



MAINTAINING THE ENERGY GRADIENT THROUGH CUSTOM SEWER STRUCTURES

Applying Fundamental Engineering Principles for Complex Solutions

To keep our essential wastewater conveyance systems operating smoothly and out of sight, engineers address many challenges. Integrating new infrastructure into existing conditions can be like completing a puzzle with several hidden pieces buried beneath our feet. In gravity sewers, these “pieces” include the upstream and downstream pipe connections, diameters, slopes, materials, geometry, and flows. Pipe depth, surrounding infrastructure, and stakeholder impacts are other pieces that can affect construction. Careful investigation and meticulous calculations are crucial for identifying these pieces of the puzzle and designing accordingly—providing the desired sewer functionality while conforming to applicable standards. This white paper delves into one application of this important process: maintaining the energy gradient in large custom sewer structures and how it can differ from typical sewer design. As we explore common methods, we'll uncover how small adjustments can significantly affect system efficiency and longevity.

Dibble has been designing successful sewer solutions since 1962. We know that while every sewer design is based on common principles, each has unique requirements, and the complexity of larger systems demands a nuanced approach. By understanding the fundamental principles of hydraulics and applying them appropriately, we can ensure that our wastewater systems continue to serve our communities effectively and reliably for generations to come.

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"Understanding the engineering principles behind design standards is essential to addressing the challenges of connecting new construction to existing infrastructure."

-Keith Faucett, PE
Principal Engineer -
Vice President, Utilities

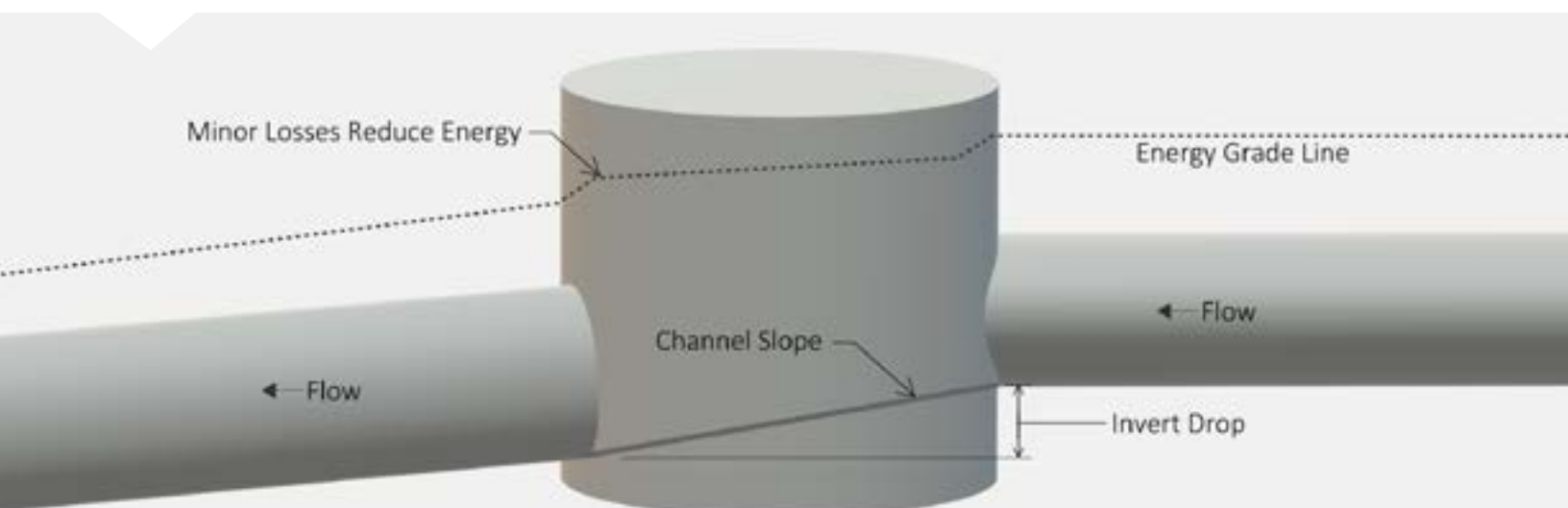
Energy in Gravity Sewer Structures (refer to the graphic below): When wastewater flows through gravity sewer structures, some energy is lost due to changes along the flow path such as expansions, contractions, bends, and merging flows (minor losses). One way engineers account for these minor losses is by providing appropriate invert drop—the drop in elevation between the inside bottom of the incoming pipe and inside bottom of the outgoing pipe.

In gravity sewer design, small details can have considerable impacts. While the general goal is to keep wastewater flowing smoothly and in the right direction, several factors are involved in this process. One essential factor is the energy that keeps wastewater moving. When wastewater flows through a sewer system, energy is lost due to dissipative forces like friction. Engineers account for this loss of energy (head loss) by designing appropriate slopes and overall elevation drop in the system, thereby minimizing odor, corrosion, solids deposition, and the potential for a sewer overflow.

