780	2390	2570			3.13'
18	1240	1840	2500	2890			3.28'
20	1270	1900	2590	3210			3.41'
22	1290	1940	2670	3460	3530		3.54'
24	1300	1970	2730	3570	3850		3.67'
26	1300	1990	2770	3640	4170		3.79'
28	1310	2010	2820	3710	4500		3.91'
30	1320	2030	2850	3770	4770	4820	4.02'

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	Transition Width
5	730	790					2.13'
6	830	960					2.22'
8	990	1270					2.39'
10	1120	1560	1600				2.55'
12	1220	1720	1920				2.70'
14	1290	1840	2240				2.84'
16	1350	1950	2570				2.98'
18	1390	2030	2730	2890			3.11'
20	1420	2100	2850	3210			3.23'
22	1450	2160	2950	3530			3.35'
24	1470	2210	3030	3860			3.46'
26	1480	2240	3100	4240	4170		3.58'
28	1500	2270	3160	4120	4500		3.69'
30	1510	2300	3210	4210	4820		3.79'

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	Transition Width
5	770	790					2.05'
6	880	950					2.14'
8	1060	1280					2.29'
10	1220	1600					2.43'
12	1330	1850	1920				2.57'
14	1430	2020	2250				2.69'
16	1510	2150	2570				2.81'
18	1570	2260	2890				2.93'
20	1620	2350	3150	3210			3.04'
22	1650	2430	3280	3530			3.15'
24	1690	2500	3380	3850			3.25'
26	1720	2550	3480	4180			3.35'
28	1740	2600	3570	4500			3.45'
30	1750	2640	3640	4720	4820		3.54'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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.*

12" VCP

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 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

15" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

Bold 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)							Transition Width
	30	36	42	48	54	60	72	
5	920	1150	1170					3.04'
6	1040	1320	1410					3.16'
8	1240	1600	1890					3.40'
10	1390	1820	2260	2370				3.61'
12	1510	2000	2520	2850				3.81'
14	1600	2150	2720	3330				4.00'
16	1660	2250	2890	3550	3800			4.18'
18	1720	2350	3040	3750	4280			4.36'
20	1760	2430	3150	3920	4720	4750		4.52'
22	1790	2480	3250	4060	4920	5240		4.68'
24	1820	2540	3330	4180	5080	5720		4.84'
26	1840	2570	3390	4280	5230	6190		4.99'
28	1850	2600	3450	4360	5340	6380	6670	5.14'
30	1850	2630	3490	4440	5450	6530	7140	5.28'

SANDS (SW, SP, SM, SC)
Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	30	36	42	48	54	60	72	
5	940	1170						2.98'
6	1070	1360	1410					3.10'
8	1290	1650	1890					3.32'
10	1450	1900	2350	2370				3.52'
12	1590	2100	2630	2840				3.71'
14	1700	2260	2850	3320				3.88'
16	1780	2390	3040	3730	3800			4.05'
18	1840	2500	3210	3950	4280			4.22'
20	1900	2590	3350	4150	4760			4.37'
22	1940	2670	3460	4310	5190	5230		4.52'
24	1970	2730	3570	4450	5390	5710		4.67'
26	1990	2770	3640	4570	5560	6190		4.81'
28	2010	2820	3710	4680	5700	6670		4.95'
30	2030	2850	3770	4770	5840	6960	7150	5.08'

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)							Transition Width
	30	36	42	48	54	60	72	
5	970	1170						2.91'
6	1120	1400	1410					3.01'
8	1360	1730	1890					3.21'
10	1560	2010	2370					3.39'
12	1720	2240	2780	2850				3.56'
14	1840	2430	3050	3320				3.72'
16	1950	2600	3270	3800				3.88'
18	2030	2730	3470	4240	4280			4.02'
20	2100	2850	3640	4470	4760			4.17'
22	2160	2950	3790	4680	5230			4.30'
24	2210	3030	3920	4860	5720			4.44'
26	2240	3100	4020	5020	6060	6190		4.56'
28	2270	3160	4120	5160	6240	6670		4.69'
30	2300	3210	4210	5270	6420	7150		4.81'

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)							Transition Width
	30	36	42	48	54	60	72	
5	1020	1170						2.83'
6	1170	1420						2.92'
8	1440	1820	1890					3.10'
10	1660	2120	2370					3.26'
12	1850	2390	2850					3.41'
14	2020	2620	3260	3320				3.55'
16	2150	2820	3530	3800				3.69'
18	2260	3000	3770	4280				3.82'
20	2350	3150	3990	4760				3.95'
22	2430	3280	4170	5110	5240			4.07'
24	2500	3390	4340	5330	5720			4.19'
26	2550	3490	4480	5530	6190			4.30'
28	2600	3570	4610	5720	6670			4.42'
30	2640	3640	4720	5880	7080	7150		4.53'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

18" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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)						Transition Width
	36	42	48	54	60	72	
5	1150	1400	1400				3.51'
6	1320	1600	1690				3.65'
8	1600	1970	2270				3.90'
10	1820	2260	2730	2850			4.13'
12	2000	2520	3050	3420			4.34'
14	2150	2720	3320	3940	4000		4.55'
16	2250	2890	3560	4240	4570		4.74'
18	2350	3040	3750	4500	5140		4.92'
20	2430	3150	3920	4720	5550	5720	5.10'
22	2480	3250	4060	4920	5800	6300	5.27'
24	2540	3330	4180	5080	6020	6870	5.44'
26	2570	3390	4280	5230	6220	7440	5.60'
28	2600	3450	4360	5340	6380	8020	5.76'
30	2630	3490	4440	5450	6530	8600	5.91'

SANDS (SW, SP, SM, SC)
Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)						Transition Width
	36	42	48	54	60	72	
5	1180	1400					3.46'
6	1360	1640	1700				3.59'
8	1650	2030	2270				3.82'
10	1900	2350	2820	2840			4.03'
12	2100	2630	3170	3420			4.23'
14	2260	2850	3470	4000			4.42'
16	2390	3040	3730	4430	4570		4.60'
18	2500	3210	3950	4710	5150		4.77'
20	2590	3350	4150	4970	5720		4.94'
22	2670	3460	4310	5190	6100	6300	5.10'
24	2730	3570	4450	5390	6360	6870	5.26'
26	2770	3640	4570	5560	6580	7440	5.41'
28	2820	3710	4680	5700	6780	8030	5.56'
30	2850	3770	4770	5840	6960	8600	5.70'

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)						Transition Width
	36	42	48	54	60	72	
5	1200	1400					3.38'
6	1400	1690					3.50'
8	1730	2110	2270				3.71'
10	2010	2470	2840				3.90'
12	2240	2780	3330	3420			4.08'
14	2430	3050	3670	4000			4.25'
16	2600	3270	3970	4570			4.41'
18	2730	3470	4240	5030	5150		4.57'
20	2850	3640	4470	5330	5720		4.72'
22	2950	3790	4680	5600	6300		4.87'
24	3030	3920	4860	5840	6860	6870	5.01'
26	3100	4020	5010	6060	7120	7450	5.15'
28	3160	4120	5160	6240	7370	8020	5.28'
30	3210	4210	5270	6410	7590	8600	5.41'

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)						Transition Width
	36	42	48	54	60	72	
5	1250	1400					3.30'
6	1450	1690					3.40'
8	1820	2200	2270				3.59'
10	2120	2600	2850				3.76'
12	2390	2950	3420				3.92'
14	2620	3260	3910	3990			4.07'
16	2820	3530	4250	4570			4.21'
18	3000	3770	4570	5150			4.35'
20	3150	3990	4850	5720			4.49'
22	3280	4170	5110	6060	6300		4.62'
24	3380	4340	5330	6350	6870		4.75'
26	3480	4480	5530	6620	7450		4.87'
28	3570	4610	5720	6860	8020		4.99'
30	3640	4720	5880	7080	8330	8600	5.11'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

21" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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) 36	42	48	54	60	72	84	Transition Width
5	1150	1400	1630					3.97'
6	1320	1600	1890	1960				4.12'
8	1600	1960	2350	2640				4.39'
10	1820	2260	2730	3190	3310			4.63'
12	2000	2520	3050	3590	3980			4.85'
14	2150	2720	3320	3940	4570	4650		5.07'
16	2250	2890	3550	4240	4940	5330		5.27'
18	2350	3040	3750	4500	5260	6000		5.46'
20	2430	3150	3920	4720	5550	6660		5.65'
22	2480	3250	4060	4920	5800	7340		5.83'
24	2540	3330	4180	5080	6020	7990	8010	6.01'
26	2570	3390	4280	5230	6220	8300	8680	6.18'
28	2600	3450	4360	5340	6380	8570	9350	6.34'
30	2630	3490	4440	5450	6530	8820	10020	6.50'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 36	42	48	54	60	72	84	Transition Width
5	1180	1430	1630					3.91'
6	1360	1640	1930	1970				4.05'
8	1650	2030	2410	2630				4.30'
10	1900	2350	2820	3290	3310			4.53'
12	2100	2630	3170	3720	3980			4.74'
14	2260	2850	3470	4100	4650			4.94'
16	2390	3040	3730	4430	5140	5320		5.13'
18	2500	3210	3950	4710	5500	6000		5.31'
20	2590	3350	4150	4970	5830	6670		5.48'
22	2670	3460	4310	5190	6100	7340		5.65'
24	2730	3570	4450	5390	6360	8010		5.82'
26	2770	3640	4570	5560	6580	8680		5.98'
28	2820	3710	4680	5700	6780	9040	9350	6.13'
30	2850	3770	4770	5840	6960	9320	10020	6.28'

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) 36	42	48	54	60	72	84	Transition Width
5	1220	1620						3.83'
6	1400	1690	1970					3.96'
8	1730	2110	2490	2640				4.19'
10	2010	2470	2940	3310				4.39'
12	2240	2780	3330	3890	3980			4.58'
14	2430	3050	3670	4320	4650			4.76'
16	2600	3270	3970	4700	5320			4.93'
18	2730	3470	4240	5030	5840	6000		5.09'
20	2850	3640	4470	5330	6220	6670		5.25'
22	2950	3790	4680	5600	6550	7340		5.41'
24	3030	3920	4860	5840	6860	8010		5.55'
26	3100	4020	5020	6060	7120	8680		5.70'
28	3160	4120	5160	6240	7370	9350		5.84'
30	3210	4210	5270	6420	7590	10020		5.98'

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) 36	42	48	54	60	72	84	Transition Width
5	1250	1500	1620					3.75'
6	1450	1750	1960					3.87'
8	1820	2200	2590	2640				4.06'
10	2120	2600	3080	3310				4.24'
12	2390	2950	3520	3980				4.41'
14	2620	3260	3910	4560	4650			4.57'
16	2820	3530	4250	4990	5320			4.72'
18	3000	3770	4570	5380	6000			4.87'
20	3150	3980	4850	5750	6650	6670		5.01'
22	3280	4170	5110	6060	7050	7340		5.15'
24	3380	4340	5330	6350	7410	8010		5.28'
26	3480	4480	5530	6620	7750	8680		5.41'
28	3570	4610	5720	6860	8050	9350		5.54'
30	3640	4720	5880	7080	8330	10020		5.66'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

24" VCP

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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)							Transition Width
	42	48	54	60	72	84	96	
5	1400	1640	1830					4.39'
6	1600	1890	2180	2230				4.58'
8	1960	2350	2730	3000				4.86'
10	2260	2730	3190	3660	3760			5.11'
12	2520	3050	3590	4150	4540			5.35'
14	2720	3320	3940	4570	5300			5.57'
16	2890	3550	4240	4940	6060			5.78'
18	3040	3750	4500	5260	6830			5.98'
20	3150	3920	4720	5550	7280	7590		6.18'
22	3250	4060	4920	5800	7650	8360		6.37'
24	3330	4180	5080	6020	7990	9130		6.55'
26	3390	4280	5230	6220	8300	9890		6.73'
28	3450	4360	5340	6380	8570	10650		6.90'
30	3490	4440	5450	6530	8820	11240	11420	7.07'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	42	48	54	60	72	84	96	
5	1430	1670	1830					4.33'
6	1640	1930	2230	2230				4.51'
8	2030	2410	2790	3000				4.77'
10	2350	2820	3290	3760	3770			5.01'
12	2630	3170	3720	4280	4530			5.23'
14	2850	3470	4100	4740	5300			5.43'
16	3040	3730	4430	5140	6060			5.63'
18	3210	3950	4710	5500	6830			5.82'
20	3350	4150	4970	5830	7580	7590		6.01'
22	3460	4310	5190	6100	8010	8360		6.18'
24	3570	4450	5390	6360	8380	9120		6.35'
26	3640	4570	5560	6580	8730	9890		6.52'
28	3710	4680	5700	6780	9040	10650		6.68'
30	3770	4770	5840	6960	9320	11420		6.84'

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)							Transition Width
	42	48	54	60	72	84	96	
5	1460	1710	1830					4.25'
6	1690	1990	2230					4.41'
8	2110	2490	2880	3000				4.65'
10	2470	2940	3420	3770				4.86'
12	2780	3330	3890	4470	4530			5.06'
14	3050	3670	4320	4970	5300			5.25'
16	3270	3970	4700	5430	6070			5.43'
18	3470	4240	5030	5840	6830			5.60'
20	3640	4470	5330	6220	7590			5.76'
22	3790	4680	5600	6550	8360			5.92'
24	3920	4860	5840	6860	8950	9120		6.08'
26	4020	5020	6060	7120	9360	9890		6.23'
28	4120	5160	6240	7370	9730	10660		6.38'
30	4210	5270	6420	7590	10070	11420		6.52'

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)							Transition Width
	42	48	54	60	72	84	96	
5	1500	1750	1830					4.16'
6	1750	2050	2230					4.31'
8	2200	2590	2980	3000				4.53'
10	2600	3080	3560	3770				4.71'
12	2950	3520	4080	4530				4.89'
14	3260	3910	4560	5220	5300			5.05'
16	3530	4250	4990	5750	6060			5.21'
18	3770	4570	5380	6220	6830			5.37'
20	3980	4850	5750	6650	7590			5.51'
22	4170	5110	6060	7050	8360			5.66'
24	4340	5330	6350	7410	9120			5.79'
26	4480	5530	6620	7750	9890			5.93'
28	4610	5720	6860	8050	10500	10650		6.06'
30	4720	5880	7080	8330	10910	11420		6.19'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

27" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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)							Transition Width
	42	48	54	60	72	84	96	
5	1400	1640	1880	1960				4.65'
6	1600	1890	2180	2480	2500			5.04'
8	1960	2350	2730	3110	3370			5.34'
10	2260	2730	3190	3660	4240			5.61'
12	2520	3050	3590	4150	5100			5.85'
14	2720	3320	3940	4570	5850	5960		6.08'
16	2890	3550	4240	4940	6380	6830		6.30'
18	3040	3750	4500	5260	6850	7690		6.51'
20	3150	3920	4720	5550	7280	8550		6.72'
22	3250	4060	4920	5800	7650	9420		6.91'
24	3330	4180	5080	6020	7990	11060	10270	7.10'
26	3390	4280	5230	6220	8300	10490	11140	7.29'
28	3450	4360	5340	6380	8570	10880	12000	7.47'
30	3490	4440	5450	6530	8820	11240	12860	7.65'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	42	48	54	60	72	84	96	
5	1430	1670	1910	1960				4.59'
6	1640	1930	2230	2500				4.96'
8	2030	2410	2790	3170	3370			5.25'
10	2350	2820	3290	3760	4230			5.50'
12	2630	3170	3720	4280	5100			5.73'
14	2850	3470	4100	4740	5970			5.94'
16	3040	3730	4430	5140	6610	6830		6.15'
18	3210	3950	4710	5500	7120	7690		6.34'
20	3350	4150	4970	5830	7580	8560		6.54'
22	3460	4310	5190	6100	8010	9420		6.72'
24	3570	4450	5390	6360	8380	10280		6.90'
26	3640	4570	5560	6580	8730	10970	11140	7.07'
28	3710	4680	5700	6780	9040	11420	12000	7.24'
30	3770	4770	5840	6960	9320	11820	12860	7.41'

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)							Transition Width
	42	48	54	60	72	84	96	
5	1460	1710	1960	1960				4.51'
6	1690	1990	2280	2500				4.87'
8	2110	2490	2880	3270	3370			5.13'
10	2470	2940	3420	3900	4230			5.35'
12	2780	3330	3890	4470	5100			5.56'
14	3050	3670	4320	4970	5970			5.75'
16	3270	3970	4700	5430	6820			5.94'
18	3470	4240	5030	5840	7500	7690		6.11'
20	3640	4470	5330	6220	8020	8550		6.29'
22	3790	4680	5600	6550	8510	9420		6.45'
24	3920	4860	5840	6860	8950	10270		6.61'
26	4020	5020	6060	7120	9360	11140		6.77'
28	4120	5160	6240	7370	9730	12000		6.93'
30	4210	5270	6420	7590	10070	12660	12870	7.08'

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)							Transition Width
	42	48	54	60	72	84	96	
5	1500	1750	1960					4.42'
6	1750	2050	2340	2500				4.77'
8	2200	2590	2980	3370				5.00'
10	2600	3080	3560	4050	4240			5.20'
12	2950	3520	4090	4660	5100			5.38'
14	3260	3910	4560	5220	5960			5.55'
16	3530	4250	4990	5750	6830			5.71'
18	3770	4570	5380	6220	7690			5.87'
20	3980	4850	5750	6650	8510	8550		6.03'
22	4170	5110	6060	7050	9060	9420		6.17'
24	4340	5330	6350	7410	9580	10280		6.32'
26	4480	5530	6620	7750	10050	11140		6.46'
28	4610	5720	6860	8050	10500	12000		6.60'
30	4720	5880	7080	8330	10910	12860		6.73'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

30" VCP

(In Pounds Per Linear Foot)
100 Pounds Per Cubic Foot Backfill Material*

***Bold 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) 48	54	60	72	84	96	108	Transition Width
5	1640	1880	2080					4.92'
6	1890	2180	2480	2690				5.37'
8	2350	2730	3110	3730				5.80'
10	2730	3190	3660	4620	4690			6.08'
12	3050	3590	4150	5270	5640			6.33'
14	3320	3940	4570	5850	6610			6.57'
16	3550	4240	4940	6380	7560			6.80'
18	3750	4500	5260	6850	8490	8520		7.02'
20	3920	4720	5550	7280	9060	9470		7.23'
22	4060	4920	5800	7650	9580	10440		7.43'
24	4180	5080	6020	7990	10060	11390		7.63'
26	4280	5230	6220	8300	10490	12340		7.82'
28	4360	5340	6380	8570	10880	13280	13300	8.01'
30	4440	5450	6530	8820	11240	13760	14250	8.19'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 48	54	60	72	84	96	108	Transition Width
5	1670	1910	2090					4.86'
6	1930	2230	2520	2700				5.30'
8	2410	2790	3170	3720				5.70'
10	2820	3290	3760	4690				5.96'
12	3170	3720	4280	5420	5640			6.20'
14	3470	4100	4740	6040	6610			6.43'
16	3730	4430	5140	6610	7570			6.64'
18	3950	4710	5500	7120	8520			6.84'
20	4150	4970	5830	7580	9400	9480		7.04'
22	4310	5190	6100	8010	9970	10440		7.23'
24	4450	5390	6360	8380	10500	11390		7.42'
26	4570	5560	6580	8730	10970	12350		7.60'
28	4680	5700	6780	9040	11420	13300		7.77'
30	4770	5840	6960	9320	11820	14260		7.94'

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) 48	54	60	72	84	96	108	Transition Width
5	1710	1960	2090					4.77'
6	1990	2280	2570	2690				5.20'
8	2490	2880	3270	3720				5.58'
10	2940	3420	3900	4690				5.81'
12	3330	3890	4470	5620	5650			6.03'
14	3670	4320	4970	6300	6610			6.23'
16	3970	4700	5430	6920	7570			6.42'
18	4240	5030	5840	7500	8520			6.61'
20	4470	5330	6220	8020	9470			6.78'
22	4680	5600	6550	8510	10430			6.96'
24	4860	5840	6860	8950	11120	11390		7.12'
26	5020	6060	7120	9360	11670	12350		7.29'
28	5160	6240	7370	9730	12180	13300		7.45'
30	5270	6420	7580	10070	12660	14260		7.60'

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) 48	54	60	72	84	96	108	Transition Width
5	1750	2000	2090					4.69'
6	2050	2340	2640	2690				5.10'
8	2590	2980	3370	3720				5.45'
10	3080	3560	4050	4680				5.66'
12	3520	4080	4660	5650				5.85'
14	3910	4560	5220	6570	6610			6.03'
16	4250	4990	5750	7260	7560			6.20'
18	4570	5380	6220	7910	8520			6.36'
20	4850	5750	6650	8510	9480			6.52'
22	5110	6060	7050	9060	10430			6.67'
24	5330	6350	7410	9580	11390			6.82'
26	5530	6620	7750	10050	12350			6.96'
28	5720	6860	8050	10500	13040	13300		7.10'
30	5880	7080	8330	10910	13600	14260		7.24'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

33" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

Bold 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)							Transition Width
	48	54	60	72	84	96	108	
5	1640	1880	2130	2220				5.17'
6	1890	2180	2480	2840				5.61'
8	2350	2730	3110	3880	4050			6.22'
10	2730	3190	3660	4620	5110			6.51'
12	3050	3590	4150	5270	6160			6.78'
14	3320	3940	4570	5850	7170	7210		7.03'
16	3550	4240	4940	6380	7860	8250		7.26'
18	3750	4500	5260	6850	8490	9300		7.49'
20	3920	4720	5550	7280	9060	10340		7.70'
22	4060	4920	5800	7650	9580	11390		7.91'
24	4180	5080	6020	7990	10060	12190	12440	8.12'
26	4280	5230	6220	8300	10490	12750	13480	8.31'
28	4360	5340	6380	8570	10880	13280	14530	8.51'
30	4440	5450	6530	8820	11240	13760	15570	8.70'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	48	54	60	72	84	96	108	
5	1670	1910	2160	2220				5.11'
6	1930	2230	2520	2830				5.54'
8	2410	2790	3170	3960	4060			6.13'
10	2820	3290	3760	4720	5110			6.40'
12	3170	3720	4280	5420	6160			6.65'
14	3470	4100	4740	6040	7210			6.88'
16	3730	4430	5140	6610	8100	8250		7.10'
18	3950	4710	5500	7120	8780	9300		7.31'
20	4150	4970	5830	7580	9400	10350		7.51'
22	4310	5190	6100	8010	9970	11390		7.71'
24	4450	5390	6360	8380	10500	12440		7.90'
26	4570	5560	6580	8730	10970	13290	13490	8.08'
28	4680	5700	6780	9040	11420	13870	14530	8.26'
30	4770	5840	6960	9320	11820	14410	15570	8.44'

