Pipeline Separation Design and Installation Reference Guide

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Pipeline Separation Design & Installation Reference Guide

Version 9

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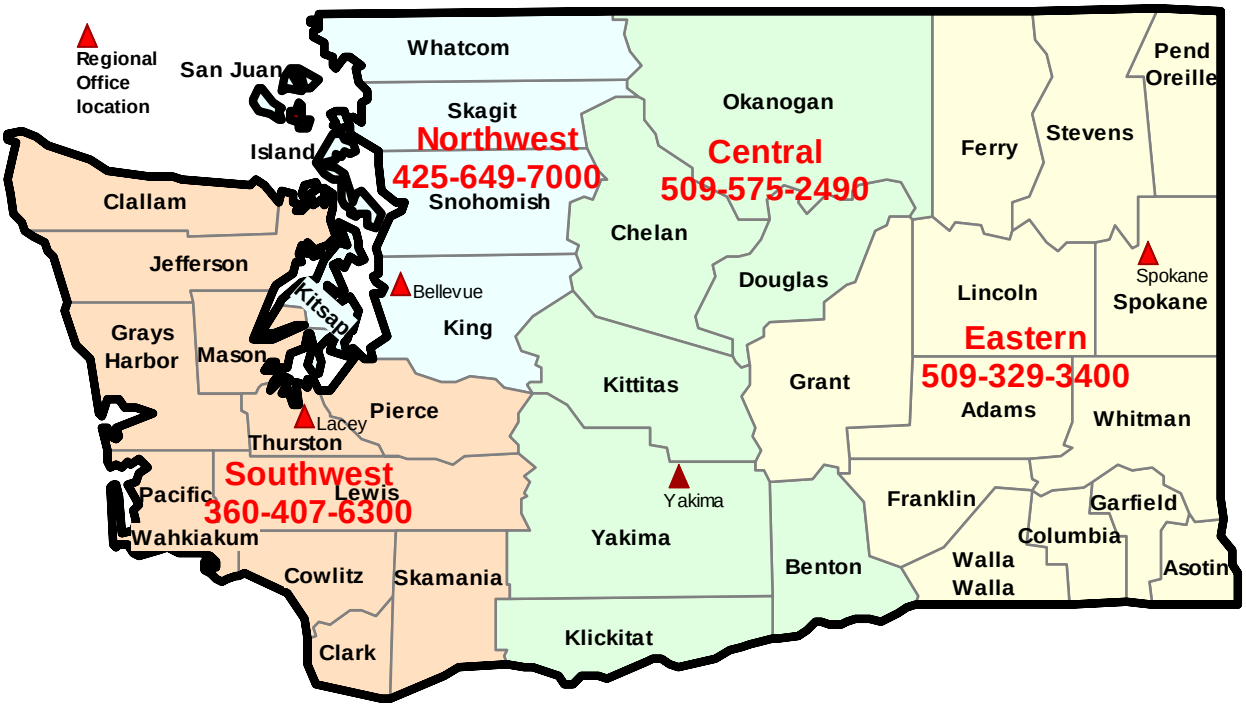

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Executive Summary

Introduction

As water reclamation and recycling assumes a larger and more important role in the management of water resources, challenges in designing and locating piping systems for the distribution of reclaimed water are daunting. Existing standards require horizontal and vertical separations between potable water, reclaimed water, storm water and sanitary sewage that are rarely available in developed urban areas. While special construction practices are allowed to overcome these obstacles, regulatory approval is required on a case-by-case basis. This process is cumbersome, and increases design and construction costs, as well as the completion schedules. The Washington State Department of Ecology and the Department of Health developed this guidance in response to the need for a streamlined process and to assist utility engineers with pipeline separation design and installation.

Pipeline separation is a necessity for protection of public health and safety, property and the quality of the pipeline contents. Pipeline failure or leaks can result in pipeline contamination that increases risks public health and safety. Pipelines do not have to rupture completely or collapse to cause concern. Even the process of excavating one pipeline to repair a leak creates the risk of complete failure of adjacent pipelines.

Separation Standards

The current pipeline separation standards are based on accumulated field and design experience, and the *Ten State Standards.*[1] These standards generally require a minimum horizontal separation of 10 feet between parallel pipes, and 18 inches of vertical separation. Many states have adopted these standards as guidance or regulation.

In 1968, engineers at Utah State University investigated the effects of trench excavation on separation distances from a buried parallel pipe. Their work resulted in a relationship between the distance from the trench face to the parallel pipe [sidewall thickness, X] necessary to prevent trench wall failure, the *critical* trench depth [Z], which depends on soil strength characteristics; the depth of bury [H] of the parallel pipe; and size of the parallel pipe [D]:

$$\frac{X}{D} = 3 \cdot \frac{H}{Z}$$

An analysis using this relationship shows that, in some instances, distances less than the standard horizontal separation distance can be justified. However, this distance is highly dependent on site and soil conditions. In almost all conditions, a minimum sidewall coverage depth of 2 to 3 feet is necessary to allow sufficient room for maintenance and repair efforts in the trench, the minimum pipe-to-pipe separation should be 3½ to 4 feet.

[1] Great Lakes Upper Mississippi River Board of State Public Health and Environmental Managers – Recommended Standards of Water Works, Criteria for Water Works, Section 8.6.

Separation-the Final Protection

Pipeline separation provides the final barrier of protection in the multi-barrier approach to pipeline protection. Other barriers include: 1) the selection of the pipe material, 2) pipe jointing method, 3) pipe bedding procedures and 4) thrust restraint or blocking. Barriers are intended to reduce risks to public health and safety; protect property; prevent contamination of the pipeline contents; protect pipeline customers and prevent collateral damage to other adjacent facilities. Pipeline separation is the final and most important barrier because it remains in place when the other barriers fail.

Special Construction Design

Most urbanized areas do not have the space available for standard separation distances. However, special construction methods can be used to assure equivalent levels of protection. Special construction methods are necessary whenever the minimum horizontal and vertical separations cannot be maintained. There are many common methods in use today. In selecting the special construction method and design, the design engineer needs to consider design factors such as external forces, impacts of ground water, and soils-strength characteristics.

Conclusions

To streamline the design and approval process, the agencies have identified three design conditions.

- Condition A exists when adequate separation distance is available and requires no unusual design considerations.
- Condition B exists when available horizontal separation is between 4 and 10 feet, and/or available vertical separation is between 6 and 18 inches. For Condition B, special construction methods developed, presented, and approved during the engineering phase of the project and included in the construction drawings through standard details are acceptable.
- When Condition C exists, available separation is less than 4 feet horizontally and/or 6 inches vertically. Under Condition C, the agencies must approve special construction on a case-by-case basis.

Introduction

Need for this Guidance

The installation of reclaimed water transmission and distribution piping is a major portion of any water reclamation project. The cost of piping and the challenges in fitting additional buried utilities into crowded utility corridors is often a deciding factor in assessing the project feasibility. Compliance with commonly used standards for horizontal and vertical pipe separation is proving difficult for nearly every project. Currently, the Department of Health and the Department of Ecology (the agencies) have allowed variations from these standards on a case-by-case approval basis. This approach is cumbersome and time consuming for the utility and the regulatory agencies. The agencies recognized the need for a more streamlined, responsive approach.

The agencies developed this guidance to streamline the approach to pipeline separation. These guidelines:

- Provide background information regarding the basis for pipeline separation standards;
- Describe the present standards developed from experience and soils mechanics;
- Describe modes of pipeline failure, the results of pipe failure, and factors that should be considered in the design of special conditions, and
- Provide general design guidance regarding approaches that can be approved by the regulatory agencies and can be applied without case-by-case, individual location approvals.

Background

Underground utility pipes provide the core services necessary to urban life. Drinking water transmission and distribution, wastewater collection and stormwater drainage systems now share underground corridors with natural gas, telecommunications, television and electrical power. In many water-limited areas, piped irrigation water lines are common, with reclaimed water being added to the collection of buried utilities. In order to allow access for maintenance and repair, utilities must compete for precious space in increasingly congested public right-of-ways.

The design of underground utilities commonly focuses on the selection of the pipe size to assure manageable pipeline velocities and internal pressure ratings. Other design concerns include:

- Pipe materials to address service life and product quality
- Pipe wall thickness to address internal and external pressures and forces
- Corrosion control needs and methods
- Valves for isolation and drainage
- Pipe jointing methods and
- Thrust restraint and control

During the design phase, engineers may not focus on the impact of existing, adjacent pipelines. This is because a construction project focuses on isolating, protecting, and addressing these conditions on a large scale. The original design should also address the needs during maintenance and repairs. Unfortunately, many pipeline failures occur because of the lack of attention to affects on and from existing pipelines.

The Need for Pipeline Separation

Importance of adequate separation

Many people do not easily understand or recognize the role of pipeline separation in protecting public health and the environment. However, pipeline contamination can expose pipeline customers to pollutants. Contamination results from cross-connections, leaks, or complete pipe failure of adjacent underground pipes. Pipeline designers can increase pipeline reliability through the proper selection of pipe materials, wall thickness, pipe joint systems, thrust restraint systems, pipe bedding, and internal and external corrosion control. But ultimately, pipelines corrode, leak, and fail. Adequate separation between pipelines provides the final barrier of protection. This minimizes incidental damage during the repair of other pipelines and leakage effects between pipes. Adequate separation also assures sufficient room to repair leaks and replace broken sections. Finally, separation reduces the potential for pipeline failure caused by a leak or failure of its neighboring pipeline.

Figure 1: Pavement damage due to pipe leak

Leakage Damage

The benefits provided by assuring pipeline integrity are neither readily recognized nor easily quantified, until a problem arises. Underground pipelines are out of sight, and out of mind. Commonly, we are aware of problems with these buried pipes only when a water line break shuts water off at home, or a sewer backs up into the basement. But these two instances represent inconveniences compared to more common results from pipeline leaks. The following photos show graphic damage created by leaking municipal utilities. Figure 1 shows pavement damage due to a leaking sewer and the consequences of a water main break in a residential area. Figures 2 and 3 show extensive damage caused to neighborhood streets by the collapse of a water or sewer line.

Public Health and Safety Protection

In extreme cases, attempts to repair damage to pipelines and the leaks from the pipeline can result in the death of utility workers. Between 1992 and 2001, 542 fatalities occurred in the United States that were attributed to trench and excavation cave-ins.[2] However, fatalities are not limited to utility workers alone. A leaking water main in North Carolina was implicated in a mudslide. The mudslide, in turn, caused the road to collapse into a house, killing a resident.

Figure 2: Water line break repair

The risk to public safety is obvious. The extent of property damage and injury can range from slight to catastrophic.

All piped utilities suffer damage, aging and wear. These problems can allow leakage or infiltration of ground water into the pipe. This reduces the quality of the pipeline contents and results in additional costs for delivery, maintenance, or disposal of the pipe contents.

Figure 3: Sewer break

Leaks in potable water lines can pose a significant health risk. In addition, they can cause a loss of revenue from a water system that has an investment in the withdrawal, treatment, and distribution.