Engineering standards and best practices streamline this effort. For example, a common practice is to provide a 0.1-foot to 0.2-foot invert drop through gravity sewer structures, such as manholes. This concept is demonstrated in many published standards, including the following examples:

- > **City of Phoenix:** "Inverts through manholes and junction boxes shall be designed to maintain the energy gradient across the structure. Manholes and junction boxes having sewer mains intersecting at 45 to 90 degrees shall have a minimum 0.10-foot drop across the structure" (City of Phoenix 2021, p. 40).
- > **Pima County:** "The flow channel, through the base of a manhole, shall be sloped to provide for a smooth transition of flow and minimize the deposition of solids... For inlet and outlet pipes with the same diameter, see [the table below] for the required invert drops" (Pima County Wastewater Reclamation 2022, p. 5-11 and 5-12).

Horizontal Deflection Angle	Invert Drop (feet)
0 to 9 degrees	Maintain average slope of incoming and outgoing sewer lines through manhole; or Invert drop = Manhole diam. in feet x (S1 + S2)/2 Where: S1 = slope of incoming reach, S2 = slope of outgoing reach
10 to 45 degrees	0.10
46 to 90 degrees	0.20



- > EPCOR: “If a manhole has a sewer direction change that is less than 45 degrees, then the manhole should be designed for a 0.1-foot drop across the manhole. If a manhole has a sewer direction change that is greater than or equal to 45 degrees, then the manhole should be designed for a 0.2-foot drop across the manhole” (EPCOR 2020, p. 30).

While the typical 0.1-foot to 0.2-foot drop is appropriate for most applications, larger structures may require additional invert drop to overcome head loss, maintain the energy gradient, and meet construction tolerances. This is illustrated in the calculations below.

Review of Minor Loss Calculations

Minor losses affect the amount of invert drop required within sewer structures. These losses can result from bends, expansion, contraction, and merging flows. There are at least a couple approaches for calculating these minor losses that produce similar results. Each approach uses the Energy equation for head loss:

$$h = K \left(\frac{V^2}{2g} \right)$$

where

h = minor head loss in feet due to bends, expansion or contraction

K = loss coefficient (unitless). Using tables from literature (Brater, et al. 1996, p. 6.37; Crowe, Elger and Roberson 2005, p. 391), we can determine the K value for each type of loss including bend loss, expansion loss, and contraction loss.

V = flow velocity in the pipe in feet per second (ft/s).

g = gravitational acceleration constant (32.2 ft/s²).

To calculate the total minor head loss ($h_{total\ minor}$) in a structure due to bends, expansion, and/or contraction, we compute the minor loss due to each condition (h) using the equation above. Once we have calculated these minor losses, we add the losses together to determine the total minor head loss in the structure, as follows:

$$h_{total\ minor} = h_{bend} + h_{expansion} + h_{contraction}$$

To illustrate this process, we will calculate the head loss in the following example.



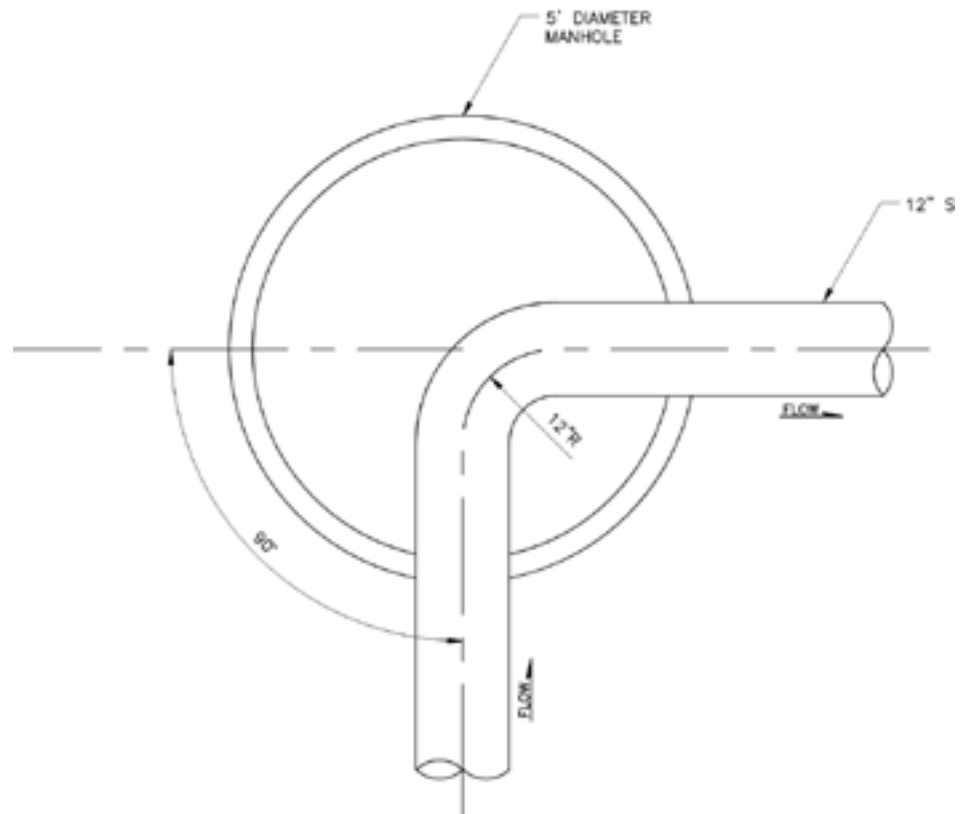
Preparing to place a large precast diversion structure