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)							Transition Width
	48	54	60	72	84	96	108	
5	1710	1960	2200	2220				5.03'
6	1990	2280	2570	2840				5.44'
8	2490	2880	3270	4060				6.00'
10	2940	3420	3900	4870	5110			6.25'
12	3330	3890	4470	5620	6160			6.47'
14	3670	4320	4970	6300	7210			6.68'
16	3970	4700	5430	6920	8260			6.88'
18	4240	5030	5840	7500	9190	9300		7.07'
20	4470	5330	6220	8020	9880	10350		7.25'
22	4680	5600	6550	8510	10520	11390		7.43'
24	4860	5840	6860	8950	11120	12440		7.60'
26	5020	6060	7120	9360	11670	13480		7.77'
28	5160	6240	7370	9730	12180	14520		7.93'
30	5270	6420	7590	10070	12660	15330	15570	8.09'

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)							Transition Width
	48	54	60	72	84	96	108	
5	1750	2000	2220					4.94'
6	2050	2340	2640	2840				5.34'
8	2590	2980	3370	4050				5.87'
10	3080	3560	4050	5020	5110			6.09'
12	3520	4080	4660	5820	6160			6.29'
14	3910	4560	5220	6570	7210			6.47'
16	4250	4990	5750	7260	8250			6.65'
18	4570	5380	6220	7910	9300			6.81'
20	4850	5750	6650	8510	10350			6.98'
22	5110	6060	7050	9060	11120	11390		7.13'
24	5330	6350	7410	9580	11800	12440		7.29'
26	5530	6620	7750	10050	12440	13480		7.43'
28	5720	6860	8050	10500	13040	14530		7.58'
30	5880	7080	8330	10910	13600	15580		7.72'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

36" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

Bold 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)							Transition Width
	54	60	72	84	96	108	120	
5	1880	2130	**2350**					5.43'
6	2180	2480	**2980**					5.86'
8	2730	3110	3880	**4380**				6.64'
10	3190	3660	4620	**5540**				6.95'
12	3590	4150	5270	6420	**6670**			7.22'
14	3940	4570	5850	7170	**7810**			7.48'
16	4240	4940	6380	7860	**8940**			7.72'
18	4500	5260	6850	8490	**10080**			7.95'
20	4720	5550	7280	9060	10890	**11220**		8.17'
22	4920	5800	7650	9580	11570	**12350**		8.39'
24	5080	6020	7990	10060	12190	**13490**		8.60'
26	5230	6220	8300	10490	12750	**14620**		8.80'
28	5340	6380	8570	10880	13280	**15750**		9.00'
30	5450	6530	8820	11240	13760	16370	**16890**	9.19'

SANDS (SW, SP, SM, SC)

Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	54	60	72	84	96	108	120	
5	1910	2160	**2340**					5.37'
6	2230	2520	**2980**					5.79'
8	2790	3170	3960	**4380**				6.55'
10	3290	3760	4720	**5530**				6.83'
12	3720	4280	5420	6570	**6670**			7.09'
14	4100	4740	6040	7370	**7810**			7.33'
16	4430	5140	6610	8100	**8950**			7.55'
18	4710	5500	7120	8780	**10090**			7.77'
20	4970	5830	7580	9400	**11220**			7.98'
22	5190	6100	8010	9970	11990	**12360**		8.18'
24	5390	6360	8380	10500	12660	**13490**		8.38'
26	5560	6580	8730	10970	13290	**14620**		8.57'
28	5700	6780	9040	11420	13870	**15760**		8.75'
30	5840	6960	9320	11820	14410	**16890**		8.93'

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)							Transition Width
	54	60	72	84	96	108	120	
5	1960	2200	**2340**					5.28'
6	2280	2570	**2980**					5.69'
8	2880	3270	4060	**4380**				6.42'
10	3420	3900	4870	**5530**				6.68'
12	3890	4470	5620	**6670**				6.91'
14	4320	4970	6300	7640	**7810**			7.12'
16	4700	5430	6920	8440	**8950**			7.33'
18	5030	5840	7500	9190	**10080**			7.52'
20	5330	6220	8020	9880	**11220**			7.71'
22	5600	6550	8510	10520	**12350**			7.89'
24	5840	6860	8950	11120	13330	**13480**		8.07'
26	6060	7120	9360	11670	14040	**14620**		8.24'
28	6240	7370	9730	12180	14710	**15760**		8.41'
30	6420	7590	10070	12660	15330	**16890**		8.57'

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)							Transition Width
	54	60	72	84	96	108	120	
5	2000	2250	**2350**					5.20'
6	2340	2640	**2980**					5.59'
8	2980	3370	4160	**4380**				6.28'
10	3560	4050	5020	**5530**				6.52'
12	4080	4660	5820	**6670**				6.72'
14	4560	5220	6570	**7810**				6.91'
16	4990	5750	7260	8800	**8950**			7.09'
18	5380	6220	7910	9620	**10080**			7.27'
20	5750	6650	8510	10390	**11210**			7.43'
22	6060	7050	9060	11120	**12350**			7.59'
24	6350	7410	9580	11800	**13480**			7.75'
26	6620	7750	10050	12440	**14620**			7.90'
28	6860	8050	10500	13040	15620	**15750**		8.05'
30	7080	8330	10910	13600	16350	**16890**		8.20'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

39" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

Bold 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)

$K\mu' = 0.165$

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)						Transition Width
	60	72	84	96	108	120	
5	2130	2540					5.83'
6	2480	3060	3220				6.25'
8	3110	3880	4660	4770			7.14'
10	3660	4620	5580	6160			7.60'
12	4150	5270	6420	7440			7.89'
14	4570	5850	7170	8510	8720		8.15'
16	4940	6380	7860	9370	9990		8.41'
18	5260	6850	8490	10160	11250		8.65'
20	5550	7280	9060	10890	12530		8.88'
22	5800	7650	9580	11570	13590	13800	9.10'
24	6020	7990	10060	12190	14360	15060	9.32'
26	6220	8300	10490	12750	15080	16330	9.53'
28	6380	8570	10880	13280	15750	17610	9.74'
30	6530	8820	11240	13760	16370	18870	9.94'

SANDS (SW, SP, SM, SC)

$K\mu' = 0.150$

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)						Transition Width
	60	72	84	96	108	120	
5	2160	2540					5.77'
6	2520	3110	3220				6.17'
8	3170	3960	4740	4770			7.05'
10	3760	4720	5700	6170			7.48'
12	4280	5420	6570	7440			7.75'
14	4740	6040	7370	8710			8.00'
16	5140	6610	8100	9630	9990		8.24'
18	5500	7120	8780	10470	11260		8.46'
20	5830	7580	9400	11260	12530		8.68'
22	6100	8010	9970	11980	13800		8.89'
24	6360	8380	10500	12660	14870	15070	9.09'
26	6580	8730	10970	13290	15650	16340	9.29'
28	6780	9040	11420	13870	16380	17610	9.48'
30	6960	9320	11820	14410	17070	18880	9.67'

SILTS AND CLAYS (CL, ML)

$K\mu' = 0.130$, L.L. Less Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)						Transition Width
	60	72	84	96	108	120	
5	2200	2540					5.68'
6	2570	3170	3220				6.07'
8	3270	4060	4770				6.91'
10	3900	4870	5850	6160			7.32'
12	4470	5620	6770	7440			7.57'
14	4970	6300	7640	8720			7.79'
16	5430	6920	8440	9990			8.00'
18	5840	7500	9190	10900	11260		8.21'
20	6220	8020	9880	11770	12520		8.40'
22	6550	8510	10520	12570	13800		8.59'
24	6860	8950	11120	13330	15070		8.77'
26	7120	9360	11670	14040	16330		8.95'
28	7370	9730	12180	14710	17280	17610	9.13'
30	7590	10070	12660	15330	18060	18870	9.30'

SILTS AND CLAYS (CH, MH)

$K\mu' = 0.110$, L.L. Greater Than 50

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)						Transition Width
	60	72	84	96	108	120	
5	2250	2540					5.59'
6	2640	3220					5.97'
8	3370	4160	4780				6.78'
10	4050	5020	6010	6160			7.16'
12	4660	5820	7000	7440			7.38'
14	5220	6570	7930	8720			7.58'
16	5750	7260	8800	9980			7.76'
18	6220	7910	9620	11260			7.94'
20	6650	8510	10390	12310	12530		8.12'
22	7050	9060	11110	13210	13800		8.28'
24	7410	9580	11800	14050	15070		8.44'
26	7750	10050	12440	14860	16340		8.60'
28	8050	10500	13040	15620	17610		8.76'
30	8330	10910	13600	16350	18880		8.91'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)

100 Pounds Per Cubic Foot Backfill Material*

***Bold 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.*

42" VCP

GRAVELS (GW, GP, GM, GC)
Kμ' = 0.165

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	60	72	84	96	108	120	132	
5	2130	2630	2690					6.13'
6	2480	3060	3390					6.54'
8	3110	3880	4660	4990				7.42'
10	3660	4620	5580	6550	6630			8.07'
12	4150	5270	6420	7570	8010			8.38'
14	4570	5850	7170	8510	9390			8.65'
16	4940	6380	7860	9370	10760			8.91'
18	5260	6850	8490	10160	11860	12140		9.16'
20	5550	7280	9060	10890	12750	13510		9.40'
22	5800	7650	9580	11570	13590	14870		9.63'
24	6020	7990	10060	12190	14360	16240		9.85'
26	6220	8300	10490	12750	15080	17450	17620	10.07'
28	6380	8570	10880	13280	15750	18270	18990	10.28'
30	6530	8820	11240	13760	16370	19040	20350	10.49'

SANDS (SW, SP, SM, SC)
Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches)							Transition Width
	60	72	84	96	108	120	132	
5	2160	2650	2690					6.07'
6	2520	3110	3390					6.47'
8	3170	3960	4740	4990				7.32'
10	3760	4720	5700	6630				7.95'
12	4280	5420	6570	7730	8010			8.24'
14	4740	6040	7370	8710	9390			8.50'
16	5140	6610	8100	9630	10770			8.74'
18	5500	7120	8780	10470	12140			8.97'
20	5830	7580	9400	11260	13140	13500		9.19'
22	6100	8010	9970	11980	14040	14880		9.41'
24	6360	8380	10500	12660	14870	16240		9.62'
26	6580	8730	10970	13290	15650	17620		9.82'
28	6780	9040	11420	13870	16380	18940	18980	10.02'
30	6960	9320	11820	14410	17070	19780	20360	10.21'

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)							Transition Width
	60	72	84	96	108	120	132	
5	2200	2690						5.98'
6	2570	3170	3390					6.37'
8	3270	4060	4840	4990				7.19'
10	3900	4870	5850	6620				7.79'
12	4470	5620	6770	7950	8010			8.05'
14	4970	6300	7640	9000	9390			8.29'
16	5430	6920	8440	9980	10770			8.51'
18	5840	7500	9190	10900	12130			8.71'
20	6220	8020	9880	11770	13510			8.91'
22	6550	8510	10520	12570	14650	14870		9.11'
24	6860	8950	11120	13330	15580	16250		9.29'
26	7120	9360	11670	14040	16460	17620		9.48'
28	7370	9730	12180	14710	17280	18980		9.66'
30	7590	10070	12660	15330	18060	20360		9.83'

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)							Transition Width
	60	72	84	96	108	120	132	
5	2250	2680						5.89'
6	2640	3230	3380					6.26'
8	3370	4160	4950	4990				7.05'
10	4050	5020	6010	6630				7.63'
12	4660	5820	7000	8020				7.86'
14	5220	6570	7930	9300	9390			8.07'
16	5750	7260	8800	10350	10760			8.26'
18	6220	7910	9620	11360	12140			8.45'
20	6650	8510	10390	12310	13510			8.62'
22	7050	9060	11110	13210	14880			8.79'
24	7410	9580	11800	14050	16250			8.96'
26	7750	10050	12440	14860	17310	17610		9.12'
28	8050	10500	13040	15620	18250	18980		9.28'
30	8330	10910	13600	16350	19130	20350		9.43'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*

For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

48" VCP

LOADS CAUSED BY BACKFILLING WITH VARIOUS MATERIALS

(In Pounds Per Linear Foot)
100 Pounds Per Cubic Foot Backfill Material*

Bold 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) 72	84	96	108	120	132	144	Transition Width
5	2620	3120	**3360**					8.00'
6	3070	3660	4250	**4360**				8.16'
8	3880	4670	5450	**5890**				8.58'
10	4620	5520	6560	**7410**				8.83'
12	5270	6420	7570	8740	**8940**			9.16'
14	5860	7170	8510	9860	**10470**			9.50'
16	6380	7870	9370	10890	**11990**			9.75'
18	6860	8490	10160	11860	**13520**			10.00'
20	7280	9070	10900	12760	14640	**15040**		10.25'
22	7660	9590	11570	13590	15640	**16570**		10.50'
24	8000	10060	12190	14360	16580	**18100**		10.67'
26	8300	10490	12760	15080	17450	**19620**		11.00'
28	8570	10880	13280	15750	18280	20840	**21150**	11.16'
30	8810	11240	13770	16370	19040	21760	**22670**	11.33'

SANDS (SW, SP, SM, SC)
Kμ' = 0.150

Depth of Backfill Over Top of Pipe (Feet)	Trench Width At Top Of Pipe (inches) 72	84	96	108	120	132	144	Transition Width
5	2650	3150	**3600**					7.83'
6	3110	3700	4300	**4300**				8.16'
8	3660	4740	5530	**5890**				8.50'
10	4720	5690	6670	**7410**				8.75'
12	5410	6570	7730	8900	**8940**			9.08'
14	6040	7370	8710	10070	**10470**			9.25'
16	6610	8110	9630	11160	**11990**			9.58'
18	7120	8780	10470	12180	**13520**			9.75'
20	7590	9400	11260	13140	15040	**15040**		10.08'
22	8010	9970	11980	14030	16110	**16570**		10.25'
24	8390	10490	12660	14870	17110	**18100**		10.50'
26	8730	10970	13290	15650	18050	**19620**		10.67'
28	9040	11410	13870	16380	18940	**21150**		10.83'
30	9320	11820	14410	17070	19780	22540	**22670**	11.08'

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) 72	84	96	108	120	132	144	Transition Width
5	2700	3190	**3600**					7.83'
6	3170	3770	**4360**					8.00'
8	4060	4850	5640	**5890**				8.33'
10	4870	5850	6830	**7410**				8.58'
12	5610	6780	7950	**8940**				8.83'
14	6300	7640	9000	10360	**10470**			9.08'
16	6920	8440	9980	11530	**11990**			9.25'
18	7500	9190	10900	12630	**13520**			9.58'
20	8030	9880	11770	13680	**15040**			9.75'
22	8510	10520	12570	14650	**14570**			10.00'
24	8950	11120	13330	15580	17850	**18100**		10.16'
26	9360	11670	14040	16450	18890	**19620**		10.25'
28	9730	12190	14710	17280	19900	**21150**		10.50'
30	10070	12660	15330	18060	20830	**22670**		10.66'

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) 72	84	96	108	120	132	144	Transition Width
5	2740	3240	**3600**					7.75'
6	3230	3830	**4360**					7.83'
8	4160	4950	5750	**5890**				8.16'
10	5020	6010	6990	**7410**				8.50'
12	5830	7000	8180	**8940**				8.66'
14	6570	7930	9300	**10470**				8.83'
16	7260	8800	10360	11920	**11990**			9.08'
18	7910	9620	11360	13110	**13520**			9.25'
20	8500	10390	12310	14240	**15040**			9.50'
22	9060	11120	13210	15320	**16570**			9.58'
24	9580	11800	14060	16340	**18100**			9.75'
26	10060	12440	14860	17320	**19620**			10.00'
28	10500	13030	15620	18250	20910	**21150**		10.08'
30	10920	13600	16340	19130	21960	**22670**		10.25'

**Adjust loads to actual trench backfill weight (see examples 4-5 and 4-6 starting on page 4 – 17)*
For information regarding the equations used to compute these loads, see the Marston Equation section starting on page 4 – 4

CHAPTER 6: STRUCTURAL DESIGN OF RIGID CONDUITS, UNDERGROUND

Figure 6-1: Rigid conduits provide a structural component needed to support service loads.

This chapter deals with the structural design as outlined by the analysis of trench loads developed in Chapter 4: Structural Analysis of Rigid Conduits Underground. Structural support is achieved by selecting and providing proper trench and bedding conditions. This chapter describes the methods by which the trench loads must be supported.

Structural Stability

It is of fundamental importance to recognize the variable supporting strengths of pipe in the trench, including a design factor of safety, under various bedding and field construction conditions.

Several factors influencing the structural stability of the proposed installation must first be considered. These factors include:

1. Design Load Versus Actual Load
2. Trench Width
3. Moving of Trench Box or Removal of Sheeting
4. Sloping Trench Walls

When these factors have been taken into consideration, the supporting strength of Vitrified Clay Pipe (VCP) can be calculated.

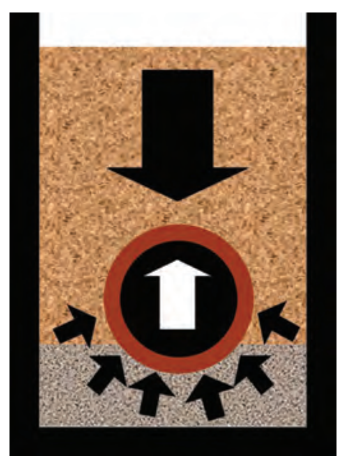


Figure 6-2: Structural support is achieved by selecting and providing proper trench and bedding conditions.

Design Load Versus Actual Load

The design load is the actual load adjusted by a factor of safety. The factor of safety is determined by dividing the field supporting strength of the pipe by the total trench load.

It should be clear that all loads considered in Chapter 4, have been the actual loads imposed upon a conduit in a given installation. In structural design all actual loads must be translated into design loads so that the factor of safety is incorporated in the final design.

An engineer determines the factor of safety based on his knowledge of local soil conditions, construction practices, plans for future development of the area and any unusual variations of land use.

The Effect of Trench Width

The trench width at the top of the pipe is one of the most important factors. It is involved not only in design, but throughout construction.

As shown in the Marston Equation (page 4-4), the load on the pipe increases in relation to the square of the trench width. Therefore, even a relatively small increase in width results in a large increase in load.

For example, an 8-inch pipe installed in a sandy soil weighing 100 lbs/ ft^3 at a cover depth of 14 ft., with a trench width of 24 in. will have a load imposed of 1,170 lbs/ LF. If the trench width is increased only 25% (6 in.) to 30 in., the load imposed will increase to 1,700 lbs/ LF, or more than 45% (Load Table on page 5-3).

The design trench width at the top of the pipe equals the sum of the outside diameter of the pipe, the minimum working space on each side of the pipe and the thickness of sheeting if removed or of the trench box wall on each side of the trench.

Controls used during the course of construction to preserve the design trench width are vital to the structural performance and useful life of the pipe.

The Effect of Moving the Trench Box or Removing the Sheeting

When a trench box is moved or sheeting is removed from a trench after bedding has been placed, a space may be created at the sides of the trench. Sufficient bedding material shall be placed so that the bedding meets the requirements of the specified class of bedding following removal of any trench sheeting or box.

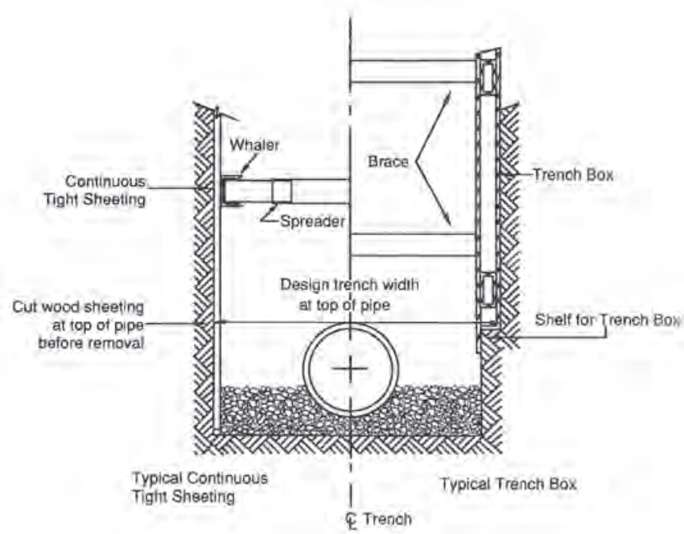


Figure 6-3: *Typical sheeting or trench box*

Good engineering practice recommends that timber sheeting be cut off at the top of the pipe. The upper portion may be removed without harming the support conditions. Thin steel sheeting may be carefully withdrawn.

The Effect of Sloping Trench Walls

Since the load on the pipe increases with the square of the width of the trench at the top of the pipe, it follows that trenches should be as narrow as practical.

All available evidence shows that the width or shape of the trench above the level of the top of the pipe does not increase the load on the pipe. The trench walls above that level may be sloped or benched outward without adding to the load on the pipe.

Supporting Strength of Vitrified Clay Pipe

The factors influencing the supporting strength of Vitrified Clay Pipe (VCP) are:

1. Bearing Strength of VCP
2. Foundation
3. Bedding Materials
4. Haunch Support
5. Load Factors

Bearing Strength of Vitrified Clay Pipe

Tests to determine the bearing strength of vitrified clay pipe are consistent throughout the country. Testing standards and protocols are established by the American Society for Testing and Materials (ASTM), as set forth in ASTM C301, *Standard Methods of Testing Vitrified Clay Pipe.*

Figure 6-4: *In a three-edge bearing test, a 12" pipe is subjected to minimum load of 2,600 pounds per linear foot.*

VCP is tested and certified at the place of manufacture, by the manufacturer to determine the bearing strength in terms of pounds per linear foot. Testing may be observed by the engineer in charge of construction or by the engineer's designated representative. VCP may also be certified by qualified testing laboratories approved by the engineer.