[2] Centers for Disease Control, *Occupational Fatalities During Trenching and Excavation Work --- United States, 1992—2001*, April 23, 2004

Potable distribution and reclaimed water pipelines that operate under pressure and are subject to customer demands, fluctuating reservoir levels, and pump operation cycles. Hydraulic transients result from pump starts and stops, power failures, main breaks system operation, or sudden demand changes. This can result in both pressure surges and negative pressure conditions in the pipe.[3] Leaks may push water out of the pipeline, as well as pull water, soil, and naturally-occurring microbes back into the pipelines. This can result in contamination of the pipeline contents from micro-organisms and chemicals present in the soils surrounding the pipeline. These micro-organisms inoculate the pipe and support microbiologic regrowth. Pathogenic microorganisms are often more prolific in microbiologic regrowth materials.

Product Contamination

Pipe leaks or breaks can cause contaminants to spread into the environment or from pipe to pipe. Either condition requires pipe repair to maintain product quality. During the excavation and repair of one pipe, adjacent pipes remain in service and vulnerable to failure. Pipes exposed or damaged during an excavation repair of an adjacent pipe (Figure 4) often represent the largest source of leaks. Pipelines undergoing repair provide the best opportunity for contaminants to enter large openings created during the repair process.

Figure 4: Pipeline exposure during repair

Contamination of the contents of underground pipelines occurs when the contents of one pipe leaks out and into the soil, and then is drawn into an adjacent underground pipe. Even small leaks present a contaminant source. Materials outside the pipe can be drawn into the pipe during pressure surges and vacuum conditions created by hydraulic transients.

Pipe-to-pipe contamination includes: 1) raw sewage leaking into water mains, 2) chemical leakage into reclaimed water mains, 3) raw ground water leaks entering potable pipelines, or 4) contaminated soil being drawn into drinking water systems. Raw sewage, petroleum, or chemical products can leak into the environment causing environmental degradation. In the case of natural gas pipelines, leaks can cause explosions.

[3] Gullick, LeChevallier, Svindland, & Friedman, *Occurrence of Transient Low and Negative Pressures in Distribution Systems*, Journal AWWA, 96:11; November 2004

Collateral Damage

All underground utilities are at risk of a leak or pipe failure. The leak or failure can severely damage adjacent utilities. The collapse of a sewer can cause damage to adjacent utilities, as depicted in Figure 5. This figure shows a worker standing on a water main as the excavation is being dewatered from another portion of the hole. Figure 6 shows damage to electrical, gas, and telephone utilities.

Figure 5: Waterline exposed by sewer collapse

Maintenance & Repair

All underground pipelines eventually require maintenance and repair. In an effort to maximize their water resources, public water systems increasingly require leak detection and correction. Maintenance to repair small leaks, broken valves, or leaking valve stems requires excavation to access the pipe or valves.

Figure 6: Collateral utility damage due to sewer collapse

The process of locating and exposing underground utilities for repair places other buried utilities in jeopardy of creating more leakage from movement of unsupported, exposed joints, or directly from excavation equipment. Primary components of any maintenance program include 1) ease of access for maintenance and 2) repair and protection of workers and adjacent utilities. Proper design decisions ease future maintenance just as poor design decisions complicate repair or replacement.

Pipeline Separation Challenges

The protective barrier provided by adequate separation creates additional design and economic challenges. With increasing needs, utilities must maximize utility corridors in public right-of-ways. Either utilities must widen utility corridors at great expense for additional land, if available, or remove and relocate an existing utility.

Alternatively engineers can devise strategies that will provide an equivalent level of protection as that afforded by adequate spacing. This alternative process requires more time; and stretches completion schedules. However, the benefits include reliability and protection for public health and safety, with potential savings in construction materials and effort.

Pipe Separation Standards

Elements of Adequate Separation

Excavations are made to install or repair underground pipes. To do so, provide sufficient room between the trench wall and the pipe on both sides to conduct the work. The agencies recommend a 12- to 18-inch minimum distance.

The design adage holds very true for underground pipelines:

> *All of the really important mistakes are made the first day (during design).*

The design must focus on maintenance and repair, not just the installation of a new pipeline.

Current Standard

The current pipeline separation standards address conditions where potable and non-potable pipelines run parallel to each other, and where these pipelines cross vertically. The best-known standards are those published in well-known and used utility design guidelines and standards. However, parallel separation requirements follow the principles of soil mechanics. The approach based on soil mechanics provides a basis for reduction of horizontal separations under some conditions, and reinforces the need for significant separations in others.

Published Separation Criteria
The current standards are based on standard practices developed decades ago and published as the *Ten State Standards*.[4] These standards have been widely adopted and can now be found in other industry standards and state regulations such as:

- American Water Works Association - Manual M24- Dual Distribution Systems and California –Nevada Section AWWA – Guidelines for Distribution of Nonpotable Water
- Washington State Department of Ecology – Criteria for Sewage Works Design
- Washington State Department of Health – Water System Design Manual

The current standards require a minimum horizontal separation of 10 feet between separate trenches, and vertical separations of at least 18 inches. Pipe crossings require a minimum vertical separation of 18 inches with the section of the top pipe centered over the bottom. When these separations cannot be provided, special construction methods must be provided.

[4] Ibid 1

Horizontal Separation

The minimum horizontal separation required between potable and reclaimed water pipelines that run parallel to other nonpotable pipelines is 10 feet of clear, pipe-to-pipe separation. Figure 7 provides a cross-section of a typical urban street with drinking water pipelines, reclaimed water distribution pipes and sanitary sewers. Figure 8 illustrates a typical cross-section after a reclaimed water retrofit.

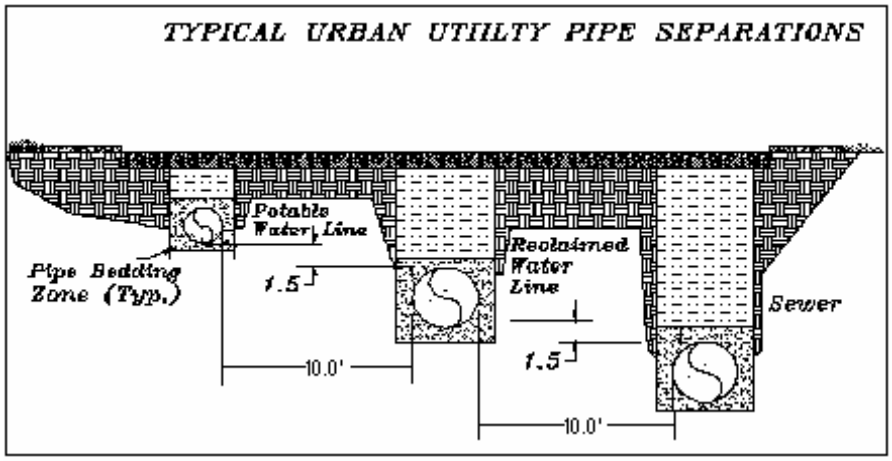


Figure 7: Standard horizontal pipe separation detail

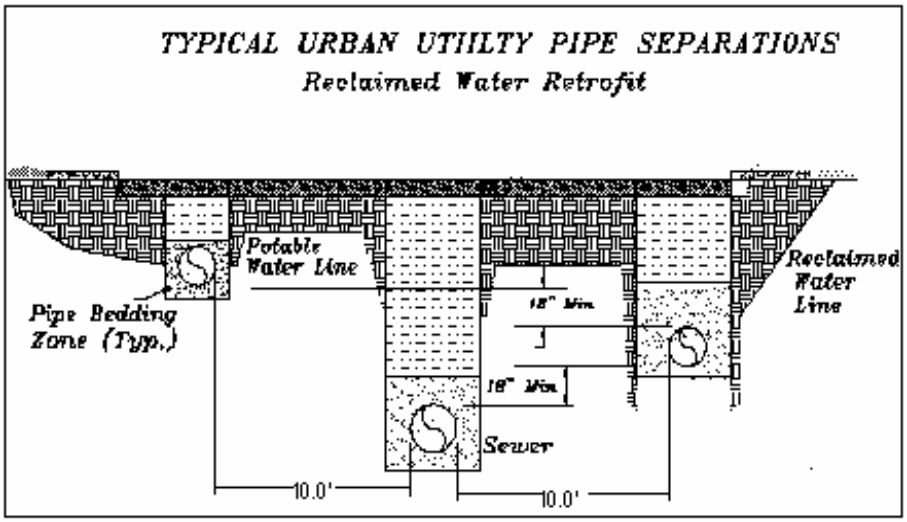


Figure 8: Standard horizontal pipe separation new construction detail of reclaimed water in developed utility corridor

Vertical Separation
The minimum vertical separation between potable and nonpotable pipelines at crossings is 18 inches (Figure 9). Potable water lines should cross above the nonpotable lines. When the nonpotable line must cross above the potable pipeline, the engineer should encase one or both of the pipelines encased with a pressure rated casing pipe extending at least 10 feet on either side of the crossing.

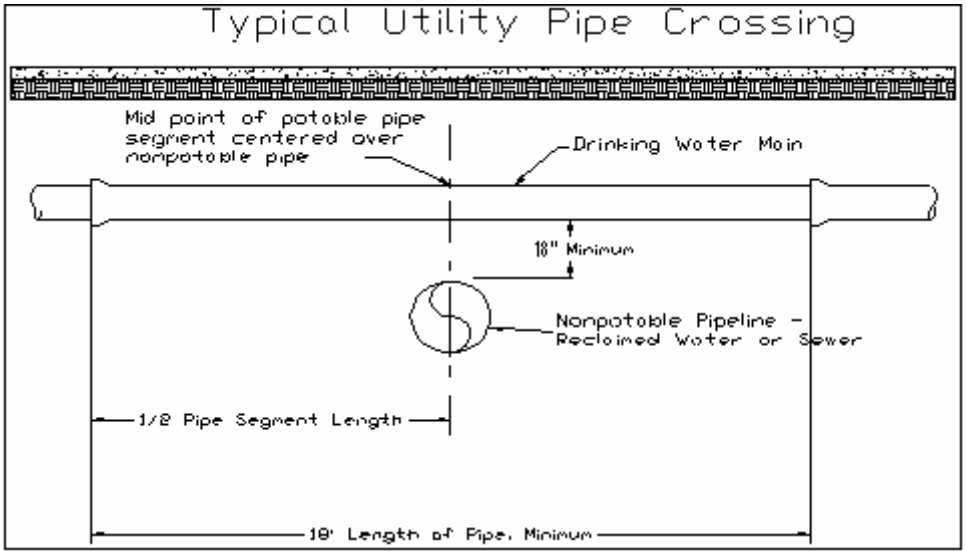


Figure 9: Standard pipe crossing new construction detail - vertical separation

Current States' Standards
While many states have adopted the *Ten State Standards* as regulation, several other states have adopted different pipeline separation standards. Some regulations address only water and sewer separations, while others address water, reclaimed water, and sanitary sewer separations jointly or separately. Unfortunately, the standards do not provide a great deal of consistency regarding horizontal and vertical separations, other than the requirements to provide a minimum separation. Table 1 provides a summary of pipeline separation standards for several states.