Bend in a manhole

Example 1: Bend with a Flow Velocity of 2 ft/s

The figure below shows a 12-inch sewer pipe bending 90 degrees within a manhole.



The radius of the bend is 12 inches, therefore the bend radius to pipe diameter ratio (R/d) = 1. If this sewer is designed to maintain a velocity of 2 ft/s when flowing full, then we can calculate the head loss due to the bend as follows:

$$h_{bend} = K \left(\frac{V^2}{2g} \right)$$

where

h_{bend} = head loss due to the bend in feet.

K = loss coefficient (unitless). According to literature (Brater, et al. 1996, p. 6.37; Crowe, Elger and Roberson 2005, p. 391), if $R/d = 1$, then $K = 0.35$.

V = flow velocity in the pipe in ft/s = 2 ft/s.

g = gravitational acceleration constant (32.2 ft/s²).

$$h_{bend} = 0.35 \left(\frac{(2 \text{ ft/s})^2}{2 * 32.2 \text{ ft/s}^2} \right) = 0.02 \text{ feet}$$

In this example, the head loss due to the bend is 0.02 feet. Therefore, the typical invert drop of 0.1 to 0.2 feet is more than enough to overcome the minor head loss in this structure.

Example 2: Pipe Bend with a Flow Velocity of 7 ft/s

Consider the same pipe bend with a higher flow velocity of 7 ft/s.

$$h_{bend} = K \left(\frac{V^2}{2g} \right)$$

where

h_{bend} = head loss due to the bend in feet.

K = loss coefficient (unitless). According to literature (Brater, et al. 1996, p. 6.37; Crowe, Elger and Roberson 2005, p. 391), if $R/d = 1$, then $K = 0.35$.

V = flow velocity in the pipe in ft/s = 7 ft/s.

g = gravitational acceleration constant (32.2 ft/s²).

$$h_{bend} = 0.35 \left(\frac{(7 \text{ ft/s})^2}{2 * 32.2 \text{ ft/s}^2} \right) = 0.27 \text{ feet}$$

In this scenario, the typical invert drop of 0.1 to 0.2 feet would not be sufficient to overcome the head loss of 0.27 feet. While a flow velocity of 7 ft/s is at the high end of acceptable, this example shows the importance of confirming whether the general practice is appropriate for a specific design.

Example 3: Another Approach for Calculating Bend Loss

Another approach for calculating head loss due to a bend is to simulate an open channel storm drain. *The Hydraulic Engineering Circular No. 22, Fourth Edition: Urban Drainage Design Manual* (Atayee, et al. 2024, p.145), known as the HEC 22 manual, also uses the Energy equation but provides an alternate method for determining the constant, K , as shown below:

$$h_{bend} = 0.0033 (\Delta) \left(\frac{V^2}{2g} \right)$$

where

h_{bend} = head loss due to the bend in feet.

Δ = angle of bend in degrees.

V = flow velocity in the pipe in ft/s.

g = gravitational acceleration constant (32.2 ft/s²)