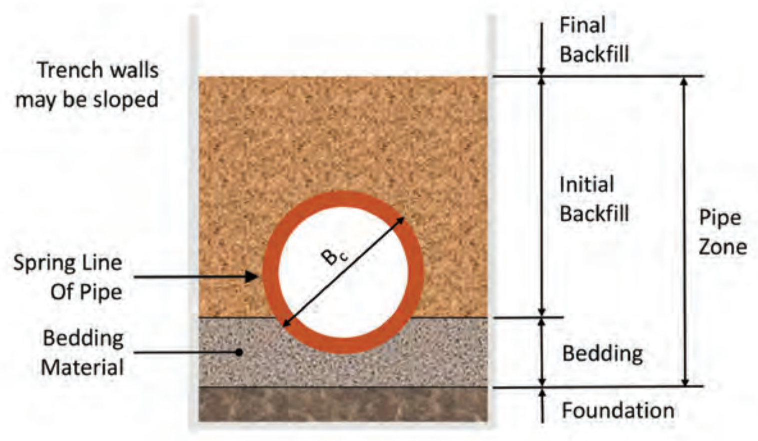


Figure 6-5: *Trench Cross Section*

Foundation

Trench load design for all pipe is based upon a firm and unyielding foundation. It is essential that the foundation remain stable during backfilling, compaction and under all subsequent trench operations.

The foundation is critical to the performance of the entire pipe installation. The foundation must be firm and unyielding as it needs to support the bedding, pipe and backfill as shown in Figure 6-5.

In cases where the trench bottom is soft and unsuitable to support the pipe, bedding and backfill; removal of material is necessary. Replacement can be accomplished with crushed rock or a woven geotextile fabric or both, to stabilize the foundation. Consult a Geotechnical engineer to ensure the foundation can support the entire trench load.

Bedding Materials

The National Clay Pipe Institute has conducted extensive laboratory and field research on bedding materials, load factors and trench load development. Subsequent field experience has confirmed that pipe movement is the leading cause of structural problems. Consequently, the objective of a quality installation must be to develop a stable pipe bedding system, which will minimize pipe movement in the long term. It is known that not all bedding materials provide the same longitudinal and circumferential pipe support.

An ideal bedding material can be defined as one that (a) provides uniform support over the greatest pipe area, (b) does not develop point load, (c) does not migrate under various trench conditions, (d) is easily placed with little or no compaction and (e) is widely available.

Uniform Soil Groups for Pipe Installation

The soil groups used in each bedding class are defined in Table 6-1.

Uniform Soil Groups for Pipe Installation[1]

Soil Class	Definition	Symbols
Class I[2]	**Crushed Rock** 100% passing 1-1/2 in. sieve, </= 15% passing #4 sieve, </= 25% passing 3/8 in. sieve, </= 12% passing #200 sieve	
Class II[3]	**Clean, Coarse Grained Soils** Or any soil beginning with one of these symbols (can contain up to 12% fines) Uniform fine sands (SP) with more than 50% passing a #100 sieve should be treated as Class III material	GW, GP, SW, SP
Class III	**Coarse Grained Soils With Fines** Or any soil beginning with one of these symbols	GM, GC, SM, SC
	Sandy or Gravelly Fine Grained Soils Or any soil beginning with one of these symbols, with >/= 30% retained on #200 sieve	ML, CL
Class IV	**Fine-Grained Soils** Or any soil beginning with one of these symbols, with < 30% retained on a #200 sieve	ML, CL
Class V[4]	**Fine-Grained Soils, Organic Soils** High compressibility silts and clays, organic soil	MH, CH, OL, OH, Pt

1 Soil Classification descriptions and symbols are in accordance with ASTM D2487 and ASTM D2488
2 For Class I, all particle faces shall be fractured.
3 Materials such as broken coral, shells, slag, and recycled concrete (with less than 12% passing a #200 sieve) should be treated as Class II soils.
4 Class V soil is not suitable for use as a bedding or initial backfill material.

***Table 6-1:** Uniform Soil Groups for Pipe Installation (from ASTM C12)*

Soil Gradations

The gradation for Class I and Class II soil for Class C bedding (Figure 6-14, page 6-11) shall have a maximum particle size of 1 in.

The gradation for Class I and Class II bedding material for Class B (Figure 6-15, page 6-12), Crushed Stone Encasement (Figure 6-16, page 6-12), and CLSM installation (Figure 6-18, page 6-13) shall be as follows:

- 100% passing a 1 in. sieve
- 40-60% passing a 3/4 in. sieve
- 0-25% passing a 3/8 in. sieve

Class II soils shall have a minimum of one fractured face. For Class B (Figure 6-15), Crushed Stone Encasement (Figure 6-16), and CLSM installations (Figure 6-18) where high and/ or changing water tables are present; Class II material shall have a minimum percentage by particle count of one fractured face-100%, two fractured faces-85%, and three fractured faces-65% in accordance with ASTM D5821 *Test Method for Determining the Percentage of Fractured particles in Coarse Aggregate.*

Due to the particles being 100% fractured, Class I material is considered to be more stable and provide better support than Class II materials that have some rounded edges.

All bedding material shall be shovel-sliced so the material fills the haunch area to support the pipe to the limits shown in the trench diagrams starting on page 6-10.

Allowable Bedding Material & Initial Backfill per Bedding Class					
Bedding Class	Allowable Bedding Material			Allowable Initial Backfill	
	Soil Class (Table 6-1)	Gradation	Size	Soil Class (Table 6-1)	Particle Size
Class D	N/A	N/A	N/A	I, II, III or IV	1"
Class C	I or II	- 100% passing a 1" sieve - 40 – 60% passing a ¾" sieve - 0 – 25% passing a ⅜" sieve	1"	I, II, III or IV	1½"
Class B	I or II		1"	I, II, III or IV	1½"
Crushed Stone Encasement	I or II		1"	I, II, III or IV	1½"
CLSM	I or II		1"	I, II, III or IV	1½"
Concrete Cradle	N/A	N/A	N/A	I, II, III or IV	1½"

Table 6-2: *Allowable Bedding Material and Initial Backfill per Bedding Class (from ASTM C12)*

Native Bedding

Many native materials taken from the trench will provide suitable support for clay pipe and may be the most cost efficient method of installation. Care must be exercised to remove rock particles larger than those indicated on Table 6-2, which could cause point loading. Native materials may be used when the required load factor design can be achieved.

Haunch Support

Proper haunch support is necessary for the achievement of the load factor and thus, the structural integrity of the pipe. Lack of proper haunch support can cause a pipeline failure.

Haunch support depends on three factors:

- Proper compaction of the bedding materials in the pipe haunches
- Mobilization of the bedding within the limits of the haunch area
- Bell or coupling holes/ pipe barrel uniform support

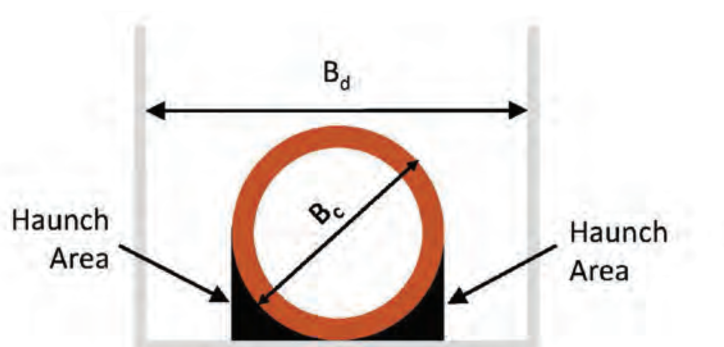


Figure 6-6: *Pipe Haunch Areas*

Compaction of Haunch Soil

Compaction of the soil in the haunch area significantly increases the support for the pipe. Gravels and crushed rock dumped into a trench beside the pipe result in the minimum densities of the soil, which is about 80-85% of their maximum density. Compacting the soil to about 95% (ASTM D4253 *Standard Test Methods for Maximum Index Density and Unit Weight of Soils Using a Vibratory Table*) can increase the stiffness (modulus) of the soil 300 to 600% (Howard 2013).

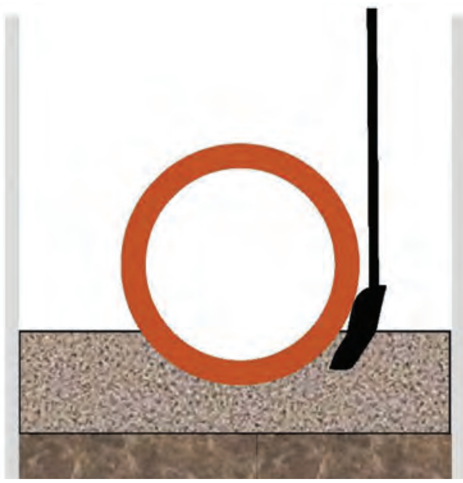


Figure 6-7: *Initial haunching should be performed before the bedding is no higher than the quarter point of the pipe diameter.*

Figure 6-8: *Shovel-slicing the bedding material into the haunches of the pipe is essential if the total load factor is to be realized.*

To obtain the installed supporting strength in accordance with the class of bedding used, the pipe barrel must be uniformly supported by direct contact with firm bedding.

Firm bedding means the pipe barrel must rest on undisturbed native or imported material. The native material in the trench bottom must be capable of excavation to a uniform undisturbed flat bottom in the case of Class D (see page 6-10). If the trench is over-excavated, the trench bottom should be brought back to grade with the required bedding material.

Shovel-slicing the bedding material in the haunch areas is critical. It takes little time, maintains grade, eliminates voids beneath the pipe and in the haunch areas, consolidates the bedding, and adds little or nothing to the cost of the installation. To be the most effective, shovel slicing should be done before the bedding is no higher than the quarter point of the pipe. Shovel-slicing the bedding material into the haunches of the pipe is essential if the total load factor is to be realized.

Bell or Coupling Holes

Bell or coupling holes must be carefully excavated so that the bells or couplings support no part of the load. The pipe barrel is designed to support the trench

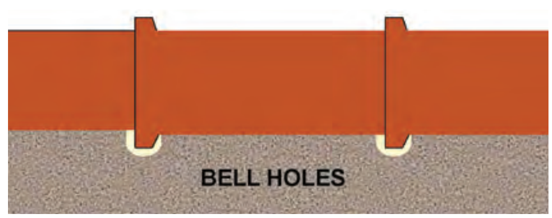


Figure 6-9: *Provide uniform and continuous support of pipe barrel between bell or coupling holes for all classes of bedding.*

load. Compaction of material around and under the bell and couplings during bedding and backfilling should be avoided because it may create a concentrated load resulting in a decreased field supporting strength. The field supporting strength of the pipe is substantially reduced when the pipe is improperly bedded. The engineer should ensure that the class of bedding specified is actually provided during construction. The need for implementation of proper installation procedures is clearly demonstrated by significant losses in the field supporting strength of the pipe as a result of improper bedding.

Increased Haunch Support by Soil Mobilization

Haunch support for pipe can be effectively actuated by providing an uncompacted bedding for the pipe. The weight of the pipe, fluid in the pipe, and the backfill soil over the pipe help push the pipe into the uncompacted material creating a small cradle. Since uncompacted bedding under the pipe has a low stiffness, minor pipe settlement will mobilize the haunch soil support. Compacted haunch material is not as effective if the pipe is resting on hard compacted bedding. The soil simply acts as a filler. However, if the pipe is raised during compaction of the haunch soil, then the haunch support can be mobilized similar to uncompacted bedding.

Discussion of Haunch Voids

Uniformly graded gravel will typically leave a void in the haunches of a pipe when it is loosely placed or dumped beside a pipe and will result in a decreased load factor no matter the bedding class. The gravel has an angle of repose, which is the angle of the slope of the material when dumped into a pile. Gravel with fractured faces will have a steeper angle than gravel with rounded edges. Figure 6-10 shows crushed rock with an angle of repose of 39 degrees dumped beside a 36 in. pipe with a 44 in. outside diameter.

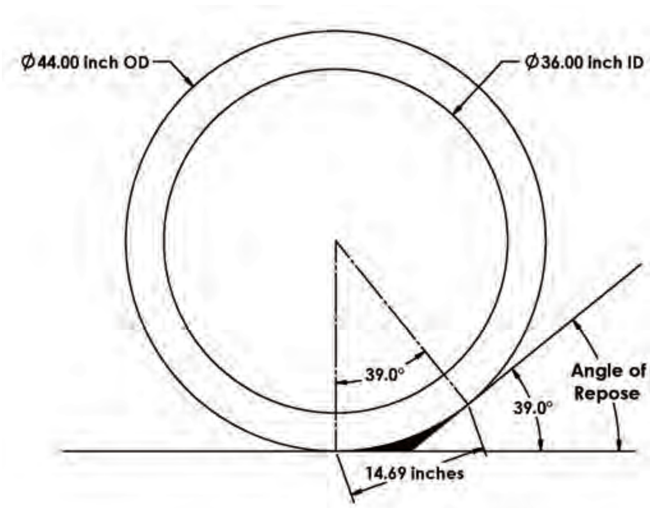


Figure 6-10: Illustration of the void space left in the haunches of a 44-in. OD pipe when the bedding material angle of repose is 39 degrees and dumped.

Figure 6-11 is a photo from a research project, which illustrates the reality of the haunch void. The photo was taken after the crushed rock had been dumped in beside a 36 in. pipe. Daylight can be seen on the other end of the pipe indicating a void running along the full length of the pipe in this lower haunch area. A video taken at the time of this photo clearly demonstrates the mechanism of the formation of a void in this area. This video is available for viewing on the NCPI YouTube channel.

Figure 6-11: 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 using a shovel, spade, or other suitable tool
- Can be attained by using CLSM (flowable fill) with the proper flowability
- Is not attained by dumping gravels and crushed rock beside the pipe
- Can be aided by pipe settling into uncompacted bedding to mobilize the strength of the haunch soil

Load Factors

The load a pipe can support varies according to the class of bedding.

Trench details shown on the following pages as well as in ASTM C12 depict the recommended classes of bedding. Load factors have been determined for each bedding class. The load factor is the ratio of the supporting strength of the pipe in the trench to its three-edge bearing test strength. It does not include a design factor of safety. The three-edge bearing strength has been established as a base and is considered equivalent to a load factor of 1.0.

Using Load Factors to Determine Field Supporting Strength

Field Supporting Strength (FSS) = Minimum Three-Edge Bearing Strength x Load Factor. See Table 6-3 (page 6-18) for a FSS of VCP pipe sizes from 6-in. to 48-in. in various bedding classes.

The load factor is used to compute the field supporting strength of vitrified clay pipe with any designated bedding class. The specified minimum three edge bearing strength of vitrified clay pipe is multiplied by the appropriate load factor to obtain the field supporting strength of the pipe. Therefore, it is possible to provide the necessary field supporting strength to exceed the calculated trench loads. Field supporting strengths of extra strength clay pipe (ASTM C 700) are shown on Table 6-3 on page 6-18. Also see the section on the discussion of haunch voids and the importance of haunching for the achievement of the bedding class load factor on pages 6-6 to 6-9.

Figure 6-12: *Load factor development at the NCPI Research laboratory*

Example 6-1: Calculating Field Supporting Strength

Per ASTM C700, a 36-in Extra Strength (ES) VCP has a minimum bearing strength of 6,000 lbs/ LF. If it is installed with a Class C Bedding (1.5 load factor), what is the FSS?

FSS = Minimum Pipe Bearing Strength x Load Factor

FSS = 6,000 X 1.5

FSS = 9,000 lbs/ LF

<u>Bedding Classes</u>

All bedding classes outlined here are in accordance with ASTM C12. For more information, refer to the original standard.

Class D Bedding, Load Factor = 1.1

The pipe shall be placed on a foundation with bell holes provided. The bottom of the entire pipe barrel shall have a continuous and uniform bearing support.

The initial backfill shall be either Class I, II, III, or IV soil having a maximum particle size of 1 inch. Refer to the Uniform Soil Groups Table (Table 6-1) on page 6-5 for specific information about soil classes..

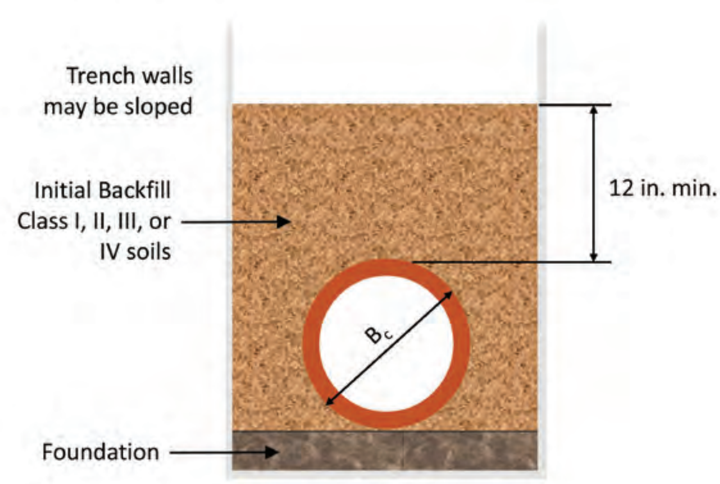


Figure 6-13: *Class D Bedding – Load Factor = 1.1*

Class C Bedding, Load Factor = 1.5
The pipe shall be bedded in Class I or Class II soil having a maximum particle size of 1 in. Refer to Bedding Materials starting on page 6-4 for requirements.

Sand is suitable as a bedding material in a total sand environment but may be unsuitable where high and rapidly changing water tables are present in the pipe zone. It may also be undesirable in a trench cut by blasting or in trenches through clay type soil. Regardless of the trench condition or bedding class, the maximum load factor for sand bedding is 1.5.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend up the haunches of the pipe one-sixth of the outside diameter of the pipe. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool.

The initial backfill shall be of selected material either Class I, II, III, or IV having a maximum particle size of 1½ in.

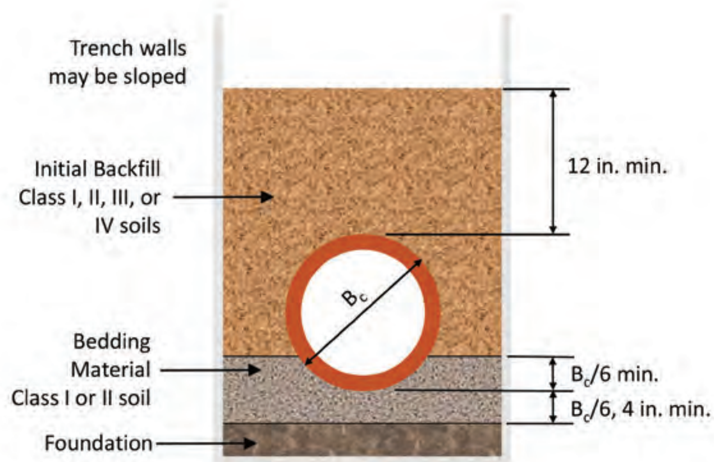


Figure 6-14: *Class C Bedding – Load Factor = 1.5*

Class B Bedding, Load Factor = 1.9
The pipe shall be bedded in Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend up the haunches of the pipe to the springline. The portion of the bedding directly beneath the pipe and above the foundation **should not be compacted**. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool. Initial shovel slicing should be performed before the bedding is no higher than the quarter point of the pipe diameter. Shovel-slicing the bedding material into the haunches of the pipe is required to achieve the 1.9 load factor.

The bedding material shall extend to the specified trench width and upward to the top of the pipe barrel following removal of any trench sheeting or boxes. The initial backfill shall be either Class I, II, III or Class IV having a maximum particle size of 1½ in.

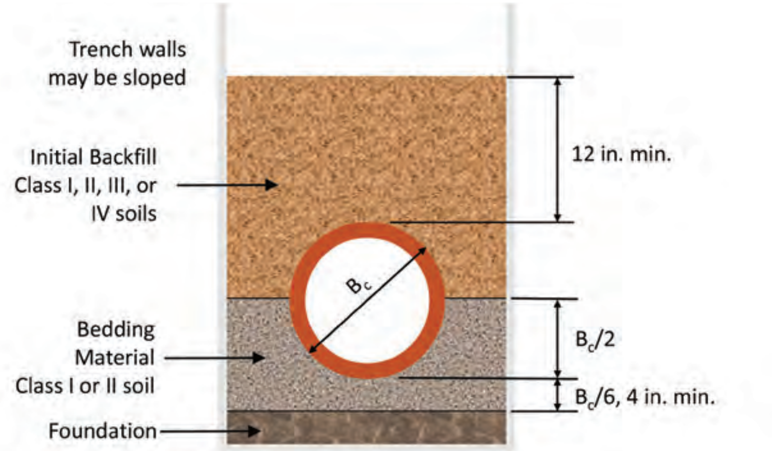


Figure 6-15: *Class B Bedding – Load Factor = 1.9*

Crushed Stone Encasement, Load Factor = 2.2

The pipe shall be bedded in Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 in. or one-sixth of the outside diameter of the pipe (B_c), whichever is greater, and shall extend upward to a horizontal plane at the top of the pipe barrel. The portion of the bedding directly beneath the pipe and above the foundation **should not be compacted**. The bedding material shall be carefully placed and sliced into the haunches of the pipe with a shovel or other suitable tool. Initial shovel slicing should be performed before the bedding is no higher than the quarter point of the pipe diameter. Shovel-slicing the bedding material into the haunches of the pipe is required to achieve the 2.2 load factor.

The encasement material shall extend laterally to the specified trench width and upward to a horizontal plane at the top of the pipe barrel following removal of any trench sheeting or boxes.

The initial backfill shall be either Class I, II, III or IV having a maximum particle size of 1½ in.

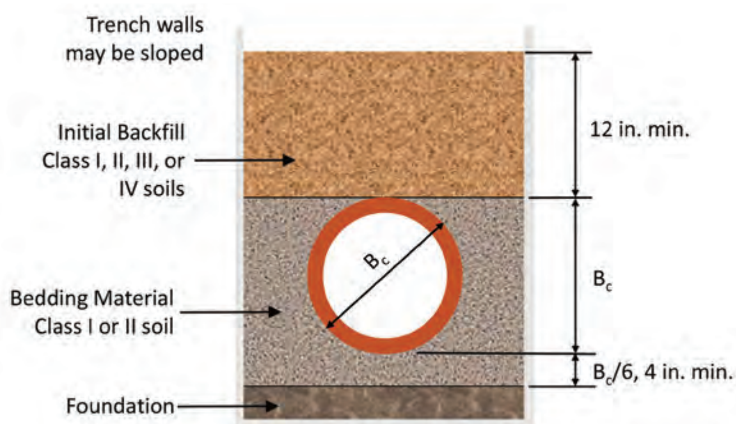


Figure 6-16: *Crushed Stone Encasement Bedding – Load Factor = 2.2*

Controlled Low Strength Material (CLSM) Bedding, Load Factor = 2.8
The pipe shall be bedded on Class I or Class II soil. Refer to Bedding Materials starting on page 6-4 for gradation and fractured face requirements.