Table 1: Utility separation regulations and standards from various states

State	Drinking Water-Sanitary Sewer	Drinking Water – Reclaimed Water	Reclaimed Water – Sanitary Sewer	Source of Standard	Notes
Utah	10 ft horizontal	10 ft horizontal	10 ft horizontal or 3 ft horizontal	Utah Administrative Code	If reclaimed water is below or above sewer
Massachusetts	10 ft horizontal		Not addressed	2001 Guidelines and Policies for Public Water Systems	Reclaimed water not specifically addressed
Oklahoma	10 ft horizontal	5 ft horizontal	Not addressed	Oklahoma Regulations for Public Water Systems; Water Pollution Control Facility Construction	Sewer and water line cannot occupy same trench
California	10 ft horizontal & 1 ft vertical	Reference to Cal-Nevada AWWA Guidelines for Distribution of Non-Potable Water	Reference to Cal-Nevada AWWA Guidelines for Distribution of Non-Potable Water	California Safe Drinking Water Act	If unable to meet separation; separation as far as possible in separate trenches
Georgia	10 ft horizontal Not is same trench with sewer	3 ft outside to outside of pipe, 18 inches from bottom of water and top of reuse	3 ft outside to outside of pipe	Georgia Guidelines for Water Reclamation and Urban Water Reuse & Minimum Standards for Public Water Systems	Maximum obtainable separation possible; water-sewer separations less than 10 ft – case by case review
Texas	9' outside to outside in *all* directions	Not specifically addressed	Not specifically addressed	Texas Administrative Code, Title 30, Part 1, Chapter 290.44	Parallel installations require separate trenches
Texas Special Conditions	Non-pressure sewers: PE determination of no leaks; water 2 ft above, minimum 4 ft horizontal New waterline: minimum 150 psi pressure rated pipe; water 2 ft above, minimum 4 ft horizontal Crossings: water 2 ft above sewer; if sewer leaking – replace 9 ft either side of water (18' total) with 150 psi rates pipe; New water line installation above sewer – segment centered over sewer 9 ft to joint both directions; New water over existing non pressure sewer – water centered over sewer, sewer to have minimum pipe stiffness of 150 psi at 5% deflection, sewer embedded in cement stabilized sand [2½ bags cementer per cubic yard of mixture] 6 inches above and 4 inches below sewer				

Engineering and Soils Mechanics Methods

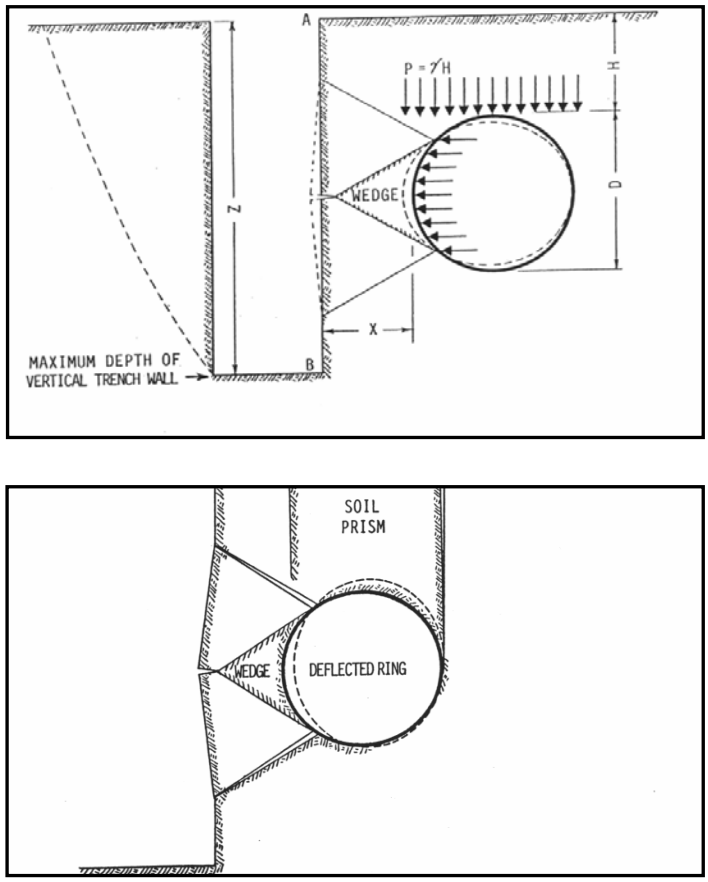
Research at Utah State University in 1968 identified mechanisms of failure and trench collapse for the excavation of parallel trenches. The researchers identified mechanisms for failure of a parallel buried pipe related to the separation distance to a newly excavated trench. They also developed design guidance to assure adequate separation from the trench wall to the parallel pipe. The information and the following illustrations in Figures 10 and 11 were taken from *Structural Mechanics of Buried Pipes.*[5]

The result was a dimensionless relationship that correlates the diameter of the buried pipe (D), the depth of bury of the pipe (H), the *critical trench depth (Z),* and the side-wall cover, or minimum horizontal spacing from the trench face to the face of the pipe (X). The ratio between the critical trench depth and the depth of bury of the pipe, and the ratio between side-wall cover to pipe size is given by Equation 1:

$$\frac{X}{D} = 3 \times \frac{H}{Z}$$

Where:

X = side cover or minimum horizontal spacing, feet
D = pipe diameter, feet
H = depth of bury of the pipe, feet
Z = critical trench depth, feet



Figures 10 and 11: Mechanism for parallel trench collapse

The critical trench depth (Z) is the depth at which the native soil will stand in a vertical cut without sloughing or raveling. The engineer can estimate critical trench depth based on field experience, from a field cut, or estimated from the principles of soils mechanics. The soils mechanics method uses soils properties of unit soil weight (pcf [γ]), soil cohesion (psf [C]), and the soil friction angle of the trench wall ([φ]) as follows:

[5] Reynold King Watkins, PhD., P.E. and Loren Runar Anderson, PhD., *Structural Mechanics of Buried Pipes*, Utah State University, CRC Press, 2000, ISBN 0-8493-2395-9

Equation 2:

$$\frac{2C}{\gamma Z} = \tan\left[\ 45° - \varphi/2\ \right] \quad \text{or} \quad Z = \frac{[2C]}{\left[\gamma \tan\left(45° - \frac{\varphi}{2}\right)\right]}$$

Soils Properties Impacts on Critical Trench Depth

Critical trench depth is directly depended upon the soil cohesive strength, C. Typical strength characteristics of soils are shown in Table 2 below.[6]

Table 2: Soil Strength Properties

Group Symbol	Soil density, g, pcf		Cohesion, C, psf		Soil friction angle		Description
	Minimum	Maximum	Compacted	Saturated	φ, degrees, ◦		
GW	125	135	0	0	38		well graded, clean sands, gravel sand mixtures
GP	115	125	0	0	37		poorly graded clean gravels, gravel-sand mixture
GM	120	135	-	-	34		silty gravels, poor graded gravel - sand silt
GC	115	130	-	-	31		clayey gravels, poorly graded gravel-sand-clay
SW	111	130	0	0	38		well graded clean sands, gravely sands
SP	100	120	0	0	37		poorly graded clean sands sand-gravel mix
SM	110	125	1050	420	34		silty sands, poorly graded sand-silt mix
SM-SC	100	130	1050	300	33		sand-silt-clay mix with slightly plastic fines
SC	105	125	1550	230	31		clayey sands, poorly graded sand-clay mix
ML	95	120	1400	190	32		inorganic silts and clayey silts
ML-CL	100	120	1350	460	32		mixture of organic silt and clay
CL	95	120	1800	270	28		inorganic clays of low-to-medium plasticity
OL	80	100	-	-	-		organic silts and silt-clays, low plasticity
MH	70	95	1500	420	25		inorganic clayey silts, elastic silts
CH	75	105	2150	230	19		inorganic clays of high plasticity
OH	65	100	-		-		organic and silty clays

Table 2 also displays the effect of soil properties on basic soil strength. Coarse-grained soils such as sands and gravels exhibit no cohesive force, which would result in predicted critical trench depths (Z) of zero. *The presence of ground water also greatly influences soils strength.* Under saturated conditions, cohesive soils such as clays, which normally exhibit significant cohesive strength, develop cohesive strength that is often less than ⅓ of the dry, compacted value. Critical trench depth depends on soil density.

Figure 12 shows a comparison of predicted critical trench depths related to soils classifications in cohesive soils based on the range of reported soil densities and the condition of the soils.

[6] *Civil Engineering Reference Manual*, Professional Publications, Inc., San Carlos CA; Page 9-17

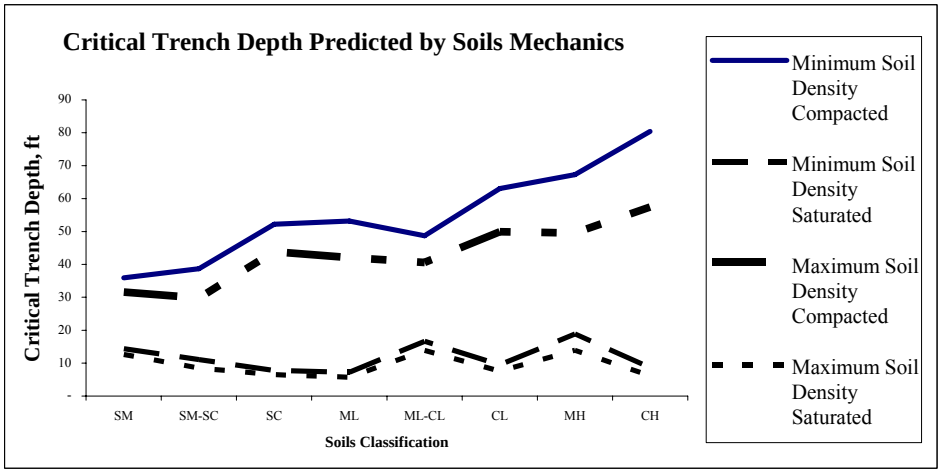


Figure 12: Critical trench depth based on soils properties

Cohesive soils have a wide range of predicted critical trench depths. The differences in the predicted critical trench depths for cohesive soils are noteworthy. These predictions reinforce the need to base design decisions on the worst-case excavation conditions expected along the pipeline route.

Parallel Trench Separation vs. Critical Trench Depth:

Estimates of pipe and trench separation distances based on soils properties and critical trench depths help confirm the written standards. Equation #1 can predict horizontal trench wall-to-pipe and pipe-to-pipe separation. Engineers should design separation to include sufficient space between the pipe and the trench wall for construction or repair activities at least 12 inches, and preferably 18 inches wide as shown in Figure 13.

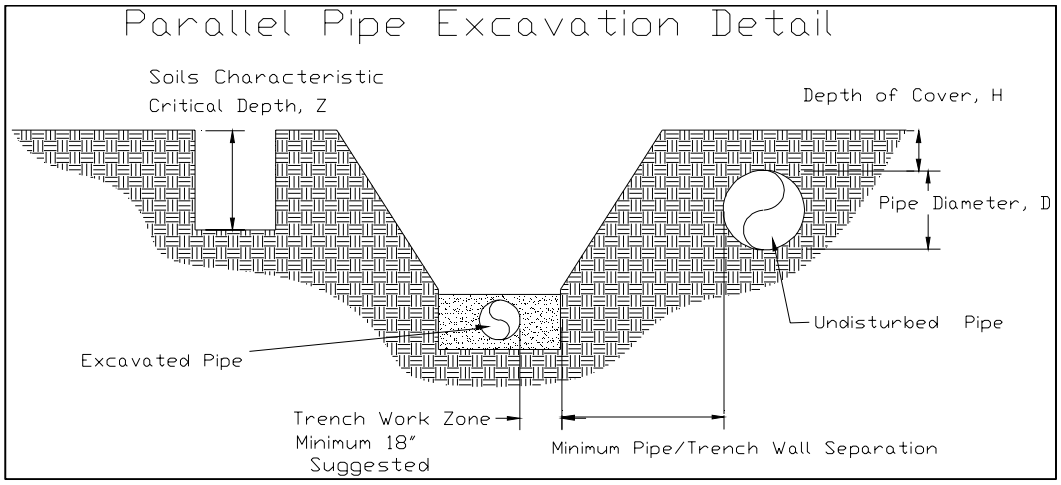


Figure 13: Parallel pipe excavation mechanics

Tables 3 and 4 illustrate the affect of soils properties and the size and depth of cover of an adjacent pipe on minimum sidewall coverage or horizontal spacing. These tables predict

the sidewall cover thickness required for excavation parallel to a water line and a sanitary sewer based on Equation 1. The calculations in Table 3 assume the water line is buried at a typical depth of 3½ feet, and varies from 6 inches to 24 inches in diameter. The calculations in Table 4 assume the sanitary sewer is buried at a typical depth of 6 feet, and varies in size from 6 inches to 24 inches.