Installing a deep cast-in-place sewer structure



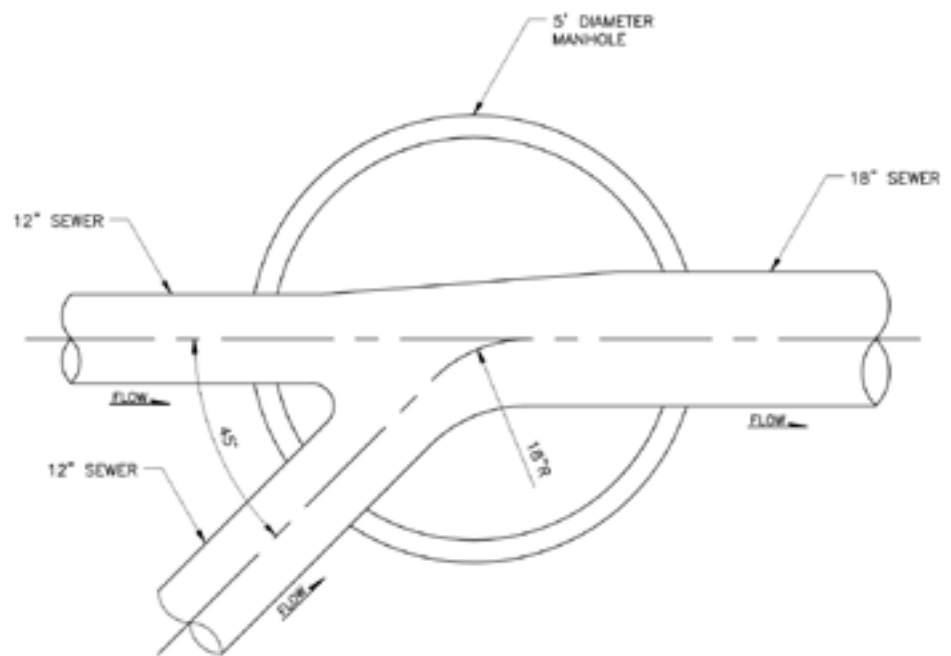
Sources of head loss in this aging siphon inlet structure included expansion and contraction losses with multiple incoming and outgoing sewers. Dibble designed a replacement structure that reduces the number of incoming sewers, provides sufficient invert drop, and lengthens transitions for smoother flow, reducing head loss and improving siphon system performance.

Consider All Sources of Head Loss

In large or custom sewer structures, there are often several minor losses involved. For example, if a structure has a bend, an expansion, and a contraction, we can calculate the total minor head loss ($h_{total\ minor}$) for that structure as follows:

$$h_{total\ minor} = h_{bend} + h_{expansion} + h_{contraction}$$

Consider if two 12-inch pipes enter a manhole and exit through an 18-inch pipe, as shown in the figure below.



In this scenario, we have head loss due to a bend, an expansion, and a contraction. Again, we can use the Energy equation for head loss to calculate each of these losses:

$$h_{bend} = K \left(\frac{V^2}{2g} \right)$$

Another consideration is head loss due to merging flows. *The Handbook of Hydraulics* (Brater, et al. 1996, p. 6.44) recommends an iterative method to determine the losses due to the momentum of merging flows in a structure. The HEC 22 manual (Atayee, et al. 2024, p. 148 to 157) provides a non-iterative approach to determine these losses based on the angles of incoming pipes relative to the outlet. Both approaches consider the energy grade line across the structure.

Summary

Maintaining energy gradients is a critical aspect of sewer infrastructure design. As we've explored throughout this paper, the requirements for large custom sewer structures can extend beyond the standard practices typically applied to smaller, more conventional systems. Key takeaways include the following:

1. Typical invert drops of 0.1 to 0.2 feet may be insufficient for larger structures.
2. Multiple sources of head loss—including bends, expansions, contractions, and merging flows—should be considered when calculating head loss in complex sewer designs.
3. Real-world applications, as demonstrated in Dibble's project examples, illustrate how theoretical principles translate into practical, effective solutions.

While our communities continue to evolve and grow, time-tested engineering principles remain constant. Standards and common practices streamline the design process but do not replace quality engineering and careful attention to detail. A thorough understanding of the engineering fundamentals is crucial for meeting infrastructure needs for generations to come.

Below are examples of large custom sewer structure projects in which we applied these concepts:

[Tucson Boulevard Diversion Structure](#)

[Northwest Outfall Sewer Siphon](#)

See also [Designing Large Custom Sewer Structures](#).

References

Atayee, A.T., Herrman, G., and Kilgor, R. 2024. *Hydraulic Engineering Circular No. 22, Third Edition: Urban Drainage Design Manual*. Washington, D.C.: U.S. Federal Highway Administration.

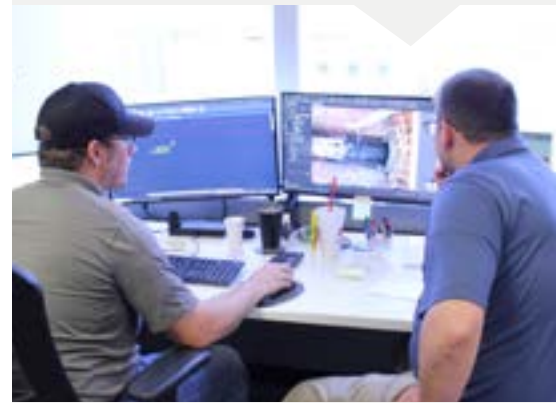
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For each project, Dibble carefully examines the overall purpose down to the small details, which helps ensure our designs operate as intended. This benefits owners and stakeholders and helps to protect public health.

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