The bedding shall have a minimum thickness beneath the pipe of 4 inches or one-sixth of the outside pipe diameter (B_c), whichever is greater.

For pipe diameters 8 to 21 inches, CLSM shall extend a minimum of 9 inches on each side of the pipe barrel. For pipe diameters 24 inches and larger, CLSM shall extend a minimum of 12 inches on each side of the pipe barrel.

Testing for flow consistency should be conducted in accordance with ASTM D6103 *Standard Test Method for Flow Consistency of Controlled Low Strength Material (CLSM).* When placed, CLSM shall have a measured spread of 7 – 9 inches. A typical result is shown in Figure 6-17.

The 28-day compressive strength shall be 100 to 300 psi as determined by Test Method ASTM D4832 *Standard Test Method for Preparation and Testing of Controlled Low Strength Material (CLSM) Test Cylninders.*

Figure 6-17: *Measuring the spread diameter to determine flowability prior to placement.*

CLSM shall be directed to the top of the pipe to flow down equally on both sides to prevent misalignment. Place CLSM to the top of the pipe barrel.

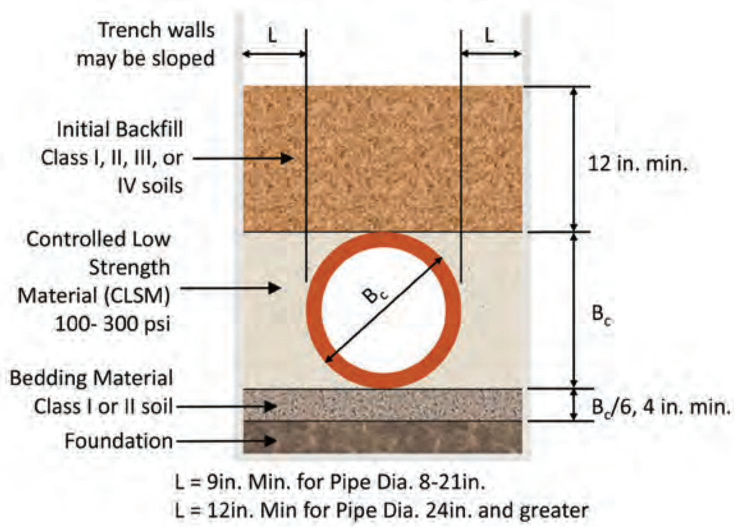


Figure 6-18: *Controlled Low Strength Material (CLSM) Bedding – Load Factor = 2.8*

Initial backfill shall only commence after a 500 psi minimum penetrometer reading is achieved as determined by Test Method C403/C403M *Standard Test Method for Time of Setting of Concrete Mixtures by Penetration Resistance*. The penetrometer shall have a maximum load capability of 700 psi and have a 1 square inch by 1 inch long cylinder foot attached to a ¼-inch diameter pin as shown in Figure 6-19. The initial backfill shall be either Class I, II, III, or IV having a maximum particle size of 1½ inches. The fill can be completed in a single pour to the top of the pipe or it can be done in two or more lifts if desired. No field installations using CLSM have resulted in flotation of clay pipe. However, buoyancy calculations done using the Archimedes' Principle (that a body wholly or partly immersed in a fluid is buoyed up with a force equal to the weight of the fluid displaced by the body) indicate that the pipe should have floated. Further research to date supports the theory that clay pipe does not float because CLSM acts as a Bingham fluid. A Bingham fluid, also known as a Bingham plastic, is a viscoplastic material that resists movement at low values of shear stress in the fluid. Buoyancy forces generate shear stress in the CLSM. If the stress applied by the buoyant force does not exceed the shear yield stress of the CLSM, the pipe will not float.

Figure 6-19: *A pocket penetrometer can be used to determine CLSM strength prior to backfill*

Optimal Mix for CLSM

NCPI conducted tests to define the optimal mix for CLSM used in gravity sewer applications with vitrified clay pipe. Varying percentages of 3/8-in. coarse aggregate, accelerator and entrained air were tested. The primary goal was to determine a mix design that would yield the fastest cure time over a maximum of six hours based on penetration resistance readings using a penetrometer.

Cement: 188 pounds (type I/II or II/V)

Fine aggregate: 75% - 80% (by weight)

Coarse aggregate: 25% - 20% (by weight)

Water: Water necessary to obtain Flowability (7"- 9" spread diameter)

Accelerator: 4% (as a percent of cement)

Air entrainment: 15% - 20%

Flowability: 8-in., +/- 1 in. spread diameter (3-in. diameter by 6-in. long cylinder, per ASTM D6103)

Further evaluation may be necessary where native soils are expansive.

For more information on CLSM as a bedding material, see the Technical Papers listed below (available on our website):

- *Guidelines for Controlled Low Strength Material (CLSM) Mix Design, Placement and Testing for use as a Bedding Material for VCP*
- *Consideration for Flotation When Controlled Low Strength Material (CLSM) is Used as a Bedding Material for VCP*
- *Optimal CLSM Mix Design*
- *Consideration for the Use of Fly Ash when Controlled Low Strength Material (CLSM) is Used as a Bedding Material for VCP*

Concrete Cradle Bedding, Load Factor = 3.4

The pipe shall be bedded in a cradle of reinforced concrete having a thickness under the barrel of at least 6 inches or one-fourth of the outside diameter of the pipe (B_c), whichever is greater, and extending up the haunches to a height of at least one-half the outside diameter of the pipe. The cradle width shall be at least equal to the outside diameter of the pipe plus 4 inches on each side or 1.25 times the outside diameter of the pipe, whichever is greater. If the trench width is greater than either of these dimensions, concrete may be placed to full trench width.

The initial backfill shall be either Class I, II, III, or IV having a maximum particle size of 1½ in.

The load factor for concrete cradle bedding is 3.4 for reinforced concrete with p = 0.4%, where p is the percentage of the area of transverse steel to the area of concrete at the bottom of the pipe barrel as shown in Section A-A of Figure 6-20.

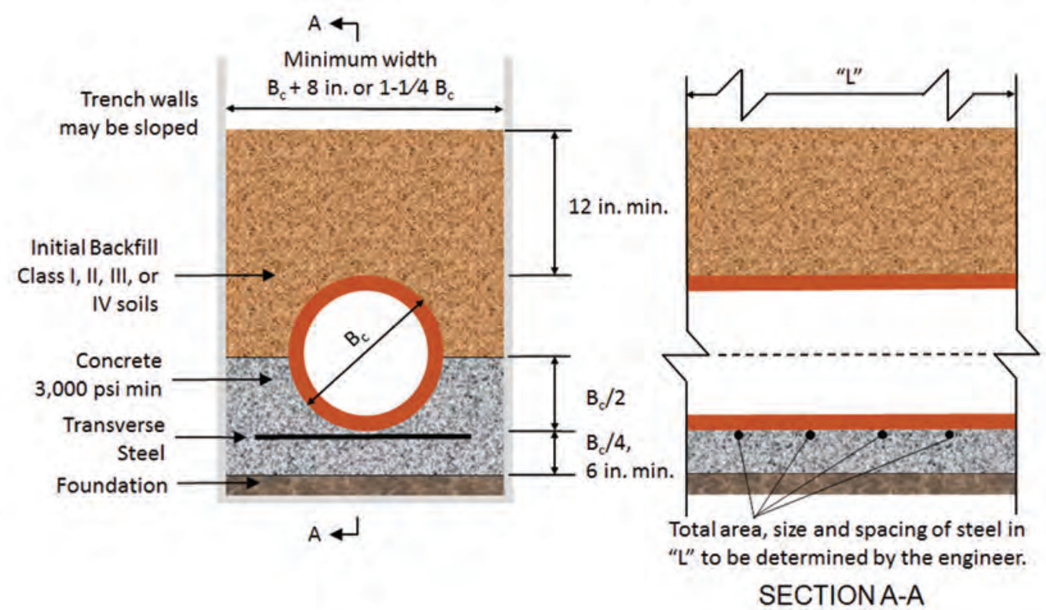


Figure 6-20: *Concrete Cradle Bedding – Load Factor = 3.4*

Full Concrete Encasement

There are specific sites where concrete encasement may be desirable. Concrete encasement shall completely surround the pipe and shall have a minimum thickness, at any point, of one-fourth of the outside diameter of the pipe or 4 inches whichever is greater.

The encasement shall be designed by the engineer to suit the specific use.

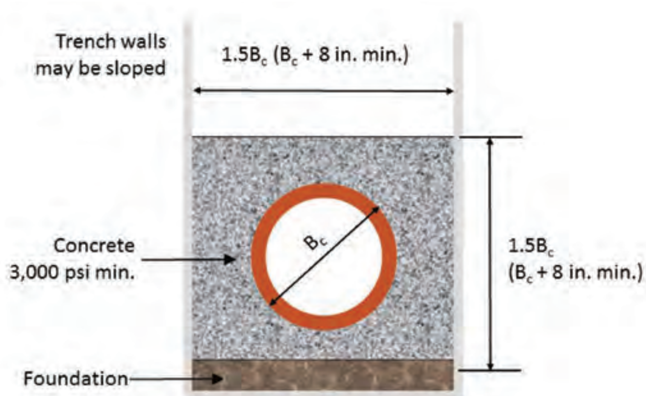


Figure 6-21: *Concrete Encasement*

Principles of Concrete Design

The use of concrete cradle or full encasement class bedding permits the pipe to support substantially higher backfill loads. A vibrator or stinger must be used when concrete is placed to ensure consolidation of the material in the pipe haunches.

Consideration must be given to the following items associated with the use of concrete bedding systems.

Figure 6-22: Special conditions may require the use of concrete encasement.

1. **Delay Backfilling the Trench**
   The trench must not be backfilled before the concrete has gained sufficient strength to support the backfill load. A minimum of two days is recommended. Although it may be impractical to delay backfilling longer than this, it is obvious that the strength of the pipe-concrete system is still in a structurally critical stage.

2. **Delay Consolidation of the Trench Backfill**
   When the trench backfill is allowed to consolidate through natural means, the maximum load on the pipe will be delayed. However, paving requirements and other considerations such as traffic flow may preclude the possibility of extended delay. In those instances the engineer and or contractor must evaluate the possible risks involved.

3. **Accelerate the Early Strength of the Concrete**
   Early strength increase is normally accomplished by increasing the cement content, adding accelerators or by the use of Type III high early strength Portland cement. The addition of fly ash or other pozzolanic material may retard early strength development and should not be used.

4. **Construction Joints**
   When using concrete as a component of a pipe bedding system, consideration should be given to the use of construction joints to maintain pipeline flexibility. For concrete cradle and full encasement installations, a construction joint is needed. These joints shall be aligned with the face of the socket (end of the pipe bell). Expanded polystyrene (EPS) foam blocks and sheets, mastic, plywood or various other means have been utilized to direct the fracture of the concrete beam (see Figure 6-23).

   Considerable success has also been achieved through the use of shaped EPS foam to support the pipe during the concrete pour.

Figure 6-23: EPS foam used to support a pipe during a concrete pour

5. Use of Steel Reinforcing

A common method of increasing the strength of the concrete is through the use of steel reinforcement. The strength increase is generally in proportion to the cross-sectional area of steel to the concrete above or below the pipe. The steel should be placed in the transverse direction to the pipe.

In concrete cradle construction, p is the percentage of the area of transverse steel to the area of concrete at the bottom of the pipe barrel as shown on Figure 6-20 on page 6-15.

Welded steel wire fabric is recommended for use in bedding design because of its uniformity and relative ease of installation.

6. Transition Joints

Where construction of the line changes from concrete bedding to another bedding class, steel casing or other rigid structure, it is necessary to provide flexibility at the transition to allow for potential differential settlement. Changes of bedding and other transitions should always terminate at the face of the bell.

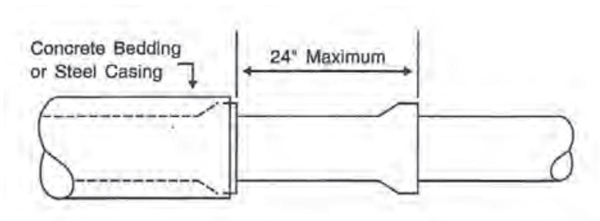


Figure 6-24: *Field Transition Joints*

Design Safety Factor

The design safety factor is a discretionary decision for the Professional Engineer during design based on the number and magnitude of unknown variables. The greater effect these unknown variables may have, the greater the need for a large safety factor. Hence, the safety factor is intended to insure a successful project, without adding unnecessary costs.

During trench design for Vitrified Clay Pipe, a safety factor having a value between 1.0 and 1.5 is typically specified. This may be accomplished by using the appropriate bedding class.

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* per ASTM C700	CLASS D	CLASS C	CLASS B	CRUSHED STONE ENCASEMENT	CONTROLLED LOW STRENGTH MATERIAL	CONCRETE CRADLE p = 0.4%**	FULL CONCRETE ENCASEMENT
								
NOMINAL SIZE	**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	13090	
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

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

Example 6-2: Bedding Design Using the Trench Load Tables and the NCPI Toolbox

A 24-inch clay pipe line is to be installed in an area of CH (Fat clay) which has a weight of 107 pounds per cubic foot and a Kμ' = 0.110 (see Soil Classification Chart on page 4-7). The depth of cover over the top of the pipe is 18 feet and the trench width at the top of the pipe is 48 inches. Determine a structurally sound and economic bedding design.

The trench load can be determined by using the Trench Load Tables as shown below:

Pipe size:	24 in.
Depth of cover:	18 ft.
Backfill – CH:	(*Kμ'* = 0.110) @ 107 lbs/ft^3
Trench width:	48 in.
From Trench Load Table pg 5-9:	4,570 x 107/100
Total Trench Load:	4,890 lbs/ LF

The trench load and factor of safety per bedding class can also be determined using the NCPI Toolbox, Trench Load program available on the NCPI website. ASTM C700, Greenbook Extra Strength or Greenbook High Strength standards can be selected. The results page for the same project is shown below:

Pipe Size:	24 in.
Pipe Standard:	ASTM C700 ES (4400 lbs/LF)
Soil Weight:	107 lbs/ ft^3
***Kμ'* Used:**	0.11
Trench Width:	48 in.
Trench Depth:	18 ft. over top of pipe
Max Load:	4,890 lbs/ LF

	Load Factor	Safety Factor	Safety Factor @ Transition
Class D	1.1	0.99	0.66
Class C	1.5	1.35	0.90
Class B	1.9	1.71	1.14
CR Stone	2.2	1.98	1.33
Concrete Cradle	3.4	3.06	2.05
CLSM	2.8	2.52	1.69

When using the trench load tables to determine the load on the pipe, the next step is to calculate the field supporting strength and safety factor per bedding class.

Example 6-2 (Continued): Bedding Design Using the Trench Load Tables and the NCPI Toolbox

ASTM 3-edge bearing strength, 24-inch Extra Strength pipe = 4,400 lbs/ LF

Class D Bedding

Load Factor for Class "D" bedding = 1.1

Field Supporting Strength = (4,400 x 1.1) = 4,840

Safety factor (4,840/4,890) = **0.99**

Class B Bedding

Load Factor for Class "B" bedding = 1.9

Field supporting strength = (4,400 x 1.9) = 8,360

Safety factor (8,360/4,890) = **1.71**

Class C Bedding

Load Factor for Class "C" bedding = 1.5

Field supporting strength = (4,400 x 1.5) = 6,600

Safety factor (6,600/4,890) = **1.35**

Evaluation:

1. Class D bedding should not be selected because it does not provide an adequate factor of safety.
2. Class B bedding provides a sufficient safety factor but is not cost effective.
3. Class C bedding should be selected because it meets the criteria for safety factor and cost effectiveness.

CHAPTER 7: OPEN TRENCH CONSTRUCTION

Figure 7-1: Open trench construction utilizing a modified vee trench.

Excavation

Generally, the contractor will select the method of excavation provided it results in an installation which complies with the project plans, specifications and applicable safety requirements. Any method not in accordance with normally accepted practice must receive prior approval of the engineer.

NCPI offers *Tips for Installing Vitrified Clay Pipe* to ensure contractor success and compliance with best installation practices.

The trench width at the top of the pipe is an important factor affecting structural loading on installed pipe. Any increase in width over the design trench width shown in the specifications or on the plans will increase the backfill load. Should the trench width exceed the specified dimensions, and provision for this condition is not covered in the specifications and plans, the revised method of construction must be reviewed and approved by the engineer.

The trench is generally excavated in the upstream direction. Any variation in this procedure should be at the direction of the engineer. It is important that the line and grade shown on the plans be followed.

Rock Excavation

In rock excavation, the pipe should be bedded with Class I or II material at a minimum depth under the pipe barrel of 6 inches or $B_C/5$ (Pipe outside diameter/ 5), whichever is greater.

Trench Walls

Where ground conditions are such that trench walls may not remain vertical, the contractor may elect to use sloping side walls or to use shoring, sheeting or trench boxes to support the trench wall.

In all cases, the critical dimension is the trench width measured at the top of the pipe (B_d).

Use of Shoring, Sheeting and Trench Box

It may not always be necessary to use shoring, sheeting or trench boxes. The primary concern is for safety and all applicable regulations should be strictly observed. Shoring and sheeting also retains trench width integrity and reduces the risk of cave-in.

Timber sheeting placed in the pipe zone shall be left in place or cut off not lower than the top of the pipe. Pulling timber sheeting creates voids at the sides of the pipe that reduce the side support provided by the soil. Thin steel sheeting may be pulled provided no voids are created and the pipe bedding is not disturbed.

Figure 7-2: *Trench sheeting and spreader bars*

Steel trench boxes are used for trench construction and safety. If possible, the trench box should ride above the top of the pipe, on the bottom of a wider step trench. Narrow backhoe buckets are available to maintain design trench width up to the top of the pipe. In this case, dragging the trench box forward does not interfere with pipe bedding and cannot pull the pipe joints apart.

If the trench box rides below the top of the pipe, care must be taken to protect the integrity of the pipe bedding, particularly when movement of the trench box leaves a void in the pipe bedding. Care must also be taken to ensure that movement of the trench box does not pull the pipe joints apart. A suggested method would be to secure the pipe with a wood cross block, cable and winch at a downstream manhole.

Examples of sheeting, shoring and trench boxes are shown in Figures 7-2, 7-3, and 7-4.

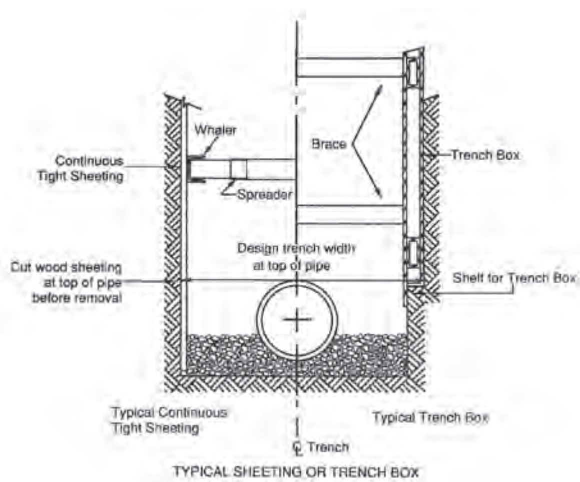


Figure 7-3: *Sheeting or Trench Box*

Foundation Preparation

Trench load design for all pipe is based upon a firm and unyielding foundation. It is essential that the trench bottom remain stable during backfilling, compaction and under all subsequent trench operations.

The foundation is critical to the performance of the entire pipe installation. The foundation must be firm and unyielding as it needs to support the bedding, pipe and backfill as shown in Figure 6-5 on page 6-4.

In cases where the trench bottom is soft and unsuitable to support the pipe, bedding and backfill; removal of material is necessary. Replacement can be accomplished with crushed rock or a woven geotextile fabric or both, to stabilize the foundation. Consult a Geotechnical engineer for other design methods to ensure the foundation can support the load.

Figure 7-4: *Trench Box within the pipe zone*

For trench bottoms above the water table, a general rule-of-thumb is that the foundation is firm and unyielding if a person can walk on the foundation without sinking into the soil or feeling it move underfoot. For trench bottoms below the water table, a Standard Penetration Test should be conducted in accordance with ASTM D1586 *Standard Test Method for Standard Penetration Test (SPT) and Split-Barrel Sampling of Soils* before construction. An "N" value of 10 or higher is used to consider the foundation firm (for details on SPT, see *Pipeline Installation 2.0*, Howard 2015).

When unstable or rocky trench bottoms are encountered, it will be necessary to over excavate and restore the trench bottom to a firm and unyielding foundation with selected materials capable of properly supporting the pipe. Select native materials, crushed stone, gravel, slag, coral or other granular materials are commonly used for this purpose. The amount of granular material necessary to stabilize the trench bottom will vary according to the field conditions encountered. See additional information on page 6-4.

Figure 7-5: *Constructing a bell hole during pipe laying*

Pipe Installation

Care should be taken in storage, handling and installation to avoid damage to the pipe and joint surface. Consult your pipe manufacturer for further information.

A visual inspection of the pipe just prior to installation should be performed by the installer.

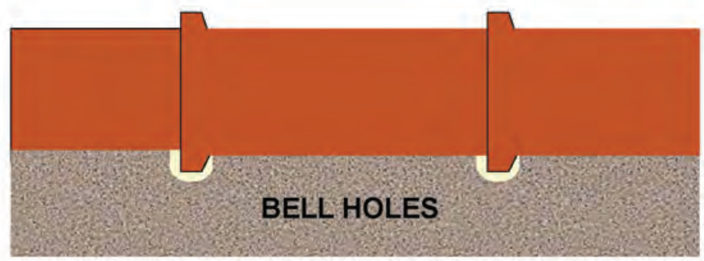


Figure 7-6: Bell hole illustration; the pipe barrel supports the trench load

Pipe are generally installed with the bells pointing upgrade. The pipe barrel must rest firmly and evenly on the trench bottom or bedding material to support the trench load. Bell or coupling holes must be dug to ensure the pipe barrel and not the bells nor couplings support the trench load as shown in Figures 7-5 and 7-6. See *Bell or Coupling Holes* section starting on page 6-7 for further information. If a trench box is used and within the limits of the pipe zone, re-excavation of the bell hole may be necessary on the last pipe laid if filled with bedding material during box advancement. The pipe shall be installed to the design line and grade. The pipe is then installed using a laser or gradeliner.