Table 3: Estimates of horizontal pipe separation vs. critical trench depth for water line buried at 3.5 feet

Horizontal Separation Requirements for Parallel Pipes

X/D = 3H/Z & X = 3HD/Z

Burial Depth, H, ft = 3.5 feet Parallel Waterline

Critical Depth, Z, ft	Pipe Diameter, D, inches 6	8	10	12	15	18	24
2.00	2.6	3.5	4.4	5.3	6.6	7.9	10.5
2.50	2.1	2.8	3.5	4.2	5.3	6.3	8.4
3.00	1.8	2.3	2.9	3.5	4.4	5.3	7.0
3.50	1.5	2.0	2.5	3.0	3.8	4.5	6.0
4.00	1.3	1.8	2.2	2.6	3.3	3.9	5.3
4.50	1.2	1.6	1.9	2.3	2.9	3.5	4.7
5.00	1.1	1.4	1.8	2.1	2.6	3.2	4.2
5.50	1.0	1.3	1.6	1.9	2.4	2.9	3.8
6.00	0.9	1.2	1.5	1.8	2.2	2.6	3.5

Table 4: Estimates of horizontal pipe separation vs. critical trench depth for sanitary sewer line buried at 6.0 feet

Horizontal Separation Requirements for Parallel Pipes

X/D = 3H/Z & X = 3HD/Z

Burial Depth, H, ft = 6.0 feet Parallel Sanitary Sewer

Critical Depth, Z, ft	Pipe Diameter, D, inches 6	8	10	12	15	18	24
2.00	4.5	6.0	7.5	9.0	11.3	13.5	18.0
2.50	3.6	4.8	6.0	7.2	9.0	10.8	14.4
3.00	3.0	4.0	5.0	6.0	7.5	9.0	12.0
3.50	2.6	3.4	4.3	5.1	6.4	7.7	10.3
4.00	2.3	3.0	3.8	4.5	5.6	6.8	9.0
4.50	2.0	2.7	3.3	4.0	5.0	6.0	8.0
5.00	1.8	2.4	3.0	3.6	4.5	5.4	7.2
5.50	1.6	2.2	2.7	3.3	4.1	4.9	6.5
6.00	1.5	2.0	2.5	3.0	3.8	4.5	6.0

As an example, a project engineer proposes a new pipeline installation parallel to and below an existing 18 inch-diameter waterline that is buried 42 inches (3½ feet) deep. If the soils along the project route are cohesive and stand to a critical trench depth of 3 feet, the engineer should provide a minimum trench side wall thickness of 5.3 feet. The design should also include an 18 inch work space. Thus, the design should provide minimum pipe-to-pipe horizontal separation of 6.8 feet (5.3 + 1.5).

These examples shown in the tables reveal that, in addition to soils strength, the size and depth of bury of the adjacent parallel pipe have a significant effect on minimum side wall cover thickness. By including a minimum 18 inch repair zone, the minimum pipe-to-pipe separation in a soil exhibiting a critical trench depth of 4 feet varies from: :

- 3 to 4 feet for typical water distribution pipes of up to 10 inches in diameter at relatively shallow depths of bury (i.e., 42 inches-Table 3) and
- 4½ to 5 feet for typical sanitary sewers at relatively shallow depths of bury (i.e., 6 feet – Table 4).

For lower strength soils that will sustain only a 2-foot vertical trench wall, the minimum required separations increase to 4 to 6 feet for the shallow water line and 7½ to 9 feet for the shallow sanitary sewer.

These computations illustrate the variability estimated for minimum pipeline separation distances when the engineer knows the soil properties and has accurate knowledge of the adjacent underground pipelines. These computations also support the established minimum separation standards that have been applied historically. These standards were established as a one-size-fits-all approach without knowledge of local soils or adjacent utilities.

Minimum Pipe Separation Determination Procedures

General

The design decisions locating underground pipelines *must* account for future excavation for repair or replacement. This protects public health and the environment, as well as the other underground utilities and surface improvements. The agencies have developed a revised approach to the review and approval process for pipeline separations and provided this guidance to allow designers discretion and more flexibility under many conditions where standard 10-foot separation distances are not available.

This section provides the revised regulatory approach to review and approval, discussions of engineering design, relevant location issues, and additional mitigation measures that could be used for justification of shorter separation distances.

Current Procedures

Present project approval procedures require special design and installation proposals whenever a nonpotable pipeline encroaches within 10 feet parallel to a potable water main or within 18 inches at a vertical crossing. Under these conditions engineers must propose special design and installation methods and then submit them to the regulatory agencies. The agencies approve these special design and installation methods on a case-by-case basis. This procedure can result in a multitude of separate reviews and approvals during the course of one pipeline installation project.

Streamlined Procedures

The agencies have established streamlined procedures for three distinct sets of design and field conditions based on space available, knowledge of soils properties and adjacent utilities, and minimum distance designated for the *sidewall safety zone*. The first condition occurs when standard separation distances are available and common design practices are applied. The second condition occurs when the available vertical and/or horizontal separation distances are less than the required minimum but greater than the sidewall safety zone. The third condition exists when the available space for separation is less than necessary for the sidewall safety zone.

Sidewall Safety Zone

The *sidewall safety zone* is a zone in which additional caution is necessary during the design, construction, or repair process. Within this zone, the designers should collaborate with representatives of all the responsible utilities and regulatory agencies. These utilities may include the potable water system, sewage, storm water, reclaimed water, gas, electric, telephone and communications, or any other underground utility purveyor.

The agencies have selected the minimum dimensions of the sidewall safety zone as *4 feet horizontally* between parallel pipes and *6 inches vertically* at pipe crossings.

The agencies selected dimensions for the sidewall safety zone to define conditions that warrant special consideration in the design and location of underground pipelines for commonly encountered conditions in pipeline designs. The primary variables affecting the decision include soils strength characteristics and the size and location of adjacent buried pipelines (variables Z, D and H in Equation 1). In addition to these engineering based concerns, engineers should include practical construction-related considerations.

These dimensions of the sidewall safety zone were selected to:

- Allow space for construction or repair activities between the pipe and trench wall.
- Provide a minimum trench sidewall cover depth for a parallel pipe.
- Assure consideration of surface surcharge affects from operating construction equipment or excavation spoil pile on the minimum trench sidewall thickness.
- Allow for a minimum cover depth to assure protection from damage to pipes during construction and from native materials and adjacent pipes.

Construction / Repair Work Space

Past practices set the definition of "adequate space" in construction trenches at 12 inches. Historically, trench dimensions used in construction estimates were based on a minimum trench width equal to the outside pipe diameter plus 1 foot on each side of the pipe. More recently, due to construction safety requirements, 4-foot trench widths are used to accommodate trench boxes and other trench safety equipment (Figure 14). This practice provides a working zone of 2 feet from the pipe centerline to the trench wall, and allows work space of at least 18 inches for pipes up to 12 inches in diameter. Construction practices for larger pipes require sufficient space for bedding under the pipe haunch in lifts and to allow for compaction by either manual tamping or the use of plate compactors. A minimum of 24 inches between the trench wall and pipe is necessary to complete this work. However, for the majority of smaller pipe installations, an 18-inch work space under normal construction practices should be adequate.

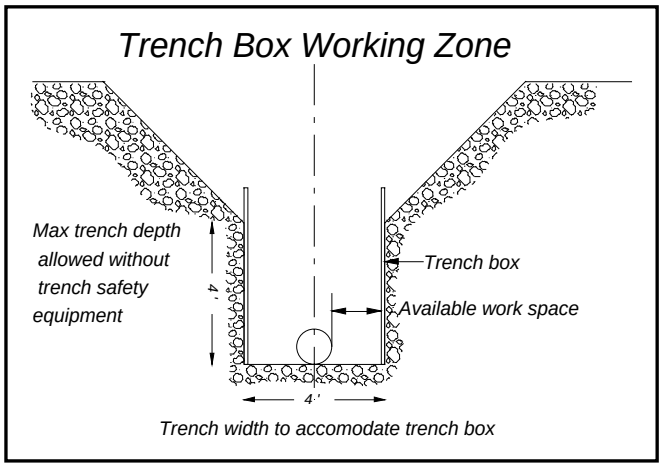


Figure 14: Trench working zone

The practice of assuring 18 inch work space is also consistent with the "best practices" of the National Utility Contractors Association, which defines an "excavation tolerance zone" as the "width of the facility plus 18 inches on either side of the outside edge of the underground facility on a horizontal plane."[7]

[7] National Utility Contractors Association, *Excavation Best Practices and Liability Protection*.

Minimum Trench Sidewall Cover Depth

The agencies used the Utah State University model presented in Equation 1 in selecting a minimum sidewall safety zone. This cover depth depends on typical soil characteristics and size and *effective* depth of bury of parallel underground pipes. Both the soil characteristics expected along a pipeline route and effective depth of bury vary much more than the expected sizes of the underground pipes. The selection of the sidewall safety zone was based on conditions that should be expected in the majority of designs and installations throughout this region. The conditions selected were:

- Pipe – 6-inch to 8-inch diameter: Current minimum pipe size for both water distribution pipes and gravity sewers of 8 inches generally represents the largest proportion of pipe lengths inventoried in water system plans and wastewater facility plans. The current minimum sizes increased from the previous minimum standard 6-inch diameter pipes.
- Soils strength characteristic – critical trench depth = 4 feet: Critical trench depth depends on the cohesive strength of soils, which depends on the characteristics of the soils that are predominant within the construction zone. These soils characteristics will presumably apply within established most cities and towns in this region. Most municipalities developed along the banks of rivers, lakes or the ocean shore, where soils are commonly alluvial sand, gravel, and silt deposits. Many alluvial soils are non-cohesive, resulting in a theoretical critical trench depth of zero. Field experience shows that where cohesive soils are encountered they exhibit trench walls up to about 4 feet without raveling or sloughing in dry conditions. Depths greater than 4 feet can occur, but infrequently.
- Effective depth of bury: Soils above a buried pipe exert pressure on the pipe, while forces created by surface activities increase the effective pressure created by the soils over the pipeline. The combination of soil pressure and surcharges create the forces that can cause collapse to a parallel trench. The pressure depends directly on the effective burial depth of the pipe.

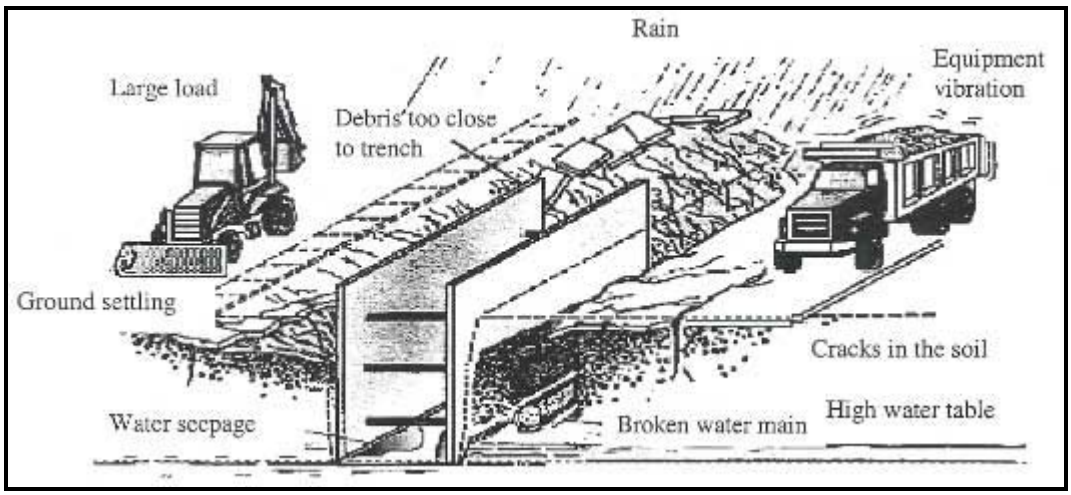


Figure 15: Causes of cave-ins (trench surcharges) from Saskatchewan Labour Ministry

The effective depth of burial depth was selected from considering common factors such as the minimum pipeline burial depth of 36 inches to assure structural adequacy of the pipe, minimum frost depth, which is 42 inches in the majority of this geographic region, and a burial depth of 8 to 9 feet to accommodate service to sanitary sewers from residential basements. In addition to the actual burial depth, surface activities requirements during construction that result in a pressure surcharge were considered. Surcharges are created by excavation spoil piles (Figure 15), operation of construction equipment at the trench, and even local traffic on roads and streets, resulting in an effective depth of bury much greater than the actual depth of bury. At a minimum, surcharge from trench excavation spoils of at least 50% of the depth of the excavation trench should be considered in establishing the effective depth of bury. For this analsyis, a minimum effective depth of bury of 6 to 7 feet was used.

Results: Table 5 shows the minimum depth of cover for a trench sidewall predicted by Equation 1 of 2.3 feet to 3.0 feet for 6 and 8-inch diameter pipes.

Table 5: Trench sidewall cover estimate

X/D = 3H/Z			
Effective Burial Depth, H, ft 6.0			
Critical Depth, Z, ft	Pipe Diameter, d, inches		
2.00	4.5	6.0	7.5
2.50	3.6	4.8	6.0
3.00	3.0	4.0	5.0
3.50	3.6	3.4	4.3
4.00	2.3	3.0	3.8

Horizontal Dimension

For the horizontal dimension of the sidewall safety zone use 4 feet. This represents the minimum dimension predicted using the Utah State University model (≈ 2½ feet), while allowing adequate work space (18 inches = 1½ feet).

Minimum Pipe Cover

This guidance recommends using a minimum vertical separation of 6 inches. The recommendation is based on recommended practices of pipe manufacturers for pipe bedding and common construction practices. Pipe manufacturers' standards require a minimum depth of cover of 6 inches surrounding a pipe to prevent damage to the pipe during installation. This depth assures sufficient separation between the pipe and any object, such as a rock that may be driven into the pipe or rub against it. The 6-inch separation allows settlement and pipe movement during compaction, without resulting in pipe failure.

The vertical separation also considers pipe bedding compaction methods for pipes in tight places. A minimum space of 6 inches achieves adequate backfill with select bedding and hand tamper compaction.

Design Review Conditions

Table 6 shows the three conditions designated based on space available.

Table 6: Conditions for separation in design with space available

	Horizontal Separation Space Available		Vertical Separation Space Available	
	Minimum	Maximum	Minimum	Maximum
➢ Condition A	≥10 feet	N/A	≥ 18 inches	N/A
➢ Condition B	< 10 Feet	> 4 feet	< 18 inches	> 6 inches
➢ Condition C		≤ 4 feet		≤ 6 inches

Regulatory Approval Requirements
Minimum requirements to receive regulatory approval will vary depending on the separation space available.

For **Condition A** situations, the engineering design report and specifications must show that the minimum horizontal and vertical separations of 10 feet and 18 inches, respectively will be maintained between potable water and any nonpotable pipe, and between reclaimed water and other nonpotable pipes.

For **Condition B** situations, engineers should include construction details and specifications in the construction documents submitted for agency review and approval. These details govern the location of pipelines within space limits shown above for Condition B. In developing these standard construction details, engineers need to consider critical or controlling design conditions such as expected soil cohesion, excavation depth, pipe materials, surface imposed damage risk, and groundwater levels.

Condition C situations require special construction details on a case-by-case basis. The engineer can identify these situations during design and provide construction details for each location in the construction drawings in addition to connection details and other critical locations.

In addition to the guidance above, Figure 16 provides a decision tree delineating the considerations for the pipe separations.

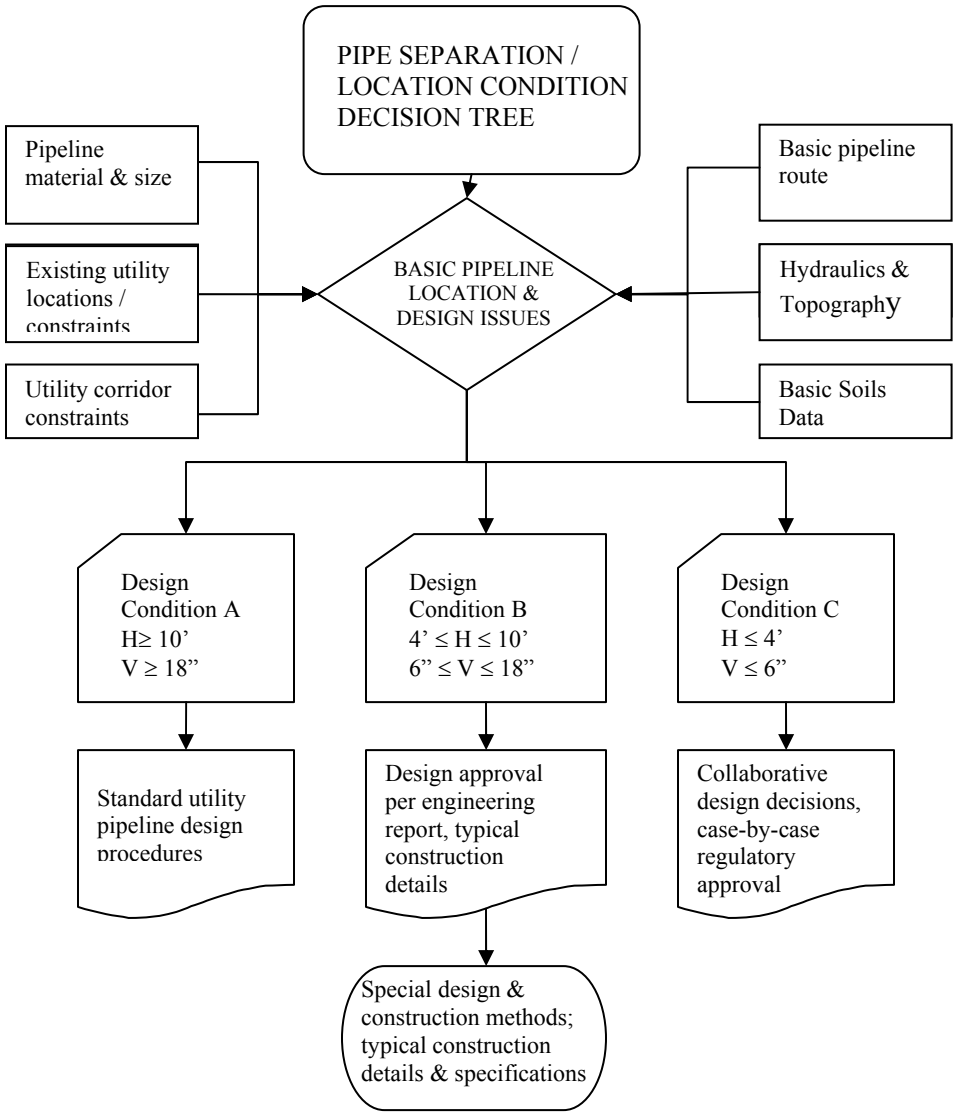


Figure 16: Pipe separation assessment decision tree

Recommendations for Alternatives to Standard Separation for Condition B

Design engineers should consider several current designs options to provide protection to public health and safety equivalent to the required minimum separations:

- Common trench construction with separate undisturbed benches
- Pipe and joint selection
  - Thick wall, pressure rated pipe
  - Special construction joints
  - Restrained joint piping versus thrust blocks
  - Substitution of pressure-rated pipe and joints in gravity installations
- Pipe sleeves
- Cement encasement
- Controlled density fill between pipelines
- Multiple pipe identification covers and location tapes
- Vapor barriers or trench curtains

Typical Construction Details Condition – B

Designers should implement alternative design procedures when Condition B spacing is encountered. The design engineer should include typical construction details (Figure 17) for these locations in construction drawings. Include limitations for use of these details such as:

- Variations in soil types that would preclude the application of normal trenching methods.
- High groundwater conditions.
- Saturated soils at the toe of the trench/
- Limits to the critical trench depth for soils encountered along the route. Both regulatory agencies should be aware of the potential conflicts of the standard separation sand the designs proposed to address these conditions. Therefore, the engineer must incorporate these limitations in the Facilities Plan, Engineering Report, or Project Report for the project.

Figure 18 *suggests* the construction details for horizontal and vertical pipe separation included as typical construction details that could be incorporated into pipe system designs for Condition B.