For additional information on installation and techniques, refer to ASTM C12 *Standard Practice for Installing Vitrified Clay Pipe Lines* and the *NCPI Installation & Inspection Handbook*.

Pipe Joining

Compression joints should be assembled in strict accordance with the manufacturer's recommendations.

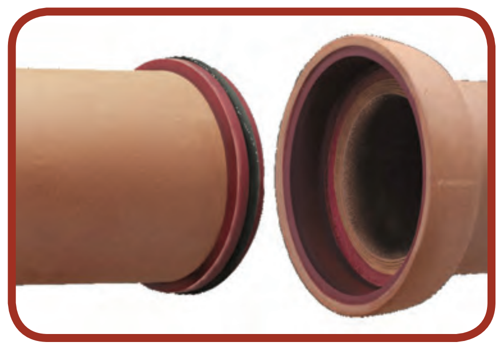


Figure 7-7: VCP flexible compression joint

Particular care should be taken to keep foreign materials from interfering with proper joint assembly. The mating surfaces of the joint should be wiped clean and lubricated prior to assembly following the manufacturer's recommendations.

All compression joints are manufactured in accordance with ASTM C425 *Compression Joints for Vitrified Clay Pipe and Fittings*.

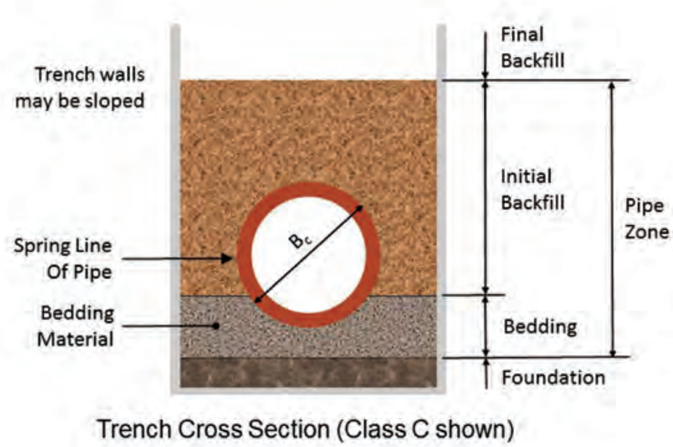


Figure 7-8: Trench Cross Section

Pipe Bedding

The bedding or backfill materials shall be sliced into the haunch areas of the pipe with a shovel or other hand tool to fill the voids in this area. (See haunch support discussion on pages 6-6 to 6-9.)

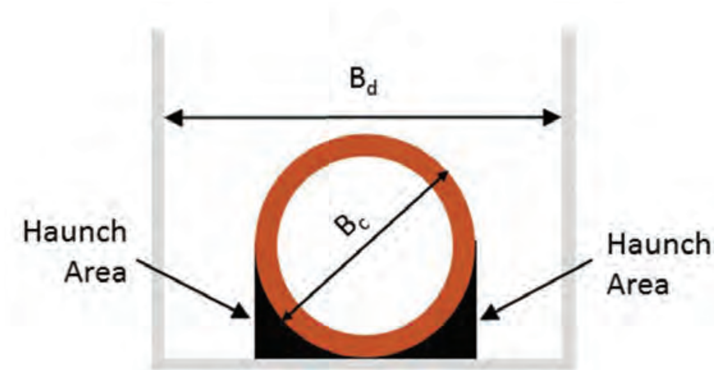


Figure 7-9: *TERMINOLOGY*
B_c = the outside diameter of the pipe.
B_d = the design trench width measured at the horizontal plane at the top of the pipe barrel.

Initial Backfill

Initial backfilling takes place after the pipe has been installed according to the engineering specifications.

The initial backfill extends from top of the bedding material, up the sides of the pipe, to a level 12 inches over the top of the pipe. The initial backfill should be carefully placed as soon as possible to protect the sewer line.

Final Backfill

The final backfill extends from the initial backfill to the top of the trench. Final backfill shall be placed in lifts or stages not to exceed 10 feet when using water consolidation or as required by designated methods of mechanical compaction. Final backfill shall have no rock or stones having a dimension larger than 6 inches within 2 feet of the top of the initial backfill. Selected backfill material may be required for the top foot or more as specified by the engineer.

Figure 7-10: *Shovel slicing the pipe haunches*

Compaction

Compaction of the backfill material is usually required to prevent settlement of the ground surface or to support paving or structures. In areas where support of the pavement over a trench is required, compaction of part or all of the backfill material may be specified. When it is necessary to achieve a high degree of compaction, it may be advisable for the design engineer or contractor to consult a geotechnical engineer.

Trench backfill specifications generally require mechanical compaction in layers, referred to as lifts, but may allow compaction using water. Most soil materials may be compacted by mechanical means in lifts. However, it is necessary to determine if the field moisture content is in the optimum moisture range in order to obtain the desired compaction with normal compactive effort.

Cohesive soils (Class III or IV) are best compacted using pressure, impact, or kneading. Cohesionless soils (Class I or II) are best compacted using vibration. Water settling methods such as flooding, ponding, jetting, or puddling may reduce the soil volume but do not result in very high densities. Amster Howard, in the book *Pipeline Installation 2.0*, describes the various methods of compaction, appropriate equipment, and testing procedures applicable for different types of soils. See www.pipeline-installation.com for more information.

Figure 7-11: *Hoe mounted sheepsfoot roller compacting final backfill*

To achieve the specified compaction with the lowest risk and cost, the correct selection of compaction equipment and methods are necessary. Depending upon the soil type and compaction requirements, wide choices of compaction equipment are available.

Extreme care should be taken when using heavy mechanical compaction equipment. There should be a minimum of 5 feet of cover over the top of the pipe before any heavy mechanical compaction equipment is employed. This will tend to reduce dangerous impact loads on the pipeline. Walk behind and hand held light compaction equipment within the trench can be used at cover depths less than 5 feet.

The selection and use of suitable compaction equipment must be made with care so that the pipe will not be disturbed or damaged. A pavement breaking type of falling weight "stomper" or drop hammer, should never be used for compacting, even with a substantial cover over the pipe. These impact devices can damage the pipe and/or force it out of alignment.

The foundation must remain firm and unyielding during all backfill and compactive efforts. Testing should be performed at the beginning of every project to ensure the compactive method utilized does not damage the pipeline.

Dewatering

Water must be removed from the trench prior to establishment of a firm and unyielding foundation. The trench must be kept dry during all phases of pipe installation.

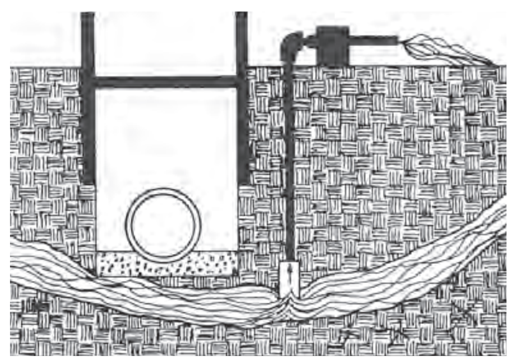


Figure 7-12: *Lowering the ground water table with well points*

- The ground water table can be lowered with well points wherever soil conditions permit. They must be located at intervals dictated by soil properties and placed reasonably close to the trench walls. They should be sunk to a depth below the elevation of the trench bottom (see Figure 7-12).
- In some cases the trench dewatering system may consist of a geotextile in addition to open graded crushed rock. Fine sands in a fluctuating water table environment are vulnerable to foundation problems and may require a geotextile encapsulation of the drain.

Geotextile

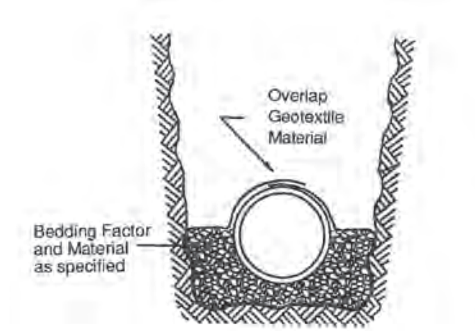


Figure 7-13: Controlling migration of bedding material with Geotextile.

Crushed rock or other coarse aggregate is recommended and used as a bedding material to improve the load bearing capacity of pipe. Thicker layers of these materials have been employed to stabilize the base of the trench. Loss of pipe support can occur when open-graded materials are used on sites with fine grained material (as described in ASTM D2487) at the base of the trench and with a water table which can fluctuate rapidly in the pipe zone. This is believed to be caused by water moving rapidly through the fines to the coarse material and carrying the fine-grained soils with it. To prevent movement of the fine grained soils into the voids of the open-graded bedding material, the material should be encapsulated in a geotextile material. Overlaps should be provided and care must be taken to prevent entry into the crushed rock or aggregate base.

CLSM bedding material is another option when fine grained soil conditions exist with a fluctuating water table. Using CLSM bedding would eliminate the threat of these materials migrating and therefore, a geotextile would not be needed.

Service Connections

In main line and lateral sewer construction, it is important to assure proper embedment, backfill and compaction of the construction materials which support and surround all Wye's or Tee's used for service connections. Some cities use Tee's instead of Wye's since there is an insignificant difference in turbulence of flow between Wye and Tee connections to small and intermediate diameter main line sewers.

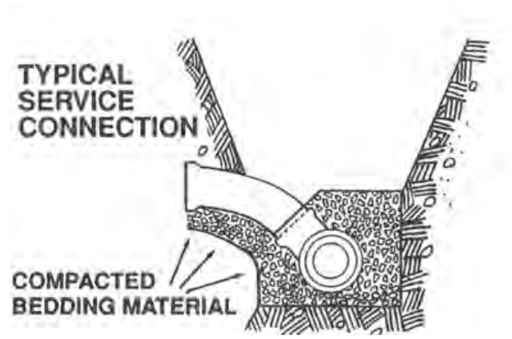


Figure 7-14: Typical Service Connection

Field Verification

After installation, backfill and compaction, the sewer shall be tested for integrity by a method specified or approved by the engineer; see Chapter 11 for applicable methods. It is recommended that testing be performed when the first manhole-to-manhole pipeline is installed, backfilled, and compacted prior to paving and periodically as the installation progresses. This will ensure both the trench design and installation methods are appropriate for the field conditions.

Figure 7-15: Pulling a trench box within the limits of the pipe zone.

CHAPTER 8: VITRIFIED CLAY JACKING PIPE & TRENCHLESS INSTALLATION METHODS

Figure 8-1: *Vitrified Clay Jacking Pipe has a low profile jointing system suited for trenchless applications*

Vitrified Clay Jacking Pipe

Figure 8-2: *Diamond ground pipe end for an elastomeric gasket and stainless steel collar resulting in a low-profile compression joint.*

Vitrified Clay Jacking Pipe has been the predominant pipe material used in the Pilot Tube Guided Boring Method (PTGBM) due to its high compressive strength, low-profile zero-leakage joint, availability in the typical 1 or 2 meter pipe lengths and elimination of an external casing pipe. With the guided accuracy of this system there is no need for a larger diameter steel casing and the grade-adjusted inner carrier pipe as is required by a non-guided boring technique. This saves the additional cost of excavation, transportation, removal of spoil and the purchase of two separate conduits, thus resulting in a lower overall project cost.

High Compressive Strength

Vitrified clay jacking pipe has an extremely high compressive strength (18,000 psi average), a feature needed to resist the high jacking forces generated as the pipe is pushed through the ground.

In smaller diameter pipe, the wall thickness of standard production pipe used for open trench construction is increased to provide a cross-sectional area on the pipe ends suitable for jacking. Standard intermediate and large diameter pipe provide sufficient cross-sectional area to handle the jacking force even after machining for the low-profile joint.

Abrasion Resistance

Anyone who has had to cut fired clay pipe knows it is difficult to do because of its rock-like characteristic. This quality is important in a pipe jacking application. In pipe bursting applications, sharp fragments of the existing host pipe do not cut or gouge clay jacking pipe during replacement. No jacking pipe has better abrasion resistance than clay pipe. This inherently natural quality of clay pipe is a great advantage over products that depend upon some form of exterior coating for corrosion protection. See Chapter 3 for further information on the abrasion resistant qualities of VCP.

Dimensional Accuracy

In a microtunneling application, the ends of the pipe are required to uniformly distribute the axial jacking load. It is common practice to use a ring of chip or particle board between the ends of the pipe to prevent pipe-to-pipe contact and to help distribute the load. Although beneficial, the rings could not do the job alone. It was necessary to make the ends of the pipe both square and parallel. The solution to this problem is simultaneous diamond cutting of the ends of the fired pipe using a lathe (see Figure 8-3).

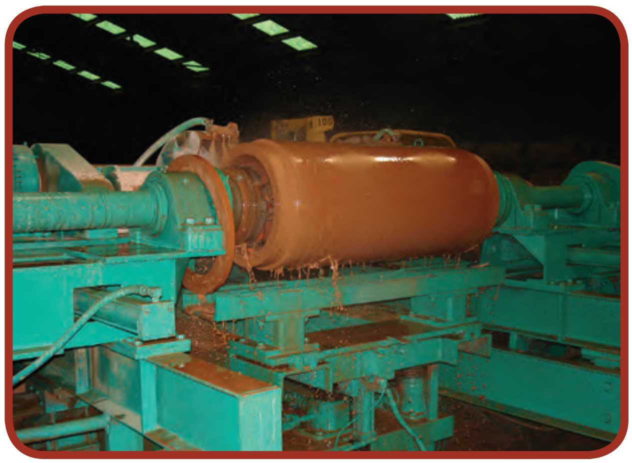


Figure 8-3: *Machining of Jacking Pipe on Lathe.*

With the ends of the pipe cut to machine shop tolerances, the jacking force can be uniformly transmitted from the jacking frame located in the launch pit through each succeeding pipe all the way to the receiving pit. In practice, the operator makes minor corrections to the cutting head as it is steered through the ground. This further emphasizes the benefit of high compressive strength.

Corrosion Resistance

A successful jacking pipe should have exceptional corrosion resistance. Trenchless methods are being selected over open cut installations in inaccessible and high traffic areas, for extreme depths or poor soil conditions. No designer or agency will want to go to the expense of installing a tunneling project only to have the pipe corrode either due to a hostile effluent or aggressive soils. Clay pipe stands alone in this respect. It does not require a coating, liner or wrap because its chemical resistance is inherent in the pipe itself. See Chapter 3 for more information on the corrosion resistant properties of VCP.

Tight Low-Profile Compression Joints

A requirement of a good jacking pipe is a strong, reliable jointing system. The joint must have a straight profile on the outside. Any projection beyond the barrel is unacceptable because of the resistance it would generate as it proceeded through the ground. A good joint for a trenchless installation requires a compression member and a collar of high quality stainless steel material.

Fortunately for the US industry, nondomestic members of the National Clay Pipe Institute in England and Australia had already ventured into pipe jacking and completed considerable early evaluation. The Japanese and German clay pipe industries had also made significant contributions in this regard.

Figure 8-4: *Jacking pipe utilize a series 316 stainless steel collar at each compression joint.*

Building on this background, the US industry turned again to diamond grinding to form a precision rebated surface on both ends. A slim profile rubber gasket and a stainless steel collar were developed to complete the jointing system (see Figures 8-2, 8-3, 8-4, 8-5 and 8-6).

Jacking Pipe Summary

Clay pipe has the high compressive strength to resist the considerable jacking force and possesses the needed abrasion resistance to prevent external damage as the pipe is pushed through the surrounding ground. Additionally, clay pipe has the chemical resistance for longevity and tight joints to prevent leakage. Special low-profile joints are designed to facilitate jacking.
ASTM C1208/C1208M *Vitrified Clay Pipe and Joints for Use in Microtunneling, Sliplining, Pipe Bursting and Tunnels*, is the first ASTM standard specification explicitly developed for vitrified clay jacking.

Figure 8-5: *Jacking pipes staged at the launch pit on a pilot tube project utilizing a powered cutter head.*

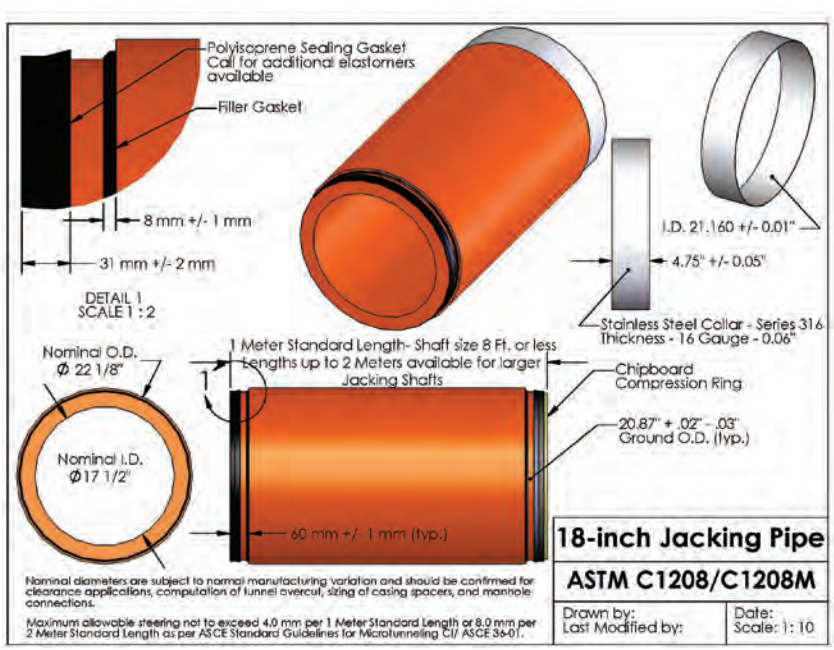


Figure 8-6: *Example Jacking Pipe shop drawing for 18-inch pipe.*

Trenchless Installation

What follows is a brief discussion of the methods of trenchless installation using vitrified clay jacking pipe. For a complete reference manual, the ASCE (American Society of Civil Engineers) offers Manual of Practice 133 (Pilot Tube and Other Guided Boring Methods). MOP 133 provides detailed descriptions of the pilot tube and guided boring methods by providing chapters on project planning, site and geotechnical assessment, shaft design, pipe characteristics and design, contract documents and construction aspects.

Pilot Tube Guided Boring Method (PTGBM)

First introduced to North America in 1995, the Pilot Tube Guided Boring Method (PTGBM) has been steadily increasing in popularity. Over the years, this installation process has also been called Pilot Tube Microtunneling (PTMT), Guided Boring Method (GBM) and Guided Auger Boring (GAB).

In accordance with the ASCE manual of practice, NCPI has elected to use the term PTGBM. The pilot tube method of installing sewer pipe is essentially a hybrid of three trenchless boring techniques:

1. Slant faced steering head similar to that of a directional drill,
2. Guided accuracy of a conventional microtunnel machine,
3. Auger type spoil removal system similar to a horizontal bore.

A few reasons for the popularity of PTGBM include:

- low equipment costs
- relatively small topside footprint
- pinpoint accuracy
- small jacking pits

Figure 8-7: *8 Ft. round jacking shaft and pilot tube frame.*

The initial capabilities of the technology were in the range of 4- to 12-in. OD pipes with single drive lengths up to 250 ft. The technology has grown. Today pipes up to 48-in. OD are installed with drive lengths in the 400 ft. range. Pilot Tube installations as long as 580 ft. in a single drive have now been completed. Accuracy in line and grade of ¼ inch is possible. Better optical guidance systems and power hydraulics in the jacking frames have made these larger diameters and longer drive lengths possible. The technology can perform in a variety of displaceable soils conditions though cobbles and boulders pose some difficulties.

Today, this technology has evolved to include mainline installations with pipe diameters up to 48 inches OD. The primary reason for this growth is the achievement of the same accurate on-line and on-grade installation as conventional microtunneling, but with significantly reduced costs. Projects are often less costly than conventional open-cut methods and solve engineering problems such as utility obstacles, poor soils, deep installations and high ground water. Costly lift stations and maintenance costs associated with them are also often eliminated from projects.

The societal advantages to this trenchless method include the elimination of traffic delays, road closures and street repairs as well as increased safety and reduced need for disposal of contaminated soils.

Guided boring methods have been used successfully in weak soils where other methods such as open-cut and auger boring failed. Consultants and owners are quite impressed and pleased with the pinpoint accurate rifle-barrel-straight installations that result from this installation method.

The reliable line and grade accuracy associated with pilot tube make it possible to place pipelines in close tolerances to existing utilities. The pilot rods installed in the first step have the capability to discover unknown underground obstacles prior to full commitment of the bore, eliminating an unplanned retrieval shaft, which would be required in most other trenchless methods. Also, a survey can be performed on the pilot tube at the reception shaft to verify the intended line and grade.

If an alignment/grade error is discovered or an obstacle is encountered during the installation, the pilot tubes can be retracted and reinstalled before proceeding to the second step of the installation.

PTGBM Installation Process

First Step

The first step in all the pilot tube installation methods is the precise installation of the pilot tube on line and grade (see Figure 8-8). The hollow stem of the pilot tube provides an optical path for the theodolite to display the head position and steering orientation. This step establishes the center line of the new installation as the remaining step(s) will follow this path of the pilot tube.

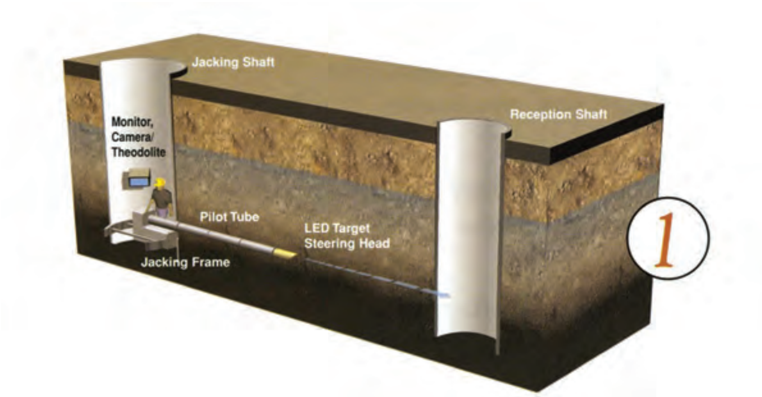


Figure 8-8: *Step 1 – Installation of pilot rods*

Once step 1 is complete, the theodolite and monitor guidance system may be removed from the jacking pit as they are no longer required.