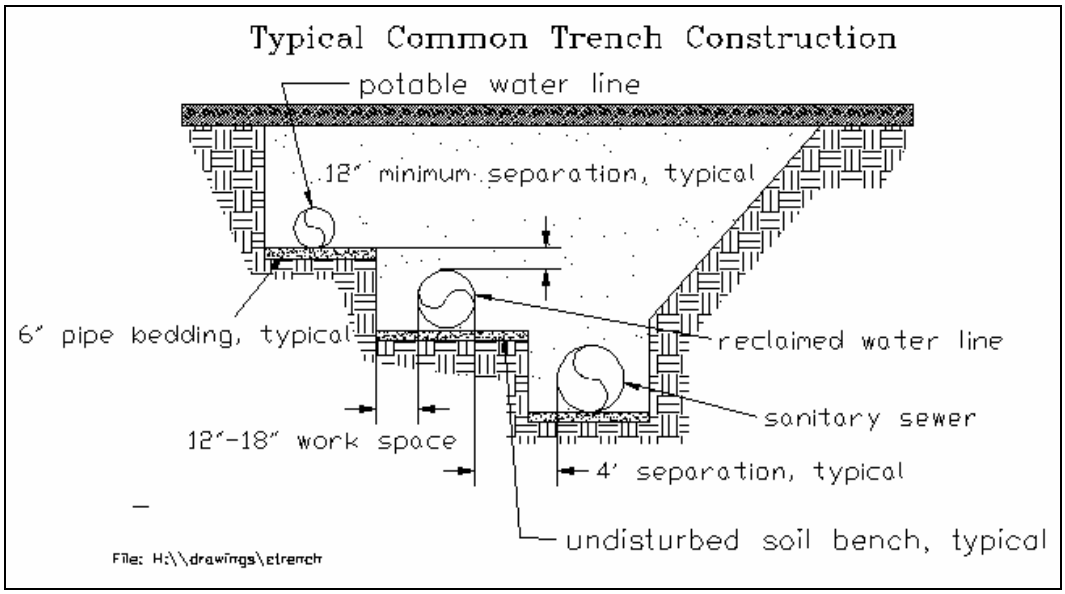


Figure 17: Typical benched - common trench construction detail

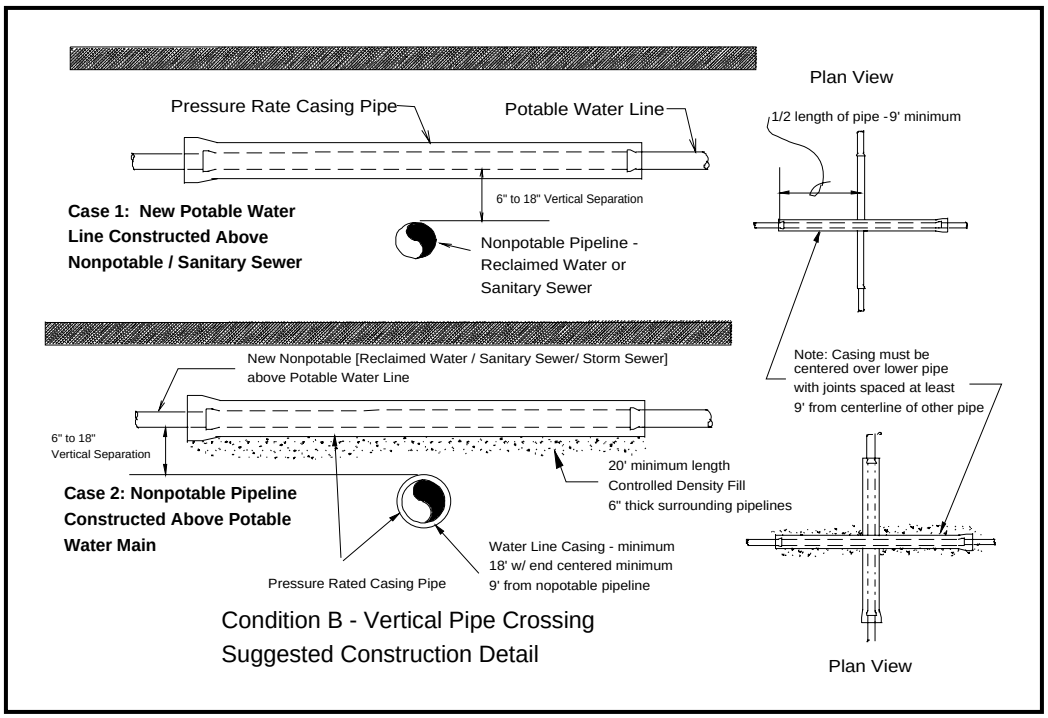


Figure 18: Typical pipe crossing construction detail Condition B separation

Case-by-case Approval Requirements – Condition C

General

Some situations will require special consideration and collaboration. The research into the effect of soil properties indicates that the point at which failure occurs between parallel trenches is sudden and catastrophic. The approach to minimum separation standards provides a sufficient side wall safety zone including a safety factor during the construction or repair phases. However, engineers may encounter some situations where an adequate side wall safety zone is not available to assure minimum pipe support by the soil structure. In these situations, the risk of pipe failure and collapse is the greatest. Prevention of pipe failure and contamination is considered critical to the integrity of the entire pipe system. All parties (the designer, management, operations staff, adjacent utility purveyors and regulatory personnel) must remain aware of these instances, ensure opportunities for collaboration, and integrate accumulated experience when the available separation distances are within the side wall safety zone.

Approval Requirements

For pipes located within the sidewall safety zone, the design must meet the following criteria: 4 feet or less horizontal pipe spacing and 6 inches or less vertical separation. In these situations, the owner must obtain regulatory review and approval on a case-by-case basis.

Approval Process

Engineers should propose Condition C design or location only when no other alternatives exist. Regulatory agencies view pipeline installation in this zone as the last resort. An engineering report must address all relevant issues in justifying the proposed location and construction methods. To receive regulatory agency approval the engineer must address all of the following factors:

1. Pipe material, wall thickness, deflection and structural integrity
2. Corrosion potential within the installation
3. Pipe joint type, deflection limits and integrity under deflection
4. Special bedding requirements or proposals
5. Pipe size, material specifications, and joint types for existing pipelines
6. Relative water quality and uses of proposed and existing pipelines
7. Relative levels of disinfectant residuals in the proposed and existing pipelines
8. Operating and surge pressures in the proposed and existing pipelines
9. Ability to control pressure and flows in adjacent underground utilities
10. Thrust restraint and thrust blocking of proposed and existing pipelines
11. Soils characteristics at the location
12. Ground water or water table conditions
13. Adjacent building and structure surcharges as it affects trench and pipe stability
14. Adjacent underground utilities and impacts
15. Comments and concerns of representatives of adjacent underground utilities potentially affected by the proposed installation
16. Construction related impacts
    a. Equipment and traffic vibration
    b. Spoil pile surcharge impacts
    c. Special structural support for adjacent pipelines

Suggested Solutions
The following sections address three potential Condition C pipeline locations:

Utility Tunnel – Condition C: The most common situation proposes a utility tunnel crossing under a stream or railroad and highway rights-of-way. Figure 19 provides a suggested construction detail to address Condition C concerns associated with utility tunnels. The project design should consider:

1. Locating potable water and reclaimed water lines above the midline of the tunnel and sanitary and storm sewers located below the midline as far as possible.
2. Encasing potable water pipeline in a pressure-rated pipe that is provided with corrosion protection or is non-corrodible, and has fused joints and providing pipe spacers to maintain the waterline centered in the water line casing.
3. Filling casing annular space or void with lean concrete, grout, bentonite or other proposed fill that assures the void is completely filled. The regulatory agencies must approve the construction methods to assure the void is completely filled.
4. Addressing methods that may be necessary to allow access for likely future maintenance and repair of *all* of the utilities using the tunnel or boring casing, such as casings that will allow removal of every utility pipe for future maintenance.

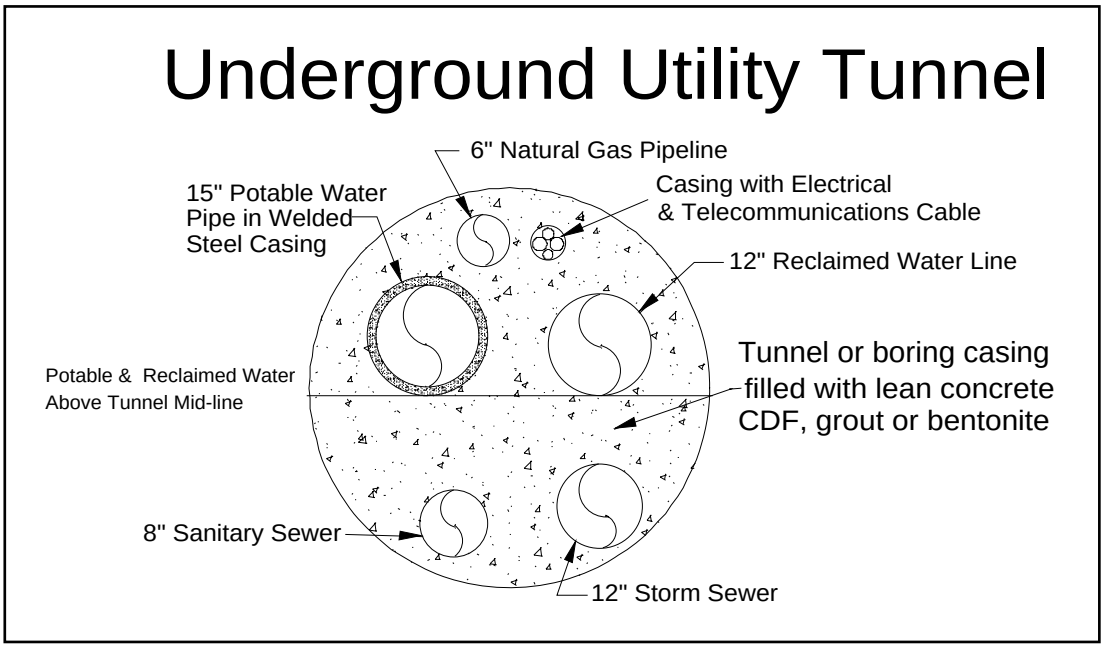


Figure 19: Condition C utility tunnel

Common Utility Corridor Construction- Condition C

At locations where a restricted, common underground utility corridor is required, the engineering report should consider:

1. Selecting pipe materials for the lowest level pipelines presuming future maintenance and repair is *not* possible.
2. Specifying fused or welded joints in the bottom and middle pipelines.
3. Limiting the length of these installations to very short distances, potentially 300 to 400 feet.
4. The upper most utilities will likely be natural gas, electrical or telecommunications. When installing these utilities consider that they will be affected by potential repair and maintenance of the water or reclaimed water pipelines and may sustain damage during such repairs.
5. Locating appurtenances for maintenance of potable and reclaimed water lines such as directional flow flushing to prevent impacts to the utility corridor from runoff, vibrations, or pressure surges.

Figure 20 illustrates a *suggested* construction detail.

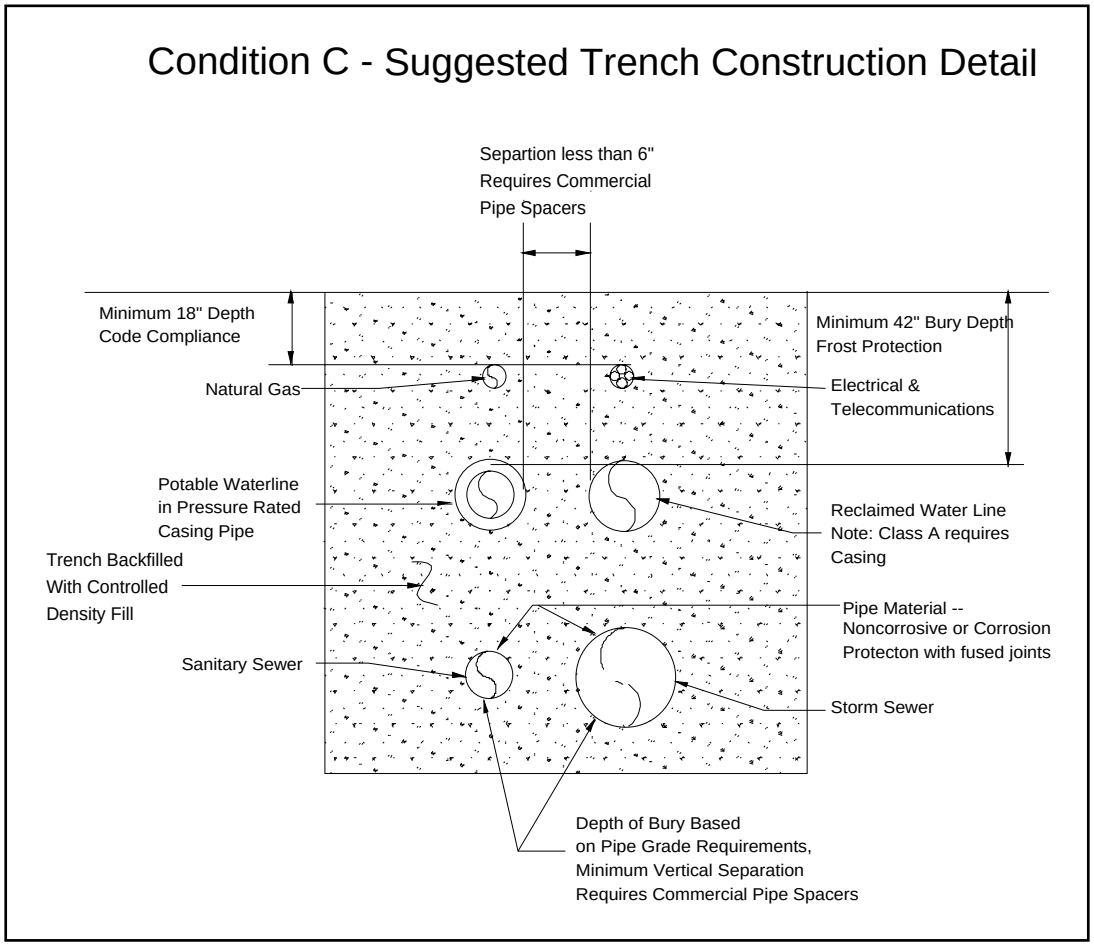


Figure 20: Common underground utility corridor

Pipeline Crossing – Condition C

For pipeline crossings of less than the required vertical separation distance, consider the following protections at a minimum:

1. Provide both the new pipeline and the existing pipe in the crossing with casing manufactured of pressure-rated pipe.
2. Provide commercial pipe spacers for the carrier pipes within each casing.
3. Provide controlled density fill of at least 6 inches in thickness around both cased pipelines for the entire length of each casing.
4. Seal the casings at the ends.
5. Provide a commercial pipe spacer between to the two casings at the crossing to assure a minimum separation is maintained.

Figure 21 provides a *suggested* construction detail.

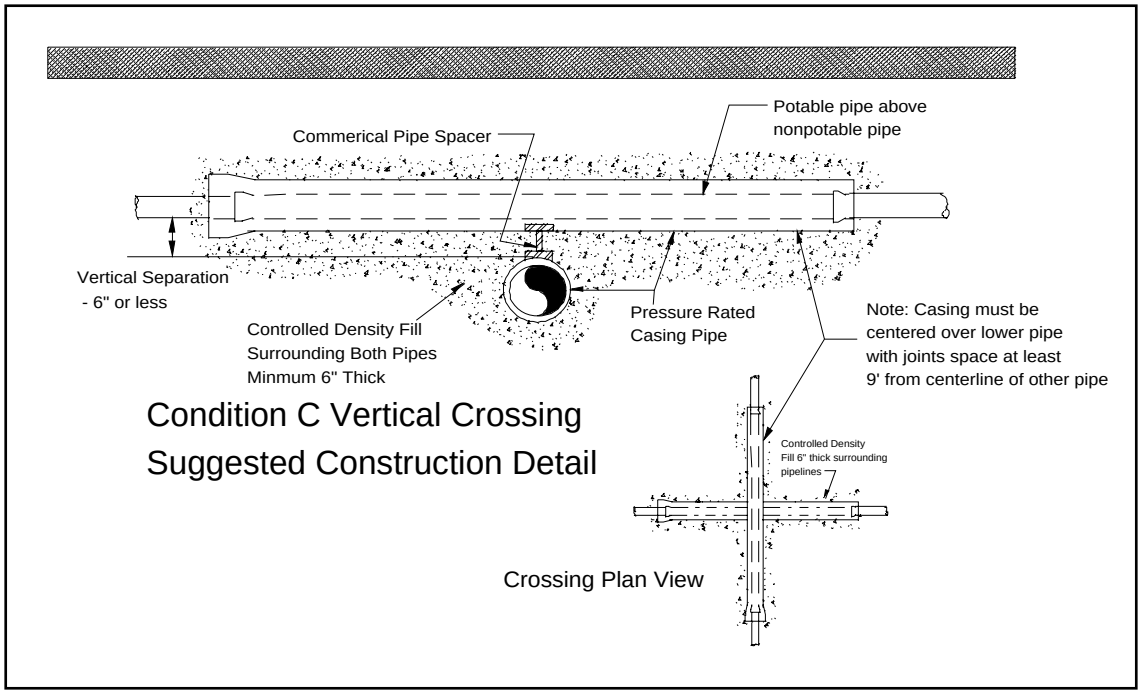


Figure 21: Condition C -vertical pipe crossing

Engineering Design and Location Approach

General Considerations
Numerous issues and constraints face the design team in selecting the proper location, size, and materials specifications. Several issues may significantly impact minimum separation distances. This section addresses specific design-related issues. The Departments of Health and Ecology (the agencies) do not intend to provide a complete or exhaustive list of design issues or variables in this guidance, but rather to address the majority of the important issues considered in the regulatory review and approval process.

Engineering Judgment
No written guidance can replace professional judgment. The agencies do not intend that these guidelines will supersede professional engineering judgment in any way. The guidelines provide a description of basic acceptable practices applicable to many, but certainly not all situations encountered. The agencies hope that deviation from these standard approaches, although expected, will be limited. We recognize that when developing other acceptable designs engineers must rely on professional engineering judgment to demonstrate the designs achieve equivalent public health protection.

Trench Protection
The agencies do not intend for this guidance to impose a single set of requirements for pipeline designers or maintenance supervisors to provide structural designs for trench shielding or trench box protection. The agencies recommend that site control be conducted by an individual certified in trench safety. The certified individual establishes a competent responsible party to assure trench protection during construction and repair excavations. These standards do not supersede or replace any trench safety and shoring protection required by the Washington State Department of Labor and Industries.

Basic Design Approach
The agencies prefer use of the minimum standard separations wherever possible in locating new or relocated buried utilities. The engineer should identify location conflicts and limits on pipeline separation during the preliminary design phase. To the extent reasonably possible, the design team should identify those locations that will trigger Conditions B and C. Potential location conflicts should become apparent from baseline information gathered from record drawings of existing pipes and utility corridors from local utilities, as well surface features found during initial field reconnaissance of potential pipeline routes.

Multiple Barriers of Protection
Pipelines provide economical and reliable transportation and delivery of consumable products and removal of waste products. The two most common underground utilities – drinking water and sanitary sewage – provide the foundation for a community's public health protection. All underground utilities provide services essential to the health and welfare of communities. All essential services must have the highest degree of reliability, and include multiple barriers of protection. Just as a potable water system provides multiple protections through source protection, treatment and disinfection, the

distribution systems also require separate and duplicative barriers. The project team – the design engineer, regulatory review staff, contractor and owner- must recognize that adequate pipe separation from other underground utilities provides the final, protective barrier.

Record Information Accuracy

Designs must begin with the best, available information. In the case of municipal underground utilities, this is often found in "as-built" or record drawings of "existing" pipelines or previous projects. Although this information can prove inaccurate, it may be the best information available as the design begins. Designers should consider as-built information during the initial design phase in determining the locations of potential separation conflicts. The extent of reliance on the accuracy of these records will depend on the judgment of the project design manager based on their professional experience.

Trigger Conditions

Special designs or pipe separation methods may not be necessary along the length of a project. Soils properties and site constraints vary along the route in most pipeline projects. Encroachment into the standard separation zones for a small portion of a pipeline does not require that the length of pipeline under Condition A be designed for Conditions B or C. The use of special pipeline designs or pipe separation methods is necessary in locations with the potential for significant risks as a result of the pipe locations. The design engineer should consider:

- The length of the parallel installations; pipe lengths greater than the length of two pipe 'sticks' or three or more pipe joints [36'-40'] would trigger special design.
- Health risks associated with the products transported in the adjacent pipes.
- The age and condition of existing pipe materials and joints.
- Non-cohesive soils which will require pipe special pipe supports or trench protection be used to excavate parallel trenches.
- Pipe installations that do not allow for full compaction of support soils between pipes.
- Pipe distribution systems subject to high pressures, large pressure variations and pipe velocity variations that tend to result in pipe thrust at bends and joints.

Design Considerations

As a project develops, site-specific conditions will be come apparent that will drive the details of the project design. The different factors that should be evaluated to justify smaller pipe separations include:

- System pressure ranges and hydraulics that may affect the tendency of the pipes to develop thrust during normal operations.
- Anticipated range of soil characteristics such as cohesive strength; critical trench depth and corrosion potential of the pipe material.
- Range of current and future pipe sizes in the utility corridor.
- Potential for saturated soil conditions at the deepest trench level.
- Types of pipe material and pipe joints preferred or available.
- Repair and patching methods for the pipe.
- Available space for spoil pile location and material stockpiling during repairs.
- Location of operating excavation and materials handling equipment.

- Separation to adjacent traffic and impacts from traffic on trench stability.
- The ability to accurately track, estimate or locate pipeline leakage.
- Risk to public health and safety that could result from cross contamination from leakage between adjacent pipes.
- Capability, facilities and equipment available to contain, control and clean and restore the pipe and produce quality to meet public health and safety standards.

Specific Design Concerns
Soils strength; trench construction – depth of bury, leakage impact, repair and replacement mitigation

Soil Strengths Data
Detailed soils data can be difficult and expensive to obtain, Fortunately, for these design purposes, only basic soils data is necessary to determine whether the soils are either cohesive or non-cohesive. Soils that provide any level of cohesive force will likely provide sufficient side wall coverage to allow smaller horizontal separation distance. Non-cohesive soils generally will not support sufficient side wall cover, and require more careful consideration.

Soils surveys provide information to a depth of 5 feet, which is valuable for most potable water lines buried between 3½ and 5 feet deep. Soil survey information is available from several locations electronically including these two websites:

National Resource Conservation Service at:
http://www.or.nrcs.usda.gov/pnw_soil/wa_reports.html

Washington State University at:
http://remotesens.css.wsu.edu/washingtonsoil/

Table 7. An Example of soils information from the NRCS Web site

General Soil Type:	*O5*	**Region:**	*O*
Map Unit Description:	*Soils derived from glacial outwash on river terraces; most soils are strongly loess-influenced in the upper part, gravelly or sandy in the lower part, and have low water-holding capacity; some are influenced by volcanic ash in the upper part*		
Moisture Regime:	*Xeric*		
Temperature Regime:	*Mesic*		
Taxonomic Classification:	*Vitrandic Xerochrepts, Vitrandic Haploxerolls, Typic Xerorthents, Typic Xeropsamments*		
Major Soil Series:	*Springdale-Garrison-Spens-Bisbee*		

Table 7 provides an example of soils information generated from the Washington State University website. The NRCS website gives greater detail.

The WSU website generates general maps of each county. Figure 22 shows maps for Lincoln and Spokane Counties. The engineer can find soils information by clicking on a soil type designated by color with a mouse.