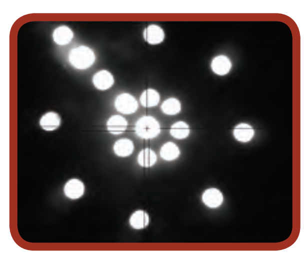


Figure 8-9: *Pilot tube monitor screen*

Guidance System: PTGBM adopts the use of an LED target, digital theodolite, monitor screen and a "real time" camera based accurate guidance system (see Figures 8-9, 8-10, and 8-11). The video camera, mounted above the theodolite, transmits the image of the battery powered LED illuminated target located in the steering head to the monitor screen visible to the operator. The straight line indicated on the

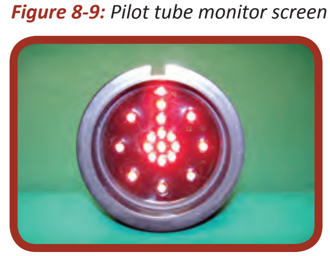


Figure 8-10: *LED illuminated target*

center of the target designates the direction and path the slant faced steering head will follow.

Hollow steel pilot tubes which fasten to each other via a threaded hex connection are available as a double or single wall tube depending on the manufacturer. On some double walled tube systems, the inner tube will rotate with the steering head during advancement for torque reduction. On other double walled systems, a bentonite lubricant may be pumped through the annular cavity between the tubes to the steering head to assist with soil friction. These pilot tubes range in length from 30 inches to 2 meters dependent on the size of the jacking frame and shaft diameter.

Figure 8-11: *Theodolite with camera*

A slant faced steering head similar to that of a directional drill houses the LED illuminated target. Steering heads of different degrees of angle are available for various types of ground conditions. During the installation process the ground is displaced by the steering head / pilot tube and directed on line and grade by rotation during advancement. At this point of the installation step 1 is complete. A survey can be performed on the pilot tube at the reception shaft to verify line and grade accuracy of the initial survey and setup. If a survey or setup error is found, the pilot tubes can be retracted and reinstalled before proceeding to the second step of the installation.

Second Step

The second step (in the 3 pass and 3 pass modified methods) is to follow the path of the pilot tube with a reaming head, which is sized to the outside diameter of the final product pipe being installed (see Figure 8-12). The front of the reaming head fastens to the last pilot tube installed in the same manner in which the pilot tubes fasten to each other. Behind the reaming head follow auger casings of the same diameter as the head transporting the spoil to the jacking shaft for removal. The spoil can be removed by a muck bucket or vacuum truck depending on the soil type. This step is complete when the reamer and auger casings reach the reception shaft and all spoil is removed.

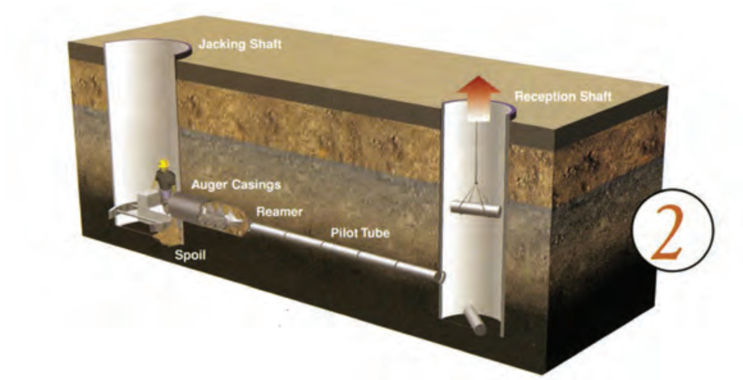


Figure 8-12: *Step 2 – Installation of auger casings*

The second step (the final step in the 2 pass method) is to follow the path of the pilot tube with the 2 pass reaming head advanced by the final product pipe. This reaming head funnels the excavated material into auger casings coupled together inside the product pipe and conveyed through to the jacking shaft for removal. These auger casings are then retracted from the inside of the carrier pipe via the jacking shaft. This method has an advantage to contractors as they are able to install multiple sizes of sewer lines while utilizing the same set of auger casings. The disadvantage to this 2 pass system is the decreased diameter auger casings will limit the maximum diameter of excavatable cobbles and hardened material. When the 2 pass method is utilized, the pipes are set into the jacking frame with the auger casings inside. The auger casings are attached to the reamer (if it is the first pipe to be installed) or previous casing for spoil transport. The product pipe is sized equal in diameter to the reamer and carries the axial load required for advancement.

Different types of reaming heads are available for a variety of displaceable soil conditions as well as heads capable to control flow when working with as much as 10 to possibly 15 feet below the water table (ultimately depending on the soil type). A swivel is required connecting the pilot tube to the reaming head when a rotating cutter head is used for harder ground.

Third Step

The third step (final step in the 3 pass method) is to replace the auger casings with the final product pipe (see Figure 8-13). The reaming head and auger casings are advanced into the reception shaft and removed as the product pipes are installed. There is no spoil to be removed in this step as the product pipe has the same outside diameter as the auger casings.

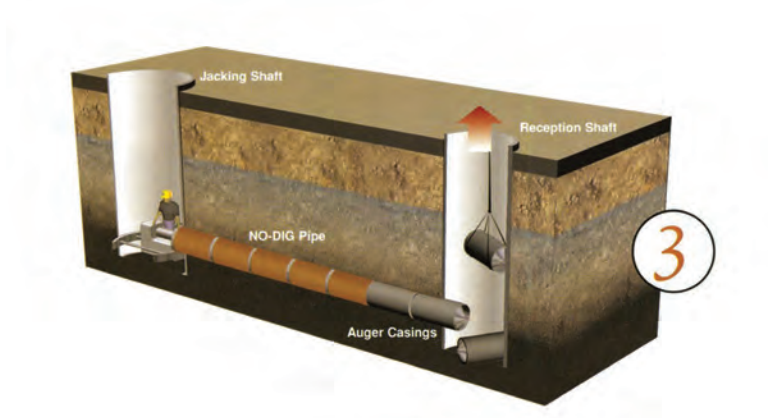


Figure 8-13: *Step 3 – Pipe installation*

The third step (final step in the 3 pass modified method) is to install a powered cutter or reaming head (see Figure 8-14) behind the auger casings, which is advanced by the product pipe. This method is the newest innovation to the Pilot Tube Methods. These hydraulically driven heads increase the bore to match the larger product pipe diameter. The excavated spoil around the previously installed auger casings is discharged via the reception shaft by reversing the auger direction. This step is complete when the powered cutter head reaches the reception shaft.

Figure 8-14: *Powered Cutter Head (PCH)   Photo courtesy of Akkerman, Inc.*

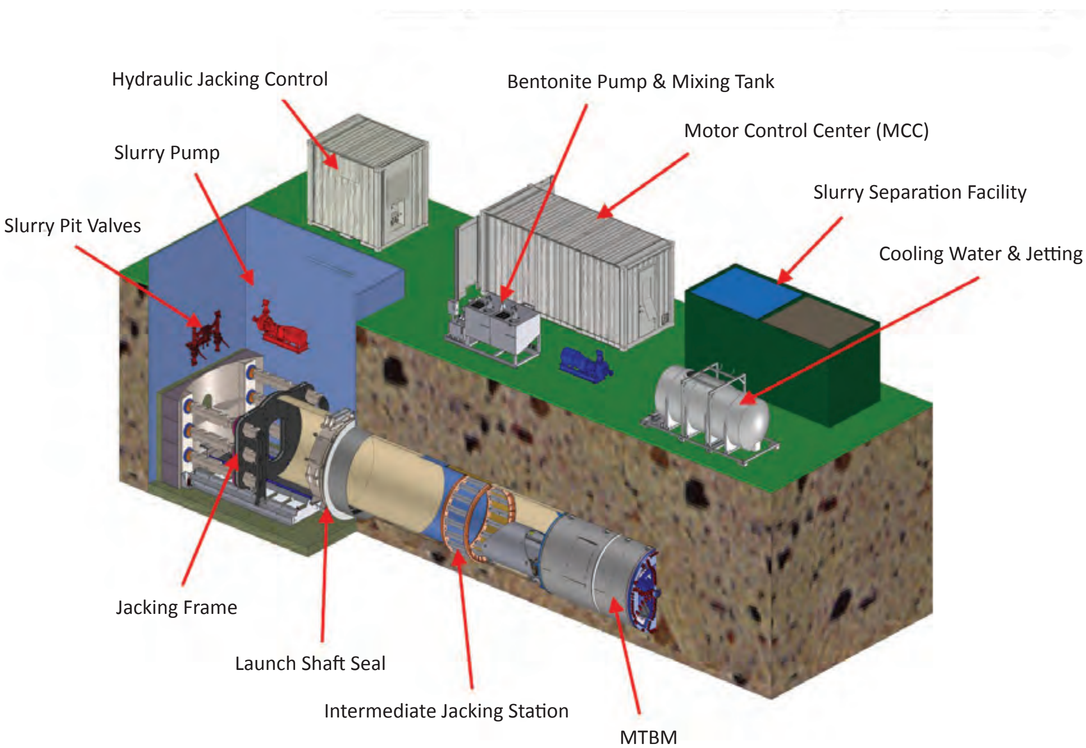


Figure 8-15: *Slurry Microtunnel Set-up*

Slurry Microtunneling

Microtunneling is a method of installing sewer pipe without the need of excavating trenches. A launch shaft is excavated at the location of a future manhole. A thrust wall is installed to resist the jacking force. A microtunnel boring machine (MTBM) is jacked into the ground at the proper horizontal and vertical alignment. Once the MTBM is in place, clay jacking pipe is used to advance the tunneling equipment through the ground. The excavated soil is conveyed back through the pipe in liquid form via slurry tubes and removed at the launch shaft. An equipment operator maintains close control of the line and grade through the articulated action of the cutting head and laser guided steering system. The operation continues until the MTBM and pipe emerge into a receiving shaft, which is normally the location of a future manhole.

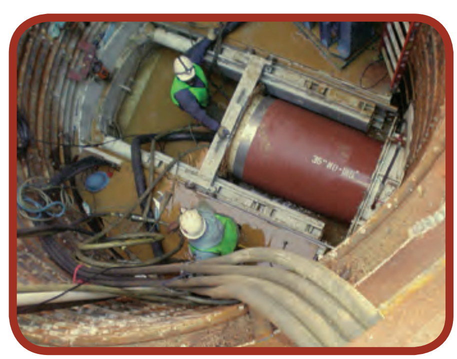


Figure 8-16: *Slurry Microtunnel Jacking Shaft*

Municipalities, engineers and contractors use slurry microtunneling for the installation of sewers in congested and confined areas, deep trenches, unstable soils and in those places where conventional excavation would be economically prohibitive, socially disruptive or unsafe.

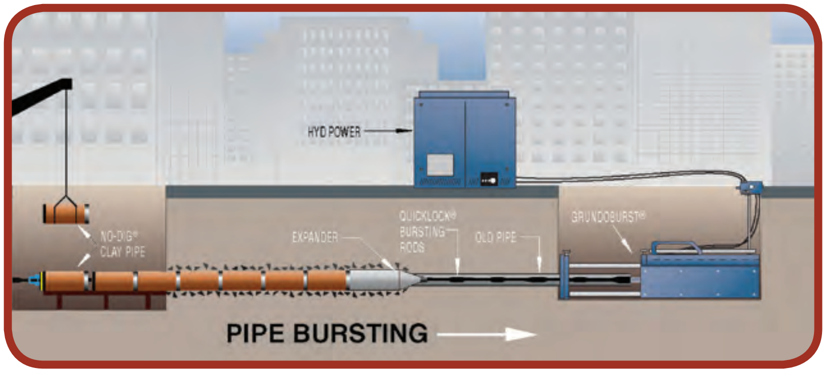


Figure 8-17: *Static Pipe Bursting process of pulling in Jacking Pipe*

Static Pipe Bursting

This method uses an expander, which can be either pulled or pushed through an existing pipeline. The existing pipe is fractured and displaced and the broken pieces are expanded into the surrounding soil while a pipe of the same diameter or larger is pulled or pushed into place. This technology offers the benefit of increasing hydraulic capacity without disrupting busy metropolitan areas.

Figure 8-18: *Launch pit showing cylinder pack, bursting rods, pipe sections, and expander.*

Over the last several years VCP has become more popular as the replacement pipe on static pipe bursting projects. Because the pipe sections have compression fit joints and are designed to be ‘jacked’ during installation, a bursting system was designed to push each pipe joint “home” as well as keep the column of assembled pipe sections in compression during bursting. A ride along hydrostatic machine (cylinder pack) attached to bursting rods inside the new pipe sections keep the column of assembled pipe segments in compression as the bursting progresses. As the bursting head is pulled forward splitting the existing pipeline and expanding the fragments into the surrounding backfill, the rear cylinder pack pressure plate keeps the assembled pipe sections in compression. Damage to the external wall is eliminated when using a replacement pipe material with a high resistance to abrasion.

The pipe bursting method keeps the jobsite footprint as well as shaft sizes relatively small and compact. Utilizing any segmented jacking pipe eliminates the need for a long lay-down area on the project site as would be required with welded or fused pipe. This is highly beneficial in high-traffic urban settings where long strings of joined pipe can be problematic. Inhibited traffic flow, blocked driveway access and local business disruption before and during the bursting operation can be minimized using this method.

CHAPTER 9: CONSTRUCTION OF SPECIAL STRUCTURES

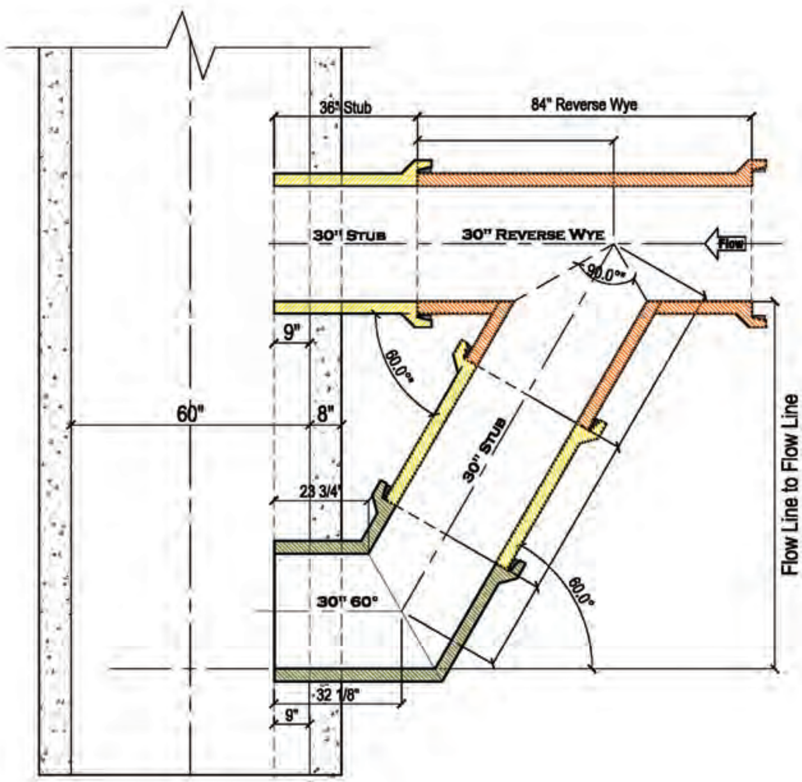


Figure 9-1: Drop Manhole Detail using a 30-inch VCP reverse wye fitting

Special Structures

Special structures and appurtenances are essential to the proper function of any complete system of sanitary sewers. These may include manholes, drop manholes, terminal cleanouts, service connections, inverted siphons, and other structures or devices of special design.

Many states have established criteria through their regulatory agencies governing safety, design and construction of appurtenances to sanitary sewer systems. In addition, each private and public engineering office usually has its own design standards, which have developed during years of experience. Therefore, many variations will be found in the design of these structures. The following discussion is limited to a general description of each of the various appurtenances, with special emphasis upon the features considered essential to good design.

Figure 9-2: Triple barrel VCP constructed under existing 72-inch conduit into a junction chamber

Manholes

Manholes are among the most common appurtenances found in a sewer system. Their principal purpose is to permit the inspection and cleaning of the sewers.

Most manholes are circular in shape, with the inside dimension sufficient to perform inspecting and cleaning operations without difficulty. A minimum inside diameter of 4 feet for circular manholes has been widely adopted for sanitary sewers.

Sewer manholes are usually constructed directly over the centerline of the sewer. Manholes should be located at pipe intersections, changes in directions, and not be more than 300 to 500 feet apart on long straight runs. The manhole may be constructed tangent to the side of the sewer for better accessibility. Consideration must be given to the need for introduction of cleaning and test equipment into the sewer.

The opening into the manhole must provide accessibility to the interior without difficulty. A minimum clear opening of 24 inches is recommended. The opening may be centered over the manhole, or constructed off-center in such a way as to provide a vertical side for the entire depth.

The flow should be carried in smoothly constructed U-shaped channels, which may be formed integrally with the concrete base. The height of the channel should be adequate to contain the flow. Adjacent shelf areas should be sloped to drain to the channel. Where more than one sewer enters the manhole, the channels should be curved smoothly and have sufficient capacity to carry the maximum flow. Where the sewer changes direction or size in a manhole, or a branch sewer enters a manhole, the surface of the sewage flow must be the same to prevent excess turbulence or backflow.

Figure 9-3: *Short stubs and/or flexible manhole connections should be used to provide flexibility*

Manhole Pipe Connections

Extreme caution should be exercised in the placement of manholes to assure an unyielding foundation. Settlement of the manhole may cause damage to the adjacent pipe. Short lengths (24-inch maximum) with flexible compression joints and/or flexible manhole connections should be used at the manhole walls to accommodate minor differential movement. A bell and spigot joint with a factory applied gasket or plain-end pipe joined with rubber compression couplings will provide the needed flexibility and water-tightness. Two points of flexibility should be used within 36 in. of each manhole connection.

This can be accomplished by using:

1. two short lengths (stubs of 24 in. or less) or
2. one short length and one flexible manhole connector (see Figure 9-4).

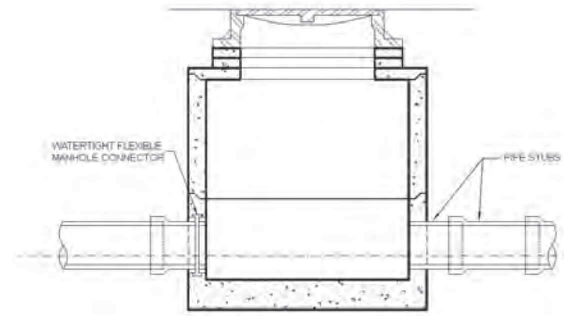


Figure 9-4: *Two points of flexibility should be provided within 36 inches of a structure.*

If a manhole connector is utilized, it is important that the pipe is centered in the connector and the tightening clamp torqued per the manufacturers' instructions in order to remain a flexible and watertight connector (see Figure 9-4). It is equally important that no mortar be placed between the pipe and the wall of the concrete structure. Both the use of mortar in this area and not centering the pipe would decrease the effectiveness of the connector to compensate for shear caused by settlement or ground movement.

The need for proper haunch support at and around manhole connections is just as important as it is for the entire pipeline (see Haunch Support section starting on page 6-6).

Manhole Frames, Covers and Steps

Manhole frames and covers are normally made of cast or ductile iron. All metal-bearing surfaces between the frame and cover, where subject to traffic, should be fabricated to ensure good seating. Locked or special bolted down covers may be used to prevent theft, vandalism or unauthorized entrance.

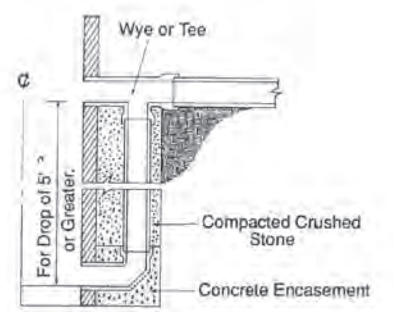


Figure 9-5: *Typical Drop Manhole (for 5 ft. or greater)*

Steps must be made of corrosion resistant materials. Firm anchorage in the wall and provision in the design to prevent slipping are desirable objectives. Since there have been many serious failures of manhole steps the use of other confined space entry equipment is preferable and may be required.

Drop Manholes

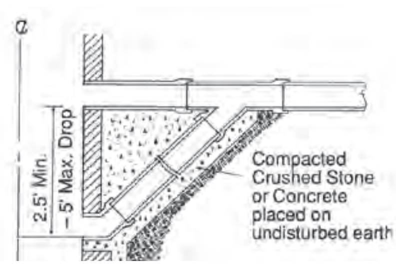


Figure 9-6: *Typical Drop Manhole (for 5 ft. or less)*

Differences in elevation of incoming and outgoing sewers, which would result in deposition of solids or nuisance to maintenance personnel, should be avoided. When it is necessary to drop the elevation of the sewer at a manhole, the drop may be made by means of an outside connection similar to that shown. Fitting dimensions govern the minimum vertical outside drop that can be made. The designer's judgment will determine, where the difference in elevation warrants using an outside drop instead of lowering the upstream or branch sewer. Support of the entire outside drop is desirable to protect it against damage during backfilling of the trench. Vertical curves may also be used to accomplish the change in elevation.

Safety Requirement for Entry into Confined Spaces

It is extremely important that qualified personnel perform entry into any confined space, such as a sewer manhole or structure. Complete knowledge of all regulations and safety equipment is required to ensure a safe, productive jobsite.

Terminal Cleanout Structures

Terminal cleanouts are sometimes used at the ends of branch or lateral sewers. Their purpose is to provide means for inserting cleaning tools, for flushing or for inserting inspection equipment into the sewer.

A terminal cleanout amounts to an upturned pipe coming to the surface of the ground. The turn should be made with bends to allow cleaning and inspection equipment. The diameter should be the same as that for the sewer.

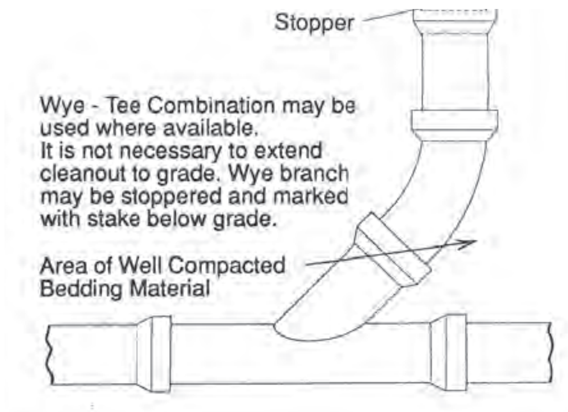


Figure 9-7: *Typical Cleanout Structure*

Terminal cleanouts are limited in usefulness and should never be used as a substitute for a manhole. They are permitted under some state regulations only at the ends of branch sewers, which may never be extended and must be within approximately 150 ft. of a manhole.

CHAPTER 10: RESIDENTIAL BUILDING SEWERS

Figure 10-1: *6-inch VCP curves connected to the sewer main via wye fittings*

Lateral Sewers

A lateral sewer is a continuation of the municipal sanitary sewerage system. This installation demands the same special care and experience as municipal sewerage construction for the line to be permanent and trouble free. Experienced, competent contractors should perform the installation.

Lateral sewers must be resistant to the action of corrosive chemicals. Ordinary sewage contains quantities of acetic, citric, sulfuric and lactic acid as well as organic acids. These sewers pass thousands of gallons of hot, soapy water, vegetable and fruit juices, a variety of cleansers and drain cleaners, which are highly corrosive. In addition, the widespread use of garbage disposals introduces a large amount of organic matter into sewers. Dishwashers and washing machines contribute large quantities of hot water, which greatly increase the sewage temperature.

Lateral sewer pipe should not deflect, deform, soften, rust, decompose or disintegrate from the effect of domestic wastes, high sewerage temperatures, moisture saturation, sustained trench loading or cleaning equipment.

Trench Excavation

Pipe trenches should be dug with the same care required for main lines. Trenches should be straight, to the required grade and width held to a minimum.

Where the soil is sufficiently firm to provide a solid foundation for the pipe, the trench bottom should provide uniform support for the barrel of the pipe. Bell or coupling holes must be dug at the proper intervals so that the barrel of the pipe supports the weight.

Figure 10-2: *Not a Typical residential sewer installation.*

Care should be taken to excavate no deeper than necessary, unless there is a supply of angular crushed stone or other suitable coarse material available to bring the trench bottom to grade and provide uniform support for the barrel of the pipe. Rock or other unyielding material, which is encountered, should be removed. The pipe foundation should be free of all lumps and irregularities.

Where the bottom of the trench is either of rock or an unstable material, it is necessary to excavate below grade and backfill to grade with angular crushed stone or similar material.

Installation

Each section of pipe should be installed to a specified line and grade. All pipe should be installed with bells or couplings upgrade.

As the installation progresses, the interior of the pipe should be cleared of all dirt and foreign material. The trench should be kept as dry as possible while the pipe is being installed. The specific manufacturers' recommendations should be carefully followed.

Figure 10-3: *Two services constructed in the same trench excavation.*

Backfilling

Normally the excavated earth is satisfactory for backfilling purposes. The trench should be backfilled as soon as inspection is completed. To protect the line from lateral movement, the bedding and backfill should be carefully placed around and above the top of the pipe.

Adding New Service Connections

Connection of a new service lateral to an existing sewer main can be accomplished by the use of various available tap saddle kits or tee fittings. All tap saddle kits and tee fittings require core drilling a hole in the existing sewer main (see Figures 10-4 and 10-5).

Figure 10-4: *Hole cored in clay jacking pipe to reconnect a lateral following a pipe burst.*

Figure 10-5: *Service connection made using a cored hole and a tee fitting.*

Another method is to cut and remove a section of the existing main line followed by inserting a plain end tee or wye fitting with rubber compression couplings on each end. Cutting of the pipe can be accomplished by using a saw or chain cutter. For reconnection to the existing mainline pipe, two couplings are needed for each new fitting installed. The replacement branch spur can be a plain end or jointed pipe (see Figures 10-6 and 10-7).

Figure 10-6: *Cutting out a section of main line to insert a factory made, plain-end wye fitting.*

Figure 10-7: *Wye fitting for lateral service connection to main line made using shielded rubber couplings.*

CHAPTER 11: INSPECTION & TESTING


Figure 11-1: Pipe Laser Beam Unit

Inspection

Inspectors are an important link between the engineer's design and an accurately completed project. The inspector is responsible for monitoring and control of the project by measuring actual construction against the plan and specifications. Inspectors must be thoroughly familiar with good practice in sewer construction, have the ability to read and understand detailed plans and specifications, translate that information to an understanding of the complete scope of work

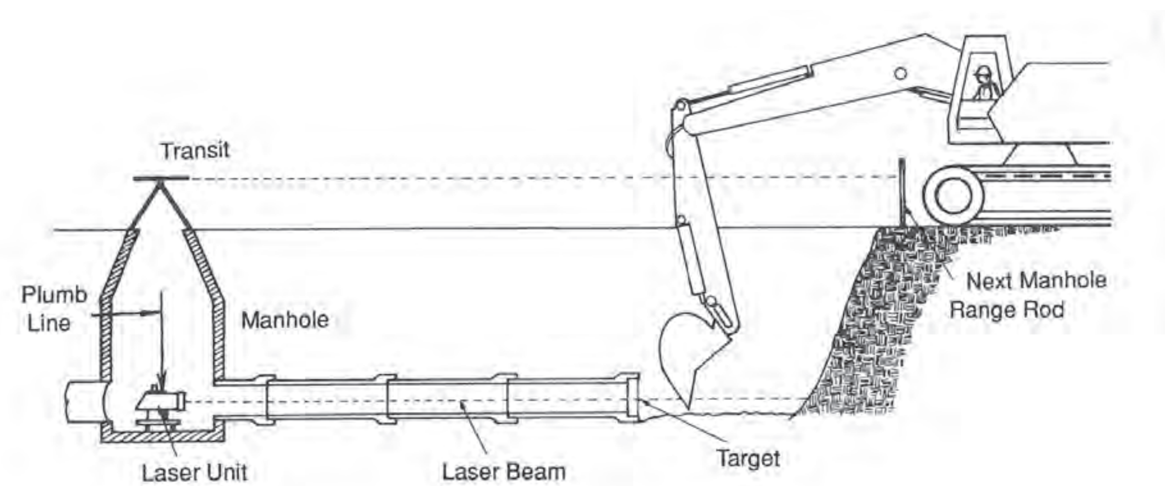


Figure 11-2: Laser Beam Setup

and make computations as needed to interpret the drawings and field conditions. The inspector must be familiar with excavation and foundation development, required bedding materials with their proper application, and recommended bedding application process. They must have knowledge of safety regulations for construction sites and see that all regulations and proper procedures are followed.

The project engineer has the overall responsibility for project design and implementation. It is therefore necessary that they be fully acquainted with the project plans, related specifications and construction contract documents. They must be sufficiently experienced to review the means and methods chosen by the contractor and evaluate their impact on design plans and specifications.

Tools

There are a variety of tools an inspector should use to ensure the proper implementation of the projects design and specifications. Typical tools used by inspectors include:

- *NCPI's Vitrified Clay Pipe Engineering Manual*
- Related industry standards and regional specifications (ASTM)
- Manufacturer handling requirements
- *NCPI's Toolbox* (ncpi.org/ncpi-toolbox.html)
- *NCPI's Installation & Inspection Handbook*
- *NCPI's Low-Pressure Air Test Booklet*
- *NCPI's Tips for Laying Vitrified Clay Pipe*
- *NCPI's Guide to Analyzing CCTV Inspection*
- Manufacturer Representatives

Duties

The long-term efficiency of sewer systems depends upon the combined efforts of the engineers, the inspector, the contractors and the material suppliers.

The inspector has many duties included in their work. They must make a complete record of all occurrences related to the construction of the pipe line and maintain a daily log.

These records are integral to any required changes that must be made in the original construction plans. Such changes may involve extra work and payment for this can be computed only after the work is done. Any deviation between design work and actual construction must be noted.

Figure 11-3: *Inspectors are a vital link between specification and construction.*

Material Evaluation

This process includes reviewing scheduled deliverables with the contractor to ensure acceptance of pipe by the owner of the project. This procedure includes:

- Verify proper pipe configuration and sizes.
- Inspect pipe at delivery and before installation.
- Ensure inspected pipe is stored in a manner to avoid damage.
- Damaged pipe may NOT be marked or defaced.
- Notify the supplier immediately of pipe rejected or damaged pipe.

Testing

Acceptance testing is the process of formalizing acceptance of a completed pipeline. Methods commonly used are CCTV Inspection, Low-Pressure Air Testing, and Hydrostatic Infiltration Testing. Common practice is to test each section from manhole to manhole after it is backfilled.

The first section of any sewer project should be tested immediately upon completion to ensure that the installation procedure will produce the results required by the specifications.

Experience demonstrates that continual testing as a job progresses improves adherence to good job site practices, increases contractor productivity and ensures compliance with engineering plans.

All acceptance tests must be performed by qualified personnel. These tests should be witnessed by the inspector or engineer’s representative.

CCTV Inspection

Television has been growing in popularity as a means of investigating the condition of all types of buried sewer lines. As an investigative tool, it is unmatched in enabling operators to pinpoint many differing conditions and provides a record of construction results. Many agencies have begun requiring television as a means of determining the acceptability of newly constructed lines.

Figure 11-4: *A CCTV camera in an 8" pipe. Photo courtesy of Plumbers Depot Inc.*

In some instances, assumptions regarding structural damage have been made erroneously. Operators of television equipment are looking for problems. These unintentional errors can lead to conclusions that become unproductive while being quite expensive. There have been instances where dig-ups have shown the problem described in the log to be either non-existent or of significantly less magnitude than originally indicated. For this reason, the low-pressure air test is the preferred method of acceptance testing.

See the NCPI document *A Guide to Analyzing CCTV Inspection* (available online).

Low-Pressure Air Testing

When the measured water table is 5 ft. or less above the pipe barrel at the midpoint of the test section, a low-pressure air test is an accurate method of testing a sewer line for acceptance (for 5 ft. or greater see "Hydrostatic Infiltration Testing" on page 11-5).

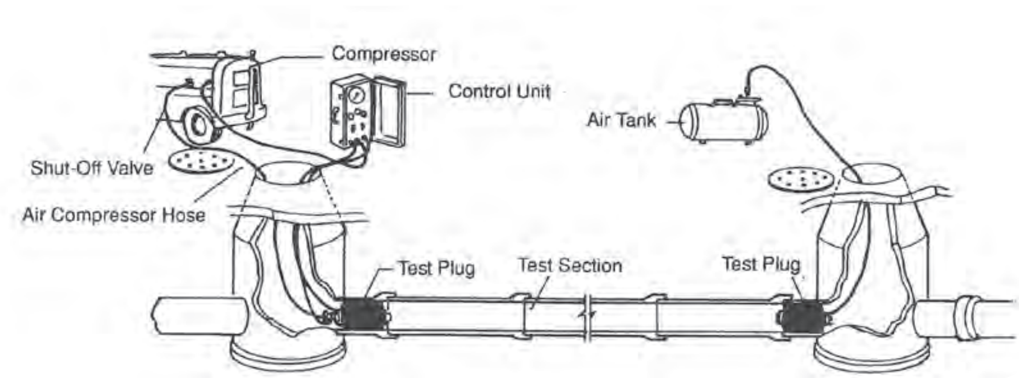


Figure 11-5: *Line Acceptance Testing*

Acceptance or failure of a line is determined by a specific drop in air pressure over a specified length of time (See Low-Pressure Air Test Booklet).

Test Procedure

Clean the sewer line by flushing before testing to wet the pipe surface and clean out any debris. Plug all pipe outlets to establish the required test pressure. All stoppers in laterals should be braced.

ASTM C828 *Standard Test Method for Low-Pressure Air Test of Vitrified Clay Pipe Lines* describes the procedure for air testing sewer lines. Air test tables found in the NCPI low pressure air test booklet are derived from this standard.

Figure 11-6: *Test Plug*

The pressure-holding time is based on an average holding pressure of 3 psi gauge or a drop from 3.5 psi to 2.5 psi.

Add air until the internal air pressure of the sewer line is approximately 4.0 psi gauge. After an internal pressure of approximately 4.0 psi is obtained, allow time for the air pressure to stabilize. The pressure will normally show some drop until the temperature of the air in the test section stabilizes.

When the pressure has stabilized above the 3.5 psi gauge reading, reduce the pressure to 3.5 psi to start the test. Record the drop in pressure for the test time. If the pressure does not drop more than 1.0 psi during the test time, the line is presumed to have passed. It is not necessary to continue the test for the total time when it is clearly evident that the rate of air loss is less than the allowable.

This procedure can be used as a presumptive test, which enables the installer to determine the acceptability of the line before backfill and subsequent construction activities.

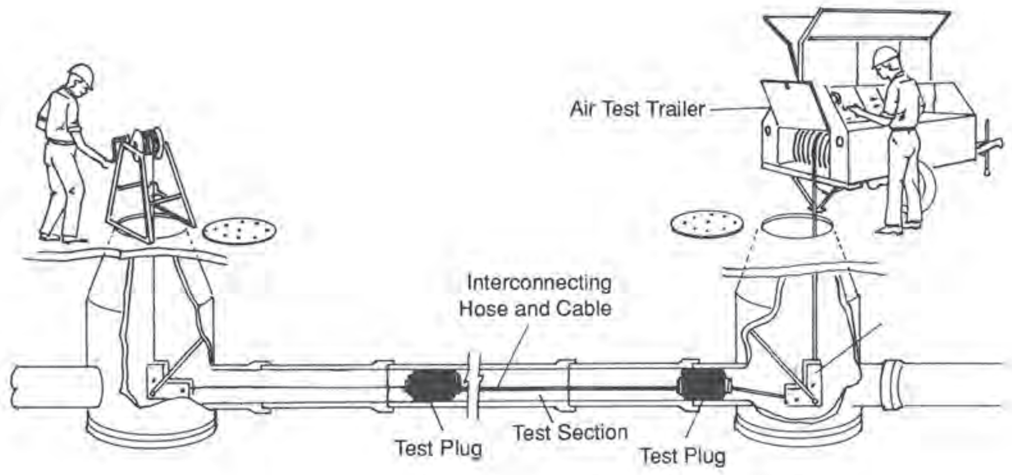


Figure 11-7: *Segmental Air Testing*

Safety During Testing

The air test can be dangerous if a line is improperly prepared due to improper training, a lack of understanding or carelessness.

Calculate the amount of back pressure the plug must withstand and be certain the plug being used is designed to withstand this pressure. Always use a pressure gauge and regulator when inflating a sewer plug. Under-inflated plugs will not be able to withstand the required back pressure. Over-inflated plugs can rupture causing possible damage and injury.

It is extremely important to install and brace the various plugs to prevent blowouts. A force of 250 Lbf is exerted on an 8-inch plug by an internal pipe pressure of 5 psi. The sudden expulsion of a poorly installed plug, or of a plug that is partially deflated before the pipe pressure is released, can be dangerous.

As a safety precaution, pressurizing equipment should include a regulator or relief valve set at 10 psi to avoid over pressurizing and damaging an otherwise acceptable line. No one shall be allowed in the manholes during testing.

Hydrostatic Infiltration Testing

When the measured water table is 5 ft. or greater above the pipe barrel at the midpoint of the test section, infiltration testing is the preferred and least expensive method of acceptance testing. The infiltration test measures the ground water, entering the pipeline. Manholes should be tested independent of the sewer line.

ASTM C1091 *Standard Test Method for Hydrostatic Infiltration Testing of Vitrified Clay Pipe Lines* describes the procedure for Infiltration Testing and allowable rate of infiltration.

If water is present in the line, isolate the section of pipeline being tested from the upstream side. Discontinue pumping of ground water for a minimum of 24 hours prior to testing. Determine the infiltration flow rate in the sewer line at the furthest downstream point of the section being tested.

It is necessary to collect and measure the infiltration over a period of time. A convenient collection time is one hour. This measurement can be converted to gallons per hour and to gallons per inch diameter per mile, per day and compared to the specified standard.

Collection of the infiltration may be obtained by using a dam at the invert of the pipe and removing the collected water, by collecting water through a flow through plug, or other convenient method.

The set up in Figure 11-8 is recommended to achieve this result. After the leakage for the pipe is determined, the lower plug in the upstream manhole can be removed and the combined infiltration from the pipeline and the manhole can be measured. The manhole infiltration is calculated by simply subtracting the pipeline infiltration from the combined pipeline and manhole infiltration. Other procedures for infiltration testing may be equally satisfactory.

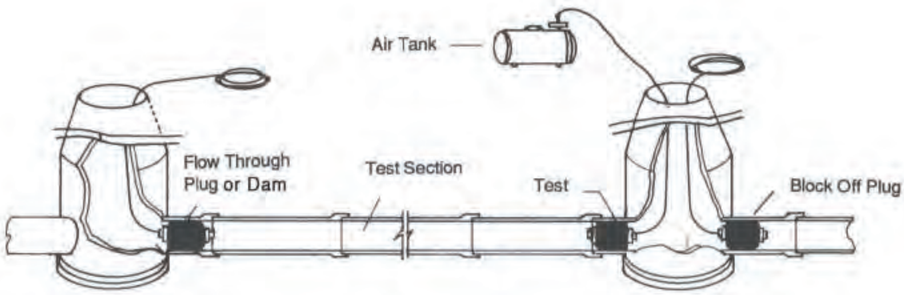


Figure 11-8: *Recommended set up for Infiltration Testing*

Example 11-1: Calculation of Infiltration Rate

Pipe Size	8 in.
Quantity Collected	0.7 gals.
Length of Test Section	485 ft.
Elapsed Time	1 hour

Infiltration Rate in Gallons/Inch Dia./Mile/Day

$$= (0.7\ gals)\left(\frac{1}{8\ in.\ dia.}\right)\left(\frac{5280\ ft./mile}{485\ ft.}\right)\left(\frac{24\ hr./day}{1\ hr.}\right)$$

$$= (0.7\ gals)\left(\frac{1}{8\ in.\ dia.}\right)\left(\frac{10.9}{mile}\right)\left(\frac{24}{day}\right)$$

$$= \frac{183.1}{8}\ gals/in.\ dia./mile/day$$

$$= 23\ \text{gals}/in.\ dia.\ /mile/day$$

CHAPTER 12: OPERATIONS & MAINTENANCE

Figure 12-1: A combination sewer cleaning truck is used to hydro-flush and vacuum sewer lines. The nozzles and tools used with similar trucks have advanced dramatically over the past 10 years.

Photo provided by Municipal Maintenance Equipment.

Operations & Maintenance

Ceramics are among the most abrasion-resistant materials known. As a ceramic, VCP is the most abrasion-resistant, commonly-used sanitary sewer pipe material. The abrasion resistance has always been an important material property of VCP, but it has become essential as modern cleaning methods intensify the concern.

Figure 12-2: Hydro-jetting set-up for an 8" VCP pipe.

The principal goal in maintaining any gravity flow sewer is to keep them clean, unobstructed and functioning as designed. A sewerage system, although buried, cannot be neglected. A properly designed and installed sewer must be maintained. Municipalities worldwide are taking a proactive and predictive approach to sewer maintenance, improving the consistent, long-term performance of their sewer systems, thus reducing Sanitary Sewer Overflows (SSOs).

Cleaning, repairing and inspecting sewer lines are essential parts of maintaining a properly functioning wastewater infrastructure and protecting the environment. From the cleaning method using hickory sticks and scrapers employed at the turn of the 20th century, to the modern high pressure hydro-jetting trucks and nozzles in use well into the 21st century, VCP has withstood both chemical and mechanical cleaning methods for over 100-years. Clay pipe manufactured well-before the modern cleaning methods were envisioned stands up to the extreme conditions introduced by these methods.

The maintenance departments of municipalities continuing to specify VCP have realized the benefits of the abrasion-resistance and inert nature of clay as a fired ceramic. And that's just one reason the maintenance departments of those municipalities have become proponents of VCP. The durability of VCP pipe is a testament to its manufacturers. Thousands of miles of VCP sewer pipe are cleaned and inspected each day. These same pipes will withstand the next century of technological changes and advances in sewer maintenance practices.

VCP Sewer Cleaning Methods

Hydro-Jetting

Hydro-Jetting is one of the most common and most effective forms of cleaning sewers.

Water is pumped into the sewer through a hose directing high pressure jets of water against the pipe wall via a nozzle.

Hydro-jetting removes debris and grease build ups, cuts roots, clears blockages and flushes the sewer pipe. The nozzle is typically sent upstream from a manhole structure and pulled back under pressure, typically 50 to 80 GPM at 2500 to 3500 psi. Debris is then removed by means of vacuuming or by utilizing specialty hand tools.

Nozzles

The most common and effective nozzels are Static and Rotational, which have replaceable jets allowing the operator to trim the nozzle to the flow rate and pressure of the pump to achieve maximum working efficiency. Static and Rotational nozzles are available with a wide range of jet angles to fit any cleaning need.

Static Nozzles: Non-rotational fixed nozzles are manufactured in a variety of sizes and shapes that meet the cleaning criteria.

Cleaning nozzle **-** primarily used to clean the entire circumference of smaller diameter sewer pipes. Jets are radially located, using a higher jetting angle (21 to 45 degrees).

Flushing nozzle **-** primarily used to move debris from the bottom of smaller sewer pipes with the use of radially located, lower degreed jets (6 to 20 degrees).

Stoppage nozzle **-** used to break up sewer blockages with the use of forward facing jets and rear facing thrust jets which penetrate and break-up a stoppage.

Figure 12-3: *Static cleaning hydro-jet nozzle.*

Photo provided by Advanced Infrastructure Technologies.

Dredging nozzle **-** weighted nozzle primarily used to move debris from the the bottom of larger sewer pipes with the use of lower degreed jets (6 to 20 degrees).

Rotational Nozzles: A series of nozzles delivering water jets throughout the entire internal circumference of the sewer pipe, using a revolving head.

Governed - this type of rotational nozzle utilizes an internal clutching mechanism to govern the rotational speed of the nozzle head delivering a consistent jetting speed and impact to the pipe wall. Rotational nozzles are available with a wide range of jet angles to fit any cleaning application.