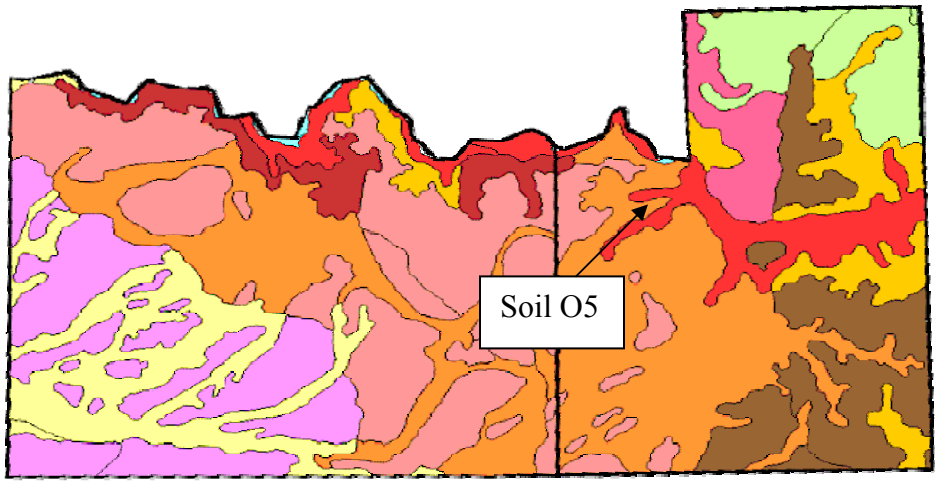


Figure 22. Lincoln and Spokane county soil types *(Soil Type O5 is displayed in red)*

In general, soils information available from soils maps or from local contactors and utilities should provide sufficient information during the initial route location stages.

Pipe Leakage

Pipe leakage is so common that designers can easily overlook the effects of leakage on the pipe design and location process. Leaks affect the amount of soil moisture or water in the immediate vicinity of a pipe. This dramatically affects the cohesive strength of the soil. Pipe failure may cause a leak; or a leak may help create pipe failure (Figure 23). Pipeline designs need to consider the fundamental conditions that create or allow leaks during the design and pipeline location process.

Figure 23: Pipe beam break due to corrosion

Conditions Causing Leaks

Pipeline leaks may be caused by external and internal forces on the pipes, corrosion and deterioration, or construction problems. External forces include traffic loads, earth loading, freeze and thaw cycles, earthquakes, and floods. External forces result in failure when:

- The pipe, acting as a beam in the soil, is not uniformly supported by adequate pipe bedding.
- The pipe is restrained from expansion and contraction, and differential thermal stress is applied.
- The force of rigid structures exerts pressure on the pipe.

Internal pressures that can result in pipeline damage include working pressure and surge pressures. All pipelines under pressure are subject to water hammer surges during normal operation of pipes, valves, and even faucets and hose bibs. If the pipes are brittle, hydraulic transients or water hammer can cause longitudinal cracks. Repetitive transient pressure surges affect the fatigue strength of the pipe material compromising the wall strength.

Pipeline Deterioration

Tuberculation and internal pipe corrosion can cause water quality degradation. Tuberculation is the development of blister-like growths of metal oxides resulting from metal pipe. Iron oxide tubercles often develop over pits in iron or steel pipe. These can seriously restrict the flow of water. Tubercules[8] not only affect the pipe wall integrity, but also increase pipe roughness. This, in turn, can result in larger pressure differentials during operation and can compound the impacts of internal and external forces.

Construction Related Problems

Poor bedding during construction can result in significant pipeline damage. Under pressure tiny leaks in gaskets result in major blowouts due to soil mining at the joint. Construction errors may include cracked bells, leaks caused by rolled gaskets (common with push-on joints), or a tiny bit of sand between the gasket and the pipe. Leaks from gaskets "sand blast" the pipe from the outside in and increase at an exponential rate. In extreme cases, the soil mining extends to the surface as shown in Figure 24.

Figure 24: Sand boils resulting from joint failure

Joint leaks in flexible pipe, including steel pipe, are common at welded joints, especially if the pipe is deflected due to soil movement or seismic forces. Bedding the pipe section with large and/or angular rocks can lead to breaks if the rock creates point stresses on the pipe wall. Such improper bedding results in punctures or breaks in the pipe ring.

Mechanics of Pipe Failure Due to Leaks

When leaks occur from beam breaks, joint leakage, main breaks or service line leaks, the liquid flushes soil particles from the region of the leak. The flushing undermines pipe

[8] The mounds characterized by reddish brown mounds of various heights attached to the interior of the pipe walls, resulting from many years of iron and manganese bacterial growth that deposit iron and/or manganese oxides along with particulate matter from the water trapped in the biomass from generations of iron bacteria. These bacteria are common in all water sources. Over twenty different iron bacteria can cause tuberculation. These bacteria are generally considered non-pathogenic. However, tubercules can aid in microbiologic regrowth, fostering the growth of pathogenic microorganisms.

bedding. The loss of pipe bedding can cause over-deflection at pipe joints, excess pull on joints, loss of thrust restraint, and loss of support from the soil underlying the pipe section. Ultimately, total pipe failure may result.

Allowable Leakage

All pipes should be expected to leak. The perception that pipelines are "sealed tight" is very common in the water and wastewater industry, but it is wrong. Standard construction specifications acknowledge this fact by establishing "allowable leakage rates" for the design life, when material quality and construction integrity are expected to be the best and external pressures are at a minimum. Designs generally consider allowable leakage limits for nearly all pipe materials, including some assumed to be "leak-free." Estimates of annual leakage shown in the spreadsheet model (Table 8) indicate that adequately constructed pipelines can be expected to lose a significant amount of water over time.

Table 8. Allowable leakage based on standard specifications

$$L = \frac{S*d*P^{1/2}}{133{,}200}$$

L = allowable leakage in gallons per hour
S= length of pipe tested in feet
P= system pressure, psi

Allowable Leakage for 300 ft of pipe [1-urban block] in one year								
Pipe Diameter	System Pressure, psi							
inches	30	40	50	60	70	80	90	100
6	1,776	2,368	2,959	3,551	4,143	4,735	5,327	5,919
8	2,368	3,157	3,946	4,735	5,524	6,314	7,103	7,892
10	2,959	3,946	4,932	5,919	6,905	7,892	8,878	9,865
12	3,551	4,735	5,919	7,103	8,286	9,470	10,654	11,838
18	5,327	7,103	8,878	10,654	12,430	14,205	15,981	17,757
24	7,103	9,470	11,838	14,205	16,573	18,941	21,308	23,676
36	10,654	14,205	17,757	21,308	24,859	28,411	31,962	35,514
48	14,205	18,941	23,676	28,411	33,146	37,881	42,616	47,351

The fluid leaked from the pipe remains in the vicinity of the pipe, and affects the soil moisture content and water levels in the pipe excavation. This, in turn, affects the cohesive strength of the soil and the critical trench depth at the excavation site.

Excavation Site Conditions

Pipeline repair excavations provide a special application of the principals used to determine minimum sidewall coverage based on soil mechanics techniques. Soil strength and external forces on trenches and parallel underground utilities differ dramatically during repair operations. Undisturbed soil almost always exhibits greater strength than disturbed soil, regardless of the compaction method used. When excavating adjacent to an old trench, the prism of soil between the two trenches is generally very unstable.[9] Often the excavation backfill spoil pile or operating excavation equipment will be located on top of the parallel utility line. This practice significantly increases the effective depth

[9] S. Arasmith & H. Mason-Ploetz, *Cave-in Protection and Competent Person Training Manual,* Pg. 27

of bury and the external loads and increases the possibility of trench sidewall failure due to the vibrations caused by equipment or materials. Figure 25 shows setback separations required for three basic soils classifications.[10] For the purposes of this description: Type A soils are classified as cemented soils, providing the highest cohesive forces; Type B soils are cohesive soils, and Type C soils are classified as granular soils. These classifications do not directly relate to the soil group classifications shown previously.

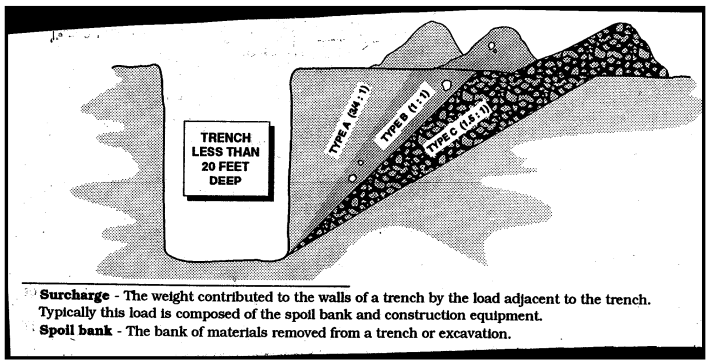


Figure 25: Typical trench surcharge conditions

Figure 26 shows the importance and potential impacts of spoil bank locations in a field excavation. Note that the right ditch bank appears to be stable at a relatively steep angle, while the left bank is sloughing.

Repair and Replacement Excavations: The effectiveness of pipe repairs or replacement of short sections during design is determined by allowing sufficient room for safe and effective repairs. Utilities with routine pipe repair procedures can justify more congested designs based on the standard practices and procedures. The design should consider the following factors:

- Availability of certified competent persons to oversee the excavation
- Experienced designers for:
  - Structural support of adjacent pipes or pipe joints
  - Trench shields
  - Trench boxes
- Provision of redundant pipe markings or pipe identification systems to prevent repair or tapping of the wrong pipe.

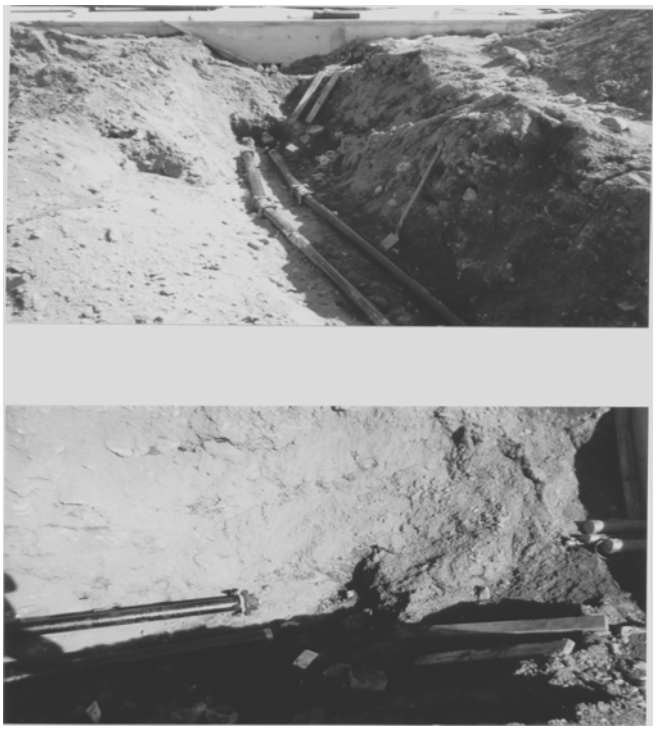


Figure 26: Field conditions - typical trench surcharge

[10] Ibid, Page 27

Conclusions

Many different issues significantly affect the decision making process used to set the final location of a new pipeline relative to existing underground utilities. The design of a new pipeline must consider needs to maintain and repair to all other adjacent utilities along its entire route. Natural and induced conditions can lead to deterioration and failure, which in turn leads to contamination and damage. The ability to readily and effectively address these needs depends predominantly on the decisions made in the original location of the pipeline.