Figure 12-4: A rotational nozzle uses a revolving head to deliver water jets throughout the entire circumference of the pipe. Photo provided by StoneAge Inc.

Spinning - these non-governed nozzles deliver variable speed and velocity water jets to the circumference of the pipe based on the pressure and volume. Both pressure and volume can be adjusted by the operator at the pump control.

Whether it's a Rotational or Static hydro-jet nozzle, a low number of larger orifice jet inserts will ensure greater force and cleaning strength across the pipe circumference. A higher number of inserts with small orifices will enable more spreading of the water for cleaning while the impact force is weaker across the pipe circumference. See Table 12-1 for a comparison of thrust power and cleaning effectiveness with varying jet angles.

Nozzle Jet Angle (degrees)	Thrust Power	Impact Force / Cleaning Effectiveness
6 to 15	Best	Poor
16 to 20	Good	Low
21 to 29	Balanced jetting angles thrust to impact force cleaning ratio	
30 to 35	Medium - water jets have moderate impact force	Good
36 to 45	Low	High impact force for removing deposits.
46 to 90	Poor	Best – used for removal of calcium, roots, calcified grease, etc.

Table 12-1: Thrust Power vs Impact Force / Cleaning Effectiveness.

Nozzle Orientation Management (NOM)

To prevent "Catfishing" (see definition below) and to obtain the maximum cleaning efficacy for the entire circumference of the pipe, a nozzle or a hydro-mechanical tool should be centered within the pipe.

Catfishing describes the behavior of a sewer cleaning nozzle when it is dragged across the bottom of the pipe without the use of a skid or centering device. "Catfishing" can reduce the effectiveness of the nozzle and potentially damage the equipment or create a safety concern.

8-Inch Pipe with 30° Rear-Facing Jets

Centering of the tool within the pipe can be managed through a finned or wire legged proofing skid, also called a centralizer. This device is essential for effective cleaning of the pipe crown and prevention of mineral deposit buildup. Centering of the tool provides uniform standoff distance as shown in figures 12-5a and b. In these figures, both showing an 8-inch pipe with 30°, rear-facing jets, the standoff distance between the nozzle and the pipe crown is reduced by almost 50% with a centralizer.

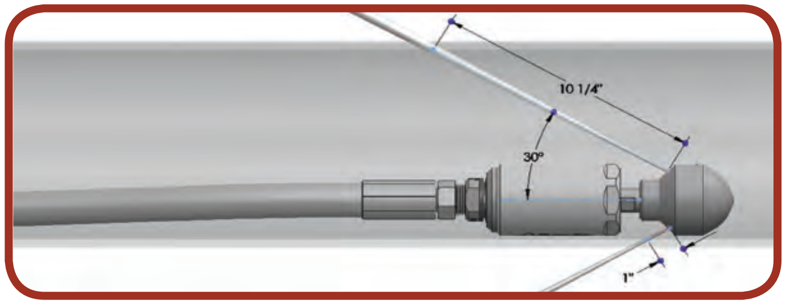


Figure 12-5a: Without Centralizer- results in a non-uniform standoff distance.

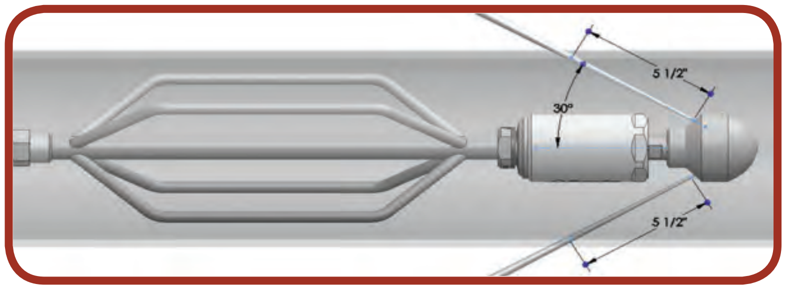


Figure 12-5b: With Centralizer- provides a uniform standoff distance

Illustrations provided by StoneAge Inc.

Utilization of a centering device not only provides more effective cleaning of the pipe, it is also an integral safety tool during the hydro-cleaning process. A centralizer offers greater control and keeps the cleaning tool from turning up a lateral or turning around in the pipe compromising operator safety .

Hydro-Mechanical Tools

Hydraulic Cutter

A hydraulic cutter is a low rpm, high torque (70 to 100 ft. lbs.) tool that cuts or scrapes the inside of the pipe wall utilizing a circular saw or a series of 3 to 4 indexed flat blades attached to the drive shaft of the hydraulic motor by a chuck.

Tap Cutter, Chain/Cable Flail

A tap cutter, chain/cable flail is a high speed cutting tool utilizing an attached chain, cable or cutting can that rotates and scrapes the inside of the pipe to remove roots, hardened debris, protruding laterals and most other solid obstructions.

Mechanical Rodding

Mechanical rodders have been utilized with success for cleaning municipal sewers for over 60 years. Because no water is required for cleaning with these machines, their popularity is showing resurgence due to the national water conservation movement.

In FY 2016-2017 the City of Los Angeles saved over 30 million gallons of water utilizing mechanical rodders to clean sewers. The water saved represents roughly the annual usage of 275 households. Mechanical rodders use an engine and a drive unit with hardened continuous rods or sectional rods to push, pull and / or turn various cleaning tools. As the tools rotate they break up grease deposits, cut roots, and loosen debris.

Mechanical rodders can hold approximately 1,200 feet of rod in a reel type cage that can push and pull. These units have a typical pulling capacity of up to 7,000 pounds continuous pull in low gear and 3,500 pounds in high gear.

Figure 12-6: A continuous mechanical rodding machine has 1200 feet of continuous rod. Photo provided by Haaker Equipment Company.

Mechanical rodders also help thread the cables for CCTV inspections and bucket machines and are most effective in lines up to 15 inches in diameter.

Because the use of mechanical rodding is fully acceptable in VCP, it is a proven water saving material.

Figure 12-7: An example of a root cutting device used with a mechanical rodder.

Bucketing

A special device designed to be pulled along a sewer for the removal of debris from the line. The bucket has one end open with the opposite end having a set of jaws. When pulled from the jaw end, the jaws are automatically opened. When pulled from the other end, the jaws close. In operation, the bucket is pulled into the debris from the jaw end and to a point where some of the debris has been forced into the bucket. The bucket is then pulled out of the sewer from the other end, causing the jaws to close and retain the debris. Once removed from the manhole, the bucket is emptied and the process repeated.

Balling

A method of hydraulically cleaning a sewer or storm drain by using the pressure of a water head to create a high cleansing velocity of water around the ball. In normal operation, the ball is restrained by a cable while water washes past the ball at high velocity. Special sewer cleaning balls have an outside tread that causes them to spin or rotate, resulting in a “scrubbing” action of the flowing water along the pipe wall.

Considerations When Selecting Cleaning Methods

One important consideration when using a mechanical rodder, bucket machine, hydraulic root saw or a chain or cable type cutter is the pipe material in which it will be used.

Equipment manufacturers and government agencies recommend against the use of these aggressive cleaning methods in many of the non-ceramic pipe materials commonly found in sewers today. In the comprehensive manual *Optimizing Operation, Maintenance and Rehabilitation of Sanitary Sewer Collection Systems* (compiled and written under the direction of an advisory committee consisting of representatives of NEIWPCC member state environmental agencies, EPA and wastewater consultants) there is information regarding cleaning of plastic pipe:

> *"With any mechanical cleaning equipment, the operator must know where plastic pipe has been installed in the wastewater collection system. High-velocity cleaning machines are least likely to damage a plastic pipe system. Power rodders can be used carefully to remove obstructions, but there is always the possibility of damaging the pipe wall if the cutter is suddenly deflected off the blockage and into the pipe wall. Mechanical cleaning tools such as cutters and brushes should not be used in plastic pipe since they can score the pipe and reduce the flow characteristics by increasing the pipe wall roughness. A suitable pipe identification system should be in place to warn the operator where plastic pipe has been installed."*

VCP manufactured in the U.S. is rated to 5000+ psi with flows exceeding 80 GPM, and at all jetting angles when hydro-flushing. All common methods of cleaning sewer pipe can safely be used in VCP sewer pipe including hydro-mechanical tooling, hydro-flush nozzles, mechanical rodding, bucketing, as well as chain/cable type cutters.

Safe, efficient, and effective sewer cleaning:

- Safety is always the key element in sewer cleaning. Ensure that all safety measures and manufacturer's instructions are followed in regards to PPE (Personnel Protective Equipment), traffic control, tool and equipment applications, etc.
- Sufficient jetting thrust to drive the high-pressure hose, nozzle or tool up the sewer.
- Proportionate volume of water to move removed debris towards the recovery manhole.
- Adequate jet impact strength at the outlet of the nozzle or tool to disintegrate and/or remove debris or obstructions.
- Ability to adjust the nozzle or tool to the volume and pressure of water supplied by the high-pressure pump.
- Proper weight of the hydro-flushing tool for use in larger diameter sewers.
- Correct outlet angle of the water jet from the nozzle or tool for the type of cleaning to be performed.
- Center the nozzle in the line.

The information provided in this chapter is not intended to replace the judgement of an experienced maintenance professional. It is intended primarily as a beginning set of considerations for design and maintenance professionals as they consider the long-term implications of material selection in sanitary sewer lines.

GLOSSARY OF TERMS

Definition

The following terms relate to the installation and use of Vitrified Clay Pipe. Many of these terms are used in reference to all pipe installations while some are specific to VCP installations. Most of these terms can be found in ASTM C896 *Standard Terminology Relating to Clay Products.*

A

Angular Material
A fractured and suitably sized bedding for pipe and fittings.

Approving Authority
The individual official, board, department, or agency established and authorized by a state, county, city, or other political subdivision, created by law to administer and enforce specified requirements.

ASTM Standard
Manufacturing, installation and testing standards issued by the American Society for Testing and Materials.

B

Backfill
All the material used to fill the trench from top of bedding to finished surface.

Backfill, initial
Material used to fill the trench from top of bedding to a designated height over the pipe.

Backfill, unconsolidated
Non-compacted material in place in the trench.

Barrel
The cylindrical portion of a vitrified clay pipe exclusive of branches, spurs, joints, and handling rings or lugs.

Bearing Strength
The non-destructive limit of pipe load, as determined by 3-edge bearing test method, used to determine field supporting strength.

Bedding
The materials, their placement, consolidation, and configuration, as designed to support and to develop field supporting strength of vitrified clay pipe.

Bedding Material
Material placed under and around clay pipe to develop the required load factor.

Bell
The flared-end portion of a vitrified clay pipe or fitting, designed to function in the joining of other such pipe.

Blister
A convex, raised area on the pipe surface indicating an internal separation.

Body
See pipe body.

C

Chip
A small piece of broken-off material, or the location where a small piece of the unit material has been broken off.

Clay
An earthy or stony mineral aggregate consisting essentially of hydrous silicates of alumina, plastic when sufficiently pulverized and wetted, rigid when dry, and vitreous when fired to a sufficiently high temperature.

Closure
See compression joint.

Compaction
Densification of soil by means of mechanical manipulation. (Per ASTM D653)

Compression Coupling
See compression joint.

Compression Disk
A disk of compressible material placed between the ends of adjacent pipe for the purpose of distributing the jacking force.

Compression Joint
A joint designed so that a sealing action is obtained by compressing elastomeric components.

Conduit
A pipe for conveying fluid.

Consolidation
The gradual reduction in volume of soil over time.

Controlled Low Strength Material (CLSM)
Flowable low compressive strength cementitious material used in the pipe zone as a bedding material. Also referred to as controlled density fill, flowable fill, slurry, or lean concrete.

Coupling
A device, typically made of an elastomer, used to connect clay pipe barrels. These devices are typically used in conjunction with stainless steel tightening bands.

D

Deadload
The load imposed on pipe that is determined by depth and width of the trench at top of pipe, as well as unit weight and character of backfill material.

Density
A value in lbs. per cubic foot of volume for a given material.

Design Trench Width
Trench width at the level of the top of the pipe.

Drains
A piping system used to collect and carry off surface and ground water.

E

Encasement
Special materials, their placement and configuration which are designed to fully surround the pipe, and develop a field supporting strength which exceeds that developed by other commonly used installation and bedding techniques.

F

Final Backfill
Material used to fill the trench from the top of the initial backfill to the finished ground surface.

Fitting
Products such as wyes, tees, elbows, adapters, etc. used in the installation of vitrified clay pipelines.

Flooding
A means of compacting trench backfill by the introduction of water by gravity.

Foundation
The native or prepared trench bottom on which the bedding is placed.

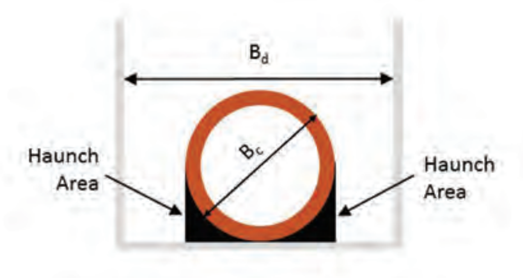
Fracture
That portion of a vitrified clay pipe from which a fragment has been broken. It is distinguished by well-define fracture faces and sharp edges where the fracture faces meet the surface of the pipe.

G

Geotextile
A drainage fabric which allows the flow of water while preventing the movement of soil.

H

Haunch
The areas bordered by the barrel outside diameter, the vertical tangents from the pipe springline and the horizontal tangents from the bottom of the pipe. See detail:



Haunching
Utilizing a shovel, spade or other suitable tool to place and compact the bedding material in the haunch to (1) assure the pipe will remain true to line and grade and (2) provide uniform circumferential support to the pipe which is essential for the total load factor to be realized.

I

Inch-Pound Units
The units of length, area, volume, weight, and temperature in common use in the United States. These include, but are not limited to: (1) length-feet, inches, and fractional inches, (2) area-square feet and square inches, (3) volume-cubic feet, cubic inches, gallons, and ounces, (4) weight-pounds and ounces, and (5) temperature-degrees Fahrenheit.

Industrial Waste
The water-conveyed residues resulting from manufacturing or processing operations.

Infiltration
The quantity of ground water entering the pipeline in the test section during a specified time period.

Initial Backfill
Location for placement of selected material, native or import, extending from the top of the bedding material to an elevation 1ft. above top of pipe.

J

Jacking
A method of installing pipe by the trenchless method using equipment and pipe designed for this purpose.

Jacking Force
The force applied to the pipe along the longitudinal axis of the pipeline by the pipe jacking equipment.

Jacking Frame
A structural component that houses the hydraulic cylinders used to propel the tunnel equipment and pipeline. The jacking frame serves to distribute the axial thrust load to the pipeline and the reaction to the shaft wall or thrust wall.

Jacking or Launch Shaft or Pit
Excavation from which trenchless technology equipment is launched for the installation or renewal of a pipeline.

Jetting
A means of compacting trench backfill by the introduction of water under pressure through a nozzle.

Joint
An individual length of pipe, or the means of closure to form a pipeline.

L

Laser
A device that sends a straight beam of light on the proper line and grade to a target.

Leachate
Liquid drainage normally associated with contaminated soils and solid waste landfills.

Live Load
The portion of the load transmitted to pipe from wheel or tread impacts.

Load Factor
The multiplier associated with class of bedding used to compute the field supporting strength (FSS). *FSS = (minimum 3-edge bearing strength of pipe) X (Bedding Class Load Factor)*

Lot
Specific group of clay pipe having characteristics of sufficient similarity that individual specimens selected from that group may be considered representative of the whole group.

M

Migration
The movement of soil into adjacent material.

Mitered Fittings
Fittings manufactured by using mitered pipe segments.

Mitered Pipe
A pipe with an end angled to mate with a complimentary pipe end or adjust to another surface

N

Native Material
Material present in or which has been removed from the trench.

Nominal Diameter
References the internal diameter in name only to the nearest unit dimension.

Nozzle
A device designed to control the direction or characteristics of a fluid flow (especially to increase velocity) as it exits or enters and enclosed chamber or pipe. Nozzles can be static or rotational.

O

OSHA
Occupational Safety and Health Administration.

P

Pilot Tube Guided Boring Method (PTGBM)
Also known as Pilot Tune Method (PTM), Pilot Tube Microtunneling (PTMT), Guided Boring Method (GBM), and Guided Auger Boring (GAB). This technique is a multistage method of accurately installing a product pipe by use of a guided pilot tube which is followed by upsizing to install the product pipe. In PTGBM, the guidance system consists of a LED target housed in the steering head, digital theodolite with camera and a monitor screen.

Pipe
See vitrified clay pipe.

Pipe Bursting
Process by which existing pipelines are broken by mechanical fracturing from either inside or outside with the remains being pushed into the surrounding soil while simultaneously inserting a new pipeline of equal or larger diameter.

Pipeline
Pipes joined to provide a conduit through which fluids flow.

R

Reach
The section of a sewer between structures.

Reception Shaft or Pit
Excavation into which trenchless technology equipment is driven and recovered following the installation of the product pipe.

Riser
Building sewers connected to deeper main lines.

S

Sample
Each pipe or group of pipe selected from a lot and used to determine whether the product complies with the specification criteria.

Sampling
Process of selecting samples from a lot for use in testing.

Sealing Element
A separate or bonded material between the sleeve and the pipe that forms a seal.

Segmental Testing
A method of isolating and testing portions of an installed pipeline to determine the location of an air loss in excess of the standard.

Sewage
Waste matter carried off by sewers.

Sewer
Generally, an underground conduit usually carrying waste matter in a liquid medium.

Sewer Line
See sewer.

Sewer Pipe
Vitrified clay pipe as described in ASTM Specification C700.

Sewerage
System for collection, treatment, and disposal of sewage.

Shale
A thinly stratified, consolidated, sedimentary clay with well-marked cleavage parallel to the bedding.

Sheeting
Wood or metal restraints used to support the trench walls.

Shield
Movable trench box used in place of sheeting and shoring.

Shoring
Equipment used to prop or support the trench sheeting or trench wall directly.

Shovel Slicing
Utilizing a shovel, spade, or other suitable tool to place and consolidate the bedding material in the haunch to assure the pipe will remain true to line and grade and provide uniform circumferential support to the pipe which is essential for the total load factor to be realized.

Sleeve
A coupling which contains or compresses the sealing element and meets the requirements of the standard. The sleeve may be affixed to one end of the pipe at the factory.

Sliplining
A method of inserting new pipe into an existing pipeline.

Slurry Microtunneling
Trenchless installation of pipe by jacking the pipe behind a remotely controlled, steerable, laser guided, microtunnel boring machine that provides continuous support to the excavated face under various geotechnical conditions including the presence of groundwater.

Socket
The portion of a jointing system that is designed to accept a plain-end pipe or a spigot-end pipe.

Specifying Agency
The individual engineer, firm, or political subdivision charged with and having the responsibility for the design of a facility, product, equipment, or material requirements.

Specimen
Sample, or portion thereof, which is to be tested and the test results to be reported.

Spigot
That portion of a vitrified clay pipe that fits into the bell or coupling of the preceding pipe.

Spring Line
The line of maximum horizontal dimension of the transverse cross section.

Steering Head
In pilot tube method, a rotatable slant faced unit located directly in front of the lead pilot tube that can be adjusted to steer the bore.

Stopper
A plug inserted in a pipe or fitting.

Superimposed Load
Load imposed by travel over, or by material brought and placed over the trench area, after pipe installation.

T

Tapping
A method used to field connect a building sewer to a main line.

Test Section
The portion of pipeline under test.

Test Specimen
Specimen, or portion thereof, which is to be tested and the test results reported, or which is to be prepared for further testing, and the test results reported.

Theodolite
An instrument for measuring both horizontal and vertical angles.

Thrust Ring
A fabricated ring that is mounted to the face of the jacking frame. It is intended to transfer the jacking load from the jacking frame to the thrust bearing area of the pipe section being jacked.

Transition width
The trench width, measured at the top of the pipe barrel, where backfill loads reach a maximum and are equal to embankment load. Further widening beyond this width will not affect the backfill load.

Trenchless Technology
(As defined by the North American Society for Trenchless Technology)
A family of construction techniques for installing or rehabilitating underground infrastructure with minimal disruption to surface traffic, businesses, and residents. Also includes technologies for inspection, leak location, and leak detection with minimal disruption and minimal excavation from the ground surface.

U

Unaided Eye
Visual inspection, without the use of special equipment or enhancement excepting the use of corrective lenses.

V

Vitrified Clay Pipe (VCP)
A pipe made from various clays or combinations thereof which are shaped, dried, and fired to a point where the glass-forming components fuse to form a bond between the crystalline grains.

W

Waterstop
Vertical barriers placed across the bottom of the trench to prevent migration of soil fines due to water movement.

Well Points
Single or multiple pipe which are usually fitted with a screen for the temporary removal of water from the bottom of the trench.

INDEX

P

Q

R

S

T

U

V

W

Our Member Companies

For specific questions about your project, please contact your pipe supplier.

LOGAN
loganclaypipe.com
800-848-2141

GLADDING, McBEAN
gladdingmcbean.com
800-776-1133

NO-DIG
no-dig-pipe.com
740-385-2184

MISSION
mission clay products LLC
missionclay.com
951-277-4600

building products company llc
buildingproductscompany.com
602-269-8314

Design – Installation – Inspection – Maintenance

NCPI offers the tools and training to ensure successful project design and installation. Vitrified clay pipelines, properly designed and installed, will serve the community indefinitely.

- **NCPI Toolbox Online**
  (Leastcost, Hyflow & Trench Load programs)
- **National Clay Pipe Institute YouTube Channel**
  Available videos range from manufacture of VCP to open trench and trenchless installations, bedding with CLSM made using native soil and haunching research, to name just a few.
- **NCPI's *Vitrified Clay Pipe Installation & Inspection Handbook***
  A reference guide covering vitrified clay pipe installation, inspection and testing practices designed for field use.
- **Educational Seminars**
  NCPI offers a variety of seminars to engineers, designers, contractors, installers, inspectors, operations and maintenance personnel. We want to ensure the success of your project. Seminars qualify for PDH credits.

For more information, or to schedule your seminar, contact your pipe supplier or call the NCPI office at 262-742-2904.

The National Clay Pipe Institute represents the clay pipe industry to sewer system decision makers. We offer the unique perspective, history and knowledge of the longest-serving and longest-lasting pipe product available.

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